AECTP 200

ENVIRONMENTAL CONDITIONS

(January 2006)

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NORTH ATLANTIC TREATY ORGANIZATION

NATO STANDARDISATION AGENCY (NSA)

NATO LETTER OF PROMULGATION

18 May 2006

1. AECTP 200 (Edition 3) – ENVIRONMENTAL CONDITIONS is a NATO/PFP UNCLASSIFIED publication. The agreement of nations to use this publication is recorded in STANAG 4370.

2. AECTP 200 (Edition 3) is effective upon receipt. It supersedes AECTP 200 (Edition 2) which shall be destroyed in accordance with the local procedure for the destruction of documents.

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Brigadier General, POL(A)
Director, NSA

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ALLIED ENVIRONMENTAL CONDITIONS AND TEST PUBLICATIONS

AECTP 200

ENVIRONMENTAL CONDITIONS

AECTP 200 is one of five documents included in STANAG 4370. It provides characteristics and data on environmental conditions for operational events and scenarios that influence the design of defence materiel. Although it is not practicable to provide data to cover all circumstances, AECTP 200 is considered to include the most relevant environmental conditions.

AECTP 200 is to be used in conjunction with the four other AECTPs included in STANAG 4370. They are: AECTP 100 Environmental Guidelines for Defence Materiel, AECTP 300 Climatic Environmental Tests, AECTP 400 Mechanical Environmental Tests, and AECTP 500 Electrical Environmental Tests.

An important application of AECTP 200 is for users to confirm that the key environmental conditions within project specific environmental requirement documents have been addressed correctly. In particular, when used in conjunction with the other AECTPs, the environmental characteristics and data contained in AECTP 200 should facilitate the development of a comprehensive and cost effective set of environmental tests and assessments.

The data presented in AECTP 200 are intended for use during the specification process but also are to be considered when extended life is under focus. Refer to STANAG 4570 with AECTP 600 for guidance.

When possible, the use of measured data to develop test severities is recommended. For many environment conditions AECTP 200 provides advice on the derivation of test levels from measured data.

AECTP 200 does not address abnormal environments arising from accidental or hostile conditions, or nuclear effects.

ENVIRONMENTAL CONDITIONS

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CATEGORY 210

INTRODUCTION

1. PURPOSE

1.1 The purpose of AECTP 200 is to provide characteristics and data on climatic, mechanical and electrical/electromagnetic environments, and also guidance on the application of the data.

2. SCOPE

2.1 AECTP 200 describes environmental conditions and data that have been compiled from established sources within NATO countries. Where possible the potential damaging effects of these conditions on defence materiel are also identified. Advice is given on the selection of suitable test methods. For mechanical conditions, guidance is also given on the determination and validation of environmental test severities from actual measured data.

2.2 AECTP 200 does not address environments arising from accident or hostile conditions, or nuclear effects.

3. APPLICATION

3.1 The characteristics and data contained in AECTP 200 should be used, where possible, in the preparation of national requirement documents for defence materiel to be procured for NATO forces. It should be used in conjunction with measured data for deriving the appropriate conditions for specific defence materiel and as the basis for determining environmental design and test criteria.

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CATEGORY 220

RELATED SOURCES OF INFORMATION

INTRODUCTION

1. The content of Category 220 comprises sets of document references. The documents are considered to contain related sources of information and data to that included in AECTP 200. The content of these documents provides, in particular applications, additional material to that in AECTP 200 that might be of benefit when compiling environmental descriptions and test specifications.

2. The references to the documents have been submitted by the members of the Task Group on Environmental Conditions and Test Procedures and are grouped according to their country of origin. NATO references are listed first. The references will be reviewed and appropriate additional references will be included in future editions of this AECTP.

NATO

1. Allied Administrative Publications 6 (AAP-6) "NATO Glossary of Terms and Definitions".

2. "Glossary of Terms and Definitions for general use within AC/310".

3. STANAG 4242 - Vibration Tests for Munitions Carried in Tracked Vehicles.

4. Allied Environmental Conditions Publication 1 (AECP-1) "Mechanical Environmental Conditions".

FRANCE

1. GAM-EG-13 Basic Environmental Test Procedures + Annexes.

   Custodian: Laboratoire de Recherches Balistiques et Aérodynamiques

2. CIN-EG01 Guidelines for Accounting for the Environment in Military Programmes

   Custodian: Laboratoire de Recherches Balistiques et Aérodynamiques

GERMANY

1. Bauvorschrift fuer Schiffe der Bundeswehr: - BV 0430 Schocksicherheit
   - BV 0440 Vibrationssicherheit

   Custodian: BWB - PAS 90

Comment: This document is included to cover the needs of the German Navy.

UNITED KINGDOM

1. Defence Standard 00-35 Environmental Handbook for Defence Materiel.

   Custodian: Defence Ordnance Safety Group, Ministry of Defence

UNITED STATES

1. Military Standard 810 Environmental Test Methods and Engineering Guidelines.

   Custodian: US Army Developmental Test Command

2. IES Recommended Practice 012.1 - Handbook Dynamic Data Acquisition and Analysis

   Custodian: Institute of Environmental Sciences and Technology

3. International Test Operations Procedure (ITOP) 1-2-601 - Laboratory Vibration Schedules.

   Custodian: US Army Developmental Test Command

4. International Test Operations Procedure (ITOP) 1-1-050 - Development of Laboratory Vibration Test Schedules.

   Custodian: US Army Developmental Test Command

CATEGORY 230

CLIMATIC CONDITIONS

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Leaflet 2311/1	Climatic Categories and their Geographical Location
Leaflet 2311/2	World-wide Ambient Air Temperature and Humidity Conditions and Levels of Direct Solar Radiation
Leaflet 2311/3	AdditionalClimaticEnvironmentalFactors

SECTION 231

GENERAL

SECTION 231 - GENERAL

LEAFLET 231/1 - GENERAL

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1. GENERAL

1.1. Purpose

a. The purpose of AECTP 200 Category 230 series of leaflets is to present characteristics and data samples of natural and induced climatic conditions that influence the design of materiel. For the purpose of this document, induced climatic conditions are the ambient environmental conditions resulting from the modification of the natural climatic conditions due to the structure in which, or on which, the materiel is utilized.

b. Leaflet 231 gives general guidance on the types and causes of natural and induced climatic environments, and gives information that is applicable to a variety of materiel types and platforms. Induced environments included are :

- Temperature (including solar radiation)
- Humidity
- Air Pressure
- Hydrostatic Pressure
- Icing
- Dust and Sand
- Wetting
- Erosion by Impact

Leaflet 231 should be consulted before any other leaflets in Category 230 are consulted.

c. Leaflets 232 to 239 cover different situations in which materiel may be found, and follw a standardised format. For each situation, the characteristics of relevant induced environments are described for each set of circumstances that may apply. The potential damaging effects of those environments are descibed, and advice is given on the selection of test methods and severities.

1.2. Scope

a. Category 230 complements, amplifies, and extends information previously contained in STANAG 2895 by identifying potential damaging effects that natural and induced environmental conditions have on materiel, and by providing guidance on the selection of suitable test methods.

b. Category 230 series of leaflets are organized around classes of materiel items. The leaflets focus on the effects of the natural environment, or on the act or process by which environments experienced by materiel items are altered by environmental factors inherent in circumstantial conditions, platforms, or other materiel items that surround them. These leaflets are not intended to be comprehensive. When used in conjunction with AECTPs 100 and 300 (and other sources of relevant information), these leaflets provide information on climatic conditions that should enable a comprehensive and cost effective set of environmental tests (type approval or qualification) to be selected, formulated, and conducted in response to project environmental and related requirements.

c. Category 230 does not address all environments arising from accident, hostile conditions or nuclear effects.

2. APPLICATIONS

The information contained in the Category 230 series of leaflets is intended for use in the following applications:

a. To permit customers or potential customers to ask intelligent questions to confirm that key environmental characteristics and issues have been, or will be addressed by suppliers or potential suppliers.

b. To assist project engineers to compile Environmental Requirement (or Life Cycle Environmental Profile) specifications by identifying all major environments and by illustrating and quantifying key environmental characteristics and parameters that may influence specifications.

c. To assist project engineers to prepare Environmental Design Specifications by providing improved environmental characteristics data that will help them to select more valid initial design values.

d. To assist design engineers by indicating potential failure modes that specific environmental characteristics could induce, and thereby providing pointers to monitor during design and testing.

e. To assist test engineers in preparing test specifications by indicating which test methods are preferred when considering how to test for specific climatic environmental effects. The test methods contained in AECTP 300 are recommended where relevant.

f. To assist test engineers to compile programmes to acquire good quality field data. This aspect is covered extensively in these leaflets. Such data are used primarily to formulate test levels for qualification trials.

3. TYPES AND CAUSES OF INDUCED CLIMATIC ENVIRONMENTS

Materiel, components, and stores may experience wide-ranging induced climatic environmental conditions in excess of outdoor ambient levels depending on their design or their location on a platform. Induced levels of climatic elements, either singly or in combination, such as temperature, humidity, air pressure etc. may degrade materiel performance and reliability. Materiel may be required to survive or to continue to operate when subjected to these induced environments, and therefore, must be designed to do so up to acceptable levels of risk.

3.1. Temperature

Solar radiation, heat dissipation from nearby materiel, air conditioning/handling in compartments, and thermal shock are factors contributing to increased and decreased induced temperatures.

3.1.1. Effects of Solar Radiation and Dissipated Heat on Temperature

a. Depending on their locations on platforms, materiel items or components may experience wide-ranging direct or indirect induced temperatures in excess of outdoor ambient levels during transportation, storage, handling and use. Solar radiation has a direct temperature elevating effect on outer surfaces of materiel. Roofs and walls of shelters and temporary covers, and of housing materiel exposed to direct sunlight can elevate temperatures on outside surfaces and in living/operating areas far above external ambient conditions. Temperatures in the enclosed areas may be alleviated by ventilation or forced-air cooling, or alternatively, aggravated by heat from operational equipment.

b. High temperatures experienced by materiel installed within the frames of their platforms are likely to exceed the local ambient conditions because of indirect effects of solar heating of the platform structure or by absorption of heat emitted by the platform power units. Temperatures of equipment installed in racks and instrument panels are likely to be influenced by self-dissipated heat and heat from adjacent electronic units and electrical power supplies.

c. Conversely when materiel is operating in cold regions, non-heat-dissipating materiel installed in enclosed compartments, stored under cover on external platform areas, may experience temperatures lower than the external ambient conditions, because the skin surfaces or enclosures are often better radiators to the night sky than the ambient air.

3.1.2. Temperatures in Fully Air-conditioned Compartments

Temperatures in fully air-conditioned compartments on or within platforms are controlled to provide a comparatively benign environment. High temperatures may be generated in unventilated compartments due to indirect effects of solar heating, heat dissipated by installed equipment and aerodynamic heating. Each compartment should be assessed to determine if individual items of materiel are located in semi-stagnant areas where the temperature could fall outside the range of the controlled conditions. Temperatures experienced by individual units and components in electronic cabinets, racks, and consoles will depend on localized levels of dissipated heat and the provision of dedicated supplies of cooling air.

3.1.3. Temperatures in Partially- and Non-conditioned Compartments

In partially- and non-conditioned compartments, temperatures may be moderated by fresh air ventilation, by a supply of warm air (e.g., when a ship is operating in low temperature regions), or by air extraction system (e.g., to alleviate the effects of temperatures in the warmer geographical regions and of heat generated by operational machinery). There is a greater likelihood that materiel installed or stored in these compartments will be located close to sources of dissipated heat or in semi-stagnant areas. Some items of materiel may be located in refrigerated areas.

3.1.4. Thermal Shock

During transportation, storage, or phases of service life, materiel may experience wide-ranging induced temperatures in excess of local ambient conditions. Some materiel may be subjected to fast transient temperatures (or thermal shocks). Such transient temperatures may be generated when materiel is handled from inside a shelter to out-of-doors or conversely. The magnitude of such a thermal shock is determined by both inside and outside temperatures and heat absorption/dissipation capacities of materiel. Examples are materiel that is moved into cold outdoor ambient environments from a comparatively hot storage area. A converse example is materiel that is exposed to direct solar radiation before immersion into water.

3.2. Humidity

Temperature, air conditioning/handling in compartments, and atmospheric pressure differentials are factors contributing to induced levels of humidity and moisture accumulation.

3.2.1. Effects of Heat on Humidity

The factors responsible for induced high temperatures inside shelters or under temporary covers exposed to direct solar radiation are likely to raise the moisture content of the enclosed atmosphere above external ambient conditions.

3.2.2. Humidity in Fully Air-conditioned Compartments

The moisture content of the atmosphere in air conditioned compartments is normally controlled to provide comfortable and optimum working conditions for crew and installed equipment. In the event of a breakdown of the supply of conditioned air, the introduction of external ambient air at a higher temperature and relative humidity can result in condensation and accumulations of moisture on the surfaces of installed materiel (e.g., when deployed in hot wet tropic regions).

3.2.3. Humidity in Partially- and Non-conditioned Compartments

The ambient conditions in partially and non-conditioned compartments can range from a dry heat to a damp heat environment. Factors influencing conditions include the level of ventilation and operational machinery contained in the compartment. Heat generated by engines and electrical power generators is likely to reduce levels of relative humidity, while condensation and steam in air conditioning plants, galleys and laundries are likely to elevate relative humidity.

3.2.4. Moisture Accumulation

a. Without adequate ventilation, the diurnal variations in solar heating and ambient temperature, plus the self-induced heating and cooling that occurs during operation and following switch-off, can induce differential pressures causing materiel to breathe in and entrap moisture from the external atmosphere. This phenomenon is evident particularly in humid tropic regions and applies to materiel under covers, to shelters, and even to otherwise sealed electronic units.

b. Conversely, extremely low levels of relative humidity may exist in localized areas of equipment when dissipated heat adds to the drying effects prevailing in hot, dry regions of the world.

c. Condensation may occur on materiel when moved from a cold area to a hot area because of the difference of temperature. Similarly, moisture may enter and condense within compartments and individual materiel during descent from altitude to ground level.

d. Under certain conditions of temperature and humidity, hygroscopic materials in an enclosure may release moisture to the air and this moisture can subsequently condense on the internal surface of the enclosure causing accumulation of water.

3.3. Air Pressure

Altitude, compartment differential pressure, blast, and rapid decompression are factors contributing to induced levels of air pressure.

3.3.1. Altitude

3.3.1.1. Elevated Land Areas

Hand-carried or mounted materiel may experience low air pressure levels that alter materiel effectiveness at high altitudes. Pressure tight components or pressure relief mechanisms may be of value to maintain materiel performance and reliability.

3.3.1.2. Altitude above Sea Level

a. Materiel transported in aircraft is required to survive or function at air pressures above and below normal ground ambient determined by the location of the materiel on the flight platform and by the flight profile. Aircraft compartments may be pressurized to limit and maintain compartment atmosphere at acceptable pressures equivalent to a nominal altitude above sea level. Such compartments include cockpit or cabins that are occupied by the crew or passengers and cargo bays or areas that house avionics or other items specific to the operation of the aircraft or air-carried stores. Materiel carried in unpressurized regions will be subject to prevailing ambient pressures at flight altitudes. Also, during take-off and landing or as a result of flight manoeuvers, rates of change of pressure far in excess of those arising from meteorological conditions may occur.

b. Frontal areas and leading edges of externally carried stores on aircraft will be subject to dynamic pressure during flight. Air pressure transients above normal ground ambient will be experienced by externally fitted materiel subject to blast from battlefield explosions. Internally fitted materiel located in pressurised compartments will be subject to steady values of overpressure during ground pressurisation tests.

c. Materiel deployed on fixed wing aircraft is required to survive or function at air pressures above and below normal ground ambient determined by its location on the flight platform and the operational scenario. Aircraft compartments may be pressurized to limit and maintain the atmosphere at an acceptable pressure equivalent to a nominal altitude above sea level, e.g., cockpit or cabins occupied by the crew or passengers, cargo bays or areas housing avionics or other items specific to the operation of the aircraft or air carried stores. Materiel carried in unpressurised areas will be subject to the prevailing ambient pressure at the flight altitude. Also, during take-off and landing or as a result of flight manoeuvres, rates of change of pressure far in excess of those arising from meteorological conditions may occur

3.3.2. Pressurized Compartments

a. Compartments of vehicles may be pressurized. Therefore, levels of pressure may be different from those arising from meteorological conditions.

b. During storage, compartments of shelters may be pressurized above outdoor ambient levels. The compartment level is then maintained above that of the external ambient pressure by an amount known as the differential pressure. Handling may require compartments to be depressurized or may result in unexpected depressurization. When handled, rates of change of pressure far in excess of those arising from meteorological conditions are likely to occur.

c. Normally during flight, materiel installed in pressurized compartments will experience air pressures ranging between local ground ambient and some lower value equivalent to that at a predetermined altitude, say 3000 m. Alternatively, materiel installed in unpressurized areas will be subject to the ambient air pressure at the flight altitude.

3.3.3. Rates of Change of Air Pressure

3.3.3.1. Normal Operational Transient Changes

a. It may be necessary for some items of materiel to remain installed during routine high pressure testing of submarine compartments. Air pressure within the hull may rise above standard ambient while submerged, especially when firing a salvo of weapons. Materiel installed or carried inside the pressure hull is likely to be subjected to cyclic variation in air pressure below standard ambient during snorting.

b. Positive and negative rates of change of pressure during flight sorties vary from those resulting from normal take-off and landing. Rates of change experienced by carried materiel depend on aircraft performance, the flight or mission profile and whether the materiel is carried in a pressurized or non-pressurized area.

c. Operational roles of rotary winged aircraft preclude the need for pressurized compartments. Pressure levels experienced by deployed materiel are the prevailing ambient conditions at all stages of operation. However, rates of change of pressure will invariably exceed those resulting from meteorological conditions and will be determined by rates of climb and descent of the flight platform.

3.3.3.2. Blast

a. Externally deployed materiel may experience overpressure caused by blast from explosions, gunfire and efflux from weapons fired or launched from the aircraft.

b. Materiel on ships deployed above deck or in magazine areas may be required to survive, remain safe or continue to operate when subjected to blast from gunfire and motors of ship-launched weapons.

3.3.3.3. Rapid Decompression

a. Abnormal rates of change of pressure may occur in normally pressurized compartments during emergency situations. The rate of depressurization following failure of the pressurization system will depend on the volume of the compartment and the initial pressure differential. In the absence of specific information regarding the size of compartments, a maximum duration of one minute should be assumed for the pressure to fall to its minimum value.

b. Emergency flight conditions caused by failure of the pressurisation system or failure of the aircraft structure induce rapid or explosive decompression during which deployed materiel may be required to remain safe, survive or continue operating.

3.4. Hydrostatic Pressure

Materiel deployed underwater or carried on the external surfaces of ships hulls, particularly on submarines, will be subjected to induced hydrostatic pressure dependent on the depth of immersion.

3.5. Icing

In addition to naturally occurring and combinations of low temperature and dew point, factors contributing to induced icing include ships manoeuvers in cold temperature, aircraft impact with super-cooled water droplets, moisture accumulations within materiel subsequently exposed to cold temperatures, and materiel stored adjacent to refrigerated units.

3.5.1. Low Temperature and Dew Point

Icing may occur during any stage of materiel service life when combinations of temperature and dew point combine at critical levels. Wet surfaces exposed to sufficiently cold atmospheric temperatures will freeze, particularly those surfaces not warmed by ground temperatures.

3.5.2. Ships Manoeuvers

When operating in low temperature regions ships manoeuvers (e.g. speed and orientation with respect to the prevailing wind) may contribute to the level of icing experienced by the superstructure and by materiel carried on deck. When submarines operate on the surface in low temperature regions, spray created by manoeuvers of the submarine in the prevailing sea and wind may contribute to the level of icing experienced by materiel on the hull and superstructure.

3.5.3. Aircraft Impact with Super-cooled Water Droplets

Induced-icing of externally carried stores may occur during the various stages of a flight sortie caused by impact with super-cooled water droplets (e.g., clouds and mist).

3.5.4. Accumulated Moisture

Materiel installed in compartments of the aircraft or air-carried stores that are susceptible to breathing and retaining moisture, may experience frosting and icing due either to sub zero temperatures at flight altitude or when cold surfaces meet warmer damp air during descent to ground level. Localized drainage may help to alleviate moisture retention and freezing problems. Icing may be counteracted by on-board de-icing systems.

3.5.5. Proximity to Refrigerated Units

Certain types of materiel carried on materiel platforms may have built-in refrigeration systems that function during operations. Surfaces of other materiel stored next to such refrigerated systems may experience induced condensation that will freeze in low temperatures unless influenced by exhaust portions of refrigerated systems.

3.6 Dust and Sand

a. Materiel deployed or stored on aircraft required to operate from airfields or landing areas in dry desert regions may be exposed to dust and sand-laden atmospheres caused by aircraft operations and movement of land-based vehicles. While parked, aircraft may become enveloped in clouds of dust created during ground operations of other aircraft and land based support vehicles. Busy airfields are likely to incur many traffic movements producing significant accumulations of dust and sand.

b. Servicing procedures will, from time to time, require that panels be removed for access to plug-in points on aircraft and air carried stores. Such servicing may allow dust to enter. The dust remains in that internal atmosphere indefinitely.

c. When ground running or hovering at low level over desert areas (or areas covered in other types of small particles), rotary winged aircraft are noted for self inducing dust and sand environments.

3.7. Wetting

Precipitation, spray, drip, splash, and immersion are factors contributing to induced levels of wetting caused by dripping condensation from overhead surfaces, fire sprinklers, fractured pipes, leaking joints, cleaning operations, and exposure to splashing or immersion directly from operations in or near open waters.

3.7.1. Condensation and Drip

a. When cold surfaces meet warmer damp air, condensation forms on colder surfaces and drips or runs onto crevices where it may accumulate and cause other problems such as corrosion or electrical short circuits in the materiel itself or in other materiel or stores.

b. This phenomenon can occur during aircraft descent from flight altitude to ground level or during vehicle operations in hot humid exterior conditions when interiors of air-conditioned vehicles are opened to hot and humid outdoor ambient conditions.

3.7.2. Spray and Splash

a. For ships manoeuvers in prevailing sea conditions, containers or stores placed above deck, and movement of vehicles or other types of service platforms that use the ship as an operational base, can result in levels of wetting ranging from mild spray or splashing to rough seas.

b. Materiel installed or stored in workshops or other areas where vehicles or machinery are maintained or repaired is likely to remain in-situ while the platform is washed down during cleaning procedures. Such materiel may be subject to occasional splashing or spraying by other types of fluids such as fuels, lubricants and cleaning fluids. Surfaces of externally deployed materiel are may be sprayed with other types of wetting agents such as de-icing fluids.

3.7.3. Immersion

a. Clearly materiel on the outer surface of the hull will be subjected to total immersion while operating underwater. While on the surface, submarine manoeuvers in the prevailing sea conditions or washing and hosing down operations can result in levels of exposure ranging from mild spray or splashing to green seas.

b. Materiel not intended for operation mainly on the ground (e.g. aircraft, stores) may be subjected to splashing, spray, or fording during movement on the ground.

c. Rotary-winged aircraft and materiel and stores on those aircraft are subject to spray generated by the downwash of the rotor of the host aircraft when hovering at low level over water.

3.8. Erosion by Impact

Leading edges and forward facing surfaces of externally carried materiel may be susceptible to erosion by impact with rain, hail, dust and sand or other forms of particulate, especially during flight.

SECTION 232 - TRANSPORTATION

LEAFLET 232/1 - TRANSPORTATION

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1. GENERAL

a. This leaflet addresses the climatic environments that may be experienced by materiel during road, rail, air or sea transportation among manufacturing sites, storage bases, forward areas, and in tactical situations. Characteristics of climatic environments induced under these transportation conditions are presented, discussed, and supplemented by data sheets. Advice is given on potential damaging effects, treatment options and, where relevant, the selection of the appropriate AECTP 300 test method.

b. For the purpose of this sub-section, materiel exposed to transportation environments may be unprotected or carried within some form of protection, package or container. The platform may be in different configurations (e.g., uncovered, covered, open, or closed vehicle).

c. All the natural environments may be encountered during this transportation in open sky and induced climatic environments. Natural environments (open sky) are addressed in AECTP 200, Leaflet 2311; the only difference is perhaps the ventilation produced by the speed of the vehicle in transit.

d. Typical types and causes of induced climatic environments (applying to transportation, handling and storage, and to deployment on aircraft and ships) are presented in Section 231, General, § 3.

2. CHARACTERISTICS OF INDUCED ENVIRONMENTS[1]

2.1. Temperature

2.1.1. Road and rail transportation

2.1.1.1. Materiel carried in covered vehicles

a. The platform environment for materiel carried in covered vehicles is characterized primarily by ambient air temperature within the enclosed area, influenced by solar radiation falling directly on the covering surface. Covered, solar-loaded platforms can elevate interior temperature to the limit allowed by the cooling effects of ventilation induced by the speed of the vehicle when the enclosure is not air-tight.

b. An example of internal vs. external temperature and humidity (by time of day) in the covered cargo area of a common carrier at rest (storage condition) and while moving at speeds of up to 90 kph (transportation condition) is presented in Annex A. Note that the air movement during transportation tends to moderate swings in temperature and humidity throughout daylight hours.

[1] General types and causes of induced climatic environments are described in Section 231 of this document. Characteristics of open sky ambient climatic environments (e.g., for vehicles on the ground not under cover) are described in Leaflet 2311.

2.1.2. Air transportation

2.1.2.1. Aircraft parked

High temperatures inside unventilated compartments may exceed local ambient temperatures due to the indirect effects of solar radiation. Therefore, systems and components contained within such compartments will be affected similarly. To determine the highest temperatures that carried stores may be expected to withstand, data should be obtained at specific locations within platforms where stores are to be carried. Examples of such data obtained at two locations within an aircraft are in Annex A. Note that temperature at one location is fairly steady throughout the diurnal cycle while temperature at the other location varies widely.

2.1.2.2. Ground operating

a. When power is applied either directly from the engine or from external supplies, on-board environmental control systems will distribute conditioned air to some compartments of the aircraft or to aircraft carried stores to alleviate the effects of induced conditions.

b. At initial switch-on, external ambient air is drawn in and distributed around the aircraft before the environmental control system has had time to become effective. External ambient air in cold regions may chill materiel in conditioned compartments at a higher rate than would be expected from the ambient air in temperate regions. As ground running continues, the environmental control system becomes more effective. In cold regions, materiel begins to benefit from any self-generated heat and from heat given off by other materiel.

c. During normal ground running, temperatures inside aircraft compartments depend on external ambient air temperatures, on materiel packing densities, on heat radiated from adjacent structures and operational materiel, on the level of any conditioning, and on the period of operation. In contrast, during long term ground running in hot regions, the combined effect of heat radiated from adjacent structures and operational materiel may tend to counteract the effects of the conditioned air. Long-term ground running without forced-air cooling should be avoided in hot, dry regions, otherwise permanent damage or degraded reliability may occur.

d. Data on induced temperatures should be derived from measurements made at the intended location of materiel on the flight platform during representative worst-case conditions. Historically, where specifically measured data have not been available, maximum switch-on temperatures for materiel carried in both conditioned and non-conditioned areas of aircraft deployed in hot, dry regions have been taken as equivalent to the maximum induced temperatures for ground conditions. For long-term ground running in hot, dry regions and where characteristics of cooling air are unknown, ambient temperatures in conditioned compartments are assumed to stabilize at 15 °C lower than at switch-on. Temperatures at switch-on should be assumed to prevail in non-conditioned areas.

e. Temperature levels may be influenced by the packing density of stores, heat dissipation of components, the number of thermal paths to external surfaces, and the incorporation of cooling systems. Where internal ambient temperatures or temperature levels of individual components are of concern, expected temperature levels should be estimated using thermal analysis programs incorporating the influences given above supported by specific measurements made in representative conditions.

f. For deployment in low temperature regions, and in the absence of measured data, the following severities may be assumed to represent worst case conditions at switch-on for materiel in enclosed compartments of which the skin surfaces are better radiators of heat to the night sky than the ambient air:

Area of Deployment (Climatic Category)	Induced Temperature (°C)
C0	-21
C1	-33
C2	-46
C3	-51
C4	-57

2.1.2.3. Flight sorties

a. Materiel installed inside aircraft compartments may be subjected to high induced temperatures from heat given off by engines and auxiliary power units, engine exhaust systems, avionics and electrical materiel, or from being located in a stagnant area such as an materiel rack or behind an instrument panel. The cooling capability of materiel operating in partially or non-conditioned compartments may be affected by lower density air at flight altitude and cause the operating temperature of that materiel to rise to unacceptable levels.

b. Materiel aboard operating aircraft may be subjected to thermal shock. Transition times between ambient temperatures at ground level and flight altitude, and vice-versa, during take-off and landing are likely induce thermal shock in materiel in non-conditioned areas. Such shock may stress materiel beyond design limits unless taken into account during design and manufacture. In the absence of measured data, severities may be derived from knowledge of maximum rates of climb and descent for the host aircraft. Rates of change should be determined from data measured during representative flight trials.

2.1.3. Sea transportation

2.1.3.1. Above deck on surface ships

a. Where no ventilation or assisted cooling is provided, high temperatures inside unventilated shelters or under temporary covers exposed to solar radiation are likely to exceed those outside of the enclosed area. Clearly, the most severe conditions will occur when shipborne materiel is installed or carried above deck in hot regions of the world. The relative angle of elevation between the sun and the exposed surface, the prevailing cloud cover, the surface finish, the color and heat capacity of the radiated surface, and the duration of exposure will determine the amount of heat absorbed. The induced ambient temperature of the enclosed atmosphere will depend on the level of any ventilation or forced air cooling.

b. Information on temperatures induced on surface ships inside sheltered areas or under temporary covers above deck is not readily available. Expected induced levels should be determined from specific measurements for particular applications. In the absence of measured data, the temperatures determined for general Transportation and Storage in Leaflet 2311 (marine category M1) should be assumed to apply to materiel in shelters or under cover above deck aboard ship. The severities for high temperature areas on open seas (marine category M1) tend to be around 2 °C lower than those for overland (climatic category A1), implying the latter should be taken into account if the ship is to operate in and out of ports in those geographic regions. A similar consideration is more appropriate with regard to temperature severities for Transport and Storage in the colder regions of the seas, (marine category M3), where temperatures may be up to 12 °C higher than those over land in the same geographical areas (climatic category C2).

c. Materiel may experience thermal shock. When the ship is operating in low temperature regions, materiel brought on deck from a hold may experience changes in temperature in the order of 45° C over a period of a few minutes or less. Conversely, materiel immersed in the sea immediately after a solar temperature soak could experience a change in temperature in the order of 50° C in a few seconds.

2.1.3.2. Air conditioned compartments

Temperatures in air conditioned compartments on surface ships may range from 15 °C to 30 °C and relative humidity of 30 to 70 %. Variations within those limits will depend on external ambient conditions and the amount of heat given off by operational materiel and personnel occupying the compartment, but may be considered constant once established in the climatic area of operation. In the event of an interruption in the supply of conditioned air, a temperature of 40 °C with relative humidity of 70 % should be assumed to occur for periods of up to 20 minutes.

2.1.3.3. Partial- and non-conditioned compartments

a. The influence of external ambient conditions on the levels of temperature and humidity in partial and non-conditioned compartments will depend on the location of the compartment within the vessel. The further the compartment is below the main deck and towards the center of the hull, the more likely the influence of external ambient conditions will be diminished. In some cases the heat and moisture dissipated by operational machinery will be the dominant factor such that when the vessel is operational, constant ambient conditions ranging from dry to damp heat can occur.

b. Some conditions may be localized to particular areas of a compartment. The closer an unconditioned compartment above the water line is to the outside walls of the hull or the main deck, then the greater will be the indirect effects of solar heating of the ships structure on the ambient temperature in the compartment, particularly when operating in category A climatic areas. In the absence of measured data, conditions in fresh air ventilated compartments range from 15 to 45°C with relative humidity of 30 to 85%, but for the reasons given above, severities for particular installations should be determined from specifically measured data.

c. Steady state conditions in unconditioned compartments may range from 0 to 80° C with 30 to 80% relative humidity. Abnormal excursions may rise to 100º C. Higher temperatures are more likely to be experienced as a result of being attached, or in close proximity, to operational machinery that has high surface temperatures or that is located in stagnant areas not served by any form of ventilation.

d. Some materiel may be located in refrigerated areas or close to external hatches. Unless otherwise specified, operational materiel near external hatches should maintain correct operation to -10 °C, with degraded performance to -30 °C.

2.2. Humidity

2.2.1. Road and rail transportation

2.2.1.1. Materiel carried in a covered platform

Absolute humidity experienced by materiel during transportation is quite the same as external ambient or meteorological humidity.

2.2.1.2. Materiel carried in an enclosed platform

The magnitude of the diurnal cycle of relative humidity experienced by materiel is normally more than the meteorological conditions for most kinds of warm/hot climatic conditions because temperature variations are increased.

2.2.2. Air transportation

2.2.2.1. Aircraft parked

Dependent on its location on the flight platform, levels of humidity experienced by materiel may exceed those of local meteorological conditions. Unventilated compartments of flight platforms deployed in wet tropical regions may breathe in moisture as a result of pressure changes induced by the diurnal temperature cycle.

Similarly, condensation and ingress of moisture occur inside compartments and individual materiel during descent from altitude to ground level.

2.2.2.2. Ground running

a. It may be assumed that when engines are running or aircraft systems are operating from external power supplies, hatches will be open and air conditioning systems will be operating, providing ventilation and a reduction in the level of moisture of the atmosphere in the previously closed compartments. The relative humidity inside installed materiel within semi-sealed, unventilated, enclosures will be reduced gradually by self-dissipated heat, although moisture content is unlikely to be reduced. When power is switched off and the materiel cools, the differential air pressure on either side of the walls of an enclosure may cause the enclosure to breathe in external air and increase the level of retained moisture.

b. Materiel transported in aircraft operating in hot-dry regions of the world may experience extremely low levels of humidity when subjected to the indirect effects of solar heating or when located close to sources of dissipated heat during ground running. Electrical/electronic systems with high packing densities and on-board air-carried armaments subject to ground running may be similarly affected. No recorded data are readily available for such induced dry atmospheres. Relative humidity levels of less than 30% are common for naturally occurring conditions in hot-dry regions of the world. Therefore equivalent or lower levels of RH may be assumed to occur inside nominally dry aircraft compartments or similar areas of individual materiel subjected to induced high temperatures.

2.2.2.3. Flight sorties

Moisture may be formed on external and internal surfaces of materiel during flight sorties as a result of the transfer between prevailing temperatures at ground level and flight altitude and vice-versa, especially when flying into and out of airfields in tropic regions. Warm air in the compartments and individual items of materiel mixes with lower temperature ambient air during the climb to altitude. When cold aircraft surfaces meet warm damp air during descent and landing, moisture condenses out as the air temperatures are reduced below their respective dew points. In the latter case, conditioning is aggravated by the change in air pressure forcing in warm, damp air. It should be assumed that RH levels in conditioned compartments will reach 90-95%, while in unconditioned compartments saturation will occur.

2.2.3. Sea transportation

2.2.3.1. Above deck on surface ships

a. Materiel stored on deck in unventilated shelters or under temporary covers is likely to be subjected to high levels of induced humidity, especially when deployed in hot-wet tropic regions. Worst cases occur where the diurnal cycle is characterized by high temperatures during the day and low temperatures at night, producing corresponding variations of pressure in the covered areas, causing them to breathe in moisture, some of which is retained when the external ambient temperature rises again. Solar radiation on the external surfaces of shelters or temporary covers during the hotter part of the diurnal cycle can result in enclosed materiel being subjected to a damp heat environment more severe than the external ambient conditions. The accumulation of moisture can lead to a higher dew-point temperature and, therefore, the possibility of saturation occurring during the cooler part of the cycle.

b. Preferably, conditions for particular applications should be determined from specifically measured data. Levels of relative humidity may be reduced by heat from operational materiel, but in the absence of measured data, the Leaflet 2310 induced conditions should be selected.

2.2.3.2. Air Conditioned Compartments

See Paragraph 2.1.3.2.

2.2.3.3. Partial And Non-Conditioned Compartments

See Paragraph 2.1.3.3.

2.3. Air Pressure

2.3.1. Road and rail transportation

Pressure inside a vehicle is generally the same as for open sky conditions.

2.3.2. Air transportation

2.3.2.1. Aircraft parked and ground running

Materiel transported in aircraft will normally experience air pressures equal to those of local ground ambient with the exceptions given in paragraphs below. While subject to routine ground pressurization tests, materiel fitted in aircraft compartments pressurized during flight may be required to remain in-situ to determine the integrity of seals. Where applicable, the value of overpressure likely to be experienced should be agreed between the aircraft manufacturer or operator and the Design Authority for the installed materiel.

2.3.2.2. Flight sorties

a. Normally during flight, materiel installed in pressurized compartments will experience air pressures ranging between local ground ambient and some lower value equivalent to that at a predetermined altitude (for example 3000 m). The internal pressure is then maintained by onboard systems above that of the external ambient pressure by an amount known as the differential pressure. Alternatively, materiel installed in unpressurized areas will be subject to the ambient air pressure at the flight altitude.

b. Rates of change of pressure vary during flight sorties from those resulting from normal take-off and landing. Rates of change experienced by carried materiel depend on aircraft performance, the flight or mission profile and whether the materiel is carried in a pressurized or non-pressurized area or container.

c. Rapid decompression (i.e., abnormal rates of change of pressure) may occur in normally pressurized compartments during emergency situations. The rate of depressurization following failure of the pressurization system will depend on the volume of the compartment and the initial pressure differential. In the absence of specific information regarding the size of compartments, a maximum decompression duration of one minute should be assumed.

2.3.3. Sea transportation

2.3.3.1. Above deck on surface ships

Materiel installed above deck normally will experience pressures equivalent to the local ambient air pressure at sea level.

2.3.3.2. Air conditioned compartments

Air pressure inside compartments of a ship may be raised above the local ambient air pressure to provide a gas tight seal against the ingress of external contamination. The absolute pressure experienced by materiel contained within the compartment should be assumed to be the maximum value of ambient pressure likely to occur at sea, (in the order of 1060 mbar), plus some specified level of overpressure determined to be appropriate. In the absence of a specified value, a level of 8 kPa (80 mbar) over pressure should be assumed.

2.4. Icing

2.4.1. Road and rail transportation

For materiel carried in covered and in enclosed vehicles, icing of materiel during transportation normally arises entirely from the prevailing meteorological conditions.

2.4.2 Air transportation

2.4.2.1. Aircraft parked

Materiel icing on aircraft that are static on the airfield normally arises entirely from the prevailing meteorological conditions at ground level.

2.4.2.2. Ground running

Icing of materiel may be counteracted by on-board de-icing systems during ground running.

2.4.2.3. Flight sorties

Freezing of induced moisture depends on the provision or otherwise of localized drainage, accumulations of water are likely to be frozen by low temperatures at flight altitude.

2.4.3. Sea transportation

Materiel on open decks is likely to be subjected to accumulations of ice formed from freezing spray. Ships manoeuvers in prevailing sea conditions can increase the amount of spray thrown over the vessel. Rates of ice accretion of up to 40 mm/h have been reported for ships operating in the Arctic region.

2.5. Dust and Sand

2.5.1. Road and rail transportation

2.5.1.1. Materiel carried in covered vehicles :

Operation and movement of common carriers are likely to generate clouds of dust and sand that intrude into the interior vehicles because they are not dust-proof. Severities of concentration and distribution of particulates are generally less than those experienced in open sky situations.

2.5.2. Air transportation

2.5.2.1. Aircraft parked

Operation and ground movement of an aircraft in the vicinity of a parked aircraft (e.g., vertical take off and landing, hovering, and normal helicopter activity) are likely to generate considerable accumulations of turbulent, driven dust particularly when deployed in hot-dry desert regions. To a lesser extent, the wheels and tracks of land-based vehicles also generate clouds of dust and sand. Severities of concentration and distribution of particulates above ground level depend on the same parameters as for naturally occurring dust and sand clouds.

2.5.2.2. Ground running

When the host aircraft is ground running on airfields in hot-dry desert regions or on temporary landing strips, the backwash from propellers or the efflux from jet engines can produce considerable concentrations of air-borne dust and sand and other types of small particulates. Areas forward of jet tailpipes are also vulnerable if reverse thrust mechanisms are exercised during engine runs.

2.6. Immersion, Precipitation and Spray

2.6.1. Sea transportation

2.6.1.1. Above deck on surface ships

No measured data indicating severities of induced forms of wetting experienced by materiel installed or carried above deck are readily available. Subjective observations indicate that materiel can be subjected to short periods of precipitation equivalent to heavy rain and accumulations of water up to 150 mm deep.

2.6.1.2. Air conditioned compartments

The levels of precipitation associated with condensation on overhead surfaces and emergencies such as fractured and leaking joints in water pipes are unpredictable. Historically, a minimum rate of 280 $l/m^2/h$ is used when testing materiel for compatibility with this type of conditioning (dripping and pooling).

2.6.1.3. Partial And Non-Conditioned Compartments

When materiel is installed or stored in unconditioned compartments (e.g., as cargo bays, aircraft hangers, garages for deck vehicles, engine and generator rooms, workshops, laundries and galleys) there is a greater probability of materiel being subjected to some form of wetting including, in some cases, the possibility of partial immersion. Severities of up to 280 $l/m^2/hr$ should be assumed for precipitation, dripping, and pooling, and depths of up to 150mm for Immersion.

2.7. Hydrostatic Pressure

During sea transportation, materiel carried on board for subsequent immersion in the sea, will be subjected to hydrostatic pressure dependent on the depth of immersion defined in the design requirement for the individual materiel. Pressure is related to the depth of immersion by the formula:

$$p = 9.8d$$

where p is the hydrostatic pressure in kPa, and d is the depth of immersion in meters.

3. POTENTIAL DAMAGING EFFECTS

3.1. Temperature

3.1.1. General

a. Induced temperatures experienced by materiel during transportation can affect the physical and chemical properties of materials used in their manufacture. Expansion and contraction of structural components accompanied by reductions in mechanical strength and changes in ductility result in interference and separation between adjacent parts and impose unacceptable levels of stress and strain leading to deformation or mechanical failure. Induced variations in the characteristics of electrical/electronic components and changes in viscosity of lubricants reduce accuracy, reliability and operating efficiency.

b. Thermal shock induces high rates of expansion and contraction, resulting in stress and fracture of materials, failure of bonded joints, and degraded performance of seals.

3.1.2. High altitude aircraft and missiles

High and low temperatures affect the physical and chemical characteristics of rocket fuels which may result in malfunction of motors of guided weapons.

3.2. Humidity

3.2.1. General

a. Induced damp heat conditions, resulting from a combination of inadequate ventilation and enforced breathing of moisture, created inside vehicles accelerate the degradation of materials.

b. Warm, damp atmospheres in unventilated areas provide ideal conditions for promotion of corrosion, chemical attack and fungus growth.

c. Induced low levels of humidity during transportation can influence the characteristics of electrical/electronic components and affect the calibration, stability and accuracy of electronic systems when used immediately after the transportation.

3.2.2. Transportation

a. Induced damp heat conditions (e.g., created inside unconditioned platform compartments, in individual materiel permanent shelters, or under temporary covers on ships above deck) result from a combination of inadequate ventilation and enforced breathing of moisture. Such breathing accelerates the degradation of materials and causes a higher frequency of malfunction of materiel than would exposure to the local meteorological conditions alone. Reduction or breakdown of insulation resistance of circuitry and components can result in degraded performance, safety hazards, reduced reliability, or total failure of electrical/electronic systems. Performance of surveillance materiel may be reduced by high humidity and by accumulations of moisture in optical systems. Low levels of humidity can influence the characteristics of electrical/electronic components and affect the calibration, stability and accuracy of electronic systems.

b. Warm damp atmospheres in unventilated areas provide ideal conditions for the promotion of mold growth and aggravated attack by corrosive agents. Issues to be addressed are the effects of moisture on materiel, achieving and maintaining dry interiors, standards and methods of sealing, water vapor barriers, drying out procedures, and humidity monitoring methods.

c. Low levels of humidity may reduce the moisture content of materials used in the manufacture of electrical/ electronic components, changing their characteristics affecting the stability that is necessary to maintain performance of systems within specified tolerances. Operating efficiency of mechanical systems can be reduced due to degradation of lubricants by both dry and damp atmospheres.

3.3. Air Pressure

3.3.1. Air transportation

3.3.1.1. Pressure differentials

Low air pressure at flight altitude and rates of change of pressure induced during flight sorties may create pressure differentials across the walls of cases and protective covers of materiel and components. Components may deform, fail structurally, or interfere with internal parts, causing those parts or platform materiel to malfunction. Although materiel may be fitted with pressure equalization devices, rates of change of pressure during flight sorties may exceed design values. Extreme cases may occur during emergency situations in normally pressurized compartments when explosion or implosion of the container may occur.

3.3.1.2. Cooling

Heat dissipating materiel that relies on convection for maintaining an acceptable operating temperature, may exhibit degraded performance due to the reduced efficiency of the cooling system because of lower air pressure at flight altitude.

3.3.2. Sea transportation

Air pressure above standard ambient may cause problems. Sealed or partially sealed materiel with low leakage rates may be susceptible to temporary distortion or permanent mechanical damage if located in compartments employing overpressure to provide an air tight seal. Protective covers of large items that withstand normal variations of standard atmospheric pressure may be of particular concern.

When subjected to hydraulic pressure, materiel of closed construction may be subjected to structural deformation, impairing the integrity of joints and seals, allowing water to enter or fluids and gasses to escape.

3.4. Icing

3.4.1. General

Frosting or freezing of accumulations of moisture caused by induced variations of temperature and pressure may result in degraded performance or total failure of materiel in partial or no-conditioned areas.

3.4.2. Sea transportation

Due to ship's manoeuvers, icing on materiel located above deck may occur. This icing will be similar to that due to natural conditions. The operation of linkages, release mechanisms and actuation systems becomes impaired or completely blocked due to interference caused by the buildup of ice. Frosting and icing of sensors and optical devices can reduce the performance of surveillance and navigation systems.

3.5. Dust and Sand

During transportation at ground level, the effects of exposure to dust and sand-laden atmospheres include impaired performance of optical systems due to accumulations of particulates, corrosion of exposed underlying materials, blockage of apertures, and reduced efficiency of cooling and ventilation systems. Dust deposits inside materiel may cause short-circuiting of insulators, tracking and build-up of static electricity, interference between moving parts and contamination of lubrication systems.

3.6. Immersion, Precipitation and Spray

3.6.1. General

The effects of exposure to precipitation and spay are described in Leaflet 2311.

3.6.2. Sea transportation

Materiel subjected to immersion, precipitation and spray is likely to suffer ingress of water through apertures, seals, joints and seepage. This ingress affects materials and operational performance of materiel in the same manner as accumulations of moisture through breathing in of high humidity atmospheres.

4. TEST SELECTION

4.1. General

a. AECTP 300 gives test procedures that may be used for simulating induced climatic environments that may be experienced by materiel during transportation. The choice of test method for temperature and humidity will depend on whether there are any requirements to simulate climatic variations such as heating effects of solar radiation when materiel is transported within enclosures, or just the maximum or minimum temperatures experienced during transportation.

b. Preferably, test severities should be derived from specific measurements made on the intended transporting platform, on the intended flight platform, at the location in the compartment, or the area on deck during representative worst-case conditions expected in service. Alternatively, severities derived from data obtained for other examples of materiel transported in similar applications may be used.

4.2. Test Severities

4.2.1. Temperature and humidity

4.2.1.1. General

a. Temperature severities used in tests simulating high temperature conditions during air carriage should be derived using one or both of the following methods in descending order of preference:

(1) From specifically measured data recorded during hot and cold weather trials. Measurements should be made at the relevant location on the intended flight platform. Other factors influencing temperature severities, such as sources of dissipated heat and supplies of conditioned air, should be represented correctly. The trials programme should include flight sorties likely to produce worst-case conditions in service (e.g., aerodynamic heating).

(2) From data for a similar application with adjustments for differences in the factors referred to in (1) above.

b. Values of temperature and humidity are quoted (Leaflet 2311) for external ambient (meteorological condition) and conditions induced by transportation. In the absence of specifically measured data, values for the latter should be assumed to represent worst-case induced conditions experienced by material during transportation.

c. The quoted values of temperature and humidity are likely to be attained or exceeded in the most severe (hottest/coldest) location for 1% of the most extreme month of the year.

4.2.1.2. Sea transportation

Generally, test methods using diurnal cycles will be applicable to materiel in enclosed areas on or above deck. In many cases, conditions for materiel in compartments between decks can be simulated using test procedures that apply constant conditions. Testing for exposure to low temperatures in all areas of the ship normally will be satisfied using test procedures that give steady state conditions. In some instances, particularly for materiel of large mass and a thermal time constant comparable to or longer than the diurnal cycle, the closer realism of a cyclic test may be preferred to ensure that seals and components are stressed representatively.

4.2.2. Air pressure

4.2.2.1. Air transportation

a. Severities for low air pressure tests may be determined from the Environmental Requirements documents and from the performance of the platform aircraft (e.g., operational altitude, rates of climb and descent and the provision or otherwise of pressurization at the location of the transported materiel).

b. When simulating ground pressure testing for materiel installed in pressurized compartments, test severities for air pressures above standard ambient should be obtained from the airframe manufacturer or aircraft operator.

4.2.2.2. Sea transportation

Severities for simulating air pressure above standard ambient conditions and hydrostatic pressure should be specified in the Environmental Requirement for the materiel or obtained from the builder or design authority for the ship. Representative simulation of blast pressure waves from explosions, gunfire and weapon launch is best achieved by subjecting materiel to the real life environment.

4.2.3. Icing

During sea transportation, tailoring environmental conditions such as icing and various forms of wetting is unlikely to be cost effective. Recommended fall-back severities should be used.

4.2.4. Wind Blown Sandf and Dust

For artificially aerated dust and sand laden open sky atmospheres, turbulent dust is the preferred method. Simulated wind blown dust and sand may be used when the former cannot adequately demonstrate penetration and erosion by sharp edged particles.

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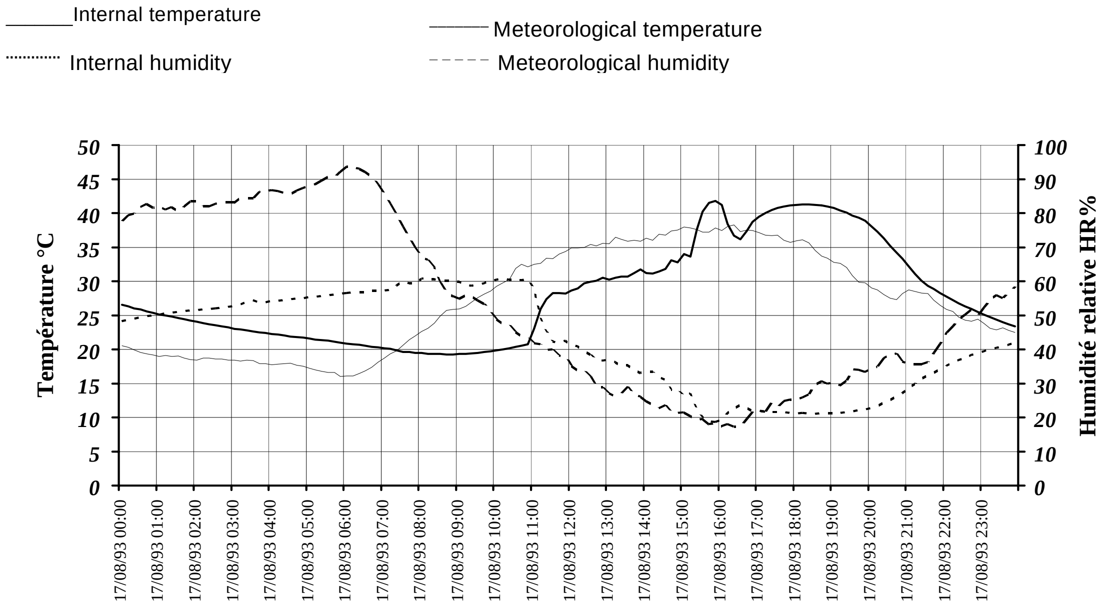
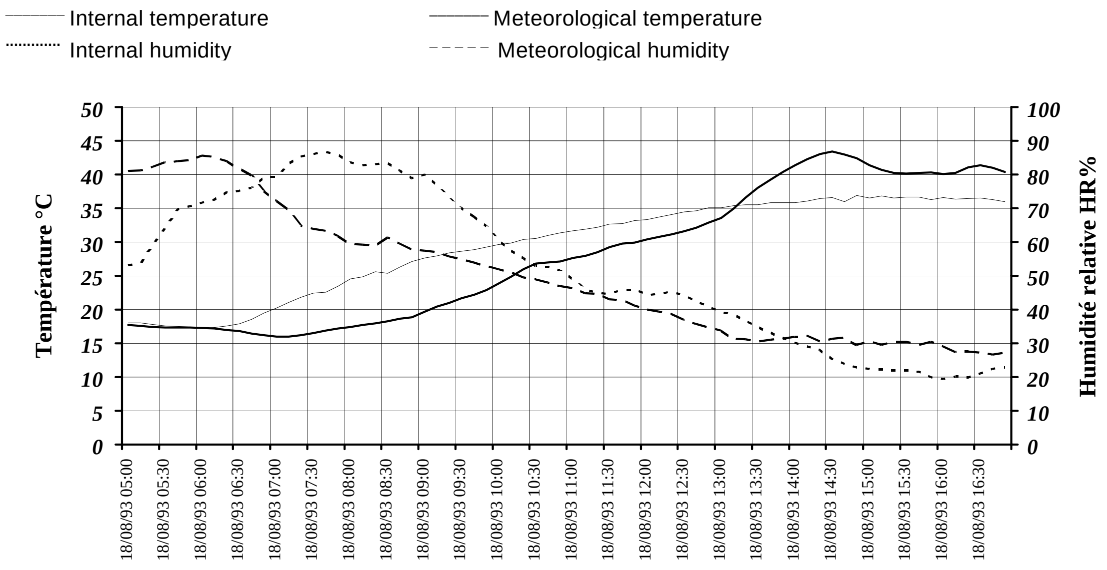
ANNEX A

Examples of Environmental Data for Road and AirTransportation Platforms

STORAGE IN COMMON CARRIER "G260" cover



TRANSPORTATION IN COMMON CARRIER " G260" cover

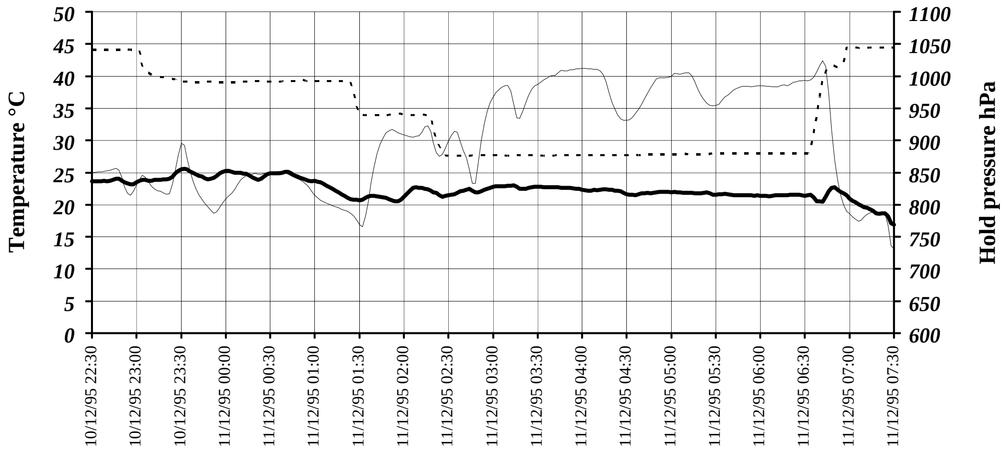


AIR TRANSPORTATION : HERCULES C130

area A1-C0 --> area A2-A3-C0

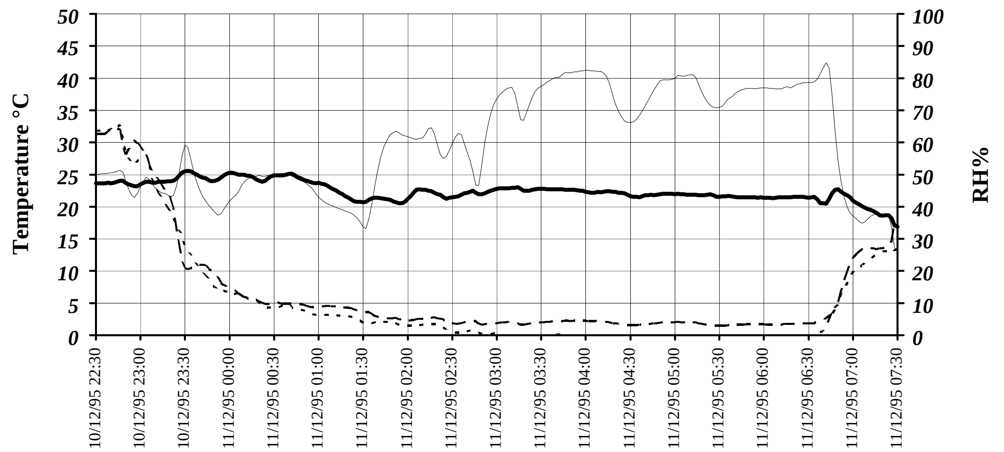
Temperature : middle hold (near the floor) — Temperature : rear hold (near the top of the loading)

Pressure : hold



Temperature : middle hold(near the floor) — Temperature : rear hold(top of materiel)

RH(%) : middle hold — RH(%) : rear hold



SECTION 233 - HANDLING AND STORAGE

LEAFLET 233/1 - HANDLING AND STORAGE

TABLE OF CONTENTS

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1. GENERAL

a. This leaflet addresses climatic environments that may be experienced by materiel during storage and handling. Characteristics of the climatic environments are presented, discussed, and supplemented by data sheets. Advice is given on potential damaging effects, treatment options and, where relevant, selection of the appropriate AECTP 300 Test Method. References are given in Annex B.

b. For the purpose of this sub-section, materiel exposed in storage or handling environments may be unprotected or within some form of protection package or container.

2. CHARACTERISTICS OF INDUCED ENVIRONMENTS

General types and causes of induced climatic environments are described in Section 231 of this document. Characteristics of open sky ambient climatic environments (e.g., for materiel on the ground not under cover) are described in LEAFLET 2311.

2.1. Temperature

2.1.1. Storage and handling

2.1.1.1. Light closed cover

Light closed cover for this chapter encompasses buildings of light construction, containers and other light temporary structures. The temperature range of the diurnal cycle experienced by materiel may be different to the meteorological conditions, especially in hot-tropic regions, where the diurnal cycle is characterized by high temperatures and high rates of solar radiation during the day. The minimum temperature experienced during storage may be warmer than the meteorological minimum. The diurnal cycle of temperature experienced by material during storage is out of phase with meteorological diurnal cycle. Thus, for a sunny day, the maximum temperature of the day is reached in the light closed cover before the maximum meteorological temperature is reached.

2.1.1.2. Heavy closed cover (e.g., explosives storage igloos)

The temperature range over the diurnal cycle experienced by material is less wide than the meteorological conditions for all kinds of climatic conditions. Examples are provided in Annex A for storage in heavy closed cover for zones A3-C3 and B3. Also in Annex A is an example of data obtained during natural desert environment storage of materiel.

2.1.2. Handling out-of-doors

a. For out-of-doors situations, most environmental characteristics are described in LEAFLET 2311.

b. Materiel may experience transient temperatures when moving or being moved from one place to another that has different climatic environments. For example, materiel may be moved from the open air to an air-conditioned room where the temperature is several degrees lower.

c. The magnitude of associated thermal shocks may be evaluated by calculating the difference of air temperature between the final location and the primary location. The bigger the heat capacity of the materiel, the smaller the temperature gradient experienced by the materiel.

2.2. Humidity

2.2.1. Storage and Handling

a. Absolute humidity experienced by materiel during storage is similar to the meteorological absolute humidity.

b. For heavy closed cover, because temperature variations are attenuated the magnitude of the diurnal cycle of relative humidity experienced by materiel is less than the meteorological conditions for all kinds of climatic conditions.

c. Condensation may occur on materiel when moved from a cold area to a hot wet one due to the difference of temperature.

2.3. Icing

Icing of storage materiel is unlikely to occur except for cold climatic zones. Icing of materiel in a light closed cover normally arises entirely from the prevailing meteorological conditions, with a lower probability of occurrence.

2.4. Dust and sand

Operation and movement of common carriers are likely to generate clouds of dust and sand that penetrate inside light closed covers because they are not dustproof. Concentration and distribution severities of particles are generally less in closed areas than those experienced in open sky situations.

3. POTENTIAL DAMAGING EFFECTS

3.1. Temperature

3.1.1. Storage

Induced temperatures experienced by materiel during storage can affect the physical and chemical properties of materials used in their manufacture. Expansion and contraction of structural components accompanied by reductions in mechanical strength and changes in ductility result in interference and separation between adjacent parts. These factors impose unacceptable levels of stress and strain leading to deformation or mechanical failure. Induced variations in the characteristics of electrical/electronic components and changes in viscosity of lubricants reduce accuracy, reliability and operating efficiency.

3.1.2. Handling

Induced transient temperatures experienced by materiel when handled may generate unacceptable levels of stress due to differential thermal expansion or contraction between materials. This phenomenon also may cause separation between adjacent parts.

3.2. Humidity

Storage and handling problems occur in enclosures experiencing high humidity. Induced damp heat conditions accelerate the degradation of materials. These conditions occur inside enclosures from a combination of inadequate ventilation and forced breathing of moisture. Warm, damp atmospheres in unventilated areas provide ideal conditions for promotion of corrosion, chemical attack and fungal growth. Induced low levels of humidity during storage can influence the characteristics of electrical/electronic components and affect the calibration, stability and accuracy of electronic systems when used immediately after the storage.

3.3. Icing

The potential damaging effects of icing of materiel are the stresses imposed at joints and interfaces of adjacent parts; damage incurred as a result of the methods used to remove the ice; and the subsequent accumulation of moisture after melting of the ice.

3.4. Dust and sand

Materiel can be affected by dust and sand during storage and handling. The effects include, but are not necessarily limited to, impaired performance of optical systems due to accumulations of particulate matter, corrosion of exposed underlying materials, blockage of apertures, and reduced efficiency of cooling and ventilation systems. Dust deposits inside materiel may cause short-circuiting of insulators, tracking and build-up of static electricity, interference between moving parts, and contamination of lubrication systems.

3.5. Precipitation and spray

The effects of exposure to wetting are described in LEAFLET 2311.

4. TEST SELECTION

4.1. General

AECTP 300 includes test procedures that may be used to simulate the effects of induced climatic environments on materiel during storage. The choice of test procedures will depend on whether there is a requirement to simulate diurnal variations (including the heating effects of solar radiation when open-sky-stored) or just the maximum or minimum temperatures of a diurnal cycle. Preferably, test severities should be derived from specific measurements made on the intended enclosure during representative worst-case conditions expected in service. Alternatively, severities derived from data obtained for other examples of materiel stored in similar applications may be used.

4.2. Fall-back test severities

If no specific environmental measurements are available, the fall-back test severities given in the AECTP 300 test procedures should be used.

4.3. Tailored test severities

4.3.1. Temperature and humidity

AECTP 300 test procedures give values of temperature and humidity for external ambient (meteorological) conditions and for conditions induced by storage. In the absence of specifically measured data, values for the latter should be assumed to represent worst-case induced conditions experienced by materiel during storage. The quoted values of temperature and humidity are those that are likely to be attained or exceeded in the most severe location for 1% of the most extreme month of the year.

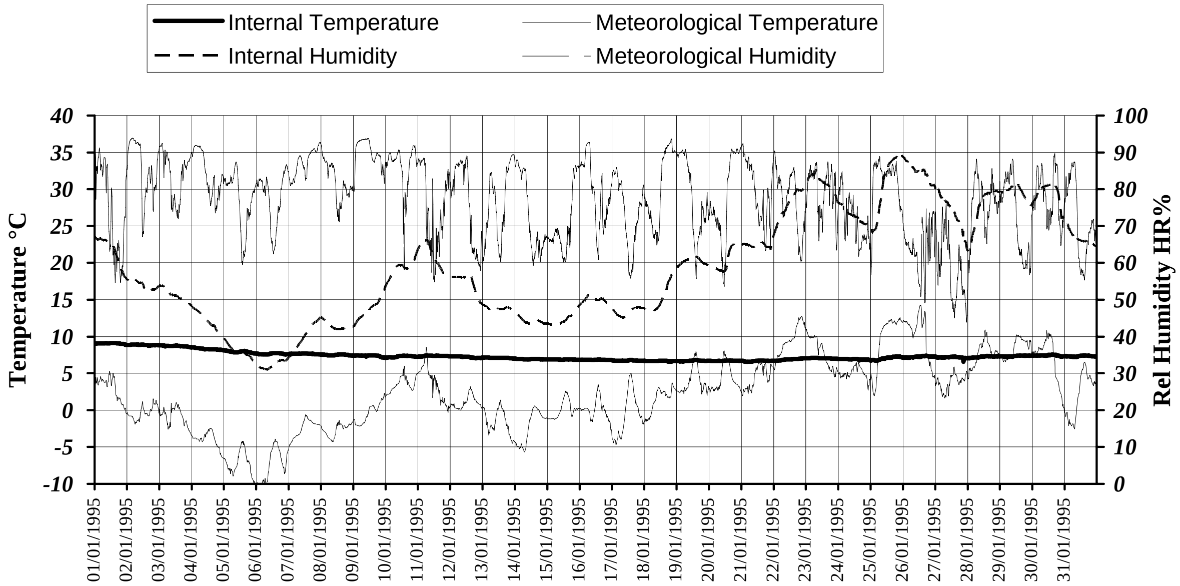
4.3.2. Dust and sand

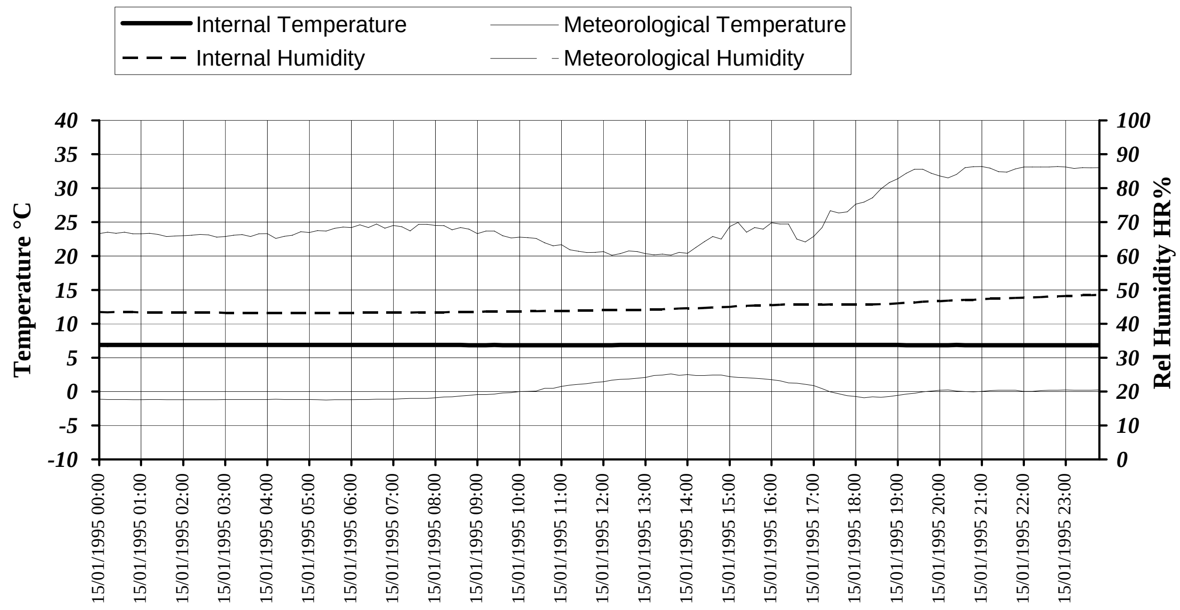
For artificially induced dust and sand laden open sky atmospheres, blowing dust is the preferred test procedure. Simulated wind blown dust and sand may be used when blowing dust cannot adequately demonstrate penetration and erosion by small, sharp-edged particles

ANNEX A

EXAMPLE OF STORAGE CONDITIONS IN A HEAVY COVER (IGLOO)

"Heavy cover : TYPE IGLOO, Category A3 - C1"

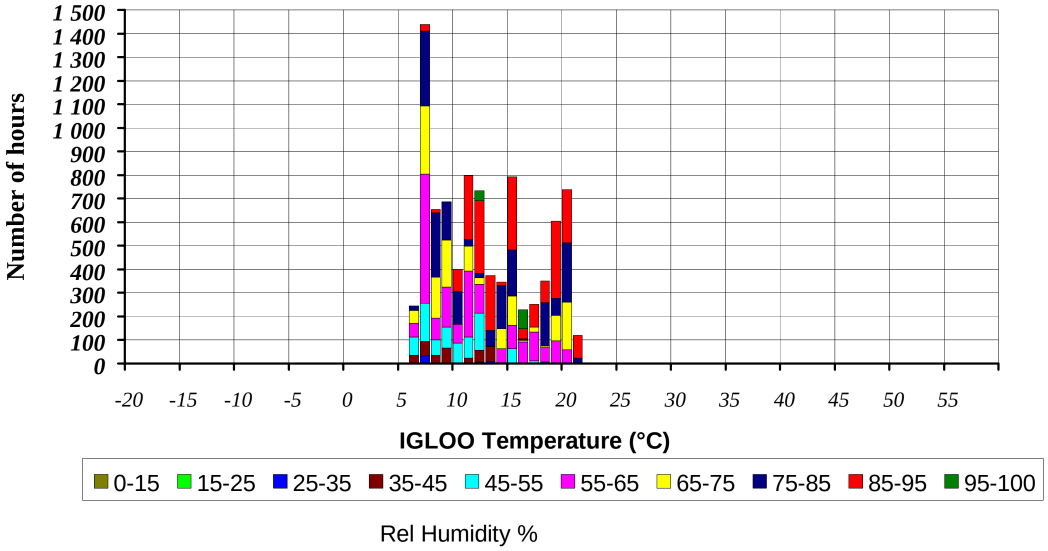




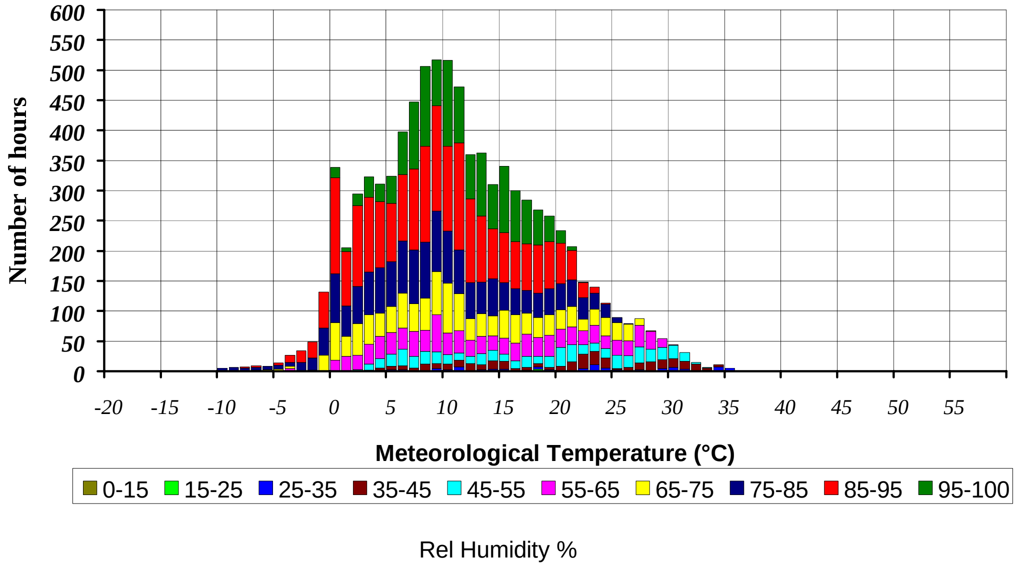
"Heavy cover : TYPE IGLOO, Category A3 - C1"

Measures : 1/05/94 to 30/04/95 (1 year)

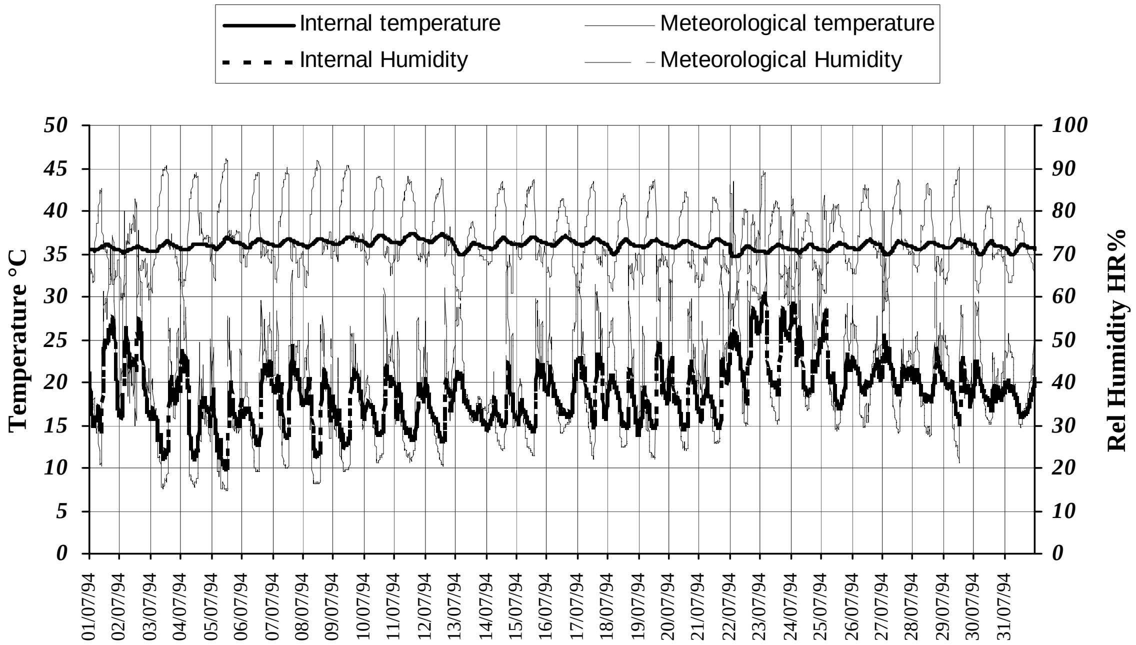
Histogram for temperature and humidity

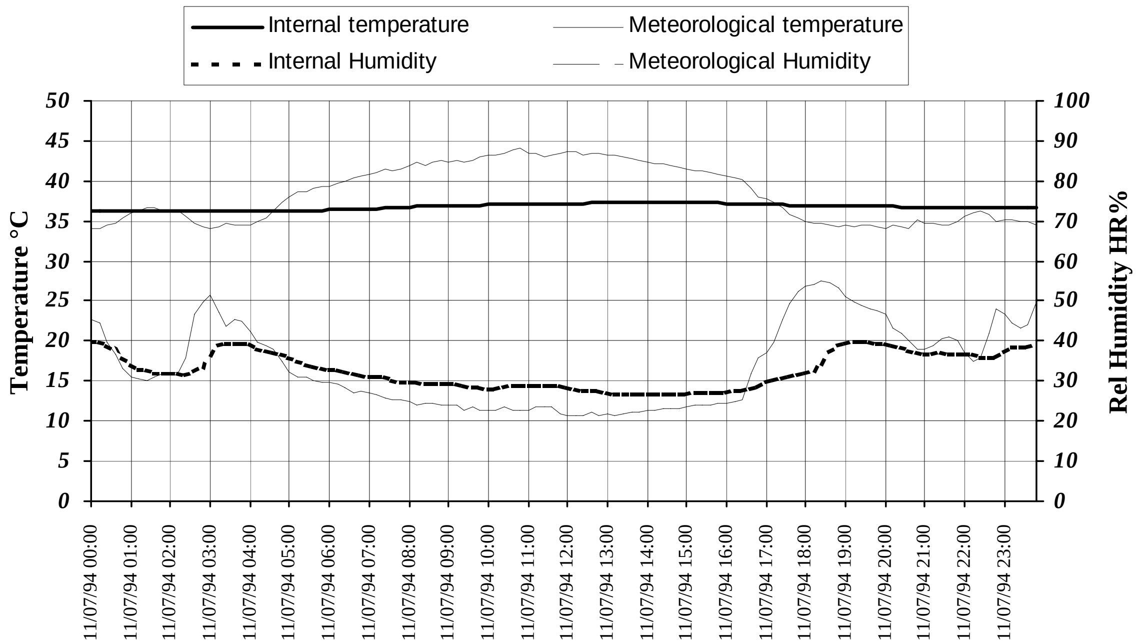


Histogram for meteorological temperature and humidity



Heavy cover : TYPE IGLOO, Category A3 - B3

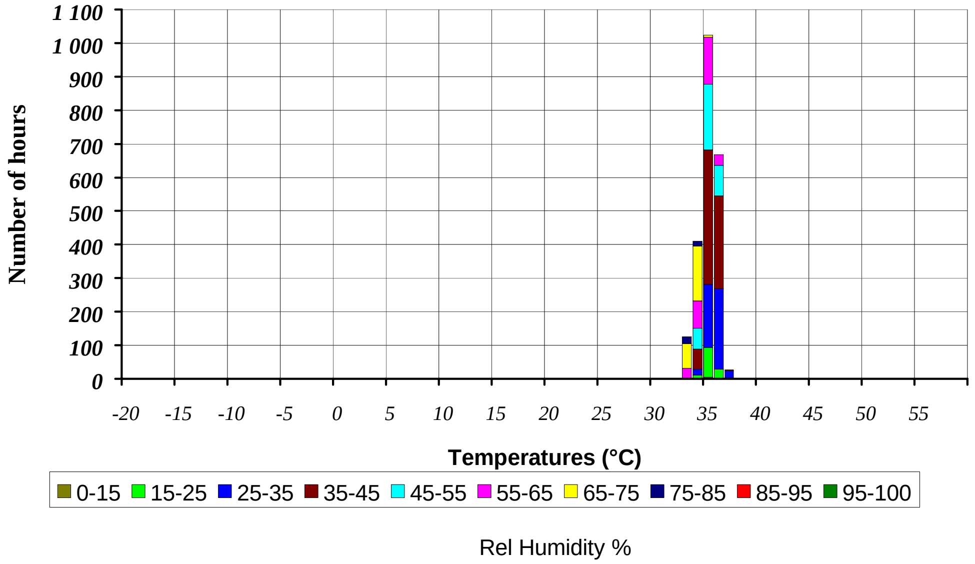




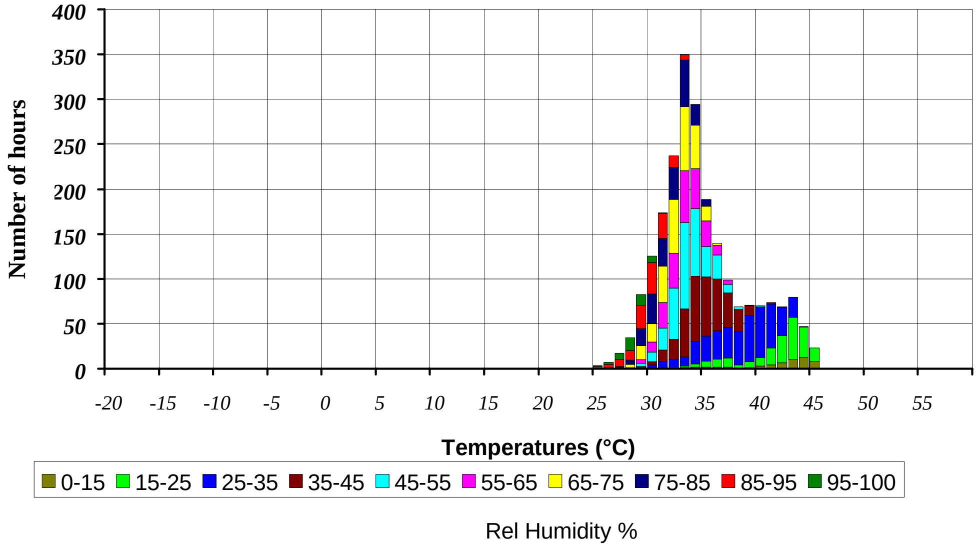
Heavy cover : TYPE IGLOO, Category A3 - B3

Measures : 25/05/94 to 27/08/94 (95 days)

Histogram for IGLOO temperature and humidity

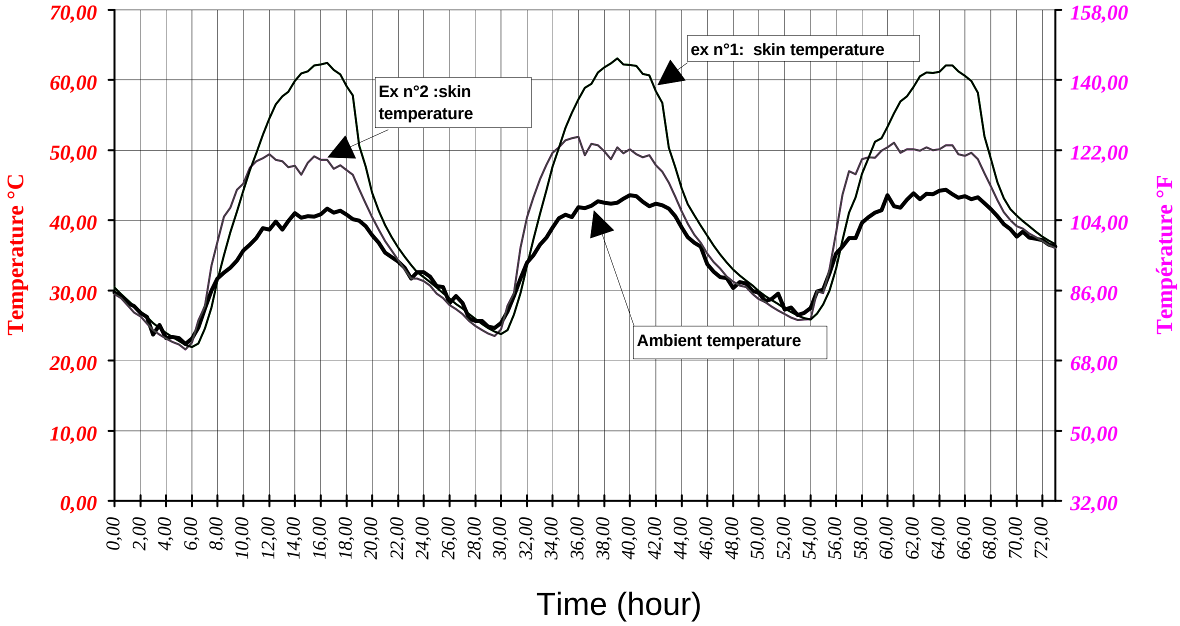


Histogram for meteorological temperature and humidity



Example of data measurements for two types of materiel

Natural desert environment storage on materiels



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ANNEX B: References

B.1 STORAGE

B.1.1 Title: Methodology investigation Final report of chamber simulation of test item response

Author :	A.K. Groff, Randolph B Patrick
Source :	U.S. Army Yuma Proving Gtound
Ref. N°:	7-CO-R87-YPO-006
Date :	June 1991
Pages :	15

B.1.2. Mission/Platform

Natural Desert Environment Storage

B.1.3. Summary of Technical Data
Ambient, skin and inside skin temperature during storage

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SECTION 234 - Man-Mounted and Portable

LEAFLET 234/1 - Man-Mounted and Portable

TABLE OF CONTENTS

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1. GENERAL

a. This leaflet addresses the induced climatic, chemical and biological environmental conditions likely to be encountered by man mounted and portable materiel (i.e. materiel deployed on or carried by personnel) such as small arms, ammunition, weapon launchers and communications and surveillance equipment. The environmental conditions covered by this leaflet are primarily those likely to be incurred by materiel carried and used by land-based forces such as foot soldiers and crew-members of military vehicles when operating beyond forward storage bases and on the battlefield.

b. Advice is given on potentially damaging effects of induced climatic, chemical and biological environments and, where relevant, the appropriate AECTP 300 test methods and severities are recommended for simulation of the effects of those environments.

c. For the purpose of this leaflet the materiel is assumed to be devoid of its transportation package but may still be protected by some form of ‘battlefield’ container of closed or open construction. The environmental descriptions and severities relate to the totally exposed or containerised materiel as appropriate.

d.. For those types of man mounted and portable materiel designed for tri-Service use and likely to be deployed on military aircraft, surface ships or submarines, reference should also be made to the appropriate leaflet of AECTP 200, Section 230, for the relevant induced climatic, chemical and biological conditions.

e. In many cases, man mounted and portable materiel will be directly exposed to the prevailing meteorological conditions during deployment beyond forward storage bases. Exceptions could include periods of tactical transportation in enclosed areas of military vehicles such as trucks, personnel carriers, fixed wing and rotary wing aircraft or in temporary buildings. For some types of materiel such as portable communications equipment, it may be a requirement for prolonged periods to be spent inside vehicles such as mobile command posts, gun carriers or main battle tanks. In these cases the severity of meteorological conditions are likely to be enhanced by the form of the enclosure, the level of ventilation and heat and moisture emitted by operational equipment installed on the vehicle. The frequency and durations of exposure in these conditions will be determined by the operational requirements.

f.. Tactical requirements may include carrying and handling materiel over various types of terrain, negotiating obstacles, immersion in various depths of water, and exposure to dust and sand laden atmospheres, which are likely to result in contamination and ingress of foreign substances including non-pure water.

2. CHARACTERISTICS OF INDUCED ENVIRONMENTS[2]

2.1. Temperature

a. Dependent on the provision or otherwise of an appropriate level of ventilation, the temperatures of materiel in confined spaces of land-based military vehicles during tactical transportation are likely to exceed those of external ambient. Worst case conditions will occur when materiel is carried in vehicles operating in open areas of hot dry regions of the world, where the indirect effect of solar radiation is liable to raise the temperature above the external ambient, as described in Leaflet232/1 of this document (covering climatic aspects of deployment on vehicles).

b. Conditions may be aggravated by heat dissipated by vehicle power units, installed operational equipment and personnel carried on board. Similar effects are likely to occur inside temporary buildings and ad hoc improvised structures that may be employed in the battlefield. These effects may be of particular concern where man mounted materiel such as communications equipment relies on the convection and radiation to the surrounding atmosphere to maintain an acceptable operating temperature.

c. Conversely, surfaces of semi-permanent buildings and temporary covers are liable to be better radiators to the night skies than the ambient atmosphere. Consequently, dependent on the insulation of materials used in their construction and the presence or otherwise of heat-dissipating equipment, temperatures in the enclosed areas may be lower than the external ambient during the low temperature part of a diurnal cycle.

d. The circumstances in which man mounted and portable materieal are likely to be deployed world-wide are infinitely variable. Therefore the temperature severities given for transit and storage in hot regions (Category A) and cold regions (Category C) in Leaflet 2311 should be assumed to apply. Reference should also be made to Leaflet 2311 to determine the grade of severity for a particular area of deployment, for example C0, C1, or C2 etc. The values of temperature are those which are likely to be attained or exceeded in the hottest/coldest locations for approximately 7.4 hours (1% of one month) of the hottest/coldest period of the year. Additional guidance is given in Leaflet 2311 to enable severities for other probabilities of occurrence to be derived. Special consideration will be necessary where materiel, enclosed behind transparent surfaces and exposed to solar radiation in hot regions, could experience temperatures above 85°C.

e. Temperatures experienced in battle-ready configuration during air carriage on fixed wing transport aircraft are likely to be similar to those given in Leaflet 236/237 of this document that addresses transportation of materiel in aircraft. Flight altitudes of battlefield helicopters during flight sorties carrying land-based fighting personnel are

[2] General types and causes of induced climatic environments are described in Section 231of this document. Characteristics of open sky ambient climatic environments are described in Leaflet 2311.

likely to be such that temperatures experienced by man-mounted materiel (up to altitudes of approximately 900 m) will be similar to meteorological values at sea level. Guidance is given in Leaflet 2311 for correction factors which may be applied for higher altitudes. Temperatures during the deployment of fighting personnel from naval vessels such as assault ships and landing craft will be similar to the prevailing meteorological conditions at sea level, except for any item which may be carried under cover, in which case the indirect effect of solar radiation may be relevant, as discussed in sub-paragraph a above. However, for man mounted and portable materiel specifically intended for deployment on fixed and rotary-wing aircraft, surface ships, and submarines, reference should be made to the appropriate leaflet of this document.

f. Man mounted and portable materiel may be subjected to rapid change of temperature during transfer from air conditioned buildings to external ambient conditions when deployed in geographical regions noted for their extremes of temperature (both high-to-low and low-to-high temperatures). A similar situation applies to materiel air dropped from conditioned cargo bays of fixed-wing transport aircraft or brought up from below decks on naval vessels, for example, when operating in low temperature regions. Temperatures will change rapidly from those given in Leaflet 236/237 for cargo areas of transport aircraft and in Leaflet 238 for naval vessels, to the prevailing meteorological conditions.

2.2. Humidity

a. Materiel carried onto the battlefield by ground troops is likely to be subjected to levels of relative humidity in excess of the local ambient if deployment includes periods spent under temporary cover or enclosed spaces without appropriate levels of ventilation. Examples include materiel located in compartments of military vehicles, trailers and temporary covers used as command posts or for conducting covert surveillance. Such conditions are particularly applicable to enclosures deployed or erected in open spaces in hot-wet tropical regions where diurnal cycling over a wide temperature range is aggravated by the indirect effect of solar heating of the external surfaces. Heating and cooling produces pressure differentials across the walls of the enclosure causing external air to be drawn in. The level of ventilation is likely to be such that any moisture in the incoming air is liable to be retained during the heating phase of the next diurnal cycle, raising the relative humidity and dewpoint temperature inside the enclosure. Circumstances contributing to conditions will be infinitely variable and unless materiel is to be deployed in a particular defined installation, it should be assumed that saturation may occur during the low temperature part of the cycle.

b. Pressure differentials are likely to occur across the walls of partially sealed cases and protective covers of individual materiels, causing moisture to be breathed in and retained. Although heat dissipated by equipment while operating will help to reduce the relative humidity, heating and cooling associated with its duty cycle may also aggravate the situation.

c. The combined effects of induced high temperatures and dissipated heat may result in very low levels of relative humidity occurring inside confined spaces of materiel deployed in hot dry regions of the world. Relative humidities lower than 30% are common for naturally occurring conditions in hot dry regions of the world. Leaflet 2311 gives recorded values of RH as being as low as between 3 and 8%. Therefore similar or lower levels may be assumed to occur inside confined areas in which there are sources of dissipated heat.

2.3. Air Pressure

a. Materiel carried or worn by airborne troops will be subjected to air pressure below standard ambient when flown and subsequently parachuted into the battlefield. Values of air pressure below standard ambient in pressurised cargo bays of fixed wing aircraft during normal conditions of air carriage are given in Leaflet 236/237 of this document. Low air pressures and explosive decompression associated with emergency flight conditions, during which carried materiel must not present any potential danger to aircraft and crew, are also specified. Low air pressure during air carriage to battlefield areas by rotary wing aircraft are likely to be similar to those of normal conditions in cargo bays of fixed wing aircraft.

b. Materiel carried or worn by ground troops may be subjected to benign levels of pressure above local ambient, during tactical transport in military vehicles which employ overpressure to prevent contamination of the atmosphere inside the vehicle, in the event of nuclear, chemical, or biological attack.

2.4. Dust and sand

a. When operating in hot dry desert regions, or where the surface is liable to break up into small particulate, virtually any movement of the carrier or of the carried materiel is likely to result in contamination by dust and sand. The movement of military vehicles in desert areas is liable to result in dust and sand-laden atmospheres in which localised concentrations may approach those of naturally produced dust and sand storms. Once disturbed, fine dust can remain in the atmosphere for days. Even materiel located in partially sealed enclosures are vulnerable. Materiel carried or worn by ground support personnel during operation of aircraft on airfields, is also likely to be directly subjected to artificially blown dust and sand.

b. During tactical manoeuvres that require foot soldiers to crawl along the ground, any man mounted or portable materiel carried or dragged over the surface is vulnerable to ingress of small particulate dust and sand.

c. The characteristics of dust and sand laden atmospheres including the distribution and physical characteristics of particulate and the levels of concentration associated with the operation of military vehicles are given in Leaflet 232 of this document.

2.5. Immersion, Precipitation and Spray

a. Wherever water has to be negotiated during tactical operations or battlefield conditions, man mounted and portable materiel is likely to experience some form and degree of wetting. Materiel is liable to be subjected, accidentally or intentionally, to splashing and spray, or to partial or total immersion in water. Circumstances are infinitely variable and waterproofing requirements such as depths and durations of immersion and expected levels of survival or subsequent operation should be specified in the Environmental Requirements document.

3. POTENTIAL DAMAGING EFFECTS

3.1. Temperature

3.1.1. High temperature

Examples of the effects of high temperature are:

a. Reduced strength and increased elasticity of materials causing overloading.

b. Dimensional changes and differential thermal expansion of structural and mechanical components causing:

- distortion and failure of structural components.
- binding and seizure of moving parts.
- failure of bonded joints.

c. Changes in the characteristics of shock and vibration isolation systems, reducing the life of materiel protected from mechanical environments.

d. Dimensional changes and permanent sets, reducing effectiveness of gaskets and seals.

e. Reduced efficiency of cooling systems, particularly those that depend on convection and radiation to the surrounding atmosphere, resulting in:

- changes in electrical characteristics of materials used in the manufacture of electrical/electronic components.
- failure of internal connections of electronic components

- degraded performance or total failure of electrical/electronic systems.

f. Lowering of viscosity and reduced efficiency of lubricants.

g. Discoloration and crazing of protective finishes.

h. Increased burning rates of explosives and propellants.

3.1.2. Low temperature

Examples of the effects of low temperature are:

a. Embrittlement and reduced elasticity of materials (especially non-metallic), reducing resistance to mechanical shock.

b. Dimensional changes and differential thermal contraction of structural mechanical components causing:

- distortion and failure of structural components.
- seizure of mechanical systems.
- failure of bonded joints.

c. Changes to characteristics of shock and vibration isolation systems.

d. Reduced performance from batteries.

e. Changes in characteristics of materials used in manufacture of electronic components causing:

- failure of mechanical joints and mechanical supports of electronic components.
- degraded performance or total failure of electrical/electronic systems.

f. Increased viscosity of lubricants reducing performance of mechanical systems.

g. Decreased burn-rate of explosives and propellants.

3.1.3. Rapid change of temperature

Examples of effects and faults arising from rapid change of temperature are:

a. Rapid expansion and contraction of materials resulting in deformation and failure of structural components.

b. Failure of bonded joints.

c. Crazing of protective finishes.

d. Cracking of grains and pellets of explosives and propellants

3.2. Humidity

Reference 1 of Annex A gives information on the protection of materiel from the effects of moisture-laden atmospheres. The effects on materiel, achieving and maintaining dry enclosures, standards and methods of sealing, water vapour barriers and drying out procedures are discussed.

3.2.1. High humidity

Examples of the effects of high humidity are:

a. Absorption of moisture by non metallic materials causing:

- swelling and reduction in mechanical strength.
- increased weight.
- change in thermal and electrical characteristics.

b. Absorption and adsorption of moisture reducing insulation resistance and producing unwanted low resistance paths in electrical/electronic circuitry.

c.Total failure or degraded performance of electrical/electronic system and components - due to (a) and (b).

d. Galvanic corrosion of metallic parts and components especially in areas of high strain and where protective finishes have been defaced.

e. Seizure of moving parts and contamination of lubricants by corrosion products.

f. Creation of micro-climates in (often hidden) areas of entrapped moisture.

g. Acceleration of chemical and biological attack.

3.2.2. Low humidity

Very low levels of relative humidity can result in a build up of static electricity causing flash-over and failure of low voltage electronic components.

3.3. Pressure

Pressure sensitive devices designed to detect and respond to small changes in pressure may incur permanent damage during air carriage in cargo bays of transport aircraft. The walls of sealed or partially sealed containers with leakage rates lower than induced rates of change of pressure may suffer temporary or permanent distortion, which in turn may cause interference with contained components.

3.4. Dust and Sand

Examples of the effects of dust and sand laden atmospheres are:

a. Blockage of apertures - reduced efficiency of ventilation and cooling systems.

b. Scratching and etching of lenses, transparent panels and surface finishes causing:

- corrosion of exposed underlying materials

- impaired performance of optical systems.

c. Clogging or seizure of mechanical devices.

d. Contamination of electrical/electronic systems causing:

- introduction of unwanted low resistance paths

- reduced reliability

e. Contaminated lubrication systems.

3.5. Immersion, Precipitation and Spray

Materiel subjected to immersion is liable to ingress of water (including contained contaminants) causing seepage and swelling of materials and inducing faults and failures similar to those associated with condensation and high levels of humidity (see Paragraph 3.2.1).

4. TEST SELECTION

4.1. General

a. AECTP 300 gives test procedures that may be used for simulating induced climatic environments that may be experienced by man-mounted and man-portable materiel. The choice of test method for temperature and humidity will depend on whether there are any requirements to simulate diurnal variations including the heating effects of solar radiation or steady-state conditions.

b. The characteristics of the materiel and previous experience of the response of similar types of materiel to real-life conditions, for example, the effects of thermal cycling on explosives and propellants, may also influence the choice of test procedure. Careful consideration of the configuration of the test item, within its enclosure where applicable, is required when simulating the effects of solar heating. Test procedures that apply steady state conditions are likely to be relevant to materiel required to spend periods of time in areas where temperature and levels of humidity are determined by dissipated heat from power supplies and operational equipment.

c. Preferably, test severities should be derived from specific measurements made at the location representative of the worst-case conditions expected in service. Alternatively, severities derived from data obtained for other situations in similar applications may be used.

4.2. Test Severities

4.2.1. Temperature and humidity

a. Test severities used in the simulation of induced temperature (and humidity) conditions should be based on information given in Operational and Environmental Requirements documents. This information should include the geographical areas where the materiel is likely to be deployed, and the detailed logistical requirements for the man-mounted/man-carried materiel. Preferably, test severities should be derived from specifically measured data including the influence of any form of conditioned or non-conditioned enclosure such as a military vehicle or temporary shelter. Test severities derived from measured data should include worse-case conditions.

b. In the absence of specifically measured data, values of temperature given in Leaflet 2311 for transit and storage in hot (Category A) and cold (Category C) climates should be assumed to represent worst-case induced conditions. In the case where materiel may be placed in an unventilated enclosure behind transparent panels directly exposed to solar radiation, temperatures greater than 85°C should be assumed.

c. Where the capacity of the test facility allows, test severities representative of meteorological conditions, including radiative heating, may be applied to a simulated structure or enclosure containing the test item(s). Preferably, the enclosure should stand on a surface with the same reflective properties as those on which it will stand in Service. Alternatively, the test item(s) should be subjected to the diurnal temperature cycle derived from data measured inside the confined space, or the relevant Category A (for dry heat) or Category B (for heat and humidity) diurnal cycle for transit and storage given in Leaflet 2311.

d. Where it is required to test materiel to induced high temperatures when diurnal variations are so small as to have an insignificant effect on the materiel, or where it is considered that the response of the test specimen or its component parts are not related to temperature cycling, constant high temperature may be used.

e. In many cases, testing materiel for exposure to induced low temperatures will be satisfied using constant low temperature. In those cases where low temperature cycling is considered more appropriate, a low temperature diurnal cycle test should be used. Typical examples include materiel containing explosives or seals and other components that need to be representatively stressed.

f. The diurnal temperature cycle should be derived from specifically measured data, or the relevant Category C diurnal cycle for transit and storage given in Leaflet 2311.

4.2.2. Air Pressure

Where it is required to simulate low air pressures experienced by man mounted and portable materiel when deployed beyond forward storage base, the relevant procedure of AECTP 300 Method 312 should be used. Test severities should be matched to the particular application. Reference should be made to Operational and Environmental Requirement documents

4.2.3. Sand and dust

a. Where it is required to determine the effects on man mounted and portable materiel to exposure to dust and sand laden atmospheres, AECTP 300 Method 313 should be used. Materiel directly exposed to artificially blown dust and sand should be tested to the Wind Blown Dust and Sand test.

b. The sand and dust concentration, air velocities and duration of exposure should be selected from the listed severities in accordance with the guidance given in Method 313. Any attempt to tailor test severities to specifically measured data for the Dust and Sand test is unlikely to be cost effective.

c. The Drag Test of Document D.14 of NATO AC 225, Panel III, which simulates small arms being carried or trailed by a soldier while crawling through sand; may be considered appropriate to other man mounted or portable materiel.

4.2.4. Immersion, precipitation and spray

a. Where it is required to determine the effects on materiel that may be subjected to immersion, AECTP 300 Method 307 should be used. The depth and duration of immersion for a particular test item will depend on the need for it to continue to operate while immersed in water, and/or of the benefits arising from its retrieval. In the absence of specific information, test severities should be selected from those listed in Method 307

b. Determination of the performance of materiel when subjected to spray and splashing may be satisfied by testing for the effects of natural precipitation, for example, driving rain or dripproofness (AECTP 300 Method 310).

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ANNEX A
REFERENCES AND BIBLIOGRAPHY

1 REFERENCES.

1. Review of Climatic Protection Techniques for Electronic Equipment; E. Napper, Procurement Executive, Ministry of Defence, RSRE Malvern, Worcs, RSRE Memorandum No. 3530.

2. QSTAG 362 Chemical Environmental Contaminants affecting the Design of Military Materiel.

3. DEF STAN 01-5 Fuels, Lubricants and Associated Products.

4. DEF STAN 08-41, Chemical and Biological Hardening of Military Equipment, Part 1 General Requirements, Assessment and Testing.

5. QSTAG 361 Fungal Contamination Affecting the Design of Military Materiel.

6. BS 2011 Part 2.1J (IEC 60068 -2-10) Test J and Guidance; Mould Growth. Appendix F.

7. DEF STAN 00-3 Issue 3 Design Guidance for the Transportability of Equipment.

8. BS 2011 Part 2.1R (IEC 60068-2-18) Test R Water and Guidance.

9. Acid Deposition in the United Kingdom, Third Report of UK Review Group on Acid Rain, J G Irwin and F B Smith, Warren Springs Laboratory, Stevenage, 1990.

10. Leaflet 2311, Extreme Climatic Conditions and Derived Conditions for use in defining Design/Test Criteria for NATO forces Materiel.

2 BIBLIOGRAPHY

Further information on the environmental conditions addressed in this leaflet and the effects on materiel may be found in the following leaflets of Part 4 of this Standard and the associated lists of bibliography.

DEF STAN 00-35 Part 4 Section 2 Leaflet 2-01 Temperature and Leaflet 2-02 The Effects of Temperature.

DEF STAN 00-35 Part 4 Section 3 Leaflet 3-01 Solar Radiation and Leaflet 3-02 The Effects of Solar Radiation.

DEF STAN 00-35 Part 4 Section 4 Leaflet 4-01 Humidity and Leaflet 4-02 The Effects of Humidity.

DEF STAN 00-35 Part 4 Section 8 Leaflet 8-01 Deleterious Atmospheres and Leaflet 8-02 The Effects of Corrosives and Contaminants.

DEF STAN 00-35 Part 4 Section 9 Leaflet 9-01 Dust and Sand and Leaflet 9-02 The Effects of Dust and Sand.

DEF STAN 00-35 Part 4 Section 10 Leaflet 10-01 Atmospheric Pressure and Leaflet 10-02 The Effects of Air Pressure.

DEF STAN 00-35 Part 4 Section 11 Leaflet 11-01 Biological Hazards and Leaflet 11-02 The Effects of Biological Hazards.

SECTION 235 - DEPLOYMENT OR INSTALLATION ON VEHICLES

LEAFLET 235/1 - DEPLOYMENT OR INSTALLATION ON VEHICLES

TABLE OF CONTENTS

1. GENERAL

a. This leaflet addresses the induced climatic environmental conditions likely to be encountered by materiel deployed on, or installed in, land-based vehicles. The vehicles include wheeled and tracked (fighting) vehicles, and associated trailers, used as Service platforms for materiel, or used for transportation of materiel beyond forward storage bases and on the battlefield.

b. Advice is given on potentially damaging effects of induced climatic environments and, where relevant, the appropriate AECTP 300 test methods and severities are recommended for simulation of the effects of those environments.

c. For the purpose of this leaflet, materiel includes items that may be packaged or unpackaged, or materiel contained within some form of battlefield container. The environmental descriptions and severities relate to the totally exposed or containerised materiel as appropriate.

d. Induced climatic conditions experienced by materiel during transportation between factory and forward storage bases are addressed in Leaflet 232 of this document. Induced climatic environments that are liable to be experienced during the loading and unloading of transported materiel are addressed in Leaflet 233.

e. The armoured structure and temporary covers provided on military vehicles for protection against the weather and armed attack, can aggravate the effects of the local meteorological conditions such as solar radiation and damp heat, especially where logistical and operational requirements preclude the provision of appropriate levels of ventilation. The induced temperatures are liable to impose thermal stresses more severe than those caused by naturally occurring meteorological conditions.

f. It should be assumed that materiel fitted to, or carried on, external surfaces will be subjected to the ambient conditions associated with the geographical area of deployment. Dependent on the provision or otherwise of appropriate levels of ventilation or forced-air conditioning, materiel carried or installed within the protective structure or under temporary covers of trucks, trailers and fighting vehicles is liable to be subjected to conditions in excess of the local ambient due to the response of the vehicle to the external ambient conditions, heat emissions from power sources and operating systems carried on the vehicle and their duty cycles.

2. CHARACTERISTICS OF INDUCED ENVIRONMENTS[3]

2.1. Temperature

a. High temperatures inside vehicle compartments are liable to exceed external ambient due to indirect effect of solar radiation on the armoured structure or temporary covers.

b. The relative angle of elevation between the source and the external surfaces of the vehicle, the prevailing cloud cover, the heat capacity of the exposed structure or cover, its colour and surface finish and the duration of exposure will all contribute to the amount of heat absorbed within the enclosed area and the induced temperatures. The latter may be tempered by some form of natural or man-made shade or ventilation.

c. Conversely, such protective structures and temporary covers are also liable to be better radiators to the night skies than the ambient air, such that temperatures in enclosed compartments may be lower than the external ambient.

d. In the absence of specifically measured data, temperature severities given Leaflet 2310, for Transit and Storage in Category A and Category C climatic areas, should be assumed to represent worst-case conditions inside parked, non-operating vehicles deployed in Hot and Cold regions.

e. In those cases where materiel is intended to be installed in enclosed areas behind transparent panels of land-based vehicles, ambient temperatures greater than 85°C may be experienced when directly exposed to solar radiation in hot-dry regions of the world.

f. The values referred to in sub-Paragraphs d. and e. above are more applicable to non-operational periods of this phase of deployment. When the vehicle and/or installed equipment is operational, temperatures inside enclosed areas will also depend on packing density of carried equipment, the levels of natural and forced air cooling and heat dissipated by operational equipment, e.g., from engine compartments or racks of electrical/electronic systems, etc. Ambient temperatures surrounding individual materiel will also depend on the location inside the vehicle, i.e., whether it is located in an open or stagnant area within the vehicle. Preferably, temperature severities at the intended location of materiel on the vehicle should be determined from specifically measured data recorded during worst-case Service conditions. Alternatively, information regarding characteristics of built-in ventilation systems and levels of heat dissipated by installed operational equipment should be sought from the vehicle and equipment manufacturers, and balanced against thermal response of the enclosure to meteorological conditions.

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[3] General types and causes of induced climatic environments are described in Section 231 of this document. Characteristics of open sky ambient climatic environments are described in Leaflet 2311.

g. Where specifically measured data have not been available, maximum switch-on temperatures for both conditioned and non-conditioned compartments of vehicles deployed in hot-dry regions should be taken as equivalent to maximum induced temperatures for ground Transit And Storage given in Leaflet 2310 for Category A1 environmental conditions. For materiel subject to solar radiation behind transparent surfaces, switch-on temperatures greater than 85°C should be assumed.

h. For long-term ground running in hot-dry regions, and where characteristics of cooling air are unknown, ambient temperatures in conditioned compartments are assumed to stabilise at 15 degrees celsius lower than at switch-on. While it may be assumed access doors and panels will have been open for a period sufficient to allow external ambient air to have some alleviating effect, in order to take account of dissipated heat from operational equipment, the temperatures at switch-on should be assumed to prevail in non-conditioned areas of the vehicle. Where such areas are behind transparent panels, a temperature of 70°C should be assumed. In cases of externally carried stores, in which packing densities of heat dissipating systems and components are liable to be relatively high, final temperatures and rates of increase are likely to be in excess of those given above. Indeed long-term ground running without forced air cooling should be avoided in hot-dry regions to prevent permanent damage or degraded reliability.

i. Internal temperatures of individual materiel will depend on similar factors to those discussed above. Packing density and heat dissipation of components, the thermal paths to external surfaces of the materiel and the incorporation of systems to distribute cooling mediums will influence the temperatures produced. Where the temperatures of the internal air space or of individual components are of concern, they should be estimated using thermal analysis programmes using specific measurements made in representative conditions.

j. For deployment in low temperature regions, in the absence of measured data, the following severities may be assumed to represent worst-case conditions at switch-on for materiel in enclosed compartments of which the skin surfaces are better radiators of heat to the night sky than the ambient air is to the materiel:

Area Of Deployment Climatic Category*	Temperature °C
C0	-21
C1	-33
C2	-46
C3	-51
C4	-57

* See Leaflet 2310

Severities may be alleviated by the on-board environmental control system during long-term ground running and/or heat dissipated by operational equipment.

2.2. Humidity

2.2.1. High humidity

a. Dependent on the provision or otherwise of natural or artificial ventilation, levels of relative humidity in enclosed areas of the vehicle may exceed those of local ambient. Diurnal temperature cycles may induce a reduction in air pressure inside the vehicle, causing a pressure differential across the walls of the enclosure or temporary cover, encouraging the breathing-in of external moist air. Some of the moisture is liable to be retained if the enclosure is not sufficiently ventilated when the temperature rises and airflow is reversed. Such conditioning is particularly applicable to materiel installed on vehicles deployed in open spaces in wet tropical regions of the world. In addition to the indirect effects of solar heating, the effect may be aggravated by the heat given off by installed equipment. The operational pattern of the vehicle and the duty cycle of installed equipment may temper or further aggravate the effects. Dew-point temperatures inside the enclosed areas may increase with the number of temperature cycles, such that conditions approaching saturation eventually occur.

b. In the absence of specific information, severities of temperature and high humidity given in Leaflet 2310 for Transit and Storage for Category B conditions should be assumed to represent worst-case conditions during non-operational phases of deployment. Levels of relative humidity (RH) during operational phases will depend on the provision of natural and forced air cooling and heat and moisture dissipated by installed equipment.

c. Individual items of materiel deployed or installed on the vehicle are liable to experience a similar pattern of induced breathing and retention of moisture. Internal temperatures of unventilated, partially sealed, heat dissipating equipment are liable to cause even greater pressure differentials. In the case of externally mounted materiel , the situation will be aggravated by the indirect effects of solar heating. Dew point temperatures are liable to rise and conditions approaching saturation may occur with an increasing number of diurnal cycles.

d. When deployed in vehicles in dense jungle or under overcast conditions in wet tropical regions, diurnal variations will be far less pronounced. Once temperature-stabilised, moisture penetration will be more by absorption than induced pressure differentials and by natural or forced-air circulation. These more constant conditions are more likely to favour mould growth and corrosion by acidic deposits. Equipment containing refrigeration systems will be particularly susceptible to condensation throughout a 24 hour period.

e. Worst-case operational conditions in wet tropical regions are likely to be at switch-on, especially if that occurs during the low temperature phase of the diurnal cycle. As systems warm up, conditions will tend to stabilise and levels of RH will probably decrease with heat dissipated by operational equipment. Exceptions to the latter may be where the vehicle is associated with services that generate moisture such as field kitchens and laundries. Conditions during continuous (24 hour) operation may be characterised by the diurnal ambient cycle. The latter is liable to be less evident when deployed in dense jungle areas where diurnal variations are less pronounced.

2.2.2. Low humidity

When deployed in vehicles in hot dry regions of the world, heat generated by operational equipment is liable to result in exceptionally low levels of relative humidity within compartments and enclosures of individual items of materiel. Relative humidities of less than 30% are common for naturally occurring conditions in hot desert regions. Leaflet 2311 quotes recorded values of RH as low as 3%, Therefore similar levels may be assumed to occur inside confined areas in which there are sources of dissipated heat.

2.3. Air Pressure

Materiel is liable to experience air pressure above local ambient when installed in internal compartments of military vehicles which employ overpressure to prevent contamination of vehicle compartments by ingress of the external atmosphere during periods of chemical and biological exposure. Values of overpressure for particular applications should be determined by reference to Operational and Environmental Requirements documents or the vehicle manufacturer.

2.4. Icing

Materiel fitted on external surfaces of land vehicles will experience icing arising from direct exposure to meteorological conditions. Some level of icing may be experienced by materiel fitted on internal surfaces of the panels forming the outer walls of vehicle compartments. Diurnal cycling about the freezing point may result in alternate freezing and thawing of accumulations (possibly hidden pockets) of moisture condensed out of the atmosphere inside the vehicle.

2.5. Dust and sand

a. Materiel mounted on external faces and inside compartments of military vehicles are liable to be subject to mechanically generated dust and sand-laden atmospheres. While worst-case conditions will occur in desert regions, some level of contamination can be expected wherever military vehicles are operated over dry surfaces composed of small loose particulate material. The heavier particles thrown up by vehicle tracks and wheels are likely to be found up to around one metre above the surface and quickly return to the ground, while fine dust can remain suspended in the atmosphere at higher altitudes for days.

b. Externally mounted equipment up to wheel height may be subjected to conditions simulating wind blown dust and sand thrown up by the wheels and tracks of the host or other vehicles operating in the area. Similar conditions may be experienced by externally mounted materiel fitted at higher levels on land-based vehicles that are within the range of wind-blown dust and sand artificially generated by aircraft propulsion systems (including rotary wing aircraft).

c. As in the case of naturally created conditions, the finer dust particles are likely to be found in suspension especially where turbulent airflows exist. They may penetrate seals and interfaces, and/or settle on surfaces of materiel installed in internal compartments.

d. The characteristics of dust and sand-laden atmospheres, including the distribution and physical characteristics of particulate and the levels of concentration associated with the operation of military vehicles, are given in Leaflet 2311.

2.6. Immersion, Precipitation and Spray

a. Materiel may be subject to dripping water as a result of condensation formed when cold overhead surfaces meet warm moist air, for example materiel carried on vehicles fitted with air conditioning systems, when used in tropical regions.

b. Materiel required to remain in-situ is liable to wetting when pressure-fed devices are used in cleaning and de-icing operations of the vehicle.

c. When vehicles are required to negotiate water, externally mounted materiel is liable to experience partial or total immersion, dependent on the depth of water and the location (height above ground) on the vehicle. Some level of immersion may be experienced by internally fitted materiel dependent on the efficiency of sealing of doors and hatches. Circumstances are infinitely variable and waterproofing requirements such as depths and durations of immersion and expected levels of survival or subsequent operation should be specified in Environmental or Operational Requirements documents.

3. POTENTIAL DAMAGING EFFECTS

3.1. Temperature

3.1.1. High temperature

Examples of the potentially damaging effects or faults resulting from high temperatures are:

a. Reduced strength and increased elasticity of materials causing overloading.

b. Dimensional changes and differential thermal expansion of structural and mechanical components causing:

- distortion and failure of structural components
- binding and seizure of moving parts
- failure of bonded joints

c. Dimensional changes and permanent sets in gaskets and seals reducing sealing efficiency.

d. Melting and exudation of non-metallic materials - the latter possibly as a result of (b) and (c) above.

e. Unintentional functioning of thermally activated devices.

f. Changes in characteristics of shock and vibration isolation systems.

g. Overloading performance of cooling systems resulting in:

- changes in the characteristics of electrical/electronic components
- failure of internal connections of electronic components.
- degraded performance or failure of electrical/electronic systems.

h. Build-up of static electricity especially where humidity is low.

i. Accelerated ageing and cracking, crazing or discoloration of protective finishes.

j. Increased burning rates of explosives and propellants.

k. Reduced viscosity of lubricants and efficiency of lubrication systems.

3.1.2. Low temperature

Examples of the potentially damaging effects or faults caused by low temperatures are:

a. Embrittlement and reduced elasticity of materials (especially non metallic), reducing resistance to mechanical shock.

b. Static fatigue of restrained glass.

c. Dimensional changes and differential thermal contraction of structural and mechanical components causing:

- distortion and failure of structural components.
- seizure of mechanical systems.
- failure of bonded joints.

d. Changes in characteristics of shock and vibration isolation systems.

e. Reduced performance of batteries.

f. Changes in characteristics of electrical/electronic components leading to:

- failure of external connections and internal joints of electronic components.
- failure or degraded performance of electrical/electronic systems.

g. Increased viscosity of lubricants reducing performance of mechanical systems.

h. Reduced burning rate of explosives and propellants.

3.2. Humidity

Reference 1 of Annex A gives advice on the protection of materiel from the effects of moisture-laden atmospheres. The effects on materials, achieving and maintaining dry enclosures, standards and methods of sealing, water vapour barriers and drying out procedures are addressed.

3.2.1. High humidity

Examples of effects of exposure to damp heat are:

a. Swelling and general deterioration of materials due to absorption of water causing:

- a reduction in mechanical strength.
- degraded performance of electrical/electronic components.
- increased weight.

b. Absorption and adsorption of moisture reducing insulation resistance causing unwanted low resistance paths in electrical/electronic circuitry.

c. Failure or degraded performance of electrical/electronic systems and components due to a. and b.

d. Galvanic corrosion of metallic parts and components especially in areas of high strain.

e. Creation of micro-environments caused by entrapped moisture encouraging localised (and often hidden) areas of chemical and biological attack.

f. Contamination of lubricants by corrosion products.

3.2.2. Low humidity

Examples of the effects of very low humidity are:

a. Excessive drying out, resulting in reduced performance of some materials.

b. Changes in characteristics of electrical/ electronic components affecting the stability and accuracy of electronic systems.

c. Tracking and reduced insulation especially when combined with dust deposits.

d. Excessive friction and electrical losses in commutators and slip rings resulting in increased temperatures and brush wear.

3.3. Pressure

Levels of overpressure used to seal vehicle compartments are benign. However, pressure-sensitive materiel designed to respond to small changes in pressure, and walls of partially sealed containers with leakage rates lower than induced rates of change of pressure, may suffer temporary or permanent damage or distortion.

3.4. Icing

Icing, frosting or freezing of trapped moisture may result in blockage or seizure of affected mechanical and electro-mechanical systems.

3.5. Dust and Sand

Examples of effects and faults caused by dust and sand are:

a. Blockage of apertures - reduced efficiency of ventilation and cooling systems.

b. Scratching and etching of lenses, transparent panels and surface finishes causing:

- impaired performance of optical systems
- corrosion of exposed underlying materials.

c. Seizure of mechanical devices.

d. Deposits on electrical/ electronic systems causing:

- build up of static electricity
- introduction of unwanted low resistance paths
- failure or degraded performance.

e. Contaminated lubrication systems

3.6. Immersion, Precipitation and Spray

The effects of dripping water and partial immersion will depend on the watertightness of vehicle doors and hatches and protective cases of installed materiel. Moisture accumulated internally may be retained dependent on the provision or otherwise of suitable drainage facilities, the effects of which are likely to be similar to those already listed in Paragraph 3.2.1.

4. TEST SELECTION

4.1. General

a. AECTP 300 gives test procedures that may be used for simulating induced climatic environments that may be experienced by materiel deployed on, or installed in, land-based vehicles. The choice of test method for temperature and humidity will depend on whether there are any requirements to simulate diurnal variations including the heating effects of solar radiation or steady-state conditions.

b. The characteristics of the materiel and previous experience of the response of similar types of materiel to real-life conditions, for example, the effects of thermal cycling on explosives and propellants, may also influence the choice of test procedure. Careful consideration of the configuration of the test specimen, within its enclosure where applicable, is required when simulating the effects of solar heating. Test procedures that apply steady state conditions are likely to be relevant to materiel required to spend periods in areas where temperature and levels of humidity are determined by dissipated heat from power supplies and operational equipment.

c. Preferably, test severities should be derived from specific measurements made made on the intended vehicle during representative worst-case conditions expected in service. Alternatively, severities derived from data obtained for other situations in similar applications may be used.

4.2. Test Severities

4.2.1. Temperature and humidity

a. Test severities used in the simulation of induced temperature (and humidity) conditions should be based on information given in Operational and Environmental Requirements documents. This information should include the geographical areas where the materiel is likely to be deployed, and the detailed logistical requirements for the materiel. It is preferred that test severities should be derived from specifically measured data including the influence of any form of conditioned or non-conditioned enclosure such as a temporary shelter. Test severities derived from measured data should include the expected worse-case climatic category conditions.

b. In the absence of measured data, test severities should be based on information given in Operational and Environmental Requirements documents such as the intended geographical areas of deployment, the type of vehicle, and the location on the vehicle. Temperatures given in Leaflet 2311 for external ambient (meteorological) and Leaflet 2310 for induced (transit and storage) in Hot Dry (Category A), Hot Humid (Category B) and Cold (Category C) regions should be assumed to be the worst-case conditions while the vehicle is non-operating. The quoted values of temperature are those which are likely to be attained or exceeded in the hottest/coldest locations in the climatic category for 1% of one month of the hottest/coldest period of the year. Additional data and guidance are given in Leaflet 2311 and Leaflet 2310 to enable the severities for 5% and 10% occurrence to be derived.

c. Preferably high temperatures inside compartments when the vehicle is in the operational mode should be derived from recorded data in simulated worst-case operational conditions. Alternatively, temperatures should be assessed taking into account indirect effects of external ambient conditions, the form and level of ventilation, and heat dissipated by vehicle systems such as engine compartments, power generators and installed equipment. Information should be sought from the vehicle manufacturers and vehicle system design authorities. For an individual materiel, location on the vehicle should also be taken into account, i.e., the influence of an air flow or a stagnant area.

d. Where the capacity of the test facility allows, test severities representative of meteorological conditions, including radiative heating, may be applied to a simulated structure or enclosure containing the test item(s). Preferably, the enclosure should stand on a surface with the same reflective properties as those on which it will stand in Service. Alternatively, the test item(s) should be subjected to the diurnal temperature cycle derived from data measured inside the confined space, or the relevant Category A (for dry heat) or Category B (for heat and humidity) diurnal cycle for transit and storage given in Leaflet 2310.

e. Where it is required to test materiel to induced high temperatures when diurnal variations are so small as to have an insignificant effect on the materiel, or where it is considered that the response of the test specimen or its component parts are not related to temperature cycling, constant high temperature may be used.

f. In many cases, testing materiel for exposure to induced low temperatures will be satisfied using constant low temperature. In those cases where low temperature cycling is considered more appropriate, a low temperature diurnal cycle test should be used. Typical examples include materiel containing explosives or seals and other components that need to be representatively stressed.

g. The diurnal temperature cycle should be derived from specifically measured data, or the relevant Category C diurnal cycle for transit and storage given in Leaflet 2310.

4.2.2. Air Pressure

Where it is required to simulate low air pressures experienced by materiel on vehicles , the relevant procedure of AECTP 300 Method 312 should be used. Test severities should be matched to the particular application. Reference should be made to Operational and Environmental Requirement documents

4.2.3. Sand and dust

a. Where it is required to determine the effects on vehicle mounted materiel to exposure to dust and sand-laden atmospheres, AECTP 300 Method 313 should be used. Materiel directly exposed to mechanically blown dust and sand should be tested to the Blowing Dust or Blowing Sand test.

b. The concentration, air velocities and duration of exposure should be selected from the listed severities in accordance with the guidance given in Method 313. Any attempt to tailor test severities to specifically measured data for the Dust and Sand test is unlikely to be cost effective.

c. The Blowing Dust method should be used for materiel installed in partially sealed compartments or those which are likely to be opened for routine inspection and maintenance.

d. If the effects of static electricity are thought to be significant (see Paragraph 3.4) advice should be sought on an appropriate test method and severity.

4.2.4. Immersion, precipitation and spray

a. Where it is required to determine the effects of immersion on materiel, AECTP 300, Method 307 should be used. The depth and duration of immersion for a particular test item (measured from the highest point on the specimen to surface of the water) will be determined by its position on the vehicle and the maximum depth of water which the vehicle is required to negotiate. The depth of partial immersion should be 0.15 m from the face on which the specimen stands to the surface of the water, unless otherwise specified in the Operational and Environmental Requirements for the materiel. The duration of exposure should be 30 minutes.

b. Determination of the performance of materiel when subjected to spray and splashing may be satisfied by testing for the effects of natural precipitation, for example, driving rain or dripproofness (AECTP 300, Method 310).

c. Confirmation of the sealing efficiency of hatches and protective covers of externally fitted materiel may be satisfied by AECTP 300, Method 310, Driving Rain, conducted to determine the effects of exposure to natural forms of precipitation. The Drip test may be used to determine the effects of dripping water from overhead surfaces.

ANNEX A
REFERENCES AND BIBLIOGRAPHY

1 REFERENCES.

1. Review of Climatic Protection Techniques for Electronic Equipment; E. Napper, Procurement Executive, Ministry of Defence, RSRE Malvern, Worcs, RSRE Memorandum No. 3530.

2. DEF STAN 01-5 Fuels, Lubricants and Associated Products.

3. DEF STAN 00-3 Issue 3 Design Guidance for the Transportability of Equipment.

4. BS 2011 Part 2.1R (IEC 60068-2-18) Test R Water and Guidance.

2 FURTHER READING AND BIBLIOGRAPHY

Further information on the environmental conditions addressed in this leaflet and the effects on materiel may be found in other leaflets in AECTP 200, Category 230.

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SECTION 236/237 - DEPLOYMENT ON AIRCRAFT

LEAFLET 236/237 - DEPLOYMENT ON AIRCRAFT

TABLE OF CONTENTS

1. GENERAL

This leaflet addresses the climatic environments that may be experienced by materiel when deployed or installed on fixed wing aircraft and on helicopters. Characteristics of the induced climatic environments are presented, discussed, and supplemented by data sheets. Also, advice is given on potential damaging effects and treatment options. Where relevant, appropriate AECTP 300 Test Methods are identified.

2. CHARACTERISTICS OF INDUCED ENVIRONMENTS

2.1. Aircraft parked

2.1.1. Temperature

a. High temperatures inside unventilated compartments are likely to exceed local ambient temperatures due to the indirect effects of solar radiation on the aircraft skin and through transparent panels. The latter may be particularly significant for those types of helicopters for which a comparatively large area of the skin of the cockpit is transparent. Materiel and components contained in carried stores will be affected similarly. Externally fitted materiel shaded by the aircraft structure may still be subject to radiation reflected off the parking apron or landing pad.

b. The relative angle of elevation between the source and exposed surface, the prevailing cloud cover, the heat capacity of the exposed structure, its color and surface finish, and the duration of exposure will contribute to the amount of heat absorbed and the induced temperature of enclosed areas. It is possible for extreme values of ambient air temperature and solar radiation to occur on the same day, but experience shows the probability of this happening is low.

c. Test conditions, therefore, should be determined from specific measurements for the particular application. Results from Sea Harrier FRS MK1 hot weather trials (Ref 1) suggest that equipment bay temperatures would stabilize approximately 20°C above the external ambient air temperature. Temperatures of 85 °C or higher have been used to represent worst-case conditions inside cockpits or other areas behind transparent panels.

d. Results from hot weather trials on a helicopter suggest that equipment bay temperatures would stabilize approximately 20 °C above the external ambient air temperature. Temperatures up to 85 °C or greater have been used to represent worst-case conditions inside cockpits or other areas behind transparent panels.

e. The skin of the flight platform is likely to be a better radiator to the sky than is the ambient air during hours of darkness. For materiel deployed on aircraft operating in cold regions, it should be assumed that non-heat-dissipating materiel installed in enclosed compartments may experience low temperatures similar to those given for Storage and Transit in the appropriate Category C climatic areas.

f. Induced low temperatures in unpowered parked aircraft may be assumed to be no more severe than those of the local conditions for storage and transit.

2.1.2. Humidity

a. Materiel fitted inside unventilated equipment bays and similar areas of air-carried stores deployed on parked, unpowered aircraft are likely to experience high levels of humidity. This is particularly applicable at airfields in hot, wet tropic regions, where the diurnal cycle (characterised by high temperatures during the day and low temperatures at night) produces variations of pressure in partially sealed, unventilated compartments. Pressure variations induce the breathing-in of moisture, some of which is retained when the high temperature is restored. If the aircraft remains idle and compartments remain closed, or if areas susceptible to ingress are protected by unventilated temporary covers, there is likely to be an accumulation of moisture.

b. During the hotter part of the diurnal cycle, especially when external surfaces, skins or compartment covers are subjected to solar radiation, equipment or components within may experience levels of damp heat in excess of the external ambient conditions. The accumulation of moisture automatically leads to a higher dew-point temperature and, therefore, to a greater likelihood of saturation occurring during the lower temperature part of the cycle.

c. Preferably, test severities should be derived from data obtained on the intended flight platform while located in the expected geographical area of deployment. In the absence of measured data, it should be assumed that conditions will be the same as those given for Transport and Storage conditions for Category B climatic areas.

d. Moisture is likely to be formed and become entrapped during ascent or descent from altitude.

2.1.3. Air pressure

a. While on the airfield, materiel deployed on aircraft normally will experience air pressures equal to those of local ground ambient with the exceptions given below.

b. Materiel fitted in aircraft compartments that are pressurised during flight may be required to remain in-situ while subject to routine ground pressurization tests to determine the integrity of seals. Where applicable, the value of overpressure likely to be experienced should be agreed between the aircraft manufacturer or operator and the design authority for the installed materiel.

c. Materiel deployed externally on aircraft may be required to remain safe or survive when exposed to the blast from a nuclear explosion in the lower atmosphere, large scale chemical explosions and blasts from sonic booms generated by aircraft flying at supersonic speed. Unless shielded by the aircraft structure, materiel located close to the muzzle(s) of guns installed on the aircraft will be subject to blast during ground testing.

d. Air-blast pressure waves from conventional, atomic or nuclear explosions propagate through the atmosphere as shock waves. Estimates of dynamic overpressure levels at certain distances from an explosion are facilitated by similarity or scaling laws that involve distance, air pressure, sound velocity and characteristic length of the charge. Theoretical approximations are available for different stages of propagation (i.e., for close-in blast, for far-out blast and for the intermediate stage). Characteristic time histories of blast waves with typical values of overpressure, blast duration, and shock front velocities, particularly of atomic weapons, are discussed in Ref. 3.

e. Blasts from sonic booms produced by aircraft flying at supersonic speeds have a time history in the far field characterized by positive and negative peaks generated by the front and rear ends of the aircraft respectively. In the near field, the flow is related to the geometry of the aircraft, producing multiple peaks. The maximum pressures generated are largely a function of altitude. For a high flying aircraft, peak pressures observed on the ground are rarely in excess of 96 N/m^2 with typical time intervals between peaks of 100 to 300 ms. For low-flying supersonic aircraft, 6895 N/m^2 has been measured. Turning or linear acceleration of the aircraft can focus the trailing shocks to produce localized superbooms with amplification factors up to 5. A superboom will occur at a fixed position on the ground, which is predictable from knowledge of aircraft acceleration rates, altitude and attitude; it does not move with passage of the aircraft.

2.1.4. Icing

Icing of materiel deployed externally on aircraft while static on the airfield normally arises entirely from the prevailing meteorological conditions at ground level.

2.1.5. Dust and sand

Operation and ground movement of other aircraft, especially with VSTOL or hover capability, are likely to generate considerable accumulations of turbulent and driven dust, particularly when deployed in hot, dry desert regions. To a lesser extent, the wheels and tracks of land based vehicles also generate clouds of dust and sand. Severities of concentration and distribution of particles above ground level depend on the same factors as for naturally occurring dust and sand clouds.

2.1.6. Erosion by impact

Erosion of materiel fitted externally on parked aircraft will be limited to that caused by natural precipitation, windblown and vehicle generated dust and sand. The levels of damage that can arise are usually of less concern than damage levels that can occur during flight.

2.1.7. Immersion and spray

a. If materiel is mounted at low positions on the aircraft (e.g. on undercarriages or appendages close to the ground) and it is possible that the aircraft may be required to be parked on airfields or temporary landing pads susceptible to flooding or accumulations of water, consideration may be given to the possibility of the materiel being partially or totally immersed.

b. Materiel deployed externally on the aircraft may be subject to pressurized spray when the aircraft is hosed down during cleaning or de-icing operations in preparation for flight.

2.2. Ground Running

2.2.1. Temperature

a. When power is applied either directly from the engine or from external supplies, on-board environmental control systems will distribute conditioned air to some compartments of the aircraft and to any aircraft carried stores to alleviate the effects of induced conditions. At initial switch-on, external ambient air is drawn in and distributed around the aircraft before the system has had time to become effective. When deployed in cold regions, materiel in conditioned compartments may experience an initial higher rate of cooling than would be expected from warmer ambient air. As ground running continues, the environmental control system becomes effective and, in cold regions, materiel begins to benefit from any self generated heat and that is given off by other systems and equipment. During long term ground running in hot regions, the combined effect of heat radiated from adjacent structures and operational equipment may tend to counteract the effects of the conditioned air.

b. Temperatures inside aircraft compartments and externally carried stores during ground running depend on the external ambient air temperature, equipment packing densities, the heat radiated from adjacent structures, heat given off by operational equipment, the level of any conditioning and the period of operation. Characteristics of the conditioned air supplied by the aircraft environmental control system should be obtained from the aircraft manufacturer.

c. Data on induced temperatures should be derived from measurements made at the intended location of materiel on the flight platform during representative worst-case conditions.

d. Historically, where specifically measured data have not been available, maximum switch-on temperatures for materiel carried in both conditioned and non-conditioned areas of aircraft deployed in hot, dry regions have been taken as equivalent to maximum values of the storage and transit diurnal cycle. For materiel subject to solar radiation when located behind transparent surfaces, switch-on temperatures of 85 °C are assumed for fixed wing aircraft, and 90 °C for helicopters. For long-term ground running in hot dry regions and where characteristics of cooling air are unknown, ambient temperatures in conditioned compartments are assumed to stabilize at 15 °C lower than at switch-on. While it may be assumed cockpit canopies, access doors and panels will have been open for a period sufficient to allow external ambient air to have an alleviating effect (dissipating heat from operational equipment), temperatures at switch-on should be assumed to prevail in non-conditioned areas. Where such areas are behind transparent panels, a temperature of 70 °C should be assumed. For externally carried stores in which packing densities of heat dissipating equipment are likely to be greater than that in aircraft compartments, final temperatures and rates of increase are likely to be in excess of those given above. Indeed, long-term ground running without forced-air cooling should be avoided in hot, dry regions, otherwise permanent damage or degraded reliability is likely to occur.

e. Internal high temperatures of individual materiel will depend on similar factors to those discussed above. Packing density and heat dissipation of components, the thermal paths to external surfaces, and the incorporation of cooling systems will influence temperature severities. Where internal ambient temperatures or those of individual components are of concern, they should be estimated using thermal analysis programs incorporating the severities given above and supported by specific measurements made in representative conditions.

f. For deployment in low temperature regions, in the absence of measured data, the following severities may be assumed to represent worst case conditions at switch-on for materiel in enclosed compartments of which the skin surfaces are better radiators of heat to the night sky than is the ambient air:

Area of Deployment (Climatic Category)	Induced Temperature (°C)
C0	-21
C1	-33
C2	-46
C3	-51
C4 .	-57

g. Severities may be alleviated by the on-board environmental control system during long-term ground running and/or heat dissipated by operational equipment.

2.2.2. Humidity

a. When materiel is intended to be used in warm, damp atmospheres or wet tropical regions, in the absence of measured data, it should be assumed that the conditions will be similar to those for Transit and Storage in Category B climatic areas.

b. It may be assumed that when engines are running or aircraft systems are operating from external power supplies, canopies and hatches will be open and air conditioning systems will be operating, providing ventilation and a reduction in the level of moisture of the atmosphere in the previously closed compartments. The relative humidity inside installed equipment with semi-sealed, unventilated enclosures, will be reduced gradually by self-dissipated heat, although moisture content is unlikely to be reduced. When power is switched off and the equipment cools, the differential air pressure on either side of the walls of the case may cause the enclosure to breathe in external air and increase the level of retained moisture.

c. For externally carried stores, especially when deployed on aircraft operating in wet tropic regions, the variation in temperature of the internal atmosphere resulting from operation of the equipment, may have a similar effect.

d. Materiel deployed or installed on aircraft operating in hot, dry regions of the world, may experience extremely low levels of humidity when subjected to the indirect effects of solar heating or when located close to sources of dissipated heat during ground running. Electrical/electronic systems with high packing densities, on-board air-carried armaments and stores subject to ground running may be affected similarly. No recorded data are readily available for such induced dry atmospheres. Relative humidity of less than 30% is common for naturally occurring conditions in hot, dry regions of the world. Therefore equivalent or lower levels of RH may be assumed to occur inside nominally dry aircraft compartments or similar areas of individual materiel subjected to induced high temperatures.

2.2.3. Air pressure

See paragraph 2.1.3.

2.2.4. Icing

Icing of materiel deployed externally on aircraft while static on the airfield normally arises entirely from the prevailing meteorological conditions at ground level. Icing may be counteracted by on-board de-icing systems during ground running.

2.2.5. Dust and sand

When the host aircraft is ground running on airfields in hot-dry desert regions, on temporary landing strips, or any other areas where there may be accumulations of small particulate materiel, the backwash from propellers, the efflux from jet engines, or the downwash from helicopter rotors can produce considerable concentrations of air-borne dust and sand. Helicopters can be enveloped in dense clouds of dust or sand. Areas forward of jet tail pipes are also vulnerable if reverse thrust mechanisms are exercised during engine runs. In the absence of specifically measured data, severities should be considered to be equivalent to naturally occurring dust and sand storms for the duration of the events.

2.2.6. Erosion by impact

See paragraph 2.1.6.

2.2.7. Immersion, precipitation and spray

See paragraph 2.1.7.

2.3. Flight Sorties

2.3.1. Temperature

2.3.1.1. Fixed wing aircraft

a. Temperature levels

(1) Materiel installed inside aircraft compartments may be subjected to high ambient temperatures due to heat given off by engines and auxiliary power units, engine exhaust systems, avionics and electrical equipment or due to being located in a stagnant area such as an equipment rack or behind an instrument panel. The cooling efficiency of materiel located in partially or non-conditioned compartments may be affected by lower density air at flight altitude and may cause operating temperatures to rise to unacceptable levels.

(2) Stabilized low temperatures experienced by materiel in unconditioned compartments of aircraft and externally carried stores (not subject to aerodynamic heating) may be assumed to correspond with the ambient air temperatures at flight altitude given in the tables of reference atmospheres (e.g. Table 1 of AECTP 300 Method 317).

b. Aerodynamic heating

(1) Materiel located in forward compartments and close to leading edges of high performance aircraft and similar areas of externally carried stores, can be subjected to high temperatures caused by aerodynamic heating during air-carriage at supersonic speeds. The amount of heat generated in the airframe is determined by the 'recovery temperature' and the heat transfer coefficient (i.e., the ability of the boundary layer to transfer heat to the structure), which in turn depends on properties of the material forming the skin and the temperature and characteristics of the air at flight altitude. Temperatures produced in the airframe are determined by structural details or thermal paths that allow any radiative or conductive exchange of heat between the structural elements and the internal atmosphere, and the distance from the 'stagnation point' (i.e., the point immediately in front of the forward surface or leading edge at which the air is brought to rest). If aerodynamic heating is a transient condition, the body temperature also will depend on thermal capacity (i.e., whether it is 'thick' or 'thin skinned'). The temperatures

experienced by installed materiel will depend on the heat transfer coefficient of the attachment to the airframe and the amount of heat absorbed by the surrounding air.

(2) Periods of aerodynamic heating will depend on the performance of the host aircraft and mission and flight profiles.

(3) A basis for estimating temperatures in enclosed compartments is given in Annex A to this chapter. Where possible, estimates should be supported by measured data.

2.3.1.2. Helicopters

a. Temperature levels

(1) High temperatures may be experienced by installed materiel during flight as a result of being located in close proximity to main or auxiliary power units, jet pipes, electrical/electronic equipment dissipating heat and/or being located in a semi-stagnant area. Estimation of induced high temperatures is a complex process and should be substantiated by measurement during flight trials in representative worst-case conditions. In the absence of measured data and characteristics of cooling air, maximum temperatures for materiel deployed in unconditioned and conditioned areas of rotary winged aircraft should be assumed to be 55 °C and 40 °C respectively.

(2) Stabilized low temperatures experienced by materiel installed in unconditioned compartments of aircraft and air carried stores may be assumed to correspond with the ambient conditions for the flight altitude given in standard tables. Information regarding low temperatures that may be experienced by materiel installed in conditioned compartments should be sought from the airframe manufacturer. Where applicable, adjustments should be made for heat dissipated by operational equipment.

b. Rates of change of temperature

(1) For fixed wing aircraft, transition times (between ambient temperatures at ground level and flight altitude and vice-versa during take-off and landing) are likely to result in materiel in non-conditioned areas being subjected to rapid rates of change of temperature. Even faster rates of change over a wider range of temperature extremes are likely to occur when materiel is subjected to aerodynamic heating during short-burst, high-speed manoeuvers of high performance aircraft. In the absence of measured data, severities can be derived from knowledge of maximum rates of climb and descent for the host aircraft. Rates of change associated with dynamic heating should be determined from data obtained during representative flight trials.

(2) For helicopters, transition between temperature extremes at ground level and altitude during take-off and landing may result in deployed materiel, particularly externally carried stores, being subjected to faster rates of change of temperature

than those occurring while the aircraft is on the ground. In the absence of measured data, worst-case severities may be determined from the maximum climb and descent rates of the aircraft and the maximum difference in ambient temperatures between ground level and flight altitude likely to be experienced in service.

2.3.2. Humidity

Moisture is likely to be formed on external and internal surfaces of materiel during flight sorties as a result of the transfer between prevailing temperatures at ground level and flight altitude and vice-versa, especially when operating into and out of airfields in sub-tropic or tropic regions. Warm air in the compartments and individual items of equipment mixes with lower temperature ambient air during the climb to altitude. Also when cold surfaces meet relatively warmer air during descent and landing, moisture condenses out as the air temperatures are reduced below their respective dew points. In the latter case, conditioning is aggravated by the change in air pressure forcing in warm damp air. It should be assumed that RH levels in conditioned compartments will reach 90-95%, while in unconditioned compartments, saturation will occur.

2.3.3. Air pressure

2.3.3.1. General

a. Normally during flight, materiel installed in pressurized compartments will experience air pressures ranging between local ground ambient and some lower value equivalent to that at a predetermined altitude, say 3000 m, which is then maintained above that of the external ambient pressure by an amount known as the differential pressure. Alternatively, materiel installed in unpressurized areas will be subject to ambient air pressure at flight altitude.

b. In most cases the pressures experienced by materiel during flight sorties will vary between the ambient pressures at ground level and flight altitude, details of which may be found in Leaflet 2311 or international standards of reference atmospheres such as ISO 5878.

2.3.3.2. Rates-of-change of pressure

a. Positive and negative rates of change of pressure during flight sorties vary from those resulting from normal take-off and landing to those associated with high speed manoeuvers such as diving and climbing to and from low-level targets or during air-combat. Rates of change experienced by carried materiel depend on aircraft performance, the flight or mission profile, and whether the materiel is carried in a pressurized or non-pressurized area.

b. Details of climb and descent rates should be obtained from the aircraft manufacturer. In the absence of manufacturer climb and descent rates, a (inclined) rate of climb and descent of 10.2 m/s (2000ft/m) should be assumed for helicopters. However, it should be noted that nominal rates of climb and descent may differ by up to 40% dependent on the type and/or role of the aircraft. A similar allowance may be required with regard to aircraft manoeuvers.

2.3.3.3. Rapid and explosive decompression

Abnormal rates of change of pressure may occur in normally pressurized compartments during emergency situations. The rate of depressurization following failure of the pressurization system will depend on the volume of the compartment and the initial pressure differential. In the absence of specific information regarding the size of compartments, a maximum duration of one minute should be assumed. Structural failure of the airframe may result in explosive decompression for which a maximum period of 100 msec should be assumed.

2.3.3.4. Overpressure

a. For exposed materiel on leading edges and on forward facing surfaces during normal forward flight, the pressure will exceed the local ambient pressure by an amount directly proportional to the square of the velocity of the flight platform related by the following formula:

$$p = 0.5\rho\, v^2$$

where p = dynamic pressure in pascals
ρ = density of air at flight altitude in kg/m^3
v = velocity of the flight platform in m/s

b. Unless shielded by the aircraft structure, externally deployed materiel located close to gun muzzles and air carried weapons will be likely to blast pressure waves during gunfire and weapon launch. No data are readily available regarding characteristics of the pressure waves, but the environment is more often characterized in terms of the shock and vibration induced in the structure of the aircraft and any attached materiel.

2.3.4. Icing

a. Impact icing can occur at all stages of flight dependent on the prevailing atmospheric conditions and velocity of the flight platform.
b. Accretions of ice on frontal areas and leading edges of externally carried stores result from impact with super-cooled water droplets in rain, fog and cloud formations that are in an unstable state, thereby freezing when subjected to mechanical shock. Impact icing depends on the impact velocity and the temperature of the impacting surface with respect to that of the water droplets, including the effect of any kinetic heating.

c. Super-cooled water droplets can exist at temperatures ranging from 0 to -40 °C. The altitudes at which this temperature band exists vary with geographical location, season of the year and the prevailing climatic conditions. Icing at lower temperatures may arise as a result of the adherence of ice crystals. This can occur when the flight speed through clouds of ice crystals raises the temperature of frontal areas of the flight platform sufficiently to melt the intercepted crystals and cause them to adhere. Therefore ice accretion can occur on exposed surfaces at all stages of flight dependent on the prevailing atmospheric conditions and the velocity of the flight platform.

d. Rates of ice accretion are determined by the amount of free super-cooled water per unit volume of air, drop size and its presence in terms of rain, fog or type of cloud formation.

e. Impact icing severity is defined as the rate of accumulation of ice in weight per unit area per unit time. However, in practice, grading is highly subjective in terms of 'severe, ' 'moderate' or 'light.' It is suggested that 'severe,' as quoted by experienced aircrews, is represented by a rate of $4g/cm^2/h$.

f. Dependent on the provision or otherwise of localized drainage, accumulations of water generated are likely to be frozen by low temperatures at flight altitude. The transition between ground level and flight altitude and vice versa may lead to the production of considerable amounts of condensation and ingress of moisture by materiel installed in partial or non conditioned compartments. Dependent on the provision of localized drainage, a build-up of retained moisture may occur which in turn may be frozen at one or more stages of flight sorties. The severity will depend on the provision or otherwise of any conditioning on the flight platform and the prevailing ambient conditions. No data giving severity of this type of icing is readily available

g. Close proximity to deployed systems that depend on built-in refrigeration and transfer of refrigerant, can result in adjacent equipment being subjected to deposits of ice and moisture. Operation of certain types of system may depend on built-in refrigeration equipment and the transfer of refrigerant. Close proximity to low temperature components combined with deposits of moisture may result in the formation of ice on the surfaces of adjacent equipment.

2.3.5. Dust and sand

See Paragraph 2.3.6.3.

2.3.6. Erosion by impact

2.3.6.1. Hail

a. Meteorological conditions normally required for the formation of hail are similar to those associated with the development of thunderstorms (i.e., warm, moist and unstable air). Larger stones are produced when powerful updraughts and a plentiful supply of moisture prevail. However, hail sometimes forms in convective clouds that do not develop into thunderstorms. Hailstorms are found more frequently in the sub-tropics and middle latitudes where larger stones are more likely to occur over large land masses. A study on hailstorms reported that occurrence of hail is greatest between altitudes of 3000 and 6000 m (7 times that at ground level), and is very low above 14000 m.

b. Damage potential from impact with individual stones depends on the type and density of the ice and the size and impact velocity. Forward facing surfaces and leading edges of cockpit canopies, aerial and radar housings, surveillance and tracking systems, landing and navigation lights and wing or airfoil sections are particularly susceptible to damage.

2.3.6.2. Rain

a. Rainfall is generally more frequent in tropic regions. Heavier rainfalls occur in mountainous regions especially where the mountain range runs parallel to the coast and intercepts on-shore moisture-laden winds. In temperate latitudes, rain is most likely in coastal regions. Rainfall amounts are generally low inside large continental land masses. However, rainfall patterns are entirely variable both in terms of time and space, and detailed advice regarding rainfall characteristics in specific localities should be obtained from the meteorological centers. The maximum diameter of raindrops that have reached their terminal velocity is around 6 mm.

b. Factors affecting the erosion of materiel by rain include drop size, impact velocity, characteristics and properties of materials used in the construction, shape and surface finish of the impacted surface, and the number of drops and rapidity of impact. Repeated collisions at the same point influence the pattern of build-up of stress and erosion of the impacted surface. Resistance is expressed in terms of the time required for droplets of 2 mm diameter in a simulated rainfall of 25 mm/hour and with an impact velocity of 225 m/s to produce various degrees of erosion.

2.3.6.3. Dust and Sand.

Studies of dust storms in hot dry desert regions indicate that dust remains suspended in the atmosphere for a considerable period after the storm has abated. Particles of up to 10 μm reach heights of 1500 m with an upper limit for dust of around 3000 m. The severity of erosion of frontal areas and leading edges of materiel externally deployed on aircraft operating at low altitudes over such regions, depends on the impact velocity, the form and hardness of the particulate and of the material or surface finish of the impacted surface.

2.3.7. Precipitation and spray

a. Materiel installed in partially or non-conditioned compartments of aircraft or externally carried stores is subject to precipitation by condensation formed on overhead surfaces during descent from low temperature at altitude to warmer atmospheres at ground level. This occurs especially when flying into airfields in hot-wet tropic regions of the world. Precipitation rates equal to the heaviest intensities of rain for short periods are known. Dependent on the provision or otherwise of drainage facilities within the compartment, some degree of immersion may be occur

b. Materiel located within the backwash of propellers, at low positions on undercarriages or when underslung from pylons/launcher rails, etc, is vulnerable to spray from ground surface water or runway de-icing fluids.

c. When operating helicopters at low level over expanses of water, especially in the hover mode, externally deployed materiel is likely to be exposed to considerable amounts of spray generated by the airflow from the rotor. No records of spray rates for such events are readily available.

3. POTENTIAL DAMAGING EFFECTS

3.1. Temperature

a. Induced high and low temperatures experienced by materiel when deployed on aircraft can affect the physical and chemical properties of materials used in their manufacture. Expansion and contraction of structural components accompanied by reductions in mechanical strength and changes in ductility, result in interference and separation between adjacent parts and impose unacceptable levels of stress and strain. Such stress and strain leads to deformation or mechanical failure. Induced variations in the characteristics of electrical/electronic components and changes in viscosity of lubricants reduce accuracy, reliability and operating efficiency. High and low temperatures affect physical and chemical characteristics of rocket fuels. These altered characteristics may cause motors of guided weapons to malfunction.

b. Aerodynamic heating rapidly generates large temperature gradients and thermal stresses (i.e., thermal shock) in the structure of the flight platform. The rapid application of thermal stress can embrittle materials and cause more failures at lower levels of strain than would be the case with a slower rate of increase to the same severity. Although normally brittle materials are more susceptible, ductile materials can fatigue under repeated cycling.

c. Thermal shock can induce dynamic effects by modifying torsional and flexural stiffness and can modify the performance of aerofoils).

3.2. Humidity

a. Induced damp heat conditions (resulting from a combination of inadequate ventilation and enforced breathing of moisture created inside aircraft compartments, air-carried stores and individual equipment) accelerate the degradation of materials, causing more system malfunctions than would exposure to local meteorological conditions alone. Reduction or breakdown of insulation resistance of circuitry and components can result in degraded performance, reduced reliability, or total failure of electrical/electronic systems. Performance of surveillance materiel may be reduced by misting and accumulations of moisture in optical systems.

b. Warm damp atmospheres in unventilated areas provide ideal conditions for promotion of fungal growth and aggravate attack by corrosive agents. The effects of moisture on materiel, achieving and maintaining dry enclosures, standards and methods of sealing, water vapor barriers, drying out procedures and registering levels of humidity need to be addressed.

c. Induced low levels of humidity can influence the characteristics of electrical/electronic components and affect the calibration, stability and accuracy of electronic systems.

3.3. Air Pressure

3.3.1. Pressure Differentials

a. Low air pressure at flight altitude and rates of change of pressure induced during flight sorties may create pressure differentials across the walls of cases and protective covers of materiel and components. Such pressure differentials may cause protective covers to deform, incur structural failure, or interfere with internal parts, and, thereby, cause malfunction of the materiel. Although materiel may be fitted with pressure equalization devices, rates of change of pressure during flight sorties may exceed design values.

b. Materiel which relies on the density of the surrounding atmosphere for maintaining an acceptable operating temperature, may exhibit degraded performance or become unreliable due to the reduced efficiency of the cooling system while at flight altitude.

c. Externally deployed materiel is likely to experience rapid rates of change of pressure when subjected to battlefield explosions, causing dynamic loading of structural components. Materiel is likely to be torn from its fixings or attacked by flying debris. Damage incurred will depend on the strength and ductility of the fixings and protective covers. Glazed areas, optronic and microphonic systems and components will be particularly vulnerable.

3.3.2. Cooling

Heat dissipating materiel that relies on convection for maintaining an acceptable operating temperature may exhibit degraded performance due to the reduced efficiency of the cooling system because of lower air pressure at flight altitude.

3.4. Icing

a. Impact icing of externally deployed materiel may degrade performance of release mechanisms, linkages, actuation systems and control surfaces, and may block apertures and impair performance of optical systems. While loading imposed by ice build-up is an important consideration, unequal distribution may be of more concern because carried stores may become unbalanced and induce unacceptable levels of compensating actions during captive flight.

b. Frosting or freezing of accumulations of moisture caused by induced variations of temperature and pressure may result in degraded performance or total failure of materiel in partial or non-conditioned areas.

c. Malfunction of materiel may be caused by frosting or freezing of accumulations of moisture produced by condensation and variations in temperature and pressure during flight sorties.

3.5. Dust and sand

a. The effects of exposure to dust and sand-laden atmospheres at ground level include impaired performance of optical systems due to accumulations of particulates, etching and scratching of surface finishes, corrosion of exposed underlying materials, blockage of apertures, and reduced efficiency of cooling and ventilation systems.

b. Dust deposits inside materiel are likely to cause short-circuiting of insulators, tracking and build-up of static electricity, interference between moving parts, and contamination of lubrication systems.

3.6. Erosion by high velocity impact

a. During high speed flight, impact with hail, rain, dust and sand may reduce sensitivity of tracking and surveillance systems by eroding radomes and protective covers. A significant reduction in the optical quality of aircraft windscreens has been reported after low-level flights at velocities of 290 to 320 m/s over desert areas. Etching and scratching of surface finishes may encourage corrosion of underlying materials.

b. Impact with rain, hail and dust can result in the build-up of electrostatic charges and cause malfunction or failure of sensitive components of electronic systems.

3.7. Immersion, precipitation and spray

Materiel subjected to immersion, precipitation and spray is likely to suffer ingress of water, (including any contained contaminants), through apertures or by seepage of materials, seals and joints, affecting structural integrity of packaging and operational performance of equipment in a manner similar to that described in paragraphs 3.2, above.

4. TEST SELECTION

4.1. General

a. AECTP 300 provides test procedures that may be used for simulating induced climatic environments against which materiel may be subjected when deployed or installed on fixed-wing aircraft. Choice of test method for temperature and humidity will depend on whether there is a requirement to simulate diurnal variations, including the heating effects of solar radiation (e.g., when the aircraft is parked on the airfield) or steady state conditions (e.g., in aircraft compartments during flight sorties), or just the maximum or minimum temperatures of a diurnal cycle. Guidance is given in the relevant chapters regarding the selection of the appropriate test procedure, test severities and performance evaluation to which reference should be made.

b. Preferably, test severities should be derived from specific measurements made on the intended flight platform during representative worst-case conditions expected in service. Alternatively, severities that are derived from data obtained for other examples of materiel deployed in similar applications may be used.

4.2. Fall-back test severities

a. If specific measurements are not available, the fall-back severities in the AECTP 300 test methods should be used.

b. Values of temperature and humidity are quoted in Leaflet 2311 for external ambient (meteorological) and induced (Transit and Storage) conditions. In the absence of specifically measured data, values for the latter should be assumed to represent worst-case induced conditions experienced by materiel deployed on aircraft while parked on airfields and naval platforms. In the case of materiel carried in cockpits or in other areas behind transparent panels, maximum temperatures of at least 85 °C should be assumed.

c. In Leaflet 2311, the quoted values of temperature and humidity are those that are likely to be attained or exceeded in the most severe location for 1% of the most extreme month of the year (excluding C3 and C4 where it may be as much as 20% of the coldest month).

4.3. Tailored test severities

4.3.1. Temperature and humidity

a. Temperature severities used in tests (i.e., simulating high temperature conditions during air carriage) should be derived using one or both of the following methods in descending order of preference:

(1) From specifically measured data recorded during hot and cold weather trials. Measurements should be made at the relevant location on the intended flight platform. Other factors influencing temperature severities such as sources of dissipated heat and supplies of conditioned air should be represented correctly. The trials program should include flight sorties likely to produce worst-case conditions in service (e.g., aerodynamic heating).

2) From data for a similar application with adjustments for differences in the factors referred to in (1) above.

b. Temperature severities used in tests simulating low temperatures during air carriage may be derived from the 1% occurrence ambient air temperatures at altitude. In the absence of measured data, a worst-case temperature of -20 °C should be assumed in temperature conditioned compartments.

c. For materiel carried at external locations on the aircraft rapid rates of change of temperature during transition between ground and flight altitude and vice versa may be determined from rates of climb and descent of the flight platform and the respective temperatures at altitude and ground level for the geographical area of deployment.

d. Worst-case levels of humidity during air carriage are normally those associated with descent from altitude to ground level, especially when operating in hot-wet tropical regions. Levels of relative humidity will be close to, or actually at saturation, especially for materiel located in non-conditioned areas. Similar severities may occur inside equipment thought to be of closed construction due to the aggravating effects of varying air pressure.

4.3.2. Aerodynamic heating and thermal shock

When the effects of dissipated heat cannot be predicted satisfactorily by calculation or modeling, testing to simulate the effects of aerodynamic heating during air carriage may be appropriate. Alternatively, testing for the effects of the thermal stresses induced by rapid rates of change of temperature may be more appropriate.

4.3.3. Air pressure

a. Severities for low air pressure tests may be determined from environmental requirements documents and from performance of the host aircraft (e.g., operational altitude, rates of climb and descent), and the provision or otherwise of pressurization data at the location of the deployed materiel on the aircraft or flight platform.

b. When simulating ground pressure testing for materiel installed in pressurized compartments, test severities for air pressures above standard ambient should be sought from the airframe manufacturer or aircraft operator. Representative simulation of blast pressure waves from explosions, gunfire and weapon launch is achieved best by subjecting the materiel to the real life environment.

4.3.4. Dust and sand, icing, erosion and induced wetting

For other environmental conditions [e.g., dust and sand, icing (induced moisture and impact), spray etc.], it is unlikely that tailoring to specifically measured data will be cost effective. In those cases, appropriate fall-back severities should be selected. For artificially created dust and sand laden atmospheres, turbulent dust is the preferred method. Simulated wind blown dust and sand may be used where artificially created dust and sand cannot adequately demonstrate penetration and erosion by sharp edged particulate. Testing for erosion by impact high velocity is usually limited to sample materials.

ANNEX A

Estimation Of Enclosure Temperatures

A.1 Enclosure boundary

A.1.1 Typical features forming an enclosure boundary are the missile or aircraft skin, bulkheads forming the section of the missile or flight platform, or the walls of a cover or equipment rack. Providing sufficient parameters are known, it is possible to estimate the mean internal temperature within the boundary.

A.2 Heat transfer parameters

A.2.1 Mean specific heat

A.2.1.1 Most materiels use a range of materials with widely differing specific heats. For electronic equipment contained in guided weapons with conventional structures, mean values of specific heat ranging between 600 and 1000 J/kg °C have been measured.

A.2.2 Overall heat transfer coefficient.

A.2.2.1 The overall heat transfer coefficient enables the quantity of heat transferred from external sources through the enclosure walls to be calculated. It is possible to calculate the theoretical coefficient itself for some applications though missile structures are normally assessed by wind tunnel experiment. The coefficient may be a total expressed in watts per °C or may be quoted in similar units per unit area of specified wall thickness. Given the higher wall surface temperature, the temperature on the opposite face of the wall may be calculated.

A.3 Heat extracted by forced air cooling.

A.3.1 Forced cooling facilities are often built into materiel where it is known that adversely high temperatures would otherwise exist. Blown air is normally used for this purpose and, from a knowledge of the mass flow, its specific heat and temperature rise, the heat extracted may be calculated.

A.4 Calculation of internal temperatures - symbols and units.

A.4.1 The following symbols and units are used in the development of the heat transfer equation to determine the temperature profile over a particular time interval:

t_1 = enclosure outer surface temperature, °C

t_2 = mean internal temperature at start of time interval, °C

t_3 = mean internal temperature at end of time interval, °C

U = overall transfer coefficient, W/°C

θ = temperature rise, °C

m = materiel mass, kg

c = mean specific heat, J/kg °C

H = net heat input, W

H_d = heat dissipated by materiel, W

H_e = heat extracted by cooling, W

H_a = heat lost or gained to adjacent equipment, W

A.5 Equipment inert

When the enclosure temperature is likely to be high without heat dissipated by contained equipment (e.g., due to external ambient conditions or supersonic flight) it may be useful to determine conditions inside the compartment without the contained equipment operational.

Heat taken in from external environment:

$$H = U(t_1 - t_2) \text{ watts}$$

Heat supplied = m c θ joules

Thus internal temperature rise = $U(t_1 - t_2)/mc$ °C from which t_3 may be determined.

Thus for materiel on the ground, values of t_3 may be plotted say at 15 minute intervals while for a missile in flight 10 second intervals against the flight profile may be more appropriate.

A.6 Equipment operational

For Heat input:

$$H = H_d + U(t_1 - t_2) - H_e \pm H_a$$

Internal temperature rise =$(H_d - He \pm H_a)/mc + U(t_1 - t_2) /mc$ °C

from which t_3 may be determined and expressions developed for t_2 in terms of t_1 and t_3. It should noted that H_d, H_e and H_a may not be fixed quantities and may vary with temperature and/or materiel duty cycles.

SECTION 238 - DEPLOYMENT ON SHIPS

LEAFLET 238/1 - Deployment on Ships

TABLE OF CONTENTS

1. GENERAL

This leaflet addresses the climatic environments that may be experienced by materiel when deployed on or installed in surface ships powered by nuclear or conventional means and in submarines. The characteristics of climatic environments are presented, discussed, and supplemented by data Sheets. Advice is given on potential damaging effects and treatment options. Where relevant, advice on selecting appropriate AECTP 300 Test Methods is provided.

2. CHARACTERISTICS OF INDUCED ENVIRONMENTS

2.1 Above Deck on Surface

2.1.1 Temperature

a. Where no ventilation or assisted cooling is provided, high temperatures inside unventilated shelters or under temporary covers exposed to solar radiation are likely to exceed those outside of the enclosed area. Clearly the most severe conditions will occur when shipborne materiel is installed or carried above deck in hot dry regions of the world. The relative angle of elevation between the source and the exposed surface, the prevailing cloud cover, the surface finish, the color and heat capacity of the radiated surface and the duration of exposure will determine the amount of heat absorbed. The induced ambient temperature of the enclosed atmosphere will depend on the provision or otherwise of any ventilation or forced air cooling. It is possible for extreme values of ambient air temperature and solar radiation to occur on the same day, but experience shows the probability is low.

b. Information on the temperatures induced inside sheltered areas or under temporary covers above deck on surface ships are not readily available and should be determined from specific measurements for particular applications. In the absence of measured data, the temperatures given for Transit and Storage diurnal cycles should be assumed to apply. The severities for high temperature areas on open seas (category M1, Leaflet 2311) tend to be around 2 °C lower than those for overland (category A1), implying the latter should be taken into account if the ship is to operate in and out of ports in those geographical regions. A similar consideration is more appropriate with regard to temperature severities for Transit and Storage in the colder regions of the seas, (M3), where temperatures may be up to 12 °C higher than those over land in the same geographical areas (C2).

2.1.2 Thermal shock

Materiel brought on deck when the ship is operating in low temperature regions may experience changes in temperature in the order of 45° C over a period of two or three minutes or less. Conversely, materiel exposed to solar radiation, could experience a change in temperature in the order of 50° C in a similar period, if immediately after a temperature soak, it is immersed in the sea or if a submarine dives immediately after a high temperature soak.

2.1.3 Humidity

a. Materiel installed or stored on deck in unventilated shelters or under temporary covers, is likely to be subjected to induced high levels of humidity, especially when deployed in hot-wet tropic regions. Worst cases occur where the diurnal cycle is characterized by high temperatures during the day and low temperatures at night, producing corresponding variations of pressure in the covered areas, causing them to breathe in moisture some of which is retained when the external ambient temperature rises again. Solar radiation on the external surfaces of shelters or temporary covers during the hotter part of the diurnal cycle can result in enclosed equipment being subjected to a damp heat environment more severe than the external ambient conditions. The accumulation of moisture can lead to a higher dewpoint temperature and, therefore, the possibility of saturation occurring during the cooler part of the cycle.

b. Preferably, conditions for particular applications should be determined from specifically measured data. The levels of relative humidity may be reduced by heat from operational equipment. In the absence of measured data, the conditions for Transit and Storage for category B climatic areas given in Sections 232 and 233 should be assumed.

2.1.4 Air pressure

Materiel installed above deck will normally experience pressures equivalent to the local ambient air pressure at sea level. Materiel may be required to survive or continue to operate following exposure to blast waves from a large scale chemical explosion or a nuclear explosion in the lower atmosphere.

2.1.5 Icing

Materiel on open decks is likely to be subjected to accumulations of ice formed from freezing spray. The interaction of the vessel's maneuvers and the prevailing sea conditions can increase the amount of spray generated. Rates of ice accretion of up to 40 mm/hour have been reported for ships operating in the Arctic region.

2.1.6 Immersion, precipitation and spray

No measured data are readily available that indicate severities of induced forms of wetting experienced by materiel installed or carried above deck. Subjective observations indicate that materiel may experience short periods of precipitation equivalent to heavy rain and accumulations of water of depths up to 150 mm. Unprotected materiel fitted to external surfaces of submarine hulls will be subjected to total immersion when the submarine operates below the surface.

2.1.7 Hydraulic pressure

Materiel carried on board for subsequent immersion in the sea, will be subjected to hydraulic pressure dependent on the depth of immersion defined in the design requirement for the individual equipment. Pressure is related to the depth of immersion by the formula:

$$p=9.8d$$

where p is the hydraulic pressure in kPa and d is the depth of immersion in meters.

2.2 Air Conditioned Compartments

2.2.1 Temperature/humidity

Temperatures in air conditioned compartments on surface ships of minesweeper (minehunter) size and above, range from 15 °C to 30 °C with relative humidity ranging from 30 to 70 %. Variations within those limits will depend on external ambient conditions and the amount of heat given off by operational materiel and personnel occupying the compartment, but may be considered constant once established in the climatic area of operation. In the event of an interruption in the supply of conditioned air, a temperature of 40 °C with relative humidity of 70 % should be assumed to occur for periods of up to 20 minutes for surface ships; for submarines, a temperature of 50 °C with relative humidity of up to 100 % should be assumed to occur for periods of up to 20 minutes.

2.2.2 Air pressure

2.2.2.1 General

Air pressure inside compartments contained within the citadel boundary of a ship is raised above the local ambient air pressure to provide a gas tight seal against the ingress of contamination from Nuclear, Chemical and Biological attack. The absolute pressure experienced by materiel contained within the compartment should be assumed to be the maximum value of ambient pressure likely to occur at sea, (in the order of 1060 mbar), plus the specified level of overpressure. In the absence of a specified value, a level of 8 kPa (80 mbar) should be assumed.

2.2.2.2 Air pressure above standard ambient

The level of overpressure that materiel will experience when it is required to remain installed during routine pressure testing of submarine compartments is referenced in the relevant design requirement document. Alternatively guidance should be sought from the ship builder. The absolute pressure experienced by materiel should be assumed to be the maximum value of ambient pressure likely to occur at sea (1060 mbar), plus the specified value of overpressure. Absolute pressures of up to 1314 mbar (131 kPa) may be assumed to occur in submarine compartments while the vessel is submerged.

2.2.2.3 Air pressure below standard ambient

Air pressure in submarine compartments is likely to be reduced to 872 mbar (87 kPa) for periods of up to 3 hours during 'snorting'. Cyclic variations inducing further reductions of up to 160 mbar (16 kPa) are likely to occur.

2.2.3 Precipitation and spray

The levels of precipitation associated with condensation on overhead surfaces and emergencies such as fractured and leaking joints on water pipes, etc. are unpredictable. Historically, a minimum rate of 280 litres/m^2/h is used when testing materiel for compatibility with this type of conditioning, including the spray from fire sprinklers.

2.3 Partial And Non-Conditioned Compartments

2.3.1 Temperature and humidity

2.3.1.1 Surface ships

a. The influence of external ambient conditions on the levels of temperature and humidity in partial and non-conditioned compartments will depend on the location of the compartment within the vessel. The further the compartment is below the main deck and towards the center of the hull the more likely the influence of external ambient conditions will be diminished. In some cases the heat and moisture dissipated by operational machinery will be the dominant factor such that when the vessel is operational, constant ambient conditions ranging from dry to damp heat can occur. Some conditions may be localized to particular areas of a compartment. The closer an unconditioned compartment above the water line is to the outside walls of the hull or the main deck, then the greater will be the indirect effects of solar heating of ships structure on the ambient temperature in the compartment, particularly when operating in category A climatic areas.

b. In the absence of measured data, conditions in fresh air ventilated compartments range from 15 °C to 45 °C with relative humidity of 30 to 85%, but for the reasons given above, severities for particular installations should be determined from specifically measured data. Steady state conditions in machinery compartments are quoted as ranging from 0 °C to 80 °C with 30% to 80% relative humidity with abnormal excursions up to 100 °C. The higher temperatures are more likely to be experienced as a result of being attached or in close proximity to operational machinery with high surface temperatures or located in stagnant areas not served by any form of ventilation.

c. Some items of materiel may be located in refrigerated areas or close to external hatches. Unless otherwise specified, operational materiel should maintain correct operation down to temperatures as low as -10 °C and with degraded performance at temperatures as low as -30°C.

2.3.1.2 Submarines

a. In the absence of measured data, conditions in fresh air ventilated compartments should be assumed to range from 15 °C to 45 °C with relative humidities of 30 % to 85%. While the submarine is underwater, conditions in all compartments are essentially induced and will depend on the level of conditioning of the air supplied to the individual compartments and the heat and moisture given off by operational materiel and crew members contained within. In machinery rooms, heat and moisture dissipated by operational plants are likely to be the dominant factors. Some conditions may be localized to particular areas of the compartment.

b. Ideally, severities should be determined from data obtained at the intended location of the equipment. If measured data, are not available, severity estimates may be based on other sources. Continuous conditions in machinery rooms are quoted as ranging from 0 °C to 40 °C with relative humidities of 20 % to 80 % plus abnormal conditions (for periods of up to 20 minutes) of up to 80 °C and RH approaching 100 %. Continuous conditions in reactor compartments are quoted as ranging from 0 °C to 60 °C and relative humidity 30 % to 80 % with abnormal conditions (for periods of up to 20 minutes) as for machinery rooms. Some items of materiel may be located in refrigerated areas or close to external hatches during which, unless otherwise specified, operational materiel should maintain correct operation down to temperatures as low as -10 °C and with degraded performance at temperatures as low as -30 °C.

2.3.2 Air pressure

Ambient air pressures in non conditioned compartments may be assumed to be equivalent to and vary in accordance with the local external ambient pressure.

2.3.3 Immersion, precipitation and spray

When materiel is installed or stored in unconditioned compartments (e.g., cargo bays, aircraft hangers, garages for deck vehicles, engine and generator rooms, workshops, laundries and galleys) there is a greater probability of materiel being subjected to some form of wetting, including in some cases the possibility of partial immersion. Severities of up to 280 litres/m^2/hr should be assumed for precipitation and depths of up to 150mm for Immersion.

3. POTENTIAL DAMAGING EFFECTS

3.1 Temperature

a. Induced high and low temperatures can affect the basic properties of materials used in the construction of materiel. Temporary or permanent changes in dimensions, reductions in mechanical strength or elasticity, chemical reaction, and variations in electrical characteristics may reduce operational performance, cause malfunction, reduce reliability or cause total failure of systems and components.

b. Thermal shock induces high rates of expansion and contraction, resulting in stress and fracture of materials, failure of bonded joints and degraded performance of seals.

3.2 Humidity

a. Induced damp heat conditions created inside permanent shelters or under temporary covers above deck, unconditioned compartments and individual equipment's are likely to cause faster rates of degradation of materials and a higher frequency of equipment malfunction than might result from direct exposure to the external meteorological conditions. Reduction or breakdown of insulation resistance of circuitry and components is likely to cause safety hazards, degraded performance, reduced reliability or total failure of electrical/electronic systems. Performance of optical systems may be reduced by misting and deposits of moisture on lenses.

b. Warm damp atmospheres in unventilated areas provide ideal conditions for the promotion of mold growth and aggravated attack by corrosive agents. Additional factors are the effects of moisture on materiel, achieving and maintaining dry interiors, standards and methods of sealing, water vapor barriers, drying out procedures and indication of levels of humidity.

c. Induced low levels of humidity may reduce the moisture content of materials used in the manufacture of electrical/ electronic components, changing their characteristics and affecting the stability that is needed to maintain performance of systems within specified tolerances. Operating efficiency of mechanical systems can be reduced due to degradation of lubricants by both dry and damp atmospheres.

3.3 Pressure

a. Sealed or partially sealed materiel with low leakage rates may be susceptible to temporary distortion or permanent mechanical damage if located in compartments employing overpressure to provide a gas tight seal. Protective covers of large items that withstand normal variations of standard atmospheric pressure may be of particular concern.

b. When subjected to hydrostatic pressure, materiel of closed construction is vulnerable to structural deformation that can impair the integrity of joints and seals and can allow ingress of water or the escape of any contained fluids and gases.

3.4 Icing

Because ships maneuvers on the surface can influence the depth and pattern of ice formation, icing of materiel located above deck will be similar to that due to natural conditioning alone. The operation of linkages, release mechanisms and actuation systems becomes impaired or completely blocked due to interference caused by the build up of ice. Frosting and icing of sensors and optical devices can reduce the performance of surveillance and navigation systems.

3.5 Immersion, Precipitation And Spray

Materiel subjected to immersion, precipitation and spray is likely to suffer ingress of water (through apertures, seals, joints) and seepage affecting materials and operational performance of equipment in the same manner as accumulations of moisture. For materiel installed or stored in engine and generator rooms, workshops, laundries and galleys, there is a greater probability of being subjected to some form of wetting or partial immersion due to condensation, fractures and leaking joints on water pipes. Severities of up to 280 litres/m^2 /h should be assumed for precipitation and depths of up to 150 mm for immersion.

4. TEST SELECTION

4.1 General

AECTP 300 of STANAG 4370 includes test procedures that may be used for simulating induced climatic environments experienced by materiel when deployed on surface ships and submarines. Preferably test severities should be determined from data obtained at the location in the compartment or the area on deck in which the materiel is to be installed.

4.2 Fall-back test severities

In the absence of measured data, the fallback severities given in the test methods in AECTP 300 should be used.

4.3 Tailored test severities

a. Test tailoring is the preferred method of specifying severities for temperature tests, especially when the test specimen is equipment which will be located where severities are determined by heat and moisture given off by operational equipment and for which data for naturally induced conditions are inappropriate. Ideally, data for deriving test severities should be recorded at the location on the ship at which the materiel is to be installed during simulated worse case service conditions.

b. Generally, test methods using diurnal cycles will be applicable to materiel in enclosed areas on or above deck. In many cases, conditions for materiel in compartments between decks can be simulated using test procedures that apply constant conditions. Testing for exposure to low temperatures in all areas of the ship normally will be satisfied by using test procedures that give steady state conditions. In some instances, particularly with equipment of large mass and thermal time constant comparable to or longer then the diurnal cycle, the closer realism of a cyclic test may be preferred to ensure that seals and components are stressed representatively.

c. Severities for simulating air pressure above standard ambient conditions and hydraulic pressure should be specified in the Environmental Requirement for the materiel or obtained from the builder or design authority for the ship. Representative simulation of blast pressure waves from explosions, gunfire and weapon launch is best achieved by subjecting equipment to the real life environment.

d. For other environmental conditions such as icing and various forms of wetting, it is unlikely test tailoring will be cost effective. In such cases, recommended fallback severities should be used.

SECTION 239 - WEAPONS

LEAFLET 239/1 - AIR AND SURFACE WEAPONS

TABLE OF CONTENTS

1. **GENERAL**

This leaflet addresses the climatic environments that may be encountered by air and land weapons, including guided missiles, bombs and projectiles during their separation from the host platform and during their autonomous flight to the target. The sources and characteristics of the climatic environments are presented and discussed. Advice is given on potential damaging effects and treatment options. Where relevant, appropriate AECTP 300 Test Methods are selected.

2. **CAUSES OF INDUCED CLIMATIC ENVIRONMENTS**

2.1. General

a. Munitions are likely to be subjected to induced climatic conditions at launch and during the trajectory between the launch platform and the intended target. The induced conditions may be different or more severe than those due to prevailing meteorological conditions alone as a result of operational or tactical procedures and the method of deployment required to have the desired effect of the munition on the target.

b. Induced climatic environments experienced by munitions at launch and during the flight to target will depend on the method of execution (i.e., the motive force and control or otherwise of trajectory). The former will range from free-fall to ejection and/or explosive propulsion and gliding, continuous motorized flight or some combination of these forms of delivery. Trajectories will be determined by various methods ranging from initially set fixed parameters to partially or fully autonomous flight control systems. Also included are those munitions that, after dispatch and laying, rely on the target approaching and emitting some form of stimulation. The success rate can depend on the reaction to the climatic conditions encountered.

2.2. Temperature

2.2.1. Induced temperatures at launch

Characteristics and severities of temperatures due to meteorological conditions alone are covered in Leaflet 2311. Reference should be made to the appropriate leaflet for causes, characteristics and effects of induced temperatures that may be experienced at separation from the launch platform (i.e., land vehicle, surface ship, submarine, fixed or rotary-winged aircraft). In some cases, the elapsed time on the launcher will be such that the effects of the various factors that induce temperature extremes will not be fully realized. Anticipated exposure times should be determined from the Operational and Environmental Requirements documents for the weapon and the service platform.

2.2.1.1. Temperature of munitions at launch will depend on the following factors:

a. The geographical area of deployment.

b. The type of launch platform and the extent to which it exposes the munition to internal and external conditioning (e.g., underground silos, canisters or exposed launchers on land or surface ships, enclosed weapons bays or exposed launch rails on aircraft).

c. The elapsed time on the launcher at the prevailing ambient conditions, including the influence of solar heating or of aerodynamic heating resulting from velocity of the launch platform.

2.2.1.2. Temperature of systems and components carried on or within the weapon depend on:

a. The location on the weapon, i.e. ventilated or unventilated area or compartment.

b. The indirect effects of solar heating.

c. The provision or otherwise of any temperature control at the location of the system or component.

d. Any heat dissipated by systems and components required to be operational prior to launch.

e. Packing density of equipment such as electrical and electronic systems.

2.2.2. Induced temperatures during free flight

2.2.2.1. General

a. Factors determining temperatures experienced by munitions during free flight include:

(1) Ambient air temperature along the flight path

(2) Flight velocity.

(3) Thermal capacity of the munition.

(4) Duration of flight

b. Temperatures of individual systems and components during free flight depend on:

(1) Effects of aerodynamic heating and characteristics of the thermal path within the structure of the flight platform.

(2) Proximity to heat-dissipating equipment such as propulsion, actuation, control and guidance systems.

(3) Packing density of electrical/electronic systems.

(4) Flight duration.

(5) Flight altitude (air density).

2.2.2.2. Glide and free-fall munitions

a. The flight velocities and time scales associated with the free-flight phase of glide and free-fall munitions such as bombs and air-launched underwater weapons are such that any changes in temperature due to heat lost or gained normally can be ignored.

b. An exception may be munitions that, near the end of the trajectory, loiter while searching and tracking the target, during which time temperatures may tend towards ambient air temperature balanced against any heat emissions from operational systems carried on board. The temperatures obtained will need to be determined by thermal analysis and confirmed by measurements made during flight trials.

c. The thermal influences affecting temperatures of air-launched underwater weapons between release and immersion will be similar to those for other weapons which reach the target by gliding and free-fall. In some cases the trajectory and flight velocity may be controlled by the deployment of aerofoils and parachutes. For weapons launched from surface ships, the thermal effects of the trajectory before immersion normally will be insignificant.

d. The most significant thermal event for underwater weapons is likely to be the rate of change of temperature experienced during the transfer from air to water. Examples are: dropping from aircraft into warm sea water following conditioning at the low ambient temperature at flight altitude during air carriage; launch into cold sea water from the deck of a surface ship while at high temperature induced by solar heating. For ambient temperatures at altitude, reference should be made to tables of standard atmospheres such as ISO 5878.

e. Temperatures experienced on board torpedoes when submerged after launch, will depend on the heat generated by power supplies and propulsion and control systems, the 'flight time' and the heat flow out of the structure into the surrounding water. Actual severities should be determined by thermal analysis supported by measurements made during sea trials.

f. See Paragraph 2.2.3 below regarding temperatures experienced by target-activated weapon systems such as land and sea mines after laying or launching.

2.2.2.3. Powered flight/aerodynamic (kinetic) heating.

Rocket and turbojet propelled munitions are likely to be subjected to aerodynamic or kinetic heating caused by compressive and viscous effects when they move at high speed through the atmosphere. This has the effect of rapidly increasing the temperature of the body in a manner governed by various parameters as described in Annex A. For most practical applications (i.e., for weapons moving at supersonic speeds and with short flight times) the effect of aerodynamic heating swamps any other transitory temperature effect such as internal heat dissipation. However in the case of projectiles such as shells, the time scales involved are such that the effects due to heat flow may be ignored.

2.2.3. Induced temperatures in target activated weapon systems (TAWS)

a. Once laid or primed, land based TAWS may be subject to induced temperatures greater than the surrounding ambient conditions especially in hot dry tropical regions. Weapons placed under unventilated cover (including the topsoil, etc., forming the surface of the ground), or inside enclosures exposed to solar radiation, are likely to experience temperatures of up 20 °C or more above local ambient. Higher temperatures may occur if the item used to cover the weapon comprises transparent material, typically 85 °C to 90 °C in hot dry regions.

b. When submerged, temperatures of sea mines, sonar and surveillance systems will stabilize at those of the surrounding seawater. In the case of pre-laid torpedoes, temperatures during 'flight' will depend on the heat generated by power supplies and propulsion and control systems, the 'flight time' and the heat flow out of the structure into the surrounding water. Actual severities should be determined by thermal analysis supported by measurements made during sea trials.

2.3. Humidity.

2.3.1. Induced humidity at launch

Factors affecting the levels of humidity experienced by munitions, sub-systems and components at launch are similar to those for temperature given in Paragraph 2.2.1.1 above. Severities and effects of natural conditions are covered in Leaflet 2311. Reference should be made to the appropriate section of this AECTP for induced levels of relative humidity dependent on the launch platform (i.e., land based, surface ship, submarine, fixed or rotary winged aircraft). In some cases, the period on the launcher will be such that the full effects of the various influences will not occur. Anticipated exposure times should be determined from the Operational and Environmental Requirements documents for the weapon and service platform.

2.3.2. Induced humidity during flight.

For air to air and air to surface weapons, any changes in humidity in compartments of munitions during flight are likely to be linked to induced temperatures. Heat dissipated by on-board systems and components and/or that due to kinetic heating is likely to reduce relative humidity inside compartments. The potential for an increase in RH levels exists where moisture is contained in any gases given off by propulsion systems and batteries that provide electrical power. Normally, the effects of changes in humidity during this phase are regarded as insignificant.

2.3.3. Induced humidity in deployed underwater weapons

a. The relative humidity inside sections and compartments of mines and torpedoes launched from surface ships may change on immersion due to the overall change in temperature of the weapon when transferred from air to water. Areas containing systems and components particularly sensitive to humidity may be filled with dry gas.

b. Subsequent changes in relative humidity inside compartments of sea mines are negligible. Humidity inside torpedoes during 'flight' may be increased by moisture contained in gases given off by batteries powering propulsion systems. The effect may be reduced where compartments are charged with a dry inert gas and/or balanced by heat generated by power supplies and operational systems on board.

2.3.4. Induced humidity in deployed target activated weapon systems (TAWS)

When TAWS are laid under unventilated cover especially in open areas in hot wet tropical regions, solar heating of the cover or enclosure may induce levels of relative humidity in excess of the ambient conditions. Pressure differentials created by the diurnal variations in temperature encourage moisture to be breathed in and accumulated, gradually raising the dewpoint which could result in saturation occurring during the cooler phases of the cycle.

2.4. Air Pressure.

2.4.1. Air pressure at launch

Levels of ambient air pressure experienced by munitions at launch and inside unsealed compartments, systems and components will be determined by the type of launch platform (i.e., land based, surface ship, submarine or aircraft) and whether they are exposed directly to the prevailing ambient conditions or launched from a pressurized container or launch tube. Extremes of ambient air pressure on land and at sea level are given in Leaflet 2311. Levels of ambient air pressure experienced by air-carried weapons at launch will be determined by the altitude of the flight platform at the time of firing or release. Values of ambient air pressure at altitude may be determined from international standards of reference atmospheres such as ISO 5878. Levels of air pressure in conditioned containers or launch tubes on surface ships and submarines should be determined by reference to Design Requirements documents, the shipbuilder or manufacturer of the launch system.

2.4.2. Air pressure during free flight

Ambient air pressures experienced by munitions during free flight will be determined by the profile of the flight altitude. For bombs, mines and projectiles that reach their target by unpowered flight, the flight profile may vary from a simple free-fall to a ballistic trajectory (induced by aircraft flight manoeuvres or gun fire). Pressures will vary directly with the variation in flight altitude and rates of climb and descent determined by the deployment or otherwise of flight control devices. While the same factors apply to rocket propelled and motor-powered guided missiles, profiles of the flight altitude are likely to be more varied with considerably greater rates of change of climb and descent, especially when pursuing high speed moving targets. Severities that may be experienced by a particular type of weapon should be determined by considering all the various flight paths and trajectories included in the design requirements for the munition.

2.4.3. Dynamic air pressure.

Forward facing surfaces and leading edges of air-carried weapons which are exposed to the airstream at the time of launch or release and of all weapons deployed to the target at high speed through the atmosphere will be subjected to dynamic pressure related by the formula:

$$q = 0.5\ \rho v^2$$

where q = dynamic pressure kg/m²
ρ = air density at flight altitude kg/m3
v = flight velocity m/s

2.5. Hydraulic Pressure.

a. Underwater weapons launched from submarines will be subjected to hydraulic pressure corresponding to the depth of immersion of the vessel at the time of launch. Torpedoes will be subjected to pressurized water in the launch tube. Maximum pressures likely to be experienced should be determined by reference to the Design Authority for the launch system or the builder of the submarine.

b. After launch, torpedoes and other types of underwater weapons will be subjected to hydraulic pressure related to the depth of immersion in accordance with the following formula:

$$p = 9.8d$$

where p = water pressure in kPa
d = depth below the surface of the water in meters.

Pressure experienced by systems and components will depend on whether they are installed in sections of open or closed construction.

2.6. Icing.

2.6.1. Icing of ground and ship-launched weapons

a. Icing of land-based weapons at launch will depend on local meteorological conditions and the duration of exposure on the launcher before separation. Orientation with respect to the prevailing wind and shielding provided by the launcher will contribute to the pattern and severity of icing.

b. When operating in low temperature conditions, the interaction of ships' maneuvers and wave motion may contribute to the amount of spray and level and pattern of icing experienced by structures, such as weapon launchers on open decks. The loading and pattern of icing experienced by individual weapons will depend upon shielding provided by the launcher and the influence of heat dissipated by systems required to be operating before separation. Rates of ice accretion of up to 40 mm/hour have been reported for structures on open decks of ships operating in Arctic regions. Minimum rates of 25 mm/hour and survival of a loading of 120 kg/m^2 should be assumed for operations in cold regions.

2.6.2. Icing of air-launched weapons

a. Dependent on the velocity of the flight platform, air-carried weapons exposed to the airstream during captive flight are likely to be subjected to impact icing, the effects of which are likely to become apparent during launch or release from the weapon rack or carrier. Impact icing of materiel while deployed on aircraft and resulting severities that can occur are described more fully in paragraph 3.6.

b. During free-flight the speed of rocket-propelled and motorized guided weapons will normally be such as to preclude any further formation and that which has accumulated will melt and/or be dispersed by the action of the control surfaces.

2.7. Impact with hail, rain, dust and sand

Forward-facing surfaces and leading edges of air-carried weapons exposed to the airstream during captive flight and of munitions intended to be launched in all weathers may be subjected to high velocity impact with hail, rain, dust and sand. External surfaces may become deformed or suffer abrasion, erosion or pitting. Panels manufactured from composite materials may suffer hidden physical damage.

2.7.1. Hail

Guidance on the risk of hail encounters related to altitude, geographical area, season and time of day is given in Leaflet 2311. Damage potential from impact with individual stones depends on the type and density of ice and the diameter and impact velocity. Forward-facing surfaces of guided weapons such as radomes and lenses of tracking systems and leading edges of aerofoils and control surfaces are likely to become damaged.

2.7.2. Rain.

Raindrops may be encountered up to altitudes of 20 km with the greater intensities occurring between sea level and 6 km. Factors affecting erosion of materials by rain include impact velocity, the material shape and finish of the impacted surface, drop size and number and frequency of impact. Repeated collisions at the same point influence the pattern of build-up of stress and erosion of the impacted surface. A complex relationship between erosion resistance and physical properties of materials exists. Resistance is expressed in terms of the time required for drops of 2 mm diameter in a simulated rainfall of 25 mm/hour, and with an impact velocity of 225 m/s, to produce various degrees of erosion.

2.7.3. Dust and sand.

Studies of dust storms in hot dry desert regions indicate that dust remains suspended in the atmosphere for a considerable period after the storm has abated. Particles of up to 10 µm can reach heights of 1500 m with an upper limit for dust of around 3000 m. The severity of erosion of frontal areas and leading edges of guided weapons depends on the impact velocity, the form and hardness of the particulate and of the material or surface finish of the impacted surface.

3. POTENTIAL DAMAGING EFFECTS

3.1. High and Low Temperature.

a. The effects of high and low temperature encountered by munitions on the launch platform up to separation are covered in the relevant section of this AECTP (i.e., for deployment on land vehicle, surface ship, submarine, fixed and rotary winged aircraft).

b. The rapid rates of change of temperature experienced by munitions when subjected to aerodynamic heating and during rapid transfer from air to water are likely to induce high rates of thermal stress in structures, systems and components. Although the resultant stress level may be the same, the high rate of application can embrittle some materials and cause failure at a much lower strain level than with a more gradual application of the temperature.

3.2. Humidity.

For high-speed guided weapons and projectiles, any harmful effects attributable to humidity are more likely to arise from previous conditioning during storage, transportation or deployment on the launch platform than as a result of the conditioning received during the comparatively brief final stage of deployment. High temperatures generated in sections and compartments are more likely to reduce the levels of relative humidity within enclosed sections and compartments. While the same rationale may be considered to apply to torpedoes, changes in relative humidity may be relevant to the deployment of other types of underwater weapons, especially where compartments are not charged with inert gas. In the case of mines that are likely to remain in a quiescent state for comparatively long periods until approached and activated by the target, an increase in relative humidity generated as a result of deployment may cause subsequent malfunction. Reduction or breakdown of insulation resistance of circuitry or components can reduce reliability, induce self ignition or cause total failure.

3.3. Air Pressure.

a. Because the amount of heat lost to the atmosphere by convection is proportional to the density of the surrounding air, the cooling efficiency at altitude will be reduced below that obtained at ground level. The working temperature of heat-generating systems and components during flight may rise above that necessary for optimum performance. Lower air density also encourages flash-over between electrical conductors, arcing within electrical/electronic components and corona discharge in the areas with strong electric fields (e.g., around aerials) causing electromagnetic interference.

b. Rapid rates of climb and descent achieved by guided weapons and projectiles may cause pressure differentials across the walls of partially sealed compartments and enclosures of individual equipments and components causing them to distort and possibly interfere with mechanical and electrical/electronic devices. The result is malfunction or total failure of the weapon. Rapid or explosive decompression may be a potential hazard for totally sealed materiel.

c. The migration of compounds used to improve heat transmission and the operation of components that rely on lubricating properties of air can cause malfunction and degraded performance.

3.4. Dynamic Pressure

Air pressure is a significant factor in determining severity of induced vibration caused by turbulent flow around guided weapons and projectiles.

3.5. Hydraulic Pressure

Hydraulic pressure imposes mechanical loads on the structure and outer casing of underwater weapons. This pressure may cause distortion at joints and seals. Any ingress of water may result in malfunction of arming and sensing devices compromising reliable operation of the munition.

3.6. Icing

a. Impact icing of air-carried weapons, launch rails, weapon racks, and pylons and the carrier/weapon interface can cause interference or total blockage of linkages and release mechanisms and present a serious hazard in terms of flight safety of the aircraft and vulnerability in combat. The pattern of ice formation may induce dynamic loads, impede a clean separation, impair the aerodynamics of both the weapon and the flight platform or interfere with deployment of aerofoils on the weapon after release.

b. Similar problems are likely to be encountered when launching from open decks of surface ships when operating in low temperature conditions, especially in those cases where the weapon is held unprotected on the launcher or firing involves the opening of some form of canister likely to be enveloped in ice.

c. Frosting and accumulations of ice on radomes and optical parts of infra-red, laser and TV seeker heads can reduce the performance of guidance systems or render firing of the weapon impracticable.

3.7. Impact with Hail, Rain, Dust and Sand.

Abrasion, deformation, erosion and pitting of external surfaces of radomes and optical devices of seeker heads of guided weapons caused by high velocity impact with hail, rain, dust and sand can reduce the sensitivity and performance of the guidance system. Delamination or fiber fracture may occur within panels manufactured from composite materials. A build-up in electrostatic charges on the impacted surfaces may cause malfunction or failure of sensitive low voltage systems and components and compromise reliability of arming devices, firing systems and operation of the warhead.

4. **TEST SELECTION**

4.1. General

a. AECTP 300 provides test procedures that may be used for simulating induced climatic environments experienced by weapons at launch and during the final stage of deployment to target. The choice of a test method for temperature and humidity will depend on whether there is a requirement to simulate climatic variations, including the heating effects of solar radiation , or just the maximum or minimum temperatures experienced during flight.

b. Reference should be made to the guidance given in the relevant chapters regarding the selection of the appropriate test procedure, severities, test techniques and performance evaluation.

c. Preferably, test severities should be derived from specifically measured data recorded during trials conducted in climatic conditions representative of those expected in service, or from data obtained during deployment of similar types of munitions. For guided weapons and projectiles, data may be required for more than one type of trajectory in order to establish worst-case conditions in flight expected in service. Alternatively, severities derived from data obtained for other examples of weapons in similar applications may be used.

d. Test methods for combined environments of temperature and low pressure are included for guided weapons with a subsonic speed during flight to target, and where the effect of the combined environments could be more stressful or different than each environment alone.

e. Tests simulating kinetic heating are recommended only when the effects generated cannot be predicted satisfactorily by calculation or computer modeling. Guidance on testing techniques involved (including guidance on control of test parameters) is given in AECTP 300. In some cases, it may be appropriate to simulate the thermal stress imposed on materiel using the simpler thermal shock test.

f. For many types of munitions, any harmful effects from environments such as humidity or high velocity impact with hail, rain, dust or sand are more likely to be incurred as a result of previous conditioning. The impacts of those factors during the comparatively very short period of launch and flight to target are of little consequence. Exceptions to that are land mines and possibly some underwater weapons that, once laid and primed, are likely to be subject to conditions that are more severe and/or of longer duration than those experienced during earlier phases of service life. The high temperatures, temperature gradients, low air pressures and rates of change of pressure experienced by guided weapons and projectiles during free flight will be far in excess of those experienced during previous stages of service life.

g. Preferably, specimens subjected to tests simulating induced climatic conditions experienced at launch and the final stage of deployment should first be subjected to a programme of conditioning representing the climatic and mechanical environments that are likely to occur during earlier stages of service life. Where this is not possible, this factor should be taken into account in assessing test results especially where operational performance is found to be marginal.

4.2. Fall-back Test Severities.

Fall-back test severities and guidance on their selection are given in the relevant section of AECTP 300 for those cases where no specific information is available for tailoring severities to the particular application.

4.3. Tailored Test Severities.

4.3.1. Temperature and humidity

a. Test severities used to simulate induced temperature and humidity conditions at launch should be based on information given in the Operational and Environmental Requirements documents regarding the intended geographical areas of deployment and characteristics of the flight profiles.

b. Leaflet 2311 classifies climatic conditions on land into three main categories, Hot-Dry (Cat. A), Hot-Wet (Cat. B) and Cold (Cat. C). Geographical areas in each category are graded by severity based on data recorded over many years. Values of temperature and humidity are quoted for external ambient (Meteorological) and induced (Transit and Storage) conditions. In the absence of specifically measured data, values for the latter should be assumed to represent worst-case induced conditions experienced by equipment immediately before launch from land and naval platforms and by mines after being laid.

c. The quoted values of temperature and humidity are those that are likely to be obtained or exceeded in the most severe location for 1% of the most extreme month of the year.

d. Temperature severities used in tests simulating kinetic (aerodynamic) heating and combined temperature-low pressure tests should be derived using one or both of the following in descending order of preference:

(1) From specifically measured data recorded during hot weather trials. Measurements should be made at the relevant locations on the munition. Other factors influencing temperature severities such as configuration, thermal mass, sources of dissipated heat, cooling air and any other types of thermal protection system should be correctly represented. The trials programme should specify flight trajectories likely to produce worst-case conditions in service.

(2) From data recorded for a similar application with adjustments for differences in the factors referred to in (1) above.

(3) From data derived from calculations and computer modeling.

4.3.2. Air pressure and hydraulic pressure tests.

a. Severities for simulation of low air pressure may be determined from the Operational and Environmental Requirements documents for the munition (i.e., equivalent pressures related to maximum operational altitude, envelope of flight trajectories and rates of climb and descent). International tables of standard atmospheres may be found in standards such as ISO 5878.

b. Severities for high air pressure and hydraulic pressure tests are determined by the working pressure of the launch system and the maximum depth of immersion at which the weapon will be launched or during deployment to target. Pressure severities at launch should be determined by reference to Design Requirements documents or the Design Authority for the launch system. Once launched, hydraulic pressures will be related to depth of immersion as defined in Paragraph 2.5, above.

4.3.3. Icing

It is unlikely that tailoring test severities to specifically measured data for simulating induced icing will be cost effective, in which case the severities are given in the test methods of the relevant section of AECTP 300.

4.3.4. Impact with rain, dust and sand.

AECTP 300 gives a test method for simulation of impact with rain, dust and sand. Testing is more applicable to air-carried stores likely to receive a number of captive flights before launch. Test facilities may not be available to simulate the higher velocities that occur during free flight

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ANNEX A

FACTORS INFLUENCING TEMPERATURES ARISING FROM KINETIC HEATING

A.1. Stagnation temperature.

When a body moves through the atmosphere, the air is deflected around it except at a point immediately in front of the body known as the 'stagnation point', where the air is brought to rest. Due to compressive effects, the temperature of the air rises at this point. The temperature attained is known as the 'stagnation temperature'. At moderate Mach numbers (i.e., <3, providing the air is chemically stable and the specific heats of air at constant pressure and constant volume are invariant), stagnation temperature, T_S, is given by the following equation:

$$T_S = T_\infty \left[1 + \frac{\gamma - 1}{2} M_\infty^2 \right] \text{°K}$$

where T_∞ is the free stream temperature in degrees Kelvin (i.e., the temperature in the region of undisturbed relative flow), γ the ratio of specific heats, and M_∞ the flight Mach number.

A useful approximation which gives the rise in temperature at the stagnation point is

$$T_S - T_\infty \approx 5 \times \left[\frac{v}{100} \right]^2 \quad \text{°C}$$

where v is the flight speed in meters per second.

A.2. Rate of heat transfer.

The rate of heat transfer determines the temperature inside the flight platform during flight. This rate which may vary considerably is dependent on the following factors:

(1) The characteristics of the boundary layer air enveloping the vehicle which in turn is governed by the altitude, speed, temperature and whether the airflow is laminar or turbulent.

(2) The surface finish of the skin, which influences the boundary layer and the effect of radiation transfer.

(3) The influence of heat generated by equipment carried inside the vehicle.

A.3. Flight profile.

During periods of acceleration, heat flow into the skin of the flight platform is likely to be very high. The initial temperature differentials created in the structure present not only the problem of the temperature itself, but also the more serious one of thermal stresses. During subsequent steady flight velocities, the inflow of heat into the structure is reduced and there follows a tendency towards a more settled heat balance with a reduction in differential stresses. The temperature distribution within the flight platform thus becomes more equable. Under these conditions, the mean temperature distribution may result in temperature limits for materials and the functional devices within the vehicle being exceeded.

A.4. Estimation of skin temperature due to aerodynamic heating

a. The estimation of temperatures resulting from aerodynamic heating is, in general, complex and no general solution can be given. However some guidance regarding methods of approach, limitations and restrictions can be recommended. This is only a simplified approach to the general problem and it is recommended that specialist agencies should be consulted.

b. The main factors involved are the recovery temperature of the boundary layer and the heat transfer coefficient. Both quantities are functions of the particular trajectory flown. In the simplified approach described here, both are taken as applying to flat plates only at zero incidence. The following symbols and units are used:

c	specific heat of skin material, J/(kg °C)
d	thickness of skin material, m
h	heat transfer coefficient, W/(m^2 . °C)
k	thermal conductivity of skin material, W/(m^2 . °C)
M_∞	free stream Mach number
Q	rate of heat flow, W/m^2
r	recovery factor
Tb	body or skin temperature, Kelvin
Tr	recovery temperature, Kelvin
T_∞	free stream temperature, Kelvin
v_∞	velocity of flight platform relative to undisturbed flow, m/s
x	distance from stagnation point, m
γ	ratio of specific heats
α	diffusivity $\left\{= \dfrac{k}{\rho c}\right\}$, m^2/s
ρ	density of skin material, kg/m^3
ρ_∞	free stream air density, kg/m^3

c. Recovery temperature

Recovery temperature is defined as the temperature at which zero heat transfer takes place between the boundary layer and the skin of the body or, the maximum temperature the skin can achieve under steady state conditions.

A simplified relationship for the estimation of recovery temperature is given by:

$$T_r = T_\infty\left[1 + r\left(\frac{\gamma - 1}{2}\right)M_\infty^2\right] \quad \text{Kelvin}$$

The product $r\left(\frac{\gamma - 1}{2}\right)$ can be simplified further to give 0.17 for laminar flow in the boundary layer or 0.18 for turbulent flow. It is usual to assume turbulent flow as this gives slightly pessimistic answers.

d. Heat transfer coefficient.

The heat transfer coefficient is a measure of the ability of the boundary layer to transfer heat from itself to the skin of the body. Heat transfer coefficients are functions of the type of flow (laminar or turbulent), characteristics of the trajectory, the shape of the body and the position on the body in relation to the stagnation point. Heat transfer coefficients can be expressed in various forms for different applications. For weapon design applications where the most pessimistic conditions must be considered, the following formula has been found to give reasonable results for flight speeds up to Mach 5:

$$hx^{0.167} = \frac{2.362(\rho_\infty v_\infty T_\infty)^{0.83}}{A^{0.583}(A + 117)^{0.167}}$$

where $A = 0.45T_b + T_\infty(0.55 + 0.035M_\infty^2)$

When considering heat transfer to small angled cones or leading edges, an approximation can be made to the heat transfer coefficient by adding 15% to the value from the above formula.

A.5. Heat transferred from the boundary layer

At any instant, the amount of heat transferred from the boundary layer to the skin of a body will be governed by the recovery temperature and the heat transfer coefficient in the following manner:

$$Q = h(T_r - T_b)$$

where T_b is a function of time, and h and T_r can also be functions of time defined by the trajectory

A.6. Estimation of body temperatures.

Body temperature is a function of the constructional details of the body (i.e., whether there is any radiative or conductive exchange of heat between various parts of the body) and the external finish, that governs the amount of heat re-radiated as well as the heat input to the body from the boundary layer. In the case of transient temperatures, the body temperature is also a function of its thermal capacity and whether it can be considered 'thin' or 'thick' skinned. The criterion for a 'thin' skin is that $\left\{\frac{hd}{k}\right\} < 0.1$.

(1) Thin skin temperatures.

Thin skins can be defined as being of high conductivity materials, including metallic skins of thickness used normally in weapon construction. They are skins in which the temperature gradient across the skin can be considered negligible. For the simplified case of a thin skin with no conduction or radiation losses, the temperature-time history for a body subjected to aerodynamic heating can be found by employing a step-by-step method of analysis as follows.

$$(T_b)_2 = P(T_r)_1 + (1 - P)(T_b)_1$$

where $P = \left\{\frac{2B}{1+B}\right\}$ and $B = \left\{\frac{h\Delta t}{2rcd}\right\}$

Δt is the time interval in seconds. Subscripts 1 and 2 refer to temperatures before and at the end of the time interval respectively. Values of h and c can, if necessary, be considered to be time dependent. In this case average values over each time interval should be used.

(2) Thick skin temperatures

Normally, thick-skinned materials are low conductivity materials. For most practical weapon design cases, they will be insulating materials. They are skins in which appreciable temperature gradients will exist. In the case of a thick-skinned or insulating material, the transfer of heat throughout the material is governed primarily by the thermal conductivity. The temperature distribution throughout the thickness of the material can be approximated by dividing into several slices each Δy meters thick and then applying the criterion:

$$(T_b)_{2,y} - (T_b)_{1,y+\Delta y} = \frac{\Delta t}{(\Delta y)^2} a\left[(T_b)_{1,y+\Delta y} + (T_b)_{1,y-\Delta y} - 2(T_b)_{1,y}\right]$$

where Δt is the time interval in seconds and subscripts y, y + Δy and y - Δy refer to the temperatures at these respective positions in the material.

The above formula gives only the distribution of temperature within the insulation material. Surface conditions can be applied by equating the flow of heat transferred from the boundary layer to the amount of heat being absorbed by the material. This results in the following condition for the surface temperature T_s, any instant:

$$T_s = (1 - X)T_r + X(T_b)_{(s-\Delta y)}$$

where $X = \left(\frac{N}{1+N}\right)$ and $N = \left(\frac{k}{h\Delta y}\right)$ and subscript $(s - \Delta y)$ refers to the temperature at a distance Δy meters inside the material.

The formulae given above to calculate the temperature gradients through the skin are based upon a one-dimensional finite difference approximation through the material. In many situations, it will be necessary to consider two-dimensional temperature distributions (e.g., the nose region of a flight platform). In these cases, the finite difference method can be extended to two directions, but it is usually more efficient to use the more recently developed finite element technique. The above formulae use a simple stepping method in order to proceed from the conditions at Time 1 to Time 2. In large-scale calculations, it would be more common to use a better stepping process such as the Crank-Nicholson method.

A.7. Computer programs.

The formulae given above for estimating temperatures induced by aerodynamic heating are simplified cases of the conditions found in practice. It would be normal to use a computer programme to obtain temperature distributions except in very simple cases. Many computer programs are tailored to the special requirements of individual cases and no suitable guidance can be given in such situations. Some general purpose programs are available.

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LEAFLET 2310/1

VALIDATION OF TEST SEVERITIES

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LEAFLET 2310/1

VALIDATION OF TEST SEVERITIES

1. SCOPE

1.1. Purpose

The main objectives of these instructions are to

a. Outline methods for calculating valid test procedures.

b. To provide Environmental Engineering Specialists on how to collect and analyse real field data for the purposes of thermal and chemical age estimation.

1.2. Application

This leaflet outlines induced environments and presents methods for predicting these induced environments from recorded data. They are applicable to materiel that will be exposed to the extremes of climate and have a known degradation mechanism that can be associated with the environments.

1.3. Limitations

These methods should not be applied where there is only limited data available or where the integrity of the data cannot be verified. As a general rule it is not recommended that induced environments be calculated where less than five years of recorded data is available, and should not be calculated if less than one year of data is available.

2. DEFINITION OF STORAGE AND TRANSIT TYPES

The following list identifies the various storage and transportation types and associated categories as defined in para 2.5.

2.1. Long Term Storage Types

Air Conditioned	(Category 1)
Mounded Building / Underground	(Category 2)
Permanent Building	(Category 2)
Semi-Permanent Structures	(Category 3)

2.2. Temporary Storage Types

Container	(Category 3)
Bunker	(Category 3)
'Hut'/'Igloo'	(Category 3)
'Tent'	(Category 4)
No Cover	(Category 5)

2.3. Shipboard Storage Types

Container	(Category 3)
Hold / RFA	(Category 1)
Purpose Built Covered Weapons Bay	(Category 2)
Deck Cargo	(Category 5)

2.4. Transportation Types

Container (all vehicles)	(Category 3)
Packaged Materials:	
Wheeled Vehicle Soft Skinned	(Category 4)
Wheeled Vehicle Hard Skinned	(Category 3 or 4)
Armoured Vehicle (Internal Hull)	(Category 1 or 2)
Armoured Vehicle (External)	(Category 5)
Rotary Wing Aircraft	(Category 3)
Fixed Wing Aircraft	(Category 3)
Rail Carriage (Modern Transport)	Category 3)
Rail Carriage (General)	(Category 5)
Man Portable	(Category 5)
Un-Packaged Materials:	
Wheeled Vehicle Soft Skinned	(Category 4)
Wheeled Vehicle Hard Skinned	(Category 4)
Armoured Vehicle (Internal Hull)	(Category 1 or 2)
Armoured Vehicle (External)	(Category 5)
Rotary Wing Aircraft	(Category 3)
Fixed Wing Aircraft	(Category 3)
Rail Carriage (Modern Transport)	(Category 3)
Rail Carriage (General)	(Category 5)
Man Portable	(Category 5)

2.5. Categories of Storage and Transportation

The following categories are defined in terms of environmental conditions that effect materiel and are not intended to specify storage design types.

2.5.1. **Category 1:** Special Storage. Environmental conditions are controlled (for example air conditioned). The temperature and humidity range should be maintained within the limits of the materiel where the rate of chemical deterioration is known to be stable. Humidity in the surrounding environment is controlled to match the humidity (measured as Total Volatile Materiel) of the materiel, and to prevent the transfer of moisture between the materiel and its surroundings.

2.5.2. **Category 2**: Standard (Long Term) Storage. Temperature is controlled and humidity does not reach extremes. It may not be air conditioned, but the temperature will not reach the extremes of the outside ambient temperature. Either the surrounding humidity is moderate, or there is sufficient protection to keep the materiel humidity within acceptable limits.

2.5.3. **Category 3**: Ventilated Storage. There is sufficient protection afforded to the materiel such that the surrounding air temperature and relative humidity are no worse than the meteorological conditions. The outer surface of the storage will dissipate direct solar radiation and while providing ventilation during hot periods, will still prevent wind and driving rain affecting the materiel.

2.5.4. **Category 4:** Temporary Cover. Affords the materiel some protection from the elements, but will not prevent some convection from raising or lowering the temperature of the materiel at a different rate from the meteorological levels. Protection from actual rainfall will be given, but humidity levels will depend more upon the environment, protective cover and materiel packaging.

2.5.5. **Category 5:** Poor or No Cover. Materiel can be affected by both convection and conduction giving extreme induced temperature conditions. Direct rainfall and ground water may affect the materiel, and humidity levels will depend heavily on the environment and protection offered to the materiel by its packaging.

3. REQUIREMENTS FOR SUCCESSFUL LIFE ESTIMATION

3.1. Data to be Collected

3.1.1. Induced conditions can be determined by laboratory or field experimentation. Laboratory experimentation is useful for gathering data on the difference made by mitigation factors (such as paint colour), but cannot wholly simulate real conditions. Field experiments do reflect real situations but can only be ‘snapshots’ of the final environment which may miss typical, but infrequent, events such as storms, or local differences such as a difference in humidity between the leeward and windward sides of a range of hills. Ideally, induced conditions should be derived by monitoring actual climatic events as they occur.

3.2. Guidance for Asset Managers

3.2.1. An Asset Manager can be considered as that authority ultimately responsible for the whole life (cradle to grave) of the materiel, or asset, in question. That responsibility will very likely transfer through several different groups during the life of the materiel. Ideally, the initial (procurement) agency should take the main responsibility for implementing data gathering programmes and defining the life assessment procedures, but this is not always the case.

3.2.2. Temperature and Humidity can be monitored by the use of small electronic recorders. By gathering daily data continuously over the life of the materiel, the asset manager can gain a very precise picture of the thermal stressing placed upon it. If supported by a full life assessment programme, this also allows for a relatively accurate estimation of the remaining life of the asset to be made at any point in time.

3.2.3. There are two basic formats for automatic data recorders:

a) Simple and compact recording devices are available off the shelf. These devices are relatively inexpensive and come as a sealed unit that has been demonstrated to be safe for use in most types of explosive magazines. The asset manager must decide where to place the recorders and how many to use for any given batch of materiel. These recorders can be introduced at any time during the materials life but are most effective if introduced early and kept with the same material throughout its life. However these recorders can also be used for monitoring climatic conditions within a particular storehouse or type of transportation.

b) For expensive, larger, assets an integrated logging system could be more effective. Integrated recorders should be considered at the design stage of the item, and will be placed to record the temperature and/or humidity at the actual point(s) that the design authority has determined will be most affected by climatic variations and, therefore, most likely to limit the life of the material. For a recorder to be integrated successfully, the design authority and asset manager would need to agree upon procedures for battery replacement/use, and the setting up and interrogation of the recorder.

Both types of recorders can also be used to uniquely identify (tag) a pallet, container, or individual item. In addition, the information could be integrated into a wider asset control system.

3.2.4. Recorders can be supplied with a variety of interfaces such as Infrared (IrDa), Contact (Serial Port) or Radio (RF). Before introducing recorders the asset manager will need to consult the appropriate National Storage and Transport Authority (NS&TA), and NSA as to which is the most appropriate interface. In some cases where there are a variety of NS&TA involved (e.g., Navy, Army, and Air Force), there may be a need for more than one type of interface. Various aspects such as asset tracking requirements, access to stores, frequency of interrogation, and impact of RF interference will need to be considered in conjunction with the NS&TA and NSA who will be the representatives of the end user for the recording devices and their associated readers.

3.2.5. It may also be necessary for the asset manager to monitor the meteorological data for the region(s) in which the monitoring is being conducted. This is needed to determine how packaging and the various forms of storage and transportation are mitigating (or augmenting) the effects of the surrounding environment. Actual meteorological (local Stevensons screen) data should also be available and compared against the cycles in Leaflet 2311/2.

3.2.6. Assuming that the environmental data are gathered correctly through continuous monitoring, the asset manager will also need to know the mechanism(s) by which the materiel deteriorates in response to the various levels of temperature and humidity, if they wish to derive a predicted life for a materiel. The ageing mechanisms can be measured using predictive testing: either as a full scale simulation of the Manufacture to Target or Disposal Sequence (MTDS) on a complete store; and/or at laboratory level by experimentation with critical components of the store. Some of these tests should be repeated at various stages during the predicted life cycle (i.e., in a surveillance programme) so that predictions can be verified and if necessary revised.

4. METHODS FOR RATIONALISING DATA

4.1. Methods for Determining Induced Levels

4.1.1. When meteorological data is collected, it can be sorted into representative diurnal cycles and yearly thresholds for predetermined climatic categories, the details of which are given in Leaflet 2311/1. In order to be consistent, a similar method for analysing the actual materiel data can be adopted.

4.1.2. The existing values, given at the end of this section, are based upon a statistical method which determines a figure from a given sample which will only be exceeded by 1% of the overall population, assuming that the population is normal. This method can be described as follows:

a) Take a sample of measured data for a given month. We know, for this sample, the maximum temperature ever recorded (b), and the maximum temperature recorded each day. If it is assumed that the mean of the maximum temperatures recorded each day is the mean of a normal distribution (μ), the standard deviation (sd) for that distribution can be derived as follows:

W = the complete range of values $\Rightarrow$ number of sd's in the complete range (k) x sd $\Rightarrow$ 2 x (b-μ) $\therefore$ sd = 2 x (b-μ)/k .....(1)

b) By assuming that the population range = sample range (W), a value for k can be taken from Normal distribution tables that estimate the number of sd in the range based upon the sample size (r). Therefore, a sd can be estimated for the population distribution using (1) above.

c) With a known mean and sd, for any temperature T, the number of days that will exceed T for that period (month) can now be calculated as follows:

z = the standardised normal variable = (T-μ)/sd

From this the probability (P) of exceeding T can be found from normal tables of z (in EXCEL the probability can be returned by the equation, =NORMSDIST(z)).

$\therefore$ The number of days exceeding T = P x number of days in the month (n). .....(2)

d) By calculating (2) above for each month in the year, and summing for the entire year (D = $\sum$Pn), then D estimates the number of days exceeding T in any year. To achieve a 1% value, T should be varied until D = 1% of 365, i.e., D = 3.65.

e) Once the maximum (or minimum) 1% value has been determined, the corresponding diurnal cycle also needs to be determined. The next step is to determine the opposite value in the cycle to that which has been determined (i.e., if you have the 1% maximum value, you need to determine the minimum value for the associated diurnal cycle). The opposite value was calculated for a maximum exactly as above, using equations (1) and (2), but T was chosen to be the temperature where D = 99% of 365 instead of 1%. For a minimum D = 1% of 365 instead of 99%.

f) Algorithms have been devised to fit a curve between the two points determined as above. An example of one of these algorithms is given below:

Time	Temperature
03:00	B + 0.10(A - B)
06:00	B
09:00	B + 0.25(A - B)
12:00	B + 0.65(A - B)
15:00	B + 0.95(A - B)
18:00	B + 0.70(A - B)
21:00	B + 0.40(A - B)

24:00 B + 0.20(A - B)

Where A = D for 1% maximum (or minimum for cold cycle)
and B = D for 99% maximum (or minimum for cold cycle)

4.2. Future Improvements

4.2.1. It is very likely that the above approach was taken due to the lack of sufficient computer power available at the time it was developed. There are improved ways of calculating the maximum diurnal cycle using modern computers to quickly analyse the data.

4.2.2. The Discrete Method: This is simply an extension of the method above but the temperatures recorded each day are discretely grouped (e.g., by hour). Using modern computers the iterative process described above can then be carried out for each discrete time step above and the points connected to give a diurnal curve.

4.2.3. The Continuous Method: In reality, the data are not discrete, but continuous. Modern statistical and computational methods will allow for the data to be analysed as a continuous cycle using Time Series methods.

4.3. Current Induced Levels

4.3.1. The fallback induced conditions, for the climatic categories identified in Leaflet 2311/1, are given at Annex A. If no data exists to generate induced cycles, Annex A provides fallback induced cycles, to be employed as test conditions, for representing the most extreme field conditions, within each category in the absence of field data.

4.4. Setting Test Levels

4.4.1. When making a life assessment of a safety critical materiel, it is customary to simulate the ageing of the materiel by subjecting it to a test in a climatic chamber based upon an accelerated test.

4.4.2. Solar radiation can also be associated with hot climates and accelerated ageing tests. However, solar radiation is very likely to have been present when the raw data was collected and it is not normal to include it at the test stage unless specific effects, such as actinic effects, are anticipated.

4.4.3. The 1% diurnal cycles given at Annex A have long been accepted as the fallback test levels for accelerated ageing of material containing propellants and explosives. To modify these levels the method for determining levels used in paragraph 3.1 can be used, but only if there is a significant amount of supporting data. These are **air** temperature and humidity levels and, therefore, the materiels are packaged for the test as they would be in their service storage and transportation configuration.

4.4.4. For a full analysis of life, the test duration is determined by estimating the climate and duration the material is expected to endure in service, and applying a reduced duration of testing with an increased level of climatic excitation - either a higher temperature or an increased peak to trough difference. The Berthelot (including work by Arrhenius and Eyring) relationship for comparing two temperatures is generally used to determine the level of acceleration. The application of this acceleration method is given in STANAG 4570, AECTP 600, and Leaflet 602.

4.4.5. In a lot of cases where a large item is composed of a number of age limited materials, the above testing cannot be completed cost effectively on a finished item. In these cases the life assessment must be based upon laboratory testing of the component materials to determine the relationship between material properties, temperature and time. Care must be taken to ensure that the compatibility of materials is not an issue in determining any life limiting factors.

4.4.6. Where data is collected using recorders any estimate of service life can be continuously updated using the actual data to replace the induced data within the age determining calculations. However, an acceptable number of recorders giving consistent readings will be needed before this can take precedent. Maximum values across the sample rather than Mean values should be used when calculating a safe age.

4.5. Determining Mitigating Factors

4.5.1. Where small scale laboratory testing is to be used, it may be necessary to assess the protection afforded the material by its packaging, casing, or colour. This way, over or under testing of the material in question can be avoided.

4.5.2. The simplest method for determining mitigating factors is to place a data recorder within the structure in question (e.g., materiel packaging), and subject the whole structure, including contents, to the expected climatic conditions for a small number of cycles. Analysis of the recorder data should then give a mitigated cycle that can be used for any further testing (without the package). It is recommended that a second recorder outside the structure is also used to act as an experimental control.

4.5.3. Where it is not possible to instrument the position within the item which is of concern, it may be necessary to rely upon design authority understanding coupled with FE modelling to determine the thermal dissipation or moisture pathways.

4.5.4. Obviously, the same methods can be used for determining mitigating factors in the field, which are afforded by storage structures. Where factors are not determined for storage structures, Category 1 can be represented by a fixed temperature/RH. Categories 2 & 3 can be represented by the meteorological cycles in Leaflet 2311/2 and Categories 4 & 5 can be assumed to offer no protection.

5. REFERENCE DOCUMENTS

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ANNEX A, DEFAULT TEMPERATURE DEFINITIONS FOR CLIMATIC CATEGORIES

TABLE 1

DIURNAL CYCLE FOR CATEGORY `A` STORAGE AND TRANSIT CONDITIONS

Category	A1	A2	A3
Local Time Hours	Induced Air Temperature °C	Induced Air Temperature °C	Induced Air Temperature °C
0100	35	33	31
0200	34	32	29
0300	34	32	29
0400	33	31	28
0500	33	30	28
0600	33	31	29
0700	36	34	31
0800	40	38	35
0900	44	42	40
1000	51	45	44
1100	56	51	50
1200	63	57	54
1300	69	61	56
1400	70	63	58
1500	71	63	58
1600	70	62	56
1700	67	60	53
1800	63	57	50
1900	55	50	46
2000	48	44	41
2100	41	38	37
2200	39	35	34
2300	37	34	33
2400	35	33	32

NOTES 1 Humidities for A1, A2 and A3 storage conditions vary too widely between different situations to be represented by a single set of conditions.

2 The vapour pressure in hot dry areas will vary according to the distance from the sea or other large expanse of water, but is likely to be within the range 3 to 12 mbar for category A1 and 12 to 25 mbar for category A2. The diurnal variation is likely to exceed 3 mbar for category A1 or 2 mbar for category A2.

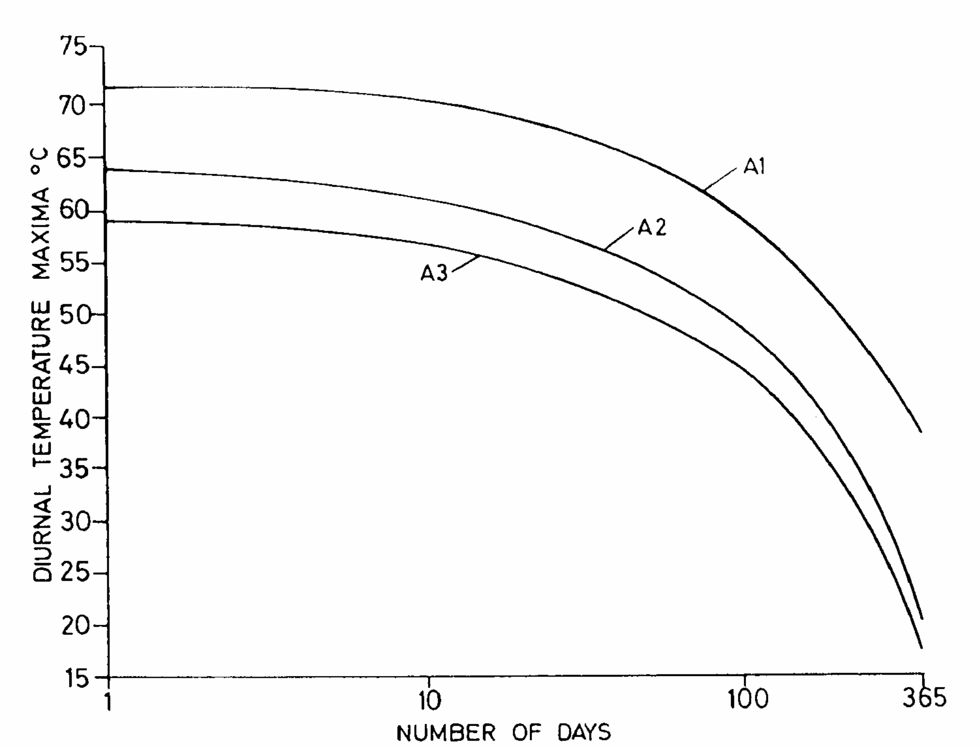

Figure 1. Distribution of the maxima of the diurnal temperature cycles for the year, for the A1, A2 and A3 storage conditions. The associated diurnal temperature cycle is obtained from Table 1.

TABLE 2

DIURNAL CYCLE FOR CATEGORY `B` STORAGE AND TRANSIT CONDITIONS

Category	B1		B2		B3	
Local Time Hours	Induced Air Temperature °C	Relative Humidity %	Induced Air Temperature °C	Relative Humidity %	Induced Air Temperature °C	Relative Humidity %
0100			33	69	35	67
0200			32	70	34	72
0300	23	88	32	71	34	75
0400			31	72	34	77
0500			30	74	33	79
0600	23	88	31	75	33	80
0700			34	64	36	70
0800			38	54	40	54
0900	28	76	42	43	44	42
1000			45	36	51	31
1100			51	29	57	24
1200	31	66	57	22	62	17
1300			61	21	66	16
1400			63	20	69	15
1500	32	67	63	19	71	14
1600			62	20	69	16
1700			60	21	66	18
1800	29	75	57	22	63	21
1900			50	32	58	29
2000			44	43	50	41
2100	26	84	38	54	41	53
2200			35	59	39	58
2300			34	63	37	62
2400	24	88	33	68	35	63

NOTE: The storage and transit conditions quoted for Category B1 relates to 358 days per year. For the other 7 days, the induced air temperatures at 24 °C, relative humidity at 100%, and the dew point at 24 °C are nearly constant throughout the 24 hours

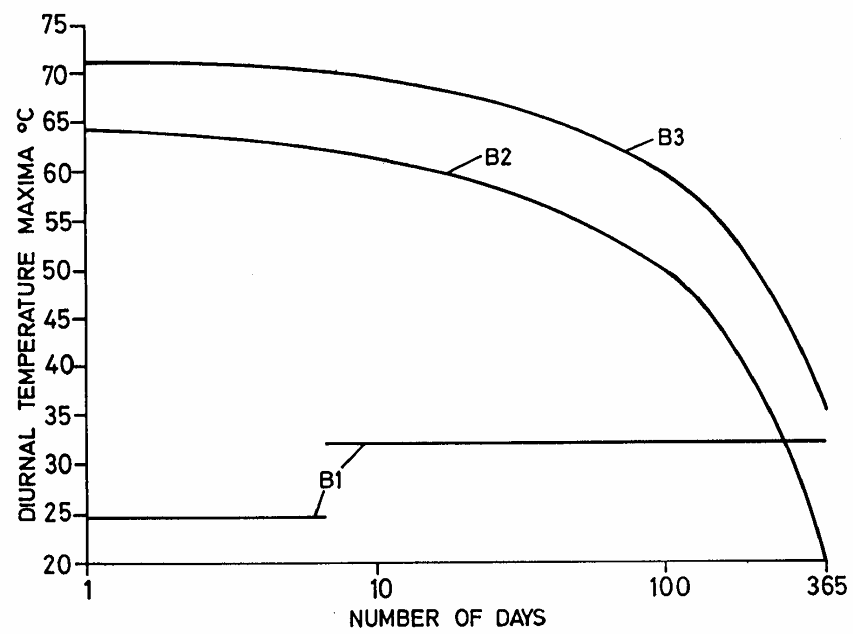

Figure 2. Distribution of the maxima of the diurnal temperature cycles for the year, for the B1, B2 and B3 storage conditions. The associated diurnal temperature cycles are obtained from Table 2.

TABLE 3

DIURNAL CYCLE FOR CATEGORY `M` STORAGE AND TRANSIT CONDITIONS

Category	M1		M2		M3
Local Time Hours	Induced Air Temperature °C	Relative Humidity %	Induced Air Temperature °C	Relative Humidity %	Induced Air Temperature °C
0100	32	52	33	71	
0200	31	56	32	73	
0300	31	56	32	70	-34
0400	30	58	31	75	
0500	30	60	30	78	
0600	30	64	31	75	
0700	33	56	34	63	-34
0800	38	42	38	51	
0900	42	31	42	40	-28
1000	48	22	45	36	
1100	53	18	51	27	
1200	61	12	57	20	-23
1300	67	9	61	16	
1400	68	8	63	13	-23
1500	69	8	63	13	
1600	68	9	62	14	
1700	65	11	60	15	
1800	61	15	57	20	-26
1900	53	20	50	26	
2000	45	32	44	36	
2100	40	39	38	51	-31
2200	36	45	35	60	
2300	34	50	34	63	
2400	33	51	33	67	-34

NOTE: The relative humidity tends to saturate at all the induced air temperatures quoted for category M3

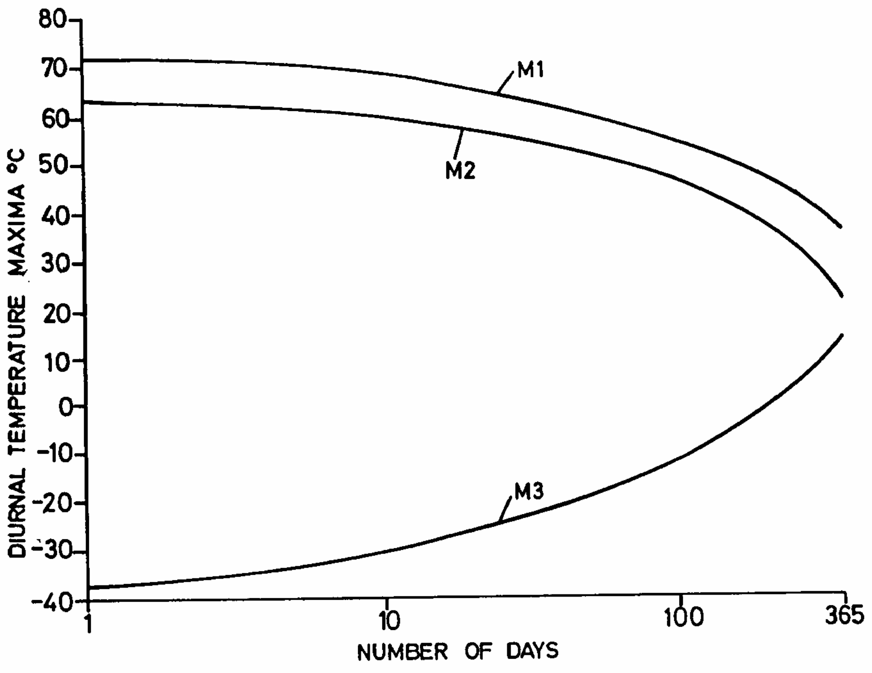

Figure 3. Distribution of the maxima or minima of the diurnal temperature cycles for the year, for the M1, M2 and M3 storage conditions. The associated diurnal temperature cycles are obtained from Table 3.

TABLE 4

DIURNAL CYCLE FOR CATEGORY 'C' STORAGE AND TRANSIT CONDITIONS

Category	C0	C1	C2
Local Time Hours	Induced Air Temperature °C	Induced Air Temperature °C	Induced Air Temperature °C
0300	-21	-33	-46
0600	-21	-33	-46
0900	-19	-33	-43
1200	-12	-28	-37
1500	-10	-25	-37
1800	-14	-29	-39
2100	-19	-32	-43
2400	-21	-33	-45

NOTES: 1 The induced air temperatures are nearly constant at -51°C for category C3 and -57°C for category C4 throughout the 24 hours.

2 The storage temperatures are slightly lower than the corresponding meteorological temperature as storage shelters are often better radiators to the night sky than either the ambient air or the ground.

3 The relative humidity tends to saturate at all the induced air temperatures quoted for categories C0 to C4.

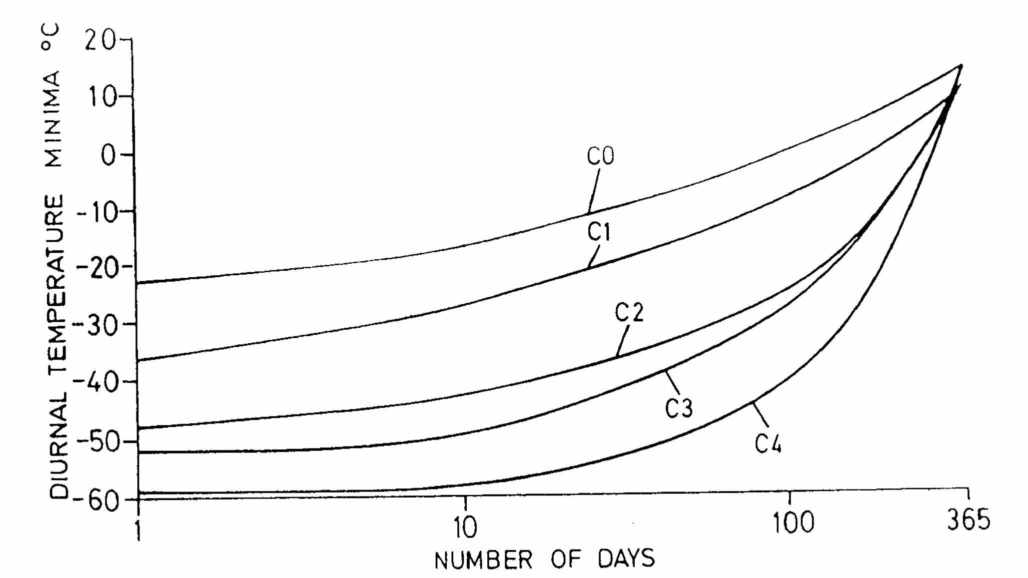

Figure 4. Distribution of the minima of the diurnal temperature cycles for the year, for the C0, C1, C2, C3 and C4 storage conditions. The associated diurnal temperature cycles are obtained from Table 4.

ADDITIONAL NOTES ON ENVIRONMENTAL CATEGORIES

General Notes on 'B' Categories	
B1	The meteorological conditions (Leaflet 2311) are derived from those recorded in Singapore. As direct solar radiation is negligible, the same set of values is given for storage conditions. Trials should be based on 7 days of saturation at 24°C, and the temperature and humidity cycles of the remaining 358 days.
B2	The storage temperatures are defined as equal to those of the A2 storage condition to take into account the relatively high ambient air temperatures and direct solar radiation, which can occur when clear skies prevail.
B3	The storage temperatures are defined as equal to those of the A1 storage condition to take into account the relatively high ambient air temperatures and direct solar radiation, which can occur when clear skies prevail.
General Notes on 'C' Categories	
C3	As the coldest days are really long nights, the temperature is constant throughout the 24 hours. The storage cycle is the same as the meteorological conditions as there is sufficient time for temperature equilibrium to be established.
C4	As for the C3 case.
General Notes on 'M' Categories	
M2	Although higher temperatures and humidities are known to occur, they rarely do so simultaneously.
M3	The storage condition is the same as for the meteorological condition because in these conditions of low radiation there is sufficient time for temperature equilibrium to be established.

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LEAFLET 2311

INTRODUCTION TO LEAFLETS 2311/1, 2311/2 AND 2311/3

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LEAFLET 2311

1 SCOPE

This section provides information on the general purpose, application and limitiations of the 2311 series of leaflets and provides additional user guidance.

1.1 Purpose

The purpose of the 2311 series of leaflets is to describe the principal climatic factors which constitute the distinctive climatic environments found throughout the world, excluding Antarctica as follows:

a. To identify each of these distinctive climatic environments in terms of categories of temperature and humidity conditions and to state in which areas of the world each category occurs.

b. To establish standard descriptions of ambient air temperature and humidity for each of these categories in terms of diurnal and annual variations.

c. To recommend in particular, diurnal cycles of temperature, humidity and direct solar radiation for use in determining design criteria.

d. To identify other climatic factors which are significant in each climatic category.

e. To recommend the intensities of these other climatic factors which should be considered when evaluating the total effect of climate upon the materiel.

f. To state how the value of the climatic factors varies with altitude.

g. To quote the most intense values ever reliably recorded for each climatic factor.

1.2 Application

These 2311 leaflets are intended primarily as reference material/guidance on regionalised world climate conditions for use when:

a. Compiling the climatic environmental clauses (related to the Life Cycle Environmental Profile) of requirements documents for materiel intended for use by NATO forces.

b. Evaluating the climatic environmental response, through analyses, of new and existing materiel when being considered for use by NATO forces, particularly when materiel is to be used under climatic conditions different from those for which it was designed.

1.3 Limitations

The 2311 series of leaflets do not prescribe tests or trials schedules, nor does it discuss all the possible effects of adverse climatic conditions upon materiel.

2 GUIDANCE FOR LEAFLETS 2311/1-3

2.1 User Information

Leaflets 2311/1-3 publish information on the principal climatic factors that comprise world climate in a probability of occurrence form suited to the needs of NATO forces.

a. Leaflet 2311/1 covers the climatic categories and their geographical locations (formerly STANAG 2895 Annex A).

b. Leaflet 2311/2 covers worldwide ambient air temperature and humidity conditions and levels of direct solar radiation (formerly STANAG 2895 Annex B).

c. Leaflet 2311/3 covers additional climatic environmental factors to be taken into account when considering materiel intended for use by NATO forces (formerly STANAG 2895 Annex C).

d. The climatic category maps were updated from STANAG 2895 using new data; however the same methods were applied in defining the climatic categories therefore the geographical boundaries remained relatively constant.

e. The analysis for the "B" categories was altered slightly in order to provide relatively homogeneous boundaries.

f. The principal locations of the land surface categories are shown on the world maps (Maps 1A, 1B and 1C) in Leaflet 2311/1, and the associated diurnal cycles are in Leaflet 2311/2.

g. The sea surface categories are associated loosely with tropical, temperate and arctic waters, but no zones of demarcation are shown as it is considered that ships could enter all waters during service.

h. The temperature and accompanying humidity and solar radiation conditions which occur throughout the entire year in each of the climatic categories are presented in Leaflet 2311/2 in the form of the number of days of the year in which, on average, a specific temperature is just attained or exceeded. In addition, the total period that a specific temperature is exceeded during the entire year is also given.

i. Although the “B” categories have been specifically associated only with regions recognized as wet for at least a substantial portion of an average year, the conditions they represent can occur occasionally, for a relatively short period, in regions normally characterized by their dryness such as deserts. Thus an appropriate high humidity climatic category should be selected or specified in requirements documents, even when it is known that the materiel will not enter any of the regions defined for the “B” categories.

j. For materiel exposed at the sea surfaces, the requirements documents should normally specify the high temperature category M1, the intermediate category M2, and the low temperature category M3, on the basis that, in general, ships enter tropical, temperate and arctic waters during service.

k. For certain materials, temperature cycling through a phase transition, such as the freezing of water, may be more severe than cycling at the temperature extremes. This should be considered and, where necessary, appropriate temperature cycles specified, based if possible on conditions for the climatic categories given in the Leaflets.

l. Temperature moderating factors are given for ground elevations substantially above sea level (Table 2 Leaflet 2311/2).

m. For explosives, propellants and pyrotechnics, it is recommended that temperature and humidity levels should be based on a probability of being exceeded for 1 percent of one month in the worst period of the year (normally 3 to 4 times a year). The diurnal cycles defined by this recommendation are included for each category in Leaflet 2311/2. The above criterion is applicable in many cases, but in other circumstances, for instance, where a temperature-induced materiel defect will not present a hazard or cause a major system malfunction, the risk situations should be assessed so that temperatures derived from related percentage values representing the optimum compromise can be adopted. Upper or lower values of temperature and humidity for such criteria may be obtained from the probability plots in Leaflet 2311/2. Care should be exercised when criteria beyond 10 percent risk (i.e. based upon a probability of being exceeded for 10 percent of one month in the worst period of the year) are being considered (see also Leaflet 2311/1 para 1.3 (b)). These data are then used as limit values for diurnal cycles having the same amplitude as the corresponding ones in Tables 6 – 19 of Leaflet 2311/2.

n. Values of temperature and humidity at altitude are given in terms of the highest, lowest and the 1 percent high and low values in Table 2 and 3 of Leaflet 2311/2. The 1 percent values are recommended for determining design criteria for materiel, particularly explosives, propellants and pyrotechnics but, as above, less severe criteria may be applicable in certain cases. Only natural effects are given; induced effects, such as aerodynamic heating, are not considered.

o. In addition to temperature and humidity, the various other climatic factors associated with each category can be identified from Leaflet 2311/3. These factors should be stated in the requirements documents and taken into account when specifying the total climatic environment.

p. It is unlikely that the temperature and humidity conditions encountered in any given year during field trials, at a particular location will approach the extreme values defined for the climatic category of that location.

q. Guidance on the calculation of the 1% values can be found in Leaflet 2310/1.

2.2 Guidance on the drafting of the climatic environmental clauses of requirements documents.

a. The climatic environmental paragraphs of the Requirements Documents (RD) for an item of materiel should give the fullest information on all aspects of the climates in which the item is required to remain safe and suitable, and/or to be capable of acceptable performance.

b. Initially the sponsor should decide in which regions of the world and for what length of time in each of these regions it is required to store and operate the item during its planned service life and embody this information in the RD in terms of one or more of the fourteen distinct climatic categories of which eleven refer to the land surfaces of the world and three to the sea surfaces, as defined at Leaflet 2311/1.

c. For materiel located on the land surfaces, the requirements documents should specify a set of conditions from the high temperature categories (A1, A2 or A3), the low temperature categories (C0, C1, C2, C3 or C4) and where high humidity is the principal consideration; one from categories (B1, B2, or B3) should also be selected. For packaged or unpackaged materiel liable to be exposed directly or indirectly to solar radiation, it is appropriate to use AECTP 200 Leaflet 2310/1 for induced Climatic Environments.

d. When preparing the requirements documents, it should be noted that when the temperatures in the regions covered by the A1, A2, A3, M1 and M2 categories are in the vicinity of their maxima, the other climatic factors (those found in Leaflet 2311/3), apart from direct solar radiation and atmospheric pressure, are unlikely to approach their levels of maximum intensity.

e. For the bulk sea surface, it is expected that all three ‘M’ categories will be specified as ships may enter tropical, temperate and arctic waters during service. For coastal waters it is more appropriate to specify the corresponding land service category.

f. Consideration of the effects of combined environments to which the item will be exposed are of principal importance when preparing Requirements Documents.

g. For any particular item of materiel, the requirements documents should state, for design purposes, acceptable probabilities of occurrence of temperature and humidity. These probabilities of occurrence can be derived from the appropriate tables in Leaflet 2311/2, to produce temperature and humidity levels for the climatic categories in which it is intended to operate the materiel.

h. The probabilities of particular temperatures being attained or exceeded in the regions of the respective climatic categories are given in Leaflet 2311/2 in terms of both the number of days a year they are likely to occur and the total time per year for which they persist.

i. For explosives, propellants and pyrotechnics, a probability of occurrence of one percent of one month during the hottest, or coldest, period of the year, as appropriate, is recommended. For convenience, the diurnal cycles corresponding to this probability of occurrence are given in both graphical and tabular form for each climatic category.

j. For all other forms of materiel, the sponsor should decide the optimum value for the probability of occurrence, taking into account all relevant factors including its cost, difficulties of design and production and modes of deployment. The values selected should be stated in the Requirements Documents.

k. The RD should state whether exposure at altitude is to be taken into account.

l. For exposure at altitude, the 1 percent values given in Tables 3 to 5 of Leaflet 2311/2 are recommended unless over-riding considerations dictate to the contrary.

m. The other climatic factors which should be taken into account in the Requirements Documents are listed in Leaflet 2311/3 and their highest and/or lowest values ever reliably recorded are quoted in the respective sections of the Leaflet.

n. In general, extreme values for pressure are often used as design criteria. However, for many other climatic factors the extreme values are not always used.

o. If the Requirements Documents call for a particular item of materiel to be safe and capable of acceptable performance when exposed to intensity levels different from those recommended in Leaflet 2311/1, Leaflet 2311/2 and Leaflet 2311/3, then any departure should be justified.

p. Materiel designed to be safe and capable of acceptable performance under the conditions specified for one category should not be expected necessarily to do so under the conditions specified for another category.

q. It is rarely required that materiel be necessarily safe and/or capable of acceptable performance when exposed to the highest and lowest temperatures ever reliably recorded in the regions of the particular categories specified for the materiel.

3. TERMS AND DEFINITIONS

The following terms and definitions are used for the purpose of these leaflets :

a. Climatic Category: a classification of the climate in each area of the world in terms of a set of temperature and humidity conditions.

b. Materiel: the generic term for all equipment, stores, packaging and supplies used by NATO forces.

c. Meteorological Temperature: is the ambient air temperature measured under standard conditions of ventilation and radiation shielding in a meteorological screen at a height of 1.2 to 2m above the ground.

d. Dew Point: the temperature at which the air is saturated with water vapor. The dew point is the temperature at which the vapor begins to condense as droplets of water when the temperature falls.

e. Solar Radiation: is the combination of infra-red, visible and ultra-violet radiation from the sun. The spectral energy distribution of solar radiation at midday at sea level when the sun is directly overhead is given in Table 1 below.

Table 1. Spectral energy distribution of solar radiation at sea level.

Spectral Region (a)	Ultraviolet (b)		Visible (c)		Infrared (d)	
Waveband (μm)	0.28-0.32	0.32-0.40	0.40-0.52	0.52-0.64	0.64-0.78	0.78-3.00
Irradiance (W/m^2)	5	63	200	186	174	492

Note: The values of demarcation between the ultraviolet, visible and infrared quoted in some reference documents differ slightly from those in the above table.

f. Effects of Solar Radiation: the two main effects of solar radiation are (i) heat and (ii) actinic effects of materials. The thermal response of materiel to this radiation will depend to an appreciable extent upon its heat capacity and surface finish but typically a rise of 20 K can result at its surface under clear skies on days when the direct solar radiation attains or exceeds 1000 W/m^2. For more precise values, field trials or accurate simulation become essential. For materiel directly exposed to solar radiation or to high levels of reflected radiation, the degradation effect of the ultra-violet and blue/green components on plastics, rubbers, paints etc., must also be considered. More advice on solar radiation can be found in Method 305, Annex A.

5. DATA SOURCES

(1) STANAG 2831: Climatic Environmental Conditions Affecting the Design of Materiel for Use by NATO Forces Operating in a Ground Role.

(2) US AFCRL-TR-74-0052: Synopsis of Background Material for Mil. Std 210B, Climatic Extremes for Military Equipment (1974).

(3) US MIL-HDBK-310 Global Climatic Data for Developing Military Products (1997).

(4) UK Met 0.617: Tables of Temperature, Relative Humidity and Precipitation for the World (1965).

(5) UK Met O 856 Tables of temperature, relative humidity, precipitation and sunshine for the world. Part 1 N. America (1980), Part 3 Europe (1973) and Part 4 Africa (1983).

(6) UK IMI Summerfield T.R. No 70/10: Application of Simulated Real-Life Climatic Cycles Derived from Available Meteorological Data (1970).

(7) GAM EG 13, Annex Environmental Data

6. REFERENCE DOCUMENTS

(1) STANAG 2805A: Minimum Fordability Requirements for Tactical Vehicles and Guns, and Minimum Immersion Requirements for Combat Equipment Normally Installed or Carried in Open Vehicles or Trailers.

(2) STANAG 4044: Adoption of a Standard Atmosphere.

(3) STANAG 4194: Standardized Wave and Wind Environments and Shipboard Reporting of Sea Conditions.

(4) UK Def Stan 00-35 Environmental Handbook for Defence Materiel, Part 4 Natural Environments, Issue 3, 7th May 1999.

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LEAFLET 2311/1

Climatic Categories and Their Geographical Location

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LEAFLET 2311/1

1 SCOPE

This section provides information on the general purpose, application and limitiations of leaflet 2311/1 and provides additional user guidance.

1.1 Purpose

To facilitate the discussion of ambient air temperatures and humidities, eleven climatic categories have been chosen to represent the distinctive types of climate to be found at the land surfaces of the world, and a further three have been selected to describe the conditions at the sea surface.

1.2 Application

a. For materiel located on the land surfaces, the requirements documents should specify a set of conditions from the high temperature categories (A1, A2 or A3), the low temperature categories (C0, C1, C2, C3 or C4) and where high humidity is the principal consideration; one from categories (B1, B2, or B3) should also be selected.

b. If real data is not available for the materiel when exposed to solar radiation, it is more appropriate to use AECTP 200 Leaflet 2310/1 for induced Climatic Environments rather than natural meteorological temperature.

c. For the bulk sea surface, it is common for all three 'M' categories to be specified as ships may enter tropical, temperate and arctic waters during service. For coastal waters it is more appropriate to specify the corresponding land service category.

d. Consideration should be given to the combination of ambient temperatures and their associated humidity to which the materiel will be exposed.

1.3 Limitations

a. The geographical areas in Maps 1-3 in this leaflet are not intended to indicate that the climate at each and every location complies exactly with the annual distributions and diurnal cycles given in Leaflet 2311/2.

b. These maps are supplied for use as a guide only in the engineering and logistic decision making processes for a particular item of materiel to determine its required climatic design and performance criteria. If data applicable only to particular parts of an area are required, relevant meteorological authorities should be consulted. To avoid limitations in deployment, this approach should be used as infrequently as possible.

c. Use of this document is intended for initial design criteria. Once the materiel is in service, it is preferable to monitor actual conditions.

d. It is considered impractical to attribute categories to specific sea areas, but as a general guide, M1 and M2 apply to regions that experience tropical or temperate conditions, while M3 is representative of arctic conditions.

1.4 User Information

a. Eight of the categories pertaining to the land surface (termed A1, A2, A3, C0, C1, C2, C3 and C4 respectively) are defined with temperature as the principal consideration while the remaining three (termed B1, B2 and B3 respectively) represent climates in which high humidity is accompanied by warm temperatures as the critical characteristic.

b. The locations to which these categories apply are shown in Maps 1-3. Further information about the land surface regions of each category accompanies the diurnal cycles of temperature and humidity given in Appendices 1 to 11 of Leaflet 2311/2.

c. For the sea surface, two categories (termed M1 and M3 respectively) are defined with temperature as the principal consideration while the third (termed M2) represents sea climates in which a warm temperature is accompanied by high humidity.

d. The upper and lower values of the cycles detailed in Leaflet 2311/2 are summarized in Table 2.

e. The “B” categories are defined in Table 1 using humidity (dew point) as well as temperature. The values available for a large number of stations were: T99 (99% temperature in the hottest month), T01 (1% temperature in the coldest month) and TDT 99 (the 99% dew point in the hottest month). TDT99 has been used as it was thought to be the best single discriminant for the B category humidity and it has the advantage that it can be calculated in the same way as T99 and applies to the same month. The table shows the criteria that were used to produce the area of each B climatic category.

f. In certain cases it may be necessary to consider another value TD99 (which is the 99% dew point for the wettest month).

g. Efforts should be made to use measured environmental data, especially for temperature and humidity when there is likely to be a temperature or humidity based failure mode.

Table 1. Definitions for the humid climatic categories

Climatic Category	T99 (99% air temperature of hottest month °C)	T01 (1% air temperature of coldest month °C)	TDT 99 (99% dew point temperature in hottest month °C)
B1 (jungle)	31 to 35	>17	>24.5
B2 (savannah with hot dry season)	35 to 39.5	-	>25.5
B3 (Persian Gulf, Aden)	>39.5	-	>29

Notes

These definitions are based on 3 or 6 hourly data from 1983-2001 for several thousand World Met Office (WMO) synoptic land stations worldwide.

B1 definition: the criterion T01>17°C is necessary to restrict the area to the wet tropics. The "jungle" areas are covered quite well by Met stations such as the Congo and the Amazon Basin, although there is a lack of good stations in West and Central Africa and parts of Amazonia. Most small tropical islands are covered by T99, as it will be below 35°C where there is a sea breeze.

B2 definition: is difficult to define as it is not obvious whether to emphasise the temperature or humidity and these may maximise in different months. Many tropical highlands particularly in Africa are not covered by the B categories. B2 stations were typically savannah areas surrounding the jungle regions and approached the A2 areas. This category may still need to be adjusted.

B3 definition: the exact position of the station relative to the desert interior and the warm sea is critical. The land side is either A1 or A2, while small islands in the Persian Gulf may only be A3 or B2, e.g., Bahrain is A2. The Gulfs of Oman and Aden are B3 as well as the Persian Gulf and southern Red Sea littorals. The B3 areas are coastal and do not extend out into the sea regions.

Table 2 Summarized Temperature and Humidity Cycles World Wide.

Cycle	Meteorological	
	Temperature (^{o}C)	Relative Humidity (%)
A1	32 to 49	8 to 3
A2	30 to 44	44 to 14
A3	28 to 39	78 to 43
B1		
7 days	24	100
358 days	23 to 32	88 to 66
B2	26 to 35	100 to 74
B3	31 to 41	88 to 59
C0	-6 to -19	
C1	-21 to -32	Tending to saturation
C2	-37 to -46	
C3	-51	
C4	-57	
M1	29 to 48	67 to 21
M2	25.5 to 35	100 to 53
M3	-23 to -34	Tending to saturation

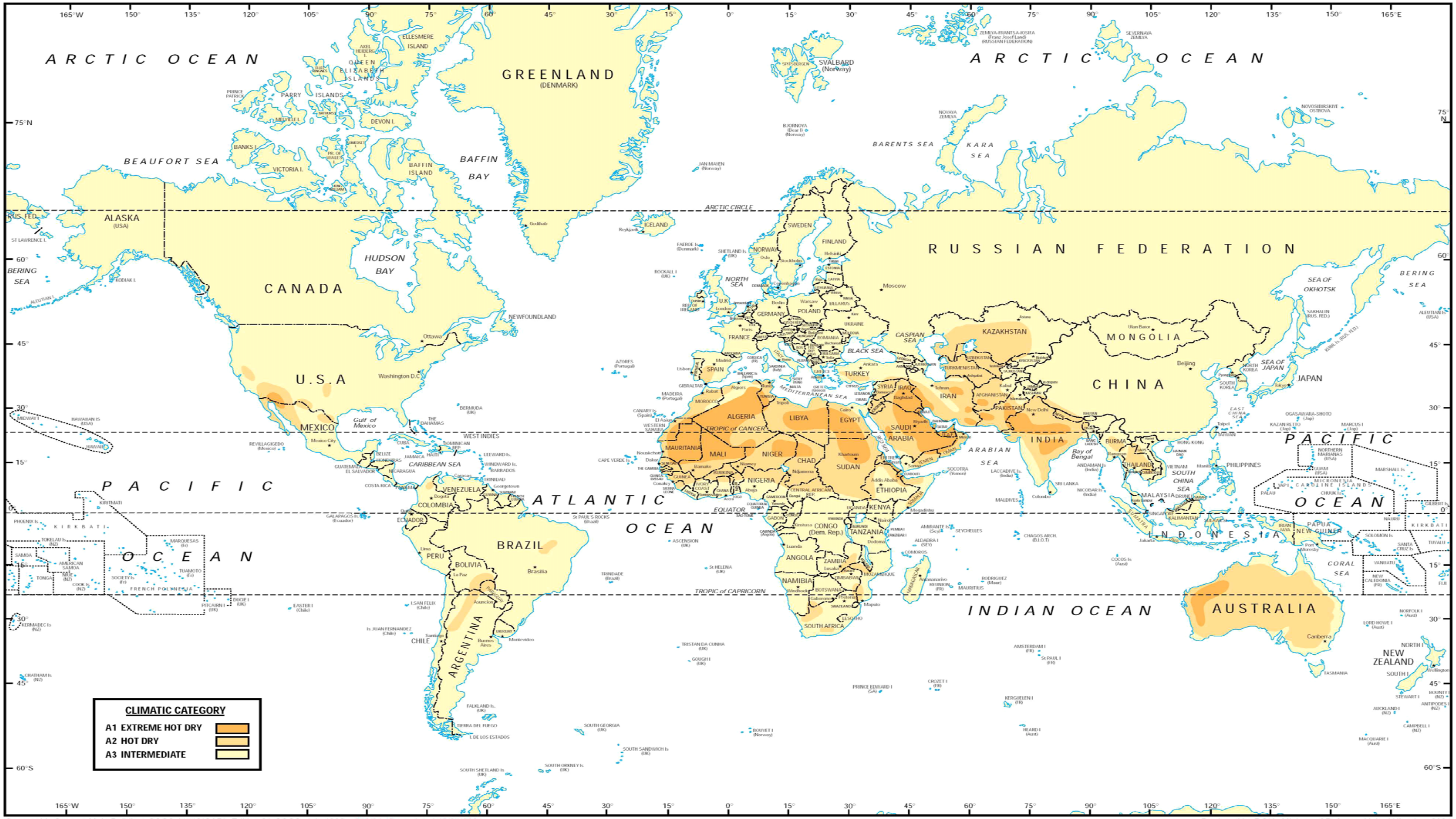
2 CLIMATIC CATEGORY LOCATION MAPS

2.1 MAP 1 Climatic Categories: Extreme Hot Dry A1, Hot Dry A2 & Intermediate A3.

2.2 MAP 2 Climatic Categories: Wet Warm B1, Wet Hot B2 & Humid Hot Coastal Desert B3.

2.3 MAP 3 Climatic Categories: Mild Cold C0, Intermediate Cold C1, Severe Cold C3 & Extreme Cold C4.

LOCATION OF CLIMATIC CATEGORIES



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Map 1, Leaflet 2311 - Climatic Categories : Extreme Hot Dry A1, Hot Dry A2 & Intermediate A3

LOCATION OF CLIMATIC CATEGORIES

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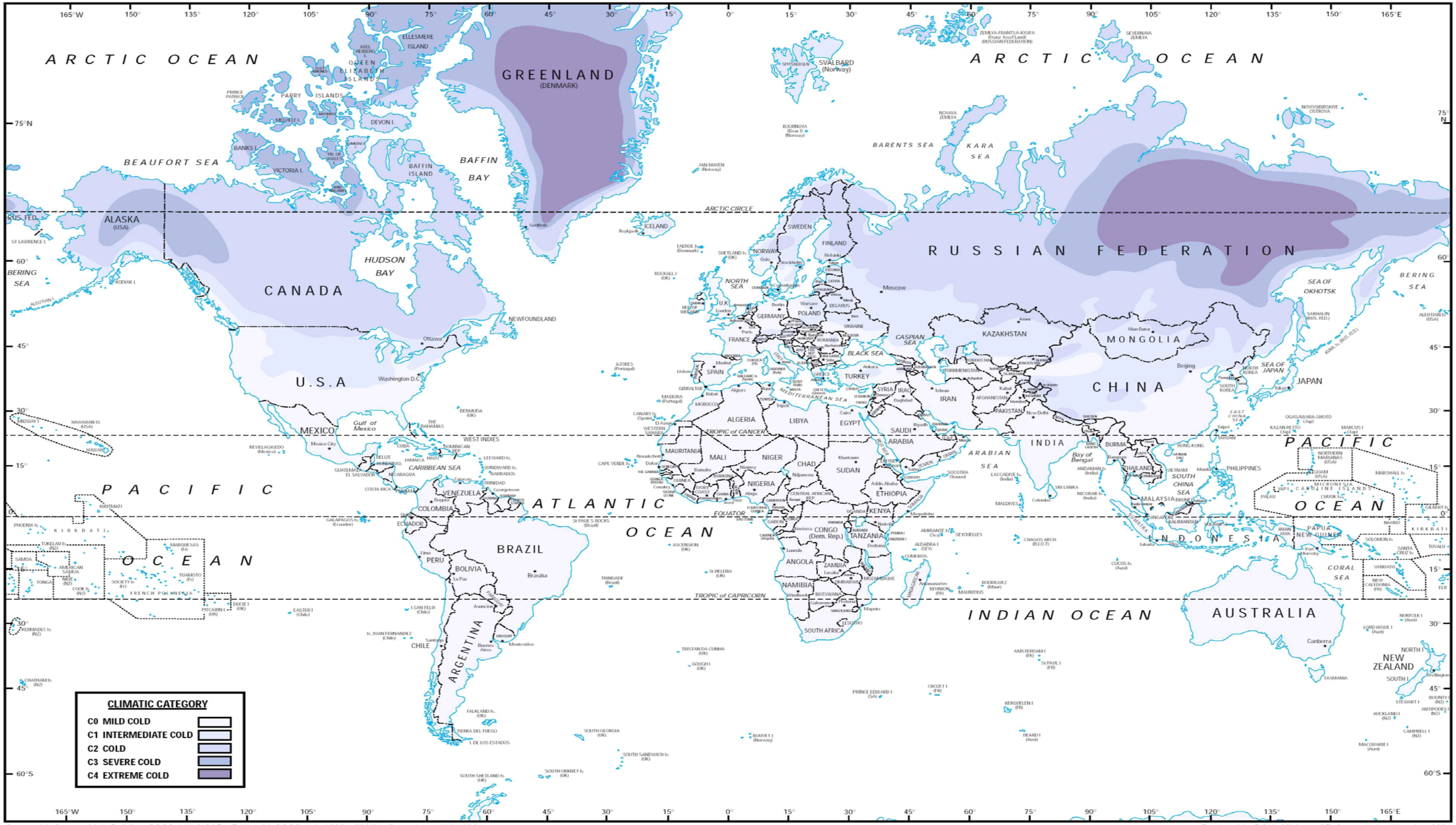
Map 2, Leaflet 2311 - Climatic Categories: Wet Warm B1, Wet Hot B2 & Humid Hot Coastal Desert B3

LOCATION OF CLIMATIC CATEGORIES



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Map 3, Leaflet 2311 - Climatic Categories: Mild Cold C0, Intermediate Cold C1, Severe Cold C2 & Extreme Cold C4

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LEAFLET 2311/2

World-Wide Ambient Air Temperature and Humidity Conditions and Levels of Direct Solar Radiation

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1 SCOPE

1.1 Purpose

This Leaflet provides information about the ambient (meteorological) temperature, solar radiation and humidity conditions found over the land at or near sea level and the sea surfaces of the various climatic categories identified in Leaflet 2311/1.

These land and sea surface conditions comprise:

a. A plot of the number of days of the year on which, on average, a given temperature is just attained or exceeded in the 5-10 percent climatically least hospitable regions of each category.

b. A plot of the relative humidity associated with the temperature.

c. The diurnal meteorological temperature cycle representative of conditions on days when extreme or near-extreme temperatures occur.

d. A plot of the total number of days and hours in the year that a given temperature is just attained or exceeded.

1.2 Application

a. These diurnal cycles are recommended for use in determining design criteria for NATO forces materiel.

b. For elevated ground, the appropriate correction factor is given in Table 2 of this Leaflet. For meteorological conditions at altitude, reference should be made to Tables 3 to 5.

c. The approximate boundaries for these categories are shown in Maps 1, 2 and 3 (Leaflet 2311/1). The description of some of the more important land surface regions of each category accompanies the diurnal cycles of temperature and humidity given in this Leaflet 2311/2. For the sea surface, two categories (termed M1 and M3 respectively) are defined with temperature as the principal consideration while the remaining category (termed M2) represents sea climates in which a warm temperature is accompanied by high humidity.

d. The upper and lower values of the cycles detailed in Leaflet 2311/2 are summarised below.

Table 1. Summarized Temperature and Humidity Cycles World Wide.

Cycle	Meteorological	
	Temperature (^{o}C)	Relative Humidity (%)
A1	32 to 49	8 to 3
A2	30 to 44	44 to 14
A3	28 to 39	78 to 43
B1		
7 days	24	100
358 days	23 to 32	88 to 66
B2	26 to 35	100 to 74
B3	31 to 41	88 to 59
C0	-6 to -19	Tending to saturation
C1	-21 to -32	
C2	-37 to -46	
C3	-51	
C4	-57	
M1	29 to 48	67 to 21
M2	25.5 to 35	100 to 53
M3	-23 to -34	Tending to saturation

1.3 Limitations

It is impractical to attribute categories to specific sea areas, but as a general guide, M1 and M2 apply to regions that experience tropical or temperate conditions, while M3 is representative of arctic conditions.

2 MODERATING FACTORS FOR CLIMATIC ENVIRONMENTAL CONDITIONS

2.1 Temperature Moderating Factors for Elevated Ground

The temperature quoted for Categories A1, A2, and A3 relate to ground elevations from sea level to 900 m. For ground elevations greater than 900 m, the moderating factor given in Table 2 should be applied. Similarly, the data for Categories B1, B2 and B3 relate to ground elevations from sea level to 1200 m, and for higher elevations the appropriate moderating factors quoted in this Table should be applied.

Table 2. Temperature Moderating Factors for Elevated Ground.

Climatic category	Ground elevations above MSL	Moderating factors
A1, A2, A3	900 m	-1 ^{o}C per 100 m
B1	1200 m	-2 ^{o}C per 300 m
B2, B3	1200 m	-1 ^{o}C per 100 m

2.2 Temperature and Humidity at Altitude

2.2.1 Ambient Air Temperature at Altitude – World-Wide

The temperatures of the ambient air which, on a worldwide basis are estimated to be attained or exceeded for 7.4 hours (i.e., 1 percent of a month) of the hottest period of the year and for all but 7.4 hours of the coldest period of an average year are quoted for a range of altitudes in Table 3. The temperatures at other altitudes in the range can be calculated by linear interpolation between the two nearest values quoted. The highest and lowest temperatures ever reliably recorded at these altitudes are also given.

Table 3. Ambient Air Temperature at Altitude – Worldwide

Altitude km	Altitude kft	Highest temperature ever recorded °C	Value of 1% high temperature occurrence level °C	Value of 1% temperature occurrence level °C	Lowest temperature ever recorded °C
0	0	58	49	-61	-68
1	3.28	41	40	-53	-54
2	6.56	32	30	-41	-47
4	13.1	19	17	-48	-53
6	19.7	8	6	-57	-61
8	26.2	-4	-5	-66	-68
10	32.8	-13	-13	-74	-75
12	39.4	-22	-22	-73	-80
14	45.9	-30	-30	-75	-77
16	52.5	-35	-37	-86	-87
18	59.1	-35	-37	-86	-88
20	65.6	-31	-32	-86	-87
22	72.2	-39	-30	-84	-85
24	78.7	-33	-33	-85	-86
26	85.3	-27	-28	-84	-84
28	91.9	-22	-23	-83	-84
30	98.4	-17	-18	-83	-85
35	115		3	-81	
40	131		25	-71	
45	148		30	-70	
50	164		37	-70	

Note: It should be noted that not all these highest (or lowest) temperatures at various altitudes occurred simultaneously nor necessarily at the same location and the set of values given in Table 3 do not represent a specific temperature-altitude profile.

2.2.2 Ambient Air Temperature at Altitude – Over Open Seas.

The range of ambient air temperatures over open seas at any altitude below 16 km (52.5 kft) is significantly less than the range over land masses. The high and low values over open seas, calculated in a similar manner as those for the worldwide condition, are given in Table 4. Values of air temperature above 16 km (52.5 kft) are the same as those for worldwide.

Table 4. Ambient Air Temperature at Altitude – Over Open Seas.

Altitude km	Altitude kft	Highest temperature ever recorded °C	Value of 1% high temperature occurrence level °C	Value of 1% low temperature occurrence level °C	Lowest temperature ever recorded °C
0	0	51	48	-34	-39
1	3.28	34	33	-29	-31
2	6.56	26	25	-31	-32
4	13.1	16	14	-39	-40
6	19.7	2	1	-46	-47
8	26.2	-8	-9	-56	-58
10	32.8	-20	-21	-69	-70
12	39.4	-36	-39	-74	-75
14	45.9	-35	-37	-75	-76
16	52.5	-35	-37	-86	-87

Note: It should be noted that not all these highest (or lowest) temperatures at various altitudes occur simultaneously nor necessarily at the same location and the set of values given in Table 4 do not represent a specific temperature-altitude profile.

The surface values are based on Abadam and Anchorage, Alaska.

2.2.3 Humidity at Altitude – World Wide

The humidities, expressed in terms of dew points, which, in an average year, are exceeded for a total of 7.4 hours during the wettest month at various altitudes up to 8 km (26 kft) are listed in Table 5, together with the highest values ever recorded.

Table 5. Humidity at Altitude

Altitude km	Altitude kft	1% high humidity occurrence level of dew point °C	Highest recorded dew point °C
0	0	31	34
1	3.28	29	30
2	6.56	24	26
4	13.1	16	18
6	19.7	3	3
8	26.2	-8	-7

2.3.4 Direct Solar Radiation at Altitude

Although the thermal effect of direct solar radiation at altitude is somewhat greater than at sea level, for the purpose of this leaflet the values that apply at sea level, defined in the various appendices of this leaflet, are also taken at altitude. The degrading effect of the ultra violet component of solar radiation on some materials (see Leaflet 2311 Part 3 Definition f) increases significantly with altitude. No figures are quoted since the effect is wavelength dependent and varies considerably from one material to another. For additional information on solar radiation at altitude see Method 305, Annex A.

3 AMBIENT AIR TEMPERATURE, HUMIDITY AND DIRECT SOLAR RADIATION CONDITIONS OVER LAND AND NEAR SEA LEVEL.

3.1 A1 – Extreme Hot Dry

a. Category A1 applies to areas which experience very high temperatures namely, hot dry deserts of North Africa, parts of the Middle East, northern India and southwestern USA.

b. The general data for the meteorological conditions are given in Figures 1 to 3.

c. In addition, the cycle of maximum temperature and associated humidity, recommended as design criteria for materiel exposed to the A1 meteorological conditions is given in Table 6. The highest temperature of this cycle is that air temperature which is attained or exceeded at the hotter locations in the category, on average, for a total time of approximately 7.4 hours (i.e., 1 percent of one month) during the hottest period of the year. The profile of this cycle is typical of those for days when this temperature is just attained.

d. The highest temperature ever reliably recorded for the A1 meteorological condition is 58^{o}C.

Table 6. Diurnal Cycle for the A1 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m^2
0100	35	6	0
0200	34	7	0
0300	34	7	0
0400	33	8	0
0500	33	8	0
0600	32	8	55
0700	33	8	270
0800	35	6	505
0900	38	6	730
1000	41	5	915
1100	43	4	1040
1200	44	4	1120
1300	47	3	1120
1400	48	3	1040
1500	48	3	915
1600	49	3	730
1700	48	3	505
1800	48	3	270
1900	46	3	55
2000	42	4	0
2100	41	5	0
2200	39	6	0
2300	38	6	0
2400	37	6	0

Note: The vapour pressure in extreme hot dry areas will vary according to the distance from the sea or other large expanses of water but is likely to be within the range 3 to 12 millibars. The diurnal variation is unlikely to exceed 3 millibars.

3.2 A2 – Hot Dry

a. Category A2 applies to areas which experience high temperatures accompanied by moderately low humidities, namely, the most southerly parts of Europe, most of the Australian continent, south central Asia, northern and eastern Africa, coastal regions of North Africa, southern parts of USA and most of Mexico.

b. The general data for the meteorological conditions are given in Figures 1-3.

c. In addition, the cycle of maximum temperature and associated humidity, recommended as design criteria for materiel exposed to the A2 meteorological condition is given in Table 7. The highest temperature of this cycle is that air temperature which is attained or exceeded at the hotter locations in the category, on average, for a total time of approximately 7.4 hours (i.e. 1 percent of one month) during the hottest period of the year. The profile of this cycle is typical of those for days when this temperature is just attained.

d. The highest temperature ever reliably recorded for the A2 meteorological condition is 53 °C.

Table 7. Diurnal Cycle for the A2 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature ^{o}C	Relative Humidity %	Solar Radiation W/m^2
0100	33	36	0
0200	32	38	0
0300	32	43	0
0400	31	44	0
0500	30	44	0
0600	30	44	55
0700	31	41	270
0800	34	34	505
0900	37	29	730
1000	39	24	915
1100	41	21	1040
1200	42	18	1120
1300	43	16	1120
1400	44	15	1040
1500	44	14	915
1600	44	14	730
1700	43	14	505

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature ^{o}C	Relative Humidity %	Solar Radiation W/m^2
1800	42	15	270
1900	40	17	55
2000	38	20	0
2100	36	22	0
2200	35	25	0
2300	34	28	0
2400	33	33	0

Note: The vapour pressure in hot dry areas will vary according to the distance from the sea or other large expanses of water but is likely to be within the range 12 to 25 millibars. The diurnal variation is unlikely to exceed 2 millibars.

3.3 A3 – Intermediate

a. In strict terms, Category A3 applies only to those areas that experience moderately high temperatures and moderately low humidities for at least part of the year. It is particularly representative of conditions in Europe except the most southern parts, Canada, the northern United States and the southern part of the Australian continent.

b. However for the purposes of this Agreement, Category A3 is considered to apply to all land masses except those designated as Category Al or A2 areas in Map 1.

c. The general data for the meteorological conditions are given in Figures 1-3

d. In addition, the cycle of maximum temperature and associated humidity, recommended as design criteria for materiel exposed to A3 meteorological conditions is given in Table 8. The highest temperature of this cycle is that air temperature which is attained or exceeded at the hotter locations in the category, on average, for a total time of approximately 7.4 hours (i.e. 1 percent of one month) during the hottest period of the year. The profile of this cycle is typical of those for days when this temperature is just attained.

e. The highest temperature ever reliably recorded for the A3 meteorological condition is 42^{o}C.

Table 8. Diunal Cycle for the A3 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m^2
0100	30	69	0
0200	29	72	0
0300	29	74	0
0400	28	76	0
0500	28	78	0
0600	28	78	45
0700	29	74	170
0800	30	67	500
0900	31	59	800
1000	34	51	960
1100	36	47	1020
1200	37	45	1060
1300	38	44	1020
1400	38	43	915
1500	39	43	660
1600	39	44	250
1700	38	46	70
1800	37	48	15
1900	35	50	0
2000	34	53	0
2100	34	56	0
2200	32	59	0
2300	32	63	0
2400	31	66	0

3.4 General Data for the Meteorological Conditions

Figures 1 and 2 for A1, A2 and A3 show the number of days in a year on which, on average a given temperature is exceeded, together with the corresponding dew points. The associated diurnal temperature cycles are in Tables 6-8.

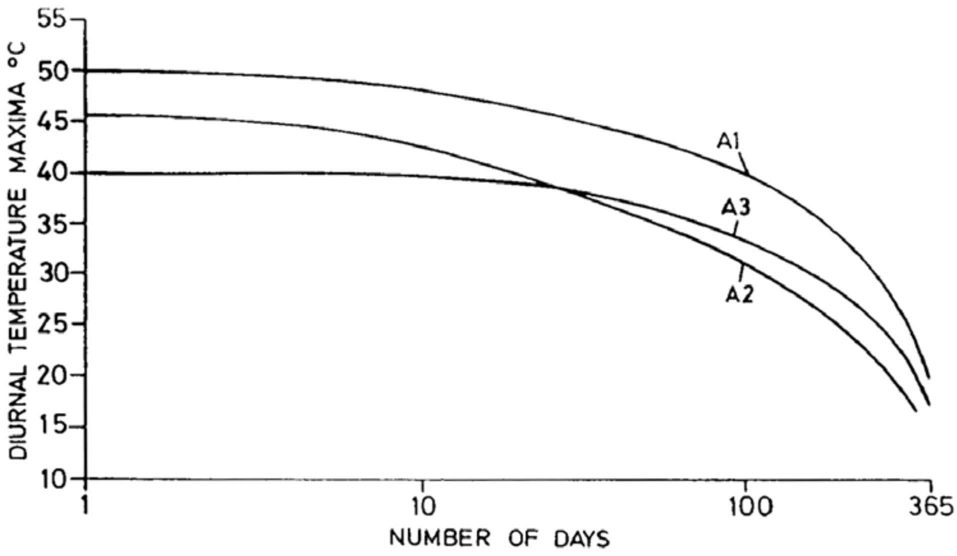


Figure 1

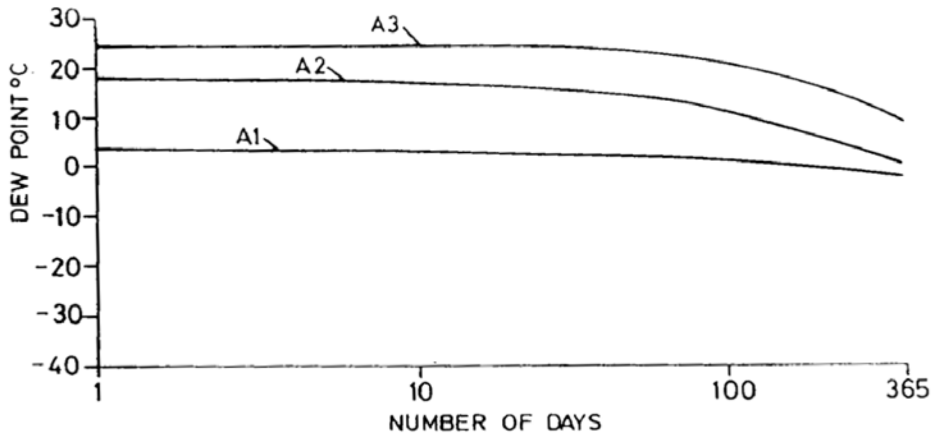


Figure 2

The number of hours in each year for which the air temperature just reaches or goes above a given value in the A1, A2 and A3 meteorological conditions. Computed from the information supplied in Figure 1 and Tables 6-8.

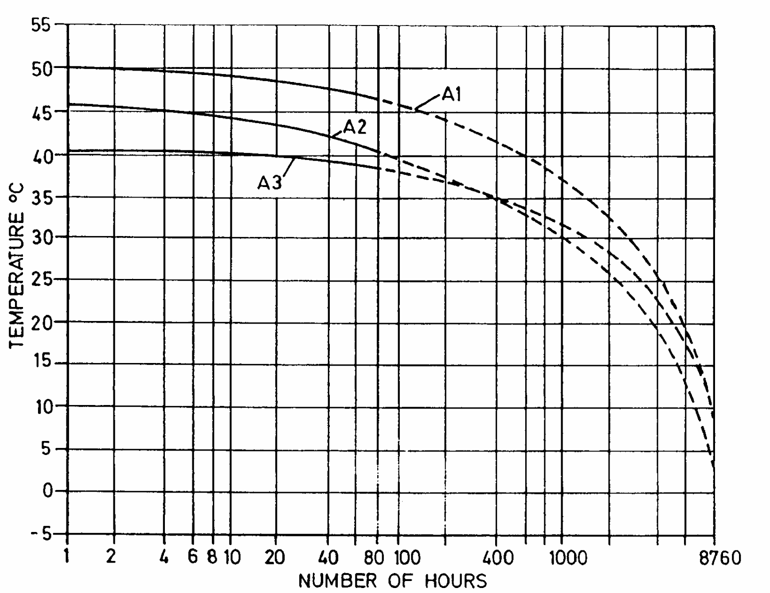


Figure 3

3.5 B1 – Wet Warm

a. Category B1 applies to those areas that experience moderately high temperatures accompanied by continuous very high relative humidity. These conditions are found in rain forests and other tropical regions during periods of continuous cloud cover, where direct solar radiation is not a significant factor. Geographical regions covered include the Zaire and Amazon basins, South East Asia including the East Indies, the north east coast of Madagascar and the Caribbean Islands.

b. The meteorological condition is derived from conditions recorded in Singapore.

c. The general data for the meteorological conditions are given in Figures 4 to 5

d. For materiel, it is recommended that trials be based on both the 7 days of saturation at 24°C and the temperature and humidity diurnal cycles, which are representative of conditions for the remainder of the year.

e. These data are given in Table 9.

Table 9. Diurnal Cycle for the B1 Climatic Category

Local Time	Meteorological Conditions			
hours	Ambient Air Temperature °C	Relative Humidity %	Dew Point °C	Solar Radiation W/m^2
7 days per year 0300 0600 0900 1200 1500 1800 2100 2400	Nearly constant at 24°C throughout the 24 h	Nearly constant at 95 - 100% throughout the 24 h	Nearly constant at 24°C throughout the 24 h	Negligible on days when the accompanying temperatures and humidities occur
358 days per year				Negligible on days when the accompanying temperatures and humidities occur
0300	23	88	21	
0600	23	88	21	
0900	28	76	23	
1200	31	66	24	
1500	32	67	25	
1800	29	75	24	
2100	26	84	23	
2400	24	88	22	

3.6 B2 – Wet Hot

a. Category B2 applies to those areas which experience moderately high temperatures accompanied by high humidity and high direct solar radiation. These conditions occur in exposed areas of the wet tropical regions.

b. The meteorological condition is derived from observations made at the Gulf of Mexico coastal stations and subsequently confirmed by observations in other tropical areas.

c. The general data for the meteorological conditions are given in Figures 4 to 5.

d. In addition, the diurnal cycles of maximum temperature and humidity, recommended as design criteria for materiel exposed to the B2 meteorological conditions are given in Table 10. Although both higher temperatures and higher humidities are known to occur in regions of the B2 category, they rarely do so simultaneously at the same location.

Table 10. Diurnal Cycle for the B2 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m^2
0100	27	100	0
0200	26	100	0
0300	26	100	0
0400	26	100	0
0500	26	100	0
0600	26	100	45
0700	27	94	230
0800	29	88	460
0900	31	82	630
1000	32	70	800
1100	33	77	900
1200	34	75	970
1300	34	74	990
1400	35	74	915
1500	35	74	795
1600	34	76	630
1700	33	79	410
1800	32	82	230
1900	31	86	45
2000	29	91	0
2100	28	95	0
2200	28	96	0
2300	27	100	0
2400	27	100	0

3.7 B3 – Humid Hot Coastal Desert

a. Category B3 applies to those areas which experience moderately high temperatures accompanied by high water vapour content of the air near the ground in addition to high levels of solar radiation. These conditions occur in hot areas near large expanses of water such as the Persian Gulf and the Red Sea.

b. The meteorological condition is derived from observations made at Dhahran and other hot, humid stations.

c. The general data for the meteorological conditions are given in Figures 4 to 5.

d. In addition, the diurnal cycles of maximum temperature and humidity, recommended as design criteria for materiel exposed to the B3 meteorological conditions are given in Table 11. Although both higher temperatures and higher humidities are known to occur in regions of the B3 category, they rarely occur simultaneously at the same location.

e. The meteorological conditions reported here are seasonal in nature and occur only during the summer months. In winter months the conditions are less severe, but for materiel requiring worldwide clearance for operational deployment the worst case meteorological conditions must be assumed.

Table 11. Diurnal Cycle for the B3 Climatic Categories

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m^2
0100	31	88	0
0200	31	88	0
0300	31	88	0
0400	31	88	0
0500	31	88	0
0600	32	85	45
0700	34	80	315
0800	36	76	560
0900	37	73	790
1000	38	69	920
1100	39	65	1040
1200	40	63	1080
1300	41	59	1000
1400	41	59	885
1500	41	59	710
1600	41	59	460
1700	39	65	210
1800	37	69	15
1900	36	73	0
2000	34	79	0
2100	33	85	0
2200	32	85	0
2300	32	88	0
2400	31	88	0

3.8 General Data for Meteorological Conditions

Figure 4 for B1, B2 and B3 shows the number of days of the year on which, on average, a given temperature is just attained or exceeded, for the B1, B2 and B3 meteorological conditions. The associated diurnal temperature cycles and corresponding dew points or relative humidities are obtained from Table 9-11.

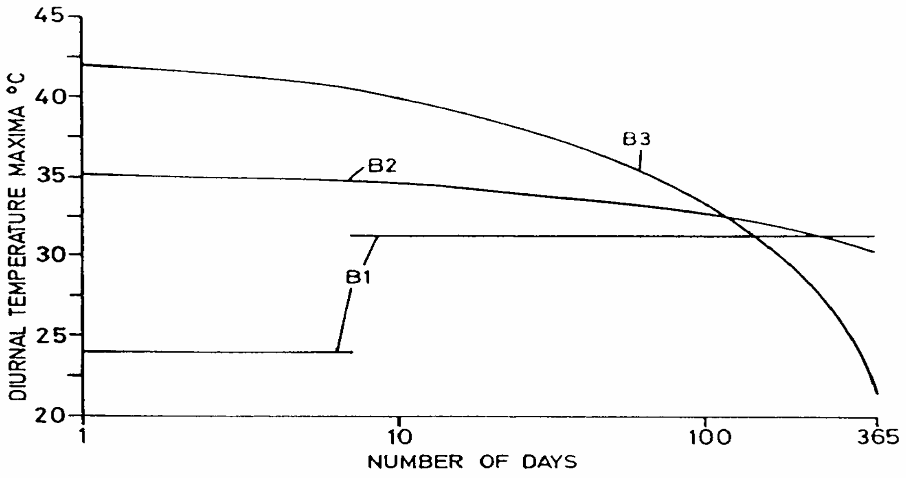


Figure 4

Figure 5 shows the number of hours in each year for which the air temperature just reaches or goes above a given value in the B1, B2 and B3 meteorological conditions. Computed from the information supplied at Figure 4 and Table 9-11.

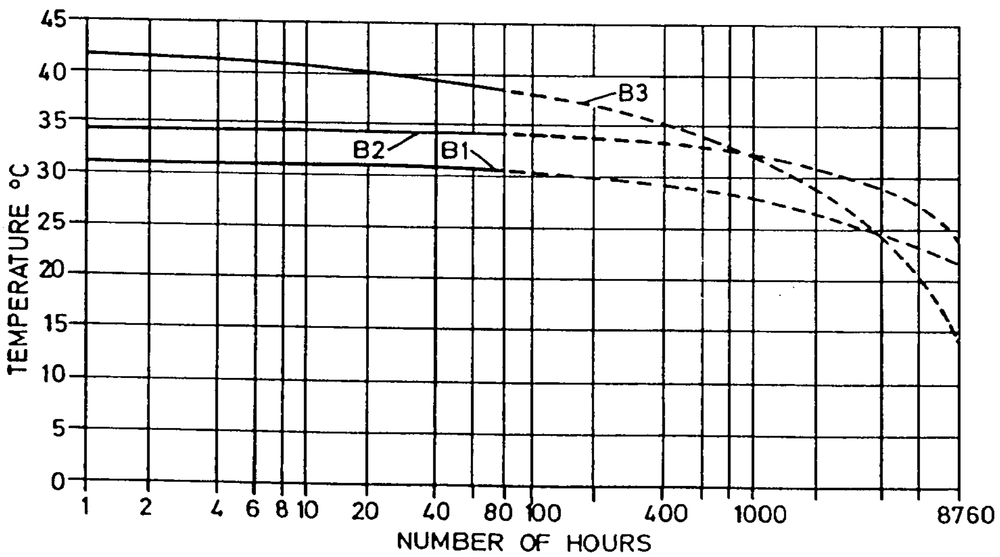


Figure 5

3.9 C0 – Mild Cold

a. In strict terms, Category C0 applies only to those areas which experience mildly low temperatures such as the coastal areas of Western Europe under prevailing maritime influence, south east Australia and the lowlands of New Zealand.

b. However, for the purposes of this Agreement, Category C0 is considered to apply to all land masses except those designated as Category C1, C2, C3 or C4 in Map 3. This applies even to areas such as the Sahara or Persian Gulf.

c. The general data for the meteorological conditions are given in Figures 6 to 8.

d. In addition, the minimum temperature cycle recommended as a design criterion for materiel exposed to the C0 meteorological condition is derived from observations made at the coldest 5-10 percent European locations of this category are given in Table 12. The lowest temperature of this cycle is that air temperature which, on average, is attained or exceeded for all but approximately 7.4 hours (i.e. 1 percent of a month) during the coldest period of the year. The profile of this cycle is typical of those for days when this temperature is just attained.

e. The lowest temperature ever reliably recorded for the C0 meteorological condition is -24°C.

Table 12. Diurnal Cycle for the C0 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m^2
0300	-19	Tending to saturation	Negligible on days when accompanying temperatures occur
0600	-19		
0900	-15		
1200	-8		
1500	-6		
1800	-10		
2100	-17		
2400	-19		

3.10 C1 – Intermediate Cold

a. Category C1 applies to those areas that experience moderately low temperatures such as central Europe, Japan and the central USA.

b. The general data for the meteorological conditions are given in Figures 6 to 8.

c. In addition, the minimum temperature cycle recommended as a design criterion for materiel exposed to the C1 meteorological condition is given in Table 13. The lowest temperature of this cycle is that air temperature which, on average, is attained or exceeded for all but approximately 7.4 hours (ie 1 percent of a month) during the coldest period of the year in North Dakota (USA) and southern Alberta (Canada). The profile of this cycle is typical of those for days when this temperature is just attained.

d. The lowest temperature ever reliably recorded for condition is -42 °C.

Table 13. Diurnal Cycle for the C1 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m^2
0300	-32	Tending to saturation	Negligible on days when accompanying temperatures occur
0600	-32		
0900	-26		
1200	-21		
1500	-21		
1800	-25		
2100	-28		
2400	-32		

3.11 C2 – Cold

a. Category C2 applies to the colder areas, which include northern Norway, the prairie provinces of Canada, Tibet and much of the USSR.

b. The general data for the meteorological conditions are given in Figures 6 to 8.

c. In addition, the minimum temperature cycle recommended as a design criterion for materiel exposed to the C2 meteorological condition is given in Table 14. The lowest temperature of this cycle is that air temperature which, on average, is attained or exceeded for all but approximately 7.4 hours (i.e. 1 percent of a month) during the coldest period of the year at several of the colder locations in Canada. The profile of this cycle is typical of those for days when this temperature is just attained.

d. The lowest temperature ever reliably recorded for the C2 meteorological condition is -56°C.

Table 14. C2 CYCLES

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature ^{o}C	Relative Humidity %	Solar Radiation W/m^2
0300	-46	Tending to saturation	Negligible on days when accompanying temperatures occur
0600	-46		
0900	-43		
1200	-37		
1500	-37		
1800	-39		
2100	-43		
2400	-45		

3.12 C3 – Severe Cold

a. Category C3 applies to the coldest area of the North American continent and the areas surrounding the coldest parts (C4) of Siberia and Greenland.

b. The general data for the meteorological conditions are given in Figures 6 to 8.

c. In addition, the minimum temperature cycle recommended as a design criterion for materiel exposed to the C3 meteorological condition is given in Table 15. It should be noted that, as the coldest days are in reality prolonged nights, the temperature is constant throughout the 24 hours.

Table 15. Diurnal Cycle for the C3 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m^2
0 0300 0600 0900 1200 1500 1800 2100 2400	Nearly constant at -51°C throughout the 24 h	Tending to saturation	Negligible on days when accompanying temperatures occur

3.13 C4 – Extreme Cold

a. Category C4 applies to the coldest areas of Greenland and Siberia.

b. The general data for both the meteorological and storage conditions are given in Figures 6 to 8.

c. In addition, the minimum temperature cycle recommended as a design criterion for materiel exposed to the C4 meteorological condition is given in Table 16. It should be noted that, as the coldest days are in reality prolonged nights, the temperature is constant throughout the 24 hours.

d. The lowest temperature ever reliably recorded for the C4 meteorological condition is -68°C.

Table 16. Diurnal Cycle for the C4 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m^2
0 0300 0600 0900 1200 1500 1800 2100 2400	Nearly constant at -57°C throughout the 24 h	Tending to saturation	Negligible on days when accompanying temperatures occur

3.14 General Data for the Meteorological Conditions

Figures 6 and 7 for C0, C1, C2, C3 and C4 show the number of days in a year on which, on average a given temperature is exceeded, together with the corresponding dew points. The associated diurnal temperature cycles are in Tables 12-16.

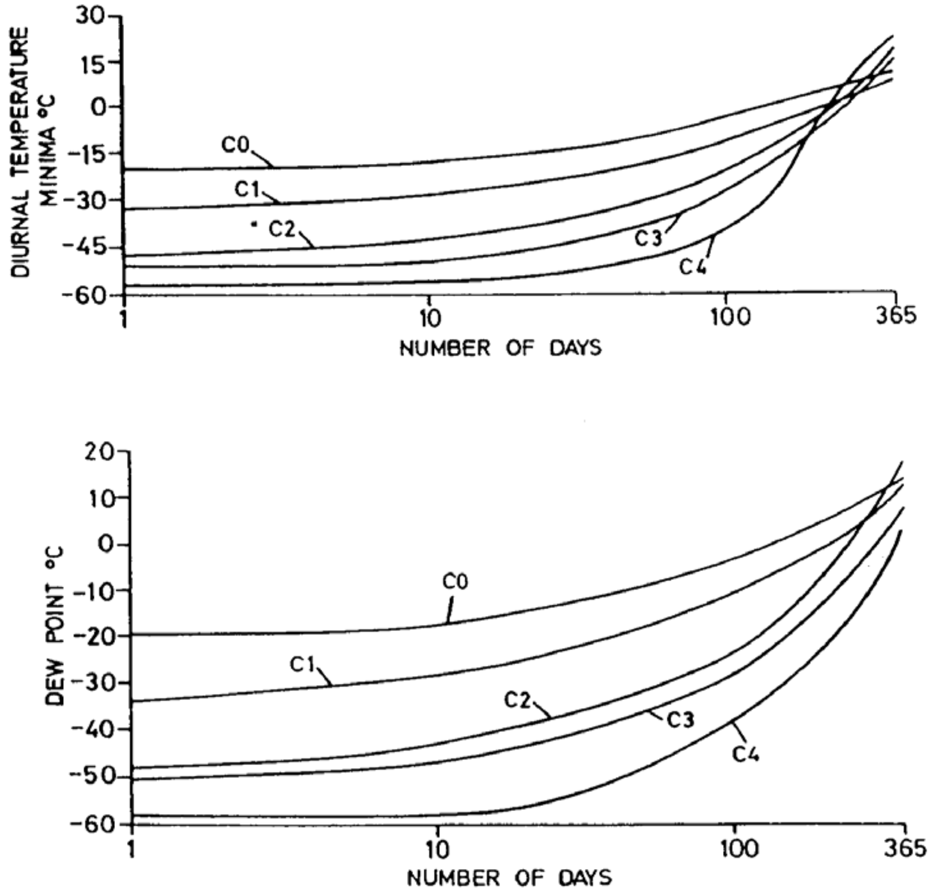


Figure 6 & 7

The number of hours in each year for which the air temperature just reaches or goes below a given value in the C0, C1, C2, C3 and C4 meteorological conditions. Computed from the information supplied at Figure 6 and Table 12-16.

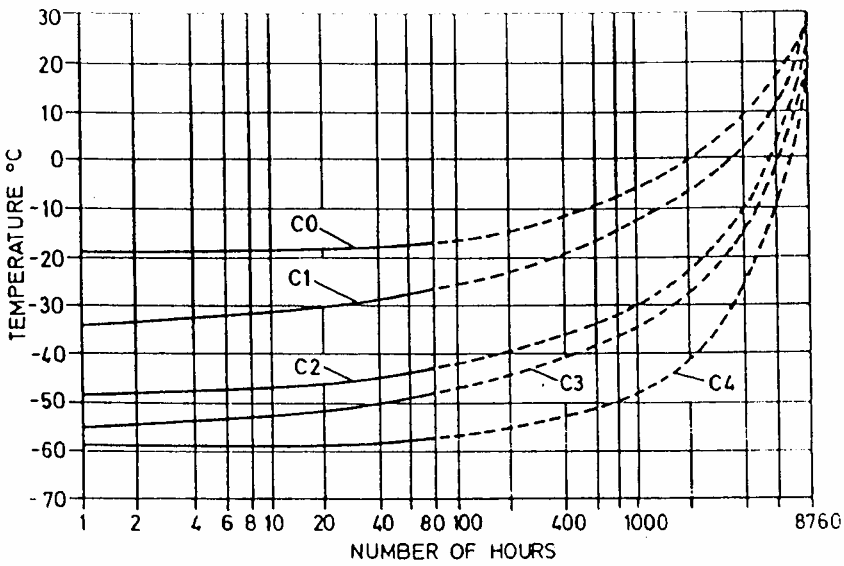


Figure 8

3.15 M1 – Marine Hot

a. Category M1 applies to tropical bulk sea areas where high ambient air temperature is the predominant climatic characteristic.

b. The general data for the meteorological and conditions is given in Figures 9 to 11.

c. In addition, the cycle of maximum temperature and associated humidity, recommended as design criteria for materiel exposed to the Ml meteorological condition is given in Table 17. The highest temperature of this cycle is that air temperature which is attained or exceeded at the hottest locations in the category, on average, for a total time of approximately 7.4 hours (i.e. 1 percent of one month) during the hottest period of the year. The profile of this cycle is typical of those for days when this temperature is just attained.

d. The highest temperature ever reliably recorded for the M1 meteorological condition is 51°C.

Table 17. Diurnal Cycle for the M1 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m^2
0100	32.5	51	0
0200	31.5	53	0
0300	31	55	0
0400	29.5	60	0
0500	29	64	0
0600	29	67	55
0700	31.5	61	270
0800	34.5	51	505
0900	38	38	730
1000	40.5	32	915
1100	43	28	1040
1200	45	25	1120
1300	46.5	22	1120
1400	48	21	1040
1500	48	21	915
1600	47.5	23	730
1700	46.5	27	505
1800	45	33	270
1900	42.5	37	55
2000	40.5	41	0
2100	38	43	0
2200	36.5	45	0
2300	35	47	0
2400	34	49	0

3.16 M2 – Marine Intermediate

a. Category M2 applies to the warmer, mid-latitude regions of the seas, particularly to temperate sea areas where high humidity combined with moderately high temperatures are the principal climatic characteristics.

b. The general data for the meteorological conditions is given in Figures 9 to 11.

c. In addition, the diurnal cycles of maximum temperature and humidity, recommended as design criteria for materiel exposed to the M2 meteorological conditions are given in Table 18. Although both higher temperatures and higher humidities are known to occur in regions of the M2 category, they rarely do so simultaneously at the same location.

Table 18. Diurnal Cycle for the M2 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temp °C	Relative Humidity %	Solar Radiation W/m^2
0100	26.5	100	0
0200	26.5	100	0
0300	26	100	0
0400	26	100	0
0500	25.5	100	0
0600	26	100	45
0700	28	90	170
0800	29.5	82	470
0900	31	74	790
1000	32.5	70	920
1100	33.5	67	1040
1200	34	63	1080
1300	35	58	1040
1400	35	55	930
1500	35	54	710
1600	34	57	470
1700	33	62	190
1800	32	71	15
1900	30	77	0
2000	29	82	0
2100	28	88	0
2200	27.5	90	0
2300	27.5	92	0
2400	27	94	0

3.17 M3 – Marine Cold

a. Category M3 applies to the colder regions of the seas, particularly the Arctic zone where low ambient air temperature is the predominant climatic characteristic.

b. The general data for the meteorological conditions is given in Figures 9 to 11.

c. In addition, the minimum temperature cycle recommended as a design criterion for materiel exposed to the M3 meteorological condition is given in Table 21. The lowest temperature of this cycle is that air temperature which, on average, is attained or exceeded in the colder regions for all but approximately 7.4 hours (i.e. 1 percent of a month) during the coldest period of the year. The profile of this cycle is typical of those for days when this temperature is just attained.

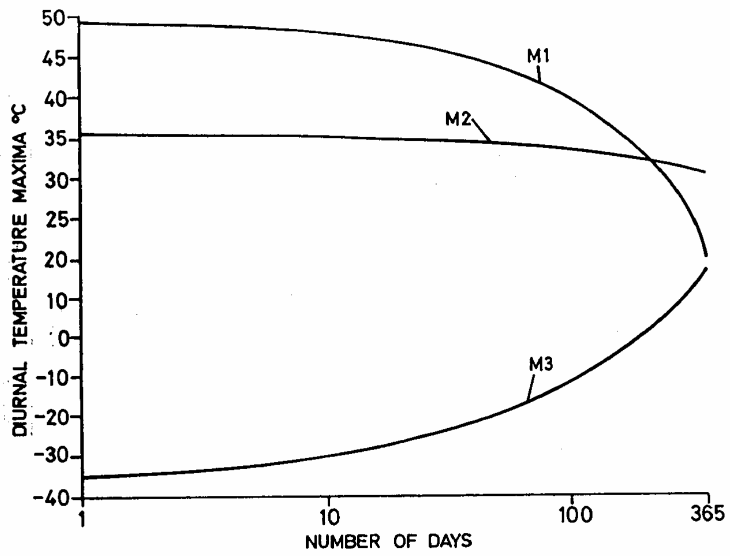
d. The lowest temperature ever reliably recorded for the M3 meteorological condition is -38°C.

Table 19. Diurnal Cycle for the M3 Climatic Category

Local Time	Meteorological Conditions		
hours	Ambient Air Temperature °C	Relative Humidity %	Solar Radiation W/m²
0300	-34	Tending to saturation	Negligible on days when accompanying temperatures occur
0600	-34		
0900	-28		
1200	-23		
1500	-23		
1800	-26		
2100	-31		
2400	-34		

3.18 General Data for the Meteorological Condition

Figures 9 and 10 show the number of days of the year on which, on average, a given temperature is just attained or exceeded or in the case of Category M3 a given minimum temperature is not exceeded, together with the corresponding dew points, for the M1, M2 and M3 meteorological conditions. The associated diurnal temperature cycles are obtained from Table 17-19.



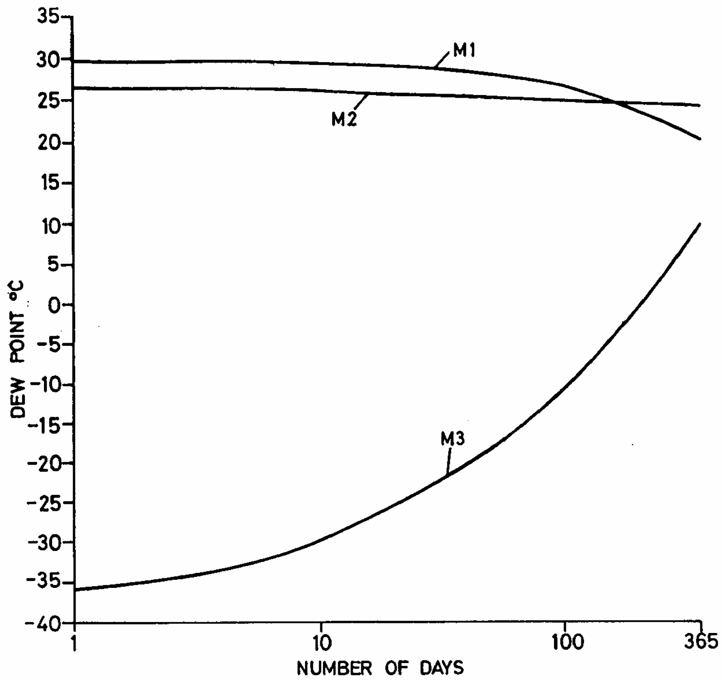


Figure 9 & 10

The number of hours in each year for which the air temperature just reaches or goes above a given value, or in the case of Category M3 a minimum temperature is not exceeded, in the M1, M2 and M3 meteorological conditions. Computed from the information supplied at Figure 9 and Table 17-19.

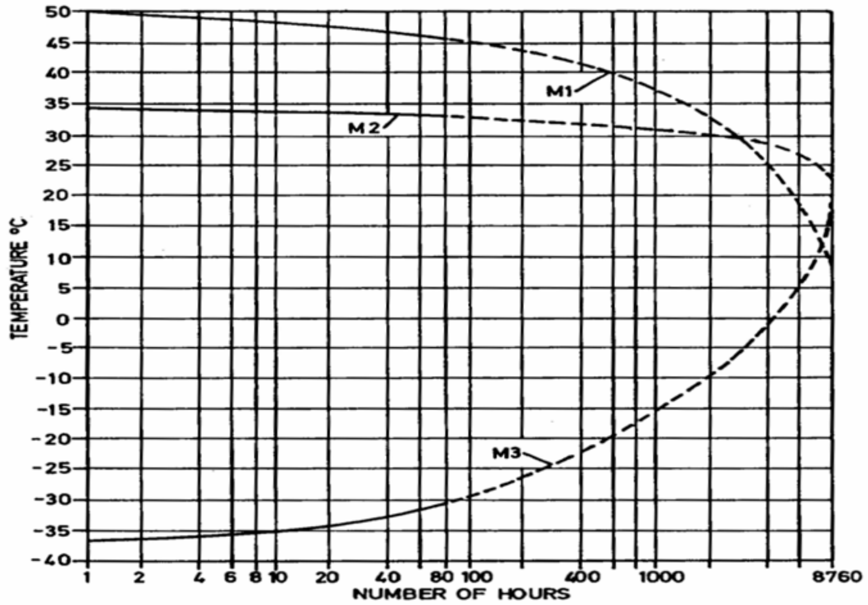

50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
TEMPERATURE °C
M1
M2
M3
1
2
4
6
8
10
20
40
80
100
400
1000
8760
NUMBER OF HOURS

Figure 11

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ADDITIONAL CLIMATIC ENVIRONMENTAL FACTORS

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1 SCOPE

1.1 Purpose

This Annex briefly discusses these additional factors and, where possible, recommends intensity levels which should be used in appropriate circumstances, as design and test criteria for materiel intended for use by NATO Forces. In addition, the highest and/or lowest intensity levels ever reliably recorded under natural conditions are quoted.

1.2 Application

Although temperature, humidity and solar radiation are primary considerations when preparing statements on the climatic environment of materiel, the additional factors covered by this document should also be taken into account.

1.3 Limitations

Some of the additional climatic environmental extremes may not be applicable depending upon the user requirements and/or the predicted manufacture to target or disposal sequence (life cycle).

2 ADDITIONAL CLIMATIC ENVIRONMENTAL FACTORS

2.1 Atmospheric Pressure

a. Materiel should remain safe and be capable of acceptable performance at all values of atmospheric pressure from the highest to the lowest recorded for each environment to which the materiel will be exposed.

b. The highest value of atmospheric pressure recorded at sea level is 1084 mbar. The lowest value recorded at the sea surface is 870 mbar, and the lowest value for the highest ground elevation contemplated for the operation, storage and transportation of materiel of NATO forces is 503 mbar.

c. The highest and lowest values of atmospheric pressure estimated for a range of altitudes up to 30 km (98.4 kft) are given in Table 1.

d. The frequency of occurrence (99% and 1%) values of atmospheric pressure up to 80km are reported in Table 1 below are taken from Mil Hdbk-310.

Table 1. Atmospheric Pressures at Altitude [1 mbar = 0.1kPa = 1hPa = 100Pa]

Altitude	Altitude	Highest Recorded Atmospheric Pressure	99% Atmospheric Pressure	1% Atmospheric Pressure	Lowest Recorded Atmospheric Pressure
km	kft	mbar	mbar	mbar	mbar
0	0	1084	-	-	870
1	3.28	930	920	847	842
2	6.56	821	817	742	736
4	13.1	643	642	550	548
6	19.7	501	499	408	406
8	26.2	385	384	299	296
10	32.8	294	293	218	215
12	39.4	226	226	157	154
14	45.9	168	167	111	111
16	52.5	123	123	79	79
18	59.1	88	88	56	56
20	65.6	65	65	41	40
22	72.2	45	45	29	28
24	78.7	35	34	21	20
26	85.3	26	25	15	14
28	91.9	20	19	11	10
30	98.4	15	15	9	7
35	114.8	-	7.6	3.1	-
40	131.2	-	4.1	1.5	-
45	147.6	-	2.2	0.67	-
50	164.0	-	1.2	0.31	-
55	180.4	-	0.71	0.15	-
60	196.9	-	0.39	0.074	-
65	213.3	-	0.19	0.035	-
70	229.7	-	0.086	0.017	-
75	246.1	-	0.037	0.0080	-
80	262.5	-	0.015	0.0035	-

Note: The reported pressures at the various altitudes do not necessarily occur simultaneously nor necessarily at the same location and the set of values given in Table 1 does not represent a specific pressure altitude profile.

2.2 Ozone Concentrations

If the requirements documents require exposure to ozone to be taken into consideration when designing particular items of materiel, the 1% concentrations given in Table 12 should be taken as representing the meteorological conditions at altitudes from 0 (sea level) to 30 km (98.4 kft).

Table 2. Ozone Concentration at Altitude for the Meteorological Condition

Altitude km	Altitude kft	Ozone concentration for Meteorological Condition $\mu g/m^3$
0	0	220
1	3.28	205
2	6.56	190
4	13.1	170
6	19.7	170
8	26.2	460
10	32.8	735
12	39.4	865
14	45.9	975
16	52.5	1100
18	59.1	1075
20	65.6	845
22	72.2	730
24	78.7	650
26	85.3	505
28	91.9	430
30	98.4	330

Note: The greatest concentration of ozone ever recorded in the open at sea level due to natural conditions is 980 $\mu g/m^3$.

2.3 Wind

Wind is subject to fluctuations on a variety of scales, with periods ranging from a fraction of a second to several minutes. Fluctuations about the mean speed comprise the gustiness of the wind. Large variations can occur between places a short distance apart, and it is not possible to indicate all the special problems which arise. This chapter attempts to provide data relating to mean winds and gustiness.

2.3.1 Mean Wind Speed

a. Variation of wind speed with height

In the lowest levels of the atmosphere friction with the earth's surface is the dominant feature so that, in general, the mean windspeed increases with increasing height above ground up to about 600 meters, above which the variation becomes primarily dependent on factors other than friction. Since the measured wind depends on height above ground all values given have been reduced to their equivalents at the World Meteorological Organization (WMO) standard height of 10 m.

b. Frequency of very strong winds

Figures 1 and 2 show the percentage frequency in the average year when the mean wind speed (measured over an interval of 5 to 10 minutes), equals or exceeds 14 ms^{-1} and 25ms^{-1} respectively. The charts are to some extent subjective and they refer to the standard height of 10 meters over the sea or fairly open and low-lying ground; they should not therefore be used to infer probabilities in mountainous areas or when special problems of aspect or exposure arise.

2.3.2 Gustiness

Gustiness results mainly from roughness of the earth's surface and is accentuated when the air flows over trees, buildings and other obstacles. However, it is also a feature of the eddies developed by convective currents and such currents form most readily when temperature near the surface falls off rapidly with height, i.e., usually during the hottest part of the day. Gustiness over land is, therefore, usually more pronounced by day than by night, whilst over the sea where frictional effects and the diurnal temperature range are both small, gustiness is relatively slight at any time of day and is usually associated with convection, which develops when cold air flows over warmer sea.

a. Period of measurement

The gust recorded by an instrument depends on the sensitivity of that instrument. For this reason it may be assumed that a speed averaged over about 3 seconds has been used for the data concerning extreme gust speeds, etc., quoted below.

b. Extreme gust speeds

Figure 3 is a world map showing the maximum gust likely to be experienced once in 10 years, based on analyses as outlined in Reference 3 and various building design codes of practice. The estimates are for the standard height of 10 meters over the sea or fairly level country and they are not applicable to mountainous regions or to places that have local peculiarities of exposure or topography. Exceptionally high gusts, which may occur in tropical storms, are also excluded.

c. Gust ratios

The ratio of the maximum speed of a gust to the mean wind speed is known as the "gust ratio" and provides a measure of gustiness of the wind.

For level sites in open country Table 3 gives the ratio of the probable, maximum gust averaged over time (t) to the mean hourly wind speed. These factors are probably too high for open coastal exposures but will be too low for city and urban situations and may be rather low for open but not level, rural exposures. The ratios given in Table 2 have therefore been proposed for estimating maximum speeds over 1 minute, 30 seconds and 10 seconds respectively, using a known mean hourly wind speed.

Since the gust ratio is largely determined by roughness of the terrain, an indication of this roughness can be obtained from the ratio of the maximum gust measured over 3 seconds to the mean hourly wind speed, both determined from many years of data. Knowing this ratio it is possible to calculate the maximum speed for any time intervals up to 1 hour, using the factors shown in Table 5. Owing to the dependence of gust ratios on terrain there may be some slight differences between Tables 3 and 4.

Table 3

Probable maximum gust for level sites in open country. Ratio of probable maximum mean speed averaged over time (t) to the mean hourly speed.										
time (t)	1 hour	10 min	1 min	30 sec	20 sec	10 sec	5 sec	2 sec	1 sec	0.5 sec
gust ratio	1.00	1.06	1.24	1.32	1.36	1.43	1.48	1.54	1.57	1.60

Table 4

Suggested ratios for estimating maximum mean speeds over short periods from a known mean hourly speed.			
	1 minute	30 seconds	10seconds
Open rural exposures	1.25	1.33	1.45
Urban and city exposures	1.45	1.60	1.80

Table 5

Factors for calculating maximum windspeed for various intervals using the mean speed measured over the hour.						
RATIO	CONVERSION FACTORS					
maximum mean speed/ mean hourly speed	10 min	1 min	30 sec	15 sec	10 sec	3 sec
1.4	1.05	1.17	1.22	1.27	1.30	1.40
1.5	1.05	1.20	1.26	1.33	1.37	1.50
1.6	1.06	1.23	1.30	1.38	1.43	1.60
1.7	1.06	1.25	1.34	1.44	1.50	1.70
1.8	1.06	1.27	1.37	1.48	1.55	1.80
1.9	1.06	1.28	1.39	1.52	1.60	1.90
2.0	1.06	1.29	1.42	1.56	1.66	2.00
2.1	1.06	1.30	1.44	1.60	1.71	2.10

2.3.3 Extreme Winds

The general term “cyclone” describes an area where atmospheric pressure is lower than in surrounding areas and the general flow of air is anti-clockwise north of the equator but clockwise in the southern hemisphere. Low-pressure systems that cause strong wind conditions may be classified but the definitions are not always exclusive and names vary from region to region.

a. Depressions or Lows

These terms are applied to cyclones of middle and high latitudes or weak tropical cyclones. These features range in size from a few hundred to around 2000 km diameter and usually move west to east. Widespread and sustained strong winds are possible especially over the North Atlantic, the southern oceans south of about 40 °S, and exposed coastal regions. In these regions winds may exceed 14 m/s (27 kt) for 10 - 25% of the year, however steady winds are usually less than 31 m/s (60 kt) although gusts may exceed 51 m/s (100 kt) about once in 10 years.

b. Tropical storms or tropical cyclones

Cyclones generated over warm tropical oceans, commonly 500 – 1000 km diameter, usually move east to west but tend to curve away from the equator. Wind speeds are normally 17 – 32 m/s (34 – 63 kt) i.e., more than gale force but less than hurricane force.

c. Hurricanes

By definition, a tropical storm becomes a hurricane (or typhoon, cyclone, etc.) if wind speeds are 33 m/s (64 kt) or more; the upper limit is unknown but speeds around 103 m/s (200 kt) have been reliably reported. Hurricanes often travel at 15 - 30 km/h (8 - 16 kt) but can exceed 50 km/h (27 kt) especially in higher latitudes, and may last from 2 days to 2 weeks. An indication of the areas affected and the probabilities is included at Figure 4.

d. Whirlwinds

(1) These narrow revolving windstorms occur commonly over most of the world. Many are small, innocuous, transient features but some are devastatingly destructive owing to the combined effects of wind strength, twisting and suction. The extreme phenomena, usually called tornadoes, are often associated with thunderstorms and may occur as a group or family of storm cells. The area most frequently affected by tornadoes is the USA where 700 - 1200 are reported each year. As in other parts of the world the most common type of tornado lasts only a minute or two and causes little damage. The path of destructive tornadoes is often 100 - 700 m wide and the track length less than 25 km and the duration perhaps 30 minutes. The most devastating tornadoes (perhaps 2% of total) may be 1.5 - 2 km wide along a track up to 450 km long and lasting 2 - 4 hours. The upper limit of wind speeds is unknown but recent estimates suggest a figure around 125 m/s (250 kt).

(2) The chance of a single location of 2.59 km^2 (l $mile^2$) being affected by a tornado in any year is less than 1 in 1000, even in the *most* vulnerable parts of the USA, and the chance of a location in NW Europe being affected is estimated at less than 1 in 10,000, a return period of 1 in at least 20,000 years.

(3) Whirlwinds that occur on a small scale in many parts of the World may also be vigorous enough to raise dust or even water to be visible as a dust devil or a water-spout.

e. Non-rotating phenomena

Violent winds may also occur over Polar regions where the katabatic outflow from ice plateaux, enhanced by the topography can reach speeds around 75 m/s (150 kt). Elsewhere in the world, squalls associated with a downburst of air from a thunderstorm may locally generate winds of 50 m/s (100 kt) at the surface.

f. Scale of wind systems

Figure 5 is a schematic diagram illustrating the relative scale and strength of meteorological wind systems.

g. Design Criteria

Unless overriding considerations dictate to the contrary, requirements documents should require materiel to remain safe when exposed to the conditions described in Figure 3. The materiel should be capable of acceptable performance when exposed to winds and gusts having speeds up to the maximum respective values given in Table 6.

Table 6. Wind and Gust Speeds at Heights of 3 m above Ground Recommended as Design Criteria

1 minute steady speed (m/s)	Gust speed(m/s) for shortest horizontal dimension of materiel					
	0.7m	1.5m	3m	8m	15m	30m
22	34	31	30	28	27	26

Table 6 is based on the 99% steady 1 minute 3 meter wind speed at Stornoway in December (22m/s) with the associated gust speeds.

2.4 Precipitation

a. Precipitation is defined as all forms of hydrometeors, both liquid and solid, which are free in the atmosphere and which reach the Earth's surface. It embraces rain, snow and hail, each of which is discussed under the appropriate heading.

b. Precipitation intensity is defined in this Agreement as the rate at which precipitation falls. Although the values in Table 6 may be considered as instantaneous rates, in practice they are averages taken over periods of one minute or longer.

c. Unlike air temperatures which, at any particular time, are often substantially the same (±5°C) over relatively large regions, a value of precipitation intensity is peculiar to the highly localized area where the measurement is made and, at a relatively short distance away, the intensity may differ by a factor of two or more. Thus, it is impracticable in this Agreement to relate precipitation intensity to specific areas of the world with adequate detail so, apart from a European rain condition, only data on a worldwide basis are given.

d. At altitudes below the freezing level, 4.5 km (14.8 kft) in the tropics, precipitation may occur as liquid or solid particles but above this level snow or hail will predominate.

e. For the general meteorological condition on a worldwide basis, materiel should remain safe and be capable of acceptable performance when exposed to precipitation whose intensity is attained or exceeded for only a specified small portion of the wettest month of the year. Normally, this small portion is taken to be 0.5 percent but in some circumstances where a higher intensity may need to be specified, the value for 0.1 percent is recommended.

f. The precipitation intensities on a worldwide basis associated with these proportions of time are given in Table 6 for a range of altitudes up to 20 km. However, for materiel destined only for Europe, the intensities at 0 altitude (sea level) may be relaxed to the values given for the European rain condition in Table 8.

Table 7. Precipitation Intensities – World Wide

Altitude km	Altitude kft	Intensity exceeded for 0.5% of wettest month mm/min	Intensity exceeded for 0.1% of wettest month mm/min	Estimated greatest ever precipitation mm/min
0	0	0.80	3.13	31
1	3.28	0.87	3.40	34
2	6.56	0.93	3.60	36
4	13.1	1.00	4.10	41
6	19.7	1.10	4.20	42
8	26.2	0.77	3.00	30
10	32.8	0.51	2.00	20
12	39.4	0.35	1.40	14
14	45.9	0.22	0.84	9
16	52.5	0.11	0.40	4
18	59.1	0.02	0.09	1
20	65.6	0	0	0

2.4.1 Rainfall

a. For rainfall, two geographical categories are considered, ‘World-wide’ and ‘Europe’. The worldwide data are based on observations in South East Asia that is recognized as the wettest region of the world.

b. Thus, in the region selected, materiel should remain safe and be capable of acceptable performance in rainfall whose intensity is attained or exceeded for only a specified small portion of the wettest month of the year.

c. For the general meteorological condition, this small portion should be 0.5 percent. However, in some circumstances where a higher intensity is considered necessary, the value which is exceeded for 0.1 percent of the time is recommended. The intensities associated with these time values are given in Table 7.

d. The intensities shown in Table 7 will seldom persist for more than a few consecutive minutes. During a rainstorm the rain intensity varies widely in an unpredictable manner and, at least on some occasions, the highest intensities experienced during the wet seasons will exceed those for the 0.1 percent level by factors of two or more. The highest values ever recorded on a worldwide basis for three durations are quoted in Table 8.

Table 8. Worldwide Rainfall Intensities (Sea Level)

Region	Intensities exceeded for 0.5% of wettest month	Intensity exceeded for 0.1% of wettest month
World wide	0.80 mm/min	3.13 mm/min
European	0.58 mm/min	0.80 mm/min

Table 9. Greatest Rainfall Intensities at Sea Level

Period	Average rate of rainfall mm/min
1 min	31.0
42 min	7.3
12 h	1.9
24 h	1.31

e. Flooding is a possible consequence of heavy rainfall and may lead to materiel being immersed in water (see Immersion 2.4.3).

2.4.2 Drip Hazard

a. When moist air comes into contact with materiel having a surface temperature below the dew point of the ambient air, condensation occurs. If, as a result sufficient water accumulates on the surface of the materiel, it will tend to form globules, which, on reaching a sufficient size, will run down gradients or drip from overhanging surfaces. Condensation will be most pronounced where the surface materials are good thermal conductors, such as metals or glass. In cold climates, a further hazard could arise from expansion of drips upon freezing.

b. In addition, unsealed items having an internal atmosphere may draw in air when subjected to cooling. Where the moisture content of the air is sufficient, condensation will occur within the item and the resulting water may not be completely expelled on a subsequent rise in temperature. Repeated cycles of this environment could cause progressive increase of liquid water inside the item. Again, freezing constitutes a further hazard in these circumstances.

2.4.3 Immersion

Immersion is defined as the total or partial covering by water for a limited or specified period. The effects of immersion upon items of materiel are principally determined by depth and duration of immersion, both of which are affected by factors other than the climate. It is agreed, therefore, that unless operational requirements specifically state to the contrary, depths for test purposes can be taken as lying between 150 mm and 4 m, with a standard time of immersion of two hours. It should be noted that when a relatively warm item of materiel is partially or totally immersed in cooler water, a reduction in air pressure within the item might result, which in turn, could cause or aggravate the ingress of moisture.

2.4.4 Hail

In those regions of the world where hail is most intense, there are, on average, two hailstorms during the most severe month for hail in each year. The average duration of each storm is about ten minutes. In view of the briefness of these periods, hail is not an essential consideration in the design of most materiel for use by NATO forces. Possible exceptions are where hail could endanger life or essential equipment. Although hailstones up to 140 mm diameter have been reported, very few exceed 25 mm diameter. The estimated 0.001% and 0.01% hailstone diameters at the most severe location during the most severe month are 50mm and 20mm respectively.

2.4.5 Ice Accumulation

The accumulation of ice on items of materiel should be taken into consideration in its design if the requirements documents indicate that it could enter the regions of the M3 and C categories. The principal sources of this ice are frosting, freezing rain, refreezing of thawing snow, and freezing of condensation. The thickness of the ice will depend upon the period of exposure, the contours of the item of materiel and the heat dissipation of the materiel if operating.

2.4.6 Snowload and Snow Crystal Sizes

a. The effects of the structural load imposed by the accumulation of snow should be taken into account for materiel such as buildings, shelters, vehicles and other relatively large items that are exposed to snow in the regions of the M3 and C categories.

b. For the purposes of the Agreement, “Snowload” is defined as the weight per unit area of snow accumulation on the ground and items of materiel are considered to experience the same snowload as the adjacent ground though, in practice, it is usually somewhat less.

c. The frequency of snow clearance is a principal factor determining the snowload on materiel. It is therefore appropriate that the specific levels of snowload defined in this document are derived from those observed on three classes of materiel, semi-permanently installed, temporarily installed and portable, each having a distinctly different frequency of snow clearance during deployment in service:

(1) Semi-Permanently Installed Materiel

This group applies principally to semi-permanent installations, which, although demountable, are not very mobile. In general, snow would not be removed between snowfalls and therefore the loading is due to the whole season's accumulation.

(2) Temporarily Installed Materiel

This group applies to large items such as portable hangars upon which snow collects. The snow is cleared between storms and the snow loading is therefore the amount resulting from any single snowstorm.

(3) Portable Materiel

This applies to items such as tents, which may be moved daily. Distortion arising from snowloading will make daily clearing essential and consequently, accumulations of snow will not exceed those resulting from a 24-hour snowfall.

d. The snowloads, associated with each of these groups of materiel are given in Table 9 and are those that, on average, are equaled or exceeded once in any ten consecutive years. The highest values of snowload are also quoted.

e. Snowloads on materiel at sea are generally not sufficient to present a hazard. However, if snowloads are to be taken into consideration in this environment for a particular item of materiel, then the value given in Table 10 for portable materiel should be used as it assumes snow will be removed regularly.

f. Snowloading is not applicable to the in-flight environment.

g The sizes of freshly falling snow crystals, accompanied by no more than light winds, range from 0.05 to 20 mm diameter with a median range 0.1 to 1.0 mm when ambient air temperatures are lower than -33 °C and a median range tending to 2.0 to 5.0 mm at higher air temperatures, the largest sizes occurring when the air temperature is just below freezing point.

h. When snow crystals are blown by winds in the region of 18 ms^{-1} or more, they become broken and abraded into grains having rounded or sub-angular corners. The diameters of these grains range from 0.02 to 0.2 mm.

Table 10. Specified Limit and Highest Recorded Snowloads

Type of materiel	Period of snow accumulation	Specified limit of snowload kg/m^2	Highest recorded snowload kg/m^2
Semi-permanently installed	Whole season	240	586
Temporarily installed	Single snow-storm	100	191
Portable	24 h	50	113

2.5 Blowing Sand and Dust

'Sand' and 'dust' are terms for solid non-cohesive particulate matter, usually of mineral origin, found on the surface of the earth or suspended in the atmosphere. The range of particle diameters of sand and dust together extends from about 0.1 to 200 μm, the latter value being the lower limit for very fine pebbles. Although sand and dust are normally differentiated on the basis of particle diameters, no universally accepted demarcation value exists.

a. In this Agreement, a classification based on their different aerodynamic behaviour is adopted. Particles of less then 75 μm diameter can remain suspended in the atmosphere by natural turbulence of the air for very long periods, even years. These are termed 'dust' by most authorities. Conversely, those greater than 150 μm diameter are unable to remain airborne unless continually subjected to strong natural winds, powerful airflows or the turbulence that may be caused, for example, by aircraft, helicopter or convoys of land vehicles. These particles are termed 'sand'. Over the intermediate range of diameters from 75 to 150 μm, there is a gradual transition in settling times and the particles are variously referred to as 'dust' or 'sand' in different documents.

b. For the purposes of laboratory simulation, the recommended demarcation value for distinguishing sand from dust is 149 μm.

2.5.1 Distribution and Hardness of Sand

a. Sand is distributed widely over the Earth's surface. There are vast sandy regions in the Sahara and in Saudi Arabia as well as significant areas in most of the world's deserts. All the continents have sandy beaches of various widths and there are large deposits at or near the surface in many inland areas formerly covered by water. On account of this widespread occurrence of sand, it should be assumed that most forms of materiel for use by NATO forces would be exposed to sandy conditions during their service life.

b. Hardness and angularity are usually the most important characteristics of sand grains. On a worldwide basis, the majority of sands are composed of quartz (SiO_2), which, in its most common form, has a hardness of 7 on the Mohs scale. Other minerals which may be found in sand range from hardness 2 for white gypsum to hardness 9 for those containing corundum.

c. Although in time, grains of sand become rounded by mutual abrasion, those having angular shape are found in substantial proportion in most samples of sand. The latter arise from the tendency of some rock—forming minerals, particularly quartz, to fracture along cleavage planes through impact action.

d. In general, the movement of sand by wind pressure is confined to the air layer within the first meter above the ground. Even within this layer, about half the sand grains (by weight) move within the first 10 mm above the surface and most of the remainder are within the first 100 mm. As a consequence of the low elevation at which the majority of sand grains move, most abrasion damage caused by sand outside high wind periods is at or near ground level.

2.5.2 Distribution and Concentration of Dust

a. In contrast to sand, dust particles, on account of their low terminal velocity, can remain suspended in air indefinitely and may settle on surfaces anywhere.

b. In dry conditions, soils with more than 9 percent by weight of dust particles become at least moderately dusty and those with 14 percent or more are potentially very dusty. Thus, as over 40 percent of the land surface of the world, excluding Antarctica, is classified as moisture deficient and a further 40 percent is seasonally dry, dust must be expected to be present over most of the land surface of the world for substantial parts of the year. Even in regions and seasons of heavy rainfall, dust continues to create problems where the protective cover has been broken. Many moist areas are so well drained that most unprotected soil becomes dust in a remarkably short time after heavy rain.

c. There is evidence that dust problems are aggravated by higher atmospheric temperatures, by relative humidity below 30 percent, and by the drying action of winds, though to what extent is not known quantitatively.

d. Probably the most effective dust production agent is man himself, especially when he is equipped with machinery to increase his speed and mobility. Tanks, trucks, bulldozers, artillery, aircraft and marching troops are effective in the destruction of protective cover and the consequent generation of small particles to such an extent that dust problems must be expected nearly everywhere these activities take place. Possible exceptions are those locations that are under permanent snow, ice or water cover, and where precipitation is so frequent that the surface never dries out.

e. Dust concentrations from three distinctly different scenarios are given in Table 11. Materiel should remain safe and be capable of acceptable performance when exposed to dust concentrations given for those scenarios most representative of its locations and modes of deployment.

Table 11. Concentration of Dust in Atmosphere

Dust concentration	Scenario
180 mg/m^3	Typical of dust picked up and transported by gale force winds (typically 18 ms at 3m) in locations remote from normal military activities.
1.0 g/m^3	Occurs where there is a military presence. Though considerably greater than for natural dust storms, it is a realistic level for military activities on a worldwide basis.
2.0 g/m^3	Representative of the most arduous conditions associated with aircraft (particularly helicopter) operations. In addition to dust, the rotor down-wash of helicopters is strong enough to raise sand grains to considerable heights.

2.6 Temperature of Surface Sea Water

a. Items of materiel which might be floated on or immersed in sea water should remain safe and be capable of acceptable performance compatible with its operational role when immersed in water at any temperature from 36° to -2°C. Seawater of average salinity freezes at -2°C.

b. The upper value is the surface sea water temperature which is exceeded for only 7.4 hours of the month of the year in which sea temperatures are at their highest. Similarly, the lower value is the surface sea water temperature which is exceeded for all but 7.4 hours of the month of the year in which sea temperatures are at their lowest.

c. The highest and lowest surface seawater temperatures ever reliably recorded are 38 °C and -6 °C respectively.

3. DATA SOURCES

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(3) "Wind Speeds over Short Periods of Time". C.S. Dust, London Meteorological Magazine, Vol 89, p.181, 1960.

(4) "Extreme Wind Speeds over the United Kingdom for Period Ending 1963." H.C. Shellard, London Meteorological Office Climatological Memorandum No 50, 1968.

(5) "Extreme Wind Speeds over the United Kingdom for Period Ending 1971." Carol E. Hardman, N.C. Helliwell and J.S. Hopkins, London Meteorological Office Climatological Memorandum No 50A, 1973.

(6) "Martiners World-Wide Climatic Guide to Tropical Storms as Sea", H.L. Crutcher & R.G. Quayle, Washington, NOAA, Naval Weather Service, NAVAIR 50-7C-61, 1974.

ANNEX A

The charts shown in Figures 1 and 2 give the percentage frequency in the average year when the mean wind speed, (measured over an interval of 5 to 10 minutes) equals or exceeds 14m/s and 25m/s. The charts refer to the standard height of 10 meters over fairly open and low lying ground and therefore should not be used to infer probabilities in mountainous areas nor when special problems of aspect or exposure arise.

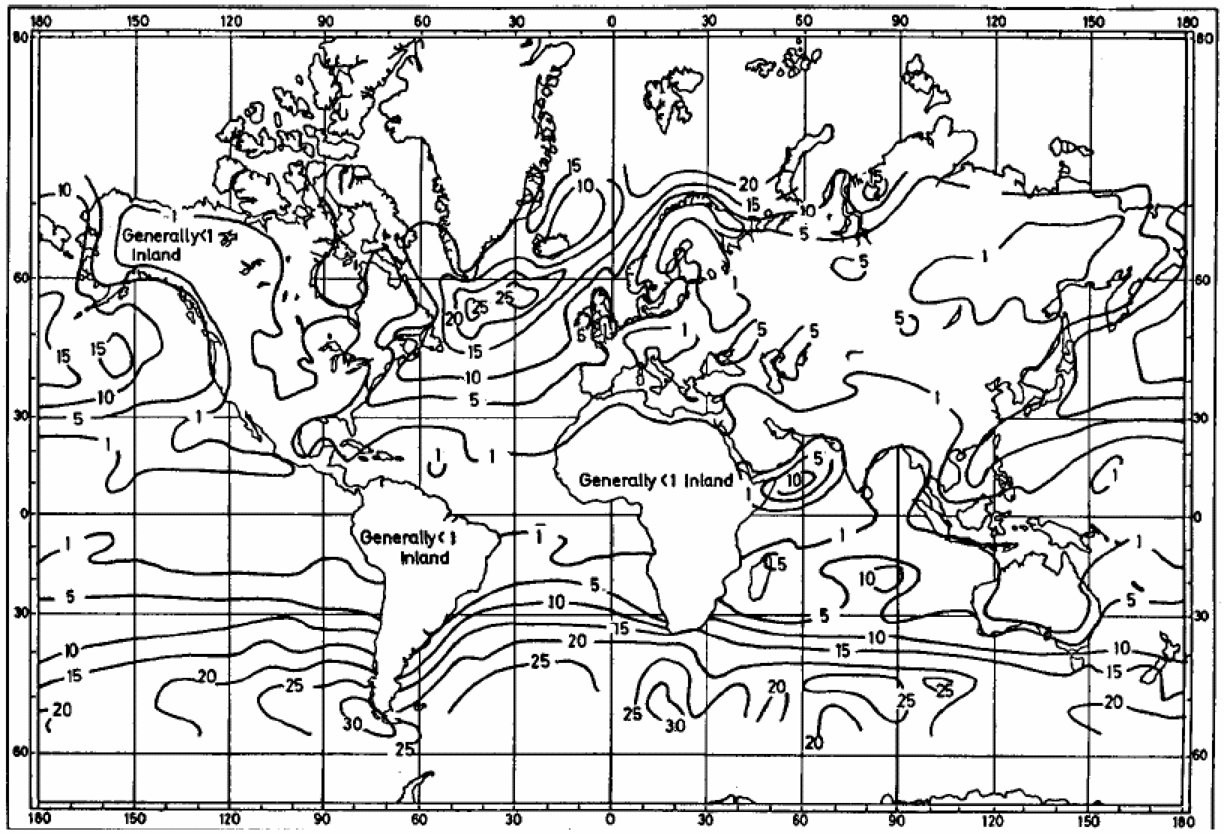

Figure 1 : Percentage Frequency of Winds ≥ 14m/s

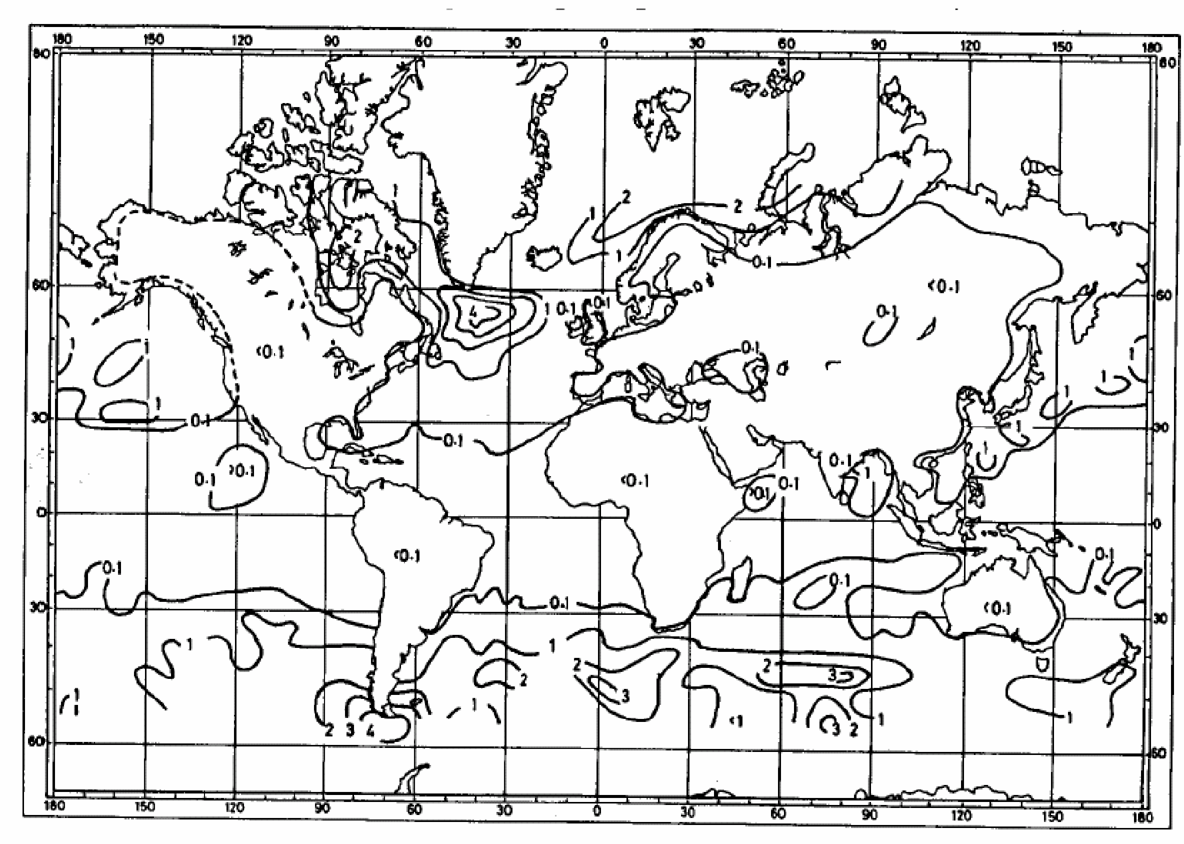

Figure 2 : Percentage Frequency of Winds ≥ 25m/s

The chart in Figure 3 shows the maximum gust likely to be experienced once in 10 years, based on the analyses as outlined in reference 3 and various building design codes of practice. The estimates are for the standard height of 10 meters over fairly level country and they are not applicable to mountainous regions nor to places that have local peculiarities of exposure or topography. Exceptionally high gusts, which may occur in tropical storms, are also excluded.

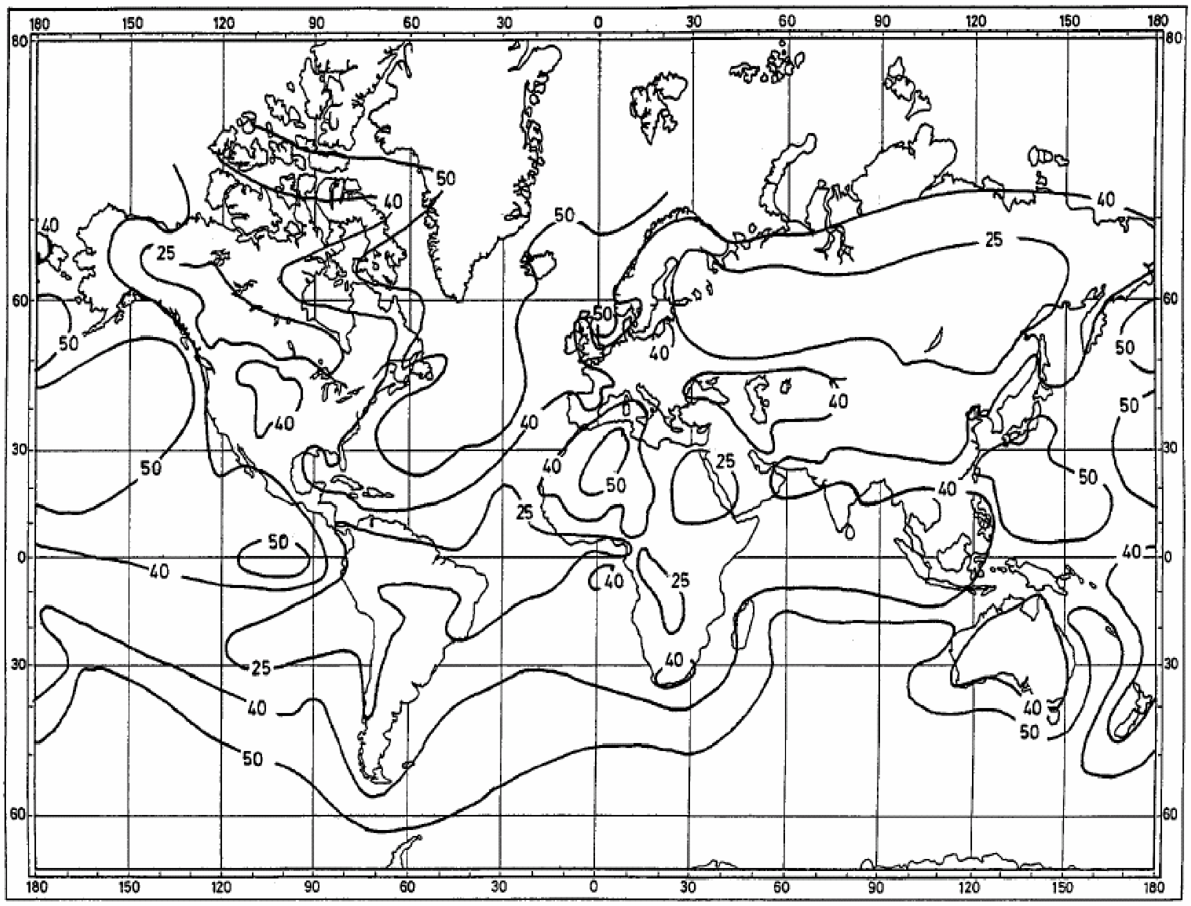

Figure 3: Maximum Gust (m/s) at 10m above open level terrain, likely to be exceeded once in 10 years on average (excluding tornadoes).

By definition a tropical storm becomes a hurricane (or typhoon, cyclone etc) if wind speeds are 33m/s (64kt) or more; the upper limit is unknown but speeds around 103m/s (200kt) have been reliable reported. Hurricanes often travel at 15 -30 km/h (8-16kt) but can exceed 50km/h (27kt) especially at higher latitudes and may last from 2 days to 2 weeks. The chart below gives an indication of the areas affected and the probabilities are included.

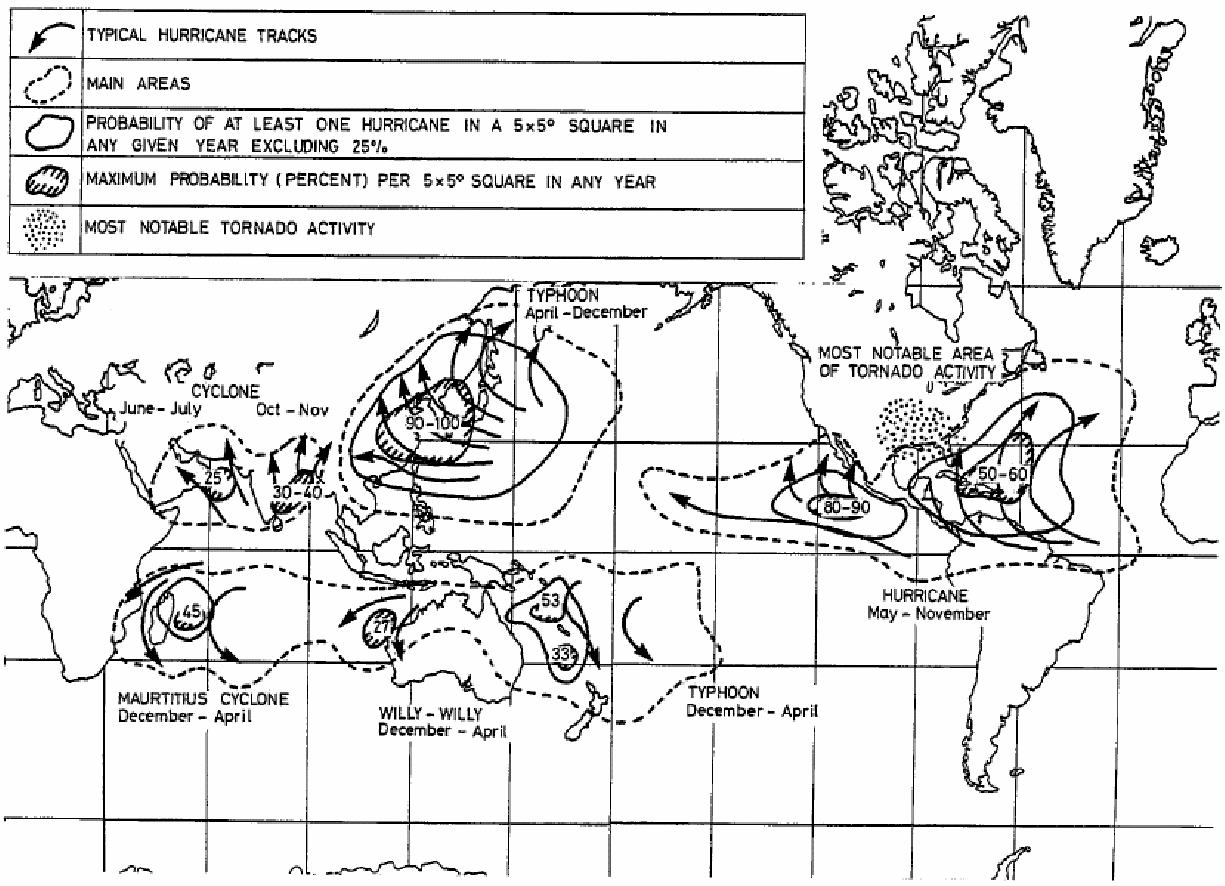

Figure 4: Areas affected by tropical storms of hurricane force

Figure 5 is a schematic diagram illustrating the relative scale and strength of meteorological wind systems. The approximate maxima of identifiable systems is 250 hours life and a diameter of 2500km. The broken lines indicate commonly accepted limits, however gusts within larger strong wind systems are often within the range 100-200m/s

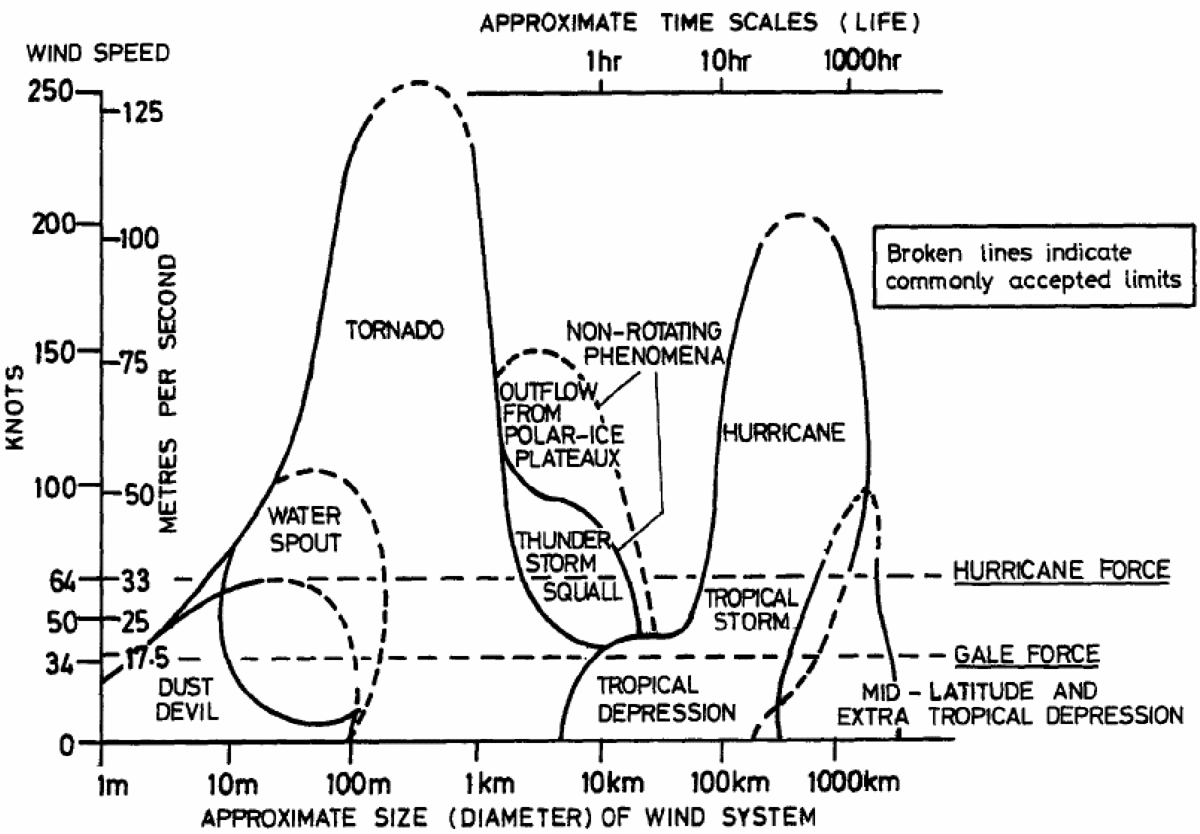

Figure 5: Characteristic Wind Speed Size and Time Scale of Meteorological Wind Systems.

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CATEGORY 240

MECHANICAL CONDITIONS

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GENERAL

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LEAFLET 241/1

GENERAL

1. GENERAL

1.1 The purpose of the AECTP 200 Category 240 series of leaflets is to present characteristics, data samples and sources for mechanical conditions, particularly vibration and shock, that influence the design of defence materiel. The information is amplified and extended by the identification of potential damaging effects of these conditions on defence materiel and also by providing advice on the selection of suitable test methods. Guidance is also given on the determination and validation of environmental test severities from actual measured data.

1.2 This series of leaflets provides sufficient data on mechanical conditions for an item of defence materiel which, when used in conjunction with AECTP 100, 300, 400 and 500, should facilitate the development of a comprehensive and cost effective set of environmental tests in response to project environmental requirements.

2. APPLICATIONS

2.1 The characteristics and data contained in the Category 240 series of leaflets are intended for use in the following applications:

a. To permit customers or potential customers to ask intelligent questions to confirm that key environmental characteristics and issues have been, or will be, addressed by suppliers or potential suppliers.

b. To assist project engineers to compile environmental design criteria specifications through the identification of all major environments, and through the illustration and quantification of the key environmental characteristics and the parameters that influence their magnitude.

c. To assist design engineers by indicating potential failure modes that specific environmental characteristics could induce, and thereby providing pointers to monitor during design and testing.

d. To assist test engineers in the preparation of test specifications by indicating the preferred test methods to evaluate the effects of the mechanical environmental characteristics. The test methods contained in AECTP 400 are recommended where relevant.

e. To assist test engineers in the compilation of programmes to acquire good quality field measured data. This aspect is extensively covered in these leaflets. Such data are used primarily to formulate the test severities for qualification trials.

f. To provide specification writers, through the appendices attached to the leaflets, sources of further information on an environment. This information can be used for setting design and test levels in the earlier project development phases, when project specific measured data are unlikely to be available.

g. To be considered when addressing life extension, role and deployment change; refer to STANAG 4570 with AECTP 600 for guidance.

LEAFLET 242/1

ROAD TRANSPORTATION UP TO FORWARD BASE

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LEAFLET 242/1

ROAD TRANSPORTATION UP TO FORWARD BASE

1. GENERAL

1.1. This leaflet addresses the mechanical environments that may be experienced by materiel during road transportation between manufacturing sites and forward storage bases. It specifically includes vibration and shock transients associated with road transportation, bounce imparted by dynamic interactions of the cargo platform and jostling due to collisions with other cargo. The sources and characteristics of the mechanical environments are presented and where appropriate, advice is also given on potential damaging effects. Additional guidance is contained in Annex A on important parameters influencing the mechanical environments. Where relevant, advice is given on the selection of the appropriate AECTP 400 Test Methods. References are given in Annex B.

1.2. For the purpose of this leaflet, materiel exposed to the road transportation environment may be unprotected or carried within some form of protection, package or container. A payload may consist of one or more items of materiel. Unless specifically stated otherwise, the environmental descriptions relate to the interface between the carriage vehicle and the payload. All axes relate to vehicle axes.

1.3. Transportation beyond the forward depot, when environments associated with off-road and combat conditions may be experienced, is the subject of Leaflet 242/5.

1.4. Handling conditions relevant to the loading and unloading of road vehicles, ie: hoisting, the use of forklifts, etc, are discussed in Leaflet 243/1.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1. Materiel Carried as Restrained Cargo

2.1.1. All the various road related sources of excitation produce at the payload a composite of continuous (vibration) and transient (shock) motions. For testing purposes, the resultant payload dynamic motions are usually considered as vibration responses and shock responses. For convenience these groupings are also used to discuss the characteristics of the environment. However, in reality the separation of the vibration and shock components can be quite a problem. Figures 1, 2, 3 and 6 contain typical descriptions of the road transport dynamic environment. The figures show for a 4 x 4 truck, rms g vibration levels, acceleration power spectral density and peak hold spectra, amplitude probability density and distributions, and a typical transient for the three principal axes. Responses were measured on the vehicle's load bed over the rear axle. The figures are from the same vehicle travelling over a range of road types (motorways, major roads and minor roads) at a range of speeds. The effects of road speed on rms g and peak g vibration levels are shown in Figures 4 and 5. The vehicle was loaded to approximately 50% capacity (by mass), the payload was firmly attached and no significant bouncing occurred.

2.1.2. The predominant characteristics of the vibration component of the payload dynamic motions are essentially random and cover a fairly broad frequency bandwidth. Acceleration amplitudes tend to be more significant at the lower frequencies and particularly at the vehicle suspension modes. As the vehicle suspension modes can be fairly low frequency (typically 4-10 Hz), significant payload displacements can be induced. In general the most severe vibrations will occur in the vertical vehicle axis with fore/aft and lateral vibrations being of secondary importance. The rotational motions cannot always be ignored, particularly the pitching and, to a lesser extent, the rolling motions. The amplitude of the vibrations will be vehicle type dependent, but will also depend significantly on vehicle velocity. To a lesser extent, road surface can also be an influence. Some periodic motions may be superimposed on the payload responses originating from the engine and transmission system. Clearly, the frequency of these components will vary with engine speed. However, they are usually of only minor importance.

2.1.3. The transients (or shocks) originating from the vehicle will originate from pot-holes, kerbs and general discontinuities in the road surface. Hence, the amplitude and profile will be dependent upon the “shape” of the discontinuity. Due to the influence of the vehicle and its suspension system transients, the initial shock pulse will be followed by a rapid exponential decay. Even for the most severe shocks the amplitude of the response decays to insignificance within 2 or 3 cycles. In most cases the dominant frequency component of the transient is that of the vertical vehicle suspension mode. The peak amplitudes of the transients appear to follow an approximately gaussian distribution. The rate of occurrence and standard deviation will be influenced for a particular vehicle by velocity and road surface condition. Typical road surface induced transients are shown in Figure 7 and their associated shock response spectra in Figure 8; measurement and vehicle conditions as per Figures 1 to 6.

2.2. Materiel Carried as Loose Cargo

2.2.1. The motions originating from the payload bouncing on the cargo deck and jostling with neighbouring cargo are usually, for test purposes, considered separately from the shocks or transients originating from the road surface. The reason for this is that the severity and characteristics of these shocks, as experienced by the payload, will be significantly different from the transients originating from the road surface.

2.2.2. The transformation of the available kinetic energy into a shock pulse will depend upon the structural stiffness of the two impacting faces (the payload platform and the package). The stiffer the two impacting faces, the shorter duration the pulse and greater its amplitude. Typical wooden packages impacting a wood load platform may induce accelerations of around 40 g during carriage over rough roads. Some evidence suggests that a package restrained, using conventional restraint systems, is still capable of sufficient motion to allow bounce to occur. However, the amplitudes are likely to be more limited than for unrestrained packages.

2.2.3. Because large vertical motions of the load platform are usually also related to large pitching motions, the payload is likely to experience both rotational and translational motions. This in turn results in different impact orientations and hence severities. Even where no vehicle pitch occurs, any asymmetry of the package centre of gravity is likely to result in rotational motions of the package prior to impact.

2.2.4. The shocks arising from bounce and jostle appear as short duration transients usually with a specific sense. The durations of the transients are likely to be markedly shorter than those occurring directly from the road surface, which have a duration related mainly to the suspension frequency. The occurrence rate will depend upon the road surface and vehicle motions. In general the occurrence rate is complicated. In theory the motions could become "chaotic"; however, for many packages the frequency of the vehicle motions is probably too low for true chaotic motions to be induced.

3. POTENTIAL DAMAGING EFFECTS

3.1. General

3.1.1. The mechanical environments arising during road transportation can induce in materiel a number of potential damaging effects. The most significant are those that relate to induced displacements or to acceleration loadings. Induced displacements within the materiel may produce relative motions which in turn may result in collisions between equipments, tension failures and connectors becoming loosened. Acceleration related failures may arise through the action of inertia loadings. These may be applied once, and could generate a threshold exceedance failure, or repeated to produce a fatigue failure. Failures resulting from an applied velocity are unusual. However, the application of velocity loadings on some electrical equipment and certain types of sensors may induce spurious voltages, which in turn may give rise to functional failures.

3.2. Materiel Carried as Restrained Cargo

3.2.1. Vibration: For many payloads the vibration environment arising from road transportation may be the most severe that it is likely to experience. However, as materiel is usually packaged during transportation, a reasonable degree of protection will probably exist. This protection is often designed to protect the materiel from shocks rather than vibration. As a result, in some packaging designs, significant amplification of the excitations can occur at certain modes of vibration. As these modes are usually of relatively low frequency (10-50 Hz), significant velocities and amplitudes can arise (with the possibility of secondary impacts of the materiel with the inside of its package). Such motions can be amplified by coupling with the vehicle suspension modes.

3.2.2. Shocks: Although the amplitude of shocks arising from poor road surfaces may not be particularly significant, the majority of the energy could well be below the frequency range where the payload’s anti-shock mounts are effective (because the major frequency of the transients will be at the vehicle suspension frequencies). Consequently, the materiel may experience the transients without any effective protection.

3.3. Materiel Carried as Loose Cargo

3.3.1. For a loose or lightly restrained container a well designed protection system (or container) should significantly attenuate the majority of the effects of the shocks arising from bounce and jostle. Moreover, in general, the amplitude of the transients will be less severe than that likely to occur as a result of any mishandling ie being dropped. However, the payload may experience a number of such transients (in the region 100-10000) giving rise to possible medium cycle fatigue failure conditions.

3.4. Packaging Parameters

3.4.1. The majority of materiel intended to encounter the transportation environment will consist of the equipment contained within some form of protection or package. Some structural interaction may well occur between the materiel and its packaging. This interaction may give rise to severities, at the equipment, more severe than those presented in this leaflet (which relate to the interface between the package and the carriage vehicle). However, when considering the possible damaging effects of the various modes of transport, it has been assumed that the interaction will not induce additional materiel failure modes. This assumption is not unreasonable for well designed protection or package. Four useful basic packaging principles are:

a. The package should not open and spill its contents, or collapse on its contents under expected conditions of impact or loading.

b. Articles contained in the packages should be restrained inside the container to prevent movement and resultant impact damage against the inside of the package itself.

c. The means of restraining the contents inside the container must transmit forces to the strongest part of the contained items.

d. The inside of the container must be designed to cushion and distribute impact forces over the maximum surface area of the contents, and possess “yield qualities” to increase deceleration time in case the contents break loose from their restraints.

4. TEST SELECTION

4.1. General

4.1.1. Options: Three approaches of simulating the road transport environment are generally available, ie: in the test laboratory using vibrators, in the field using suitable test tracks, or on real road surfaces using real transportation conditions. The simulation of the environment in the laboratory has the advantage that it allows the simulation to be undertaken in defined and controlled conditions, including temperature. Moreover, laboratory testing permits reduced test times, reduced costs as vehicle operations are eliminated, and increased safety standards (particularly for munition testing). The simulation using a test track or real road conditions may be more convenient for large and awkward payloads, and may be essential where the payload interacts significantly with the dynamics of the carriage vehicle.

4.1.2. Laboratory Testing: The simulation of the environment in the laboratory is usually viable for all but the largest payloads.

4.1.3. Test Tracks: Due to the difficulties of establishing “worst case” road conditions, use is often made of standard test tracks. A wide range of test tracks is available. Not all of these are designed to simulate road transportation; some are designed to investigate aspects of vehicle handling, and reliability. Therefore, care is needed when selecting suitable surfaces to ensure representative payload responses. High amplitude bounce and jostle can be induced at a rate of occurrence many orders greater than that experienced in-service. For some payloads and materiel, this may induce modes of failure that are unlikely to occur in practice.

4.1.4. Road Trials: Trials conducted over public roads have the advantage that they are representative of real conditions. The difficulty of using real road conditions is that vehicle speed and manoeuvring are influenced by the prevailing traffic conditions.

4.2. Materiel Carried as Restrained Cargo

4.2.1. Laboratory Vibration Testing: When a vibration test is required specifically to simulate road transportation vibration, a broad band random vibration test is recommended. The test procedure used should be that of AECTP 400, Method 401 - Vibration.

4.2.2. Laboratory Shock Testing: Shock or transient testing is undertaken to reproduce the structurally transmitted transients arising from the vehicle. In general, this test is less severe than the Loose Cargo test and will only be necessary if a Loose Cargo test is not undertaken. This testing is often applicable for large and/or heavy payloads when the payload is sufficiently constrained to prevent bounce and jostle. With regard to the selection of test procedures AECTP 400, Method 403 - Basic Shock, is applicable. This test method should suffice for most applications, but where a closer simulation is required the shock spectrum procedure contained in AECTP 400, Method 417 - SRS Shock, is recommended.

4.3. Materiel Carried as Loose Cargo

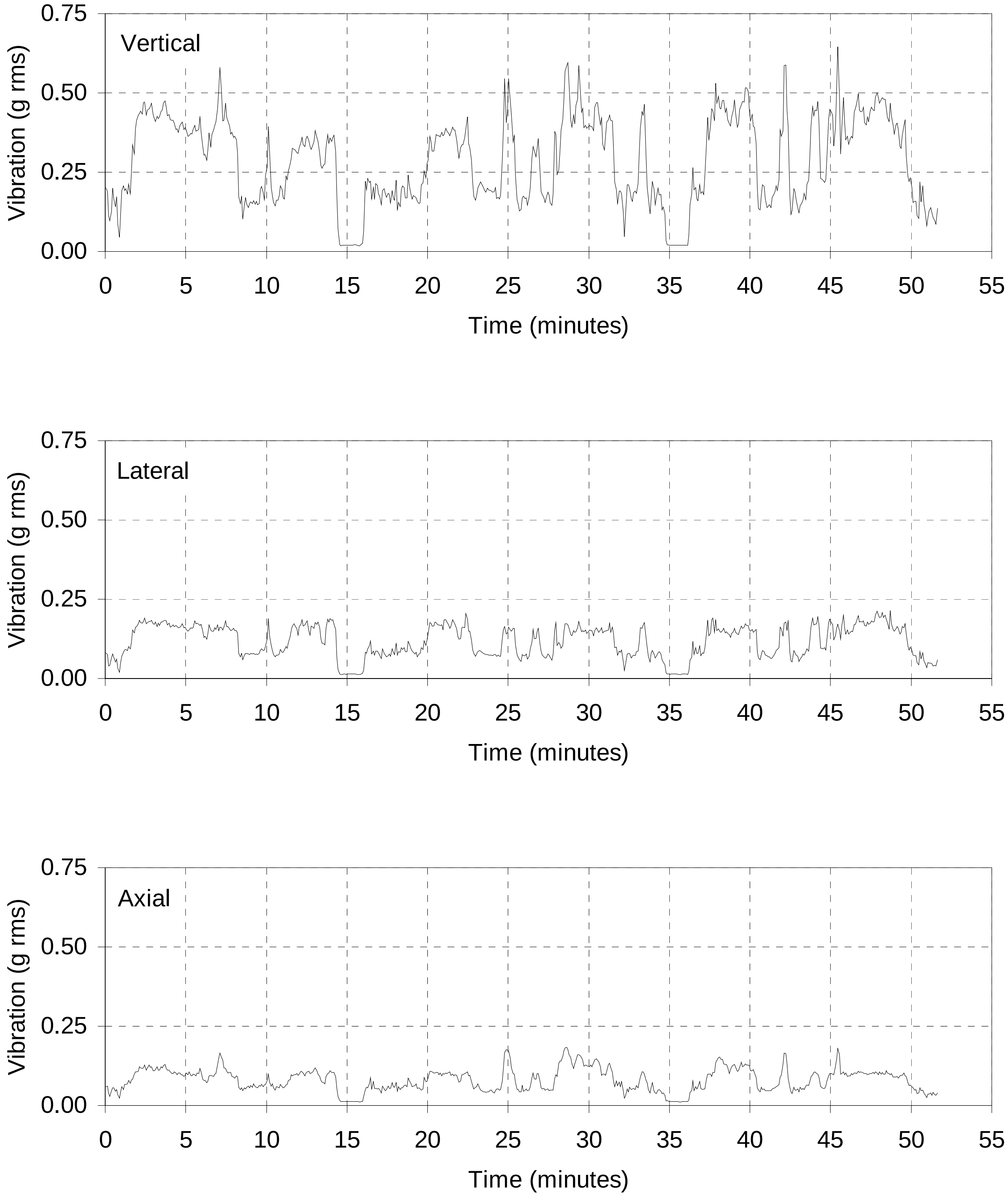
4.3.1. Laboratory Testing: The motions experienced by the payload are simulated by use of Loose Cargo test (AECTP 400, Method 406). This test offers very little scope for “tailoring” to the actual environmental conditions. This is primarily due to the limitations of the test machine normally used. Test severities for the loose cargo test, are controlled mainly by adjusting the duration of exposure.

4.3.2. Provided that the specified motions can be generated in the test laboratory, such as a suitably modified vibrator, it is not mandatory to use the purpose built test machine for the Loose Cargo test.

4.3.3. For some payloads, care needs to be taken when using the Loose Cargo test in the laboratory as the rate of occurrence of the shocks is many times greater than the real occurrence rate. In some instances this increased rate can result in unrealistic degradation of anti-shock mounts, foam supports, etc.

4.4. Vehicle Acceleration

4.4.1. Quasi-static inertia loadings are usually of such low amplitude that they are not of concern. Moreover, they are usually encompassed by testing or calculation for inertia loadings from other deployment phases.



Notes: i. Vibration measured on the vehicle load bed over the rear axle
ii. Vehicle loaded to approximately 50% capacity by mass
iii. Payload secured

Figure 1: Vibration (g rms) from a Bedford 4x4 truck on a good quality road

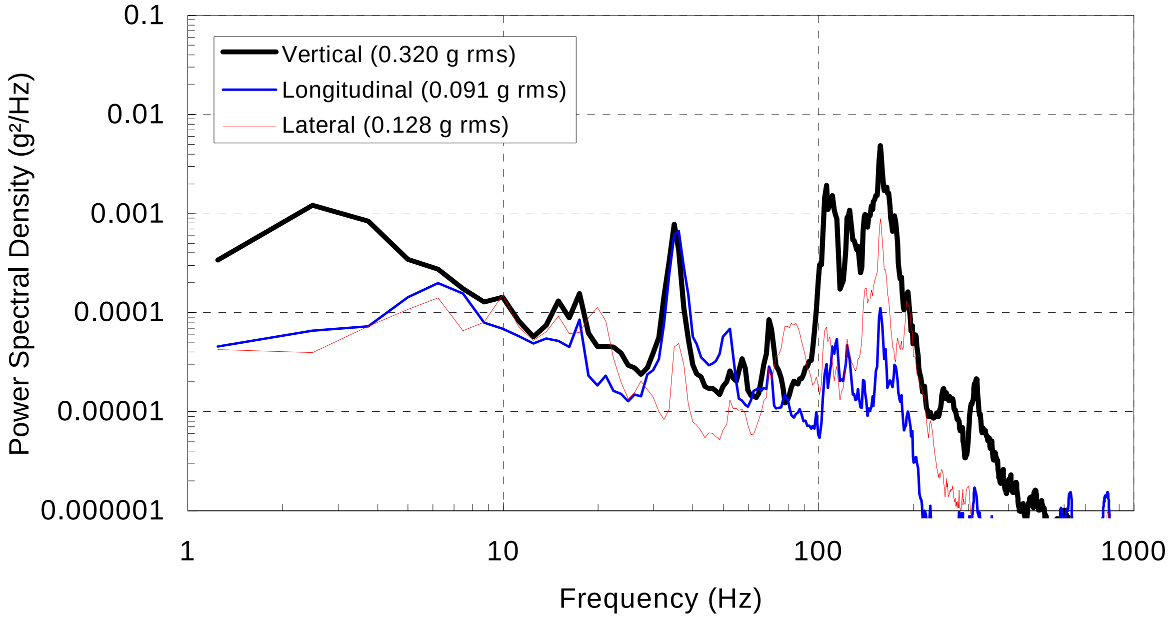


Figure 2: PSDs from a Bedford 4x4 truck on a good quality road

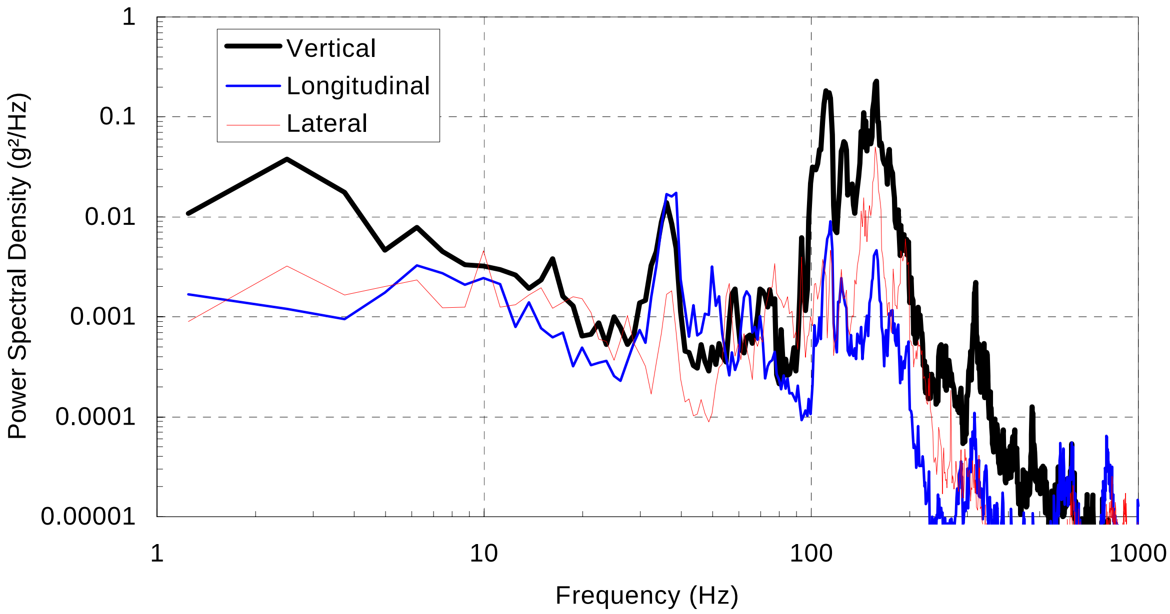


Figure 3: Peak-hold spectra from a Bedford 4x4 truck on a good quality road

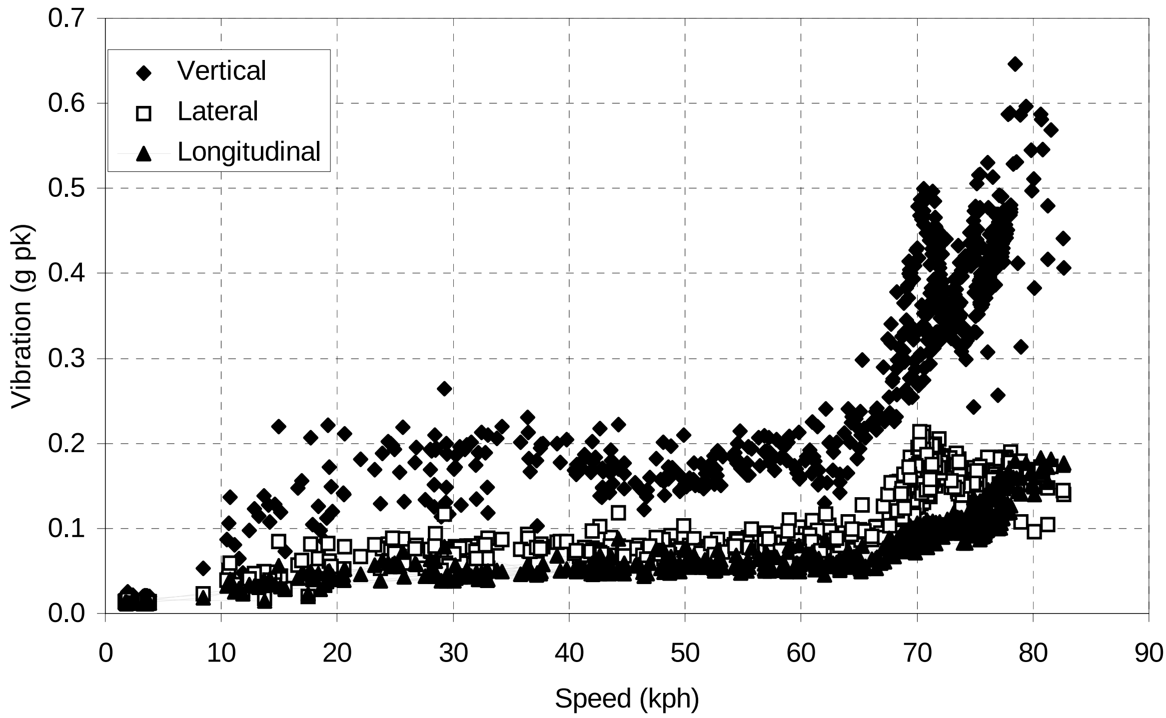


Figure 4: Effect of road speed on block rms values from a Bedford 4x4 truck on a good quality road

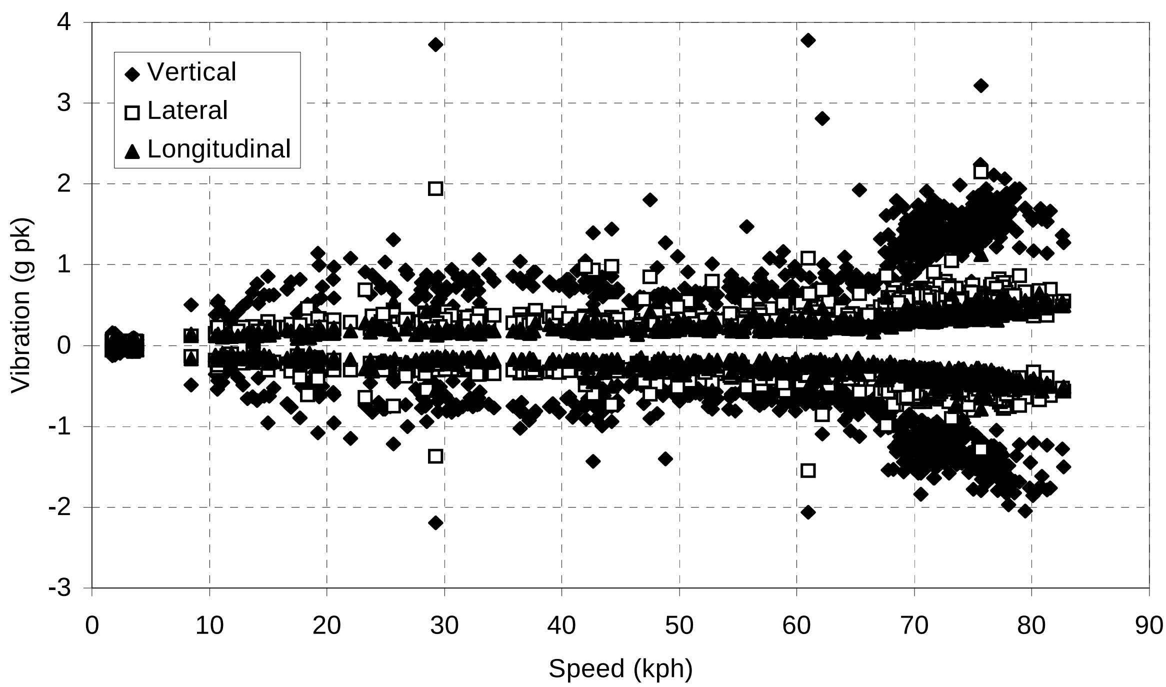
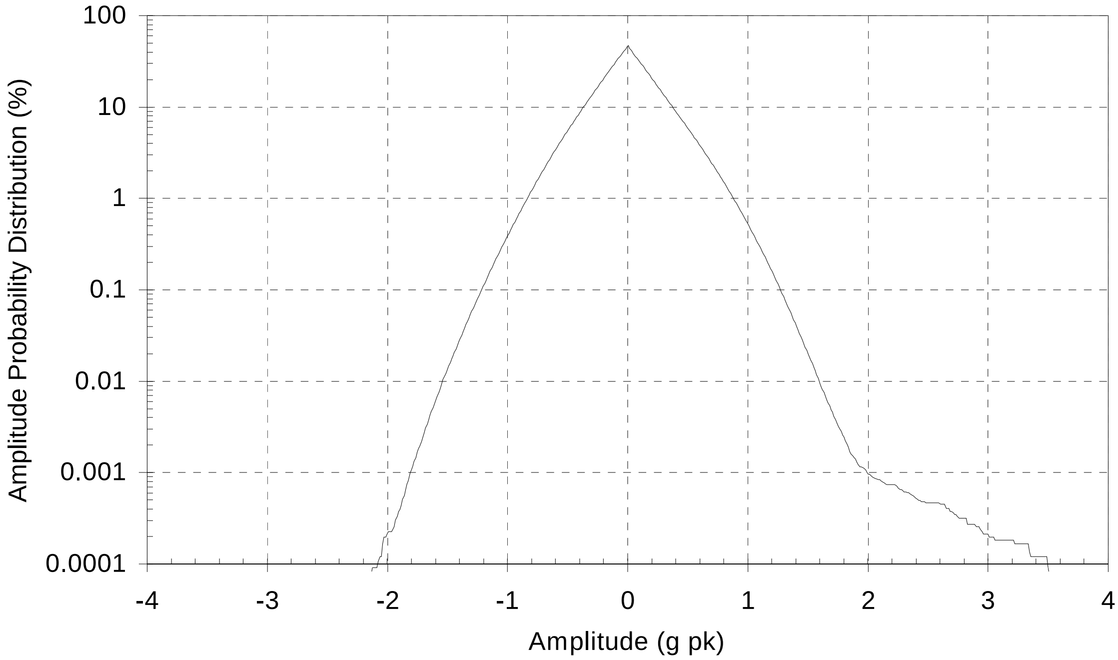


Figure 5: Effect of road speed on block pk values from a Bedford 4x4 truck on a good quality road



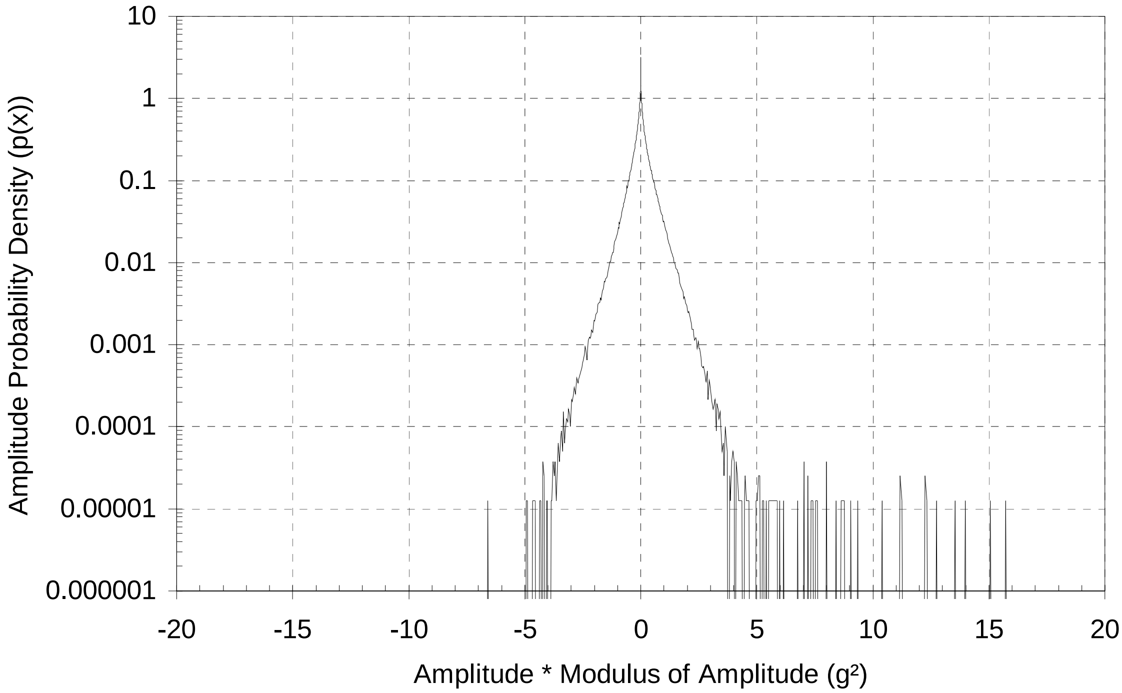


Figure 6: Probability functions (vertical axis) from a Bedford 4x4 truck on a good quality road

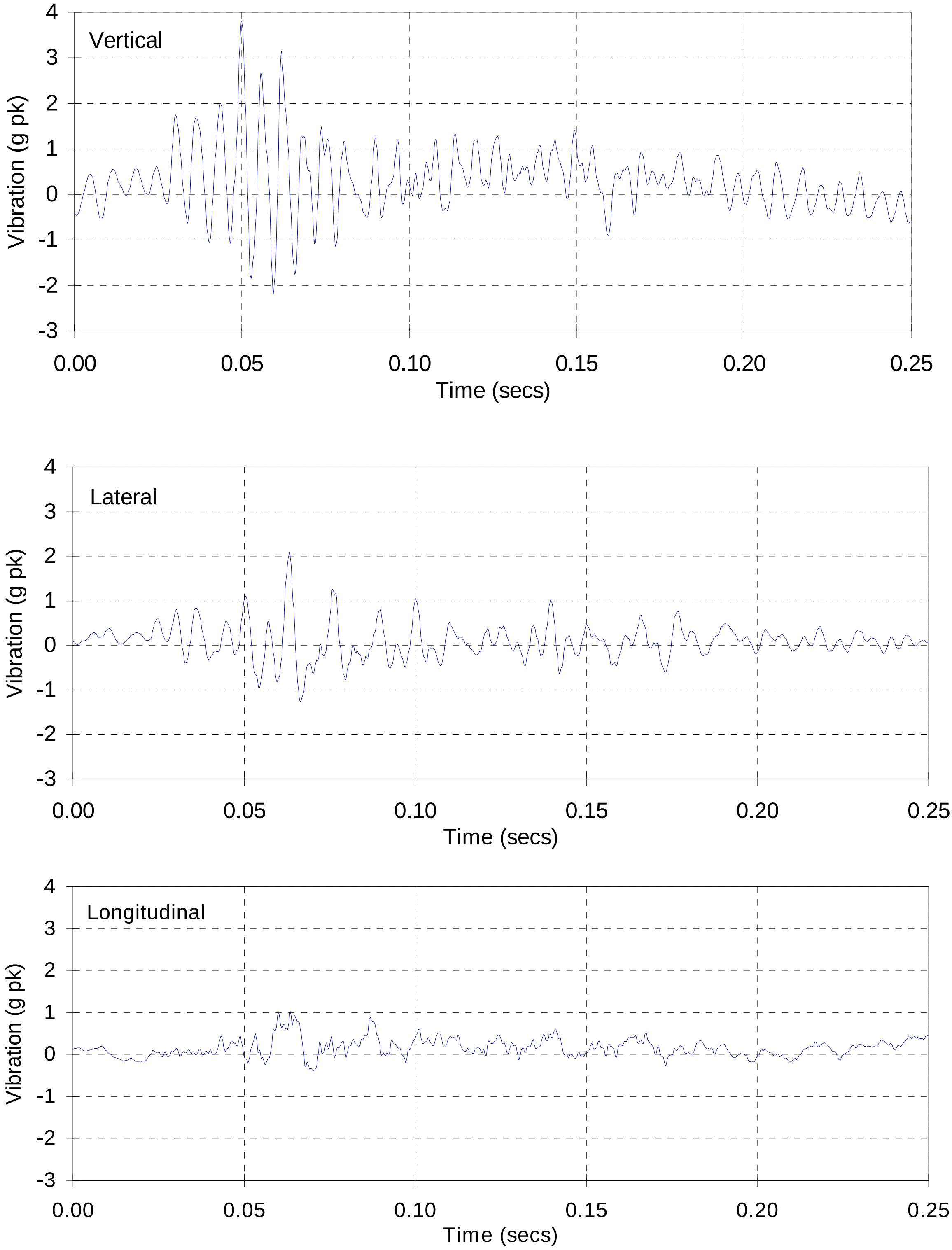


Figure 7: Transient responses experienced on a Bedford 4x4 truck on a good quality road

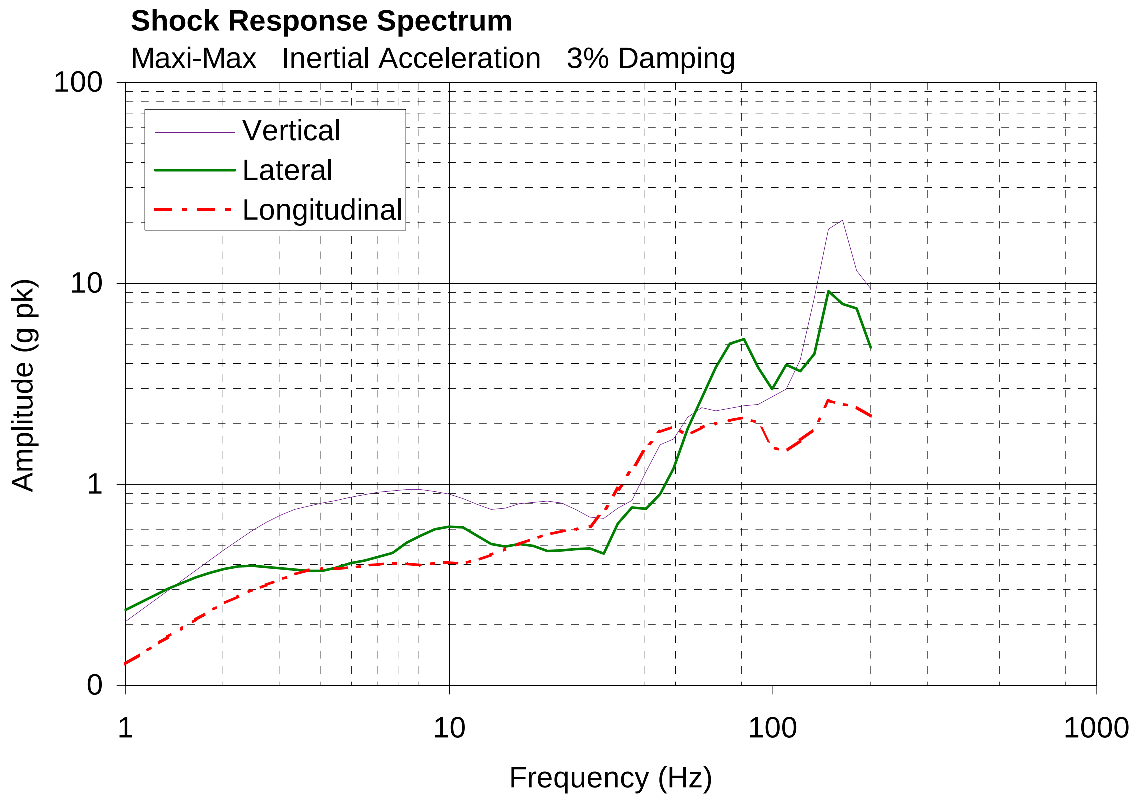


Figure 8: Shock response spectra of a transient experienced on a Bedford 4x4 truck on a good quality road

ANNEX A

PARAMETERS INFLUENCING THE MECHANICAL ENVIRONMENTS WHEN MATERIEL IS CARRIED AS RESTRAINED CARGO

A.1 ROAD SURFACE INDUCED

A.1.1 General: Dynamic responses of payloads originate from the interaction of the vehicle road wheels with the road surface. The mechanism producing these motions is dependent upon the irregularities of the road surface, vehicle velocity as well as wheel and suspension characteristics. In addition, the response of the payload to this form of vehicle excitation will be modified by the vehicle dynamic characteristics, the payload location on the vehicle and also vehicle wheel geometry. The latter is of importance because not only does this form of excitation occur at all road wheels but a high degree of correlation can exist between the motions originating at each wheel.

A.1.2 Road Surface Quality: Measurements undertaken in recent years indicate that, in broad terms, road type has some effects on the amplitude of vibrations. However, this variability may not be as significant as the effects of variations in vehicle speed arising from the use of different road types. Road type does appear to have an effect on the amplitude distribution of the transient motions with the lower class roads generally producing a larger amplitude spread. Long measurement periods (several hours) on public roads, suggests that the continuous excitations (normally called the vibrations) are very broadly gaussian distributed although not necessarily with a stationary variance. Moreover, on to this distribution is superimposed the effects of the transient excitations (bumps, pot holes etc).

A.1.3 Velocity Effects: Vehicle velocity appears to be one of the most predominant parameters affecting the severity of payload dynamic responses arising from road surface. An approximate relationship between the root mean square of payload response and vehicle velocity has been noted in some instances. Variations in acceleration root mean square values during a typical journey are shown in Figure 1 of this leaflet. These are shown plotted against vehicle speed in Figure 5 of this leaflet.

A.1.4 Vehicle Dynamics: Both the continuous and transient excitations, induced by road surface effects, are modified by the vehicle dynamics. The main modifier is the dynamic characteristics of the vehicle suspension system. The effects of the suspension system are usually to attenuate the higher frequency (>20 Hz) excitations and amplify the lower frequencies (in a nonlinear fashion), particularly at the vehicle suspension modes (typically 4-10 Hz). In some cases the suspension modes dominate the payload responses to the extent that superficial inspection of the responses suggests an almost periodic response (although closer inspection usually indicates a Raleigh distribution) of amplitude.

A.1.5 Vehicle Loading Configuration: The mass of the total payload carried by a vehicle will affect payload responses. In general, the lower the total payload mass, the greater the amplitude of responses. This effect is accentuated beyond that expected from ordinary mass loading considerations because of the non-linear nature of most suspension systems. Whilst worst case vibration and shock severities are likely to occur on an unloaded vehicle, Mil-Std-810D correctly observed that “nothing is carried on an empty vehicle”.

A.1.6 Location on Vehicle: The dynamic response experienced by a payload is affected by its location on the vehicle. There are several rules of thumb which are often found to be applicable, although not necessarily for every vehicle and loading condition. For a fixed chassis vehicle the worst case vertical motions are usually over the rear axles. For an articulated vehicle vertical motions may be particularly significant both above the rear trailer axles and above the fifth wheel. If air suspension is fitted to the trailer the latter may prove to be the worst case location.

A.1.7 Wheelbase Geometry: The dynamic response of a vehicle may be influenced by its wheelbase geometry, ie: the excitation from the road surface is not independent at each road wheel and may be highly correlated (with a different correlation at each wheel). The effects of correlation on payload response will depend upon the location and number of road wheels. It is unlikely that this effect will be significant for small base area payloads. However, for payloads with a base area which is significant in proportion to the size of the vehicle, the degree of correlation may have to be considered when setting test severities.

A.2 Engine and Transmission Induced

A.2.1 The excitations arising from engine and transmission sources are, as would be expected, predominantly periodic vibrations. They occur at frequencies related to engine speed and can be at least an order greater than those of the predominant vehicle/suspension modes. Unless the payload is located close to the engine/transmission system the vibrations arising from these sources are unlikely to be particularly significant.

A.3 Aerodynamic Induced

A.3.1 While vibrations can be induced from aerodynamic sources it is unlikely these will produce any appreciable payload response unless it is exceptionally “microphonic”. The excitations from these sources are usually random in nature and are usually more noticeable at the higher frequencies. In some instances cavity resonances may be induced which appear as periodic responses. However, unlike the periodic excitations from the engine and transmission, their frequency does not vary significantly with vehicle or engine speed.

ANNEX B

REFERENCES

B.1 TRM 10000 VEHICLE

B.1.1 Title: Characterisation of the TRM 10000 mechanical environment
Author: LEBEAU Roger
Source: DGA/DME/LRBA
Ref No: E.T. No:159/92/ECM
Date: June 1992
Pages: 233

B.1.2 Mission/Platform

Road transportation of materiel (missiles in containers)

B.1.3 Summary of Technical Data

Environment description in different situations (road, off-road, cross country, Belgian block, pot holes, motorway) and for many speeds.

B.2 TRAFFIC RENAULT VEHICLE

B.2.1 Title: Characterisation of the TRAFFIC RENAULT mechanical environment
Author: LEBEAU Roger
Source: DGA/DME/LRBA
Ref No: E.T. No:159/92/ECM
Date: June 1992
Pages: 233

B.2.2 Mission/Platform

Road transportation of materiel

B.2.3 Summary of Technical Data

Environment description in different situations (road, Belgian block, pot holes, motorway) and for many speeds.

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LEAFLET 242/2

RAIL TRANSPORTATION TO FORWARD BASE

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LEAFLET 242/2

RAIL TRANSPORTATION TO FORWARD BASE

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be experienced by materiel during rail transportation between manufacturing sites and forward storage bases. The sources of excitation and characteristics of the mechanical environments are presented and supplemented by references. Information is given on potential damaging effects and, where relevant, on the selection of the appropriate AECTP 400 Test method.

1.2 Although the information contained in this leaflet relates mainly to payloads transported on the UK rail network, the ride characteristics of mainland European and North American trains are largely similar to those in the UK. The dynamic conditions produced by UK train systems are discussed in Annex A.

1.3 For the purpose of this leaflet, materiel exposed to the rail transportation environment may be unprotected or carried within some form of protection, package or container. A payload may consist of one or more items of materiel. Unless otherwise stated, the environmental descriptions relate to the interface between the wagon and the payload. All axes relate to wagon axes.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 General

2.1.1 With the exception of shunting shocks in the longitudinal axis, the dynamic responses arising from rail transportation are generally less severe than those for road transportation.

2.1.2 The traditional four wheeled simple loose coupled wagon has two axles, a simple suspension and a wheelbase of around 3 m in the UK (compared to approximately 6 m in mainland Europe and North America). This class of vehicle is limited to around 72 km/h (45 mph). It is unlikely that loose coupled wagons would now be used for transporting materiel because current practice is to use only fully braked, tight coupled trains. Consequently, the data quoted for loose coupled wagons should be regarded as 'worst case' for rail systems.

2.1.3 In recent years improved suspensions for longer wheelbase four wheel vehicles have been designed to allow higher speeds. Vehicles with bogie wheeled configurations offer a generally superior ride performance along with the ability to carry longer and heavier payloads. To meet the need for very low vibration levels at higher speeds, services are available that use vehicles with superior ride qualities.

2.1.4 The dynamic environment experienced by a payload transported by rail can be considered to consist of continuous excitations that arise during motion along the track and transient excitations that mainly arise during marshalling (shunting operations) or switching.

2.2 Motion Along the Track

2.2.1 The major factors influencing the severity and characteristics of the vibration environment experienced by a payload transported by a rail vehicle are track condition, vehicle speed, vehicle loading condition and vehicle type (running gear, suspension, wheelbase, etc). The vehicle response to track imperfections is broadly of a random nature. An important spectral peak results from wagons passing over sleepers, which when spaced at 0.7 m intervals results in frequencies of around 40 Hz at 100 km/h (62 mph). The fundamental body modes of the vehicle and its suspension system may also be apparent in the spectral data. Vehicles in a worn condition generate the highest vibration levels. Response amplitudes for the vertical and lateral axes of rail vehicles in a worn condition are given in the following tables. Vibration in the longitudinal axis is usually insignificant, values are less than ±0.15 g at 10 Hz.

(a) Vibration in the vertical axis.

Vehicle		**Vibration**		
Type	Speed km/h & (mph)	Mean (g)	Max (g)	Freq (Hz)
Freightliner 4 Wheel-simple 4 Wheel-advanced	120(75) 72(45) 120(75)	0.25 0.45 0.15	0.8 1.6 0.75	3-4 2-6 2-4

(b) Vibration in the lateral axis.

Vehicle		**Vibration**		
Type	Speed km/h & (mph)	Mean (g)	Max (g)	Freq (Hz)
Freightliner 4 Wheel-simple 4 Wheel-advanced	120(75) 72(45) 120(75)	0.2 0.25 0.1	0.45 1.0 0.5	3-5 1-2 0.5-2

2.2.2 During transportation minor shocks arise during traction, braking and gradient effects. In such cases the shock magnitude is generally determined by train coupling and braking conditions. Vehicles may be equipped with air or vacuum brakes, or no brakes at all. Coupling between wagons may be either 'tight', which ensures buffers are in contact and limits longitudinal movement, or 'loose', which leaves a gap and permits longitudinal movement. Lightly loaded vehicles may experience accelerations approximately twice those of well loaded vehicles. Typical maximum longitudinal accelerations are;

Tight coupled, fully braked train	0.2 g
Loose coupled, fully braked train	0.5 g
Loose coupled, unbraked or partially braked train	2.0 g

2.2.3 Steady state inertia acceleration loadings for the rail transportation environment, such as those that arise from the train accelerating or braking, are considered insignificant compared to those from other modes of transport and handling.

2.3 Shunting and Marshalling

2.3.1 The most severe shocks arising from heavy impact shunting or switching manoeuvres in marshalling yards are strongly aligned to the longitudinal axis. The shock magnitude is dependent upon impact speed, buffering equipment characteristics and the total mass of the wagons involved. The effects of impacts are strongly aligned to the axes of the vehicle, the most severe occurring in the longitudinal axis.

a. Spring Buffers: At one time all wagons were fitted with spring buffering equipment which provided minimal protection for wagons and their contents at impact velocities commonly found in marshalling yards. Typically, with fully laden wagons and at impact velocities between 8 km/h (5 mph) and 15 k m/h (9.3 mph), spring buffers will close solid and the effect is then of two solid bodies colliding. In addition, energy is stored in the buffers which can result in 'shuttling' of vehicles as the energy is released. Longitudinal decelerations while the buffers are being compressed are not particularly high, around 1.5 g for a heavily loaded wagon and 3 g for a lightly loaded one, but once the buffers are fully compressed, shocks up to 6 g can result on 6 m wheelbase wagons and up to 15 g on traditional loose coupled (3 m wheelbase) wagons.

b. Hydraulic Buffers: Hydraulic buffers are now fitted to all new wagons in order to minimise impact shocks. They are designed to give a constant retardation over their entire travel when the wagon is fully loaded. Decelerations of around 2 g for an 8 km/h (5 mph) impact velocity are typical, but this can rise to 4 g at 15 km/h (9.3 mph). The value of 4 g is typical of the maximum shock induced by a "cushioned" wagon fitted with hydraulic buffers.

2.3.2 The position of the centre of gravity of many wagons is above the buffer height, and therefore a vertical component of the shunting shock may be induced in the payload.

2.4 Bounce and Jostle

2.4.1 Generally the bounce and jostle originating from rail transportation is less severe than that from road transportation. However, the excitation mechanisms producing the motions are similar to those generated by road transportation. As the severities of the loose cargo test cannot easily be tailored to specific environments, little value is gained by addressing this aspect of rail transportation separately from that of road transportation, which is discussed in Leaflet 242/1.

3. POTENTIAL DAMAGING EFFECTS

3.1 General

3.1.1 The mechanical environments arising during rail transportation may induce a number of potentially damaging effects. The most significant are those that relate to induced dynamic displacements or accelerations arising from shunting or rail impact shocks. Induced dynamic displacements within materiel may produce relative motions that can result in collisions between materiel, tension failures and connectors becoming loose. Acceleration related failures may arise through the action of dynamic inertia loadings, which may be applied once to generate a threshold exceedance failure, or be repeated to produce a fatigue induced failure.

3.2 Motion Along the Track

3.2.1 The dynamic environment experienced by a payload during motion along the track is relatively benign. In nearly all circumstances, the effects of rail transportation will be encompassed by the effects of other modes of transport, especially since transportation by rail is rarely the sole method of transportation.

3.3 Shunting and Marshalling

3.3.1 Historically, shunting or rail impact shocks have been considered the most significant of mechanical rail environments. In recent times the use of modern rolling stock and rail operational procedures means that the severity of such shocks has significantly diminished, if not eliminated. However, should shunting occur, the environment experienced by a payload can generate unique loadings on the payload, because although the amplitude of the transient may not be particularly high (when compared with operational events), the long durations involved, 0.25 s to 1.00 s, may induce significant displacements in the payload. This may result in permanent deformation and failure of materiel attachments, or the "bottoming out" of anti-shock mounts.

4. TEST SELECTION

4.1 General

4.1.1 Requirements for testing materiel for the rail transportation vibration and shock environment are rare because, with the exception of shunting shocks in the longitudinal axis, they are encompassed by those associated with road transportation.

4.1.2 If a separate rail test is considered necessary, the options available for simulating the effects of the rail transport environment are laboratory or field trials. The simulation of the effects in the laboratory is useful because it allows the simulation to be undertaken in defined and controlled conditions. However, the use of field trials may be more convenient for large and awkward payloads. The use of field trials is essential if the payload interacts significantly with the dynamics of the wagon.

4.2 Laboratory Trials

4.2.2 The simulation of the effects of the environment in the laboratory is usually viable for all but the largest payloads.

4.2.3 When testing for rail transportation vibration is required, the procedure to be used is that contained in AECTP 400, Method 401 - Vibration.

4.2.4 The shock test severities associated with transportation by rail are usually either encompassed by those associated with road transportation (see AECTP 400, Method 403 - Shock) or by testing for bounce and jostle (see AECTP 400, Method 406 - Loose Cargo). When specific testing for rail shunting (or impact) shock is required, see paragraph 4.3.2 below.

4.3 Field Trials

4.3.1 Trials conducted over a rail network have the advantage that they are representative of real conditions. The difficulty of using real rail conditions is that vehicle speed is difficult to control. Moreover, it may be difficult to establish that the materiel has been subjected to worst case conditions.

4.3.2 Because the use of modern rolling stock and current rail operational procedures means that the occurrence and severity of shunting shocks is now significantly diminished, for the majority of materiel the advice referred to in paragraph 4.2.3 above should be adequate. However, when transportation is required on another country's rail network, consideration will need to be given to the operational procedures of that network. For example, if transportation is required within the US, it is mandatory that the test procedure used be that of AECTP 400 Method 416 - Rail Impact, which is considered to be a relatively severe trial.

5. DERIVATION OF TEST SEVERITIES FROM MEASURED DATA

5.1. The extraction of rail test severities from measured data follows a philosophy similar to that for deployment on wheeled vehicles (see Leaflet 245/2). In general, the primary response frequencies will be lower than those arising from wheeled vehicles. Typically the spectral peak due to the wagon passing over sleepers (spaced at 0.7 m apart) will occur in the 20-40 Hz region. In situations where loose shunting can occur the shock transients arising from shunting will almost certainly encompass those occurring during normal rail transportation and will require processing in shock spectra format. Where loose shunting is not anticipated, a methodology suitable for identifying transients from within the continuous vibration needs to be adopted. The methodology is essentially identical to that used for wheeled vehicles.

ANNEX A

DYNAMIC CONDITIONS PRODUCED BY RAIL FREIGHT SERVICES

A.1 GENERAL

A.1.1. The dynamic conditions experienced by a payload during rail transportation are dependent upon the type of service used. Typically, freight may be carried by the following types of service.

A.2. FREIGHT WAGONS

A.2.1. Freight wagons are the traditional method for the carriage of freight. In recent times freight wagons have been largely phased out and today, defence materiel is unlikely to be transported in this manner. Such services involve goods being brought to a freight depot by road, and loaded onto wagons. These wagons are then conveyed to a marshalling yard where they are sorted into trains of suitable length for transit to their destination or another marshalling yard. The wagons used may be of any type including short wheelbase vehicles with simple suspension, ie: those giving generally the worst vibration environment. In such cases, speeds are generally low, ie: less than 72 km/h (45 mph). In marshalling yards, vehicles are sorted into different sidings by propelling them without a locomotive attached. In certain UK and US yards retarders may be used to help control wagon impacts. Impacts can occur between vehicles at speeds up to 24 km/h (15 mph), with a mean of 9.5 km/h (5.9 mph). Figure A1 shows the distribution of impact speeds in a typical marshalling yard. The effects on vehicle payloads of these impacts will be partly mitigated by the buffering gear.

A.3. AIR-BRAKED VEHICLES

A.3.1. An advancement on freight wagons are air-braked vehicles. The vehicles are loaded as for freight wagons and are conveyed to a point where they can be marshalled into a scheduled train service. They remain coupled to the locomotive during marshalling and are thus not subjected to impacts at velocities greater than 2-3 km/h (1.2-1.9 mph).

A.4. BLOCK TRAINS

A.4.1. Block or company trains run from one origin to one destination. They usually comprise air-braked vehicles and are not normally marshalled at intermediate points.

A.5. FREIGHTLINER SERVICE

A.5.1. In such services, containers are collected from a customer's premises by road, conveyed to a freightliner terminal, and loaded onto purpose-built air-braked vehicles. These vehicles may be marshalled at intermediate points but are not subject to high impact velocities.

A.6. PARCEL FREIGHT

A.6.1. Such services, for small consignments or single items uses both bogie vehicles, similar to passenger coaches, and long-wheelbase four-wheel vehicles. Re-marshalling may be involved but not loose shunting.

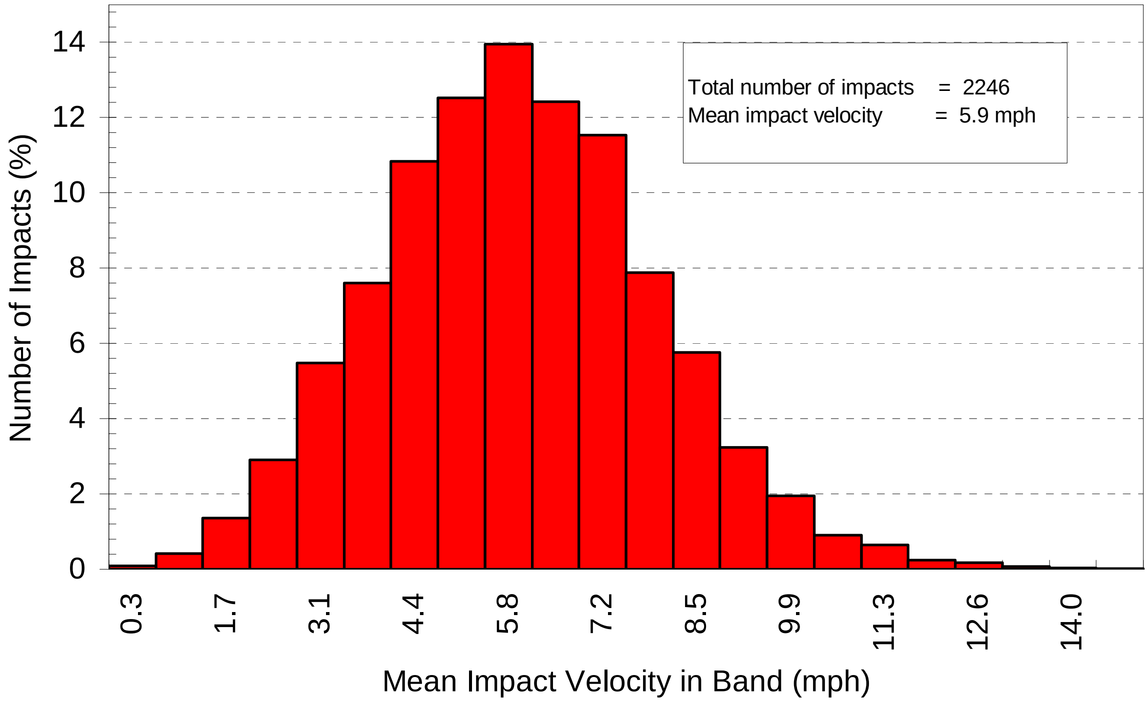

Figure A1: Distribution of wagon impact speeds in a marshalling yard

ANNEX B

REFERENCES

B.1 MOTION ALONG THE TRACK

B.1.1 Title: Measurement and analysis of lengthways rail shock
Author: T E Feltault
Source: Association of American Railroads
Ref No: Report DP 3-95
Date: July 1995

B.2 SHUNTING AND MARSHALLING

B.2.1 Title: Rail freight shock and vibration environment
Author: K Poole
Source: British Rail Technical Report
Ref No: TR FT4
Date: August 1980

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LEAFLET 242/3
AIR TRANSPORTATION UP TO FORWARD BASE

TABLE OF CONTENTS

LEAFLET 242/3

AIR TRANSPORTATION UP TO FORWARD BASE

1 GENERAL

1.1 This leaflet addresses the mechanical environments that may be experienced by materiel during air transportation between manufacturing sites and forward storage bases. The sources and characteristics of the mechanical environments are presented and supplemented by references. Advice is also given on potential damaging effects, treatment options and, where relevant, the selection of the appropriate AECTP 400 Test Method. This leaflet also refers to advice on the derivation of test severities from measured data.

1.2 The leaflet considers air transportation by fixed wing jet aircraft, fixed wing propeller aircraft and rotary wing aircraft. In general the payloads are considered to be carried internally within the aircraft. In addition, the particular cases of helicopter underslung loads and air dropped payloads are also included. The aircraft considered are those normally used for transportation purposes ie: transport aircraft. In practice the characteristics of most types of propeller aircraft and helicopters are likely to be encompassed, although transportation in high performance jet aircraft would almost certainly not be encompassed.

1.3 For the purpose of this leaflet the materiel which is the subject of the transportation environment may consist of an item of unprotected materiel or materiel carried within some form protection, package or container. A payload may consist of one or more items of materiel. Unless specifically stated otherwise the environmental descriptions and test severities relate to the interface between the carriage vehicle and the payload. All axes relate to aircraft axes.

2 CHARACTERISTICS OF THE ENVIRONMENT

2.1 General

2.1.1 The environments experienced by materiel, when carried as a payload within transport aircraft, depend on the type of transport aircraft used, ie: whether the transport aircraft is a fixed wing jet aircraft, a fixed wing propeller aircraft or a rotary wing aircraft.

2.2 Fixed Wing Jet Aircraft

2.2.1 The dynamic excitations experienced by equipment carried as payload within fixed wing jet aircraft arise predominantly from aerodynamic sources, power plant sources and jet plume effects.

2.2.2 The vibration environments experienced by payloads carried within fixed wing jet aircraft are generally characterised as gaussian broad band random motions with superimposed periodic components possibly just discernible. The broad band random vibration arises from both jet noise and aerodynamic sources. The periodic vibrations are generated by the rotating components within the turbines and transmitted mechanically throughout the aircraft structure.

2.2.3 The extent to which excitations may be generated by the above sources depends upon the flight conditions. Four flight conditions are considered for illustration, namely take-off, climb, cruise and landing. Typical vibration severities for these conditions, using the rear engined VC 10 aircraft for illustration, are shown in power spectral density format in Figure 1. Corresponding root mean square values are shown in Figure 2.

a. Take-off gives rise to significant vibration levels, but only short durations. Taxiing generates low level vibration, which is normally encompassed by that from take-off.

b. Significant vibration may be apparent during climb when high demand is placed upon the power plant. However, levels are unlikely to exceed those of take-off.

c. Vibration levels associated with cruise conditions are of low level mainly because the flight dynamic pressures are relatively low. Also, the effects of aircraft manoeuvres, such as turns do not produce significant vibration responses of the payload although they may produce the largest loadings on restraint systems. Descent generally produces negligible levels, although if spoilers or flaps are used to provide air-braking low frequency vibration can be experienced.

d. Landing can produce two distinct excitations: touch down, giving a transient excitation, and reverse thrust, giving a vibration excitation. Transient amplitudes levels can attain 1 g pk and can be characterised by a decaying sinusoid. However, in some cases (including the example shown) the transient cannot be distinguished from the vibrations. Vibration during reverse thrust can exceed the levels associated with take-off, although for shorter periods.

2.3 Fixed Wing Propeller Aircraft

2.3.1 Vibration measured at any point on a propeller aircraft will be the sum of many sources and mechanisms. Almost all these mechanisms arise as a result of the propellers, which can generate vibration directly or produce noise which generates vibrations when it impinges on the aircraft structure. Consequently, the maximum vibration severities within the cargo bay are experienced by materiel situated in the plane of the propellers. The relative severities along the length of the fuselage are shown in Figure 3.

2.3.2 Because the dominant source of vibration arises from the aircraft's propellers, the spectral characteristics of the environment is dominated by peaks corresponding to the blade passing frequency and its subsequent harmonics. Generally, blade passing frequencies are more significant than shaft frequencies. However, the latter are still often important, especially given the low frequencies involved. The periodic motions are superimposed upon a background of broad band random vibration.

2.3.3 The extent to which excitations may be generated depends upon the flight conditions. Four flight conditions are considered for illustration, namely take-off, climb, cruise and landing. Typical vibration severities for four conditions, using the four engined, four bladed, Hercules C130 propeller aircraft for illustration, are shown in power spectral density format in Figure 4. Root mean square values for these and other conditions are shown in Figure 5.

a. Take-off: The highest vibration severities occur during take-off as shown in Figures 4 and 5.

b. Climb: Significant vibration levels are generated during climb, although these are generally enveloped by those of take-off.

c. Cruise: Vibration during cruise is relatively low level, even if the aircraft's engines are allowed to operate out of synchronisation with one another. Aircraft manoeuvres, such as turns, do not significantly increase vibration levels within the aircraft. Descent generally produces negligible levels.

d. Landing: Vibration during reverse thrust can equal the levels associated with take-off, although for shorter periods. Transient response levels can attain 2 g pk and be characterised by a decaying sinusoid. Typical landing shocks are shown in Figure 6.

2.3.4 Many environmental descriptions of transportation severities in propeller aircraft indicate that the accelerations occurring at blade passing frequency are the most significant. This is not always the case. The second or third harmonic of blade passing frequency may be the most significant in some cases.

2.3.5 The vibration characteristics for fixed wing propeller aircraft are similar to, but usually less severe than, those of helicopter carriage. However, it should be noted that the blade passing frequency on fixed wing propeller aircraft is likely to be significantly higher than that on helicopters. As such, the fixed wing propeller vibration environment is unlikely to be encompassed within that experienced by materiel carried on helicopters.

2.4 Rotary Wing Aircraft

2.4.1 The dominant source of vibration arises from the action of the helicopter's main rotor blades and gear boxes. Consequently a typical helicopter vibration spectrum is dominated by peaks at the main rotor blade passing frequency and its subsequent harmonics. For single rotor helicopters, components at frequencies associated with the tail rotor may be also be noted. For dual rotor helicopters, significant responses occur at twice the blade passing frequency due to interaction between the two sets of blades. In all cases the peaks in response spectra are superimposed against a background of broad band random vibration.

2.4.2 The extent to which excitations may be generated by the above sources depends upon the flight conditions. Typical vibration severities for four conditions, using the Chinook dual rotor helicopter for illustration, are shown in power spectral density format in Figure 7. Root mean square values for these and other conditions are shown in Figure 8.

a. Take-off: Vibration severity during take-off and hover (Figure 7b) is low and almost always encompassed by the levels encountered during flight. Vibration during taxi, when applicable, is also low.

b. Straight and level flight: Under these conditions vibration severity is mainly dependent upon forward speed, although not linearly related to it. A typical acceleration spectral density for straight and level flight is shown in Figure 7d where the contributions from shaft and the first four blade passing frequencies are clearly visible.

c. Transient conditions: Short duration conditions, such as transition to hover, are likely to generate high vibration levels, but for only a few seconds. Maximum power climbs can also generate high vibration over several minutes.

2.4.3 The variation of vibration severity along the fuselage of a Chinook helicopter is indicated in Figure 9.

2.5 Underslung Payloads.

2.5.1 Materiel may be underslung from helicopters, either directly in nets, or within containers. In either case, the dynamic environment experienced by the payload is largely independent of that of the carriage helicopter. Vibration responses tend to be broad band in character and of very low amplitude. Excitation is mainly due to aerodynamic forces such as atmospheric turbulence.

2.5.2 The pick-up of materiel can give rise to transients of a decaying sinusoid nature. Response amplitudes are generally enveloped by those of set-down which can typically attain a peak amplitude of 4 g. Measured data indicate that impact velocities of up to 2.5 m/s are possible. Typical shock responses during set-down are shown in Figure 10.

2.5.3 The high set-down velocities that can occur on naval vessels at sea, will result in severe transient response amplitudes. Measured data are not available for these conditions.

2.5.4 For some suspension arrangements, usually multi-cable suspension systems, rigid body dynamic interaction between the helicopter and payload can occur which can produce very high loads on the attachment cables (and any container if connected directly).

2.6 Air Dropped Payloads

2.6.1 Air dropped payloads will experience additional transients arising from parachute deployment and during impact. Air dropped payloads are usually arranged in a manner so as to mitigate the effects of impact. This mitigation often takes the form of shock absorbers intended to modify the impact transient to one with a longer duration and lower amplitude.

2.6.2 Severe impact conditions may be experienced by payloads intended for low level drops. Measured data are not available for these conditions.

2.6.3 Air dropped payloads should be capable of withstanding impact velocities up to 9 m/s (30 ft/s). Those intended for low level drops, may be required to withstand higher impact velocities.

2.7 Steady State Acceleration

2.7.1 Quasi-static accelerations are experienced during flight. However, these are usually less than those experienced during other deployment phases.

3 POTENTIAL DAMAGING EFFECTS

3.1 Failure Mechanisms

3.1.1 The mechanical environments arising during the air transportation of materiel may induce a number of mechanisms of potential materiel failure. The most significant of these mechanisms are related to either displacements induced in the materiel or as a result of acceleration loadings. Induced displacements within the materiel may produce relative motions which in turn may result in collisions between equipments, tension failures and connectors becoming loosened. Acceleration related failures may arise through the action of inertia loadings. These may be applied once, to produce a threshold exceedance failure, or repeated to produce a fatigue induced failure.

3.2 Fixed Wing Jet Aircraft

3.2.1 As the dynamic environment experienced by payloads carried within fixed wing jet aircraft is benign any potential damage effects are unlikely to require special consideration.

3.3 Fixed Wing Propeller Aircraft

3.3.1 The vibration responses, experienced by a payload at the blade passing frequency and its subsequent harmonics, can be significant. In particular, the blade passing frequency can often be quite close to the internal mounting frequency of equipment within its container.

3.4 Rotary Wing aircraft

3.4.1 As the blade passing frequency may be less than the internal mounting frequency of the equipment within its container, the mounting arrangement may offer little protection against the vibration environment.

3.5 Underslung Loads

3.5.1 The potential damage associated with carriage as an underslung payload arises mainly from impact on set-down. With the exception of the relatively severe VERTREP (replenishment at sea) conditions, for which no information is available, the loadings are similar to those for general handling conditions. Only for large items of materiel are set-down shock loadings likely to exceed those for handling. The most likely damage mechanism is that of materiel moving excessively within its packaging, such that the capabilities of the cushioning material are exceeded.

3.6 Air Dropped Payloads

3.6.1 Payloads subject to transients arising from air drop, are usually arranged to reduce peak acceleration amplitudes. As a consequence the duration of the transient is increased so that for most equipment it appears essentially as a quasi-static acceleration. A significant potential damage effect is that the impact can give rise to large relative displacements. This may be a problem for large mass items held in flexible restraints, eg vehicle engines.

4 TEST SELECTION

4.1 General

4.1.1 Options: Two approaches of simulating the air transport environment are generally available: in the laboratory or by use of field trials. The simulation of the environment in the laboratory is useful as it allows the simulation to be undertaken in defined and controlled conditions. However, the use of field trials may be more convenient for large and awkward payloads. The use of field trials is essential if the payload interacts significantly with the dynamics of the aircraft floor.

4.1.2 Laboratory Testing: The simulation of the environment in the laboratory is usually viable for all but the largest payloads. The test severities defined in this leaflet are intended for use in laboratory trials.

4.1.3 Field Trials: Trials conducted using actual aircraft have the advantage that they are representative of real conditions. The difficulty of using actual air transport conditions is that flight conditions are difficult to control.

4.2 Fixed Wing Jet Aircraft

4.2.1 Vibration: A broad band random vibration test is recommended. The appropriate procedure is that of AECTP 400 Method 401 - Vibration.

4.2.2 Shock: Since the shock severities during transportation in jet aircraft are small compared to the vibration severities no separate shock testing is usually considered necessary. In rare circumstances when a shock test is required that proposed in this leaflet for propeller aircraft is suggested.

4.3 Fixed Wing Propeller Aircraft

4.3.1 Vibration: The preferred test for this type of transportation consists of three narrow bands of random vibration, superimposed on a background of shaped broad band random vibration. An alternative, using three sinusoids superimposed on a background of random vibration is also acceptable. The appropriate procedure is that specified in AECTP 400, Method 401 - Vibration.

4.3.2 Shock: The test procedure associated with these shock loadings is that specified in AECTP 400, Method 403 - Shock.

4.4 Rotary Wing Aircraft

4.4.1 Vibration: The simulation of the vibration environment experienced by a payload carried in a helicopter is best achieved by using either narrow bands of random vibration superimposed on a background of shaped broad band random vibration, or sinusoids similarly superimposed. The appropriate procedure is that specified in AECTP 400, Method 401 - Vibration.

4.4.2 Shock: As the shock severities during transportation in rotary wing aircraft are small compared to the vibration severities no separate shock testing is usually considered necessary. In the rare circumstances when a shock test is required, that proposed in this leaflet for propeller aircraft is recommended.

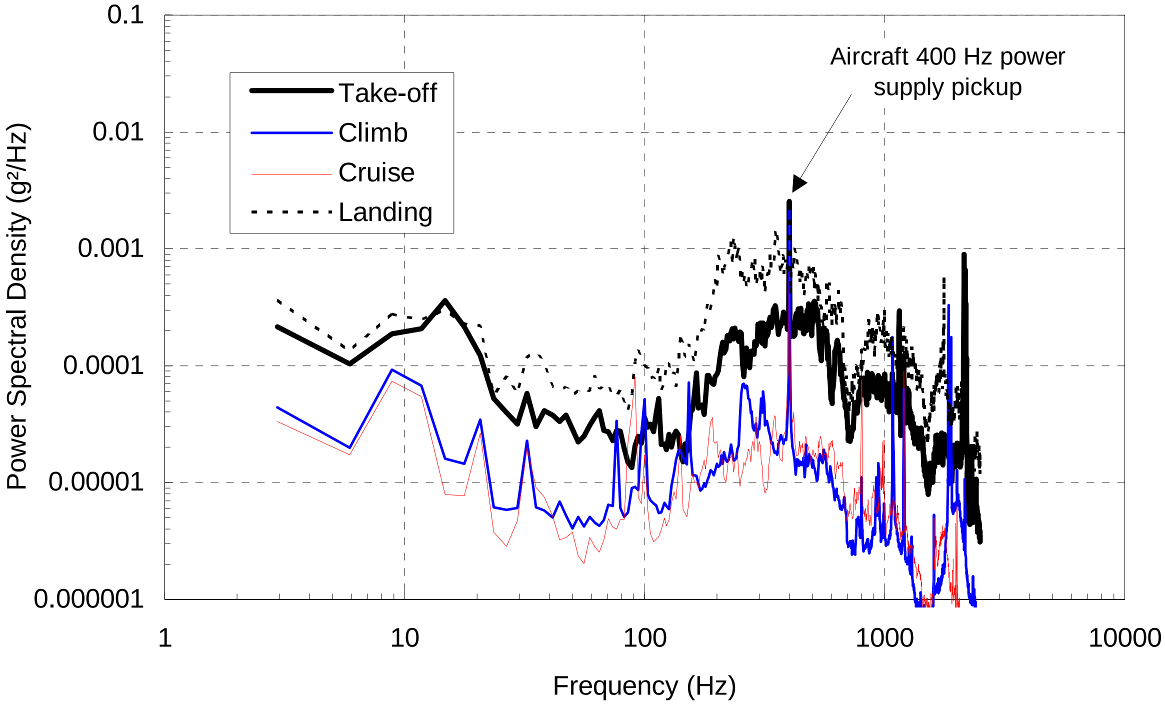
4.5 Underslung Loads

4.5.1 Vibration: The appropriate procedure is that specified in AECTP 400, Method 401 - Vibration.

4.5.2 Shock: The appropriate procedure is that specified in AECTP 400, Method 414 - Handling.

4.6 Air Dropped Payloads

4.6.1 Normally, specific testing of payloads for the transient arising from air drop conditions is not undertaken.



Note: All data from the rear of the aircraft and in the vertical axis

Figure 1: Vibration spectra from a VC10 jet transport aircraft

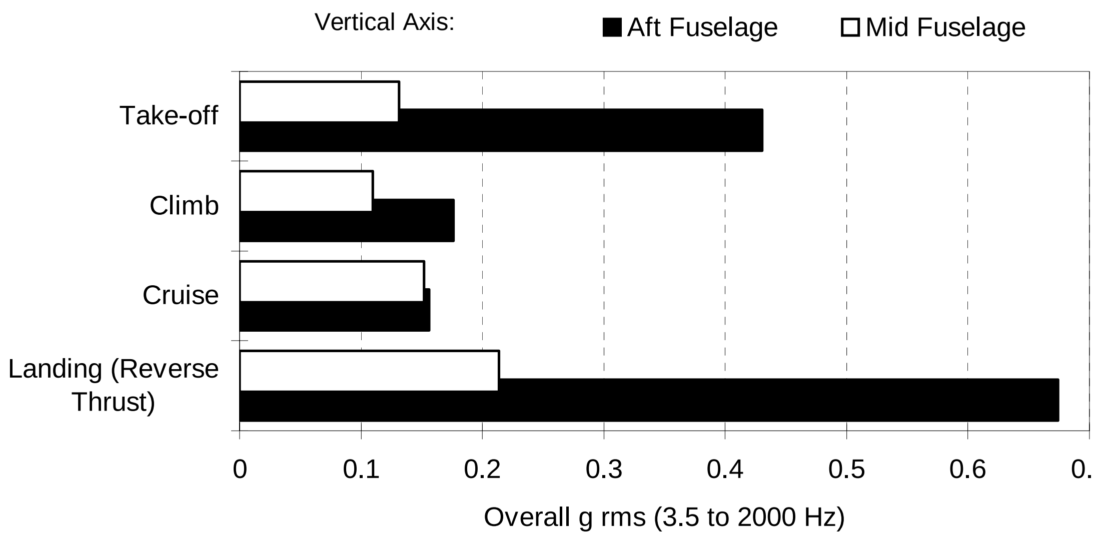


Figure 2: Variation of vibration severity in various manoeuvres and at two locations

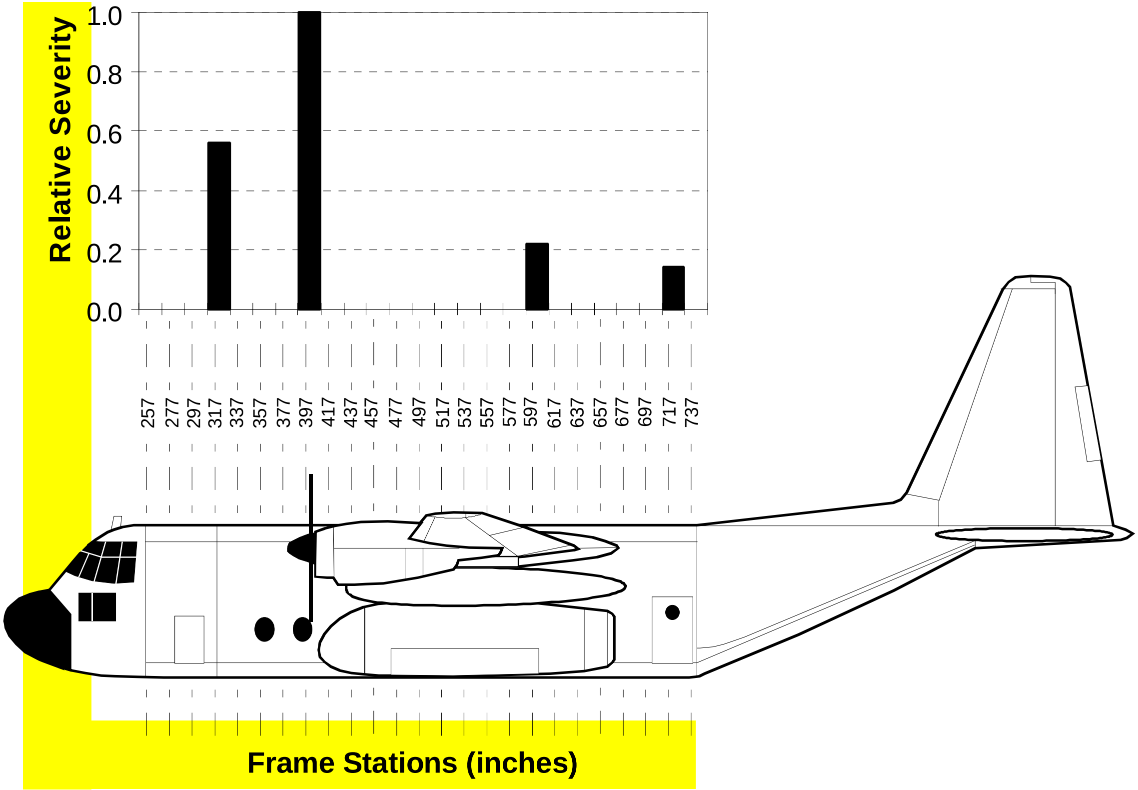
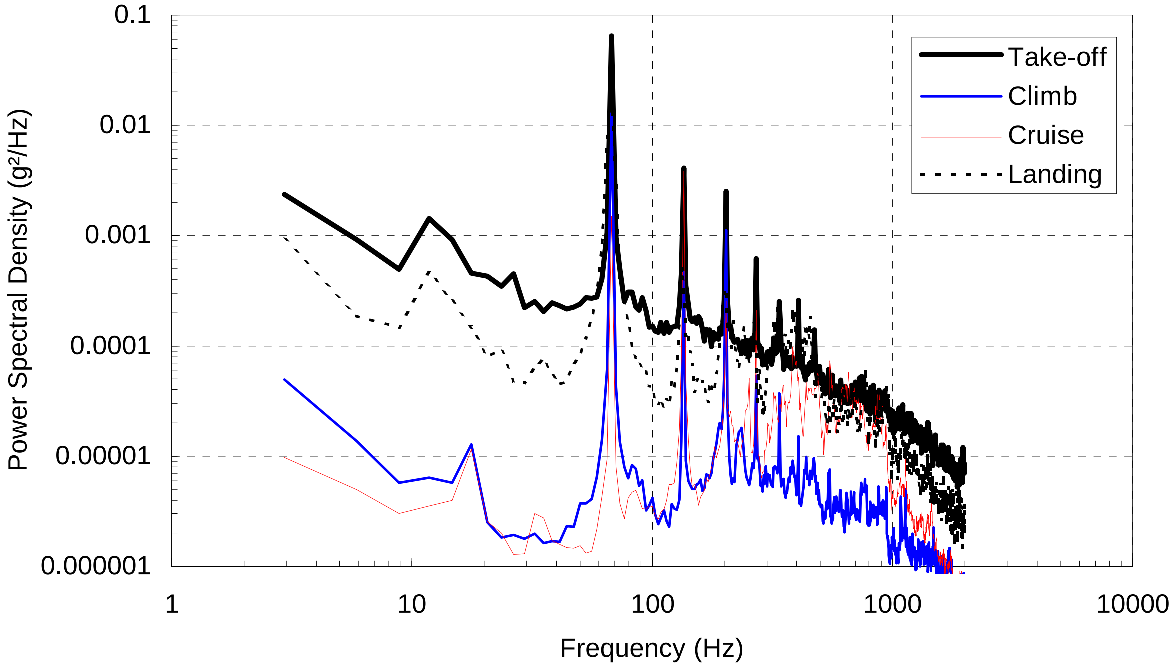
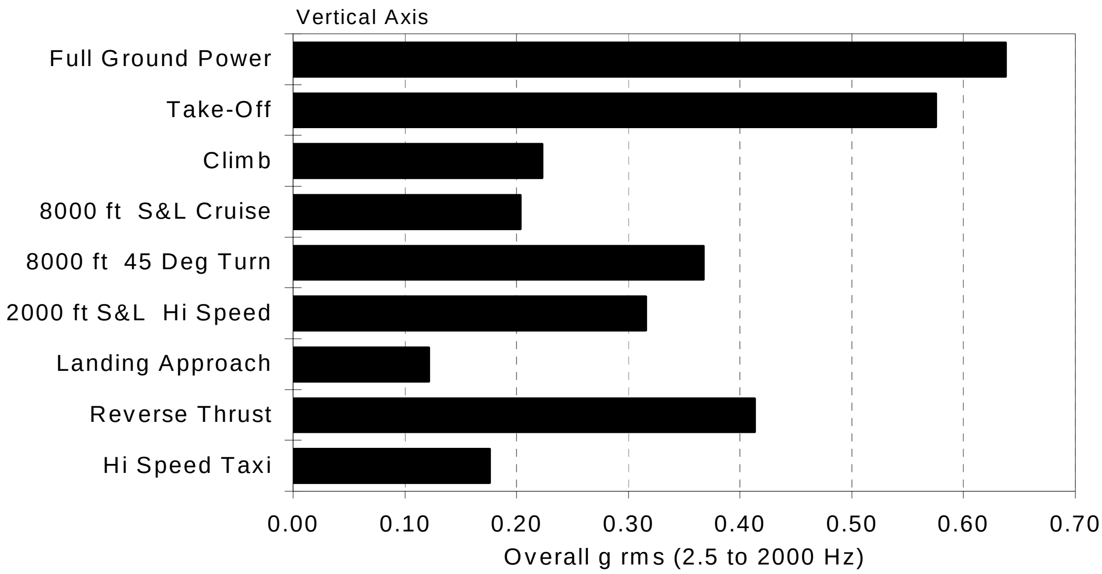


Figure 3: Variation of vibration severity along the fuselage of a C130 aircraft



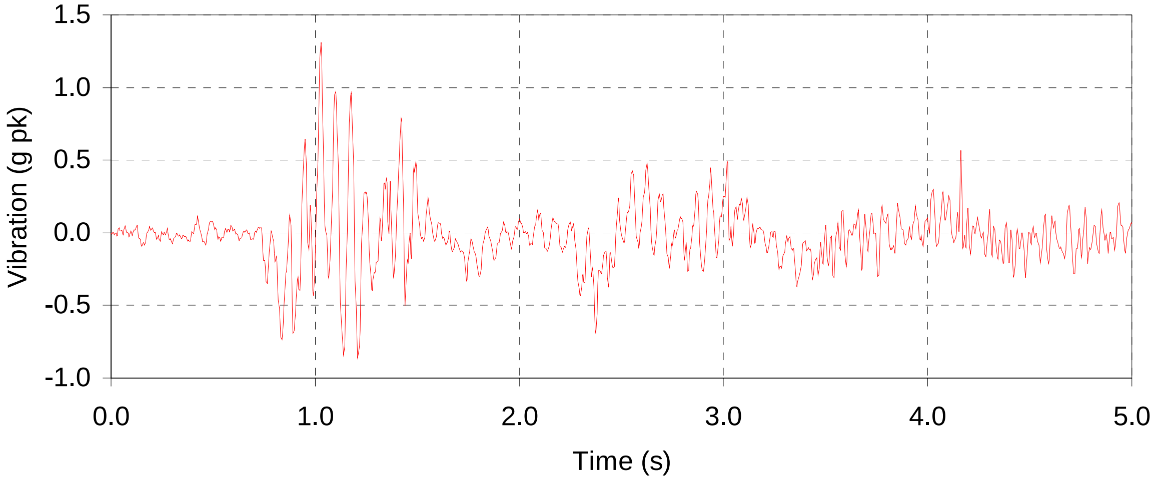
Note: all data from the plane of the propellers and in the vertical axis

Figure 4: Vibration spectra from a C130 Hercules turbo-prop transport aircraft

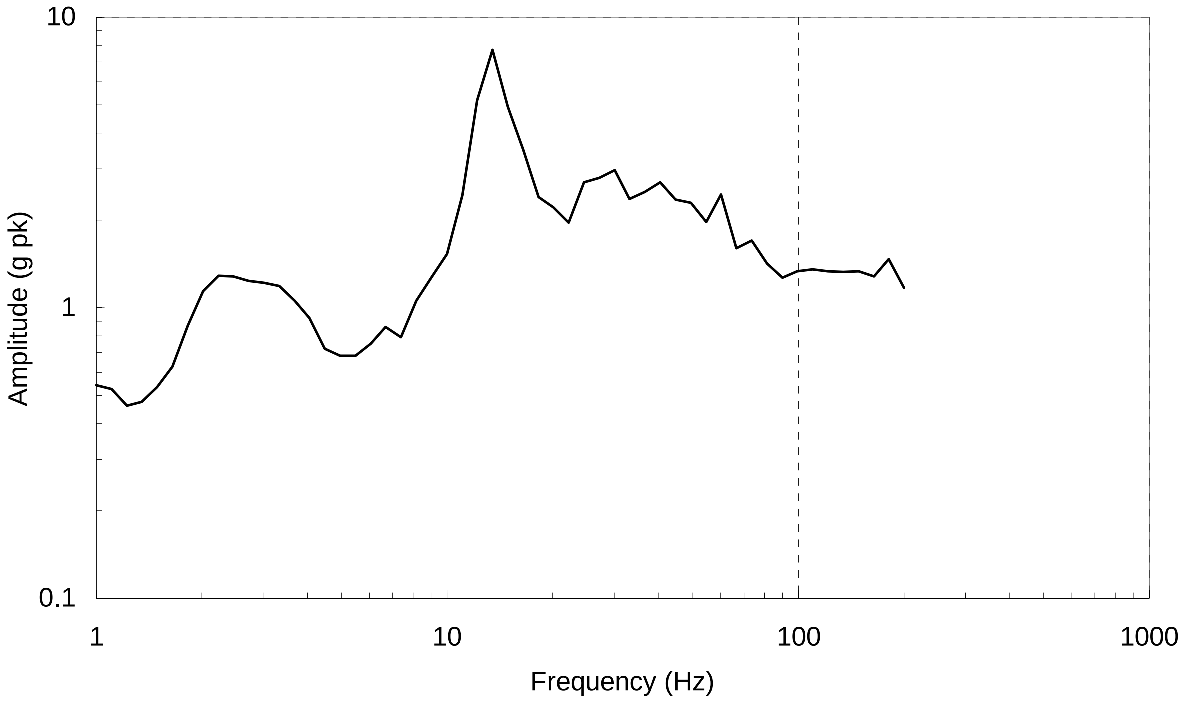


Note: All data from the plane of the propellers

Figure 5: Variation of vibration severity in various manoeuvres for a Hercules C130 turbo-prop aircraft

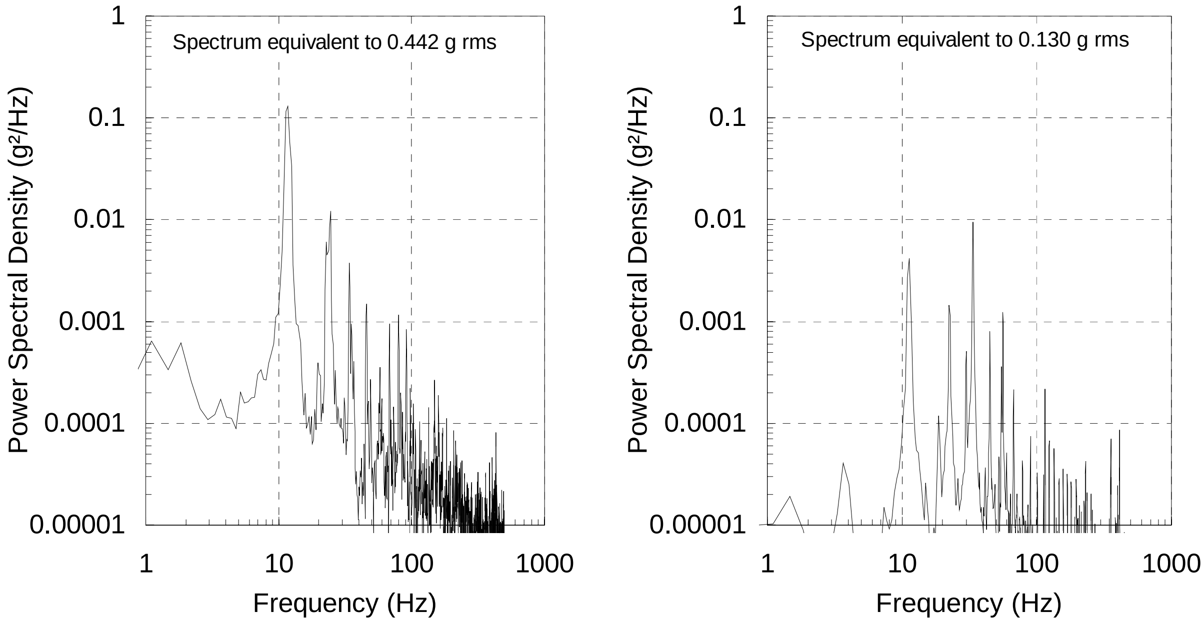


a: Shock history

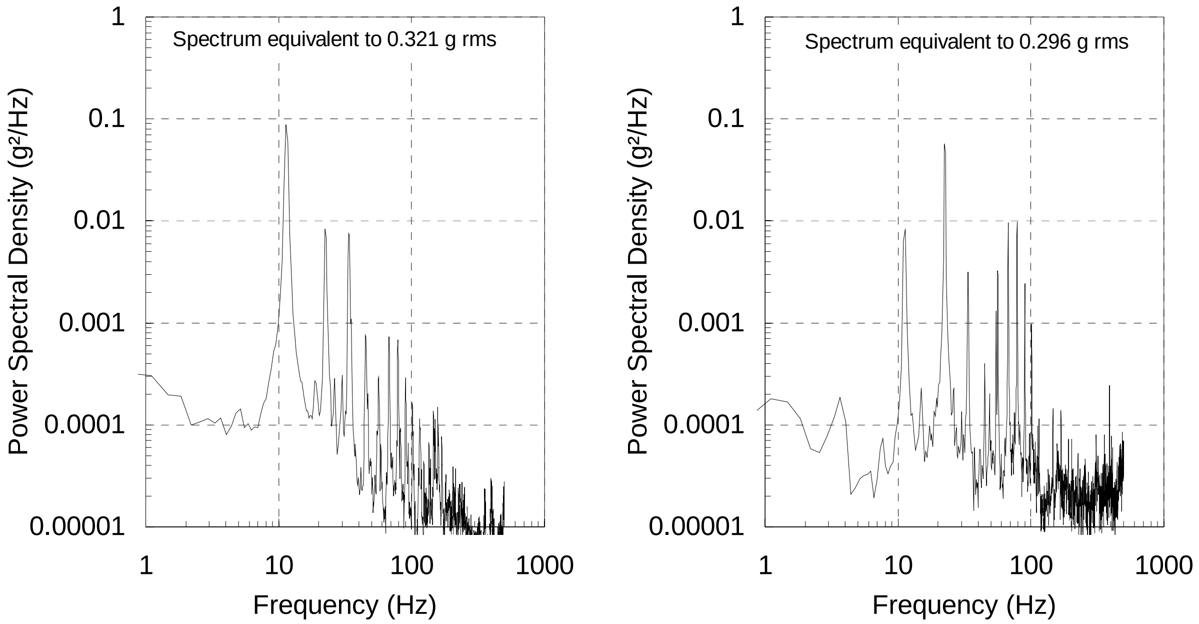


b: Shock response spectrum

Figure 6: Propeller transport aircraft tactical landing shock



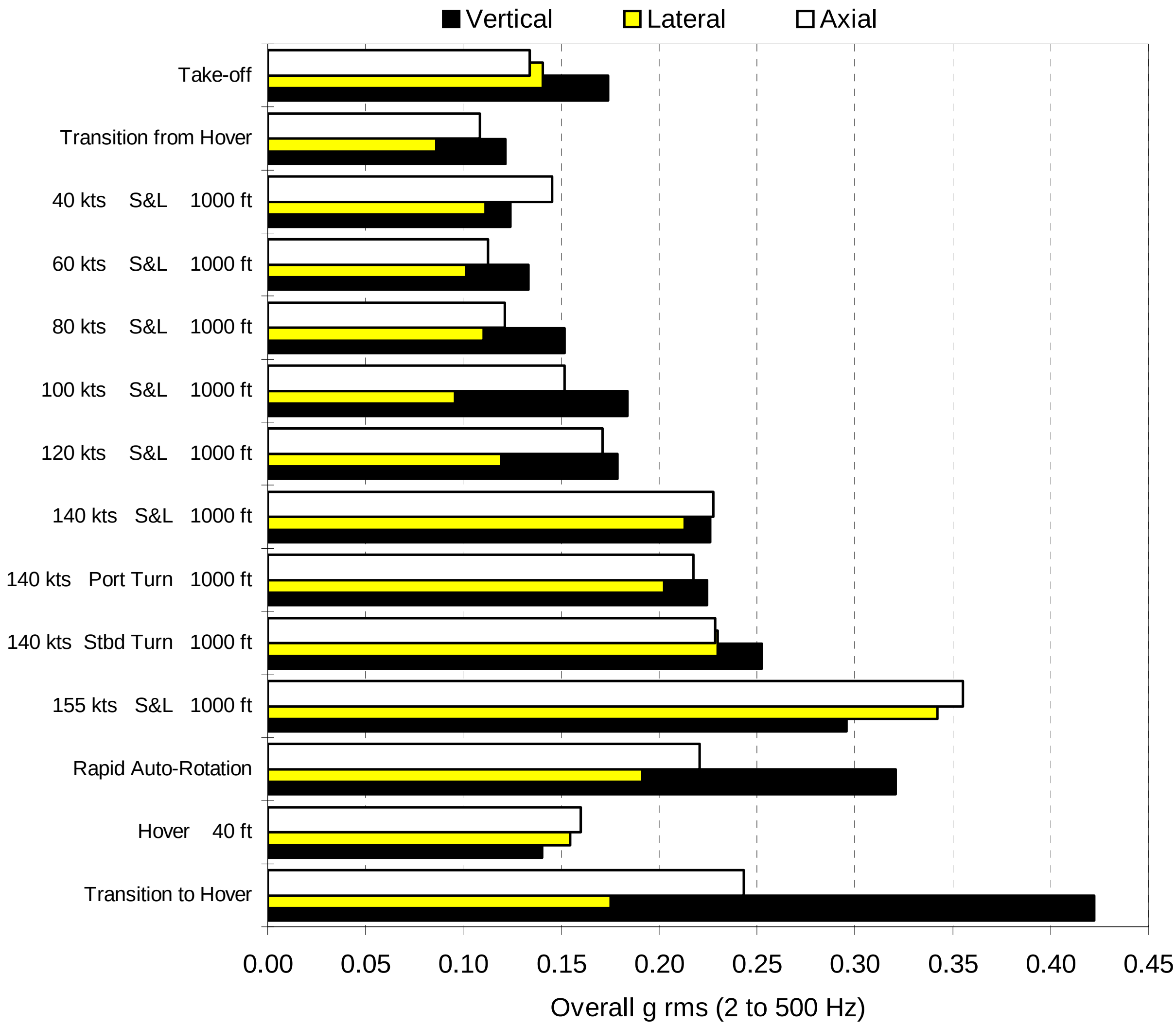
a: Transition to hover **b: Hover**



c: Recovery from auto-rotation **d: 155 kts Straight and level**

Note: All data measured in the vertical axis at Frame Number E160 (see Figure 9)

Figure 7: Vibration responses from a Chinook HC Mk2 transport helicopter during various flight conditions



Note: All data measured at Frame Number E160 (Stbd) at floor level (see Figure 9)

Figure 8: Variation of vibration severity in various flight conditions for a Chinook HC Mk2 helicopter

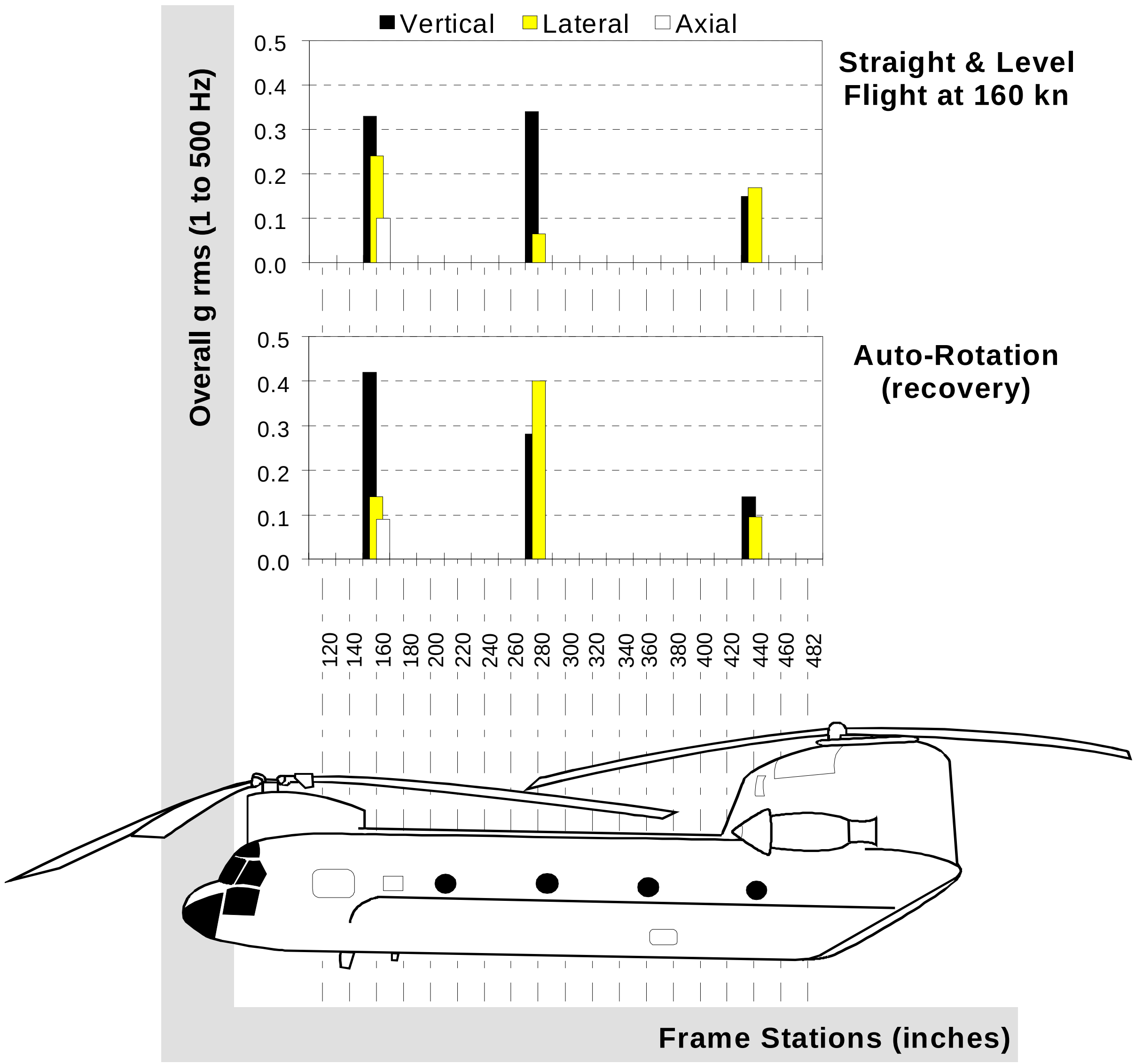


Figure 9: Variation of vibration severity along the fuselage of a Chinook HC Mk 1 helicopter

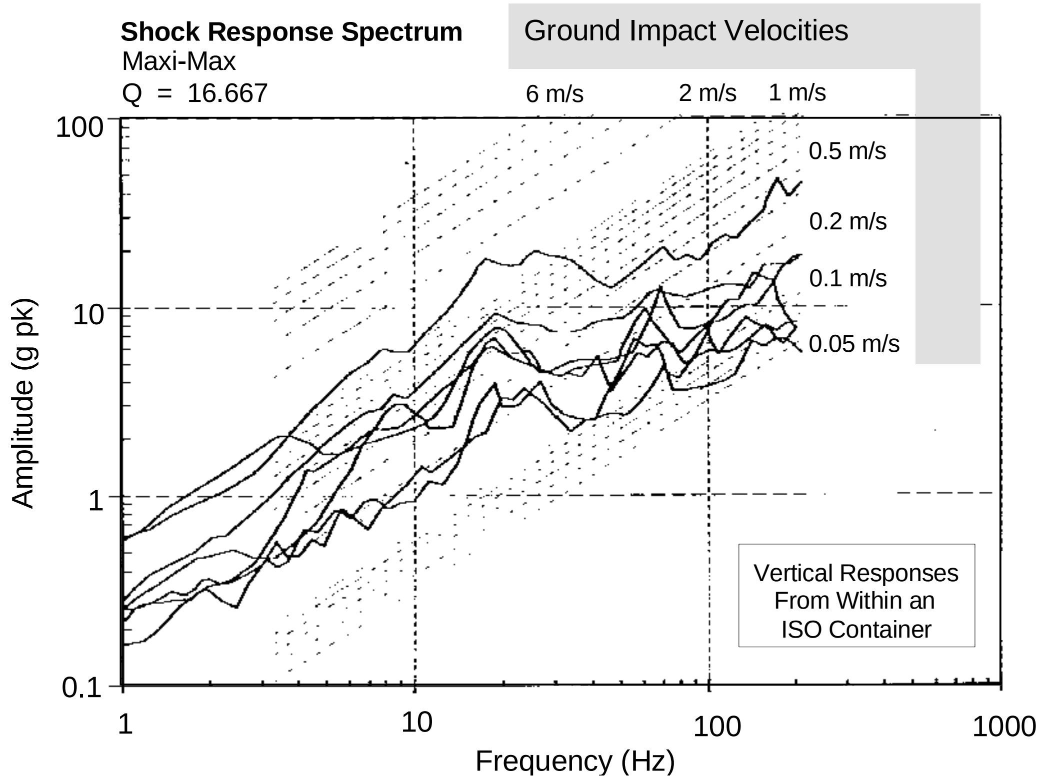


Figure 10: Measured shock responses from the set-down of a load underslung from a Chinook HC MK 1 helicopter

ANNEX A

DERIVATION OF SEVERITIES FROM MEASURED DATA

A.1 Derivation of an Environment Description

A.1.1 Requirements: It is first necessary to establish from the relevant requirements the type of aircraft(s) in which the materiel is to be installed, the role of the aircraft(s) and the flight segments associated with air transportation, the aircraft's operating speeds, and the location of the materiel in the aircraft(s). Having established the requirements, relevant vibration data may be acquired from data banks, should the data exist, or from field measurement trials.

A.1.2 Environment Descriptions: An environment description for materiel installed in an aircraft should generally include for each relevant flight sequence over the range of operating speeds, frequency response characteristics, amplitude probability plots, and time histories of any transients. This information will be used to examine trends, such as how severity is influenced by manoeuvre, altitude and speed. The flow diagram outlined in Figure A.1 points out the steps to be adopted to derive an environment description from measured data. This diagram enables frequency response characteristics and dynamic response amplitudes to be quantified for all the relevant test conditions. A process for using these components of the environment description to produce test spectra and durations is discussed below.

A.2 Derivation of Vibration Test Severities

A.2.1 General: Test severities are defined in terms of the characteristics and amplitudes of the broad band background vibration, narrow band components associated with passing blades frequencies or jet noise, and durations. Advice on establishing these parameters is given below.

A.2.2 Broad Band Component

a. Characteristics: In general, it can be expected that the broad band component spectral characteristics, i.e.: the shape of ASD plots, will be stable with respect to many parameters, including aircraft speed and altitude.

b. Amplitude: amplitude probability analysis helps to check the data stationarity. An approach is to use amplitude probability distributions (APD).

A.2.3 Narrow Band Components.

a. Characteristics: For propeller aircraft and rotary wing aircraft, the frequency of the narrow band components at a given speed can be calculated from knowledge of the passing blade frequencies. Those frequencies are expected to be easily recognisable in measured data, at least under constant speed conditions. For jet aircraft, even under constant speed conditions, narrow band conditions may be hardly discernible.

b. Amplitudes: Establishing the amplitudes of these components can be a problem because of their changing frequency with aircraft speed. This can lead to an under-estimation of severity because of averaging effects implicit in a ASD analysis.
A solution is to gather data at a given flight segment and for constant speeds. Thus, the stationarity of the data and the repeatability of the acquisition process are both guaranteed. Those data can then be analysed separately.
Alternatively, if the speed is not constant throughout a record, evolutionary spectra (waterfall plots) can be used.
In either case, the severity, expressed in either ASD or RMS form, should be associated with the resolution bandwidth to make the definition unambiguous.

A.2.4 Test Duration: Test durations should be based upon the required life of materiel and the usage profile of the relevant aircraft(s). In order to avoid impracticably long test durations, it is general practice to invoke equivalent fatigue damage laws such as Miner's Rule. This rule is also known as the "Exaggeration Formula" and is expressed as follows:

$$t_2 = t_1 \left(S_1 / S_2\right)^n$$

where

t_1	=	the actual duration in the requirements ~~at~~ of the flight segment characterised by the measured level
t_2	=	the equivalent duration at the test level
n	=	the exaggeration exponent

For rms level

S_1	=	the rms level of the measured spectrum
S_2	=	the rms level of the test spectrum
n	= b =	the exaggeration exponent (values between 5 and 8 are generally acceptable).

For ASD level

S_1	=	the ASD level of the measured spectrum
S_2	=	the ASD level of the test spectrum
n	= b/2 =	the exaggeration exponent (values between 2.5 and 4 are generally acceptable).

(b corresponds to the slope of the fatigue (S/N) curve for the appropriate material)

For rms levels, the exaggeration exponent is the slope of the fatigue (S/N) curve for the appropriate material. This expression is applicable to metallic materials such as steels and aluminium alloys which possess an essentially linear stress-strain relationship. This expression is used with less confidence with non-linear materials and composites. Although the expression has been shown to have some merits when applied to materiel, it should be used with extreme caution, if unrepresentative failures are to be avoided. On no account should test levels be increased beyond the maximum levels that equipment may be expected to experience during its Service life. Furthermore, where there is evidence that the materiel is not fully secured to the aircraft, Miner's Rule is totally invalid and should not be used. In such cases the Loose Cargo Test (AECTP 400, Method 406) should be considered as an alternative.

A.3 Comparing Measured Data With Test Specifications

A.3.1 When comparing measured spectra from a vehicle trial with that contained in a test specification or generated by test house equipment, care must be taken to avoid an under-estimation of the severity of the measured data. This is because of the different amplitude distributions and peak to rms ratios of these types of data. These differences can be compensated for, as shown in this example:

Measured peak APD level = $9.0\ g$ (at the 1 in 500 occurrence level, i.e.: 2.88 sigma)

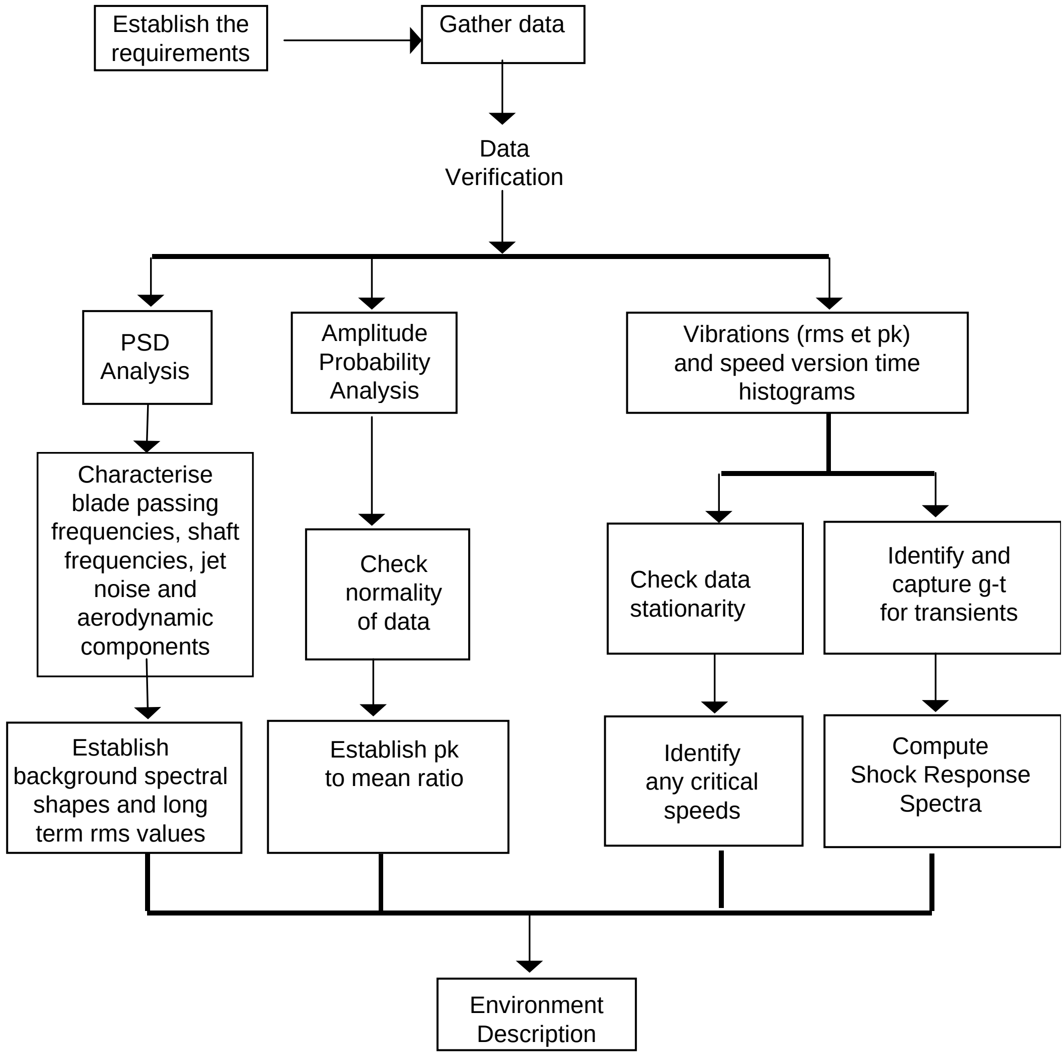
Equivalent gaussian rms $\dfrac{9.00}{2.88} = 3.1 g \text{ rms}$

Measured non-gaussian rms = $1.4 g \text{ rms}$

Factor on measured g rms = $\dfrac{3.1}{1.4} = 2.2$

Factor on measured ASD = $2.22^2 = 4.8$

Whilst this analysis indicates that in this instance a factor of 4.8 should be applied to the measured ASD levels, these higher levels would be appropriate for a relatively short duration.



Note: The steps outlined above would normally be carried out for each flight segment and for all relevant installations

Figure A1: Derivation of an environment description from measured data

A.4 Derivation of a test severity (level and duration) from measured data

This example deals with the mechanical fatigue caused by vibrations that may be experienced by a fully secured cargo during air transportation within a DC8 cargo (jet aircraft) or a C130 Hercules or a C160 NG Transall (propeller aircraft).

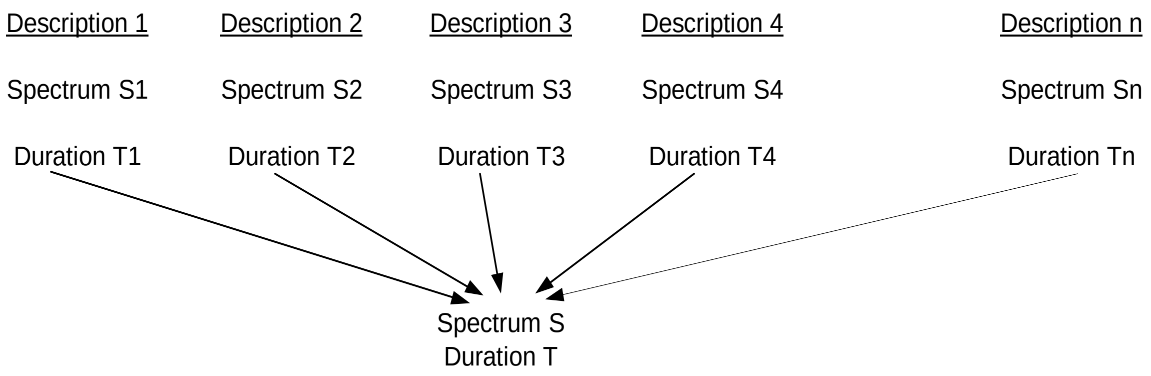
This example deals only with the mechanical fatigue as a default mode.
Although each of the induced mechanical environments associated with the different flight segments are unlikely to be critical in terms of generating potential damaging fatigue on their own, they all contribute in varying degrees to the materiel's fatigue damage.

Hence, as emphasised previously in A.2.3-b, the first step to be performed is to identify the role of the aircraft and the flight segments associated with air transportation and the location of the cargo within the aircraft.

The following 3 pages describe the flight segments identified for each of the possible aircraft. Data are then gathered from field measurement trials for each of the specified aircraft and for each of the identified flight segments. The stationarity of the measurements allows calculation of ASD to describe the mechanical environment over the range 5 to 1500 Hz (for this example).

The calculation results are presented for the different flight segments under the classical ASD format for the Z-axis only. For an actual test program, the following methodology should be applied for each of the 3 axes.

The next steps are taken from leaflet 2410/1 where several technical aspects are developed. The objective is to combine different induced mechanical environments into one single test.



The typical mission profile (consecutive flight segments) for an air transportation in a DC8 cargo is the following.

Flight segment	Rate	Duration
Taxi	25 km/h	0 h 10
Take off	290 km/h	0 h 05
Climb	2500 ft/min	0 h 40
Cruise	900 km/h	3 h 30
Descent	5500 ft/min	0 h 20
Approach	250 km/h	0 h 05
Landing	250 km/h	0 h 01
Taxi	25 km/h	0 h 09
Total		**5 h 00**

DC8 Cargo
four engined jet aircraft

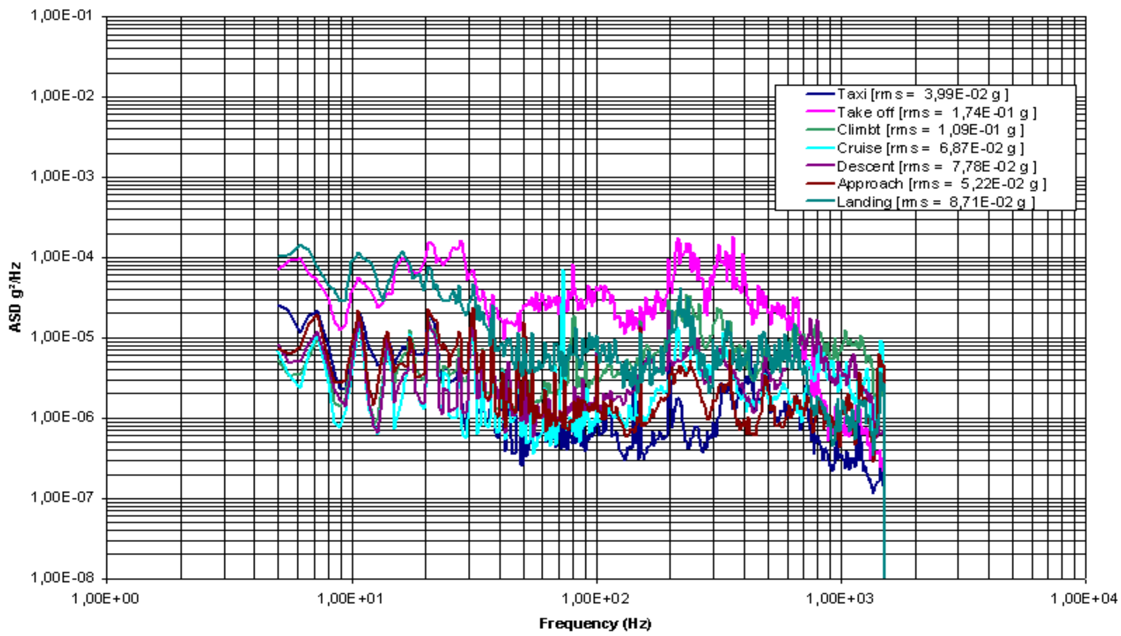


Figure A2: ASD associated with DC8 Cargo air transportation

The typical mission profile (consecutive flight segments) for an air transportation in a C160

Transall is the following. One can notice the change in passing blade frequency with the aircraft speed.

Flight segment	Rate	Duration (min)
Full ground power		0 h 05
Taxi		0 h 14
Take off		0 h 05
Climb	500 ft/min	0 h 40
Cruise	FL 170 190 kt	6 h 30
Descent	750 ft/min	0 h 20
Approach		0 h 05
Landing		0 h 01
Total		**8 h 00**

C160 Transall
double engined, four bladed propeller aircraft

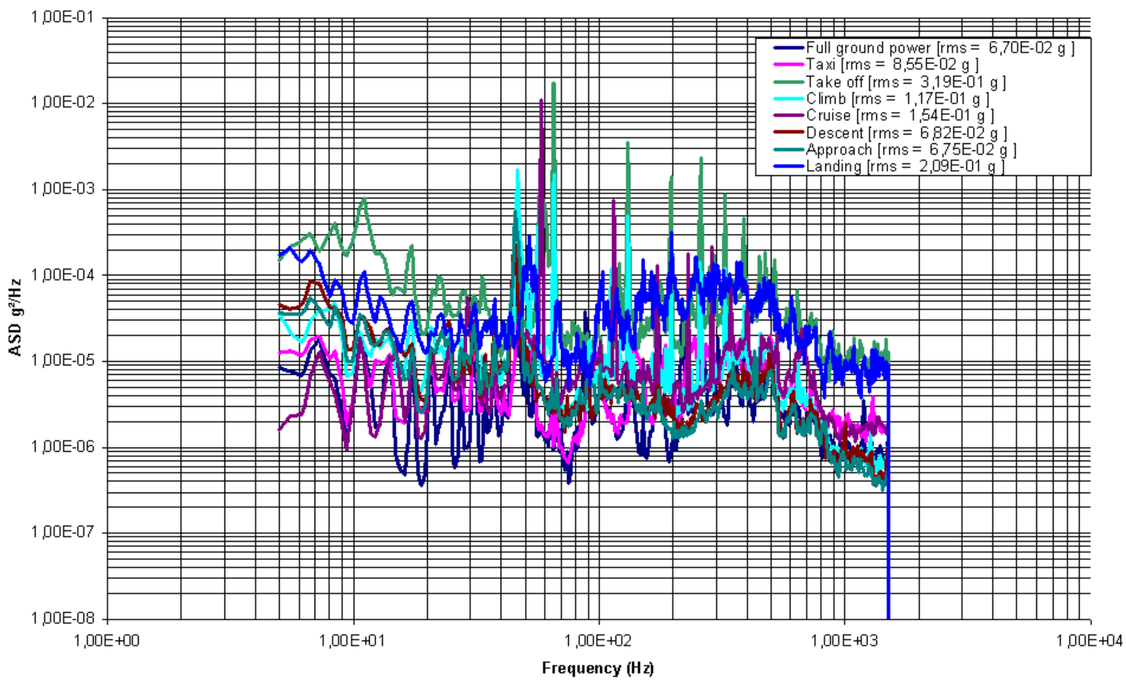


Figure A3: ASD associated with C160 Transall air transportation

The typical mission profile (consecutive flight segments) for an air transportation in a C130

Hercules is the following. One can notice that there is no change in passing blade frequency with speed.

Flight segment	**Rate**	**Duration**
Full ground power	70% low speed =19000 lb/engine	0 h 05
Taxi		0 h 14
Take off		0 h 05
Climb	500 ft/min	0 h 40
Cruise	FL 250 300 kt	6 h 30
Descent	700 ft/min	0 h 20
Approach		0 h 05
Landing		0 h 01
Total		**8 h 00**

C130 Hercules
four engined, four bladed propeller aircraft

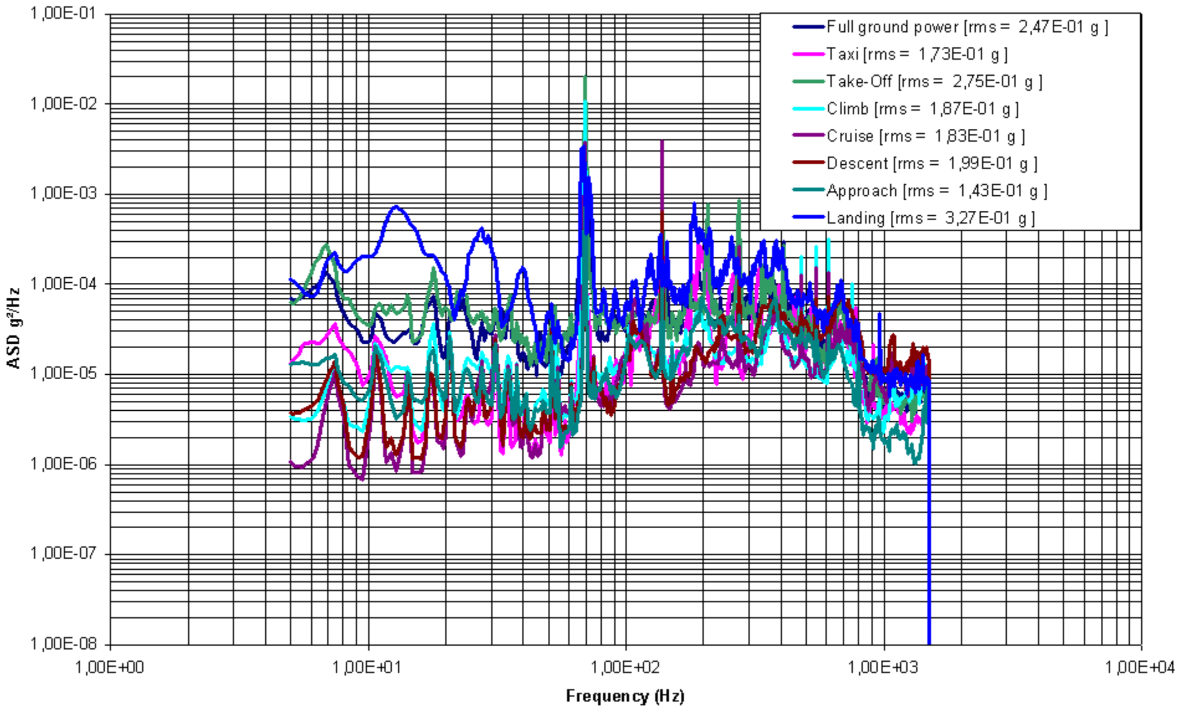


Figure A4: ASD associated with C130 Hercules air transportation

Leaflet 2410 proposes a methodology for the computation of the accumulated fatigue damage. The results presented are based on the formula described in the 2410 leaflet, chapter 2.

Once the flight mission profile and associated ASD have been collected, it becomes possible to determine the total mechanical fatigue, that materiel will accumulate over one flight.
The results are presented under the Fatigue Damage Spectrum (FDS) format, as noted in the 2410. The FDS is the curve that represents variation of the damage as a function of the natural frequency for a given damping and slope of the material SN curve.

Assumptions used for the calculations are:
- single DOF system, as modelled for the Shock Response Spectrum, see leaflet 403, figure C4,
- damping equal to 5% i.e. 'Q' equal to 10 (see leaflet 2410, Annex B, chapter 2.2).
- computation uses a slope 'b' of the fatigue (S-N) curve equal to 8 (see leaflet 245/1, Annex A, chapter A.2.4).
- This value is adequate to describe the behaviour of the mainly metallic structure of the materiel. The electronic equipment are qualified from another test, which takes into account their own required life duration and their own LCEP. For electronic equipment and non metallic materials, elastomers, composites, plastics, explosives, a value of 'b' equal to 5 is recommended.

For a given aircraft, one can sum the damage generated by each flight segment, prorated by the duration of the segments. By performing the calculations for each possible aircraft, one can compare the fatigue damage accumulated by a materiel over one whole flight corresponding to a real air transportation sequence. The following figure illustrates the fatigue corresponding to one flight for each aircraft.

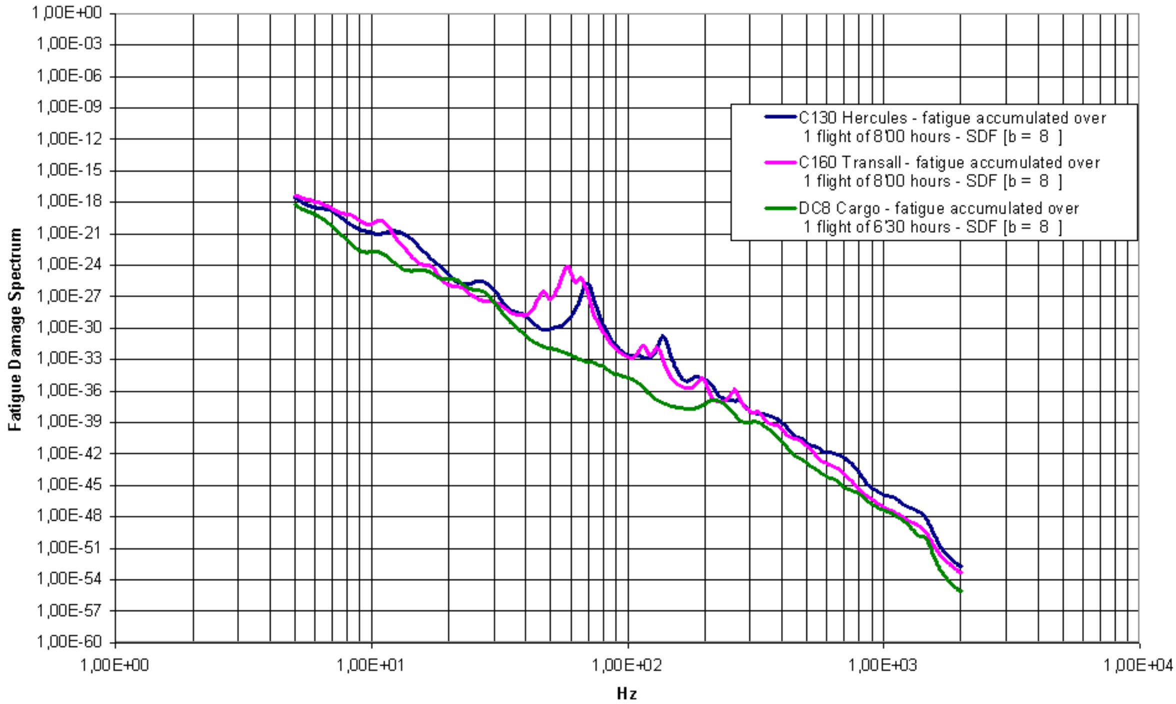


Figure A5: FDS for 1 flight associated with each aircraft

The fatigue accumulated over N flights for each frequency is equal to N times a single flight fatigue.

The principle used is to develop one unique ASD that will generate during a test the same mechanical fatigue that would occur during a real air transportation with all its different flight segments.

A.4.1 Application for one aircraft

If there is only one aircraft scheduled for air transportation, then the test severity should generate the same fatigue as the number of flights in accordance with the requirements for that particular aircraft.

For example the requirements are 200 hours of flight in a DC8 cargo jet aircraft over the whole lifetime of the materiel.

The lower ASD amplitude of the following figure represents an ASD that, when applied for 200 hours, will generate along the Z-axis the same mechanical fatigue as 200 hours of flight, whatever its natural frequencies.

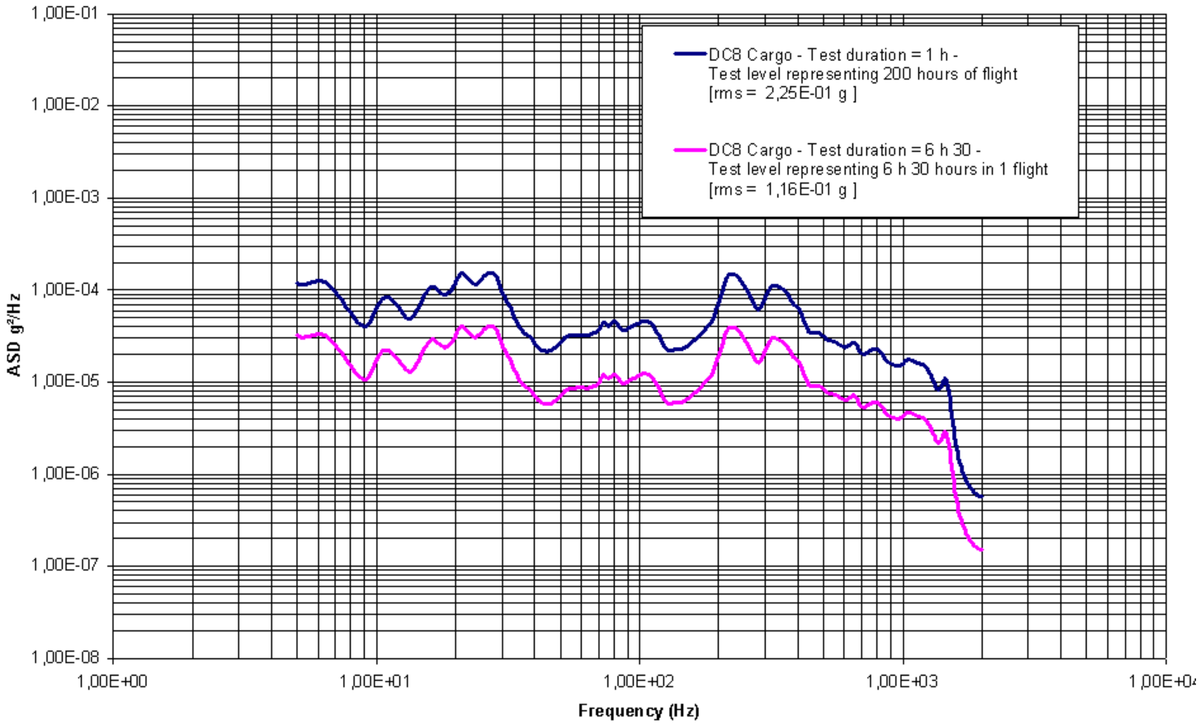


Figure A6: ASD associated with test level for DC8 Cargo air transportation

It is obviously cost-effective to reduce the test duration in order to avoid a 200 hours test. The criterion of equivalence in mechanical fatigue leads to increase the test level with the decreasing of test duration. Thus, Figure A6 compares the test level that should be applied for 200 hours to be fatigue equivalent with 200 hours of flight with the test level for a 1 hour test only (upper ASD amplitude in Figure A6).

A duration of about 1 hour represents the shortest test applicable without excessively increasing the test ASD over the measured environment in terms of robustness for the materiel. Thus, the Maximum Response Spectrum associated with the ASD test level will stay within realistic stresses in comparison with the ultimate stress that would be attained with the real environment. See recommendations in leaflet 2410, Annex B, Chapter 2.4.

Note that the value of b directly impacts the reduced test duration as for the exaggeration exponent in the 'exaggeration formula'. See for example leaflet 245, chapter A.2.4.

A.4.2 Application for several aircraft (composite example)

In a case where several different aircraft should be considered in accordance with the requirements, a composite test may be derived from real measured data. This possibility exists when a total number of flights are required without knowing which aircraft will be used for each flight.
Alternatives exist.

a) One test item – Multiple aircraft:
   one can test an item for each possible aircraft. This solution leads to over-qualifying the materiel since the total number of hours of flight will be applied for each considered aircraft and then the accumulated fatigue will be greater than in reality.
b) One test item – Prorated Multiple aircraft:
   one can assume that each possible aircraft will be used for a given fraction of the total number of hours of flight. But the validity of the time distribution is often questionable.
c) Multiple test items – Multiple aircraft:
   one can test individual items for each possible aircraft, ensuring that the materiel will be able to survive any of the aircraft environments. However, this increases both cost and time.

A composite test would allow checking the ability of a materiel to survive a given duration of air transportation without knowing the prorated use of each possible aircraft.
An adequate composite test would also not over-test the materiel.

In order to accomplish those aims, one has to prove for each aircraft the fatigue-resistance of the materiel in accordance with its natural frequencies. The envelope of the Fatigue Damage Spectrum provides for each possible natural frequency of the materiel the overall accumulated fatigue.

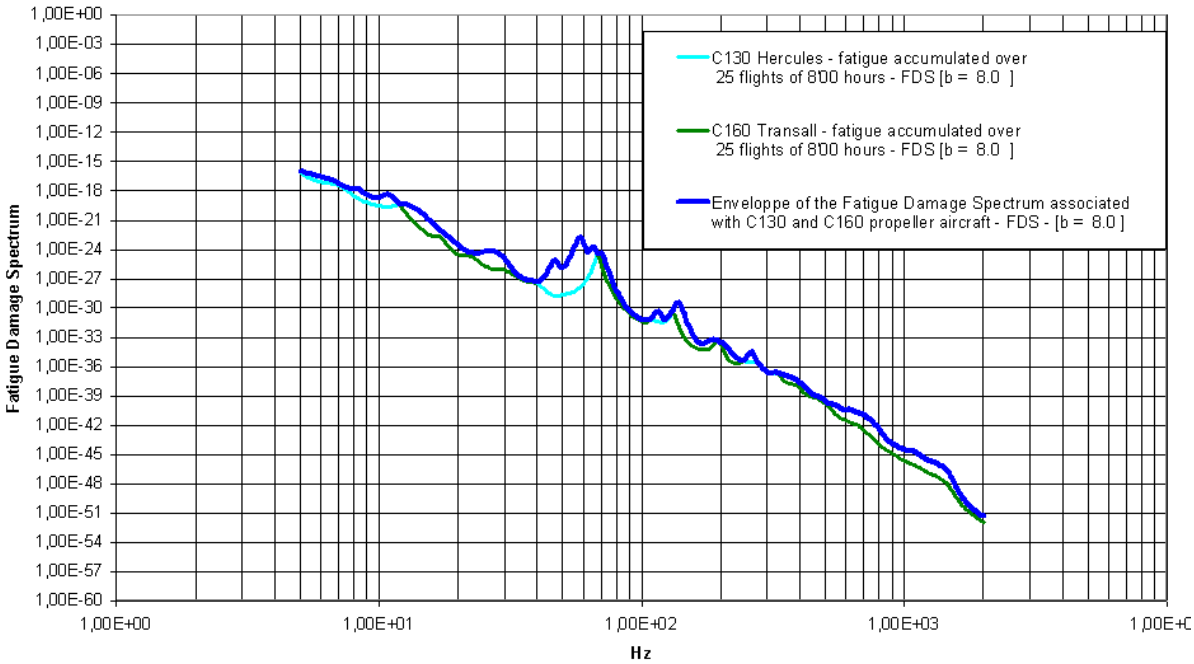


Figure A7: FDS envelope i.e.:
covering 25 flights indifferently split between a C130 Hercules and a C160 Transall

To develop a composite example, figure A7 illustrates the FDS enveloping the fatigue generated by 200 hours of air transportation in Hercules and in Transall aircraft.

Figure A7 shows the relative severity of a C160 Transall compared with a C130 Hercules for each frequency: For example,

- the Hercules aircraft is more severe in terms of mechanical fatigue for materiel which has a natural frequency at about 70 Hz (this frequency corresponds to the constant passing blade frequency for the C130),
- the Transall aircraft is more severe in terms of mechanical fatigue for materiel which has a natural frequency between 40 and 60 Hz (these frequencies correspond to the passing blade frequency variable with speed for the C160).

To develop a test severity covering 200 hours of air transportation split between a Hercules and a Transall, one calculates an ASD generating the Fatigue Damage described by the envelope of the two FDS.

Figure A8 illustrates the result of such a calculation.
The lower ASD amplitude of the following figure represents an ASD that, when applied for 200 hours, will generate along the Z-axis the same mechanical fatigue as 200 hours of flight, whatever its natural frequencies.
The assumption is that fatigue is the only considered failure mode. If other failure modes are expected, then refer to leaflet 2410.

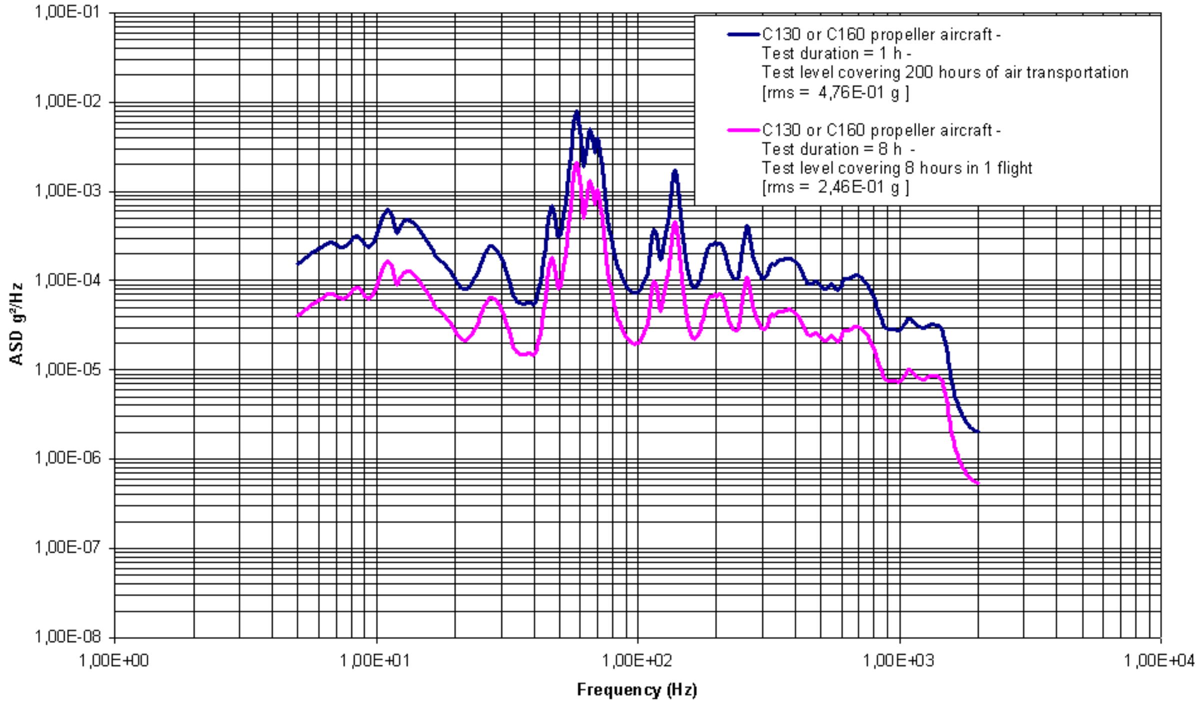


**Figure A8: test level for air transportation i.e.:
ASD covering 200 hours in either a C130 Hercules or a C160 Transall**

For example, we consider a requirement of 200 hours of air transportation of a fully secured cargo within an Hercules C130, or a Transall C160 over the whole lifetime of the materiel.

It is obviously cost-effective to reduce the test duration in order to avoid a 200 hours test. The criterion of equivalence in mechanical fatigue leads to increase the test level with the decreasing of test duration. Thus, Figure A8 compares the test level that should be applied for 200 hours to be fatigue equivalent with 200 hours of flight with the test level for a 1 hour test only (upper ASD amplitude in Figure A8).

A duration of about 1 hour represents the shortest test applicable without excessively increasing the test ASD over the measured environment in terms of robustness for the materiel. Thus, the Maximum Response Spectrum associated with the ASD test level will stay within realistic stresses in comparison with the ultimate stress that would be attained with the real environment. See recommendations in leaflet 2410, Annex B, Chapter 2.4.

Note that the value of b directly impacts the reduced test duration since it is the exaggeration exponent in the 'exaggeration formula'. See for example leaflet 245, chapter A.2.4.
When applied to a single ASD, the just illustrated methodology is strictly equivalent to the 'exaggeration formula' used with the same value of 'b'.

This methodology, when applied for:
- all possible locations for a materiel,
- all possible aircraft within the NATO forces,

leads to more severe test severities (level and/or duration).

Test severities, covering a large set of both locations and aircraft and including conservatism factors, are described in leaflet 401:
- figure 5 for jet aircraft transport,
- figure 6 for propeller aircraft transport,
- figure 7 for helicopter transport.

ANNEX B

REFERENCES

B.1 Fixed wing propeller aircraft - Hercules C130

B.1.1 Title: Characterisation of Hercules C130 mechanical environment
Author: LEBEAU Roger
Source: DGA/DME/LRBA
Ref No: E.T. No:636/92/ECM
Date: August 1992
Pages: 163

B.1.2 Mission/Platform:

Air transportation of materiel (missiles in containers)

B.1.3 Summary of Technical Data:

Environment description in different situations (full ground power, take-off, 370 ft cruise, reverse thrust, landing approach, landing)

B.2 Fixed wing propeller aircraft - Transall C160 NG

B.2.1 Title: Characterisation of Transall C160 NG mechanical environment
Author: LEBEAU Roger
Source: DGA/DME/LRBA
Ref No: E.T. No:654/92/ECM
Date: August 1992
Pages: 315

B.2.2 Mission/Platform:

Air transportation of materiel (missiles in containers)

B.2.3 Summary of Technical Data:

Environment description in different situations (full ground power, take-off, 300 ft and 180 Kt, 14000 ft and 200 Kt, 19000 ft and 190 Kt, landing approach, landing)

B.3 Helicopter - Super Frelon

B.3.1 Title: Characterisation of the Super Frelon helicopter mechanical environment

Author:	LEBEAU Roger
Source:	DGA/DME/LRBA
Ref No:	E.T. No:401/94/ECM
Date:	May 1994
Pages:	48

B.3.2Mission/Platform:

Air transportation of materiel (missiles in containers)

B.3.2Summary of Technical Data:

Environment description in different situations (taxi operations, take-off, 500 ft and 110 Kt, 500 ft and 130 Kt, 500 ft and 83 Kt, landing approach).

B.4 Fixed wing jet aircraft - DC8 Cargo

B.4.1 Title: Characterisation of the DC8 Cargo aircraft mechanical environment

Author:	DELOY Christian
Source:	DGA/DME/LRBA
Ref No:	E.T. No:636/92/ECM
Date:	August 1992
Pages:	163

B.4.2Mission/Platform:

Air transportation of materiel (missiles in containers)

B.4.2Summary of Technical Data:

Environment description in different situations (taxi operations, take-off, climb 2500ft/min, cruise FL 370 and M0.82, descent, landing approach, landing).

LEAFLET 242/4

SEA TRANSPORTATION UP TO FORWARD BASE

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LEAFLET 242/4

SEA TRANSPORTATION UP TO FORWARD BASE

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be experienced by materiel during sea transportation between places of manufacture and storage bases. The sources and characteristics of the mechanical environments are presented and supplemented by references. Advice is also given on potential damaging effects, treatment options and, where relevant, the selection of the appropriate AECTP 400 Test Method. This leaflet also refers to advice on the derivation of test severities from measured data.

1.2 The leaflet considers sea transportation by either naval or commercial ships. For environmental conditions encountered when deployed on warships reference should be made to Section 248. Some critical design loads for warships are set by hostile conditions which are not usually relevant to transportation.

1.3 For the purpose of this leaflet the materiel, which is the subject of the transportation environment, may consist of an item of unprotected materiel or materiel carried within some form protection, package or container. A payload may consist of one or more items of materiel. Unless specifically stated otherwise the environmental descriptions relate to the interface between the carriage vehicle and the payload. All axes relate to ship axes.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Vibration Environments

2.1.1 The dynamic excitations, experienced by a payload during transportation by ship are mainly continuous vibratory motions. The continuous motions are principally vibrations arising from propulsion equipment and auxiliary machinery. In addition some responses occur due to sea motions. Accurate quantitative identification of the various sources of shipboard dynamic motions is often difficult due to the low levels involved. Any transient motions that do occur are usually associated with adverse sea states.

2.1.2 Engine and Propulsion System: Vibration measurements made on payloads, carried in holds and on deck, usually indicate periodic motions related to engine speed and propeller blade passing frequency. The degree of contribution, from each of these components, appears to be related to proximity of the payload to the engine room or propulsion system. Responses from the holds of a Naval Armament Vessel (RMAS Arrocher) are shown in Figure 1. The responses illustrate the considerable number of essentially periodic components. These periodic components arise from auxiliary equipment in addition to the engine and propulsion system.

2.1.3 Auxiliary Equipment: The operation of auxiliary equipment gives rise to a general background random vibration. This apparently random vibration is generally composed of periodic motions arising from the auxiliary systems. The severity of these periodic motions is related to the proximity of specific auxiliary equipment. Air conditioning and power generating equipment may give rise to significant amplitudes. However, measured data are not available for payloads in close proximity to such equipment.

2.1.4 Sea State Induced: The effects of sea condition are often difficult to discern at low sea states. However, the severity of payload vibratory motions seems to increase at higher sea states. Very little evidence exists to allow a relationship to be quantified, but a trend of increasing vibration severity with sea state can be identified in Figure 2. The information presented is from the same measurement source as for Figure 1. The severity of lateral responses seems to be influenced by the relative heading of the ship to the direction of the sea. Specifically the higher levels arise when the sea is transverse to the heading of the ship.

2.2 Transient Environments

2.2.1 Green Sea Loading: Equipment carried as deck cargo may experience green sea frontal loadings of 70 kPa acting over 350 ms with transient loadings of 140 kPa for 15 ms.

2.2.2 Slamming: Higher sea states can give rise to transitory motions arising from waves impacting (or slamming) the ships hull. The actual payload would not experience these excitations directly but rather the dynamic responses of the ships hull (natural frequencies are in the 2-5 Hz region) arising from these excitations. The severity and occurrence rate of such conditions, for the various categories of sea state, do not appear to be quantified.

2.3 Quasi-Static Environments

2.3.1 Quasi-Static Accelerations: During all forms of transportation steady state inertia accelerations are experienced. However, these are usually less than those experienced by most materiel during other phases of deployment. For general cargo the worst case values are:

a. Upwards 2 g

b. Downwards 2 g (including gravity)

c. Lateral 0.8 g

d. Forward 2 g

e. Aft 1 g

2.3.2 Tilt: Materiel may be subject to static tilt of up to 30 degrees.

3. POTENTIAL DAMAGING EFFECTS

3.1 Failure Mechanisms

3.1.1 The mechanical environments arising during the sea transportation of materiel may induce a number of mechanisms of potential materiel failure. The most significant of these mechanisms are related to either displacements induced in the materiel or as a result of acceleration loadings. Induced displacements within the materiel may produce relative motions which in turn may result in collisions between equipments, tension failures and connectors becoming loosened. Acceleration related failures may arise through the action of inertia loadings. These may be applied once, to produce a threshold exceedance failure, or repeated to produce a fatigue induced failure. Failures induced as a result of an applied velocity are fairly unusual. However, the application of velocity loadings on some electrical equipment and certain types of sensors may induce spurious voltages. These in turn may give rise to functional failures.

3.2 Vibration Environments

3.2.1 For equipment with low natural frequencies, the periodic nature of the excitations arising from sea transportation coupled with the long duration of exposure can result in large cycle fatigue damage. In addition the low frequency, and hence large displacement, motions can result in internal damage of sensitive items. (Some VDU screens have been found to be particularly sensitive.)

3.3 Transient Environments

3.3.1 At higher sea states a significant proportion of the transitory motions, experienced by a payload, occur at the lower flexible body modes of the ship. The frequencies of these modes (typically less than 5 Hz) are very low compared to the flexible modes of all, but a few, payloads. The consequence of this is that the payload, in effect, experiences mainly quasi-static loading rather than dynamic motions.

3.4 Quasi-Static Environments

3.4.1 The quasi-static inertia loadings are usually of such low magnitude as not to cause any concern. In general the quasi-static loadings due to handling exceed those of sea transportation.

4. TEST SELECTION

4.1 Vibration Environments

4.1.1 It may be possible to subsume the sea transportation vibration environment into the road transportation test which is inevitably required for materiel.

4.1.2 Where a specific sea transportation vibration test is required to encompass vibration arising from the engine and propulsion system or from auxiliary equipment, a sine sweep test should be used. The appropriate test procedure is included in AECTP 400 Method 401 - Vibration.

4.2 Transient Environments

4.2.1 Green Sea Loading and Slamming: No specific test for these loadings is identified. The materiel is normally evaluated by calculation.

4.3 Quasi-Static Environments

4.3.1 Quasi-Static Inertia Accelerations: Testing is not necessary because these loadings are either encompassed by testing or calculation for other phases of deployment.

4.3.2 Tilt: Testing for tilt is not normally undertaken.

5. DERIVATION OF TEST SEVERITIES FROM MEASURED DATA

5.1 The recommended procedure for the derivation of test severities from measured data, for materiel transported by sea, is identical to that used for materiel installed within surface ships. Reference should be made to Leaflet 248/1.

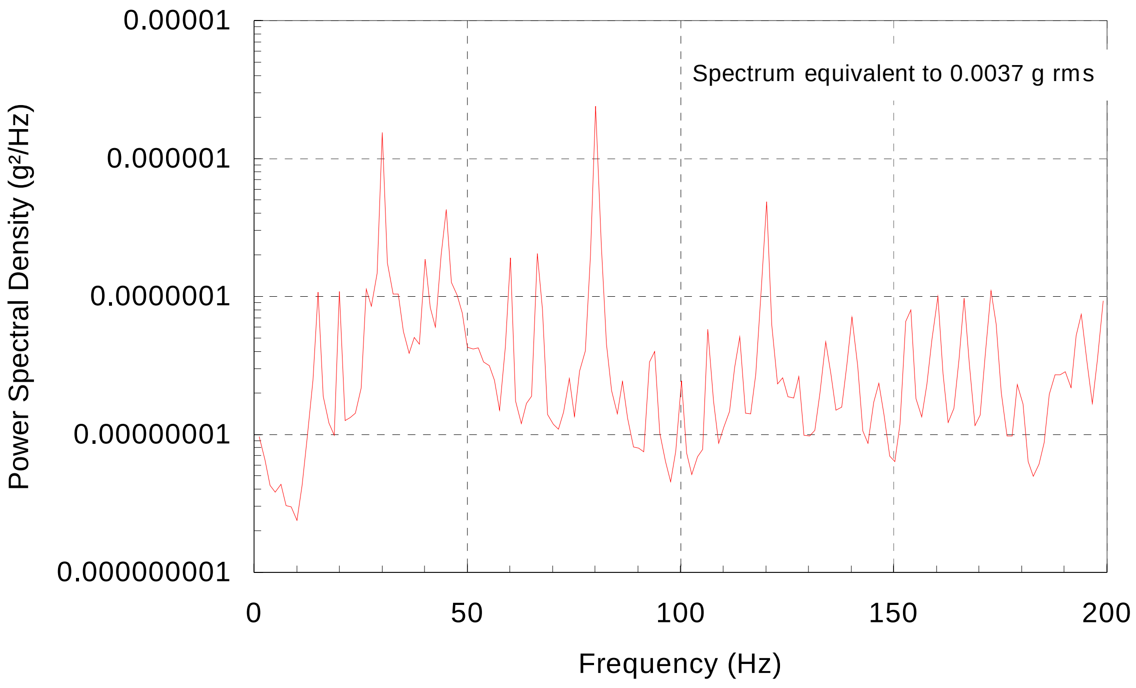

Figure 1: Vibration spectrum for a transport ship's hold (vertical axis)

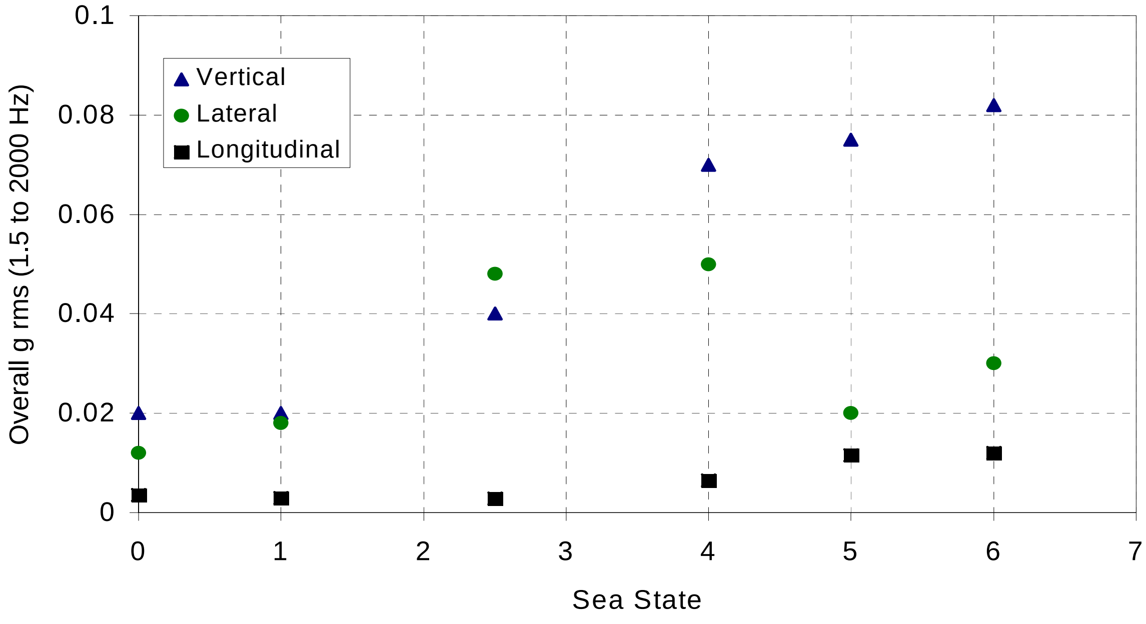

Figure 2: Variations of vibration severity with sea state for a transport ship

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ANNEX A

REFERENCES

A.1 REPLENISHMENT TANKER

A.1.1	Title:	Characterisation of a replenishment tanker mechanical environment
	Author:	LEBEAU Roger
	Source:	DGA/DME/LRBA
	Ref No:	E.T. No:91/92/ECM
	Date:	February 1992
	Pages:	49

A.1.2 Mission/Platform:

Sea transportation of materiel (missiles in containers)

A.1.3 Summary of Technical Data

Environment descriptions for different speeds (13 kt, 14 kt, 15 kt, 15 kt, 20 kt)

A.2 FERRY

A.2.1	Title:	Characterisation of a ferry boat mechanical environment
	Author:	LEBEAU Roger
	Source:	DGA/DME/LRBA
	Ref No:	E.T. No:82/94/ECM
	Date:	June 1994
	Pages:	191

A.2.2 Mission/Platform

Sea transportation of materiel

A.2.3 Summary of Technical Data

Environment descriptions for different speeds (20 kt, entering and departing port)

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LEAFLET 242/5

TRANSPORTATION BEYOND FORWARD BASE

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LEAFLET 242/5

TRANSPORTATION BEYOND FORWARD BASE

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be experienced by materiel during transportation beyond the forward storage base. It specifically includes environmental conditions that may occur during carriage by wheeled vehicles on degraded and off road conditions. It also includes transportation by tracked vehicles such as Armoured Personnel Carriers (APC's). The sources and characteristics of the mechanical environments are presented. Advice is also given on potential damaging effects, treatment options and, where relevant, the selection of the appropriate AECTP 400 Test Method. This leaflet also refers to advice on the derivation of test severities from measured data.

1.2 This leaflet considers only transportation over land because the mechanical environments experienced by materiel when transported by air, sea and rail beyond the forward base are essentially identical to those up to the forward base. For specific information on the mechanical environments experienced by materiel occurring up to the forward base reference should be made to Leaflets 242/1, 242/2, 242/3 and 242/4 for road, rail, air and sea transportation respectively.

1.3 Procedural constraints during land transportation will be minimal beyond the forward base and therefore motions arising as a result of carriage as loose or unrestrained cargo are more likely.

1.4 For the purpose of this leaflet the materiel, which is the subject of the transportation environment, may consist of an item of unprotected materiel or materiel carried within some form protection, package or container. A payload may consist of one or more items of materiel. Unless specifically stated otherwise the environmental descriptions and test severities relate to the interface between the carriage vehicle and the payload. All axes relate to vehicle axes.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 General

2.1.1 Transportation beyond the forward base may utilise good quality roads, however, it must be assumed that transportation can equally occur over poor quality or damaged road surfaces, rough tracks or even over cross country routes. All of these conditions are capable of producing dynamic responses more severe than those occurring during normal road transport. In addition certain types of vehicles may be utilised which are not ordinarily used for normal carriage, such as tracked vehicles.

2.1.2 Payloads transported with limited restraint systems comprising straps, ropes, etc, are insufficient to prevent bounce and jostle. For such payloads it is prudent to assume that the payload is both sufficiently well coupled to the vehicle to induce some vibration and shock responses and sufficiently uncoupled to allow bounce and jostle to occur.

2.2 Wheeled Vehicles

2.2.1 Transportation over rough and degraded roads will change the relative contributions of the dynamic responses arising from the various mechanisms and sources, compared to those occurring during transportation on classified road surfaces. In particular, severely degraded road surfaces will result in much larger displacement motions at low (suspension) frequencies. In addition degraded road surface quality will produce higher severity transient responses. Figures 1 to 3 show the effects of carriage over rough road conditions (a rough concrete track at 24 km/hr - the highest speed the driver could be persuaded to traverse the track using a 4x4 10 tonne vehicle). These figures can be compared with figures in Leaflet 242/1 for normal road use (which originate from the same vehicle with the same driver and payload). The particular points to note are the increase in severity at low frequency and the perturbations in the probability density caused by the high amplitude/ low occurrence rate transients.

2.2.2 Transportation over off-road and cross country conditions will exacerbate the conditions referred to in the preceding paragraph. The severity of the low frequency responses will increase due to the rough nature of the terrain. For the same reason the number and amplitude of the transients will also increase. Vehicle speed is likely to decrease as a result of the extreme motion. Contributions from the higher frequencies (ie: from vehicle dynamic characteristics, engine, transmission etc) will also decrease as a result of extreme motion.

2.2.3 The use of trailers beyond the forward base will produce in most cases payload dynamic responses almost identical to those occurring on the vehicle itself. However, where trailers of lower mass, and with less sophisticated suspension systems are used, responses can become notably more severe than on the vehicle itself.

2.3 Tracked Vehicles

2.3.1 A full description of the characteristics and excitation mechanisms causing dynamic responses within tracked vehicles when using normal roads is given in Leaflet 245/1.

2.3.2 During transportation over rough and degraded roads the effects of the track plates on payload responses become less pronounced and the low frequency displacements and higher severity transient responses increase. These increases are greater than those on wheeled vehicles due to the less sophisticated suspension systems and greater speed capability of tracked vehicles on such surfaces.

2.3.3 During transportation over off-road and cross country routes the effects of track patter essentially disappears. However, both the low frequency displacements and transient responses increase. The latter can become very severe especially when the suspension system "bottoms out". The ability for a tracked vehicle to move at speed when using off-road and cross country routes exacerbates these responses.

2.3.4 The observations regarding transportation of materiel by tracked trailers are essentially identical to those for wheeled vehicles.

3. POTENTIAL DAMAGING EFFECTS

3.1 Failure Mechanisms

3.1.1 The mechanical environments arising during the transportation of materiel beyond the forward base may induce a number of mechanisms of potential failure. Often these mechanisms are related to either displacements induced in the materiel or as a result of acceleration loadings. Induced displacements within the materiel may produce relative motions which in turn may result in collisions between items of materiel, tension failures and connectors becoming loosened. Acceleration related failures may arise through the action of inertia loadings. These may be applied once, to produce a threshold exceedance failure, or repeated to produce a fatigue induced failure. Failures induced as a result of an applied velocity are fairly unusual. However, the application of velocity loadings on some electrical equipment and certain types of sensors may induce spurious voltages. These in turn may give rise to functional failures.

3.2 Wheeled Vehicles

3.2.1 Vibration: For many payloads the vibration environment arising from road transportation may be the most severe that it is likely to experience. However, as materiel is usually packaged during transportation, a reasonable degree of protection will probably exist. Unfortunately this protection is usually designed to protect the materiel from shocks rather than vibration. As a result, in some designs of packaging, significant amplification of the excitations can occur at certain modes of vibration. As these modes are usually of fairly low frequency (10-50 Hz), significant displacements and velocity amplitudes can arise. This may give rise to the possibility of the materiel impacting the inside of its package. Such motions can be further amplified because of the correlation between vertical, pitching and rolling excitations of the vehicle. If any modes of the materiel within its package occur below 20 Hz, the possibility of such modes coupling with the vehicle suspension modes must be considered.

3.2.2 Shocks: In general the amplitude of any shocks arising from poor road surfaces are not usually of particular significance. However, the majority of the transitory dynamic energy could well be below the frequency range where the payloads anti-shock mounts are effective. This situation arises because the major excitation contributions will be at the vehicle suspension frequencies. Consequently the equipment may experience the transients without any effective protection.

3.2.3 Bounce and Jostle: For a loose or lightly restrained container a well designed protection system (or container) should significantly attenuate the majority of the effects of the shocks arising from bounce and jostle. Moreover, in general, the amplitude of the transients will be less severe than those likely to occur as a result of any mishandling, i.e. being dropped. However, the payload may experience a significant number of such transients giving rise to possibly medium cycle fatigue failure conditions. Permanent deformation or damage to the package itself may arise after repeated impacts. Such damage may in turn result in greater loadings on the materiel.

3.3 Tracked Vehicles

3.3.1 Vibration: Both the amplitude and characteristics of the vibrations occurring as a result of track patter are distinctly different to those of the vibrations occurring during transportation by wheeled vehicle. The frequency range over which the main responses occur encompasses the modes of vibration of many packages. As such the potential exists for packages to be excited at one of its modes of vibration sufficiently to generate significant materiel responses.

3.3.2 Shock: The potential damage effects of shocks occurring during transportation by tracked vehicle are similar to those occurring during transportation by wheeled vehicles.

3.3.3 Bounce and Jostle: The potential damage effects of bounce and jostle during transportation by tracked vehicle are similar to those occurring during transportation by wheeled vehicles.

4. TEST SELECTION

4.1 General

4.1.1 Options: Three approaches of simulating the road transport environment are generally available, ie: in the test laboratory using vibrators, in the field using suitable test tracks, or on actual road surfaces under real conditions. The simulation of the environment in the laboratory has the advantage that it allows the simulation to be undertaken in defined and controlled conditions. Moreover, laboratory testing permits reduced test times, reduced costs because vehicle operations are eliminated, and increased safety standards (particularly for munition testing). The simulation using a test track or actual road conditions may be more convenient for large and awkward payloads, and is essential where the payload interacts significantly with the dynamics of the carriage vehicle.

4.1.2 Laboratory Testing: The simulation of the environment in the laboratory is usually viable for all but the largest payloads.

4.1.3 Test Tracks: Due to the difficulties of establishing "worst case" road conditions, use is often made of standard test tracks. A wide range of test tracks is available. Not all of these are designed to simulate road transportation, some are designed to investigate aspects of vehicle handling, and reliability. Therefore, care is needed when selecting suitable surfaces to ensure representative payload responses. High amplitude bounce and jostle can be induced at a rate of occurrence many orders greater than that experienced in-service. For some payloads and materiel, this may induce modes of failure that are unlikely to occur in practice.

4.1.4 Road Trials: Trials conducted over public roads have the advantage that they are representative of real conditions. The difficulty of using real road conditions is that vehicle speed and manoeuvring are influenced by the prevailing traffic conditions.

4.2 Wheeled Vehicles

4.2.1 Laboratory Vibration Testing: When a test is required specifically to simulate wheeled vehicle transportation vibration, a broad band random vibration test is recommended. The test procedure should be that of AECTP 400, Method 401 - Vibration. The severities used will depend upon whether carriage is restricted to rough and degraded roads or encompasses off road and cross country transportation.

4.2.2 Loose Cargo Testing: The loose cargo test has considerable historic precedent as a realistic "minimum ruggedness" test. As a ruggedness test it is applicable to all types of wheeled vehicles likely to be used for the transportation of materiel beyond the forward base as well as certain types of tracked vehicles (APC's etc). It is appropriate for rough and degraded roads as well as off road and cross country conditions. The test procedure used should be that of AECTP 400 Method 406 - Loose Cargo.

4.2.3 Laboratory Shock Testing: The vibration test is intended to be undertaken in addition to the loose cargo test. However, if the loose cargo test is not applicable (ie for large payloads normally well secured) then the vibration test needs to be augmented by a transient test. Several alternative permissible tests are:

a. Basic Shock Test: This test utilises the procedure of AECTP 400, Method 403.

b. Shock Response Spectrum Test: This test utilises the procedure of AECTP 400 Method 417.

4.2.4 Static Acceleration Test: The steady state acceleration levels experienced by payloads during transportation are usually encompassed by those from other environments.

5. DERIVATION OF TEST SEVERITIES FROM MEASURED DATA

5.1. Wheeled Vehicles

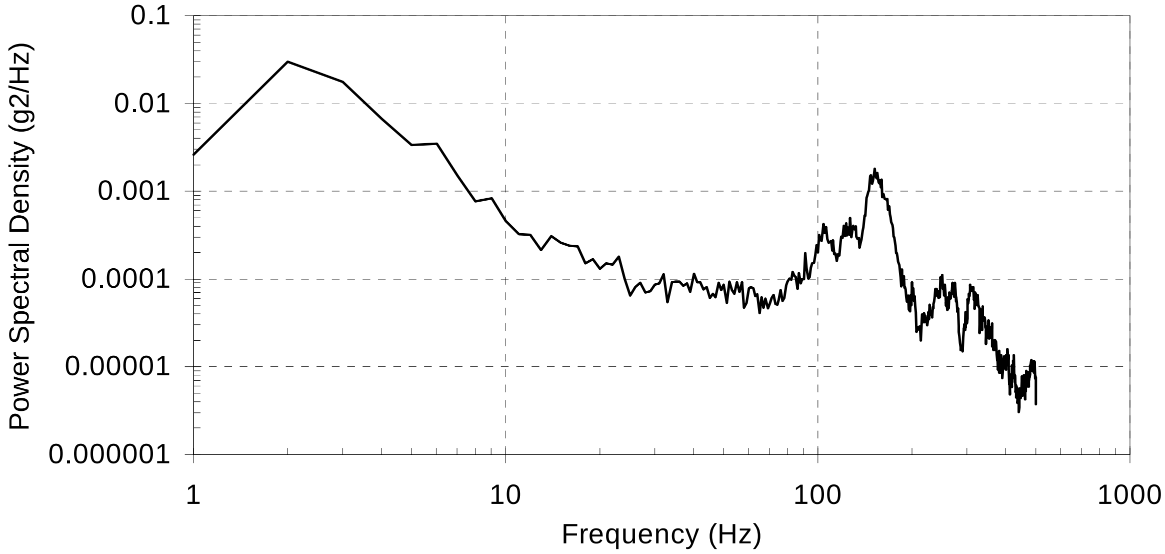
5.1.1. Vibration, Shock and Transients: A considerable range of opinion exists as to the most appropriate methods for the processing of measured vibration data from both wheeled and tracked vehicles. A common approach for wheeled road vehicles is addressed in Leaflet 245/2.

5.1.2. Bounce and Jostle: Since the test severities for the bounce and jostle test cannot be tailored, it is inappropriate to derive test severities from measured data.

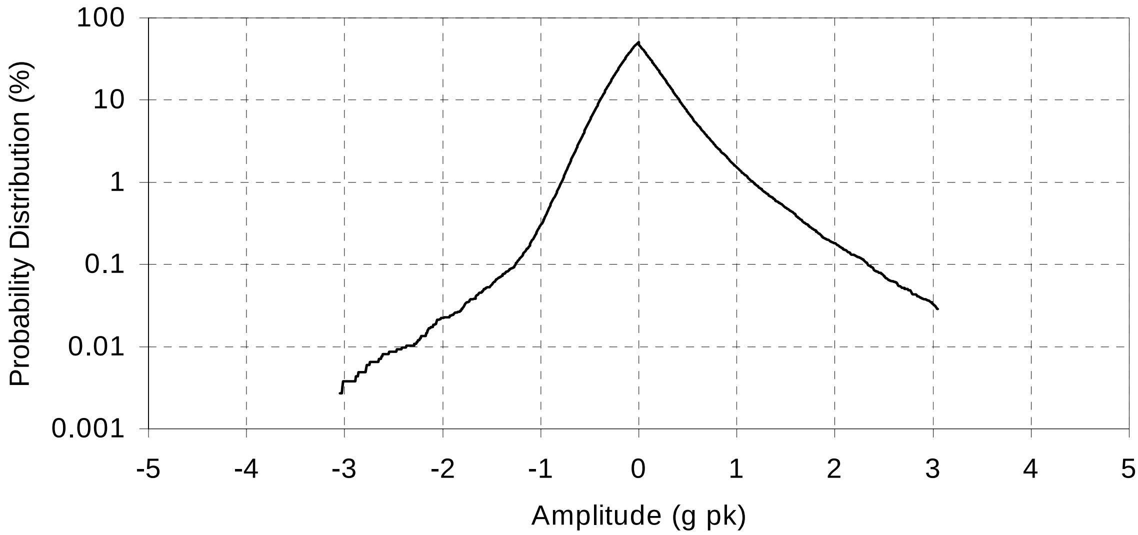
5.2. Tracked Vehicles

5.2.1. Vibration, Shock and Transients: Information on the derivation of test severities from measured data for tracked vehicles is given in Leaflet 245/1.

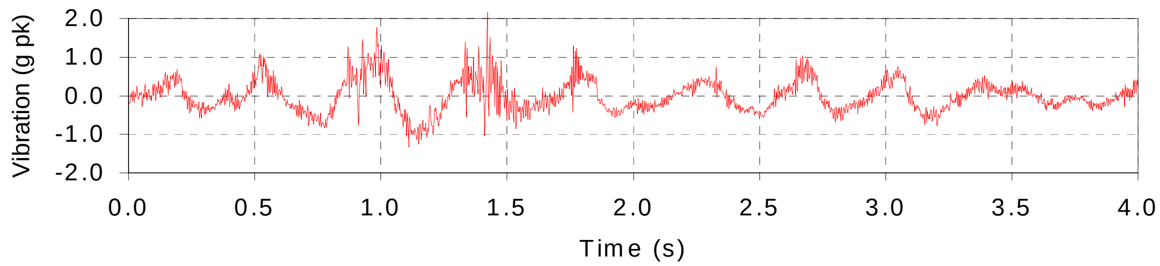
5.2.2. Bounce and Jostle: Since the test severities for the bounce and jostle test cannot be tailored, it is inappropriate to derive test severities from measured data.



a: Vibration spectrum

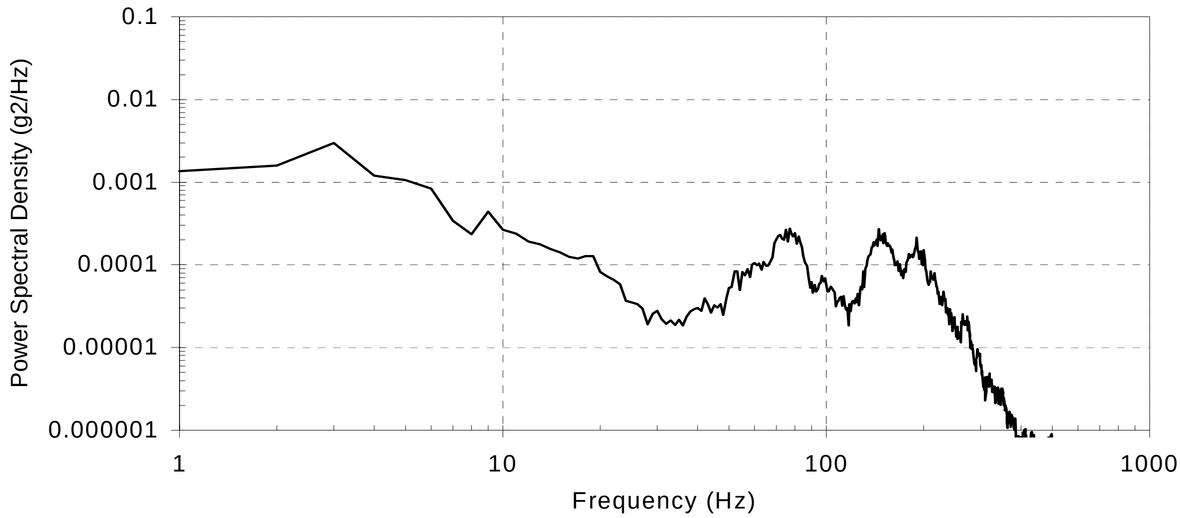


b: Amplitude probability distribution

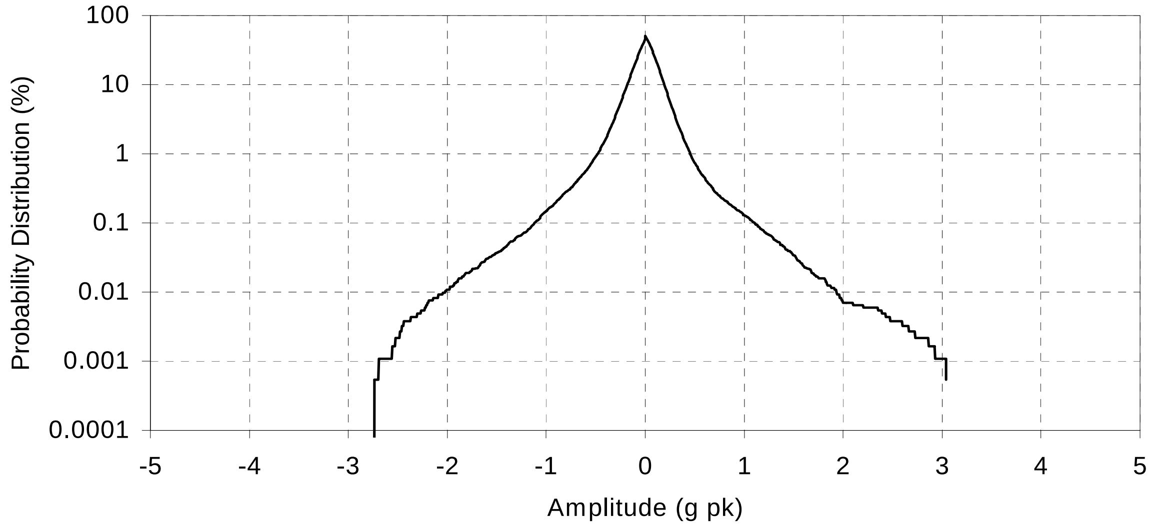


c: Transient response

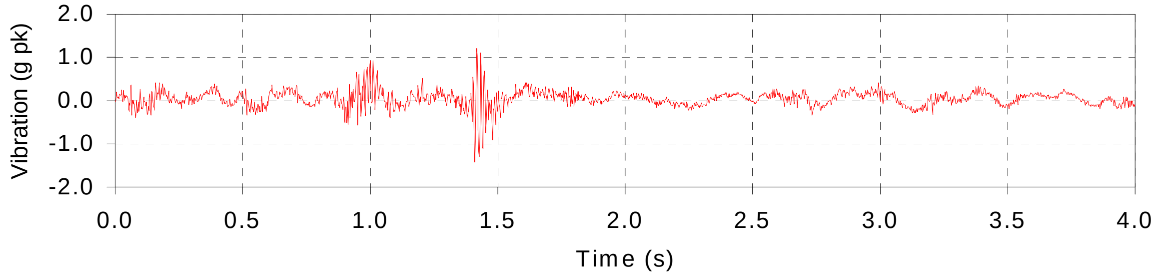
Figure 1: Vibration responses in the vertical axis measured during transportation on a rough road



a: Vibration spectrum

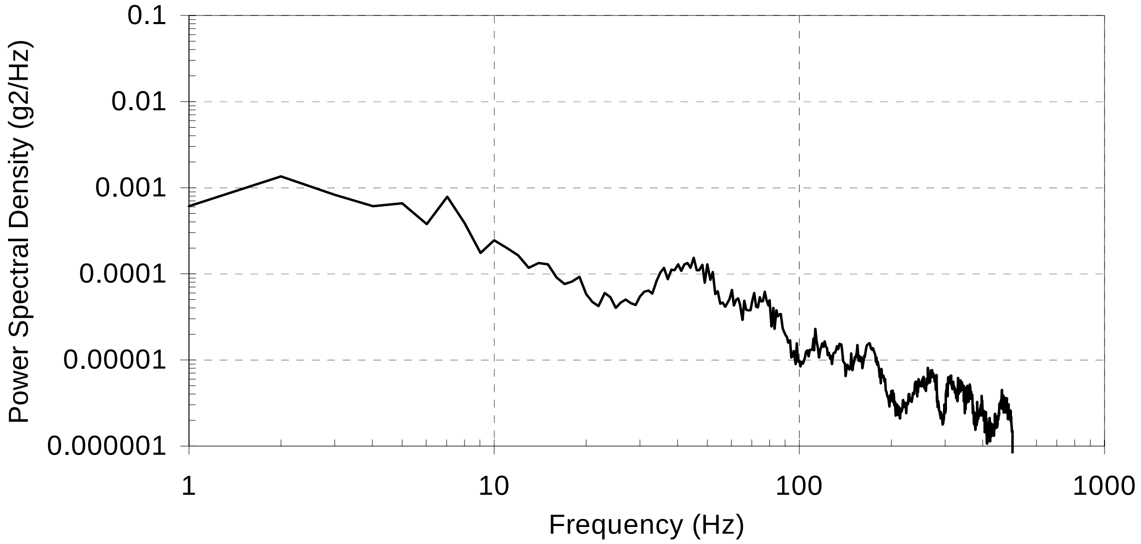


b: Amplitude probability distribution

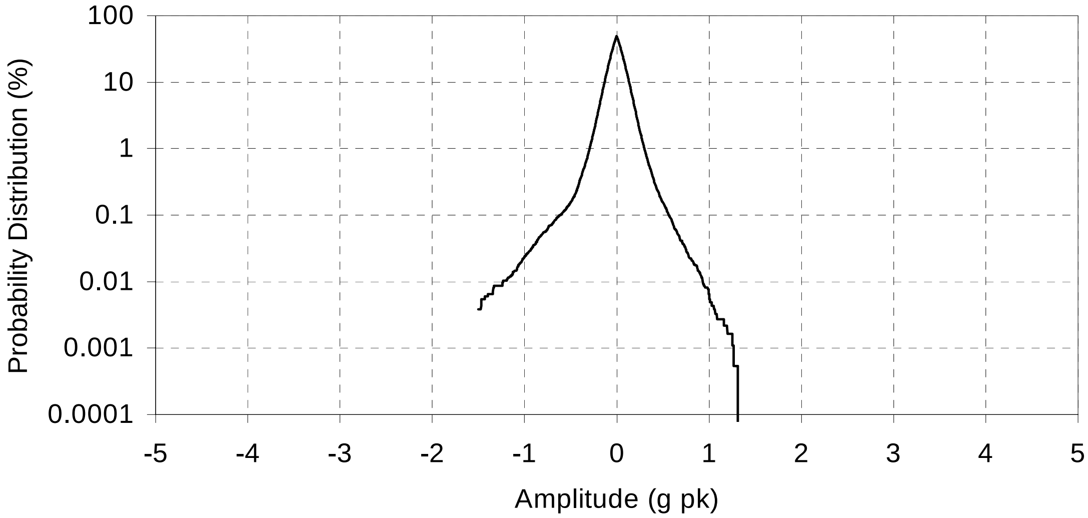


c: Transient response

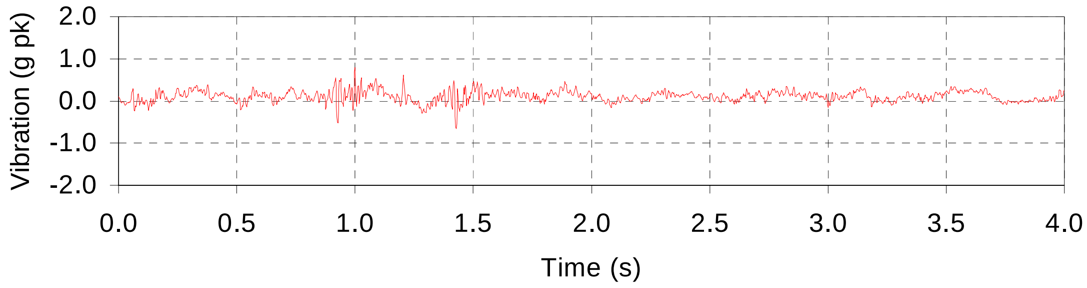
Figure 2: Vibration responses in the transverse axis measured during transportation on a rough road



a: Vibration spectrum



b: Amplitude probability distribution



c: Transient response

Figure 3: Vibration responses in the longitudinal axis measured during transportation on a rough road

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LEAFLET 243/1

HANDLING

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LEAFLET 243/1

HANDLING

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may occur during the handling of materiel. It includes the handling conditions associated with transportation and related logistical movements, and also those associated with deployment and operational use. The sources and characteristics of the mechanical environments are presented. During transportation materiel is usually packaged, while during deployment the materiel is normally in its unpackaged state and as such may be relatively vulnerable.

1.2 For the purpose of this leaflet, materiel may consist of an item of unprotected equipment or equipment carried within some form of protection, package or container. A container may contain a single or several items of materiel.

1.3 Although for most materiel the mechanical environments experienced during handling are relatively benign, for sensitive materiel to be used in fixed installations these environments could be the most severe they are ever likely to experience.

1.4 The range of mechanical environments that may be experienced by sensitive materiel during handling is often constrained by specified procedures, or the use of special handling equipment or protective devices.

1.5 It is impractical to address the wide range of handling operations that could be applied to materiel. Therefore the following descriptive information relates only to the more commonly encountered modes of handling.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Forklift Vehicles

2.1.1 Several dynamic environments can arise from handling by forklift vehicles. These include shocks associated with lifting and setting down, and vibration during the vertical movement of the forklift platform. In general, these environments are benign. Of more significance are the transient dynamic motions that can be generated by a forklift vehicle when traversing irregular surfaces. Although procedures can specify the maximum speed of such vehicle operations, in practice it is difficult to enforce.

2.1.2 While the type and size of the forklift vehicle, and the degree of loading, appear to have some influence on transient responses, their effects are not profoundly significant. Figure 1 shows envelope shock response spectra, in three axes, for four different (US) forklifts. Also, because most forklift vehicles have only small wheels and are equipped with only the simplest of suspension systems, it is not surprising to learn that the dynamic motions experienced by materiel during fork-lift vehicle operations are not often of a gaussian distribution.

2.2 Hoisting and Lifting

2.2.1 During hoisting, acceleration and deceleration levels of around 2 g can be induced in the materiel. In most cases these conditions can be treated as quasi-static loadings.

2.3 Intra-Facility Transport

2.3.1 Transportation within a facility may utilise wheeled vehicles or trailers. Usually such transportation is undertaken with restricted speeds and over good surfaces, and therefore the levels are usually benign. However, recent work revealed that higher than expected levels can arise at commercial facilities such as airports. The particular levels arose mainly because intra-facility transportation speeds were above those anticipated, but were generally below those that arise from road transportation.

2.4 Rough Handling

2.4.1 The preparation of materiel for operational use, and operational use itself, allows considerable potential for rough handling. At this stage materiel is often unprotected and is most vulnerable to such treatment. Potential incidences of rough handling should be identified through detailed examination of the relevant sections of the Manufacture to Target Sequence.

2.4.2 A severe condition usually adopted is to assume that equipment could be dropped from a bench or whilst being man carried (0.7 to 1 m). However, most materiel is unlikely to survive such a drop without serious (and obvious) damage. Moreover, clearly only small items can be dropped in such a manner and it is usually difficult to subject large or heavy items to rough handling to this extent.

2.4.3 One method of establishing a rough handling severity is to determine the drop height that which will just produce visible external damage. The rationale is that visible external damage will necessitate a full performance check before the equipment is released for operational use.

2.5 Special Purpose Handling Equipment

2.5.1 Special purpose handling equipments, such as most forms of packaging, are designed with the prime aim of protecting the materiel against the handling environment. This type of handling equipment need not be considered further in this leaflet. Other special purpose handling equipments, such as trolleys, are used for logistics and transportation purposes.

2.5.2 Transient responses from a UK S-trolley, used to move stores around airfields, are shown in Figures 2 and 3. These figures show responses arising from traversing typical airfield obstacles such as landing lights at 5 and 10 mph, and also the effects of snatch starts and emergency stops by the towing vehicle.

2.5.3 Trolleys, if improperly used, can induce in some circumstances severe vibration and shock conditions. One well known example is associated with trolleys used to load torpedoes under helicopters. The height constraint imposed on such trolleys allows only simple suspension systems to be employed. As a consequence any improper movement of these trolleys over deck discontinuities can result in severe induced shocks.

3. POTENTIAL DAMAGING EFFECTS

3.1 Failure Modes

3.1.1 The mechanical environments arising during the handling of materiel may induce a number of failure modes. The most significant are related to either displacements induced in the materiel or as a result of acceleration loadings. Induced displacements within the materiel may produce relative motions which in turn may result in collisions between equipments, tension failures and connectors becoming loosened. Acceleration related failures may arise through the action of inertia loadings. These may be applied once, to produce a threshold exceedance failure, or repeated to produce a fatigue induced failure. Failures induced as a result of an applied velocity are uncommon. However, velocity loadings on some electrical equipment or types of sensors may induce spurious voltages, which in turn could lead to functional failures.

3.2 Shocks and Transients

3.2.1 The most severe mechanical aspects of handling are usually associated with the shocks and transients arising from rough handling, and particularly from the materiel being dropped. Such events may cause local structural damage and internal fractures. However if the package or equipment, at the impact face, is very stiff then failure of internal equipment or structure may be induced as a result of acceleration loadings. During drop events significant displacements of the materiel can arise which may cause the materiel to impact with the inside of its package.

3.3 Vibration

3.3.1 For most payloads the vibration environment arising from handling is less severe than that it is likely to experience during transportation. However, it is likely that any packaging will be designed to protect the materiel from shocks rather than vibration. As a result, in some designs of package, significant amplification of the excitations may occur at low frequencies (10-50 Hz) which may give rise to the materiel impacting with the inside of its package.

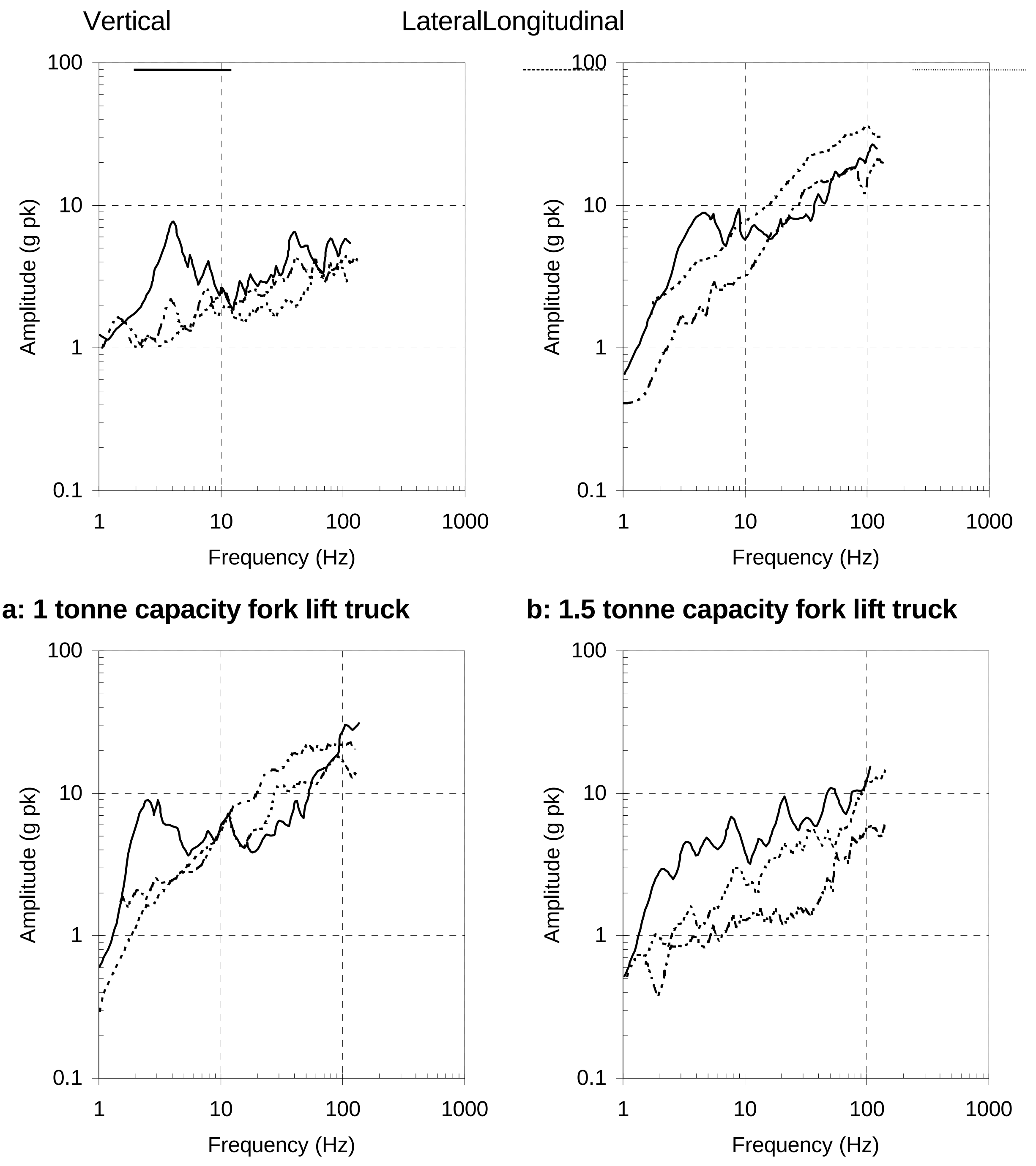
4. TEST SELECTION

4.1 Shocks and Transients

4.1.1 The tests usually undertaken to cover the shock and transient events associated with handling are those specified in AECTP 400, Method 414 - Handling. In addition, where materiel is to be strapped down, or lifted, consideration should also be given to Method 407 - Tiedown and Method 409 - Lifting.

4.2 Vibration

4.2.1 It is unusual to select tests only to accommodate the vibration elements of the handling environment. In most cases these vibration elements are covered by the tests specified for road transportation conditions, see Leaflet 242/2.



a: 1 tonne capacity fork lift truck

b: 1.5 tonne capacity fork lift truck

c: 2 tonne capacity fork lift truck

d: 3.5 tonne capacity fork lift truck

Note: all SRS computed using Q = 16.667

Figure 3: Shock response spectra for transients measured on four forklift trucks

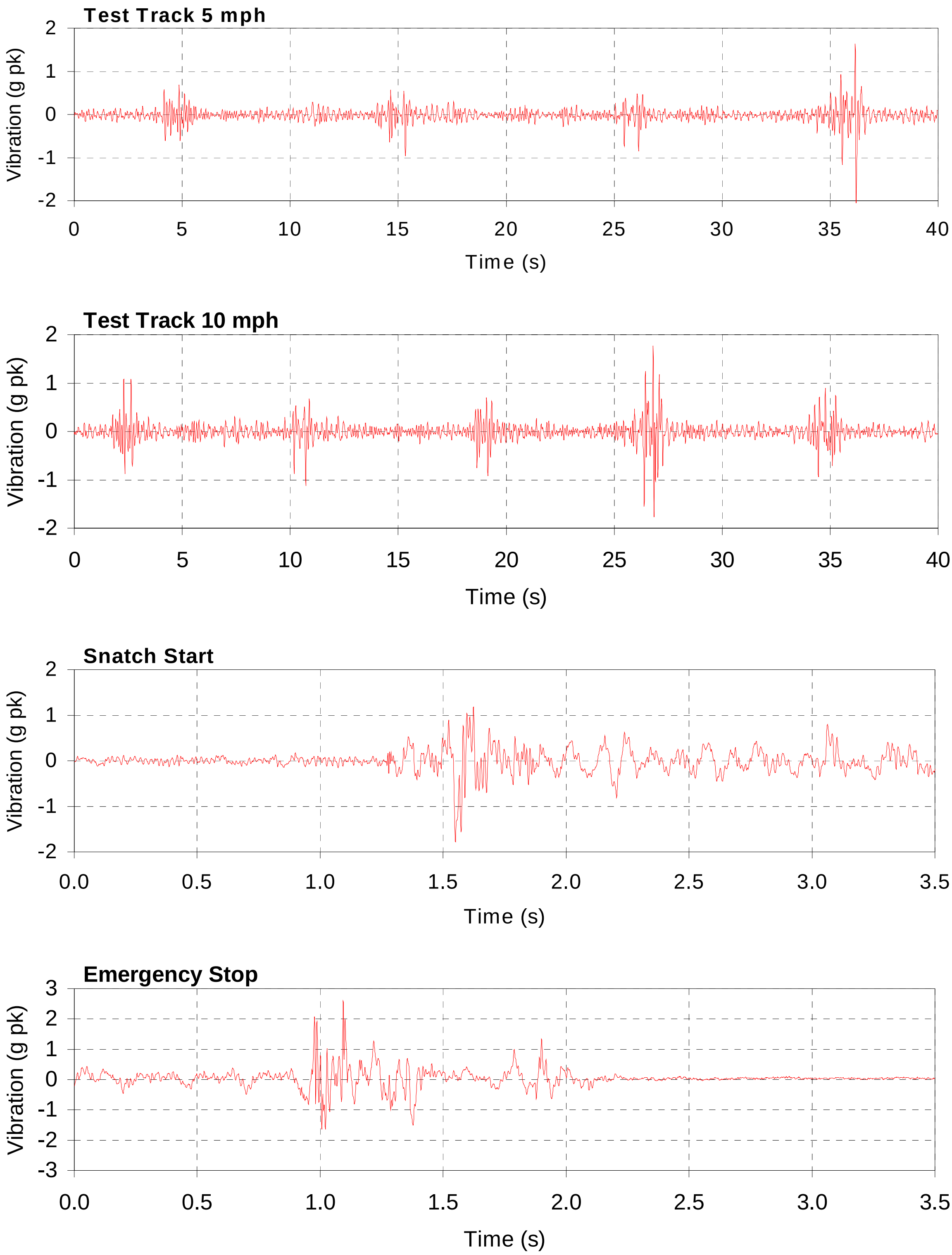


Figure 2: Vertical responses from an airfield S-trolley measured above rear axle

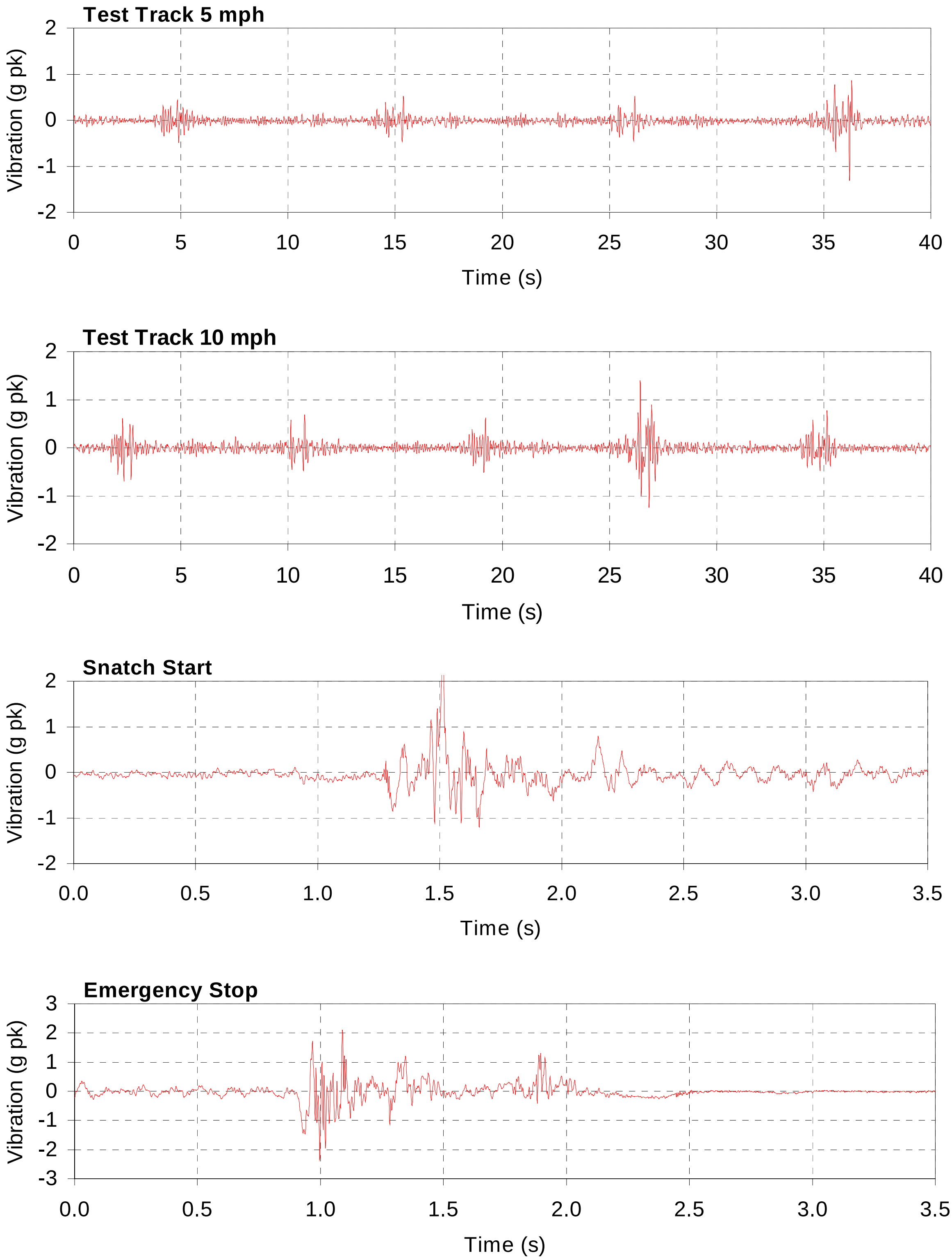


Figure 3: Longitudinal responses from an airfield S-trolley measured above rear axle

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LEAFLET 243/2

STORAGE

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LEAFLET 243/2

STORAGE

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be experienced by materiel during storage at a facility such as its place of manufacture, a depot, a shelter, a transit site, etc. It also encompasses storage conditions beyond such facilities, when environments normally associated with deployment may be experienced. The sources and characteristics of the mechanical environments are presented. Where relevant, advice is given on the selection of the appropriate AECTP 400 Test Methods.

1.2 For the purpose of this leaflet, materiel may consist of an item of unprotected equipment or equipment carried within some of form of protection, package or container. A container may contain a single or several items of materiel.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Mechanical loadings can be induced during storage as a result of:

a. the mass and stiffness distributions of the materiel

b. the permitted stacking configurations for the materiel

c. uneven floor and racking levels on which the materiel is stored

These loadings can be treated using quasi-static analyses and test methods.

2.2 No significant dynamic mechanical environments are identified during storage. Dynamic environments arising from handling are the subject of Leaflet 243-1.

2.3 Although ageing during storage can cause mechanical defects in materiel, such as permanent deformation in seals and drive belts, it is not in itself a mechanical induced environment.

3. POTENTIAL DAMAGING EFFECTS

3.1 The following are examples of problems that could occur when materiel and its container are subjected to the quasi-static mechanical loadings arising from the conditions described in paragraph 2.1:

a. failure or displacement of structural elements

b. loosening of screws, rivets, fasteners, etc

c. unacceptable deflection of cushioning elements

d. deterioration of climatic protection

e. damage to protective coatings

4. TEST SELECTION

4.1 A series of three test methods has been included in AECTP 400 to accommodate the mechanical loadings experienced by materiel during storage. They are:

a. Method 410 Stacking

b. Method 411 Bending

c. Method 412 Racking

4.2 If any potential storage conditions are identified that may exceed those covered by the above three tests then field measurements should be acquired from which environmental descriptions and test severities can be determined.

4.3 If the materiel to be tested is believed to be sensitive to adverse climatic conditions involving temperature and/or humidity, then it is important that these tests are conducted as a series of combined environments tests incorporating the relevant climatic conditions. See AECTP 300 for specific environments and tests.

LEAFLET 244/1

MAN MOUNTED AND PORTABLE

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LEAFLET 244/1

MAN MOUNTED AND PORTABLE

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be experienced by man mounted and portable materiel (ie: materiel deployed on or carried by personnel). The conditions encompassed are those that may arise beyond the forward storage base. The sources and characteristics of the mechanical environments are presented and where appropriate, information is given on potential damaging effects. Advice is given on the selection of the appropriate AECTP 400 Test Methods.

1.2 The mechanical environments experienced by man portable materiel during tactical transportation include those that may arise from wheeled vehicles under both on-road and off-road conditions. They also encompass those that may occur in certain types of tracked vehicles such as Armoured Personnel Carriers (APCs). The mechanical environments considered also include tactical air transportation in fixed and rotary wing aircraft.

1.3 The majority of conditions experienced by man mounted materiel are identical and indistinguishable from those of man portable materiel. Therefore, only in very specific instances will the mechanical environmental conditions experienced by man mounted materiel vary from those of man portable materiel. Moreover, in these specific instances the environmental conditions (when man mounted) will be less severe than those occurring during other man handling conditions.

1.4 For the purposes of this leaflet materiel is considered to be unprotected by its normal transportation package or container. It may still be protected by secondary systems or "battlefield" protection devices.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Tactical Ground Transportation

2.1.1 The environmental conditions occurring during tactical transportation of man portable and mounted materiel are in many respects similar to those occurring during tactical transportation. In addition to being essentially unprotected, the materiel is probably not securely restrained within the carriage vehicle. Any restraint that exists is unlikely to be sufficient to prevent bounce and jostle of the materiel occurring and consequently, the resulting motions generate the major dynamic responses.

2.1.2 While tactical transportation may utilise good quality made up roads, it must be assumed that transportation can also occur over poor quality or damaged road surfaces, unmade tracks and even over cross country routes. These inferior conditions are capable of producing significantly higher dynamic responses. Moreover, certain types of vehicles may be utilised which are not ordinarily used for normal transportation, eg: APCs.

2.1.3 For unrestrained cargo the most damaging environmental conditions are those producing relatively large low frequency displacements and velocities. Increasingly rough surfaces and cross country conditions produce increasingly more severe dynamic responses. However, these conditions also reduce vehicle speeds and act to some extent to limit response amplitudes.

a. Wheeled Vehicles: The conditions causing dynamic responses in materiel during tactical carriage in wheeled vehicles are described in Leaflet 245/2. The characteristics of the environments described in that chapter are very similar to those likely to be experienced by man portable materiel during tactical transportation.

b. Tracked Vehicles: The conditions causing the dynamic responses in materiel during tactical carriage in a tracked vehicle are described in Leaflet 245/1. Although that leaflet deals with deployed materiel the characteristics of the environments are very similar to those likely to be experienced by materiel during tactical transportation.

2.2 Tactical Air Transportation

2.2.1 The characteristics of the environments arising from tactical transportation in fixed wing and rotary wing aircraft are unlikely to be sufficient to generate any significant bounce and jostle. As such, the circumstances causing the mechanical environmental conditions will be essentially identical to those set out for normal air transportation in Leaflet 242/3.

2.3 Man Carriage

2.3.1 During man carriage, man portable materiel may be picked up, put down, dropped, moved or even thrown. The exact type and severity of environments arising from such handling will depend upon the size, mass and operational use of the materiel in question. In the majority of cases the most significant dynamic environments will arise from impact conditions. Such impacts can occur against a wide range of surfaces from soft mud to concrete. In addition the geometry of the surface may be flat or exhibit a high degree of irregularity.

2.3.2 In attempting to identify the limiting conditions it is useful to consider the wide range of possible impact scenarios. These scenarios should generate the worst case dynamic deceleration loads, penetration and bending likely to occur during battlefield handling conditions.

a. Impact. The materiel may be assumed to impact, at any conceivable angle, a hard rigid surface. The impact velocity is unlikely to exceed 3 m/s. This velocity should generate the limit deceleration conditions.

b. Spigot intrusion. The materiel may be assumed to impact, at any conceivable angle, a spigot. Again the impact velocity is unlikely to exceed 3 m/s. This velocity should generate the limit penetration conditions. The dimensions of the spigot will depend upon the operational scenarios.

c. Bending. Impact of the materiel over a trench, whose dimensions are such as to just prevent the materiel falling into it, will generate the limit dynamic bending conditions. Again the impact velocity is unlikely to exceed 3 m/s. In some cases the limit bending condition may be caused by the weight of a man acting at the centre of the materiel when deployed over a trench.

2.3.3 The previous paragraph indicates maximum potential impact velocities. However, these are considered to be upper limits for small, low mass materiel in tactical operational environments. For larger, heavier and bulky materiel these values may be reduced significantly.

2.4 Man Mounted

2.4.1 The conditions experienced by man mounted materiel are in general similar to those for man portable materiel. Where differences do occur it is because the materiel is only deployed when attached to the man. In some circumstances man survival limits may drive the degree of materiel protection. However, in most cases the necessary degree of robustness will be set to similar levels as for man portable materiel. Important exceptions may be aircrew helmet mounted materiel such as gun and night sights.

3. POTENTIAL DAMAGING EFFECTS

3.1 Failure Modes

3.1.1 The mechanical environments arising during the deployment of man portable and mounted materiel may induce a number of mechanisms of potential materiel failure. The most significant of these mechanisms are related to either displacements induced in the materiel or as a result of acceleration loadings. Induced displacements within the materiel may produce relative motions which in turn may result in collisions between equipments, tension failures and connectors becoming loosened. Acceleration related failures may arise through the action of inertial loadings. These may be applied once, to produce a threshold exceedance failure, or repeated to produce a fatigue induced failure. Failures induced as a result of an applied velocity are unusual. However, the application of velocity loadings on some electrical equipment and certain types of sensors may induce spurious voltages. These in turn may give rise to functional failures.

3.2 Vibration

3.2.1 The vibration environment, experienced during tactical transportation, is essentially similar to that likely to be experienced by man portable materiel during normal transportation. However, during tactical transportation, the materiel is unlikely to be as well protected, if protected at all, against vibration. Moreover, because the materiel is likely to be only lightly restrained, low frequency vibrations are likely to result in bounce and jostle.

3.3 Bounce and Jostle

3.3.1 The damage potential of bounce and jostle can be significant for lightly, or unprotected, materiel. A well designed protection system (or container) should significantly attenuate the majority of the effects of the shocks arising from bounce and jostle.

3.4 Impact

3.4.1 Impacts against a hard surface may result in plastic deformations and distortions at the impact point. In addition the resultant deceleration loads may have the potential to produce loss of structural integrity or failure of the internal equipment.

3.5 Spigot Intrusion

3.5.1 Impact against a spigot may result in penetration and equipment failure or puncture of pressure vessels.

3.6 Bending

3.6.1 High bending loads may produce loss of structural integrity and deformation sufficient to produce failure.

4. TEST SELECTION

4.1 Tactical Transportation

4.1.1 The relevant test procedures set out in paragraph 4 of Leaflet 242/5 - Transportation beyond the forward base.

4.2 Man Carriage and Man Mounted

4.2.1 Impact: The test procedure set out in AECTP 400, Method 414 - Handling should be used for these conditions. The materiel should be subject to an impact against a hard rigid surface. The angle and orientation of impact should be that likely to cause maximum damage to the materiel.

4.2.2 Spigot Intrusion: The test procedure set out in AECTP 400, Method 414 - Handling should be used, but in addition the materiel should be subjected to an impact with a steel spigot. The angle and orientation of impact should be that likely to cause maximum damage to the materiel. The dimensions of the spigot will depend upon operational conditions. A 25 mm diameter spigot is generally applicable to relatively small materiel, whilst a 100 mm diameter is generally applicable for larger materiel.

4.2.3 Bending: The test procedure set out in AECTP 400, Method 414 - Handling should be used. The materiel should be subjected to an impact against two hard rigid surfaces arranged such that conditions of greatest bending are induced. In addition, consideration should be given to the condition where the weight of a man is applied instantaneously to the centre of the materiel when arranged between the hard surfaces.

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LEAFLET 245/1

DEPLOYMENT ON TRACKED VEHICLES

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LEAFLET 245/1

DEPLOYMENT ON TRACKED VEHICLES

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be encountered by materiel when deployed on or installed in tracked vehicles. The following categories of tracked vehicles are considered: main battle tanks, armoured fighting vehicles (including armoured personnel carriers) and logistics vehicles. The use of these vehicles in both on and off-road situations is addressed.

1.2 The sources and characteristics of the mechanical environments are presented and where appropriate, information is given on potential damaging effects. Advice is given on the selection of the appropriate AECTP 400 Test Methods. Guidance is given in Annex A on the compilation of environment descriptions and test severities from measured data.

1.3 Some critical design loadings arise from the effects of hostile action such as blast, or the use of explosive reactive armour. Such hostile environments are not addressed in this leaflet.

1.4 When a tracked vehicle moves across a terrain, interactions between the vehicle's tracks and irregularities in the terrain result in vibration excitation being transmitted to the vehicle's installed materiel via the suspension system and hull structure. Vibration is also generated by the action of the tracks moving over their wheels, sprockets and rollers (see Figure 1) which can pass directly into the vehicle's hull. In addition, materiel will experience inertial loadings arising from the vehicle's acceleration, eg: when increasing speed, braking, cornering, etc.

1.5 The action of the vehicle's engine, transmission, pumps, etc, can also give rise to vibration, which is likely to be most significant at discrete frequencies associated with rotating shafts, gear meshing, etc. The significance of these excitations is strongly dependent on the position of the materiel relative to these sources.

1.6 Vibration spectra acquired from the measurements on tracked vehicles comprise a wide band random spectrum upon which is superimposed a number of relatively low frequency narrow band peaks. An example of such a spectrum is shown in Figure 2. The impact of successive track plates on the ground is perceived within the vehicle as narrow band spectral components, which can be severe. These narrow band components are speed dependent and relate to the fundamental track patter frequency and usually several higher harmonics. The wide band component is generated by the combined effects of the rolling of the wheels on the tracks, interactions between the track links and the various other sources including engine, gearbox, generators, etc. Peaks in response frequencies corresponding to the vehicle's suspension system can be expected to be low, eg: <3 Hz. Relatively broad band peaks in frequencies may also be evident corresponding to structural dynamic modes of the vehicle itself. These modes may lie in the 20 to 100 Hz frequency range.

1.7 The dynamic responses of materiel deployed on tracked vehicles depend on the factors discussed below.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Terrain Type

2.1.1 The nature of terrain experienced by a tracked vehicle will significantly influence the response of the materiel. Terrain which may need to be considered depends upon the vehicle's role, and could include classified roads, rough roads, Belgium Block (pavé), etc, in addition to cross-country. As noted above, the action of the track plates impacting on the ground may be a major source of vibration. Therefore hard surfaces, including classified roads, are likely to provide a more severe environment than softer terrain such as cross country, which tends to cushion the impact of track links on contact with the ground. This is in contrast to the trend associated with wheeled vehicles, which produce relatively benign vibration loadings on classified roads. An example for a tracked vehicle of how vibration responses, expressed as overall g rms, vary with respect to terrain type, is shown in Figure 3.

2.2 Vehicle Characteristics

2.2.1 The vibration environment associated with main battle tanks is particularly severe. The contributing factors are the stiffness of their suspension systems, their overall structural rigidity and lack of damping, their powerful engines and track systems.

2.2.2 Other tracked armoured fighting vehicles (AFV) tend to produce a similar dynamic environment to that of main battle tanks but the severity is dependent upon vehicle design.

2.2.3 Logistics vehicles are not armoured and are often based on standard chassis designs. The vibration severity of these vehicles is likely to reflect the design aims of their chassis, which may be to meet either commercial or military requirements. The vibration environment for logistics vehicles built on military chassis would be expected to be more severe than those built on commercial chassis because of their relatively high suspension system stiffness and structural rigidity.

2.2.4 The type of track plates fitted to a tracked vehicle is a major influence on the vibration environment within the vehicle. Two aspects of plate design can influence vibration severity.

a. Plate Connections: There are a number of different designs used to connect the plates together. Recent work has shown that for AFVs, hull vibration in terms of the overall g rms (0 to 1000 Hz) associated with a dry pin design of track is up to 2 times as severe as that associated with end connector track. See illustrations at Figures 4 and 5.

b. Plate Facings: The type of facing fitted to the metal track plates should reflect the type of terrain that a vehicle may be expected to encounter. For example, rubber facings are often used when a vehicle is to spend a high proportion of its time on classified roads. Whilst these are fitted to avoid damage to the road surface by the track, a secondary effect is to reduce significantly the severity of track patter vibration.

2.2.5 The agility of a vehicle is related to its power to weight ratio. Modern AFVs tend to have high power to weight ratios and are therefore capable of high speeds, eg: greater than 60 km/hr As vibration severity tends to increase with speed, there is reason to expect that high power to weight ratio vehicles will produce an increase in the severity of the dynamic environments. Higher speeds will also extend the frequencies of the track patter harmonics.

2.3 Vehicle Operation

2.3.1 In general, vehicle structural vibration severity can be expected to increase as vehicle speed increases but g rms levels do not increase linearly with speed.

2.3.2 If resonances are excited, the maximum vibration responses of installed materiel do not necessarily occur at the vehicle's maximum speed. Such resonances could be associated with the vehicle's structure, the particular item of materiel or its mounting arrangements.

2.3.3 Recent work indicates that for AFVs, vibration during cornering is considerably more severe than when travelling in a straight line, eg: by up to 2 times for the hull and up to 2.5 times in the turret in terms of the overall g rms (0 to 1000 Hz).

2.3.4 Some materiel might be susceptible to vehicle tilt, which may become significant in off-road conditions. In such circumstances, tilt angles approaching 90 degrees may be encountered.

2.3.5 Steady-state accelerations will be experienced by the vehicle when increasing speed, braking or cornering. Such levels are unlikely to exceed 1 g during use on classified roads. During off-road use, accelerations arising from jolts when uneven terrain is traversed may exceed 1 g.

2.4 Materiel Position and Mounting

2.4.1 The severity of the environment perceived by materiel installed in a vehicle depends on where the materiel is mounted. Evidence suggests that hull vibration, expressed as the overall g rms (0 to 1000 Hz), can be between 1.3 and 5.7 times more severe than in the turret, depending on vehicle type and measurement axis. With respect to the relative severity of axes, vibration in the vertical axis in the hull or turret has been seen to be around 1.5 times more severe that in the transverse or longitudinal axes. The mass and mounting arrangements of the materiel can also influence its response.

2.5 Gunfire and Launch of Weapons

2.5.1 The launch of weapons and the firing of guns can subject the vehicle to high levels of shock, vibration and blast pressure. These conditions are highly specific to particular installations and therefore generalised guidance on their characteristics is inappropriate.

3. POTENTIAL DAMAGING EFFECTS

3.1 Failure Modes

3.1.1 Materiel may be susceptible to three possible failure modes, ie: related to displacement, velocity and acceleration. Displacement related failures in materiel can arise through collisions between materiel after relative movement; tension failures after relative movement; connectors becoming loose leading to a break in electrical continuity. Acceleration related failures may arise through the action of inertial loadings. These may be applied once, to produce a threshold exceedance failure, or repeatedly to induce a fatigue failure. Velocity related failures are not as common as those of displacement or acceleration. However, velocity loadings on some electrical equipment, including sensors, could induce spurious voltages, which in turn could lead to functional failure.

3.2 Vehicle Operation

3.2.1 As tracked vehicle operations can induce high levels of vibration in deployed materiel, potentially, any of the above failure modes could occur. For items that are not securely fastened, additional problems can arise through the action of rattling, eg: scuffing, fretting and brinelling. These kinds of surface degradation could provide problems for optical instruments such as sighting equipment. Another area of concern is of possible coupling between vehicle excitation at track patter frequencies and the response of equipment, ie: associated with the equipment itself or its mounting arrangement. As the fundamental track patter frequency varies, according to vehicle speed, between 0 and perhaps 150 Hz depending on vehicle type, it can be difficult to avoid such coincidences at all times. This problem is exacerbated when strong harmonics of track patter are evident.

4. TEST SELECTION

4.1 Testing Options

4.1.1 Three approaches of simulating the tracked vehicle environment are generally available, ie: in the test laboratory using vibrators and other facilities as necessary, in the field using suitable test tracks, or in the field using road and terrain surfaces under real conditions. The simulation of the environment in the laboratory has the advantage that it allows the simulation to be undertaken in defined and controlled conditions. Moreover, laboratory testing permits reduced test times, reduced costs as vehicle operations are eliminated, and increased safety standards (particularly for munition testing). An advantage of field trials is that all units are in their correct relative positions and all mechanical impedances are realistic; consequently, field trials can be expected to expose materiel to all relevant failure mechanisms. Field trials may be necessary if inadequate data are available from which to base laboratory test severities. A simulation using field trials may be more convenient for large and awkward payloads, and is essential where the payload interacts significantly with the dynamics of the carriage vehicle.

4.2 Laboratory Vibration Testing

4.2.1 The simulation of the environment in the laboratory is usually viable for all but the largest items of materiel. When a vibration test is required the test procedure used should be that of AECTP 400, Method 401 - Vibration.

4.3 Laboratory Shock Testing

4.3.1 In some cases it may be necessary to undertake shock or transient testing to reproduce the structurally transmitted transients arising from the vehicle. The test procedure used should be that of AECTP 400, Method 403 - Shock. The basic pulse procedure should suffice for most applications, but where a closer simulation is required AECTP 400, Method 417 is recommended.

4.4 Test Track Trials

4.4.1 Due to the difficulties of establishing 'worst case' road conditions, use is often made of standard test tracks. A wide range of test tracks is available. Not all of these are designed to simulate tracked vehicle environments, some are designed to investigate aspects of vehicle handling, and reliability. Therefore, care is needed when selecting suitable surfaces to ensure representative materiel responses. High amplitude responses can be induced at a rate of occurrence many orders greater than that experienced in-Service, which for some materiel may induce modes of failure that are unlikely to occur in practice. The test procedure used should be that of AECTP 400 Method 408 -Large Assembly Transport.

4.5 Road and Terrain Trials

4.5.1 Trials conducted over representative roads and terrain for representative durations are the most realistic. Such trials are only valid when detailed knowledge is available of the materiel's installation and the intended use of the tracked vehicle. Even when conducting these trials, it may be desirable to include some test track trials as a convenient way of incorporating limit conditions. The test procedure used should be that of AECTP 400 Method 408 - Large Assembly Transport.

4.6 Acceleration Testing

4.6.1 Testing by the application of quasi-static loadings to simulate vehicle accelerations is usually unnecessary, because the loadings are either encompassed by testing for other in-Service environments or the adequacy of the materiel is demonstrated by assessment.

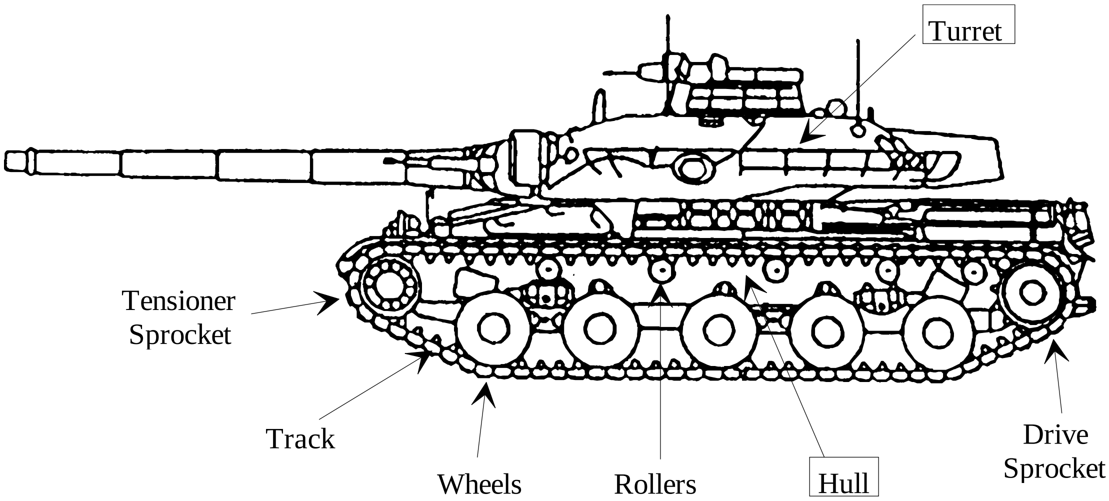
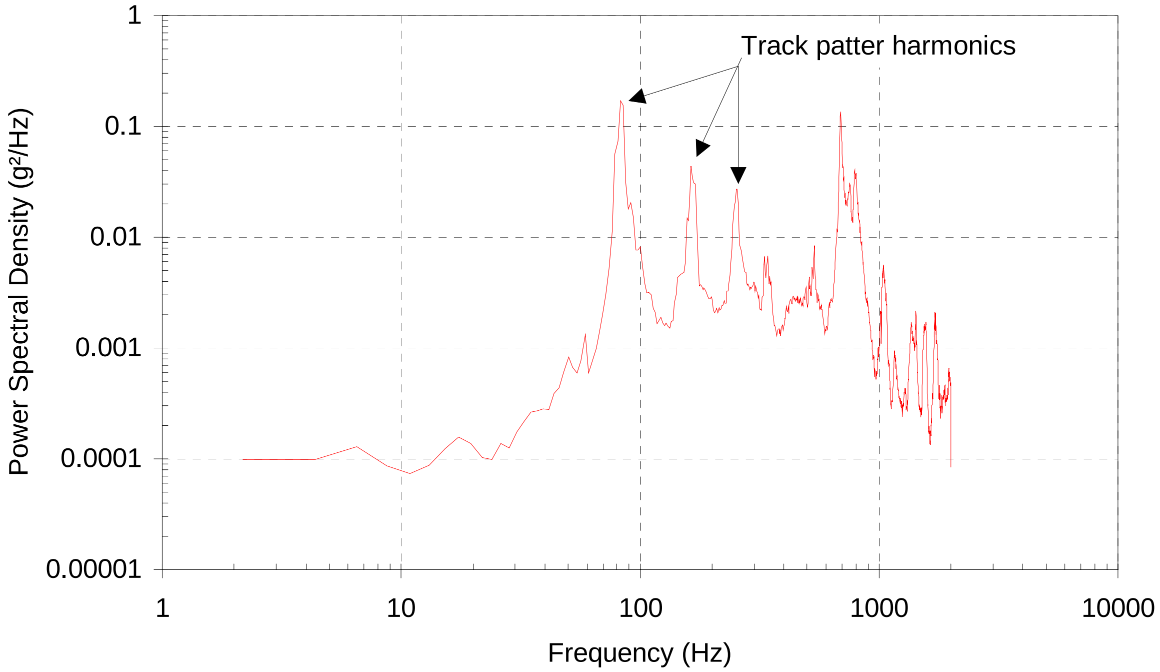


Figure 1: Equipment mounting zones and track features for a main battle tank



Notes:
1. Data from the hull of an armoured fighting vehicle running on a Tarmacadam surface at 50 km/h
2. Spectrum is equivalent to 3.25 g rms (vertical axis)

Figure 2: Vibration spectrum for a tracked vehicle (Armoured Personnel Carrier)

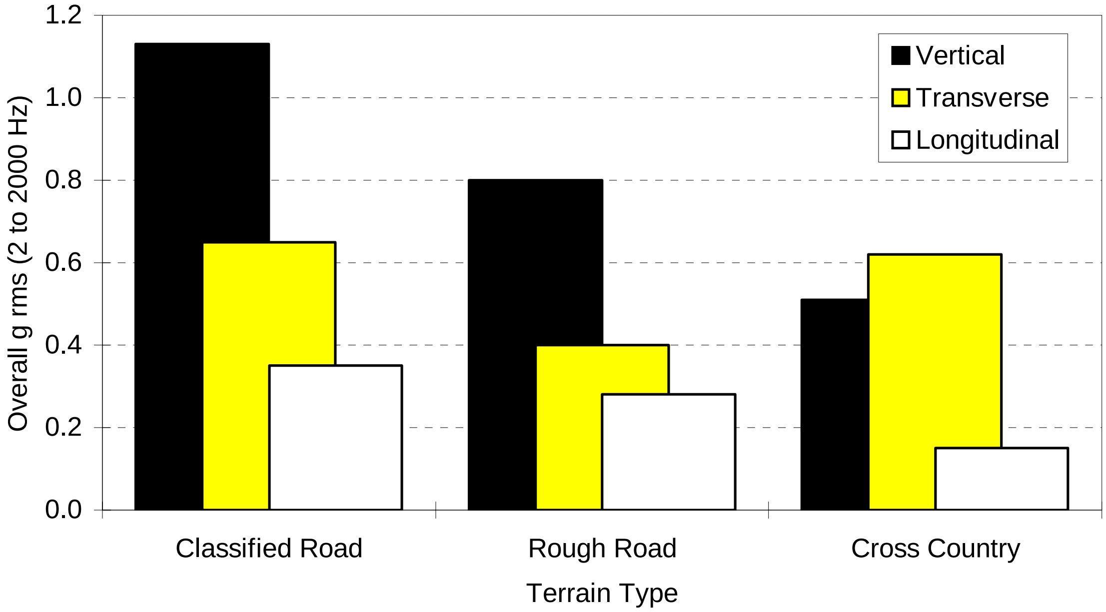
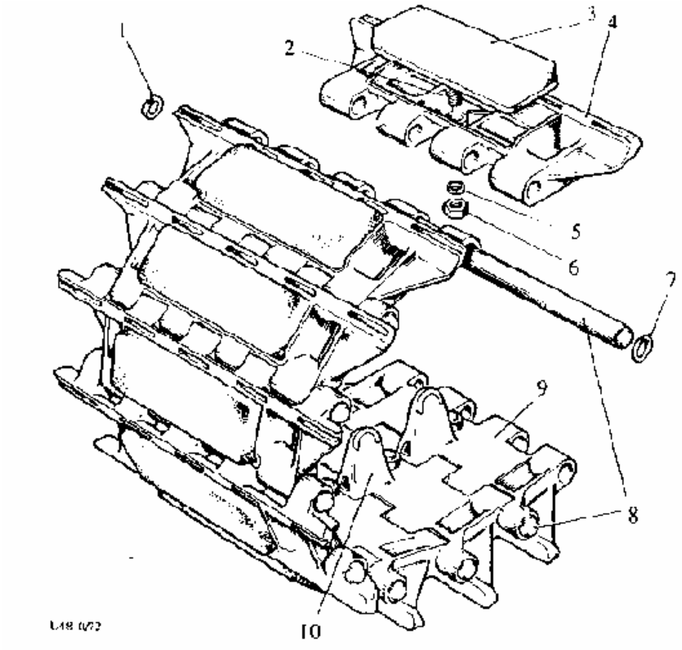


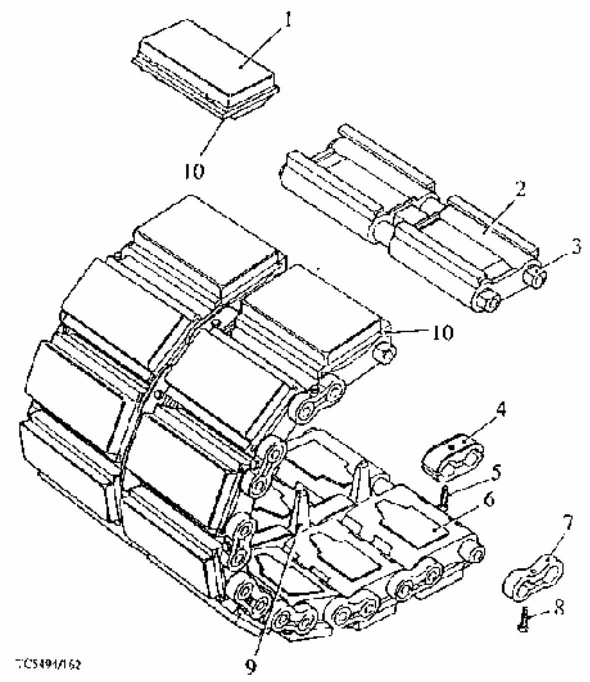
Figure 3: Relative severity of terrain for the hull of a tracked vehicle (Armoured Personnel Carrier)



Key

1. Circlip
2. Retaining bolt
3. Rubber pad
4. Link grouser
5. Lock washer
6. Nut
7. Circlip
8. Track pin
9. Track pin lugs
10. Horn

Figure 4: Dry pin track type



Key

1. Track pad
2. Track link
3. Track pin
4. Centre connector
5. Screw
6. Rubber insert moulding
7. End Connector
8. Screw
9. Horn
10. Projection

Figure 5: End connector track type

ANNEX A

DERIVATION OF SEVERITIES FROM MEASURED DATA

A.1 Derivation of an Environment Description

A.1.1 Requirements: It is first necessary to establish from the relevant requirements the type of tracked vehicle in which the materiel is to be installed, the role of the vehicle and the terrain over which it will travel, the vehicle's operating speeds, and the location of the materiel in the vehicle. Having established the requirements, relevant vibration data may be acquired from data banks, should the data exist, or from field measurement trials.

A.1.2 Environment Descriptions: An environment description for materiel installed in a tracked vehicle should generally include for each relevant terrain over the range of operating speeds, frequency response characteristics, amplitude probability plots, and time histories of any transients. This information will be used to examine trends, such as how severity is influenced by terrain and vehicle speed. The flow diagram outlined in Figure A.1 points out the steps to be adopted to derive an environment description from measured data. This diagram enables frequency response characteristics and dynamic response amplitudes to be quantified for all the relevant test conditions. A process for using these components of the environment description to produce test spectra and durations is discussed below.

A.2 Derivation of Vibration Test Severities

A.2.1 General: Test severities are defined in terms of the characteristics and amplitudes of the broad band background vibration, narrow band components associated with track patter, and durations. Advice on establishing these parameters is given below.

A.2.2 Broad Band Component

a. Characteristics: In general, it can be expected that the broad band component spectral characteristics, ie: the shape of ASD plots, will be stable with respect to many parameters, including vehicle speed and terrain type.

b. Amplitude: The severity of the test spectrum may not in general be obtained directly from ASDs because, for tracked vehicles, they are unlikely to be an adequate description of the environment. This is a consequence of the character of this type of data; it can be non-stationary resulting in relatively high peak to rms ratios. It is therefore also non-gaussian. These properties of non-stationary and non-gaussian are in contrast to the character of vibration generated in test laboratories. Consequently, special steps may need to be taken to avoid under testing in the laboratory. In some cases conservatism can be incorporated into the test spectrum by the technique of enveloping to produce an adequate test severity. An alternative approach is to use amplitude probability distributions (APD) as the basic measure of severity and to derive appropriate factors which can then be applied to mean spectra. This approach is preferred for tracked vehicles and an example of its use is given in paragraph A.3.

A.2.3 Narrow Band Components.

a. Characteristics: The frequency of the narrow band components at a given speed can be calculated from knowledge of the track pitch dimension, and can be expected to be easily recognisable in measured data, at least for hard terrain and under constant speed conditions. To accommodate these effects in a test spectrum, ie: that the frequency of these components are speed dependent, the narrow bands should be swept over an appropriate frequency range. Alternatively, the broad band spectrum could simply be shaped to accommodate these peaks, rendering the narrow bands unnecessary, albeit at the considerable risk of excessive testing.

c. Amplitudes: Establishing the amplitudes of these components can be a problem because of their changing frequency with vehicle speed. This can lead to an under-estimation of severity because of averaging effects implicit in a ASD analysis. One solution is to gather data at a number of constant speeds which can then be analysed separately. Alternatively, if the speed is not constant throughout a record, evolutionary spectra (waterfall plots) can be used. In either case, the severity, expressed in either ASD or RMS form, should be associated with the resolution bandwidth to make the definition unambiguous.

A.2.4 Test Duration: Test durations should be based upon the required life of materiel and the usage profile of the relevant tracked vehicle. In order to avoid impracticably long test durations, it is general practice to invoke equivalent fatigue damage laws such as Miner's Rule. This rule is also known as the "Exaggeration Formula" and is expressed as follows:

$$t_2 = t_1 (S_1/S_2)^n$$

where

t_1	=	the actual duration in the requirements characterised by the measured level
t_2	=	the equivalent duration at the test level
n	=	the exaggeration exponent

For rms level

S_1	=	the rms level of the measured spectrum
S_2	=	the rms level of the test spectrum
n	= b =	the exaggeration exponent; values between 5 and 8 are typically used

For ASD level

S_1 = the ASD level of the measured spectrum

S_2 = the ASD level of the test spectrum

n = b/2 = the exaggeration exponent; values between 2.5 and 4 are typically used

The exponent 'b' corresponds to the slope of the fatigue (S/N) curve for the appropriate material. A value of 'b' equal to 8 is adequate to describe the behaviour of metallic structures such as steels and aluminium alloys which possess an essentially linear stress-strain relationship. This expression is used with less confidence with non-linear materials and composites. For electronic equipment and non metallic materials, elastomers, composites, plastics, explosives, a value of 'b' equal to 5 is recommended.

Although the expression has been shown to have some merits when applied to materiel, it should be used with caution, if unrepresentative failures are to be avoided. It is inadvisable for test levels to be increased beyond the maximum measured levels that equipment may experience during in-service life, with a statistically based test factor applied. Furthermore, where there is evidence that the materiel is not fully secured to the vehicle Miner's Rule is totally invalid and should not be used. In such cases the Loose Cargo Test (AECTP 400, Method 406) should be considered as an alternative.

A simplified example of the derivation of a test duration using Miner's Law is given below.

Terrain	**Speed (mph)**	**Severity index**	**Duration** %	**Time (min)** Actual t_1	Equivalent t_2
Pavé	25	1.0	5.0	3	3.00
Pavé	20	0.7	6.7	4	0.67
Rough road	15	0.6	13.3	8	0.62
Cross country	35	0.5	16.7	10	0.31
Main road	45	0.4	30.0	18	0.18
Main road	35	0.3	20.0	12	0.03
Main road	<20	0.2	8.3	5	<0.01
		Totals:	**100.0**	**60**	**4.82**

Notes

(1) 4.82 minutes test is equivalent to 60 minutes real time vehicle vibration.

(2) The "Severity Index" for a terrain is the overall g rms normalised with respect to the maximum measured overall g rms (associated with pavé in this example). It is important to check that the ASD spectrum profile associated with the reference level (again, pavé in this example) either reflects, or is modified to reflect, the maximum amplitudes observed over the total frequency range.

(3) This method of calculating test durations would normally be applied subject to a maximum of 17 hours per axis.

A.3 Comparing Measured Data With Test Specifications

A.3.1 When comparing measured spectra from a vehicle trial with that contained in a test specification or generated by test house equipment, care must be taken to avoid an under-estimation of the severity of the measured data. This is because of the different amplitude distributions and peak to rms ratios of these types of data. These differences can be compensated for, as shown in this example:

Measured peak APD level (at the 1 in 500 occurrence level, ie: 2.88 sigma) = 9.0 g

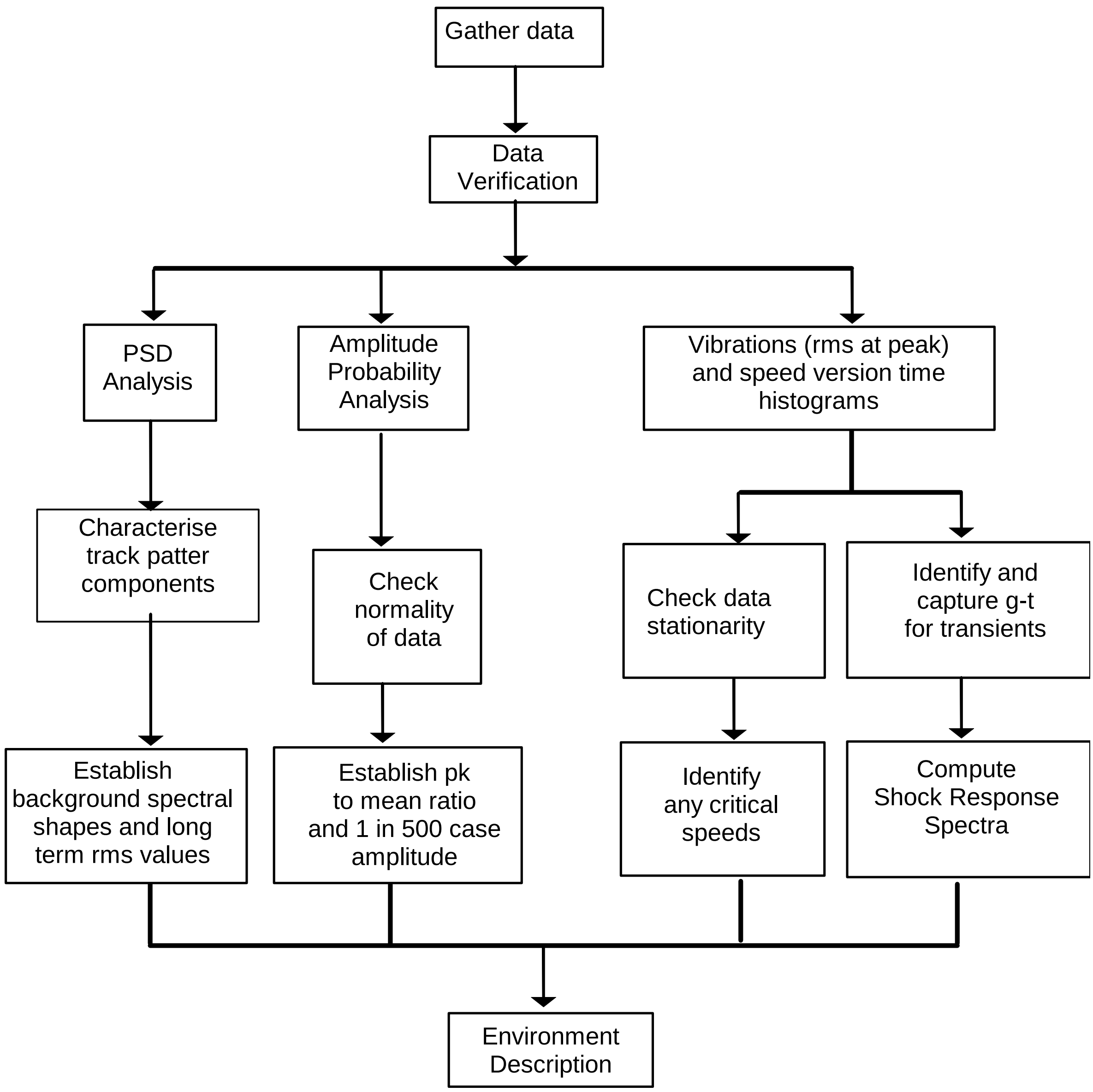
Equivalent gaussian rms $\frac{9.00}{2.88} = 3.1\text{g rms}$

Measured non-gaussian rms = 1.4g rms

Factor on measured g rms = $\frac{3.1}{1.4} = 2.2$

Factor on measured ASD = $2.22^2 = 4.8$

Whilst this analysis indicates that in this instance a factor of 4.8 should be applied to the measured ASD levels, these higher levels would be appropriate for a relatively short duration.



Note: The steps outlined above would normally be carried out for each terrain and for all relevant installations

Figure A1: Derivation of an environment description from measured data

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LEAFLET 245/2

DEPLOYMENT ON WHEELED VEHICLES

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LEAFLET 245/2

DEPLOYMENT ON WHEELED VEHICLES

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be encountered by materiel when deployed on or installed in wheeled vehicles.

1.2 The vehicles considered in this leaflet range from large conventional trucks to small four wheel drive types, and may be armoured or unarmoured. Trailers are also considered and may be of two or four wheeled types, ranging in size from those towed behind a small four wheel drive vehicle to those towed behind the largest logistic vehicles. Many different types of trailers are in general use, some of which may be custom built for specific applications.

1.3 The application modes considered are the “Common Carrier” mode which covers vehicle use on predominantly classified roads and includes commercial transportation, and the “Mission/Field” mode which covers vehicle use in predominantly off-road situations.

1.4 The sources and characteristics of the mechanical environments are presented and where appropriate, information is given on potential damaging effects. Advice is given on the selection of the appropriate AECTP 400 Test Methods. Guidance is given in Annex A on the compilation of environment descriptions and test severities from measured data.

1.5 When a wheeled vehicle moves across a terrain, interactions between the vehicle's tyres and irregularities in the terrain result in vibration excitation being transmitted to the vehicle's installed materiel via the suspension system and chassis structure. In addition, materiel will experience inertial loadings arising from the vehicle's acceleration, eg: when increasing speed, braking and cornering.

1.6 The action of the vehicle's engine, transmission, pumps, etc, can also give rise to vibration excitation. Such excitation is likely to be most significant at discrete frequencies associated with rotating shafts, gear meshing, etc. Tyre resonances can also be a source of excitation. The significance of these excitations is strongly dependent on the position of the materiel relative to these sources.

1.7 Vibration spectra acquired from measurements on wheeled vehicles and trailers are essentially wide band random. Peaks in the spectra can be expected to be associated with the vehicle's mass and the compliance of its suspension system. Discrete peaks may be evident in such spectra at frequencies associated with the various rotating components, eg: associated with the engine and transmission.

1.8 Considering structurally transmitted shock, only moderate severities are expected in the common carrier role, which involves medium mobility vehicles that spend a high proportion of their life on normal paved roads. Conversely, higher shock levels can be expected in the mission/field role, which involves high mobility vehicles that may operate in an off-road role, possibly in combat.

1.9 The dynamic responses of materiel deployed on wheeled vehicles depend on the factors discussed below.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Terrain Type

2.1.1 The nature of terrain experienced by a wheeled vehicle will significantly influence the response of the materiel. Depending upon the role of the vehicle, terrain which may need to be considered include classified paved roads, rough roads, Belgium Block (pavé), and cross-country. As may be expected, hard and rough terrain, such as broken concrete tracks, give rise to a more severe environment than classified roads, as illustrated in Figure 1. Further examples of how vibration responses, expressed as overall g rms, vary with respect to terrain type, are shown in Figure 2.

2.1.2 Even for a classified road with a nominally good surface, a whole range of surface irregularities such as pot-holes and railway tracks may be encountered in normal use. Consequently, the distinction between vibration and shock is often obscure in measured dynamic responses from wheeled vehicles. Evidence of this can often be seen in measured amplitude probability distributions, see Figure 3a. This figure shows a characteristic of a smooth, continuous curve from the region of high probability low amplitude to regions of lower probability higher amplitudes. It is further noted from Figure 3b that the flared character of the corresponding probability density plot indicates that this data is not from a simple, stationary gaussian process, which would result in a triangular characteristic.

2.1.3 Regarding classified roads, the classification is likely to be indicative of minimum road width but not necessarily of surface quality. While recent work has indicated that, for a given speed, least vibration is usually associated with “multiple” track roads and worst vibration with “contra-flow” respect. This is because it can be expected that the reduced width of a “contra-flow” track road will increase the likelihood of encountering shock transients, caused by running over a recessed gutter drain cover or mounting a kerb.

2.1.4 On rough roads and pavé when shocks might be expected, the dynamic environment can be so severe for so much of the time that it is usual to describe this environment as a continuous vibration condition. In these cases, both the rms and peak response amplitudes can be high.

2.1.5 On cross country tracks, the general level of severity can be low but severe shocks can occur. Consequently, rms amplitudes can be low but peak amplitudes relatively high.

2.2 Vehicle Characteristics

2.2.1 The vibration perceived by materiel will be significantly influenced by the vehicle's suspension system and tyres. A vehicle with a soft suspension system with plenty of available travel, fitted with soft tyres, can be expected to produce a benign environment. Conversely, vehicles with stiff suspension systems and hard tyres, eg: armoured vehicles, can be expected to produce a relatively harsh environment, particularly when negotiating rough hard surfaces such as broken concrete or desert shale. Severe shocks can occur if all the available suspension travel is expended and the bump stops are used.

2.2.2 The laden weight of a particular vehicle can also be expected to influence vibration severity. Evidence indicates that the vibration severity decreases as the vehicle load increases, as illustrated in Figure 4.

2.2.3 The position of materiel in a vehicle or trailer can influence its dynamic response. For example, Figure 5 shows the pattern of vibration severity along the length of an articulated, multi-axle semi-trailer. The mass and mounting arrangements can also influence its dynamic response, particularly if anti-shock mounts are used.

2.2.4 Vibration perceived by materiel is the vector sum of excitation transmitted from each wheel, together with any other sources associated with the engine or transmissions etc. It has been suggested that the excitation at each wheel from the road surface is not independent but may be highly correlated. These effects are unlikely to be significant for small installations, such as those with a small base area, but may need to be taken into account when compiling test severities from measured data for large installations, particularly in respect of the vehicle's rotational motions.

2.2.5 For trailers the severity of the dynamic environment is likely to be most severe for a small two wheeled type. As the size of trailers increase, the environment tends to that of a wheeled vehicle of similar load carrying capacity. As a general rule, if a trailer's laden weight exceeds 2 tonnes it is likely to behave as an equivalent wheeled vehicle. Lost motion in a vehicle/trailer coupling can give rise to significant shocks both to the towing vehicle and trailer. In practice, all but the smallest trailers would be expected to benefit from couplings incorporating longitudinal dampers.

2.3 Vehicle Operation

2.3.1 The severity of a vehicle's structural dynamic response, described by the overall rms amplitude, can be expected to increase as vehicle speed increases, as illustrated in Figure 6. The measurements were taken on the load bed above the rear axle of a large articulated truck travelling over a variety of road surfaces. If resonances are excited, the maximum vibration of particular installed materiel does not necessarily occur at the vehicle's maximum speed, as shown in Figure 7. Such resonances could be associated with the particular item of materiel or its mounting arrangements.

2.3.2 For heavy trucks (>35 tonnes) on good quality roads, g pk responses during snatch starts and emergency stops are likely to be encompassed by those associated with normal road running. In addition, as may be expected, relatively high levels can be experienced during these events in the vehicle's longitudinal axis when compared to normal road running. In general steady-state accelerations experienced by the vehicle are unlikely to exceed 1 g. Vibration during acceleration, braking and cornering is unlikely to be very different from that during equivalent steady speed conditions.

2.3.3 Any wheeled vehicle running with one or more deflated tyres can be expected to experience a worse dynamic environment than under normal circumstances with all tyres properly inflated. In terms of spectral characteristics, the effects of deflated tyres may be limited to only a part of the spectrum. These effects are illustrated in Figure 8.

2.3.4 Vehicle tilt may be especially significant for sensitive materiel deployed in off-road vehicles in the Mission/Field role.

2.4 Gunfire and Launch of Weapons

2.4.1 Materiel responses to gunfire are discussed in detail in Leaflet 246/1, Deployment on Jet Aircraft.

2.4.2 The launch of weapons can subject the vehicle to high levels of shock, vibration and blast pressure. These conditions are highly specific to particular installations and therefore their characteristics are not addressed in this leaflet.

3. POTENTIAL DAMAGING EFFECTS

3.1 Failure Modes

3.1.1 Materiel may be susceptible to three possible failure modes, ie: related to displacement, velocity and acceleration. Displacement related failures in materiel can arise through collisions between equipments after relative movement; tension failures after relative movement; connectors becoming loose leading to a break in electrical continuity. Acceleration related failures may arise through the action of inertial loadings. These may be applied once, to produce a threshold exceedance failure, or repeatedly to induce a fatigue failure. Velocity related failures are not as common as those of displacement or acceleration. However, velocity loadings on some electrical equipment, including sensors, could induce spurious voltages, which in turn could lead to functional failure.

3.2 Vehicle Operation

3.2.1 Materiel installed using anti-shock mounts could experience relatively large displacements if the natural frequency of the materiel on its mounts coincides with vehicle suspension frequencies.

3.2.2 Should any resonant frequencies of the materiel correspond to any of the rotational sources of vehicle vibration such as drive shaft speed, excessive vibration could result. These effects could be significant during convoy operations.

3.3 Gunfire

3.3.1 As sensitive materiel is likely to be mounted within the vehicle, the effects of blast pressure waves associated with gunfire are unlikely to be significant. However, possible adverse effects could arise from a coupling of gun firing rate with vehicle structural frequencies or with the installed frequencies of materiel.

4. TEST SELECTION

4.1 Testing Options

4.1.1 Three approaches of simulating the tracked vehicle environment are generally available, ie: in the test laboratory using vibrators and other facilities as necessary, in the field using suitable test tracks, or in the field using road and terrain surfaces under real conditions. The simulation of the environment in the laboratory has the advantage that it allows the simulation to be undertaken in defined and controlled conditions. Moreover, laboratory testing permits reduced test times, reduced costs as vehicle operations are eliminated, and increased safety standards (particularly for munition testing). An advantage of field trials is that all units are in their correct relative positions and all mechanical impedances are realistic; consequently, field trials can be expected to expose materiel to all relevant failure mechanisms. Field trials may be necessary if inadequate data are available from which to base laboratory test severities. A simulation using field trials may be more convenient for large and awkward payloads, and is essential where the payload interacts significantly with the dynamics of the carriage vehicle.

4.2 Laboratory Vibration Testing

4.2.1 The simulation of the environment in the laboratory is usually viable for all but the largest items of materiel. When a vibration test is required the test procedure used should be that of AECTP 400, Method 401 - Vibration.

4.3 Laboratory Shock Testing

4.3.1 In some cases it may be necessary to undertake shock or transient testing to reproduce the structurally transmitted transients arising from the vehicle. The test procedure used should be that of AECTP 400, Method 403 - Shock. The basic pulse procedure should suffice for most applications, but where a closer simulation is required AECTP 400, Method 417 is recommended.

4.4 Test Track Trials

4.4.1 Due to the difficulties of establishing “worst case” road conditions, use is often made of standard test tracks. A wide range of test tracks is available. Not all of these are designed to simulate tracked vehicle environments, some are designed to investigate aspects of vehicle handling, and reliability. Therefore, care is needed when selecting suitable surfaces to ensure representative materiel responses. High amplitude responses can be induced at a rate of occurrence many orders greater than that experienced in-Service, which for some materiel may induce modes of failure that are unlikely to occur in practice. The test procedure used should be that of AECTP 400 Method 408 - Large Assembly Transport.

4.5 Road and Terrain Trials

4.5.1 Trials conducted over representative roads and terrain for representative durations are the most realistic. Such trials are only valid when detailed knowledge is available of the materiel installation and the intended use of the tracked vehicle. Even when conducting these trials, it may be desirable to include some test track trials as a convenient way of incorporating limit conditions. The test procedure used should be that of AECTP 400 Method 408 - Large Assembly Transport.

4.6 Acceleration Testing

4.6.1 Testing by the application of quasi-static loadings to simulate vehicle accelerations is usually unnecessary, because the loadings are either encompassed by testing for other in-Service environments or the adequacy of the materiel is demonstrated by assessment.

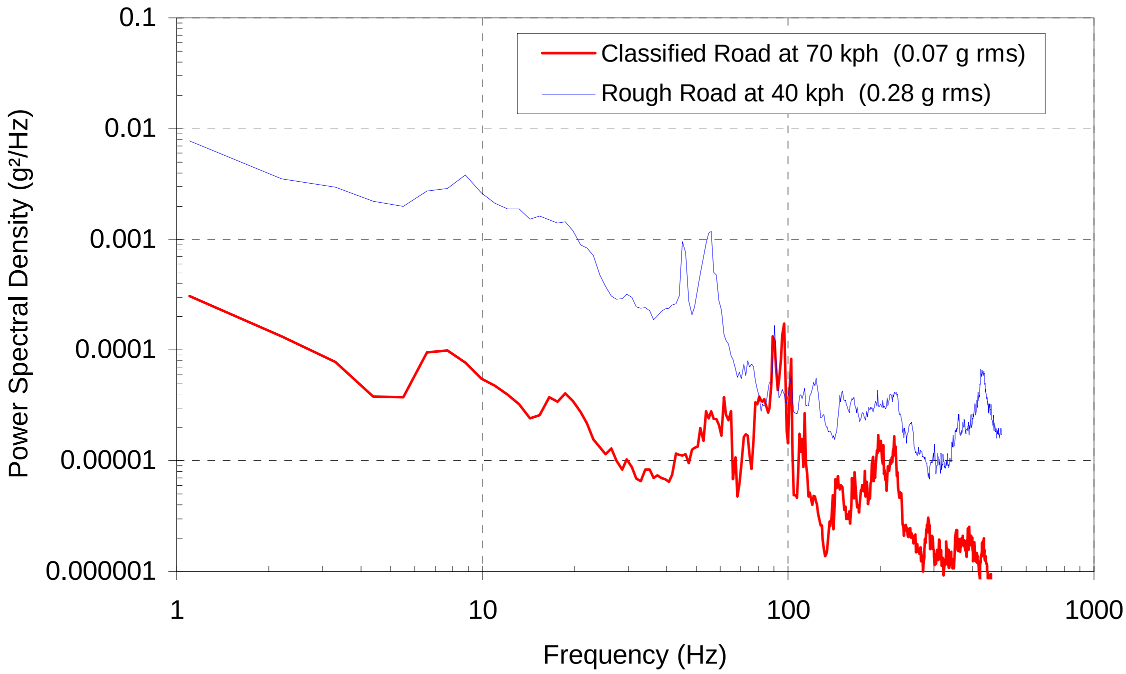


Figure 1: Vibration spectra (vertical axis) for rough and classified roads - load bed above rear axle on a small four wheel drive vehicle (short wheel base Land Rover)

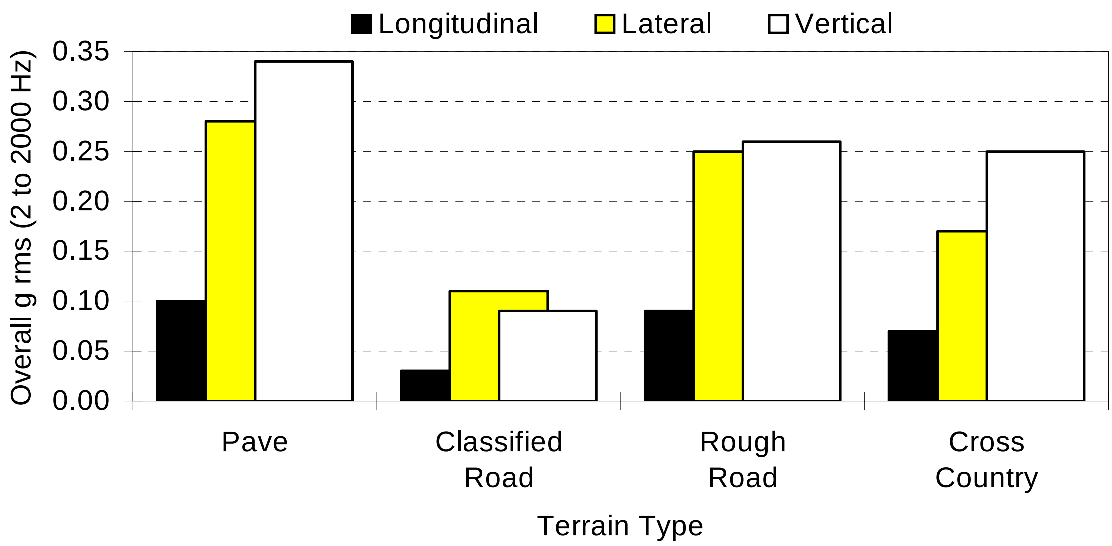
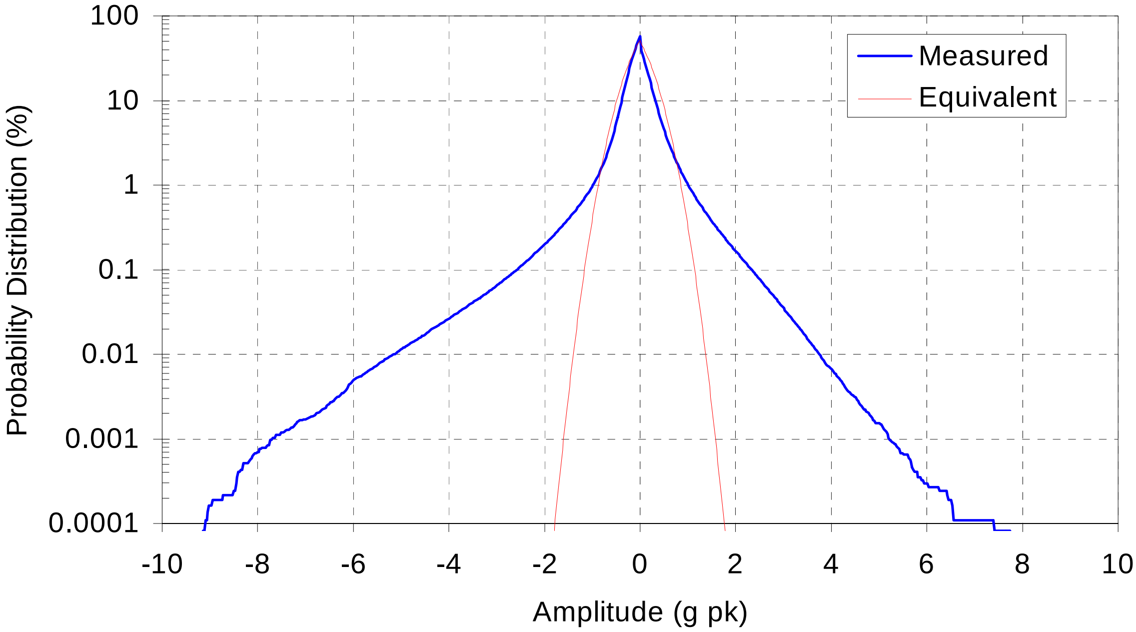
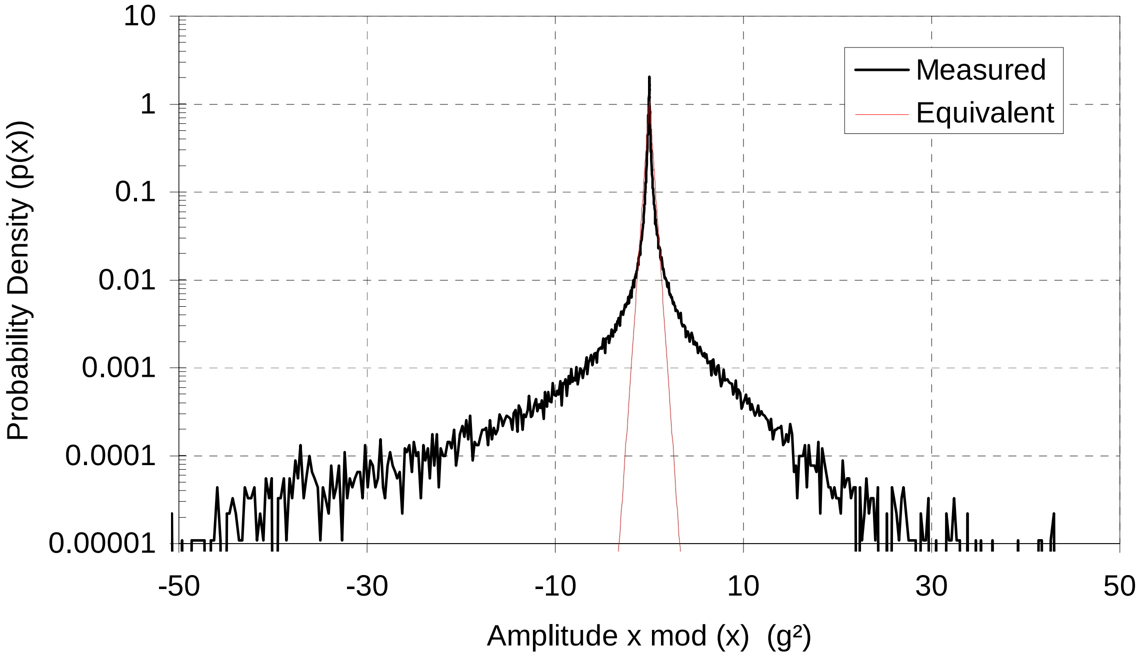


Figure 2: Effects of terrain on vibration - load bed above rear axle on a small four wheel drive vehicle (short wheel base Land Rover)



a: Amplitude probability distribution



b: Amplitude probability density

Notes: 1. Measured data are from the load bed (vertical axis) of a 4 t truck on a rough road

2. Equivalent data are from a gaussian distribution of the same rms value as that measured

Figure 3: Measured amplitude probability functions

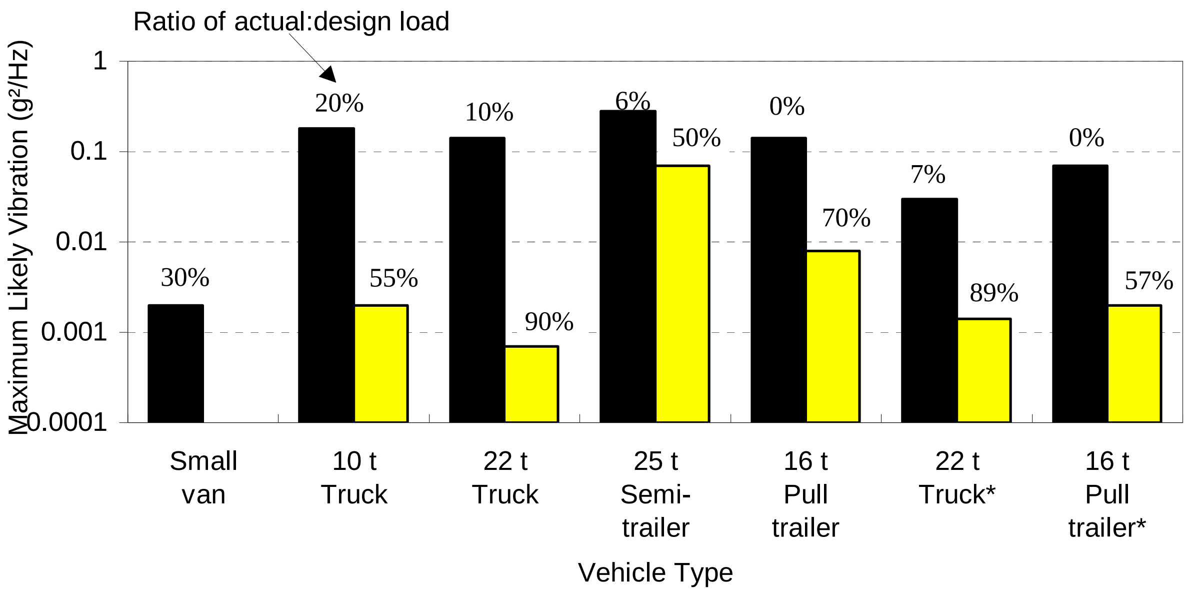


Figure 4: Effect of laden weight on vehicle vibration (vertical axis)

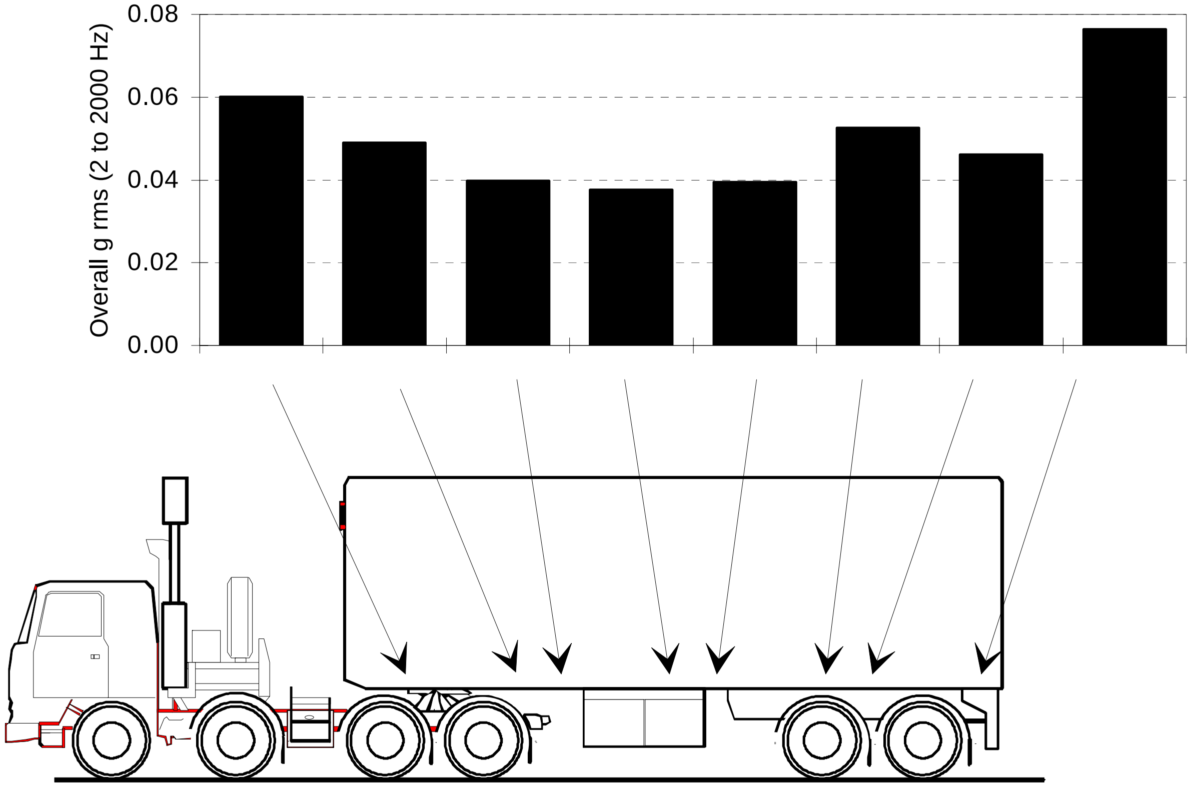


Figure 5: Articulated trailer vibration amplitude (vertical axis)

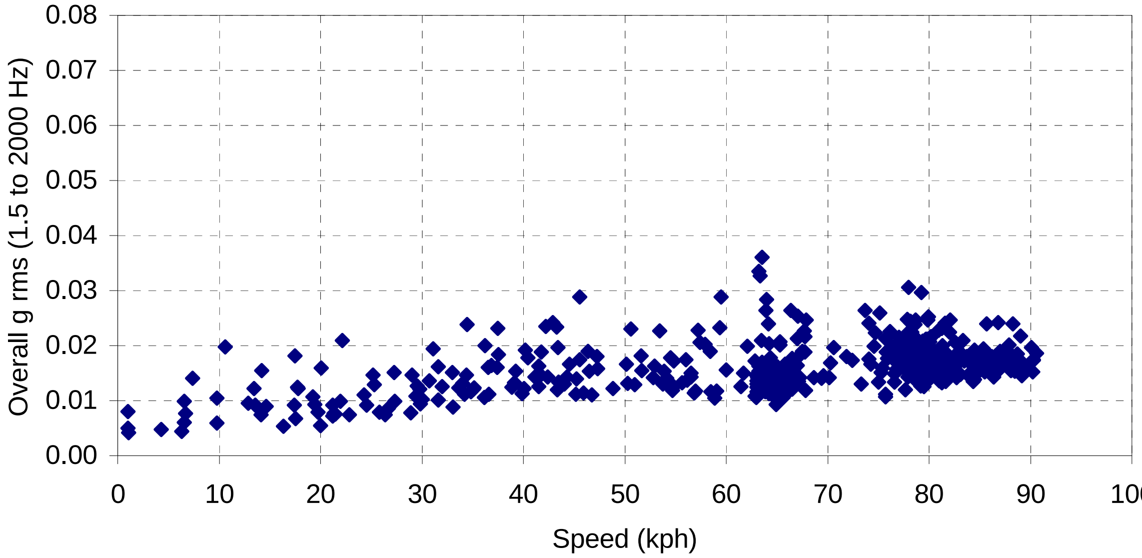


Figure 6: Vehicle structural vibration versus speed (vertical axis)

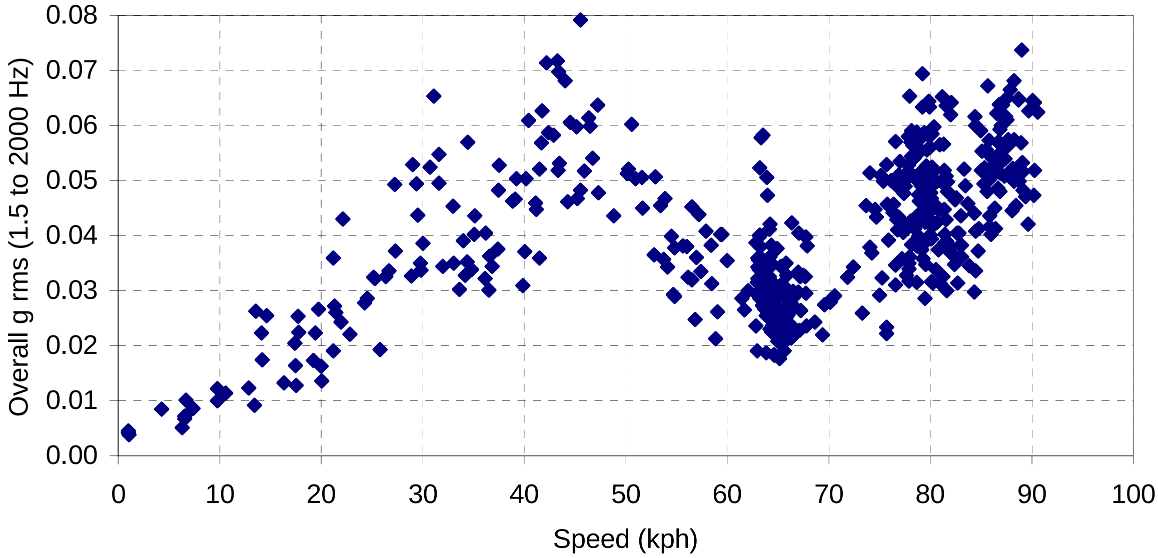


Figure 7: Materiel vibration response versus speed (vertical axis)

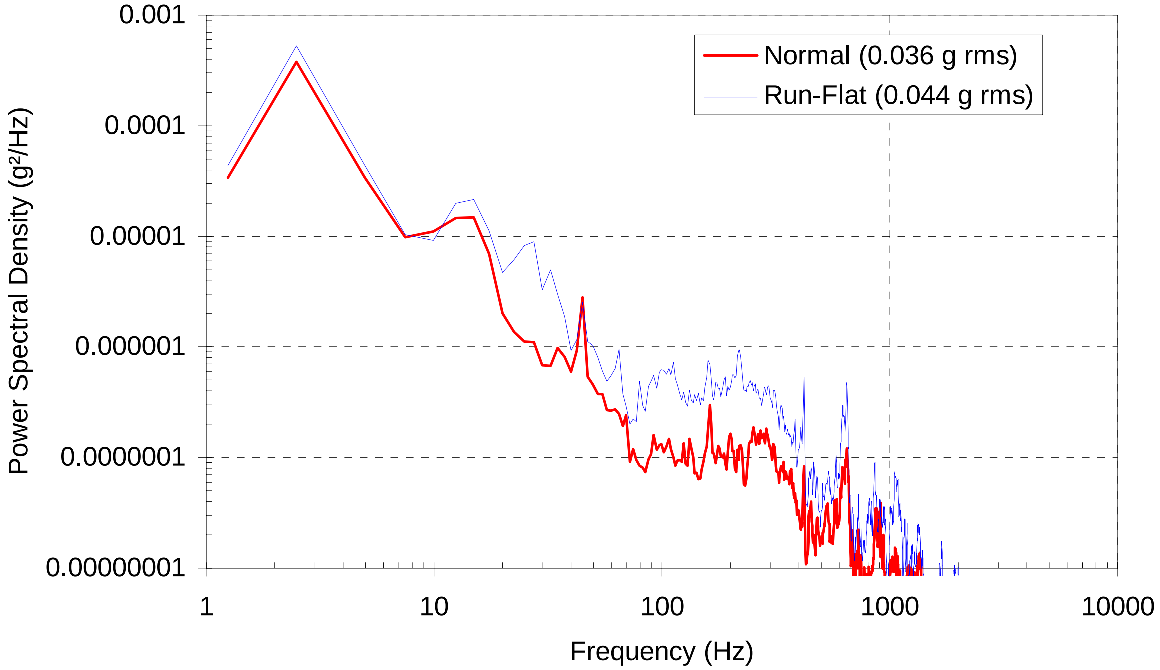


Figure 8: Effect of deflated tyres on vehicle vibration (vertical axis)

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ANNEX A

DERIVATION OF SEVERITIES FROM MEASURED DATA

A.1 Derivation of an Environment Description

A.1.1 Requirements: It is first necessary to establish from the relevant requirements the type of tracked vehicle in which the materiel is to be installed, the role of the vehicle and the terrain over which it will travel, the vehicle's operating speeds, and the location of the materiel in the vehicle. Having established the requirements, relevant vibration data may be acquired from data banks, should the data exist, or from field measurement trials.

A.1.2 Environment Descriptions: An environment description for materiel installed in a tracked vehicle should generally include for each relevant terrain over the range of operating speeds, frequency response characteristics, amplitude probability plots, and time histories of any transients. This information will be used to examine trends, such as how severity is influenced by terrain and vehicle speed. The flow diagram outlined in Figure A.1 points out the steps to be adopted to derive an environment description from measured data. This diagram enables frequency response characteristics and dynamic response amplitudes to be quantified for all the relevant test conditions. A process for using these components of the environment description to produce test spectra and durations is discussed below.

A.2 Derivation of Vibration Test Severities

A.2.1 General: Test severities are defined in terms of the characteristics and amplitudes of the broad band background vibration, narrow band components associated with track patter, and durations. Advice on establishing these parameters is given below.

A.2.2 Broad Band Component

a. Characteristics: In general, it can be expected that the broad band component spectral characteristics, i.e.: the shape of ASD plots, will be stable with respect to many parameters, including vehicle speed and terrain type.

b. Amplitude: The severity of the test spectrum may not in general be obtained directly from ASDs because, for tracked vehicles, they are unlikely to be an adequate description of the environment. This is a consequence of the character of this type of data; it can be non-stationary resulting in relatively high peak to rms ratios. It is therefore also non-gaussian. These properties of non-stationary and non-gaussian are in contrast to the character of vibration generated in test laboratories. Consequently, special steps may need to be taken to avoid under testing in the laboratory. In some cases conservatism can be incorporated into the test spectrum by the technique of enveloping to produce an adequate test severity. An alternative approach is to use amplitude probability distributions (APD) as the basic measure of severity and to derive appropriate factors which can then be applied to mean spectra. This approach is preferred for tracked vehicles and an example of its use is given in paragraph A.3.

A.2.3 Narrow Band Components.

a. Characteristics: The frequency of the narrow band components at a given speed can be calculated from knowledge of the track pitch dimension, and can be expected to be easily recognisable in measured data, at least for hard terrain and under constant speed conditions. To accommodate these effects in a test spectrum, i.e.: that the frequency of these components are speed dependent, the narrow bands should be swept over an appropriate frequency range. Alternatively, the broad band spectrum could simply be shaped to accommodate these peaks, rendering the narrow bands unnecessary, albeit at the considerable risk of excessive testing.

b. Amplitudes: Establishing the amplitudes of these components can be a problem because of their changing frequency with vehicle speed. This can lead to an under-estimation of severity because of averaging effects implicit in a ASD analysis. One solution is to gather data at a number of constant speeds which can then be analysed separately. Alternatively, if the speed is not constant throughout a record, evolutionary spectra (waterfall plots) can be used. In either case, the severity, expressed in either ASD or RMS form, should be associated with the resolution bandwidth to make the definition unambiguous.

A.2.4 Test Duration: Test durations should be based upon the required life of materiel and the usage profile of the relevant wheeled vehicle. In order to avoid impractically long test durations, it is general practice to invoke equivalent fatigue damage laws such as Miner's Rule. This rule is also known as the "Exaggeration Formula" and is expressed as follows:

$$t_2 = t_1 \left(S_1 / S_2 \right)^n$$

where

t_1 = the actual duration in the requirements characterised by the measured level
t_2 = the equivalent duration at the test level
n = the exaggeration exponent

For rms level

S_1 = the rms level of the measured spectrum
S_2 = the rms level of the test spectrum
n = b = the exaggeration exponent; values between 5 and 8 are typically used

For ASD level

S_1 = the ASD level of the measured spectrum

S_2 = the ASD level of the test spectrum

n = b/2 = the exaggeration exponent; values between 2.5 and 4 are typically used

The exponent ‘b’ corresponds to the slope of the fatigue (S/N) curve for the appropriate material. A value of ‘b’ equal to 8 is adequate to describe the behaviour of metallic structures such as steels and aluminium alloys which possess an essentially linear stress-strain relationship. This expression is used with less confidence with non-linear materials and composites. For electronic equipment and non metallic materials, elastomers, composites, plastics, explosives, a value of 'b' equal to 5 is recommended.

Although the expression has been shown to have some merits when applied to materiel, it should be used with caution, if unrepresentative failures are to be avoided. It is inadvisable for test levels to be increased beyond the maximum measured levels that equipment may experience during in-service life, with a statistically based test factor applied. Furthermore, where there is evidence that the materiel is not fully secured to the vehicle Miner's Rule is totally invalid and should not be used. In such cases the Loose Cargo Test (AECTP 400, Method 406) should be considered as an alternative.

A simplified example of the derivation of a test duration using Miner's Law is given below.

Terrain	**Speed (mph)**	**Severity index**	**Duration**	**Time (mn)**	
			%	Actual t_1	Equivalent t_2
Pavé	25	1.0	5.0	3	3.00
Pavé	20	0.7	6.7	4	0.67
Rough road	15	0.6	13.3	8	0.62
Cross country	35	0.5	16.7	10	0.31
Main road	45	0.4	30.0	18	0.18
Main road	35	0.3	20.0	12	0.03
Main road	<20	0.2	8.3	5	<0.01
		Totals:	**100.0**	**60**	**4.82**

Notes

(1) 4.82 minutes test is equivalent to 60 minutes real time vehicle vibration.

(2) The "Severity Index" for a terrain is the overall g rms normalised with respect to the maximum measured overall g rms (associated with pavé in this example). It is important to check that the ASD spectrum profile associated with the reference level (again, pavé in this example) either reflects, or is modified to reflect, the maximum amplitudes observed over the total frequency range.

(3) This method of calculating test durations would normally be applied subject to a maximum of 17 hours per axis.

A.3 Comparing Measured Data With Test Specifications

A.3.1 When comparing measured spectra from a vehicle trial with that contained in a test specification or generated by test house equipment, care must be taken to avoid an under-estimation of the severity of the measured data. This is because of the different amplitude distributions and peak to rms ratios of these types of data. These differences can be compensated for, as shown in this example:

Measured peak APD level = $9.00g$
(at the 1 in 500 occurrence level, ie: 2.88 sigma)

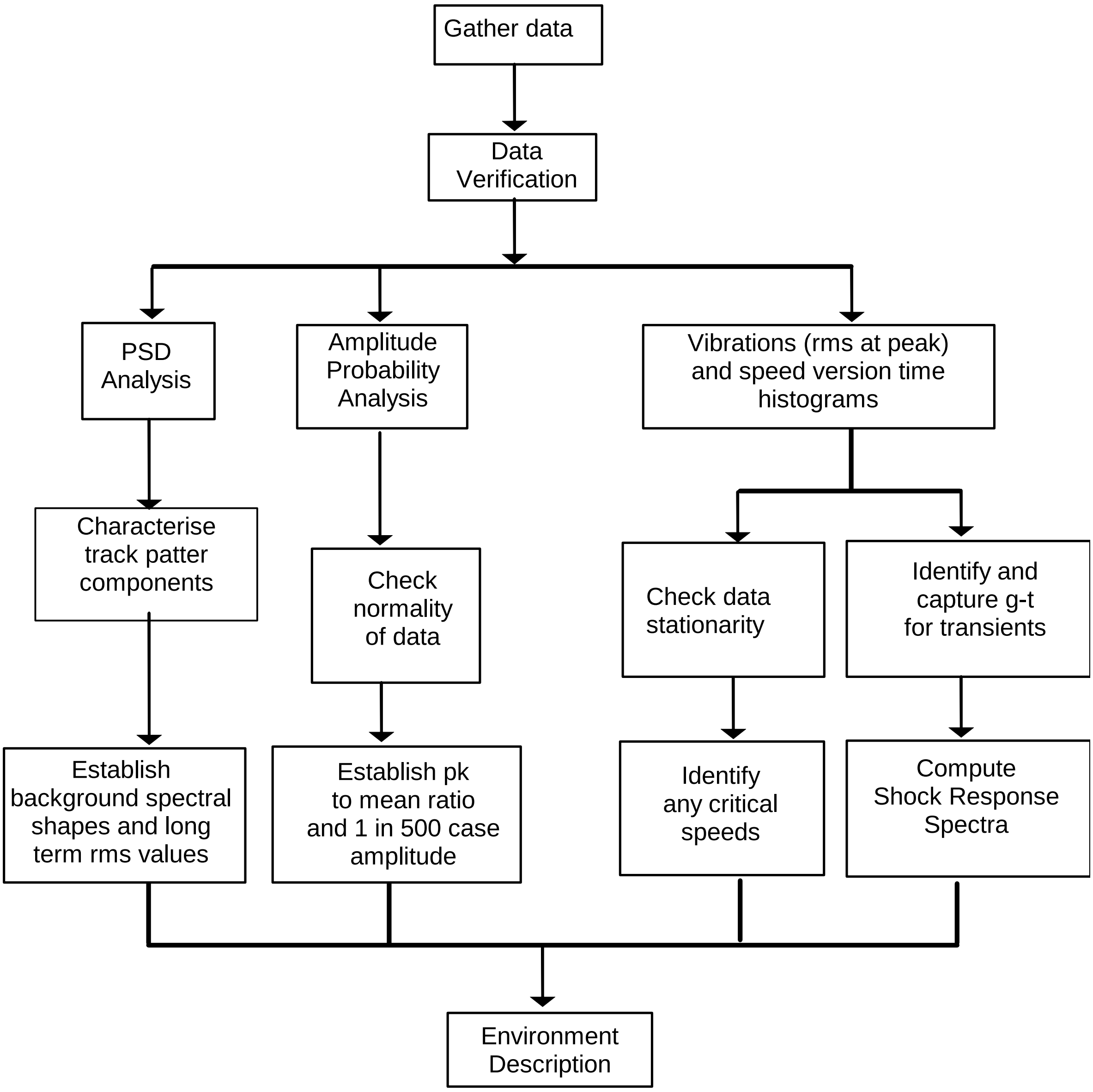
Equivalent gaussian rms = $\frac{9.00}{2.88} = 3.1g$

Measured non-gaussian rms = $1.4g$

Factor on measured g rms = $\frac{3.1}{1.4} = 2.2$

Factor on measured ASD = $2.22^2 = 4.8$

Whilst this analysis indicates that in this instance a factor of 4.8 should be applied to the measured ASD levels, these higher levels would be appropriate for a relatively short duration.



Note: The steps outlined above would normally be carried out for each terrain and for all relevant installations

Figure A1: Derivation of an environment description from measured data

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LEAFLET 246/1

DEPLOYMENT ON JET AIRCRAFT

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LEAFLET 246/1

DEPLOYMENT ON JET AIRCRAFT

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be experienced by materiel when deployed on or installed in fixed wing jet aircraft. The sources and characteristics of the mechanical environments are presented and where appropriate, information is given on potential damaging effects. Additional guidance is contained in Annex A on important parameters influencing the mechanical environments. Where relevant, advice is given on the selection of the appropriate AECTP 400 Test Methods.

1.2 The following aspects are not included in this leaflet:

a. Materiel deployed on or installed in helicopters. For information on this subject refer to Leaflet 247/1.

b. Engines and associated equipment, ie: the environments experienced by an engine and its associated equipment arising from their own operation. For information on such induced environments reference should be made to the engine manufacturer.

c. Airframe and other primary structure. For information on loads and severities relating to these structures, reference should be made to the aircraft manufacturer.

d. Abnormal conditions, such as crash and blast.

1.3 Unless specified otherwise the environmental descriptions relate to the interface between the aeroplane and the installed equipment, and all axes relate to aircraft axes

1.4 The mechanical environments experienced by materiel installed on fixed wing jet aircraft arise from a wide range of sources. No general rules can be set down as to the dominant source for every item of materiel, especially as some of the potential sources produce very intense but localised effects. For the majority of materiel the most severe continuous conditions arise from only one or perhaps two sources. In addition, severe conditions of a transitory nature can occur due to buffet and the operation of guns. While each application of these transitory conditions may occur for only a few seconds, their cumulative effect over the life of the aircraft can be significant.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Airfield Movements

2.1.1 Materiel can be expected to experience continuous vibration and transient responses as a consequence of aircraft movements about an airfield. The transient responses are caused by the wheels traversing the inevitable irregularities in the taxi-way surfaces. The severity of these vibrations and transients will be influenced principally by aircraft speed and the size of the aircraft wheels. The responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft.

2.1.2 As airfield surfaces are usually of good quality and aircraft movements are usually controlled, the severities resulting from airfield movements are usually low and significantly less than those from the flight phase. However, this may not be the case when temporary or repaired taxi-ways are used. In such cases it can be expected that a significant increase in the severity of the transients will occur. However, these conditions are unlikely to be more severe than those occurring during take-off and landing on temporary and repaired runways.

2.2 Take-off and Landing

2.2.1 Normal Take-off and Landing Conditions: During take-off and landing short duration oscillatory transients may be induced in the installed materiel. These transients arise mainly as a result of the aircraft traversing runway surface irregularities at speed. Again, the responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft. As both take-off and landing are usually controlled, the amplitudes of the resultant transients are benign. Consequently, the dynamic responses experienced during take-off and landing are normally considered to be encompassed within those of the flight phase. Take-off and landing usually involves high levels of engine power, which in turn may induce vibration and acoustic noise conditions. These related aspects are dealt with in paragraph 2.4.5. Typical take-off vibration severities are shown in Figure 1, and typical landing shocks are shown in Figure 2.

2.2.2 Temporary or Repaired Runways: Continuous vibration and transient shock severities are likely to be more severe when temporary or repaired runways are used. The maximum permitted severity resulting from the use of such surfaces will depend upon the capabilities of the aircraft under consideration and in particular upon the ruggedness of the aircraft undercarriage. Consequently, where necessary, advice on severities should be sought from the aircraft manufacturer. However, any test procedures used to simulate these conditions are likely to be similar to those recommended for normal take-off and landing conditions.

2.2.3 Catapult Launch and Arrested Landing: Oscillatory transients will be induced in materiel during a catapult launch and/or arrested landing of an aircraft. In general catapult launch will show two transient events corresponding to initial load application and catapult separation from the aircraft. Both transient events have a distinct oscillatory nature, approximately sinusoidal, at a relatively low frequency determined by aircraft mass and landing gear damping characteristics. Arrested landing conditions produce only a single transient but with similar characteristics to catapult launch. At installed materiel locations the pulse durations associated with catapult launch and arrested landing are relatively long and therefore these transients are usually treated as quasi-static conditions.

2.2.4 Vertical Take-off and Landing: During vertical take-off and/or landing, efflux from the engine nozzles may impinge on parts of the aircraft structure or stores not subjected to such conditions during normal flight. In addition, efflux reflected from the ground may impinge on the majority of the lower aircraft surface. In consequence severe acoustic and vibration conditions may be induced.

2.2.5 Ski-jump Assisted Take-off: The dynamic environment induced during the use of ski-jump assisted take-off is of very low frequency and is usually considered as a quasi-static, rather than as a dynamic condition.

2.3 Flight Vibration

2.3.1 Aerodynamic Flow: The most common source of aircraft equipment vibration is associated with airflow surrounding the aeroplane. This air flow over the structure may be attached or detached. These two conditions produce significantly different vibration excitations. The more severe vibration conditions are associated with detached flow which exists in areas remote from the leading edge surfaces on all aeroplanes.

a. Attached Flow: Where the airflow is attached to the aircraft surface a nominally classical boundary layer type flow will exist, and structural vibration can be expected to be at a minimum. Vibration intensity is broadly proportional to the dynamic pressure (q) and the broad band random frequency spectrum is related through Strouhal Number with the boundary layer thickness and velocity.

b. Detached Flow: Where detached flow exists the intensity of the pressure fluctuations can rise to typically five times those associated with attached flow. In addition, the area over which the fluctuations are correlated increases by several orders. This increase in area has the potential to significantly increase the effectiveness by which the flow can excite the structure. The increased pressure fluctuations will continue to relate with dynamic pressure ‘q’ (but with a higher coefficient of efficiency) and the frequency scaling will continue to relate with Strouhal Number. In practice the increased pressure fluctuations will result in increased structural vibration responses over a broad frequency range while the increase in area of correlated pressures may result in a very significant increase of structural vibration responses over narrow frequency ranges.

The parameters influencing flight vibration levels are discussed in Annex A.

2.3.2 Vortex Impingement: On high performance aircraft under certain conditions of angle of attack, heading and airspeed, it is possible for vortices originating from parts of the aeroplane to impinge on downstream structure. The characteristics of these vortices are such that severe structural vibrations may arise. In general these vibrations may be dominated by the lower structural modes of the particular portion of the airframe (wing, empennage etc). The severe vibratory conditions are transitory in nature and rarely occur for more than a few seconds at any one time.

However, during the life of an aeroplane the total number of such occurrences may be significant. The resulting vibration characteristics, severities and areas of airframe affected will be unique to aircraft type. An example of the responses due to vortex impingement is shown in Figure 3.

2.3.3 Buzz: This condition is sometimes categorised as a type of single degree of freedom flutter. However, whereas conventional flutter is associated with the generalised aerodynamic flow over the wing (or control surface), buzz is normally associated with shock wave oscillation and the inducted structural oscillation is of a higher frequency than occurs with conventional flutter. To aircraft structure, the phenomenon will appear as a good quality sine wave, with some amplitude modulation, at a frequency of typically 60 Hz.

2.3.4 Engine Intake Flow Effects: Variable intakes can have a geometry such that the main flow into the intake can pass over a cavity used for ducting away excess air. Experience has shown that strong acoustic discrete frequency resonances can occur in the duct which can in turn produce high strain levels in the duct structure and any splitters or guide vanes in the duct. Vibration responses from this source have been noted in wing structure, installed equipment and stores. Neither the intensity nor the frequency of excitation can be calculated with much accuracy because the effective dimensions of the duct space cannot be estimated accurately.

2.3.5 Powerplant Effects: Powerplant induced vibration in aircraft installed equipment is predominantly due to impingement of engine noise on the aircraft structure. It can also arise as a result of the local ‘attachment’ of a jet plume to the aircraft structure. Sources of jet noise are described below.

a. Jet Noise Mixing: The noise created by the turbulent mixing of an issuing jet (jet noise) has been troublesome and a prime source of structural vibration which has affected many aircraft. The usual effect is to produce long-term fatigue in cleats, corners of stringers, ribs and, more frequently, under rivets. In severe noise fields, over 160 dB, shorter term fatigue can occur in more important structural locations, such as rib webs and at the centre of panels. At higher levels still, over 170 dB, failures in prime structure can occur in conventional designs. In such cases special features may need to be incorporated into the design. The problem was recognised early and much theoretical and experimental work was done to combat the problem. Today it is assumed that adequate attention is given to detail design and to the use of certain basic rules in order to alleviate these problems. Extensive literature exists on these aspects.

b. Choked Jets: In an under-expanded supersonic jet, shock cells exist which, relative to a subsonic jet, results in an increase in the spectral density of the random pressure fluctuations in a particular region of the frequency spectrum. These particular frequencies are associated with the dimensions of the shock cells which can change during flight if the jet pressure-ratio changes. There have been cases where the frequency of the spectral peak has coincided with the frequency of structural panels and damage has resulted.

c. Jet Attachment: A jet which is close, but nominally clear of a structure can attach itself to the structure by a mechanism which is sometimes referred to as the Coanda effect. This occurs when due to a manoeuvre or a change in the jet dimensions, as a result of a pressure-ratio change (eg: altitude), the boundary conditions required for the full mixing of the jets are not met. This will occur for instance when the necessary full air-entrainment on one side of the jet is restricted as the jet moves towards the fuselage. The jet will then move further towards the fuselage so that the boundary-layer existing on the fuselage and the flow at the jet edges will merge 'sucking' the jet towards the fuselage so that it eventually sticks to it. This produces an upward and sudden step in the level of vibration and nose, as well as producing a heating effect.

2.3.6 Cavities: Cavities exposed to a grazing airflow passing the aeroplane can be a significant source of both noise and vibration. The frequency spectrum of such disturbances can be wide in range and usually features sharp peaks and troughs over the frequency range. The main peaks arise from the excitation of acoustic 'space' modes which are a direct function of the dimensions of the cavity. A bomb bay is an obvious example of such a cavity. The frequencies of the main modes can be calculated with some confidence from standard formulae. The majority of the less dominant modes are usually harmonics of the main modes and can persist up to quite high orders. The amplitudes of the pressure fluctuations are less easily estimated because they are affected by geometrical factors such as the sharpness of the edges of the cavity, the direction of flow over the cavity and the contents of the cavity. The contents of the cavity can have the effect of making the main modal peaks less discernible whilst increasing the level of the background broad-band 'noise' which is always present.

2.4 Flight Manoeuvres and Gusts

2.4.1 Materiel will experience low frequency acceleration loadings due to flight manoeuvres and gusts. These are normally considered as quasi-static loadings for design and test purposes. At a particular aircraft location the loadings arise mainly from the vector sum of the six ‘rigid body’ aircraft degrees motions, ie: vertical, lateral, longitudinal, roll, pitch and yaw. In some cases these could be amplified by the dynamic motions of the lower aircraft modes.

2.4.2 The severity of the flight acceleration environment will depend mainly upon the type of aircraft under consideration. Generally the flight accelerations are a specified design requirement for a particular aircraft type and hence are well defined early in a design. These accelerations are usually constrained by flight limits or the aircraft control system. In some instances these loadings are monitored for fatigue purposes.

2.5 Gunfire

2.5.1 Significant vibration and shock excitations in aeroplane structure, installed equipment and stores can arise from the operation of guns situated either within the aeroplane or in external pods. While the total duration of these excitations is relatively short the amplitudes can be several orders of magnitude greater than the vibrations arising during normal flight. Moreover, the characteristics of the responses can be significantly different to the vibrations occurring during normal flight conditions and may induce different equipment failure modes.

2.5.2 The effects of gunfire potentially induce vibrations from three different sources. These are overpressure or blast emanating from the gun muzzle, recoil of the gun on its mounts and motions of the ammunition and its loading system. Usually the most significant of these on installed equipment is that due to blast, which produces the most widespread vibration effects on structure and equipment.

2.5.3 Gun blast overpressure is created by the sudden expansion of the propellant gas from the muzzle after the projectile emerges. This gun blast propagates through the air and impinges on the surrounding structure. The pressure wave may affect equipment directly or indirectly via the aeroplane structure. The severity of the pressure waves is dependent upon a number of factors such as altitude, airspeed, type of gun and ammunition, distance from the muzzle and the incidence of the blast wave. These factors and a method for computing the magnitude of the blast pressure wave impinging on the surrounding structure are detailed in UK Defence Standard 00-970, Volume 1, Leaflet 501/5.

2.5.4 The character of structural responses arising from gun blast will depend upon the location of the structure or equipment with respect to the gun muzzle. These responses can be considered to have distinctly different characteristics in each of the near, middle and far spatial fields.

a. Near Field: The character of structural responses arising from gun blast near the gun muzzle, ie: in the near spatial field, is largely influenced by the impulse of the blast pressure wave. Structural and equipment responses will appear as a sequence of distinct shock pulses. The near spatial field will include the muzzle breakout point and structure in its immediate vicinity. In the absence of a spatial definition the near field should be considered to be a circular area of 0.5 m^2 extending around the gun muzzle in the plane normal to the gun muzzle. When uncertainty exists as to whether equipment is located in the near or middle fields, and particularly for equipment critical to aeroplane safety, the near field should be assumed.

b. Middle Field: The response of structure and materiel more distant from the gun muzzle, ie: in the middle spatial field, is largely influenced by the coupling of the pressure pulse with the dynamic characteristics of the structure. The character of the response is dominated by the periodic motions arising from the gunfire rate and its subsequent harmonics. If no better information is available, the middle spatial field should be considered to extend beyond the near field up to 150 calibres from the muzzle. When doubt exists equipment and structure should be considered to be located in the middle field in preference to the far field.

c. Far Field: For materiel and structure well away from the gun muzzle the vibrations arising from gunfire overpressure may not be readily discernible within the normal flight vibration levels. The higher harmonics of the gunfire rate tend to become less significant eventually leaving only the periodic motions at the fundamental gunfire rate. In the far spatial field because the amplitude of the responses from gunfire are less than those form normal flight aerodynamic excitations, the difference in character is unlikely to have a significant effect. The far field encompasses all the remaining zones of the aeroplane not considered as near or middle field.

Further information is given in Annex A.

2.5.5 Vibrations arising from gun recoil tend to be less severe than those from blast. This is because the effects of gun recoil tend to be filtered by the high gun mass and mount stiffness effective at the gunfire frequency. Consequently gun recoil usually only significantly affects equipment close to the gun mounts. The vibrations due to ammunition loading and handling systems are the least significant of the three potential sources. This source only effects equipment very close to the handling system. However, it is likely to be a significant source for the ammunition itself.

2.6 Launch of Weapons

2.6.1 The launch or firing of weapons (excepting gunfire) can, in certain circumstances induce high level of shock, vibration and pressure blast in the aircraft structure and equipment, nearby weapons or stores.

3. POTENTIAL DAMAGING EFFECTS

3.1 Airfield Movements

3.1.1 The motions arising from aircraft movements will result in low amplitude, high frequency of occurrence continuous responses which could cause damage through fretting fatigue mechanisms.

3.2 Take-off and Landing

3.2.1 The motions arising from normal take-off and landing are largely dictated by the characteristics of the undercarriage system. Therefore, potential damaging effects are likely to be associated with displacements at low frequencies.

3.3 Flight Vibration

3.3.1 Aerodynamic Turbulence: Vibration arising from aerodynamic turbulence can generate brinelling, fretting, and high cycle fatigue.

3.3.2 Vortex Impingement: The potential high levels of vibration, coupled with the knowledge that the dominant structural responses occur at the lowest structural modes, the most likely damage effects are those associated with high acceleration loadings and low to medium cycle fatigue.

3.3.3 Jet Noise: As the character and structural response mechanisms of the vibrations attributable to jet noise are similar to those from aerodynamic turbulence, similar failure mechanisms are likely to result.

3.3.4 Cavities: The most likely damage effects associated with cavity resonances are those associated with high acceleration loadings and medium cycle fatigue.

3.4 Flight Acceleration

3.4.1 The most probable damaging effect is that due to acceleration loadings producing internal forces within the equipment, often at its mountings, of sufficient magnitude to cause structural or fatigue failure. In some cases such loadings may cause deflections of sufficient magnitude to prevent the proper operation of mechanisms.

3.5 Gunfire

3.5.1 In the near field the amplitude of the blast pressure wave may be sufficient to cause structural failure of panels and their supports. Materiel in close proximity to the muzzle, but protected from the direct blast pressure wave, may fail due to the severity of the discrete and repetitive shock pulses. The most likely failure modes of equipment in the middle field are those associated with high intensity, low frequency vibration.

4. TEST SELECTION

4.1 General

4.1.1 The following paragraphs provide recommended treatments for the mechanical environments identified in paragraph 2, and where relevant indicate the appropriate AECTP 400 Test Method.

4.2 Airfield Movements

4.2.1 Because the severities associated with this environment are relatively low, they are often considered in conjunction with other more severe conditions such as flight vibration. In cases where testing is considered appropriate a broad band random vibration test should be used, adopting AECTP 400, Method 401 - Vibration.

4.3 Take-Off and Landing

4.3.1 Again, because the severities are relatively low, testing for this environment is only carried out in special circumstances. In cases where testing is considered appropriate a decaying sinusoidal wave form test would normally be utilised, as specified in AECTP 400, Method 403 - Shock.

4.4 Flight Vibration

4.4.1 Aerodynamic Turbulence: The random vibration test as given in AECTP 400, Method 401 - Vibration should be selected for this environment.

4.4.2 Vortex Impingement: Although vortex impingement only occurs infrequently and for short periods over the life of an aircraft airframe, the accumulative duration of the narrow band random or predominantly sinusoidal vibration responses can be sufficient to warrant a test. Appropriate test procedures are given in AECTP 400, Method - 401 Vibration. The test procedure selected should be one that is compatible with the vibration characteristics.

4.4.3 Jet Noise: For most materiel the effects of jet noise are encompassed within the severities of the flight vibration conditions. For sensitive materiel upon which engine noise impinges directly, ie: when the excitation is predominantly transmitted by air, a test procedure should be selected from the three given in AECTP 400, Method 402 - Acoustic Noise, that is to say, Diffuse Field, Grazing Incidence or Cavity Resonance. The test procedure selected should be one that is compatible with the noise characteristics.

4.4.4 Cavities: If materiel is mounted within, or close to, a cavity which is open to the airstream, a cavity acoustic resonance noise test should be undertaken. An appropriate test procedure is given in AECTP 400, Method 402 - Acoustic Noise.

4.5 Flight Acceleration

4.5.1 Testing is undertaken when the adequacy of materiel cannot be suitably demonstrated by calculation or static strength testing. When environmental testing is required it is normally undertaken in accordance with AECTP 400, Method 405 - Constant Acceleration.

4.6 Gunfire

4.6.1 Significantly different responses arise from gunfire in each of the three spatial fields defined earlier. Therefore, a different treatment should be considered for each spatial field.

4.6.2 Near Field: A sequence of shock loads is required to replicate the effects of the blast overpressures. While the practicality of reproducing such a series of transient pulses rarely permits a precise simulation, modern vibration generation equipments permit reasonably good approximations to be achieved. The simulation of gunfire should, where relevant, be undertaken using AECTP 400, Method 405 -

Gunfire. Alternatively the use of special purpose excitation equipment may be utilised. The specific nature of the blast shock loads in the near field prevent the derivation of generalised severities; preferably test levels should be based upon measured data. In some cases the analytical determination of severities may be practical using the procedure of Defence Standard 00-970, Volume 1, Leaflet 501/5, Annex A.

4.6.3 Middle Field: Simulation of the gunfire environment in the middle spatial field is usually undertaken by superimposing, on broad band random vibration, a series of in-phase sinusoidal components of vibration or narrow band random vibration components. The appropriate frequencies of these narrow band or sinusoidal vibrations occur at the fundamental frequency of gun firing and the subsequent harmonics. AECTP 400 Method 405 should be adopted for this test. For cases where estimates of structural and equipment responses are required, and no appropriate measured data exists, then Method 519.3 of Mil Std 810E is recommended. Experience has shown that this method gives acceptable estimates of gunfire vibration severity in many circumstances. This method utilises four sinusoidal vibration components, occurring at the fundamental frequency of gun firing and the next three harmonics, superimposed on a background of shaped broad band random vibration. The method also permits the use of four narrow bands of random vibration instead of sinusoidal vibrations. This latter option is preferable because the gunfire rate may not be perfectly constant and the use of narrow bands protects against the arbitrary nature of equipment responses. However, for high amplitude responses the use of narrow bands may not be within the capabilities of available vibration generators.

4.6.4 Far Field: In the far field, when the response due to gunfire is less than those occurring due to normal flight conditions, the specific simulation of gunfire is usually not necessary.

4.7 Launch of Weapons

4.7.1 In most cases the induced loadings can be treated as quasi-static analytical methods. However, in some cases such loadings may induce significant dynamic responses on airframe structure or stores. Consequently, additional shock and/or pressure blast testing may be required to simulate these effects. In cases where testing is required AECTP 400, Method 403 - Shock should be considered.

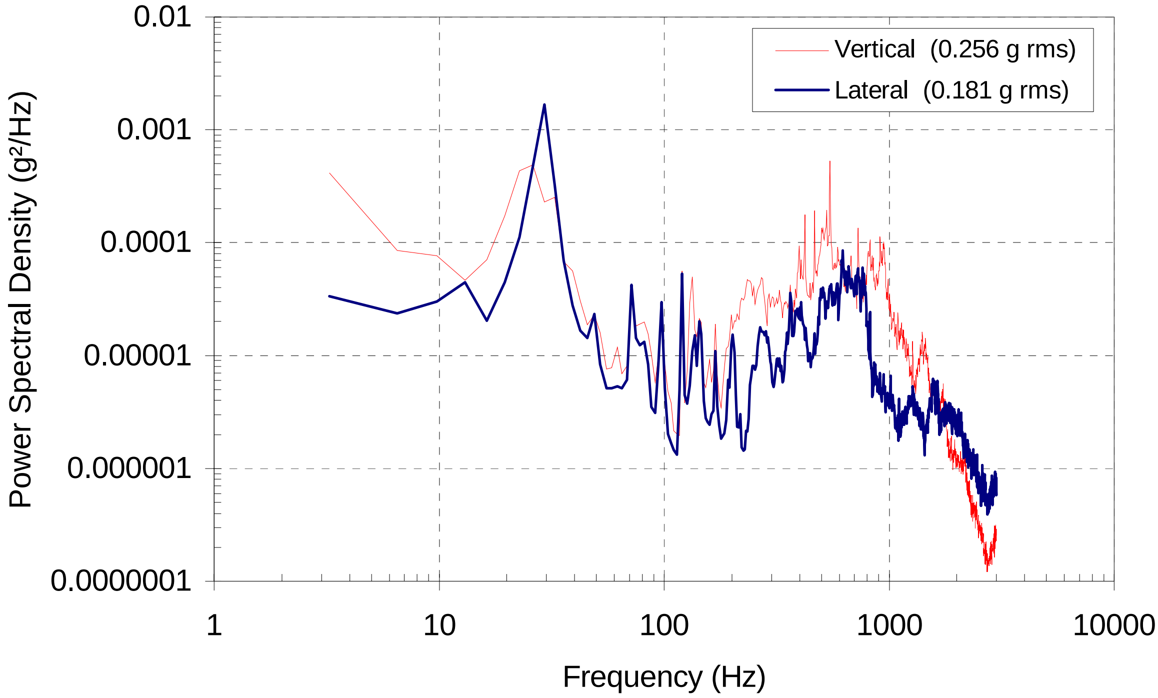


Figure 1: Vibration occurring during take-off

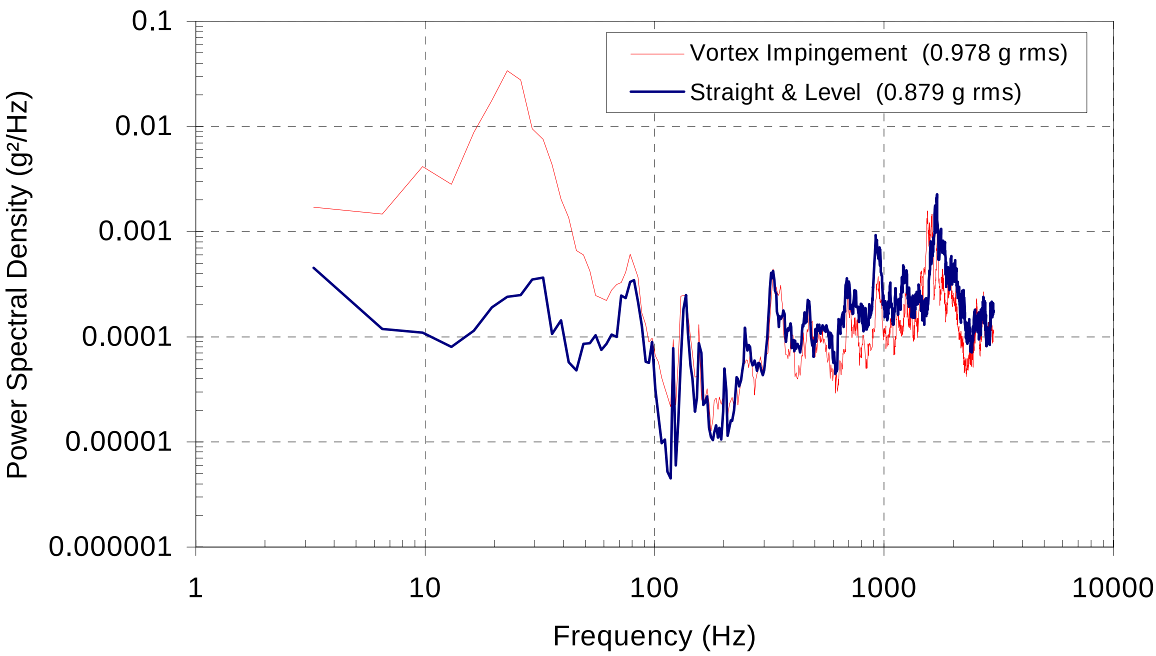
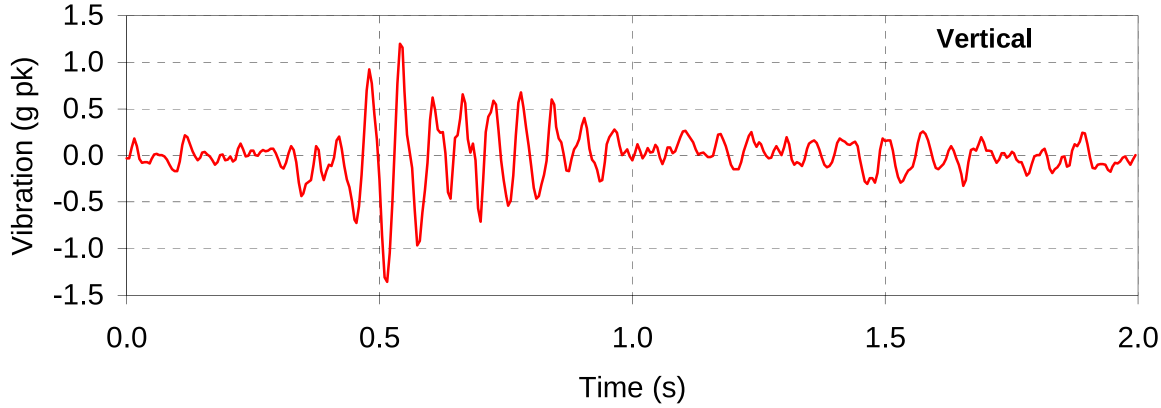


Figure 2: Increase in vibration due to vortex impingement



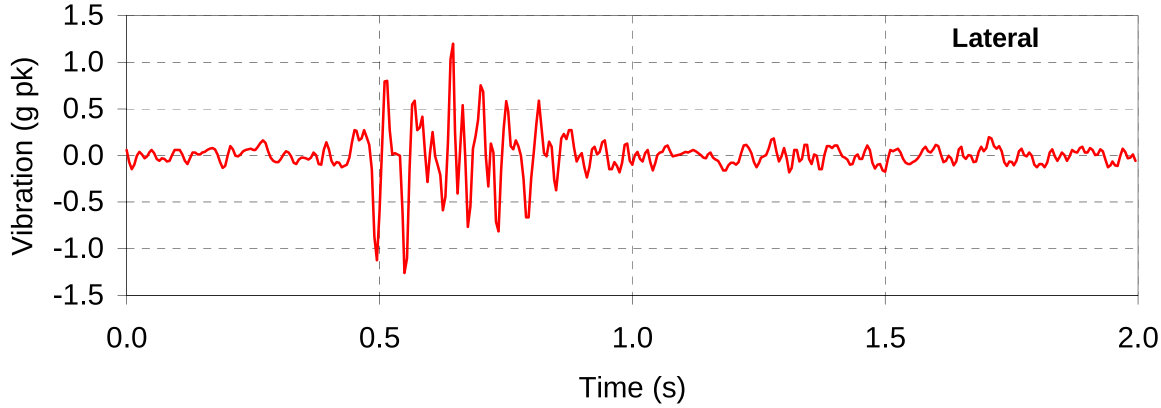


Figure 3: Transients occurring during a normal landing

ANNEX A
PARAMETERS INFLUENCING THE MECHANICAL ENVIRONMENTS

A.1 Flight Vibration

A.1.1 Flight measured vibration data will rarely be available for all in-service conditions, therefore it is useful to establish, where practical, a working knowledge of the effects of various parameters on vibration severity. This is usually achieved by the derivation of empirical predictive models from measured data acquired from a well planned programme.

A.1.2 Experience indicates the following parameters and trends are worthy of consideration.

a. Altitude and Airspeed: An important parameter influencing vibration severity is flight dynamic pressure; which in turn is related to altitude and airspeed. This parameter is particularly significant when considering severities for high performance jet aeroplanes. Investigations may be undertaken by examining plots of overall root mean square (rms) vibration versus flight dynamic pressure.

b. Powerplant Demand: Variations in this parameter and its effect on vibration severity may be especially appropriate for VSTOL aeroplanes.

c. Axis and Location: Investigations of the general variations in vibration responses by axis and location is particularly useful for the cargo areas of transport aircraft. The variations can be examined in terms of overall rms vibration and spectral profile. It may also be applicable to establish the general trend of vibration levels around the aeroplane. Establishing a precise description is unlikely to be practicable due to the complicated nature of the structural dynamic characteristics. However, such precise descriptions are rarely necessary in practice.

d. Payload Configuration: The effects of payload configuration (total mass and distribution) on vibration levels may be investigated where significant variation in payload configuration is likely to occur. These effects can also be examined in terms of overall rms vibration and spectral profiles.

e. Vortex Impingement: The effects of vortex impingement can be examined using plots of peak amplitudes in the time domain. However, the onset and magnitude of the vibration responses cannot be readily correlated with the usual monitored aircraft parameters. Moreover, the effects of vortex impingement are difficult to model using empirical prediction techniques.

f. Flight Manoeuvres: These can include non-stationary conditions such as take-off, landing, reverse thrust, wind-up-turns, etc. In these cases, plots of overall rms vibration versus time are usually appropriate.

g. Mach Number: While the effects of airspeed are normally related to flight dynamic pressure, in some instances the relationship may change at higher Mach numbers. Consequently it is prudent to establish the relationship between vibration severity and Mach number in addition to the more usual relationship with dynamic pressure.

A.2 Gunfire

A.2.1 The parameters examined will depend upon the proximity of the materiel to the gun muzzle, ie: whether it is located in the near, middle or far fields.

a. Near Field: In the near field the blast pulse will almost certainly be the dominant feature in the measured dynamic responses. Moreover, the preferred test will consist of reproducing this pulse. Hence the extraction of the characteristics of the pulses will be the prime concern. This is probably best achieved in the time domain as the use of either frequency spectra and shock response spectra will cause problems due to the presence of the background aerodynamically induced broadband random vibrations.

b. Middle Field: In the middle field equipment responses will be dominated by structural responses rather than by the blast pulses. As the simulation is usually a broadband random it is appropriate to evaluate the measured responses in the frequency domain. The nature of the responses will be broadband random with superimposed ‘near periodic’ components at the gunfire rate and subsequent harmonics. Accurate determination of these latter components may require very narrow bandwidth analysis which may be incompatible with the identification of the broader frequency range random vibration. Under such circumstances separate frequency spectra aimed at quantifying each aspect separately may be needed. Even then it may be prudent to use mean square values to quantify the individual harmonics.

c. Far Field: As gunfire is unlikely to cause problems in the far field no specific recommendations are offered.

LEAFLET 246/2

EXTERNAL CARRIAGE ON JET AIRCRAFT

TABLE OF CONTENTS

LEAFLET 246/2

EXTERNAL CARRIAGE ON JET AIRCRAFT

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be experienced by stores during external carriage on fixed wing jet aircraft. The sources and characteristics of the mechanical environments are presented and where appropriate, information is given on potential damaging effects.

1.2 Advice is given on the relative merits of the test options and where relevant the selection of the appropriate AECTP 400 Test Method. Information is given in Annex A on the parameters influencing store vibration. Guidance is given in Annex B on the compilation of environmental descriptions and test severities from measured data.

1.3 Environments associated with store separation from the aircraft are covered in Leaflet 249/1 - Air and Land Weapons. Environments associated with the aircraft itself are covered in Leaflet 246/1 - Deployment on Jet Aircraft.

1.4 The vibration experienced by stores during external carriage on high performance jet aircraft is relatively high. As a consequence considerable testing is usually necessary to ensure that the store is capable of meeting its in-Service requirements.

1.5 Many aspects influence store vibration under external carriage conditions, and in view of the associated high severities, it is important to acquire an understanding of the major influences that could affect the vibration severities of a particular store/aircraft configuration in order to derive an effective test specification. The following paragraphs introduce these major influences and discuss their associated vibration characteristics and severities.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Taxi-ing, Take-off and Landing

2.1.1 Normal Conditions: During taxiing, take-off and landing oscillatory transients may be induced in a store and its equipment. These transient arise as a result of the aircraft traversing the taxi-ways and runways. Generally the responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft as well as the lower suspension modes of the store. These transients are usually relatively benign and encompassed within those of flight carriage. The severities are likely to be more severe when temporary or repaired taxi-ways and runways are used. Take-off usually involves high levels of engine power, which in turn may induce vibration and acoustic noise conditions. The noise levels may be greater than those of flight because of the effects of ground reflection.

2.1.2 Reverse Thrust Devices: Some aircraft utilise reverse thrust devices during landing. These devices not only involve high levels of engine power but may also redirect the engine efflux back towards the aircraft. This can produce particularly high levels of localised acoustic noise and vibration, albeit for only a few seconds. Figure 1 shows the characteristic responses from the rear of a store as a result of impingement of redirected engine efflux occurring during the operation of a reverse thrust device.

2.1.3 Catapult Launches/Arrested Landings: Short duration oscillatory transients will be induced in a store during an aircraft catapult launch or an arrested landing. In general, a catapult launch will show two transient events corresponding to initial load application and catapult separation from the aircraft. Both transient events have a distinct oscillatory nature, approximately sinusoidal, at a relatively low frequency determined by aircraft mass and landing gear damping characteristics. Arrested landing conditions produce only a single transient but with similar characteristics to catapult launch. While the pulse amplitudes associated with catapult launch/arrested landing are low, the long (several seconds) periods of application and high frequency of occurrence have the potential to cause damage.

2.1.4 Vertical Take-Offs and Landings: During vertical take-off or landing, efflux from the engine nozzles may impinge on stores not normally subjected to such conditions. In addition, and probably more importantly, jet efflux reflected from the ground may impinge on the majority of the lower aircraft surface including stores. In consequence severe vibration conditions unique to vertical take-off and/or landing may be induced.

2.1.5 Ski-jump Assisted Take-Off: The dynamic environment induced during the use of ski-jump assisted take-off is of very low frequency and usually considered as a quasi-static aircraft loading condition rather than as a vibratory or transitory one.

2.2 Flight Operations

2.2.1 General:

a. The mechanical environments experienced by externally carried stores during flight carriage on fixed wing jet aircraft are mainly vibratory and originate from the relatively steady aerodynamic flow traversing the store external surface. However, under certain flight conditions, other sources such as buffet manoeuvre may induce responses even more severe than those from steady state aerodynamic flow. Both conditions are addressed below, together with vortex impingement and jet noise. Further detailed information on the effects of aerodynamic flow, buzz, engine intake flow and powerplant can be found in Leaflet 246/1. Also, the effects of manoeuvres and gusts, and structural cavities are fully covered in Leaflet 246/1 and therefore are not repeated under this heading.

b. The physical parameters of a store and its deployment configuration can significantly influence vibration responses, although it is usually impractical to quantify their interaction with the applied unsteady aerodynamic pressures to predict vibration responses. The influence of the major parameters, which include dynamic pressure, store type, location etc, on vibration severities are discussed in Annex A.

2.2.2 Aerodynamic Flow:

a. The most significant source of store vibration is associated with the unsteady pressures in the airflow surrounding the store. The airflow over the store, particularly over the forward regions, may be smoothly attached to the store, or it may be detached, as it usually is over the aft regions of a store. The more severe vibrations experienced by stores are associated with detached flow.

b. The effects of attached and detached flow are demonstrated in Figure 2. The dotted curve indicated responses when the flow is mainly attached, whilst the solid curve shows the effects following the onset of detached flow. Corresponding wind tunnel measurements indicate that unsteady pressures increase by a factor of between 2 and 2.5 over a broad frequency range. These increased pressures can result in significantly increased vibration responses of panel modes, as indicated in Figure 2.

c. As the vibration excitation arising from the normal aerodynamic flow over the store is essentially broad band random vibration, damage effects are likely to be fatigue related, such as the fretting failure of small mechanisms, electrical connections, etc. For high modal density stores the frequency range of excitation is such that modes of vibration up to at least 3 kHz are excited; the highest vibration amplitudes often occurring around the store ring mode frequencies. For low modal density stores the responses may be dominated by only a few frequency peaks; but the vibration amplitude at each peak is likely to be relatively high.

d. Further details on aerodynamic flow are given in Leaflet 246/1, paragraph 4.1.

2.2.3 Vortex Impingement:

a. At certain aircraft manoeuvre conditions, it is possible for vortices originating from, say, the air intake of a high performance aircraft to impinge on a downstream store. During these conditions severe transitory vibration responses can be generated but rarely occur for more than a few seconds at any one time. The characteristics of the vibration responses are unique to the particular store/aircraft installation, and may only occur during a very limited range of combinations of airspeed, attitude, heading and angle of attack. Should the vortex frequency coincide with a local resonance, high amplitude vibration would occur which might result in fatigue damage.

2.2.4 Buffet Manoeuvre:

a. When the vortex impingement conditions described in paragraph 3.3 excite the fundamental modes of a wing mounted store, or the rigid body modes of a wing mounted store on its relatively flexible carriage equipment, very severe vibration responses can be generated. Typical comparative vibration responses are shown in Figure 3 of a wing mounted slender missile on a high performance aircraft during straight and level flight and when undertaking a wind-up turn. The dominant vibration response around 30 Hz is the missile's fundamental bending mode.

b. For relatively long and slender missile systems, the vibration response levels at the affected modal frequencies can be the most severe the system will experience during its operational life. Due to the non stationary data characteristics for these buffet conditions it is difficult to assign amplitudes with any confidence, but at the forward section of a slender missile system, vibration responses have been observed that exceed 10 g in the time domain and 10 g^2/Hz in the frequency domain. Moreover, although the high vibration responses only occur for a few seconds during each buffet manoeuvre condition, the resulting amplitudes at relatively low frequencies can generate sufficient displacements that can, when coupled with their potential frequency of occurrence, adversely influence the fatigue life of the missile structure.

c. Similar buffet manoeuvre conditions can arise from rigid body motions of a wing mounted store or missile resulting from aircraft wing bending or torsion. Comparable vibration amplitudes under such conditions for a 1000 lb store during straight and level flight and when undertaking a wind-up turn are shown in Figure 4, where store responses in the vertical axis of the store’s cg are seen to increase by more than three orders of magnitude at low frequency. The response at around 25 Hz is attributed to a wing torsion mode. Further studies on this response indicate that it is related to angle attack and dynamic pressure as shown in Figure 5. Vibration responses are more pronounced for forward mounted slender missiles on outboard wing stations and can attain amplitudes comparable with those cited in the previous paragraph.

2.2.5 Jet Noise:

a. Power plant induced vibration in externally carried stores arises predominately from the noise generated by the turbulent mixing of the issuing jet, reflecting from the ground during take off. Resulting store vibration amplitudes are usually less than those induced from high speed flight, but could be the dominant vibration source for stores carried towards the rear of low performance aircraft. The characteristic of this vibration is usually wide band random. Further details on powerplant effects are presented in Leaflet 246/1 paragraph 4.5.

2.3 Gunfire

2.3.1 Significant vibration and shock responses can arise in externally carried stores due to the operation of guns installed within the carriage aircraft or in adjacent external pods. While the total duration of these excitations is relatively short, the amplitudes can be significantly higher than the vibrations arising during normal flight. Moreover, the characteristics of the responses are significantly different to the vibrations arising from normal flight conditions and may induce different failure modes.

2.3.2 The effects of gunfire potentially induce vibrations from three different sources. These are the blast emanating from the gun muzzle, the recoil of the gun on its mounts, and the motions of the ammunition and its loading system. For externally carried stores the most significant of these is almost always that due to blast. Typical vibration responses of a store skin panel and internal equipment due to gunfire blast effects are illustrated in Figure 6. Further information on the treatment of gunfire effects for all three sources is given in Leaflet 246/1 - Installation in Jet Aircraft.

2.4 Launch of Weapons

2.4.1 The launch of weapons can induce high levels of shock, vibration and pressure blast in nearby stores. In most cases the induced loadings are considered as quasi-static conditions and are dealt with accordingly. In some cases they can induce low frequency dynamic responses of the aircraft wing structure, which in turn may produce high store loads. Store attachment arrangements have been known to fail under such loads. Additional shock, vibration and/or pressure blast testing may be necessary to simulate these effects, but as these loading conditions are project specific it is inappropriate to offer general advice.

3. POTENTIAL DAMAGING EFFECTS

3.1 Failure Modes

3.1.1 The mechanical environments arising from deployment externally of stores on fixed wing aircraft can induce a number of failure modes. The most significant of these modes are those related to acceleration loadings. Acceleration related failure modes may arise from a single application of a load, to produce a threshold exceedance failure, or from the repeated application of a series of loads to produce a fatigue induced failure.

3.1.2 Displacement related failures, such as tension failures and loose connectors, are also significant for stores and can arise from relative motions of component elements or from collisions between equipments.

3.1.3 Failures induced as a result of an applied velocity are unusual. The application of velocity loadings on some electrical equipment and certain types of sensors may induce spurious voltages, which in turn could give rise to functional failures.

3.2 Potential effects

3.2.1 General: As the primary sources of potential damage for externally carried stores are the loading actions that arise from the aerodynamic flow processes present during flight carriage, the following paragraphs address only those sources. The effects of gunfire are covered in Leaflet 246/1 - Installation in jet aircraft.

3.2.2 Aerodynamic Flow: Since the vibration excitation arising from the aerodynamic flow over the store is essentially broad band random vibration, damage effects are likely to be fatigue related, such as the fretting failure of small mechanisms, electrical connections, etc. For high modal density stores the frequency range of excitation is such that virtually all modes of vibration up to at least 3 kHz are excited; the highest vibration amplitudes often occurring around the store ring mode frequencies. For low modal density stores the responses may be dominated by only a few frequency peaks; but the vibration amplitude at each peak is likely to be relatively high. These high amplitudes at specific modes may not be indicated by the overall vibration severity when displayed in terms of g rms, which can indeed show the reverse trend.

3.2.3 Vortex Impingement: Vibration amplitudes arising from a vortex impinging on a store can be severe. These conditions can arise when vortices are shed from adjacent structure such as an aircraft intake. Should the vortex frequency coincide with a local resonance high amplitude vibration could occur which may result in fatigue damage.

3.2.4 Buffet Manoeuvres: Although the high vibration responses occur for only a few seconds during each buffet manoeuvre condition, the amplitudes and frequencies generate significant displacements that can adversely influence the fatigue life of missile structures.

4. TEST SELECTION

4.1 Flight Operation - Aerodynamic Flow

4.1.1 Test Options: The aerodynamic excitation source is distributed externally about the store surface. Consequently, it is difficult, particularly at the higher frequencies, to simulate this source effectively by point excitation techniques such as mechanical vibrators. For this reason, use is often made of acoustic excitation methods. However, acoustic excitations alone may not be adequate to simulate responses at the lower frequencies, and therefore may need to be augmented by a mechanical vibration test. If acoustic excitation testing is not viable, then a mechanical vibration test covering a broad frequency range is usually acceptable.

4.1.2 Acoustic Testing: Two methods are available for generating the required acoustic excitation. The first produces the acoustic pressure levels within a reverberant chamber, the second by means of a progressive wave tube. With either method a supplementary, preferably simultaneous, application of mechanical excitation is required. The severities used for acoustic testing may be defined either as acoustic sound pressure levels or store vibration responses. Because the former requires major assumptions, including that relating to the efficiency of the coupling of sound pressures with store dynamic characteristics, the later is always preferred. Suitable acoustic test procedures are those presented in AECTP 400, Method 402 - Acoustic noise.

4.1.3 Mechanical Testing: The mechanical vibration test may be used to cover the complete frequency range, or to augment the acoustic test at the lower frequencies. Since the source and amplitude of vibration is distributed along the entire length of the store, it is preferable for the excitation to be applied to more than one location along the store's longitudinal axis. If this approach is not viable the application of the excitation through one location may be a possible alternative, although significant over testing is almost certain to result at this location. Moreover, when using any form of mechanical vibration test for this environment, it is prudent to anticipate at least some unrepresentative damage around the excitation points. A suitable test procedure for mechanical testing is that presented in AECTP 400 Method 401 - Vibration.

4.1.4 Combined Environments: The need to simulate several environmental conditions simultaneously is the preferred requirement for complete stores. Such combined tests may be required for approval and/or for reliability purposes. Two combined environmental test methods are in common use:

a. Vibration/Acoustic/Temperature: This method, which is presented in AECTP 400 Method 413, allows mechanical vibration, acoustic and temperature conditions to be applied simultaneously.

b. Vibration/Temperature/Altitude: This method, which is presented in AECTP 300 Method 318, allows mechanical vibration, temperature and altitude conditions to be applied simultaneously.

4.2 Gunfire

4.2.1 Test Options: Pulse and vibration test methods are available to replicate store responses arising from aircraft gunfire. The vibration method is applicable only where the individual pulse characteristics are not discernible; ie: to store mounted equipment positioned away from the store skin and where the store is positioned some distance from the aircraft gun muzzle. In all other cases the preferred approach is to select a test method that generates a sequence of pulses.

4.2.2 Pulse Method: Considerable practical difficulties exist in producing a series of pulses to represent the blast effects of gunfire. However, some recently developed vibration generation equipment is capable of achieving relatively good approximations. The particular pulse method to be adopted can be selected from those presented in AECTP 400 Method 405 - Gunfire, but care is needed to ensure a satisfactory simulation.

4.2.3 Vibration Method: Simulation of gunfire by vibration test methods is usually undertaken by superimposing on broad band random vibration, a series of in-phase sinusoidal components of vibration or narrow band random vibration components. The frequencies of the narrow band or sinusoidal vibration are the fundamental frequency of the gun firing rate and the subsequent harmonics. The most commonly used procedure utilises four sinusoidal vibration components, occurring at the fundamental frequency of gun firing and the next three harmonics, superimposed on a background of shaped broad band random vibration. Also acceptable is the use of four narrow bands of random vibration instead of sinusoidal vibration. This latter option is preferable as it accommodates variations in both the gunfire rate and the equipment's response. However, at high amplitudes the use of narrow bands may be outside the capabilities of the vibration generator. Appropriate test procedures are presented in AECTP 400 Method 401 - Vibration.

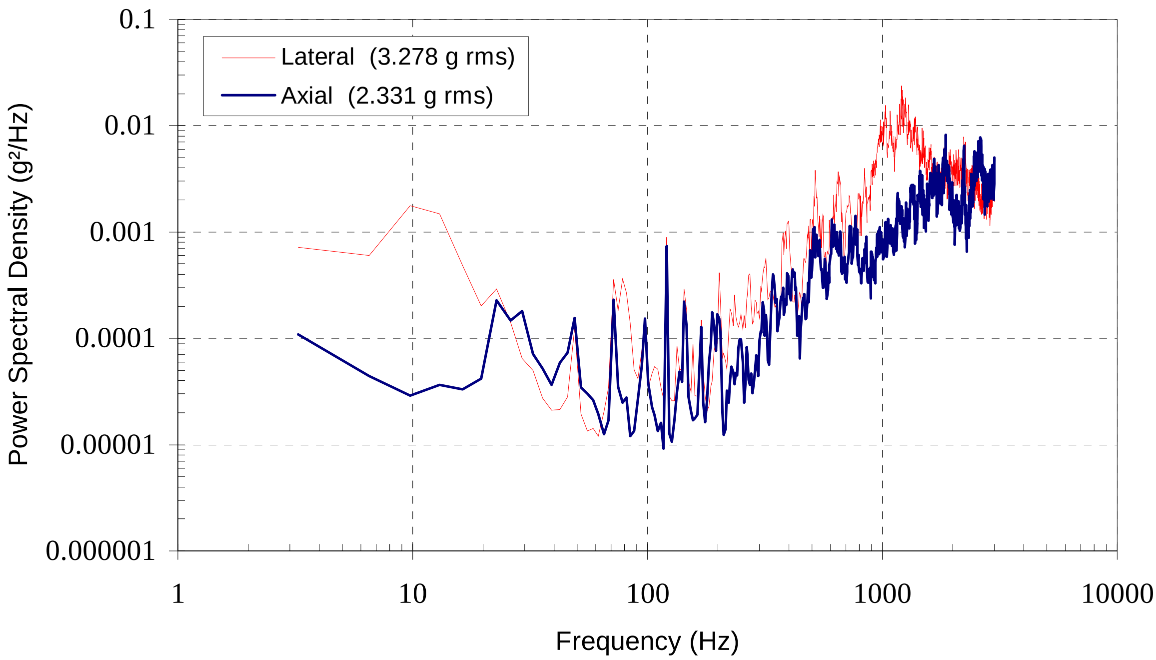


Figure 1: Vibration response of a store panel directly ahead of aircraft engines during reverse thrust

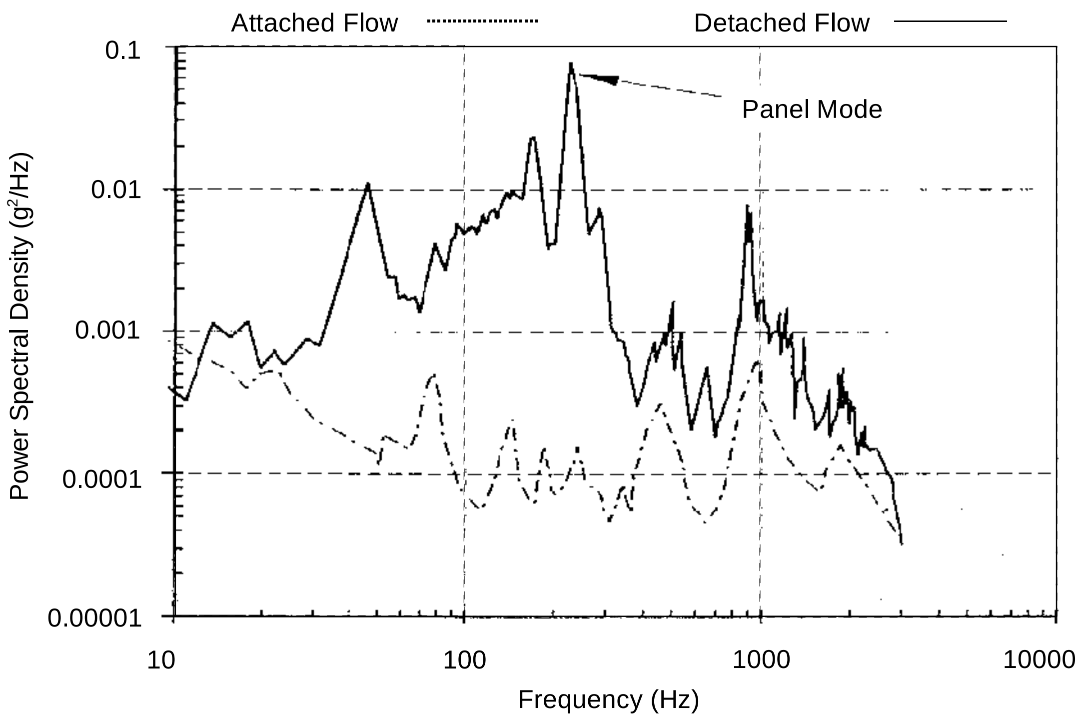


Figure 2: Effects of attached and detached flow on store vibration responses

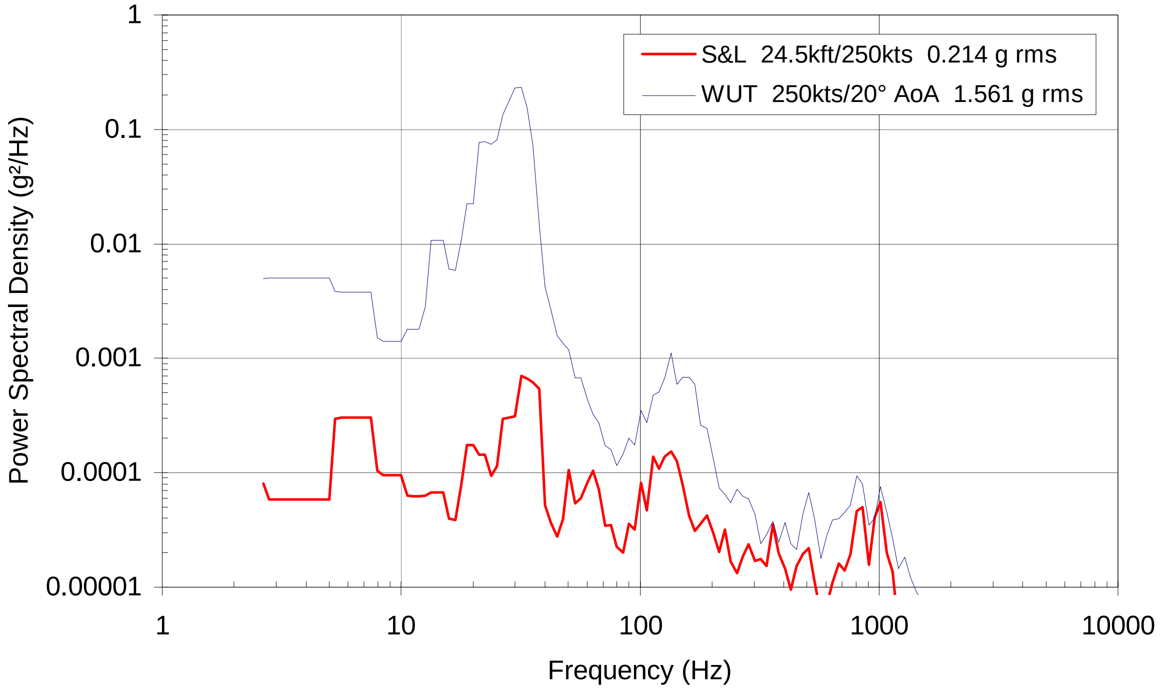


Figure 3: Comparison of vibration of a slender missile during straight and level flight and in buffet on a fast jet aircraft

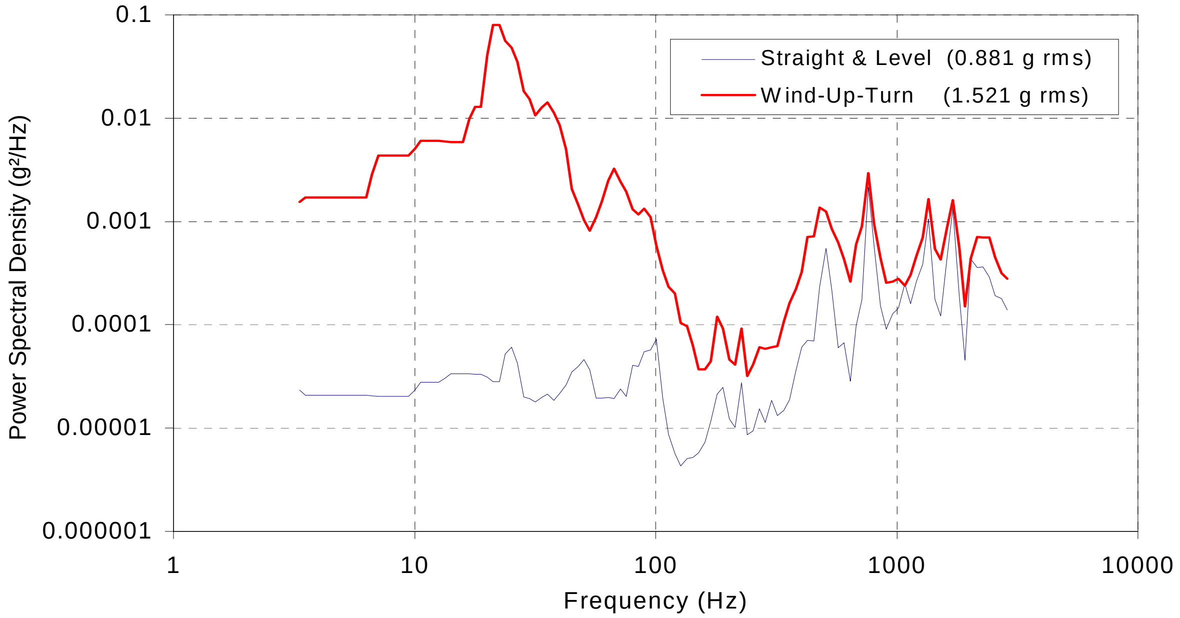
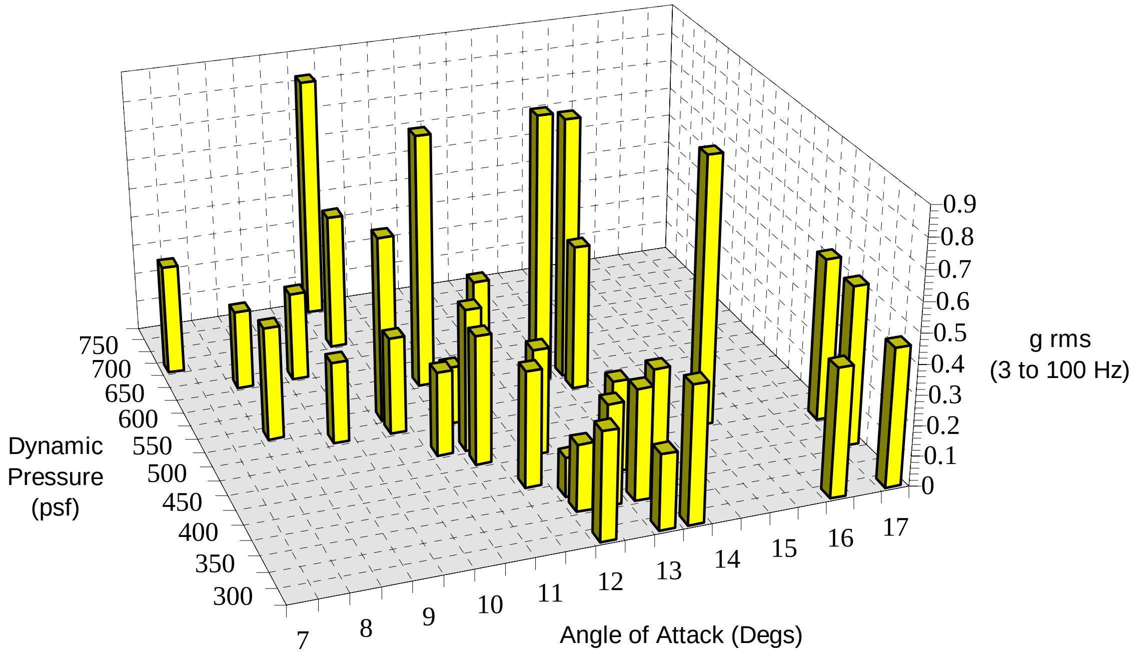


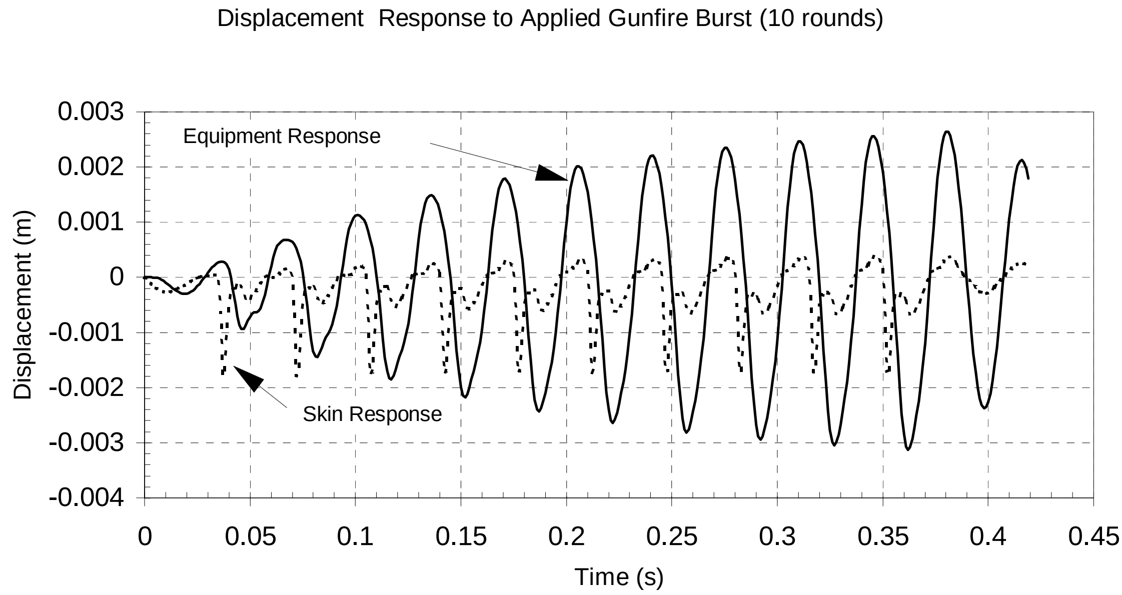
Figure 4: Comparison of store vibration in straight and level flight and in buffet at 420 psf on a wing pylon on an agile fast jet



<u>Notes</u>:

1. Data acquired over the frequency range where store buffet was known to occur, ie: 3 to 100 Hz
2. Data were acquired under stationary conditions of buffet
3. Store externally carried on a wing pylon of an agile fast jet

Figure 5: Store vibration as a function of angle of attack and flight dynamic pressure



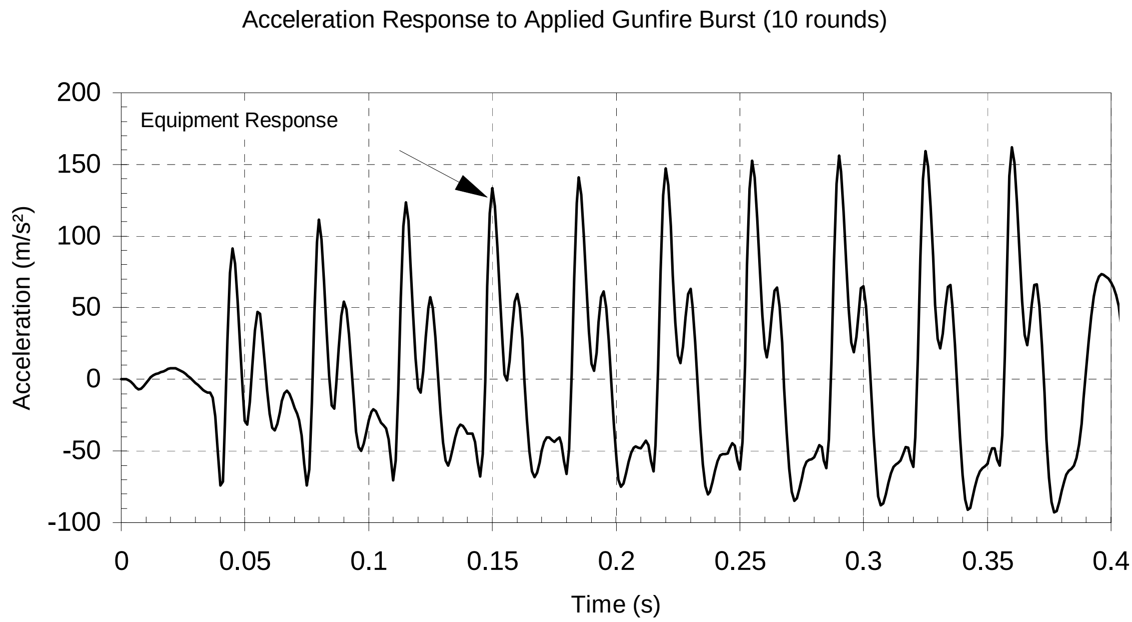


Figure 6: Vibration responses of a store skin panel and internal equipment due to gunfire

ANNEX A
PARAMETERS INFLUENCING STORE VIBRATION

A.1 General

A.1.1 This Annex provides information on the influence of store properties, store deployment conditions and aircraft flight conditions on vibration severity.

A.2 Dynamic Pressure

A.2.1 The intensity of store vibrations arising from the relatively steady flow traversing the store external surface has been shown to be related to dynamic pressure. Moreover, provided that the flow regime around a store remains reasonably stable the relationship between store vibration and dynamic pressure can be quantified with a high degree of confidence. Knowledge of this relationship is particularly important, because it can be applied very effectively to estimate vibration severities. A typical dynamic pressure versus vibration severity relationship for external stores is shown in Figure A1.

A.3 Store Type

A.3.1 Store type, in terms of both shape and construction, is one of the most influential parameters effecting vibration severity. The variation in store responses is illustrated in Figures A2 to A5. The store responses are from similar locations on four different stores normalised to the same flight conditions. Although store type is one of the most important aspects influencing both vibration characteristics and levels, it is difficult to quantify these relationships. Extensive use is often made of simple scaling parameters. Typical parameters used are store density, mass, surface area, skin thickness and radius. Experience indicates that such parameters can be reasonably effective when used to indicate trends in vibration severities. Three examples are presented in Figures A6 to A8. However, the application of such parameters is limited, because a single parameter cannot describe effectively vibration severities for all stores, or for the entire relevant frequency range. For this reason such parameters should be used with care.

A.4 Location

A.4.1 The thicker boundary layer towards the rear of a store and the associated higher unsteady pressures usually result in increased vibration severities in that region. These higher severities affect almost the entire frequency range of interest. In addition it is probable that detached flow will occur in the aft region. Such flow will result in even higher severities than would be expected from attached flow alone. When detached flow is extensive it may couple well with particular store modes and produce a very significant increase in amplitude over a relatively narrow frequency band. Variations of 8 to 1 have been noted in the overall vibration severity from the rear to the front of a store. For specific store vibration modes the increase may be even greater. Typical variations in responses due to store location are shown in Figure A9.

A.5 Axis

A.5.1 For store structural locations, the shape of the store external surface, the distribution of the unsteady pressure field and the store structural dynamic characteristics all contribute toward a trend which produces lower vibration severities in the axial (longitudinal) axis. This trend applies to the total frequency range of interest. Typically severities in the longitudinal axis are one half to one quarter of those in the vertical or lateral axes. Variations in response amplitude between the vertical and lateral axes are usually small. Typical effects of axis are shown in Figure A10.

A.6 Aircraft Type

A.6.1 The carriage aircraft type has only a relatively small effect on store vibration levels, and is illustrated in Figure A11 which shows the equivalent responses for the same store on different aircraft. The variations are restricted to the low frequency region, ie: below 200 Hz. At higher frequencies the effects of aircraft type are negligible; an exception being the effects of detached flow such as vortices shed from the aircraft. When the carriage aircraft configuration significantly disrupts the airflow over the store, such as for conformal carriage stores, significant changes to vibration responses may be expected to occur.

A.7 Aircraft Station

A.7.1 The effects of mounting stores at different stations on the carriage aircraft usually produce only a marginal change of vibration level. The effects are restricted to the low frequencies, in a manner similar to that of aircraft type, but usually to a lesser extent. There may be exceptions when another source of excitation such as jet noise or aircraft detached flow occurs.

A.8 Store Mounting

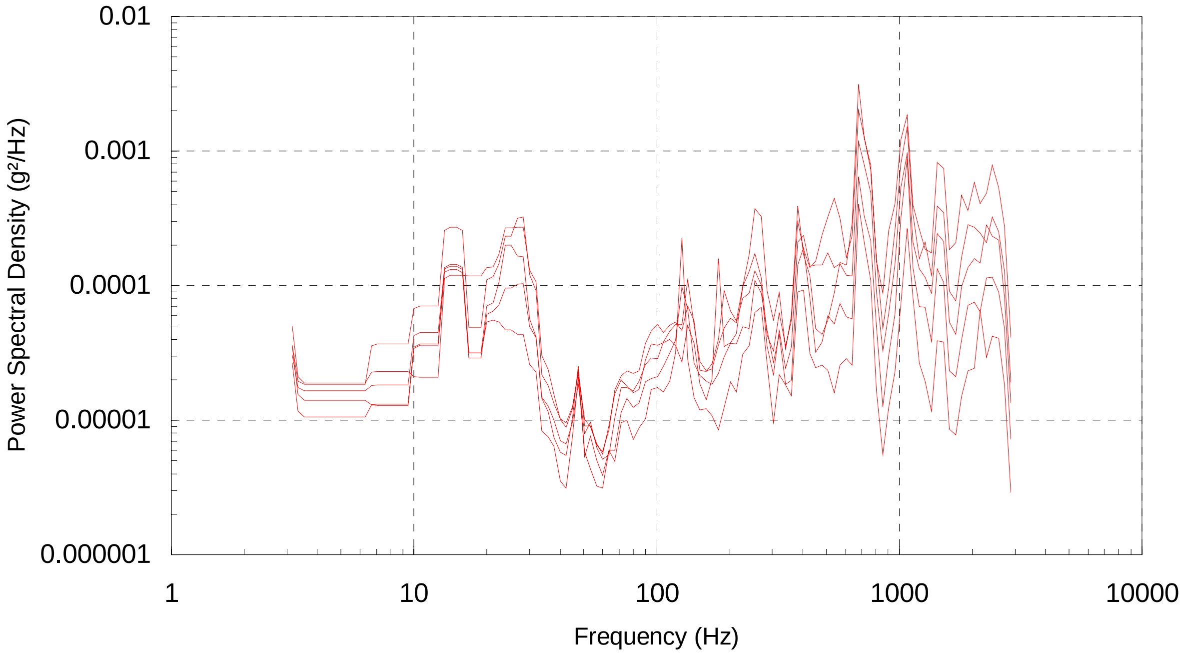
A.8.1 Again, while the type of store mounting (ERU, MACE etc) has some effect, it is usually very small and limited to the low frequency region.

A.9 Multiple Carriers

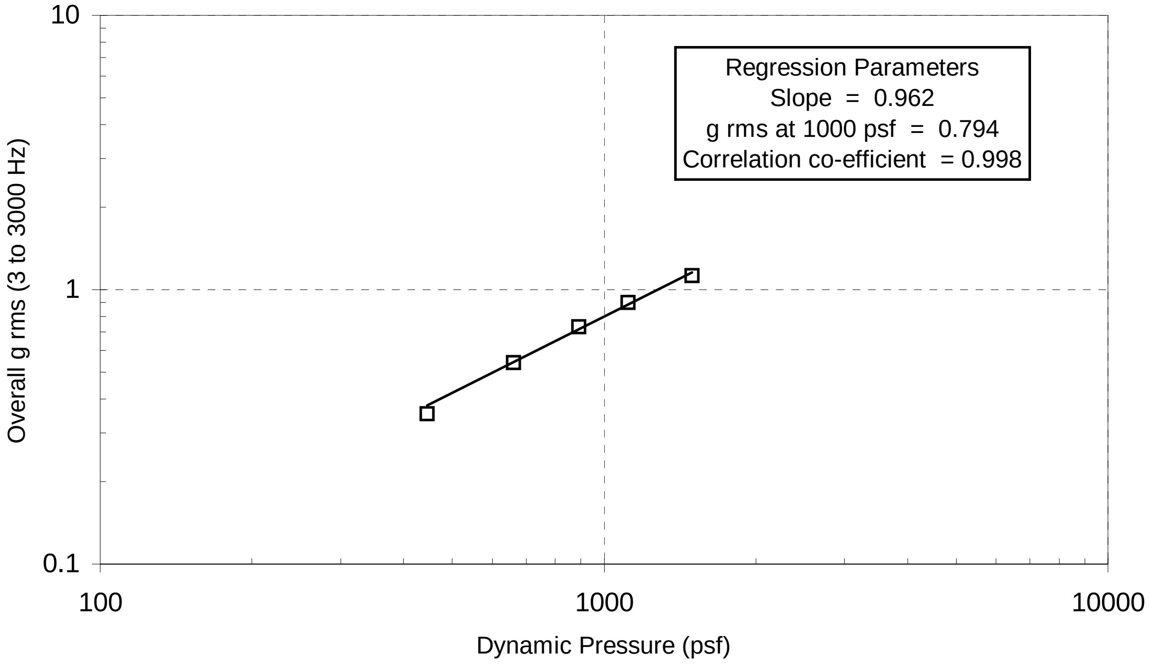
A.9.1 The use of multiple carriers has been shown to increase vibration severity. However, this appears to be a consequence of the close proximity of the carried stores restricting aerodynamic flow, see paragraph A10 below, rather than a characteristic of the carrier itself.

A.10 Adjacent Stores

A.10.1 Some carriage configurations place stores in very close proximity to each other. In these cases the aerodynamic flow can be modified resulting in significantly increased store vibration responses. Increases in overall vibration severity of 2 to 3 have been noted, in conjunction with very large increases (200 plus) at specific frequencies.



a: Vibration responses from five different flight dynamic pressures



b: Vibration severity (Overall g rms) versus flight dynamic pressure

Figure A1: Relationship between store vibration and flight dynamic pressure

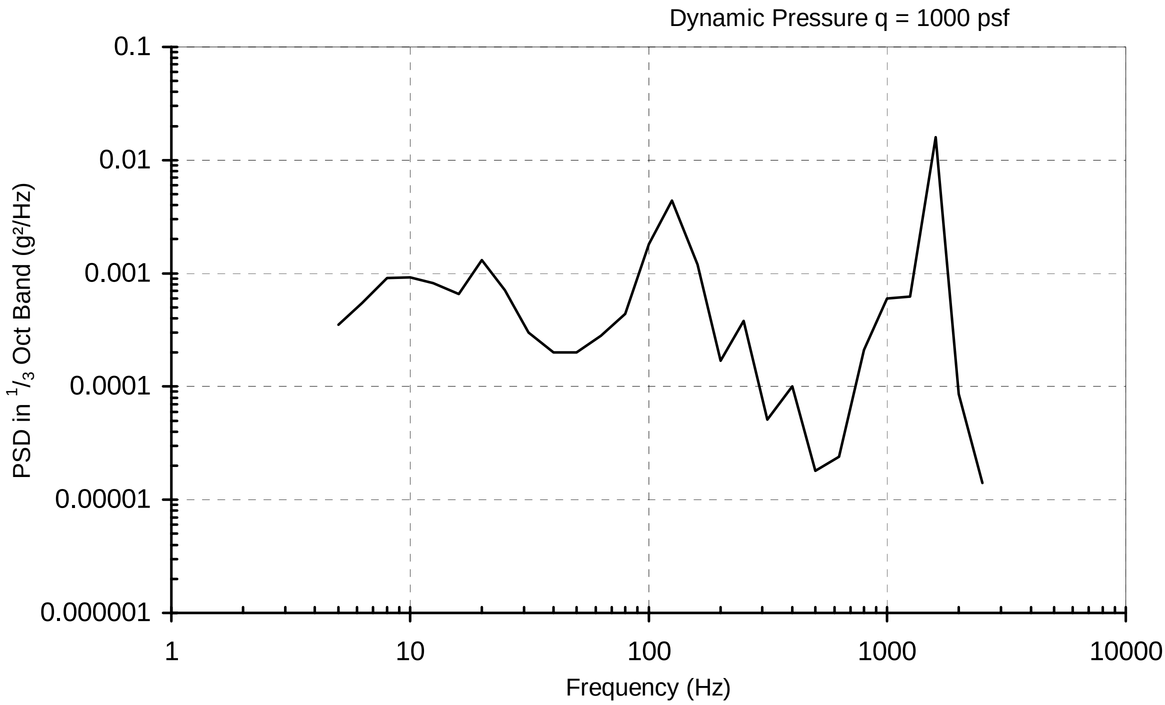


Figure A2: Vibration response of a medium size thick skin thickness store

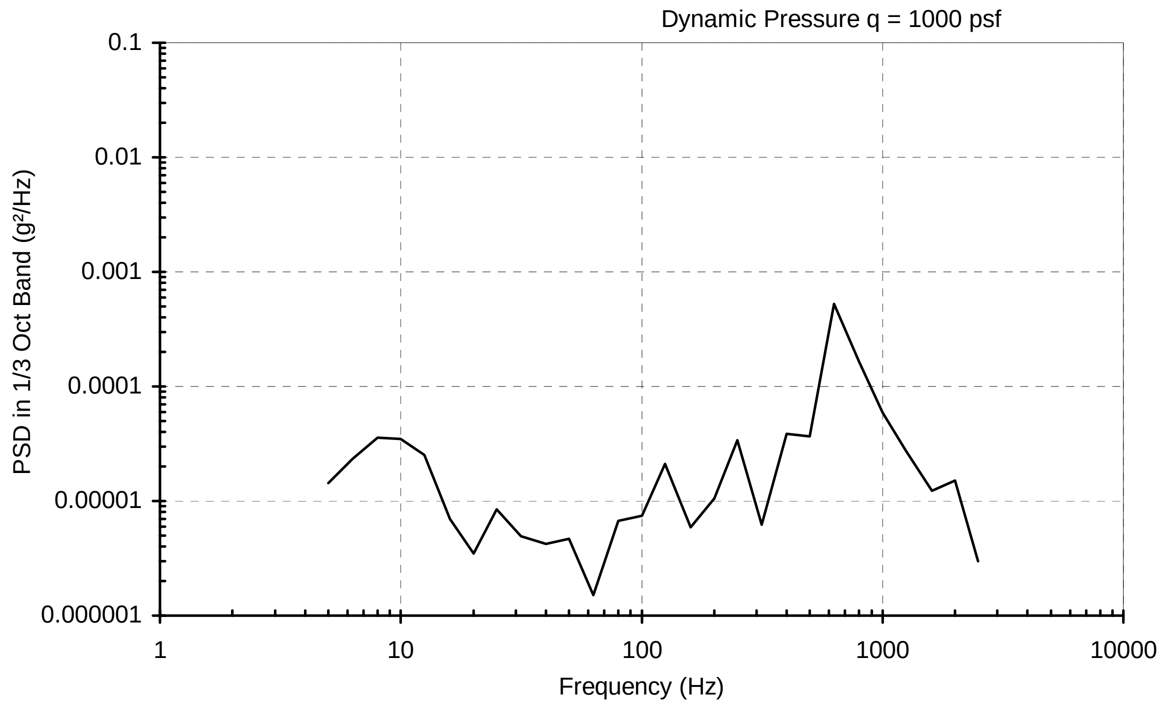


Figure A3: Vibration response of a medium size medium skin thickness store

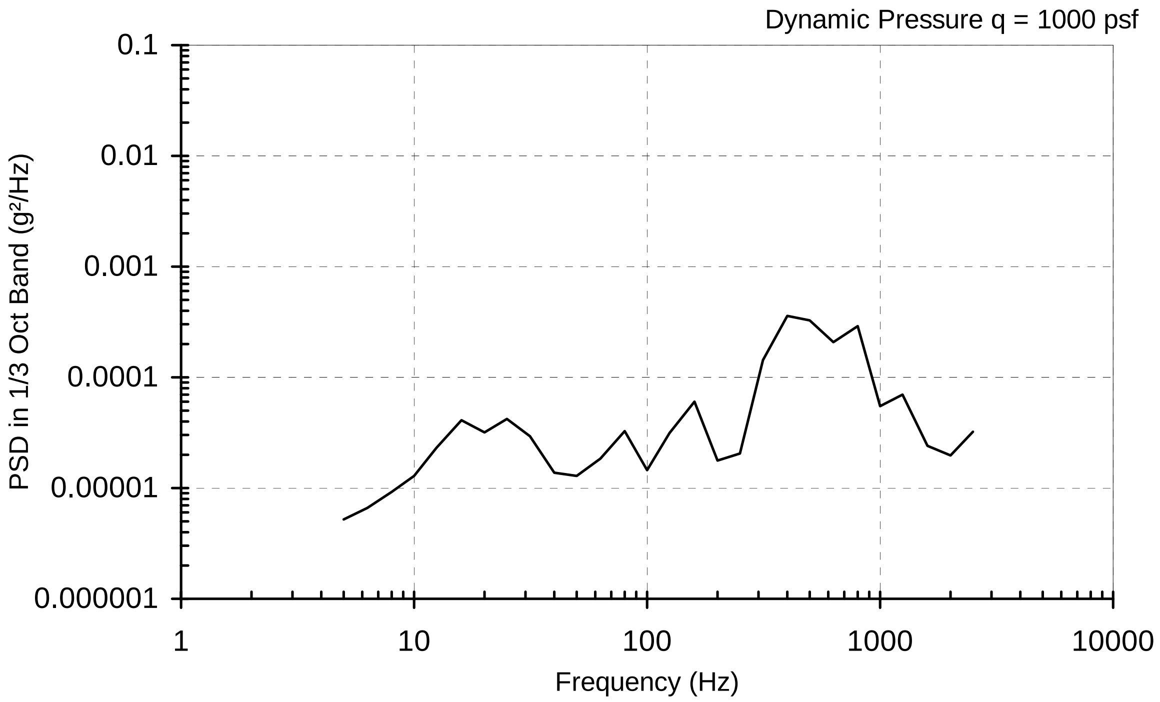


Figure A4: Vibration response of a medium size medium skin thickness store

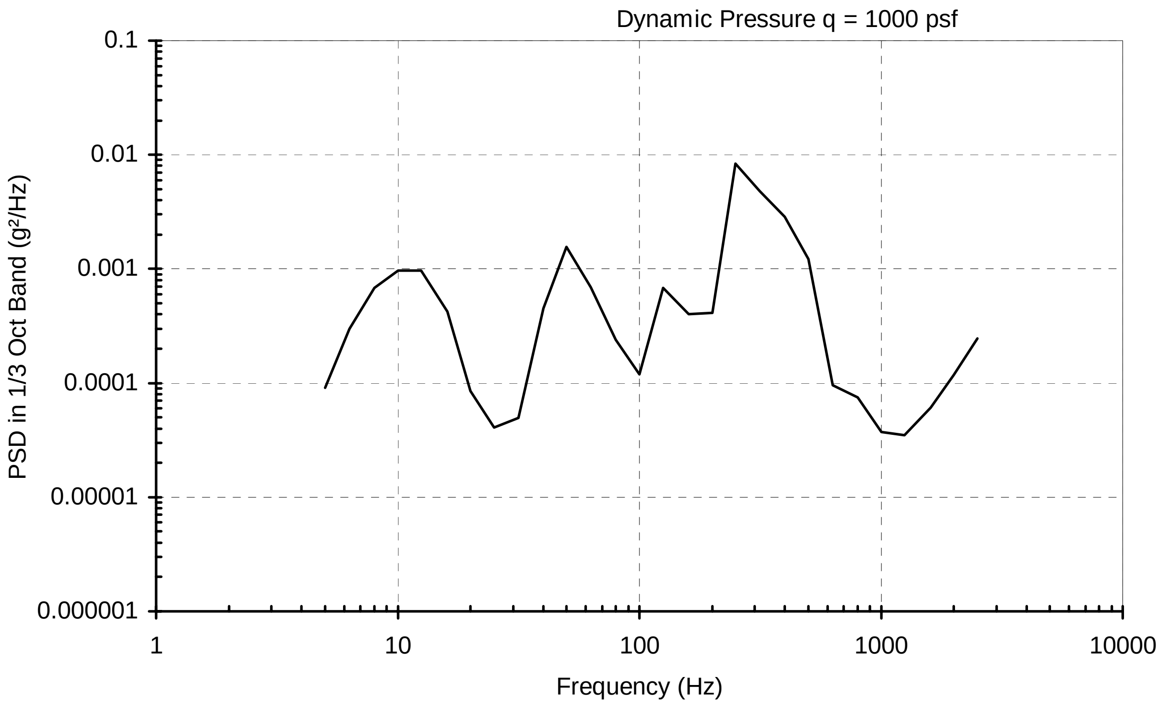


Figure A5: Vibration response of a large size thin skin thickness store

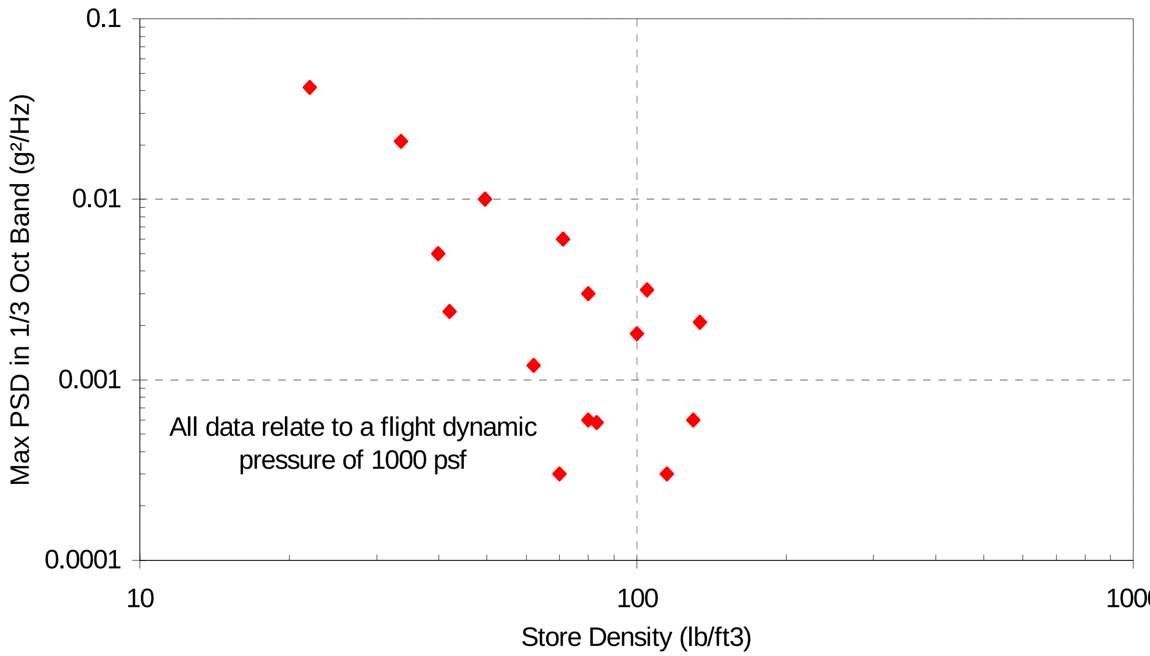


Figure A6: Relationship between store density and maximum psd response amplitude

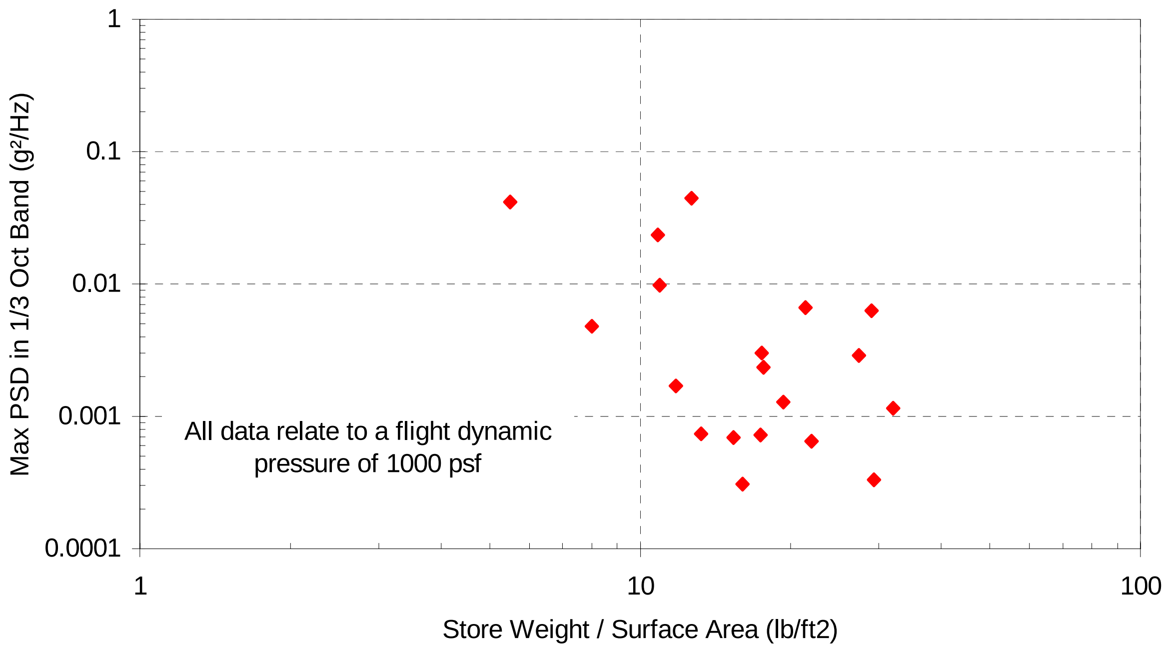


Figure A7: Relationship between the ratio of store weight to surface area and maximum psd response amplitude

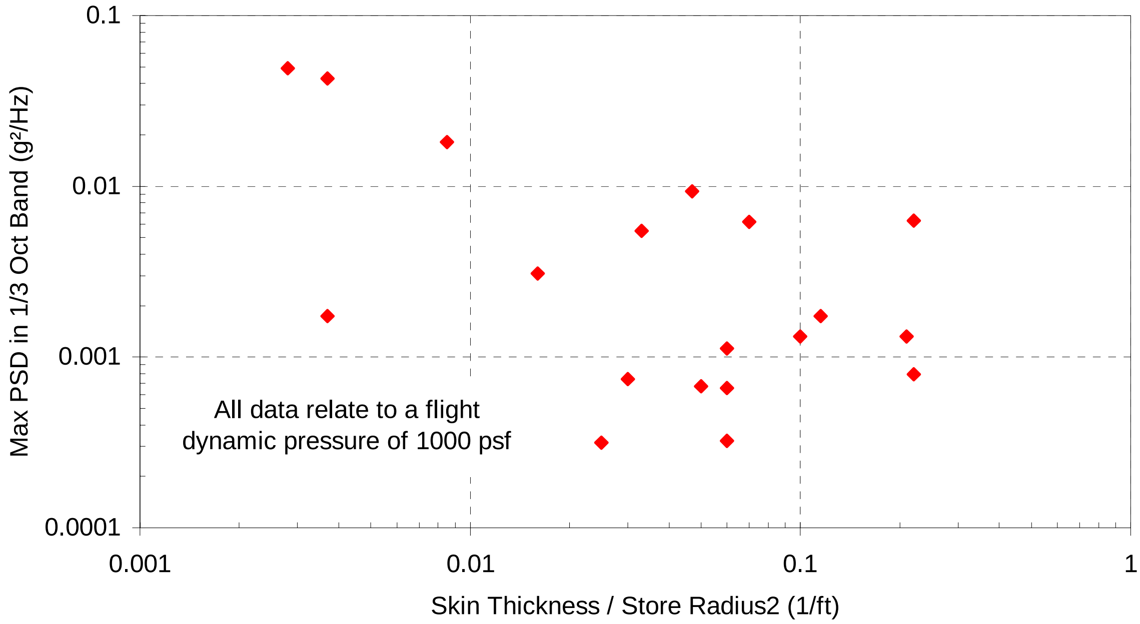


Figure A8: Relationship between the ratio of skin thickness to store radius and maximum PSD response amplitude

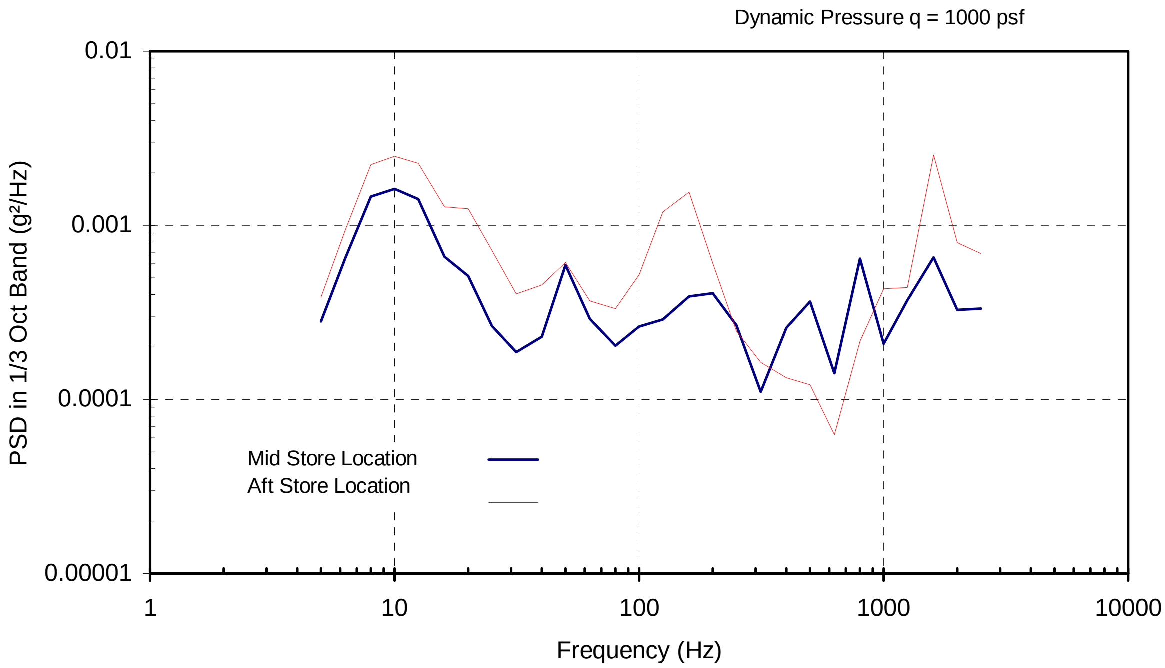


Figure A9: Variations in vibration response attributed to measurement location

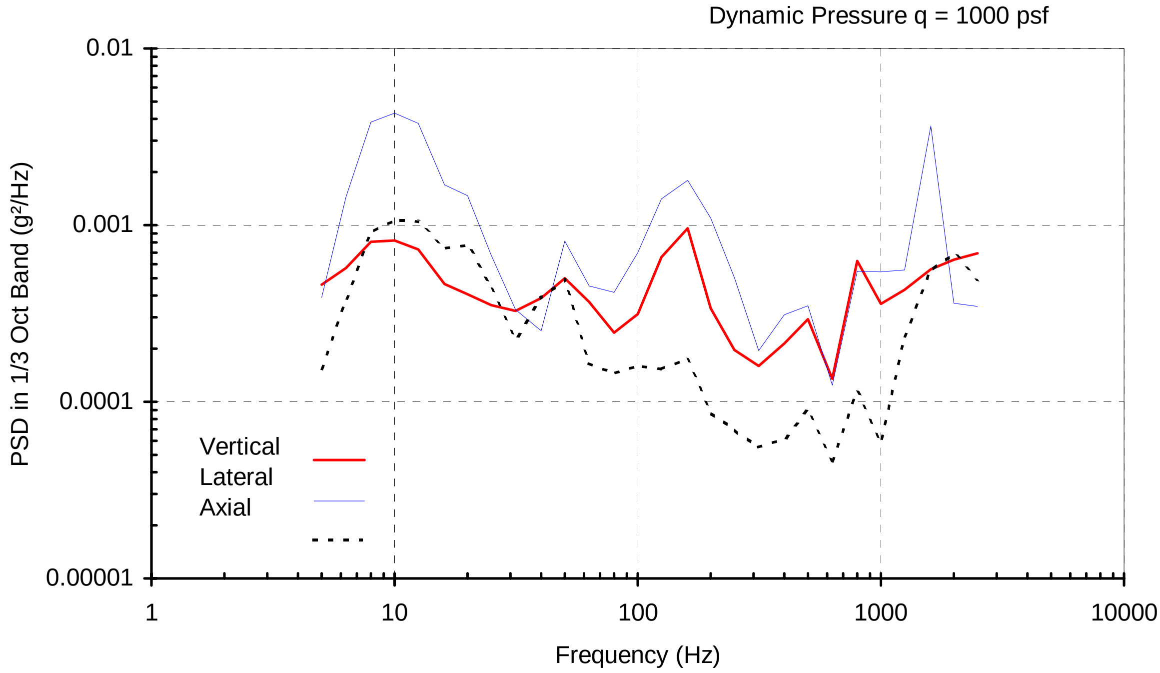


Figure A10: Variations in vibration response attributed to measurement axis

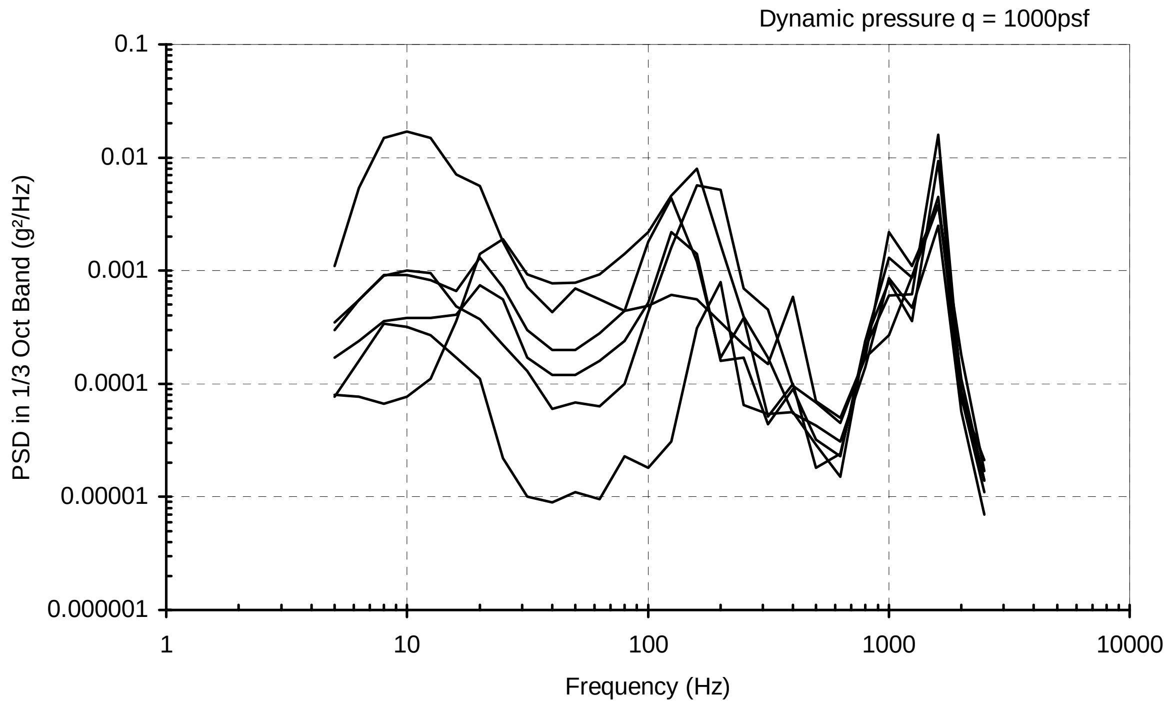


Figure A11: Variations in vibration response attributed to aircraft type

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LEAFLET 246/3

DEPLOYMENT ON PROPELLER AIRCRAFT

TABLE OF CONTENTS

LEAFLET 246/3

DEPLOYMENT ON PROPELLER AIRCRAFT

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be experienced by materiel during carriage on fixed wing propeller aircraft. The sources and characteristics of the mechanical environments are presented and where appropriate, information is given on potential damaging effects. Additional guidance is contained in Annex A on propeller and engine vibration sources, and in Annex B on the parameters influencing propeller and engine vibration. Where relevant, advice is given on the selection of the appropriate AECTP 400 Test Methods.

1.2 The leaflet encompasses both internal equipment as well as external items such as stores. However, the following aspects are not included in this leaflet:

a. Materiel installed on helicopters. For information on this subject refer to Leaflet 247/1.

b. Engines and associated equipment, ie: the environments experienced by an engine and its associated equipment arising from their own operation. For information on these induced environments, reference should be made to the engine manufacturer.

c. Airframe and other primary structure. For information on loads and severities related to these structures, reference should be made to the aircraft manufacturer.

d. Abnormal conditions, such as crash and blast.

1.3 Unless specified otherwise the environmental descriptions relate to the interface between the equipment and the aircraft. All axes relate to aircraft axes.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Airfield Movements

2.1.1 Materiel can be expected to experience vibration and transient responses as a consequence of the aircraft movements about the airfield. Such responses are caused by the wheels traversing the inevitable irregularities in the taxi way surfaces. The severity of these vibrations and transients will be influenced principally by aircraft speed and size of the aircraft wheels. The responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft.

2.1.2 As airfield surfaces are usually of good quality and aircraft movements are usually controlled, the severities resulting from airfield movements are usually low and significantly less than those for flight carriage. This may not be the case when temporary or repaired taxi-ways are used. In such cases it can be expected that a significant increase in the severity of the transients will occur. However, these conditions are unlikely to be more than those occurring during take-off and landing on repaired and temporary runways.

2.1.3 During ground running and airfield movements the noise and vibration arising from the engine and propeller can become significant. The mechanisms causing such effects are addressed in paragraph 2.3.

2.2 Take-off and Landing

2.2.1 Normal Take-off and Landing Conditions: During take-off and landing short duration oscillatory transients may be induced in the installed materiel. These transients arise mainly as a result of the aircraft traversing runway surface irregularities at speed. Again, the responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft. As both take-off and landing are usually controlled, the amplitudes of the resultant transients are usually benign. Consequently, the dynamic responses experienced during take-off and landing are normally considered to be encompassed within those of the flight phase. Take-off and landing usually involves high levels of engine power, which in turn may induce vibration and acoustic noise conditions. These related aspects are dealt with in paragraph 2.3.

2.2.2 Temporary or Repaired Runways: Continuous vibration and transient shock severities are likely to be more severe when temporary or repaired runways are used. The maximum permitted severity resulting from the use of such surfaces will depend upon the capabilities of the aircraft under consideration and in particular upon the ruggedness of the aircraft undercarriage. Consequently, where necessary, advice on severities should be sought from the aircraft manufacturer. However, any test procedures used to simulate these conditions are likely to be similar to those recommended for normal take-off and landing conditions.

2.2.3 Catapult Launch and Arrested Landing: Oscillatory transients will be induced in materiel during a catapult launch and/or arrested landing of an aircraft. In general catapult launch will show two transient events corresponding to initial load application and catapult separation from the aircraft. Both transient events have a distinct oscillatory nature, approximately sinusoidal, at a relatively low frequency determined by aircraft mass and landing gear damping characteristics. Arrested landing conditions produce only a single transient but with similar characteristics to catapult launch. At installed equipment locations the pulse amplitudes associated with catapult launch and arrested landing are relatively low, and the periods of application are relatively long. Therefore, these transients are usually treated as quasi-static conditions.

2.3 Flight Operation - Engine and Propeller

2.3.1 The action of the propellers and engines is usually the major source of vibration for this type of aircraft. However, vibration measured at a point in an aircraft's fuselage will be the sum of many sources and mechanisms. Some generate vibration directly whilst others generate noise which produces vibration when it impinges on the aircraft's structure.

2.3.2 Because of their diverse nature and interactions, vibration spectra can possess features which may be complicated to explain, eg: the cancelling or enhancement of certain propeller blade passing harmonics. Examples of vibration spectra obtained during cruise conditions are illustrated in Figures 1 to 4 for four different aircraft. The relative severity of vibration at propeller blade passing frequencies for these aircraft is illustrated in Figure 5.

2.3.3 Further information on several vibration sources arising from propeller and engine actions is given in Annex A.

2.3.4 The severity and character of the vibration environment experienced by a particular item of equipment installed at a specific location in a propeller aircraft can depend on a number of parameters, such as aircraft type, flight condition, etc. The effects of these parameters are discussed in Annex B.

2.3.5 Figures 1 to 4 show that the vibration environment associated with propeller aircraft is comprised of broad band random vibration spectrum, upon which is superimposed relatively strong forcing centred at frequencies associated with harmonics of the propeller blade passing. Vibration can also be evident, usually at relatively low levels, at frequencies associated with harmonics of propeller shaft rotation. The severity of the background random vibration is usually low. Periodic vibration at the propeller blade passing frequencies may amount to 90% of the overall g rms in a 2 to 2,000 Hz frequency bandwidth.

2.4 Flight Operation - Aerodynamic Flow

2.4.1 Another significant source of propeller aircraft equipment vibration is associated with the turbulence in the airflow surrounding the aircraft. This airflow over the structure may be smoothly attached to it, or it may be detached. These two conditions produce significantly different vibration excitations. The more severe vibration conditions are associated with detached flow which, exist on all aircraft at some times. Vibration arising from aerodynamic flow is presented in Leaflet 246/1.

2.5 Flight Operation - Vortex Impingement

2.5.1 At certain conditions of angle of attack, heading and airspeed it is possible for vortices originating from parts of the aircraft to impinge on downstream structure. The characteristics of these vortices are such that severe structural vibrations may arise at the downstream structure. In general these vibrations may be dominated by the lower structural modes of the particular portion of the airframe (wing, empennage etc). These vibratory conditions are transitory in nature and rarely occur for more than a few seconds at any one time. However, during the life of an aircraft the total number of such occurrences may be significant. The resulting vibration characteristics, severity and areas of airframe significantly effected will be unique to a specific aircraft type.

2.6 Cavities

2.6.1 Cavities exposed to a grazing flow as it passes the aircraft can be a significant source of both noise and vibration. The frequency spectrum of such disturbances can be wide in range and usually features sharp peaks and troughs over the frequency range. The main peaks arise from the excitation of acoustic “space” modes which are a direct function of the dimensions of the cavity. A weapon or bomb bay is an obvious example of such a cavity. The frequencies of the main modes can be calculated with some confidence from standard formulae. The majority of the less dominant modes are usually harmonics of the main modes and can persist up to quite high orders. The amplitudes of the pressure fluctuations are less easily estimated because they are affected by geometrical factors such as the sharpness of the edges of the cavity, the direction of flow over the cavity and the contents of the cavity. The contents of the cavity can have the effect of making the main modal peaks less discernible whilst increasing the level of the background broad-band “noise” which is always present.

2.7 Manoeuvres and Gust

2.7.1 Materiel will experience low frequency acceleration loadings due to flight manoeuvres and gusts. These are normally considered as quasi-static loadings for design and test purposes. At a particular aircraft location the loadings arise mainly from the vector sum of the six “rigid body” aircraft degrees motions, ie vertical, lateral longitudinal, roll pitch and yaw. These may be amplified by the dynamic motions of the lower aircraft modes.

2.7.2 The severity of the flight acceleration environment will depend mainly upon the type of aircraft under consideration. Generally the flight accelerations are a specified design requirement for a particular aircraft type and hence are well defined early in a design. These accelerations are usually constrained by flight limitations procedures or the control system computers. Many aircraft contain equipment which monitor these loadings for fatigue purposes.

2.8 Gunfire

2.8.1 Significant vibration and shock excitations in aircraft structure, equipment and stores can arise from the operation of guns installed either within the aircraft or in external pods. While the total duration of these excitations is relatively short, the amplitudes can be several orders of magnitude greater than the vibrations arising during normal flight. Moreover, the characteristics of the responses for some equipment and structure can be significantly different to the vibrations occurring during normal flight conditions, and may induce different equipment failure modes.

Details of the mechanisms causing dynamic mechanical responses as a result of gunfire are presented in Leaflet 246/1.

2.9 Launch of Weapons

2.9.1 The launch or firing of weapons can, in certain circumstances, induce high level of shock, vibration and pressure blast in the aircraft structure, nearby weapons or stores.

3. POTENTIAL DAMAGING EFFECTS

3.1 Airfield Movements

3.1.1 The motions arising from aircraft movements will result in low amplitude, high frequency of occurrence continuous responses which could cause damage through fretting fatigue mechanisms.

3.2 Take-off and Landing

3.2.1 The motions arising from normal take-off and landing are largely dictated by the characteristics of the undercarriage system. Therefore, potential damaging effects are likely to be associated with high displacements at low frequencies.

3.3 Flight Operation - Engine and Propeller

3.3.1 The frequency of the blade passing periodic component of the vibration responses usually occurs in the range 50-100 Hz. This range will coincide with the first mode of vibration of many items of equipment, especially those on flexible mounts. As such the periodic excitations may result in significant velocity and displacements occurring, which in turn may result in damage particularly to lightly damped equipments.

3.3.2 The potential damaging effects of the broad band random component of the vibration responses are typical of those from this class of excitation, eg: brinelling, fretting, high cycle fatigue etc.

3.4 Flight Operation - Aerodynamic Flow

3.4.1 As the vibrations arising from aerodynamic turbulence are broad band random, the potential damaging effects encountered are typical of those from this class of excitation, eg: brinelling, fretting, high cycle fatigue etc. Detached flow can result in a significant increase in efficiency by which particular modes are excited. As a result the amplitude of response of certain modes can increase by several orders of magnitude which may lead to rapid structural failure due to fatigue.

3.5 Flight Operation - Vortex Impingement

3.5.1 The vibrations arising in structure under the leading edge of a vortex appear almost periodic in nature. The severity can be high but relatively localised. The vibrations may rapidly result in acoustic fatigue of panels and, in some cases, of nearby equipment. The vibrations arising down stream of a vortex are considerably more significant and can induce high amplitude vibrations at lower frequency modes of the structure. In some cases the accrued fatigue damage may be equal or greater than the accrued damage from normal flight manoeuvres.

3.6 Cavities

3.6.1 Acoustic waves can induce failure of panels within a cavity very rapidly. In addition high levels of vibration may be induced in materiel within the cavity.

3.7 Gust and Manoeuvre

3.7.1 The most significant potential damaging effect is due to the loadings producing internal forces within the materiel and often at its mountings sufficient to cause structural fatigue failure. In some cases the loadings may cause deflections sufficiently great so as to prevent proper operation of mechanisms.

3.8 Gunfire

3.8.1 In the near field the blast pressure wave is sufficient to cause structural failure of panels and their supports. Materiel in close proximity to the muzzle, but protected from the direct blast pressure wave, may fail due to the severity of the repetitive but discrete shock pulses it experiences. The most likely failure modes of equipment in the middle field are those associated with high intensity, low frequency vibration.

4. TEST SELECTION

4.1 General

4.1.1 The following paragraphs provide recommended treatments for the mechanical environments identified in paragraph 2, and where relevant indicate the appropriate AECTP 400 Test Method.

4.2 Airfield Movements

4.2.1 Because the severities associated with this environment are relatively low, they are often considered in conjunction with other more severe conditions such as flight vibration. In cases where testing is considered appropriate a broad band random vibration test should be used, adopting AECTP 400 Method 401 - Vibration.

4.3 Take-Off and Landing

4.3.1 Again, because the severities are relatively low, testing for this environment is only carried out in special circumstances. In cases where testing is considered appropriate a decaying sinusoidal wave form test would normally be utilised, as specified in AECTP 400 Method 403 - Shock.

4.4 Flight Operation - Engine and Propeller

4.4.1 The sine on broad band random test, or narrow band random on broad band random test, as given in AECTP 400 Method 401 - Vibration, should be selected for these conditions.

4.5 Flight Operation - Aerodynamic Flow

4.5.1 Aerodynamic Turbulence: The random broad band vibration test as given in AECTP 400 Method 401 - Vibration should be selected for this environment.

4.6 Flight Operation - Vortex Impingement

4.6.1 Although vortex impingement only occurs infrequently and for short periods over the life of an aircraft airframe, the accumulative duration of the narrow band random or predominantly sinusoidal vibration responses can be sufficient to warrant a test. Appropriate test procedures are given in AECTP 400 Method 401 - Vibration. The test procedure selected should be the one that is compatible with the characteristics.

4.7 Cavities

4.7.1 If materiel is mounted within, or close to, a cavity which is open to the airstream, a cavity acoustic resonance noise test should be undertaken. An appropriate test procedure is given in AECTP 400 Method 402 - Acoustic Noise.

4.8 Manoeuvres and Gust

4.8.1 Testing is undertaken when the adequacy of an item of materiel cannot be suitably demonstrated by calculation or static strength testing. When environmental testing is required it is normally undertaken in accordance with AECTP 400 Method 404 - Constant Acceleration.

4.9 Gunfire

4.9.1 As significantly different responses arise from gunfire in each of the defined spatial fields, a different treatment is applicable for each field. Suitable treatments are presented in Leaflet 246/1, paragraph 5.6.

4.10 Launch of Weapons

4.10.1 In most cases the induced loadings can be treated as quasi-static analytical methods. However, in some cases such loadings may induce significant dynamic responses on airframe structure or stores. Consequently, additional shock and/or pressure blast testing may be required to simulate these effects. In cases where testing is required AECTP 400 Method 403 - Shock should be considered.

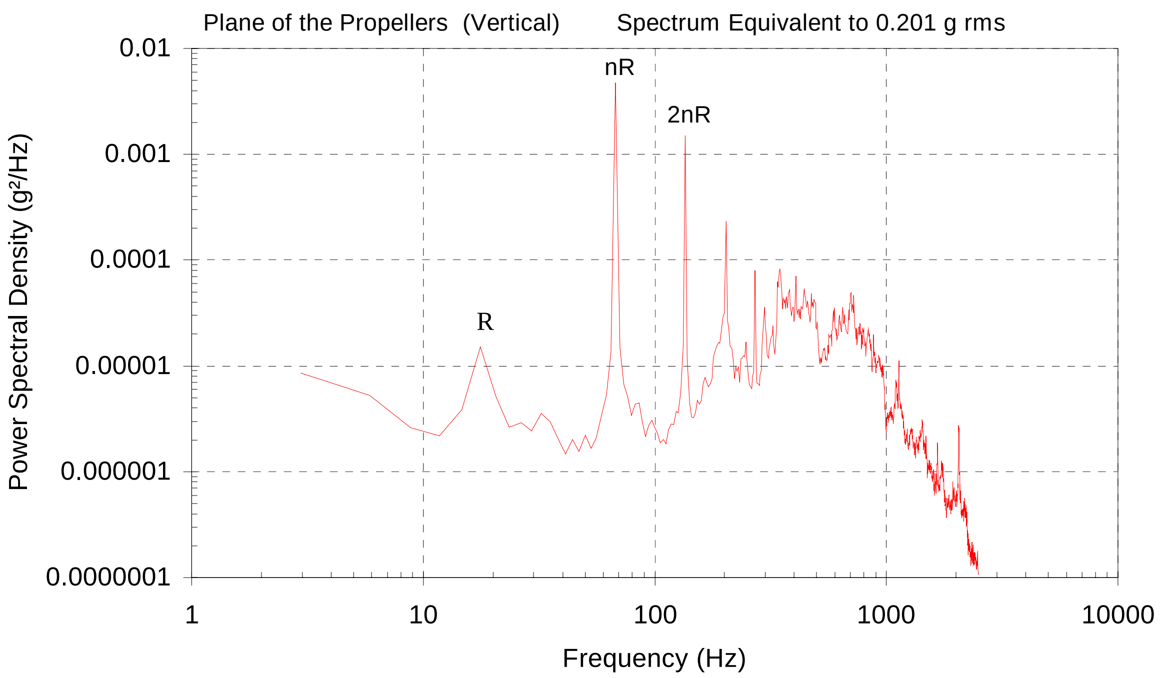

Figure 1: Vibration spectrum from a C130 Hercules Mk 1 during cruise

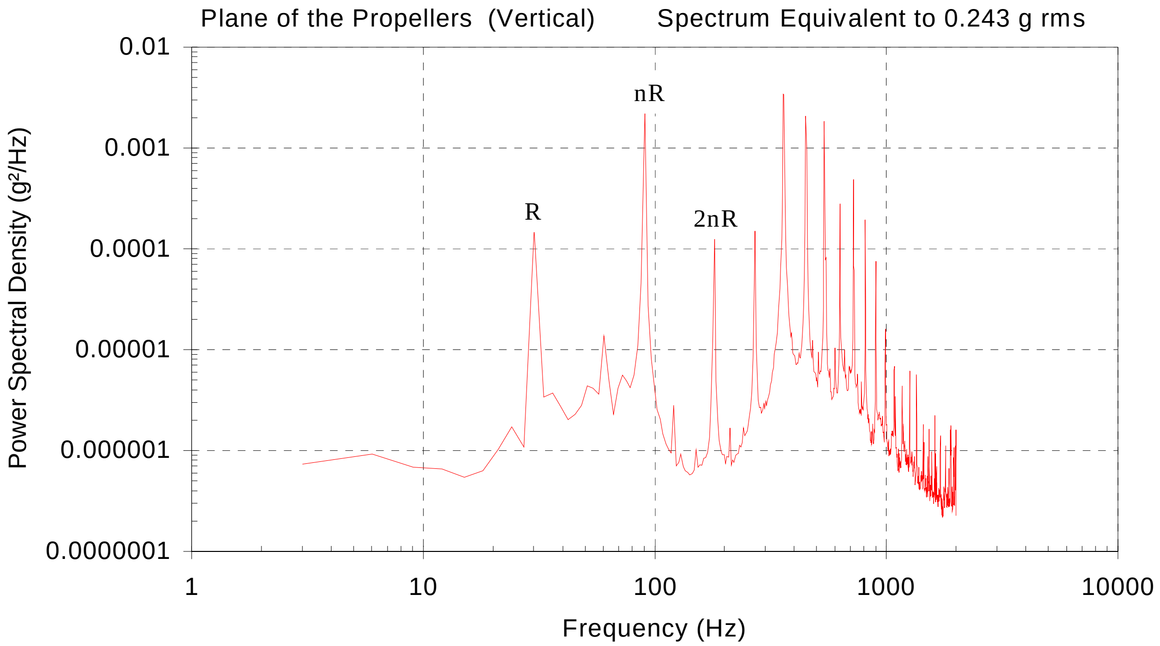

Figure 2: Vibration spectrum from a Jetstream Mk 1 during cruise

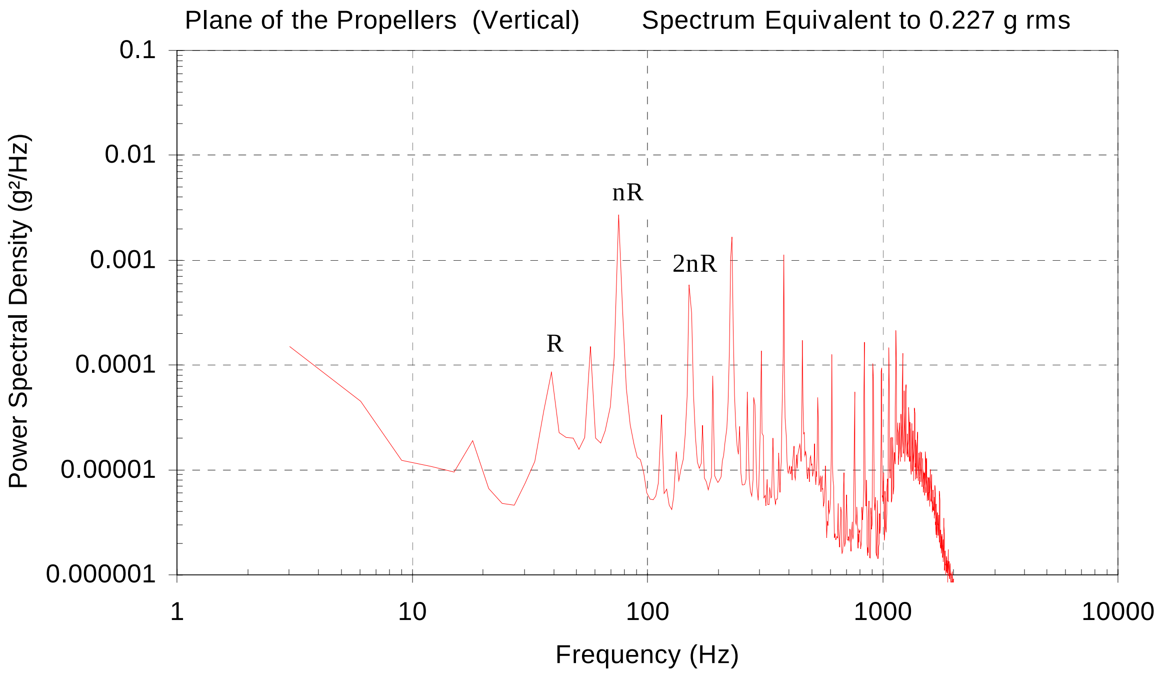

Figure 3: Vibration spectrum from an Islander during cruise

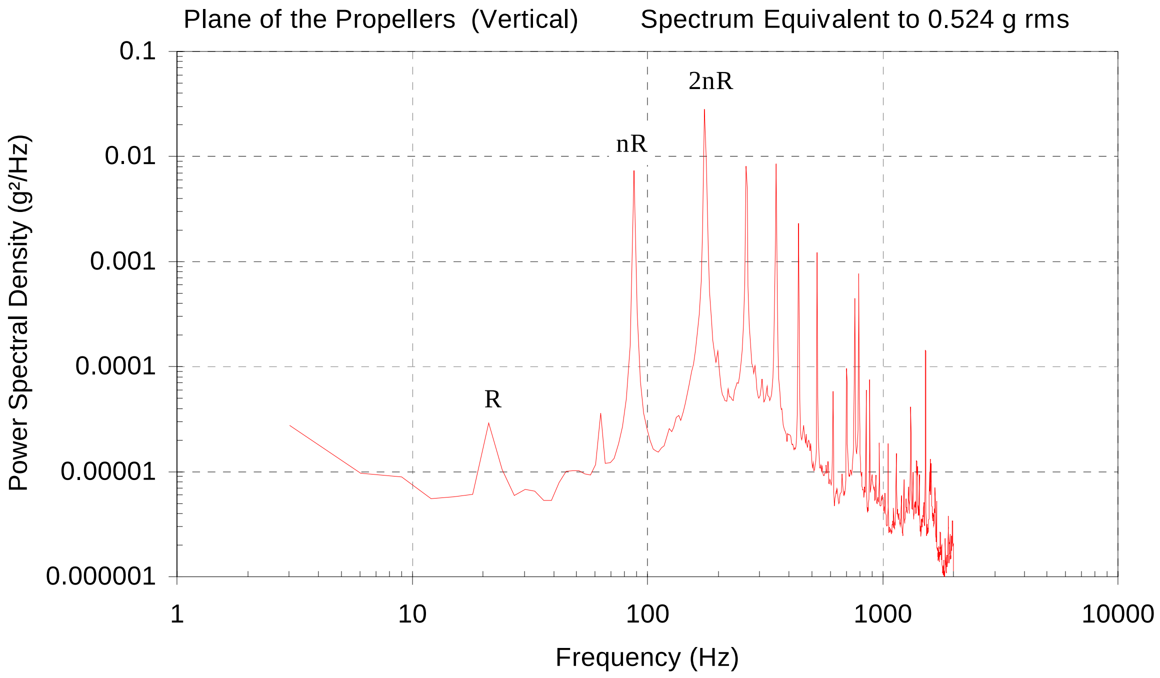

Figure 4: Vibration spectrum from a BAe 748 during cruise

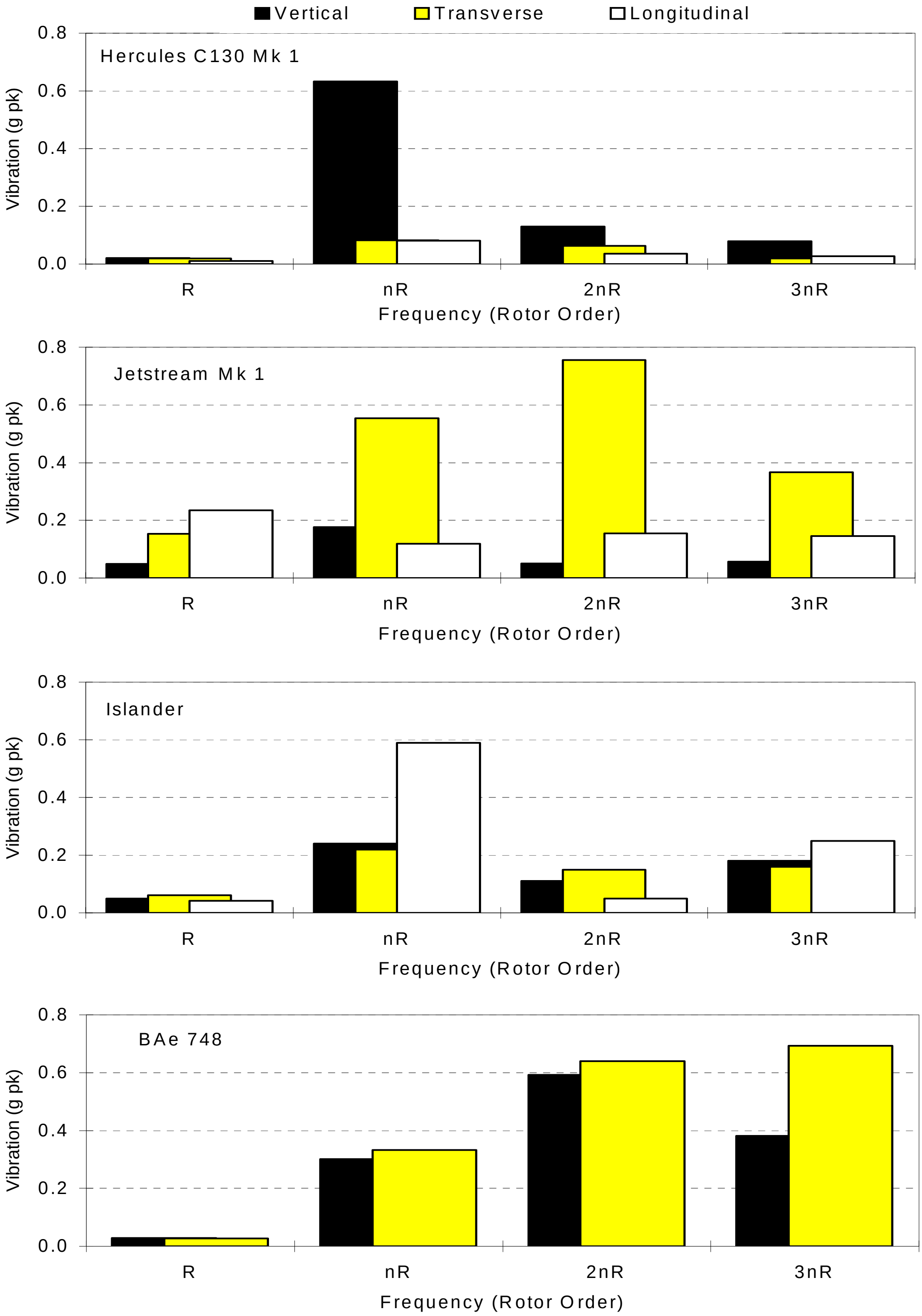

Figure 5: Vibration at rotor orders for four propeller aircraft at cruise

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ANNEX A
PROPELLER AND ENGINE VIBRATION SOURCES

A.1 Mechanical Imbalance

A.1.1 Vibration is caused by mechanical imbalance of a propeller and will be apparent at the shaft rotation frequency and subsequent harmonics. Imbalance can arise through the natural action of erosion over a period of time. Routine aircraft maintenance should minimise this vibration, but some residual imbalance is likely as it can be difficult to dynamically balance a variable pitch propeller.

A.2 Propeller Blade Modes

A.2.1 Propeller blade modes can be excited by forcing functions such as the air moving through the propeller disc or by blade-wing interactions (see below), and this can cause vibration to be transmitted through the propeller's hub bearing and into the aircraft's structure. This is unlikely to be a major source of vibration as designers will attempt to minimise blade vibration to prolong the life of the propeller.

A.3 Airflow Interference

A.3.1 Vibration can be induced into the propeller blades, and transmitted to the aircraft's structure via the propeller hub bearing, by the air flow streaming back from the propeller meeting an impedance caused by the presence of the wing and its surrounding pressure field. This vibration occurs at a characteristic frequency dependant on the number of interferences per revolution of the blade and the blade passing frequency. Some harmonics may be missing in measured spectra because the resultant force acting on the blades is the vector sum of the forces acting on the whole propeller, ie: some harmonics may add and others subtract. The significance of this source, which is only applicable when the propeller is in front of the wing, is dependant upon the propeller to wing dimension. The worst type of propeller with respect to blade-wing interaction effects is a two bladed type.

A.4 Propeller Pressure Fields.

A.4.1 Excitations arising from propeller rotation can be conveniently considered in two different regimes, that is with the blades developing thrust and at zero thrust. In the latter case flow noise is produced which is usually referred to as thickness noise. In the former condition thickness noise is still produced but this may be augmented by another form of flow noise referred to as rotation or force noise.

a. Thickness Noise. In the zero thrust case, noise is generated as a consequence of the finite thickness of the propeller blades. This noise is generated by air moving out of the way of an advancing blade and then returning after the blade has passed. The resulting pulsation of air acts as a classic noise source. When considering this mechanism the propeller disc is seen to consist of a set of pulsating sources with appropriate phase relationships. At the fuselage, this is perceived as a series of broad band pulses arriving at the blade passing frequency.

b. Rotation or Force Noise. When a blade develops thrust additional flow noise may be generated as a result of blade encountering disturbed airflow, in particular vortices originating from the preceding blade. Usually thickness noise dominates whether rotation or force noise is present or not. However, under certain conditions this may not necessarily be the case. The rotation noise produced by a blade developing thrust cannot be calculated as accurately as that for just thickness noise. This is due in part to the complicated nature of the velocity field of the airflow past the propeller disc. The many approaches that have been used to consider this mechanism have all had to assume some approximated pressure distribution over a blade and to transfer these total pressures to the equivalent fixed force acting around the propeller disc. As for thickness noise, the noise source is identified as acoustic dipoles and the total acoustic power is derived by integrating over the propeller disk.

A.5 Vortices.

A.5.1 Vortices are shed from the tips of rotating propeller blades. This mechanism produces a broad band noise spectrum which is likely to peak at a frequency (f) associated with the Strouhal Number, ie:

$$f = KV / d$$

where V = the rotational velocity of the blade tip
d = a dimension which typifies a blade chord
K = a constant

Vibration effects arising from vortices would not be expected to be significant for an aircraft that has a pusher propeller because of the directivity characteristic of vortex noise.

A.6 Directivity Effects.

A.6.1 The sources of vibration, detailed above, are each characterised by a particular directivity pattern. Propeller rotation noise is at a maximum in the plane of the propellers. Mechanical and aerodynamic imbalances also tend be most significant close to the plane of the propellers. Effects of vortices shed from the tips of the propellers will be most apparent towards the rear of the aircraft. Blade thickness noise also tends to radiate most strongly to the rear of the plane of the propellers. Figure A1, which shows aircraft structural vibration spectra from positions at the plane of the propellers and at the rear fuselage of a Jetstream Mk 1 aircraft, illustrates the effects of the directivity and the nature of the various sources discussed above. It can be seen from this figure that periodic vibration, particularly at the blade passing frequency and its harmonics, is most severe in the plane of the propellers, and that broad band vibration in the 500 to 1200 Hz range is most severe at the rear of the aircraft.

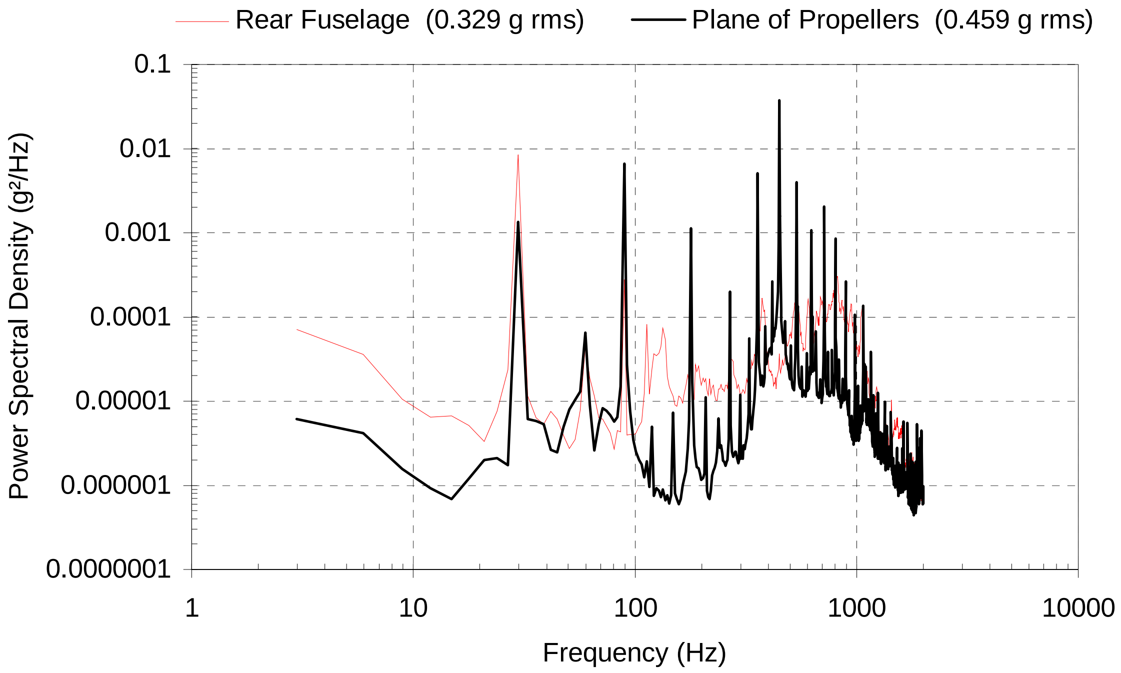

Figure A1: Comparison of spectra from forward and rear locations in a Jetstream Mk 1 aircraft

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ANNEX B
PARAMETERS INFLUENCING PROPELLER AND ENGINE VIBRATION

B.1 Aircraft Type.

B.1.1 Different aircraft can be expected to have different engine operating speeds, and to have different numbers of propeller blades, leading to different blade passing frequencies, as illustrated in Figures 1 to 4. As a result, it cannot be expected that vibration data relating to one particular propeller aircraft is applicable to another. This is somewhat different from the case of jet aircraft, where a prime parameter governing vibration severity is flight dynamic pressure, ie: aircraft speed. For propeller aircraft, parameters associated with the aircraft itself, rather than its speed or the air through which the aircraft travels, most significantly affect vibration severity. Some current propeller aircraft have fixed speed engines, ie: the engines are governed to within a few per cent of their nominal speed. For these types of aircraft, power demand is achieved by the use of variable pitch propeller blades. Some aircraft, however, have fixed pitch propellers but variable speed engines, that is, reciprocating engines, although in these cases there are usually recommended engine speeds for particular manoeuvres, for example,: take-off or cruise. Other aircraft may generate the required power demand by varying both engine speed and propeller pitch. Clearly, equipment installed in an aircraft with a variable speed engine would be expected to experience excitation over a wider frequency range than its fixed engine speed counterpart. Blade passing frequencies are usually in the range of 60 to 100 Hz. This results from a number of physical constraints, eg: the propeller diameter, and the need to maintain efficiency by avoiding supersonic blade tip speeds.

B.2 Flight Condition.

B.2.1 For propeller and most other forms of aircraft, maximum vibration usually occurs during periods of maximum power demand such as during take-off. Take-off is, however, a short duration event, eg: 25 s. Climb can also produce relatively high levels of vibration. Cruise is less severe in terms of amplitude, and descent more so. Vibration severity associated with landing can be as severe as take-off if reverse thrust is applied, although the duration of this is likely to be even less than that of take-off, eg: 10 s. While the severity of cruise is usually relatively low, the blade passing frequency associated with this condition could nevertheless be critical for particular equipment. Furthermore, cruise can be most significant in terms of structural fatigue because of the long durations associated with this flight condition. The relative severity of a variety of flight conditions is illustrated in Figure B1 in terms of the overall acceleration rms (2 to 2000 Hz) measured on an aircraft’s structure. It can be deduced from this figure that vibration severity is dependant on power demand. This deduction is broadly confirmed by the graphs of vibration versus power demand presented in Figure B2 for a Jetstream Mk 1 aircraft.

B.3 Position in the Aircraft.

B.3.1 Vibration severity is dependant upon the distance from the plane of the propellers, where vibration severity is usually at a maximum. A diagram showing how vibration severity varies along the length of a Jetstream Mk 1 aircraft is presented in Figure B3. It can be seen that in this particular aircraft, vibration in the dominant lateral axis at the rear of the aircraft is only around 25% of that in the plane of the propellers. Spectra relating to positions in the plane of the propellers and at the rear of a Jetstream Mk 1 aircraft are compared in Figure A1. From this figure it can be seen that while the severity at frequencies related to propeller blade passing is lower at the rear position, the severity of the broad band vibration is greater at the rear than in the plane of the propellers. This broad band vibration is likely to be associated with vortex shedding and blade thickness noise.

B.4 Equipment Mounting.

B.4.1 Equipment mounting arrangements can influence its vibration response. Clearly it is desirable that designers ensure that frequencies associated with their equipment do not coincide with propeller shaft rotation or blade passing frequencies associated with the host aircraft. Whilst this may not be possible if the engine is a variable speed type, at least the dominant frequencies which are present for the majority of the time, eg: during cruise, should be avoided. In practice, this can be difficult because of the number of significant blade passing harmonics, as illustrated in Figures 1 to 4. Potential problem areas are associated with the unit's installed natural frequency (dependant upon the unit's mass and the stiffness of its mounts) and resonances within a unit (eg: flexing of printed circuit boards). Installed natural frequencies can be expected to be relatively low, eg: < 200 Hz and relatively simple to modify. Internal resonances associated with units can occur at much higher frequencies and can be more difficult to alter in a predictable way. In such cases, testing may be required to include the higher frequency harmonics.

B.5 Equipment Alignment.

B.5.1 Considerable variations have been seen in the relative severity of three vibration measurement axes, depending on aircraft type. While the most severe vibration tends to occur in either the vertical or transverse axis, relatively high levels have been observed in the longitudinal axis. This suggests that if flight measurements are being made, all three axes should be included.

B.6 Other Parameters.

B.6.1 Differences in the vibration severity of nominally identical propeller aircraft have been attributed to indeterminable structural differences. For example, in a survey of twelve flights of different C130 (Hercules) aircraft, involving different airframes, the coefficient of variation, ie: standard deviation divided by the mean value, was around 30% for the dominant frequency components. Such variations in severity need to be taken into account when compiling environment descriptions or test specifications, eg: by enveloping measured data by appropriate margins.

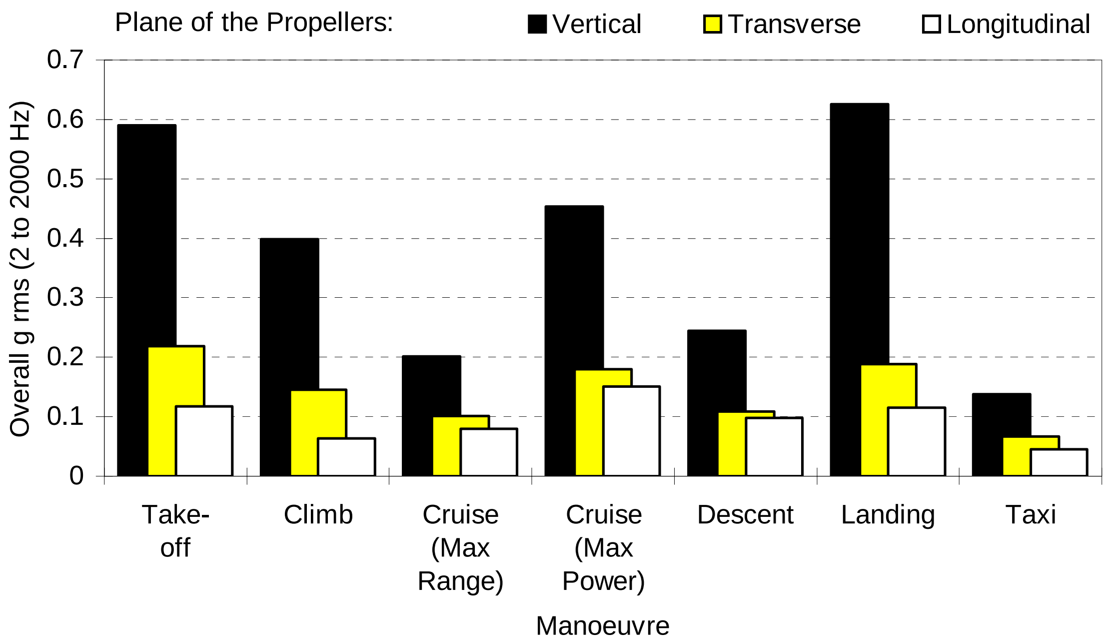

Figure B1: Examples of Hercules C130 Mk 1 vibration severity for various flight conditions

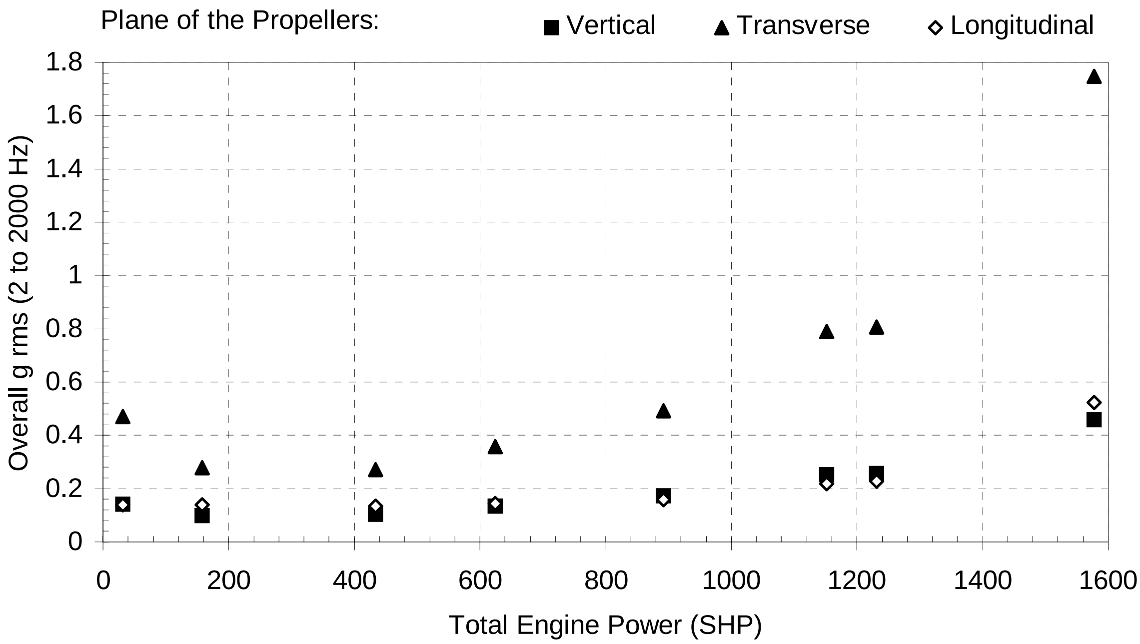

Figure B2: Vibration severity versus power demand for a Jetstream Mk 1 aircraft

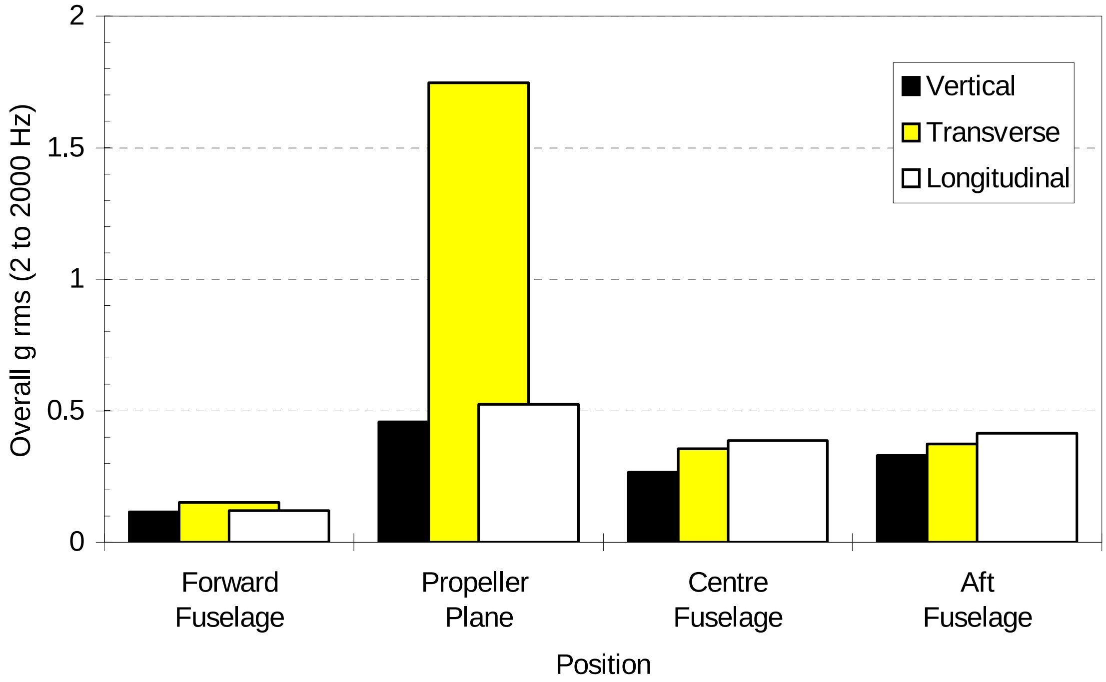

Figure B3: Variation of vibration severity along the fuselage of a Jetstream Km 1 aircraft in cruise

LEAFLET 247/1

DEPLOYMENT ON ROTARY WING AIRCRAFT

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LEAFLET 247/1

DEPLOYMENT ON ROTARY WING AIRCRAFT

1. GENERAL

1.1 This leaflet addresses the mechanical environments encountered by materiel when deployed on or installed in rotary wing aircraft such as helicopters. The sources and characteristics of the environments are presented and where appropriate, information is given on potential damaging effects. Additional guidance is contained in Annex A on the important parameters influencing the severity of the mechanical environments. Where relevant, advice is given on the selection of the appropriate AECTP 400 Test Methods.

1.2 Advice is given in Annex B on the manipulation of measured data to compile environment descriptions and test severities. Also addressed in Annex B is the use of suitable data processing techniques for dealing with helicopter vibration characteristics.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 General

2.1.1 Consideration of the sources of vibration, as presented in Annex A, suggests that it is realistic to characterise vibration spectra associated with helicopters by discrete peaks superimposed upon a background of broad band random vibration. Helicopter engine speeds are governed generally to within 2% and so the frequencies of the rotating components are similarly bounded.

2.1.2 In the course of their missions, helicopters carry out many flight conditions, which may include hover, straight and level flight (forwards, backwards and sideways), climb, descent, turns, acceleration, deceleration, etc. For data processing purposes these conditions may need to be classified into two groups, ie: steady and non-steady state, because different techniques are appropriate for each group. The former group would include straight and level flight and other relatively steady-state conditions, while the latter group would include the transition from forward flight to hover and other relatively transient conditions.

2.1.3 Typical acceleration histories from a store carried externally on a Sea King helicopter during straight and level flight at maximum speed (Vne) are presented in Figure 1. This figure presents data from the vertical, transverse and longitudinal axes. Figure 2 shows a frequency analysis up to 500 Hz for the vertical axis acceleration history presented in Figure 1. In Figure 2 the excitation harmonics associated with the main rotor blade passing frequency of the Sea King can be clearly seen. A further frequency analysis of this data up to 3000 Hz is presented in Figure 3. It can be seen from Figure 3 that responses above 200 Hz are at a very low level, apart from a peak centred around 700 Hz which is attributed to gear tooth meshing.

2.1.4 An amplitude probability density (APD) analysis has also been carried out on this vibration record; the resulting plot is shown in Figure 4. The characteristic of the APD data is midway between that of random vibration and that associated with sinusoidal vibration.

2.1.5 Studies have shown that parameters which influence the vibration characteristics of helicopter equipment fall into four categories, i.e.: flight conditions, helicopter variations, load configuration and measurement position/axis. These parameters should be considered when compiling test specification from measured data.

2.2 Flight Conditions

2.2.1 Helicopter vibration usually depends on the speed of the helicopter, as illustrated in Figure 5. It should be noted from this figure that maximum vibration does not always occur at maximum speed, but can be associated with a sub-cruise speed.

2.2.2 The transition to hover from forward flight is generally the most severe flight condition. Moreover, the severity of the transition to hover condition can exceed that of cruise by up to four times, albeit for only a few seconds. The transitory nature of this manoeuvre is illustrated by the acceleration history presented in Figure 6. Effects of take-off and landing are not significantly different to those associated with the hover condition.

2.2.3 During flight the helicopter will experience extreme low frequency accelerations. These loadings, which are generally of low severity, can be caused by manoeuvres such as banked turns or can be caused by gusts. For design and test purposes, these acceleration loadings are usually considered as being quasi-static in nature. Their effects can sometimes be amplified by coupling with the dynamic motions arising from the lower frequency airframe modes of vibration, although such coupling would be expected to be considered and prevented at the helicopter design stage.

2.3 Helicopter Variations

2.3.1 Observations from cabin measurements, the vibration characteristics of which are particularly applicable to internal equipment, rank helicopters according to severity in the order of Chinook, Lynx and Sea King. However, data relating to externally carried stores on the Sea King and Lynx, indicate that Sea King is the most severe. The variation in severity, ie: best to worst, for samples of Lynx and Chinook helicopters, has been seen to be up to 5:1 for the dominant frequency components. For a given helicopter type, the variation in store vibration amplitude due to carriage station has been seen to vary by up to 3:1.

2.4 Load Configuration

2.4.1 The attachment of massive equipment (particularly of stores) produces installed natural frequencies of the equipment/carrier/helicopter combination. Problems of excessive vibration can occur if such frequencies coincide with any of the major forcing frequencies, such as blade passing, associated with the host helicopter. Mixed carriage loads of external equipment can also influence vibration severity, increases of 1.6 times have been observed.

2.5 Measurement Position and Axis

2.5.1 A helicopter vibration measurement will be influenced by its proximity to the various sources of excitation and also the type of structure to which the measurement transducer is attached. For external stores, where significant rigid body motions may occur, additional influences can be the position of the transducers along the store and the sensing axis.

2.6 Gunfire

2.6.1 Materiel responses to gunfire are discussed in Leaflet 246/1, Deployment on Jet Aircraft.

2.7 Launch of Weapons

2.7.1 This environment encompasses the launch of weapons from the host helicopter, eg: the launch of TOW missiles. The launch of weapons can subject the helicopter airframe to high levels of shock, vibration, blast pressure and rocket motor efflux. These conditions are highly specific to particular weapon/helicopter installations and therefore generalised guidance is inappropriate.

3. POTENTIAL DAMAGING EFFECTS

3.1 Failure Modes

3.1.1 Materiel may be susceptible to three possible failure modes, ie: related to displacement, velocity and acceleration. Displacement related failures in materiel can arise through collisions between equipments after relative movement; tension failures after relative movement; connectors becoming loose leading to a break in electrical continuity. Acceleration related failures may arise through the action of inertial loadings. These may be applied once, to produce a threshold exceedance failure, or repeatedly to induce a fatigue failure. Velocity related failures are not as common as those of displacement or acceleration. However, velocity loadings on some electrical equipment, including sensors, could induce spurious voltages, which in turn could lead to functional failure.

3.2 Taxi Operations

3.2.1 This is a benign environment for most materiel and no special damaging effects need usually be considered.

3.3 Takeoff, Landing and Flight

3.3.1 A major potential problem area for materiel mounted on helicopters is possible coupling between the helicopter's blade passing related frequencies and frequencies associated with the equipment, ie: of the equipment on its mounts or of its internal components. Not only can this lead to equipment failure but excessive loads can be introduced into the helicopter's airframe.

3.3.2 As a result of in-flight manoeuvres or the effect of gusts, inertial loadings can be induced within equipment and at its attachment points to the airframe. Such loadings can produce structural fatigue failures or degrade the correct functioning of mechanisms.

3.4 Gunfire

3.4.1 The blast pressure wave associated with the action of gunfire can cause structural damage to the airframe close to the gun's muzzle, ie: in the near field. Also in this area, equipment close to the muzzle, but protected from the blast, may suffer the effects of the structurally transmitted mechanical shock. Further from the gun's muzzle, ie: in the far field, equipment may suffer the effects associated with intense low frequency vibration corresponding to the gun fire rate. Possible adverse effects in this region could arise from a coupling of the gun firing rate with fuselage modes of vibration or with the installed natural frequencies of equipment.

4. TEST SELECTION

4.1 Flight Vibration

4.1.1 Two methods of simulating this environment are generally available, ie: laboratory tests or field trials. Laboratory tests allow the simulation to be undertaken in closely defined and controlled conditions. The test procedure used should be that of AECTP 400, Method 401 - Vibration.

4.1.2 Field trials are potentially more realistic and may be most convenient for large items of equipment. Field trials are essential if the equipment interacts significantly with the host helicopter, such as in the case of heavy external stores.

4.2 Gunfire

4.2.1 The test methods to be adopted for this environment are discussed in full in Leaflet 246/1 Installation in jet aircraft, paragraph 5.6 Gunfire.

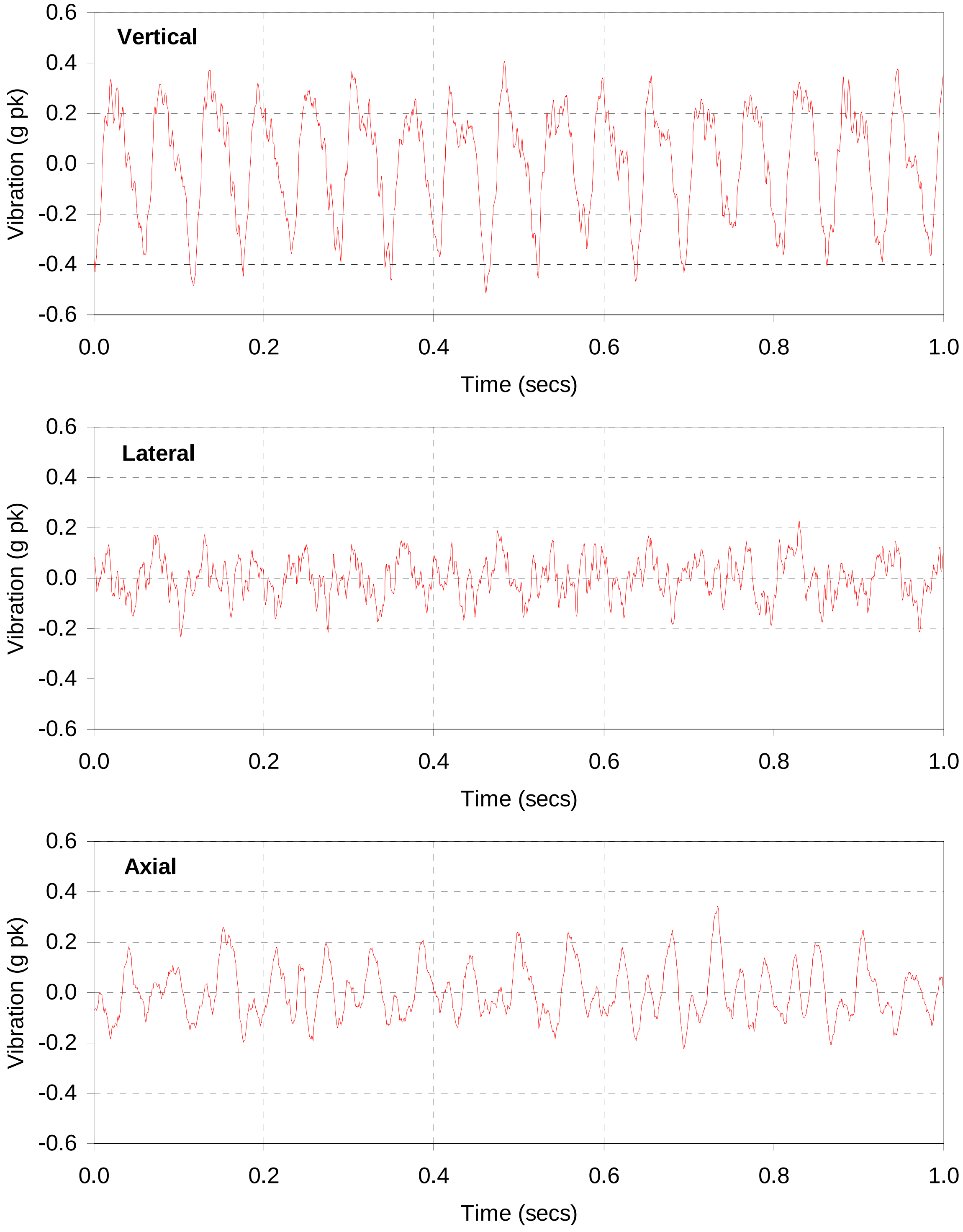


Figure 1: Vibration histories of an externally carried store during straight and level flight on a Sea King helicopter.

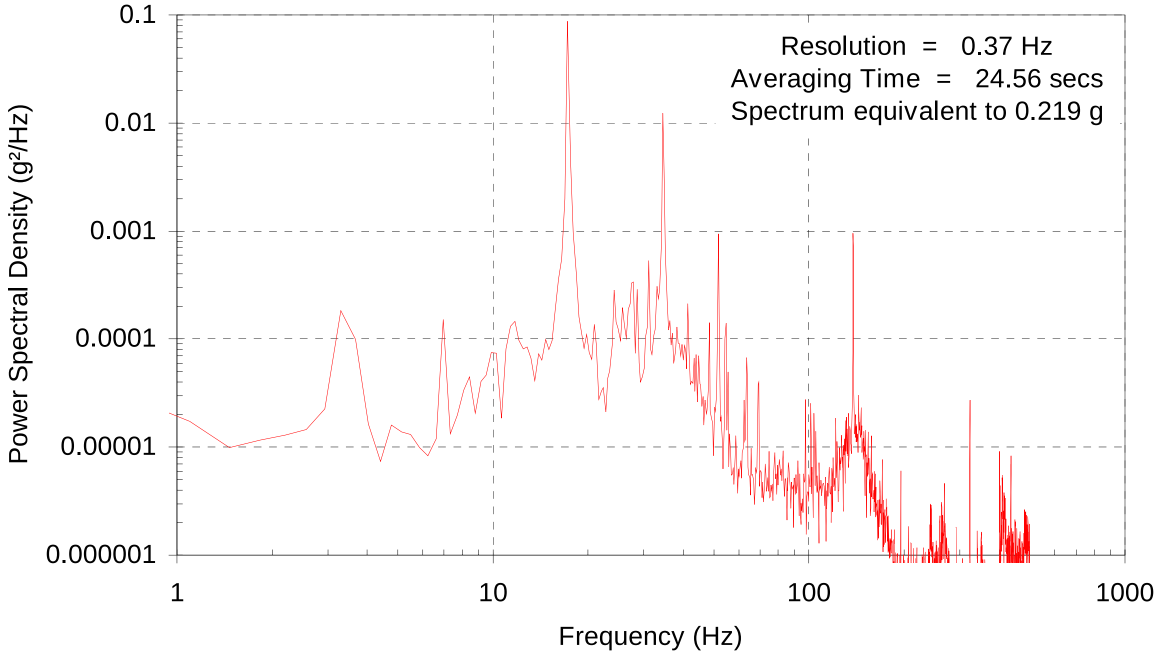


Figure 2: Store vibration spectrum for external carriage on a Sea King helicopter

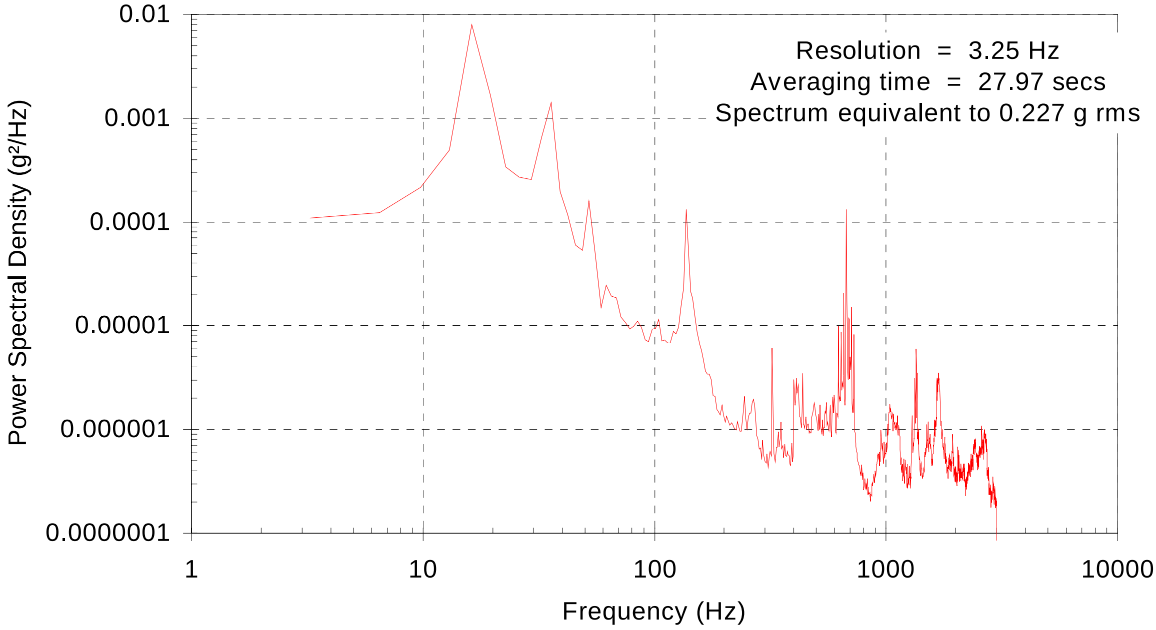


Figure 3: Store wide band vibration spectrum for external carriage on a Sea King helicopter

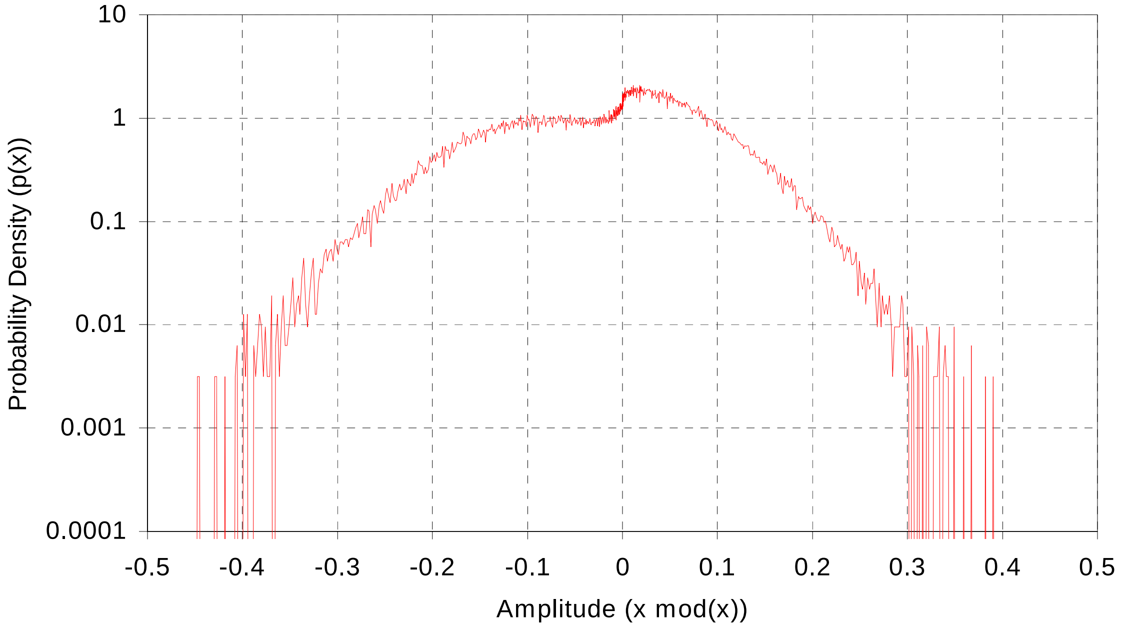
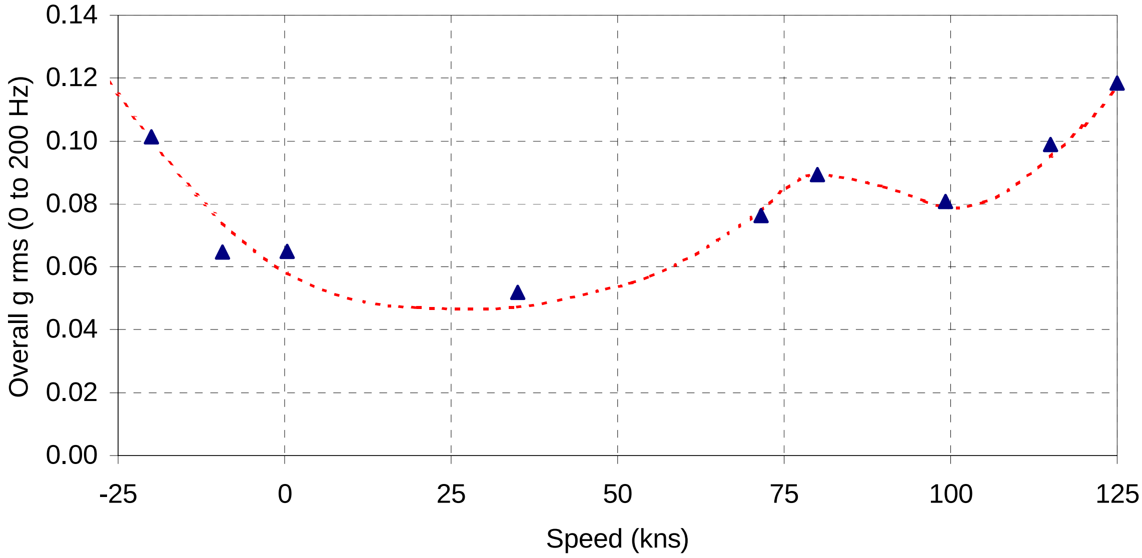


Figure 4: Amplitude probability density for a store externally carried on a Sea King helicopter



Note: Data from an externally carried store on a Lynx helicopter

Figure 5: Helicopter vibration versus speed characteristic

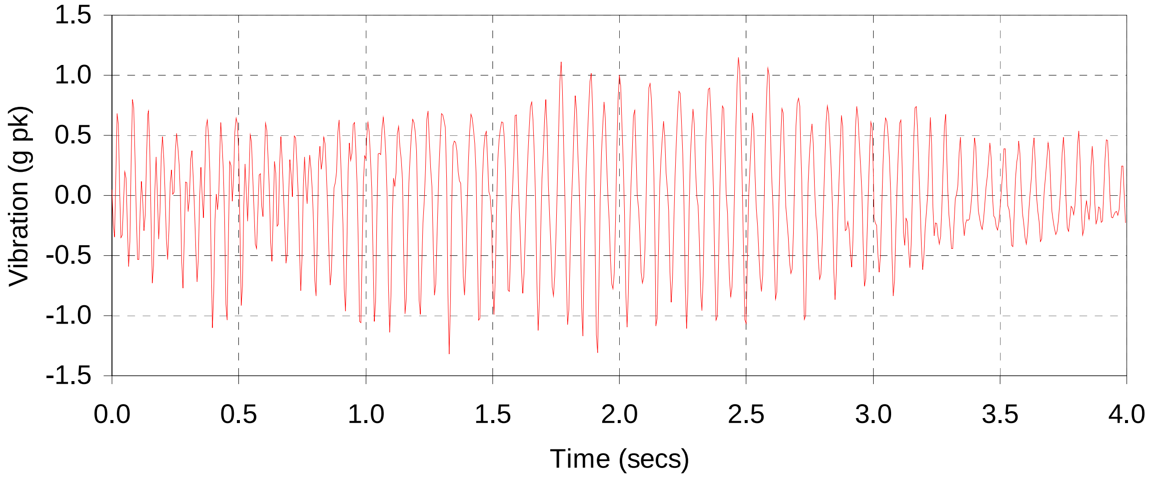


Figure 6: Store vibration history for transition from forward flight to hover

ANNEX A
PARAMETERS INFLUENCING THE MECHANICAL ENVIRONMENTS

A.1 Taxi Operations

A.1.1 During taxi operations around an airfield, a helicopter can be expected to experience vibration and transient inputs arising from the interaction of the wheels of the helicopter's undercarriage with the surface of the runway. The severity and character of these inputs will be dependent upon the mass of the helicopter, the size of its wheels, the compliance of its undercarriage and the quality of the runway surface. This environment may not be applicable to all helicopter types, such as those types fitted with skids in place of wheels.

A.2 Take-Off and Landing

A.2.1 The characteristics and severities arising from these conditions are generally encompassed by those of flight (see below). A possible exception is that of arrested landing, such as may occur on the flight deck of a ship.

A.3 Flight Conditions

A.3.1 For materiel installed either internally or externally on helicopters the dominant source of vibration is that associated with the main rotor blade passing frequency. Depending upon the position of the materiel within the airframe, significant vibration response levels can occur at the frequencies of associated higher harmonics and also, albeit usually at lower levels, the main rotor, and the tail rotor and its blades. Excitation over a wide frequency range also arises from the action of other rotating components, such as drive shafts, engines, pumps and gear tooth meshing.

A.3.2 A notation system has evolved for describing the various rotational frequencies. If R is the rotational speed of the rotor and n is the number of blades on the main rotor, then the blade passing frequency is given by nR, and subsequent harmonics are 2nR, 3nr, etc. Similarly, for the tail rotor, blade passing frequencies are denoted by nT, 2nT, etc., where T is the rotational speed of the tail rotor and n denotes the number of blades.

A.3.3 A typical vibration spectrum measured on a helicopter could include components from the following sources:

Source	Frequency Range (Hz)
Ride motions, effects of turbulence	0-3
Main Rotor R	3-7
Fuselage bending modes	5-8
Rigid body modes of external stores on their carriers	6-20
Main Rotor blade passing nR	11-26
Tail rotor T, multiples of nR, tail drive shaft, pumps, gearboxes	8-80
Tail rotor blade passing nT, Pumps, engines and gearbox, output shafts	100-140
Main gearbox tooth meshing	450-700
Further gearbox tooth meshing frequencies	1000-5000
Engine turbine blades passing	10000-plus

A.3.4 For a dual rotor helicopter such as the Chinook, the dominant frequency tends to be the frequency of interaction between the two sets of blades, that is at 2nR.

A.3.5 Vibration can originate from several mechanisms associated with the action of the rotor system. Some of these mechanisms generate vibration directly while others first generate noise which produces vibration when it impinges on the helicopter's airframe. Because of the diverse nature of these sources, and their interactions, measured vibration spectra can appear complicated and possess features which are not easily explained, such as the cancelling or enhancement of certain blade passing harmonics. Some of these sources of vibration are:

a. Rotating Pressure Fields: Pressure fields rotating with the rotor blades produce noise which in turn produces periodic vibration at the blade passing frequency and harmonics when it impinges on the helicopter's fuselage.

b. Vortices: Vortices shed from the tips of the rotating blades cause broad band random vibration when they impinge on the helicopters fuselage.

c. Blade Thickness Noise: This noise is generated by air moving out of the way of an advancing blade and then returning after the blade has passed. This pulsation of noise is perceived at the fuselage as noise at the blade passing frequency, and can produce periodic vibration in the helicopter's structure.

d. Mechanical Imbalance: Periodic vibration is caused by mechanical imbalance of a rotor assembly and will be apparent at the rotor shaft speed and its harmonics. Imbalance can arise through the natural action of erosion over a period of time. Routine maintenance should act to minimise this vibration but some residual imbalance is likely.

e. Airflow Interference: When a rotor is producing lift, an airflow streams below it. If this flow is interfered with, eg: by the helicopter's tail boom, vibration can be induced into the rotor blades and transmitted to the helicopter's structure via the rotor bearing.

f. Rotor Blade Modes: Blade modes can be excited by forcing functions such as the air moving through the rotor disc or by airflow interference. If there is coupling between the blade mode frequencies and the forcing functions then the blades vibrate with large amplitude and there is little reaction at the rotor bearing. If the frequencies are well separated, however, the blades will suffer forced vibration which will be transmitted to the helicopter fuselage via the rotor bearing.

A.3.6 The rotor system assembly itself has inherent periodic vibration generating characteristics. In forward flight, the rotor blades experience periodic changes in loading because of their rotation in relation to the forward velocity of the helicopter and also to changing angles of attack.

A.3.7 Aerodynamic excitation of materiel, arising from the motion of the helicopter through the air, is not deemed to be significant because of the relatively low flight speeds of helicopters. However, this may not always be the case as blade technology improves and the speed of helicopters increases.

A.3.8 As for internally mounted materiel, that mounted externally experiences vibration which is predominantly mechanically transmitted from the rotor hub. Downwash from rotor blades is not regarded as a significant excitation mechanism for external materiel. This is because, it is argued, it is the tips of the blades that generate most lift, and therefore, when in its usual mounting sites, externally carried materiel will tend to benefit from being in a region of less disturbed air.

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ANNEX B
DERIVATION OF SEVERITIES FROM MEASURED DATA

B.1 General

B.1.1 This section explains how vibration test severities may be derived from measured data. The severities are themselves based upon an environment description, the derivation of which is presented first.

B.2 Derivation of an Environment Description

B.2.1 This section discusses the compilation from field data of environment descriptions in terms of vibration data formats. The underlying logic of the procedure can be considered to be generally applicable to all materiel carried internally or externally on helicopters.

B.2.2 The following procedure to derive environment descriptions has been found to be satisfactory in a number of situations; however, no general approach can be expected to be universally successful. The procedure, illustrated as a flow diagram in Figure B.2, comprises the following stages:

a. From the vibration spectra computed from the measured data, identify any critical installed natural frequencies associated with the integration of the materiel with the helicopter, and separately deal with any potential problems regarding the coupling of this frequency with any of the blade passing related frequencies.

b. Select reference sites on the materiel, typically three on relatively stiff structure, one in each of a set of orthogonal axes. Establish the g rms versus speed characteristic at these reference sites, thereby confirming the vibration amplitudes at normal operating (Vno) conditions. It is convenient to present these data in graphical form with amplitudes normalised with respect to that of a maximum as illustrated in Figure B.1. The maximum chosen should be appropriate for the materiel and its application; it is generally appropriate to use the maximum flight speed, Vne, for this purpose.

c. Derive a description of the random vibration background spectrum for each reference site by producing an 'overlay' PSD plot of all the measured flight conditions. It is to be expected that the g rms of this background vibration will be relatively low. Consequently, an element of conservatism can be built in at this stage with little adverse effect in terms of damage potential by including PSDs from both steady state and transient flight conditions.

d. From peak hold spectra obtained from the measured data, produce two sets of g pk levels, ie: one set for steady state and one set for transient flight conditions, at the dominant forcing frequencies, eg: nR, 2nR, etc. It is desirable to check that the g peak levels for the transient conditions are supplemented by the peak levels observed from the acceleration histories for the more severe transient conditions, such as transition to hover, to avoid their possible underestimation.

e. Using the PSDs and listings of g peak amplitudes, quantify any trends in the data. Suitable areas for investigation include the relative severity of flight conditions, relative severity of axes, effects of mixed loads, and In-Ground-Effects (IGE).

B.2.3 At this point, the vibration amplitudes experienced by the materiel are quantified by direct measurement for all the operational conditions included in the trial programme. A procedure utilising the elements of the environment description to produce vibration test spectra is presented below.

B.3 Derivation of Vibration Test Amplitudes

B.3.1 To transform an environment description derived from flight measured data into test severities, the elements derived above need to be modified to represent an acknowledged maximum severity level of an anticipated in-Service condition. While in principle it is desirable that test amplitudes representing limit conditions are expressed in terms of a probability of occurrence, eg: 1 in 500 case or 2.88 sigma level, it is rarely practicable to do so rigorously because of the large amount of data required to establish the statistics. Therefore, in most circumstances, recourse must be made to engineering judgement when establishing limit conditions from measured data. As a guide, only in exceptional circumstances would test severities exceed the fallback levels presented in AECTP 400, Method 401, Annex A.

B.3.2 The transformation of the background random vibration related elements and the blade passing frequency related elements of the environment description into test spectra is accomplished separately. The logic for this procedure comprises the following stages:

a. The background random element of the environment description often needs to be simplified to provide a practicable test spectrum. This can be achieved by enveloping the measured spectra by a number of straight line segments which follow the basic trend of the PSD characteristic. The resulting g rms should represent the actual limit conditions or the nominated probability of occurrence, eg: the 1 in 500 level.

b. The g peak amplitudes measured at the blade passing related frequencies nR and 2nR etc, are considered separately for the steady state and transient flight conditions. For both sets of flight conditions, amplitudes corresponding to the actual limit conditions or the nominated probability of occurrence, eg: 1 in 500 level, should be established.

c. The values derived in paragraph (a) above, for the background random element, and paragraph (b) above, for the steady state flight conditions of the blade passing related element, are then reconsidered to determine whether any further enhancement of the levels is necessary to cover the following helicopter parameters:

Flight condition.

Helicopter variations, both within a type and flight-to-flight.

Alternative carriage stations and load configurations.

Measurement position and axis.

The effects of these parameters are discussed in paragraph 2. In practice, it is unlikely that the background random element will require further enhancement to cover these parameters, but the blade passing related components will usually require some adjustment.

a. The levels derived for the severe transient conditions in paragraph (b) above may exceed by a considerable margin, typically by a factor of four, those for Vno. Moreover, there is insufficient evidence to suggest that the variations affecting the steady state conditions apply equally to the high amplitude transient conditions. Therefore, to avoid excessive and unrepresentative test amplitudes it is suggested that the enhanced steady state levels, ie: those that take into account the variability parameters in paragraph (c) above, should form the basis of the test amplitudes. It should be noted that such a strategy may not always be applicable, and therefore, each case should be treated on its merits.

b. The resulting limit condition or test overall g rms should be compared to that relating to the Vno condition. As a guide, this test g rms typically exceeds that at the Vno flight condition by a factor of between 2.5 and 3.5 times.

B.4 Derivation of Test Duration

B.4.1 Test durations should be based upon the required life of materiel and the usage profile of the relevant tracked vehicle. In order to avoid impracticably long test durations, it is general practice to invoke equivalent fatigue damage laws such as Miner's Rule. This rule is also known as the "Exaggeration Formula" and is expressed as follows:

$$t_2 = t_1 (S_1/S_2)^n$$

where

t_1	=	the actual duration in the requirements characterised by the measured level
t_2	=	the equivalent duration at the test level
n	=	the exaggeration exponent

For rms level

S_1	=	the rms level of the measured spectrum
S_2	=	the rms level of the test spectrum
n	= b =	the exaggeration exponent; values between 5 and 8 are typically used

For ASD level

S_1	=	the ASD level of the measured spectrum
S_2	=	the ASD level of the test spectrum
n	= b/2 =	the exaggeration exponent; values between 2.5 and 4 are typically used

The exponent ‘b’ corresponds to the slope of the fatigue (S/N) curve for the appropriate material. A value of ‘b’ equal to 8 is adequate to describe the behaviour of metallic structures such as steels and aluminium alloys which possess an essentially linear stress-strain relationship. This expression is used with less confidence with non-linear materials and composites. For electronic equipment and non metallic materials, elastomers, composites, plastics, explosives, a value of 'b' equal to 5 is recommended.

Although the expression has been shown to have some merits when applied to materiel, it should be used with caution, if unrepresentative failures are to be avoided. It is inadvisable for test levels to be increased beyond the maximum measured levels that equipment may experience during in-service life, with a statistically based test factor applied. Furthermore, where there is evidence that the materiel is not fully secured to the vehicle Miner's Rule is totally invalid and should not be used. In such cases the Loose Cargo Test (AECTP 400, Method 406) should be considered as an alternative.

B.4.2 It is first required to establish the major characteristics of the nominated or dominant sortie profile(s), which will generally take the form of the percentage of time spent in particular flight conditions. Based upon these detailed sortie profile(s), a simplified idealised profile can be derived by grouping together conditions of similar severity. Suggested group headings are hover; sub-cruise; cruise and maximum. A suggested classification of flight conditions is shown in Figure B.1. By grouping flight conditions together in this way, the percentage times spent in each of the three groups can be allocated.

B.4.3 Having derived the percentage durations as above, these data can be combined as indicated in the table below to calculate the test time equivalent to an hours flying time. For the purpose of illustration relative severities are taken from Figure B.1. Using Miner's Rule, equivalent durations spent at high-cruise levels are calculated for sub-cruise and cruise. These durations are then summed, as shown in the following example.

Condition	**Severity Index**	Time		
		%	Mins	Equivalent
Hover	0.3	15	9.0	0.02
Sub-Cruise	0.6	20	12.0	0.93
Cruise	0.5	40	24.0	0.75
Maximum	1.0	25	15.0	15.0
	Totals:	100	60.0	16.7

ie: 16.70 minutes test is equivalent to 60 minutes flight time.

B.4.4 The basis for the procedures described in paragraphs B3 and B4 are represented as a flow diagram in Figure B.3.

B.5 Data Format for Testing

B.5.1 Amplitudes at blade passing frequencies have been derived from either peak hold spectra or acceleration histories to avoid their possible underestimation in an PSD. Further information is given in paragraph B.7. For testing purposes, these g peak values may used directly as sinusoidal amplitudes, or preferably, converted to PSD levels assigned to narrow band random components. This conversion is also discussed in paragraph B.7.

B.5.2 It is suggested that the bandwidth of the narrow bands should be 10% of the centre frequency, ie: for the Sea King helicopter with a blade passing frequency of 17.4 Hz, the bandwidth of the narrow bands representing the first two harmonics of blade passing would be 1.74 and 3.48 Hz, respectively.

B.6 Composite Helicopter Test

B.6.1 The following procedure, applicable when flight data are available, is suggested for accommodating a number of helicopter types within one laboratory test.

B.6.2 Blade Passing Frequencies

a. Amplitude: As the blade passing frequency may be different for each helicopter type, as shown in the following table, the formulation of one (composite) test to cover materiel for all possible helicopter types must inevitably involve a degree of compromise. Such a compromise may be acceptable in most applications. In the preceding paragraphs, it has been suggested that excitation at blade passing related frequencies be represented by narrow band random vibration. It is further suggested that, for a composite test, these narrow bands are swept in the frequency domain to cover the helicopter types under consideration. In practice, the sweep range of the narrow band components could be expected to be about 10 Hz. It is required, in this situation that the sweep rate is sufficiently slow to permit any structural resonance to occur at their in-Service levels.

Helicopter	nR (Hz)	Helicopter	nR (HZ)
Chinook	11.25	**Puma**	17.7
EH101 (Merlin)	17.5	**Sea King/Commando**	17.4
Gazelle	18.7	**Wasp/Scout**	26.7
Lynx Mk1, Mk2, Mk3	21.8	**Wessex**	15.3
Lynx 3	22.1		

b. Durations: A further requirement regarding the sweeping narrow bands is that the test duration is such that it adequately tests the store for each of the nominated helicopter types. As a minimum criterion, each narrow band should be tested for at least 30 minutes per axis. Therefore, to include all the swept bands representing blade passing frequencies, the test should not need to exceed a duration of some 25 hours per axis, which in many instances represents a reasonable maximum total test time.

B.6.3 Background Random

a. Amplitude. As the g rms of the random background vibration is relatively low, the PSD plots from the various flight conditions, as derived above, can usually be overlaid for all helicopter vibration without generating excessive levels. This resulting amplitudes can then be incorporated into a test spectrum using the procedure described in paragraph B.3.2.(a).

b. Durations. The background random vibration is applied in conjunction with the narrow band components as discussed in paragraph B.4.

B.7 Key aspects of processing

B.7.1 This paragraph discusses some important aspects that arise when processing helicopter vibration data.

B.7.2 Power Spectral Density (PSD) is the most commonly used data format and describes the spectral content of vibration records. When the units of measurement are acceleration it is also referred to as Acceleration Spectral Density (ASD); amplitude is commonly expressed as g^2/Hz. ASD is usually produced using the Fast Fourier Transform (FFT) algorithm.

B.7.3 Typical parameters for the production of PSD data might be as follows:

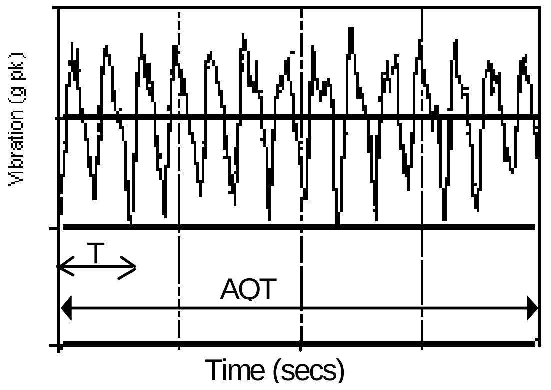
Parameter	**Abbreviation**	**Typical Value**
Maximum frequency	Fmax	200 Hz
Acquisition rate	AQR	512 sps
Transform rate	N	2048
Resolution bandwidth	B	0.25 Hz
Record duration	AQT	30 seconds

B.7.4 The frequency range of 0.25 to 200 Hz and resolution bandwidth of 0.25 is sufficient to resolve the lowest forcing frequency (R) and all the significant harmonics of blade passing. Higher frequency excitations, such as those arising from the gearbox tooth meshing, are not included but are not present at significant amplitudes on most materiel.

B.7.5 Amplitudes from PSD plots are the result of two averaging processes, ie:

a. Averaging in the time domain, according to the record duration (AQT).

b. Averaging in the frequency domain, according to the resolution bandwidth (B).



Parameter	Value
Record length :	AQT secs
Acquisition rate :	AQR sps
Transform size :	N samples
Resolution bandwidth :	$B = \frac{AQR}{N}$ Hz
Block length :	$T = \frac{1}{B}$ secs
Number of blocks averaged :	$\frac{AQT}{T}$ blocks

PSD Analysis Parameters

The results of these averaging processes can be handled differently to produce mean and peak hold spectra. The above plot illustrates how a vibration record is divided into a number of blocks according to the parameters T and B. The duration of a single block is 1/B seconds and it contains N samples where N is the size of the Fourier Transform.

B.7.6 After the data from a block has been digitally sampled, according to the specified AQR, a typical computer program producing PSD data might operate as indicated in Figure B.4. At the completion of the analysis of a vibration record, both a mean and a peak hold spectrum have been produced. The mean PSD is the result of both the averaging processes described above.

B.7.7 The peak hold PSD has eliminated the effect of averaging in the time domain, but is still based on frequency domain averaging. Peak hold spectra (= Equivalent Peak Spectra) are sometimes presented in terms of g pk amplitude, although the measurements are based on the mean square value. In deriving the g pk value a peak to rms ratio has to be assumed, usually a factor of 1.414 is used.

B.7.8 Where vibration test amplitudes at rotor order frequencies are given in terms of g peak, they are suitable for sinusoidal representation. These peak levels are based on measured mean square acceleration. Consequently, if it is desired to represent vibration at rotor orders by narrow band random peaks in preference to sinusoids, the required g^2/Hz values can be obtained as follows:

$$\frac{g^2}{Hz} = \frac{1}{B}\left[\frac{g\,pk}{\sqrt{2}}\right]^2$$

where B in this case is the bandwidth of the narrow band peak.

It should be noted that the above expression does not constitute a general purpose sine to random conversion. It applies only in this special case because the sine levels were originally based on measured mean square values.

B.7.9 Helicopter PSD levels are not meaningful unless the resolution bandwidth is specified. Helicopter data is not always stationary and tends strongly for power to be concentrated around a set of discrete frequencies, ie: harmonics of blade passing. Consequently, the form of a PSD of helicopter data can be sensitive to both record length and resolution bandwidth. This is in contrast to stationary broad band random vibration, as usually exists for jet aircraft.

B.7.10 Non-stationary manoeuvres are best processed into acceleration histories for the most reliable characterisation. Equivalent Peak Spectra will not provide a true estimation of peak amplitude. There is often a requirement for fine frequency resolution, eg: to assist in recognising rigid body modes. Consequently, relatively long block lengths are used, eg: 0.25 Hz resolution implies a block length duration of four seconds. In terms of the transitory nature of certain helicopter manoeuvres, four seconds is sufficiently long for the maximum levels to be averaged down. To avoid underestimation, records of non-stationary manoeuvres should be treated separately as acceleration-time histories.

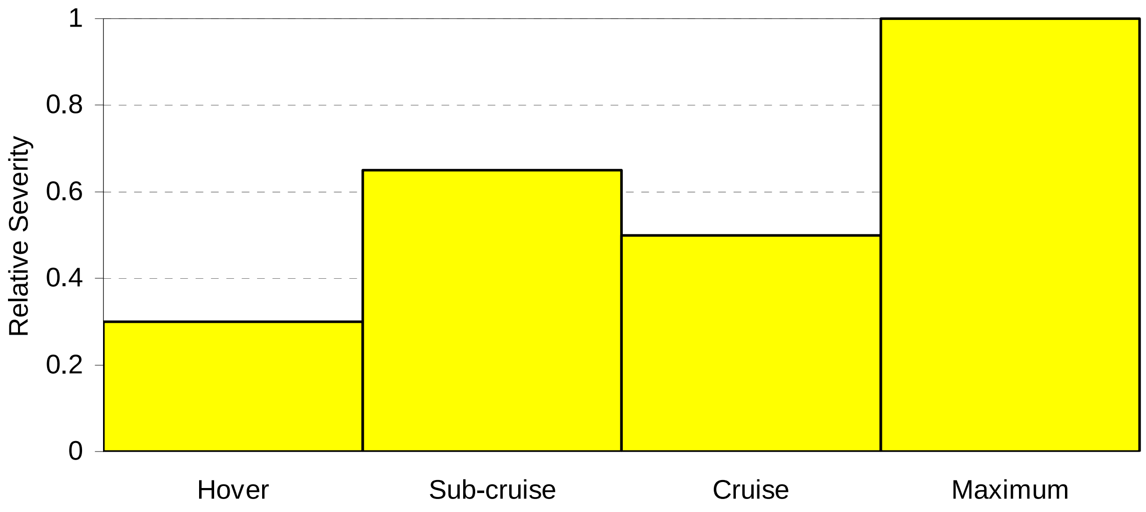


Figure B1: Flight conditions and their relative severity

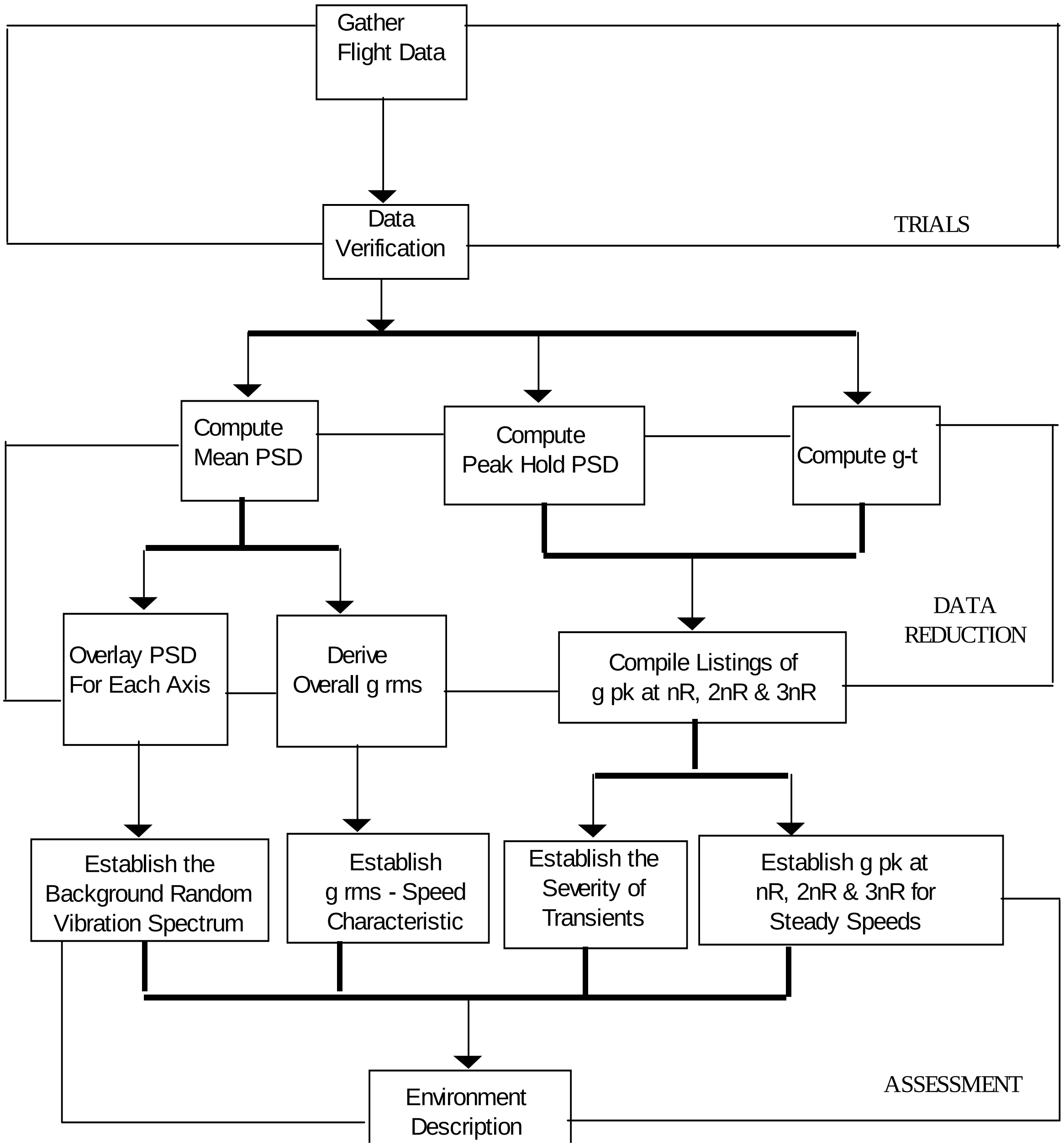


Figure B2: Derivation of an environment description from measured data

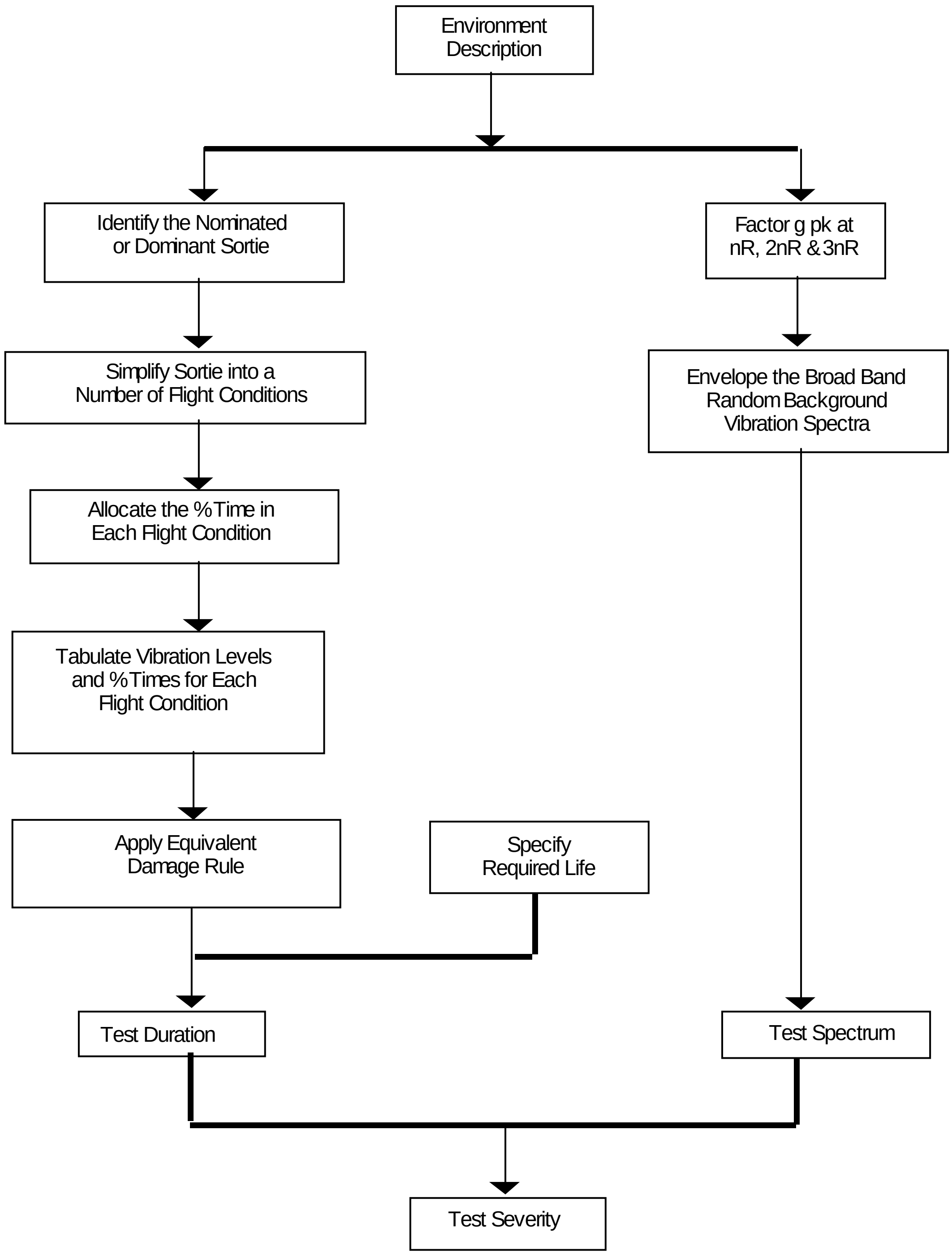


Figure B3: Derivation of vibration test severities from an environment description

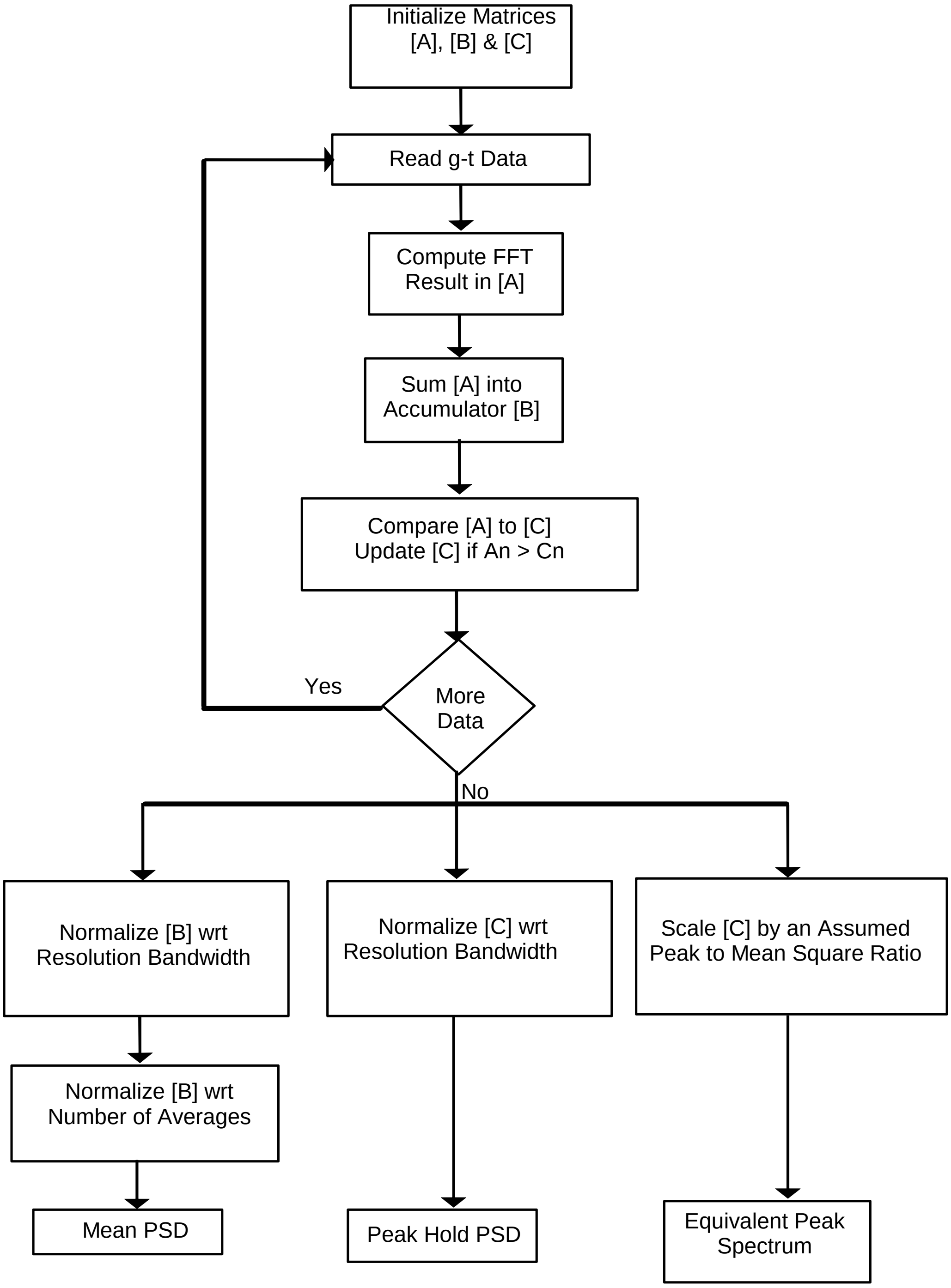


Figure B4: Computation of mean and peak-hold PSD

LEAFLET 248/1

DEPLOYMENT ON SURFACE SHIPS

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LEAFLET 248/1

DEPLOYMENT ON SURFACE SHIPS

1. GENERAL

1.1 The content of this leaflet addresses the mechanical environments that may be encountered by materiel when deployed on or installed in surface ships powered by nuclear or conventional means.

1.2 The sources, characteristics and damaging effects of the mechanical environments are described. Information is contained in Annex A on the important factors influencing the mechanical environments. Where relevant, advice is given on the selection of the appropriate AECTP 400 Test Methods. Guidance is given in Annex B on the compilation of environmental descriptions and test severities from measured data.

1.3 The information within this leaflet refers only to surface ships of conventional hull design. Craft such as hydrofoils and hovercraft are not included.

1.4 Aspects relating to deployment or installation of materiel in surface ships that are not addressed in this sub-section are:

a. Hostile actions: Even though environments arising from hostile actions such as underwater or aerial attack may drive major design parameters, they are outside the terms of reference of this STANAG. For guidance on such actions reference should be made to the procurement authority.

b. Propulsion systems: The environments experienced by equipment on the propulsion raft, induced by the operation of the propulsion system, are excluded. Reference should be made to the propulsion equipment supplier for guidance and data. The environments at the raft/vessel interface are included.

1.5 Vibration amplitude levels in surface ships are relatively benign. Moreover, stealth requirements demand ever decreasing levels. Another factor that acts to keep vibration levels low is the tolerance of the crew, because unlike tanks, trucks or aircraft, a ship's crew lives on-board, sometimes for several months at a time.

1.6 The mechanical environments experienced by installed equipment arise from the actions of on-board machinery and of the sea. The following environments may be experienced.

2. CHARACTERISTICS OF THE ENVIRONMENTS

2.1 On-board machinery

2.1.1 The action of on-board machinery, including generators, transformers, propulsion engines, gearboxes, rotating shafts and propellers will induce vibration in deployed or installed materiel. The vibration characteristics of this machinery, as experienced by the materiel will typically comprise excitations at discrete frequencies superimposed upon a background of broad band random vibration.

2.1.2 The excitations at discrete frequencies will correspond to the various rotational sources dependent upon the position of the materiel relative to these sources. Often, vibration at the propeller blade passing frequency, and its associated harmonics is relatively strong. These frequencies may change for different speeds according to the type of ship. For example, some ships achieve different speeds by varying both engine revolutions and propeller blade pitch angle according to a control law. A typical example of a vibration spectrum originating from the aft area of a UK anti-submarine frigate is presented in Figure 1. This figure also indicates the shaft order frequencies. Acceleration and ASD spectra from the aft area of a French anti-aircraft frigate are presented in Figure 2.

2.1.3 The broad band random component of a typical vibration spectrum will arise from the cumulative effect of all activity onboard ship, the prevailing sea condition and the influence of the ship's own dynamic response characteristics.

2.2 Wave Slap

2.2.1 The effects of waves impacting on the ship's hull, ie: wave slap, can give rise to shock loadings. It is not usually necessary to carry out tests for these conditions. Any shocks that may be expected to occur are likely to be encompassed by those associated with handling events.

2.3 Sea Slamming

2.3.1 Slamming is a localised phenomenon occurring when the relatively flat underside of a ship's hull slaps onto the surface of the sea at a relatively high velocity when driving into heavy seas. It is therefore more applicable to materiel installed in the hull below the water line. Transient accelerations caused by slamming in frigates and larger ships can reach 1 g. In smaller ships, eg: mine-sweepers, transient accelerations up to 5 g have been recorded. It is not usually necessary to carry out tests for these conditions.

2.4 Ship Motions

2.4.1 The action of the sea and weather can give rise to cyclical motion at low frequencies (periods of several seconds) in roll, pitch and yaw. These motions are approximately simple harmonic with a natural period depending on the characteristics of the ship. Examples of values of ship motion for Sea State 7 are given in Table 1. Because the levels are so low it is not usually necessary to carry out tests for these conditions.

2.5 Gunfire and Launch of Weapons

2.5.1 A ship's guns can cause a shock response in nearby equipment. This arises from the effects of blast and to a lesser extent, recoil. Blast is caused by the exit and rapid expansion of propellant gases following the emergence of the projectile from the gun's muzzle. These conditions, and those associated with the launch of missiles, are highly specific to the gun or missile type, and so the provision of generalised information regarding the need for tests is inappropriate.

3. POTENTIAL DAMAGING EFFECTS

3.1 Failure Modes

3.1.1 Materiel may be susceptible to three possible failure modes, ie: related to displacement, velocity and acceleration. Displacement related failures in materiel can arise through collisions between equipments after relative movement; tension failures after relative movement; connectors becoming loose leading to a break in electrical continuity. Acceleration related failures may arise through the action of inertial loadings. These may be applied once, to produce a threshold exceedance failure, or repeatedly to induce a fatigue failure. Velocity related failures are not as common as those of displacement or acceleration. However, velocity loadings on some electrical equipment, including sensors, could induce spurious voltages, which in turn could lead to functional failure.

3.2 Implications

3.2.1 To protect against the effects of underwater attack, materiel is often fitted with shock mounts. Unfortunately, materiel mounted using these devices can consequently possess installed natural frequencies in the frequency range associated with onboard rotating machinery. If this coincidence of excitation and response frequencies occurs, then excessive materiel displacements can result. Such coincidence can lead to degradation of the anti-shock mount and, of course, to the materiel.

3.2.2 Although the vibration environment on-board ship is, for most materiel, benign, it should be noted that because of the operational deployment patterns for ships, materiel can be exposed to the environment continuously for several months. Consequently, the most common failure mechanisms likely to be encountered are of the time dependent variety such as high cycle fatigue, fretting and brinelling. These types of failure are of particular relevance to flexible and lightly damped components, which may have resonances in the range associated with a ship's propeller blade passing frequencies.

3.2.3 The blast pressure wave associated with the action of gunfire can cause structural damage to the ship's structure close to the gun's muzzle, ie: in the near field. Also in this area, materiel close to the muzzle, but protected from the blast, may suffer the effects of the resulting mechanical shock associated with gun fire. Further from the gun's muzzle, ie: in the far field, materiel may suffer the effects associated with intense low frequency vibration corresponding to the gun fire rate. Possible adverse effects in this region could arise from a coupling of the gun firing rate with structural modes of vibration or with the installed natural frequencies of materiel.

4. TEST SELECTION

4.1 Options

4.1.1 Laboratory tests or sea trials are possible means of testing materiel to be used in the environments identified in paragraph 2. Sea trials are essential if the materiel interacts significantly with the dynamics of the ship. Sea trials may be required if the materiel is sensitive and no adequate data are available upon which to base laboratory test severities of adequate precision. An advantage of sea trials is that all units are in their correct relative positions and all mechanical impedances are realistic. Consequently, sea trials can potentially expose materiel to relevant failure mechanisms, which may not be the case for a laboratory test. In practice, however, a sea trial is highly unlikely to be of sufficiently long duration to generate those time dependent failure mechanisms discussed in paragraph 3 above. Furthermore, the severity of mechanical environments onboard ship can depend upon the prevailing sea state and this cannot be anticipated when trials are planned. The simulation of the environment in a laboratory is usually viable for all but the largest items of materiel.

4.1.2 Excepting Gunfire (see paragraph 2.6), the only environment identified for which testing may be required is that to cover the effects of on-board machinery and the shaft propeller.

4.2 On-board Machinery

4.2.1 The swept frequency sinusoidal test as given in AECTP 400 Method 401 - Vibration Procedure 1 should be selected for this environment. This test is applicable to materiel installed in all regions of surface ships including mast heads, exposed upper decks, protected compartments and in the hull below the water line.

Roll (Unstabilised)		Pitch		Yaw	Heave	
Period (s)	Amplitude (deg)	Period (s)	Amplitude (deg)	Acceleration under Ship's Motion (deg/sec^2)	Period (s)	Amplitude (m)
10	±18	5 to 6	±8	1.75	7	±3.5

Notes

(1) All data relates to Sea State 7, significant wave height 6 to 9 m
(2) These statistically significant values are defined as the average of the third highest peaks and there is a 13% probability of exceeding these values
(3) RMS values, which have a numerical value equal to half the significant value, are exceeded 60%

(Derived from UK specification NES 1004)

Table 1: Ship motion data.

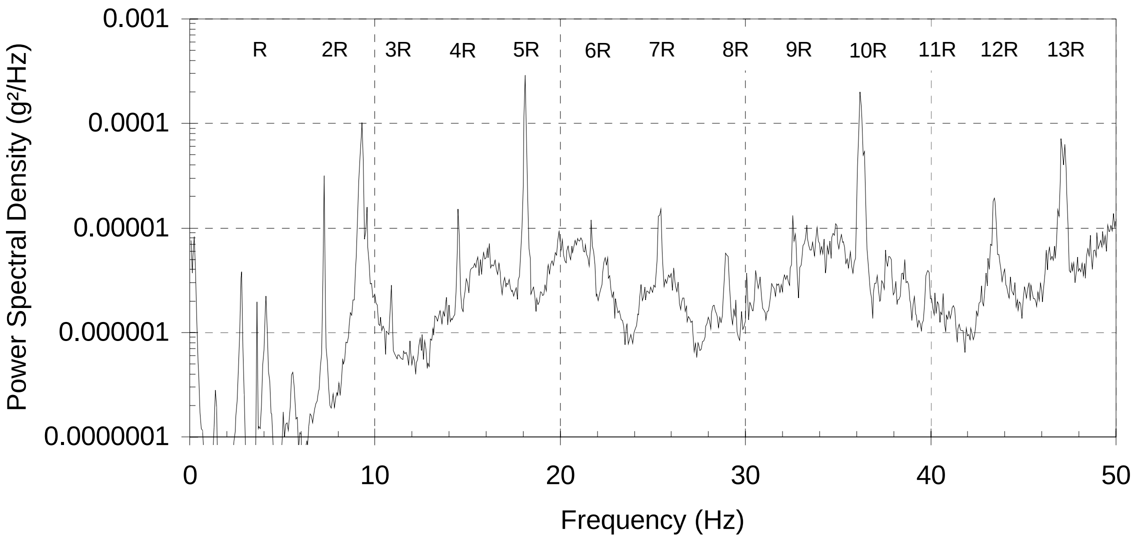
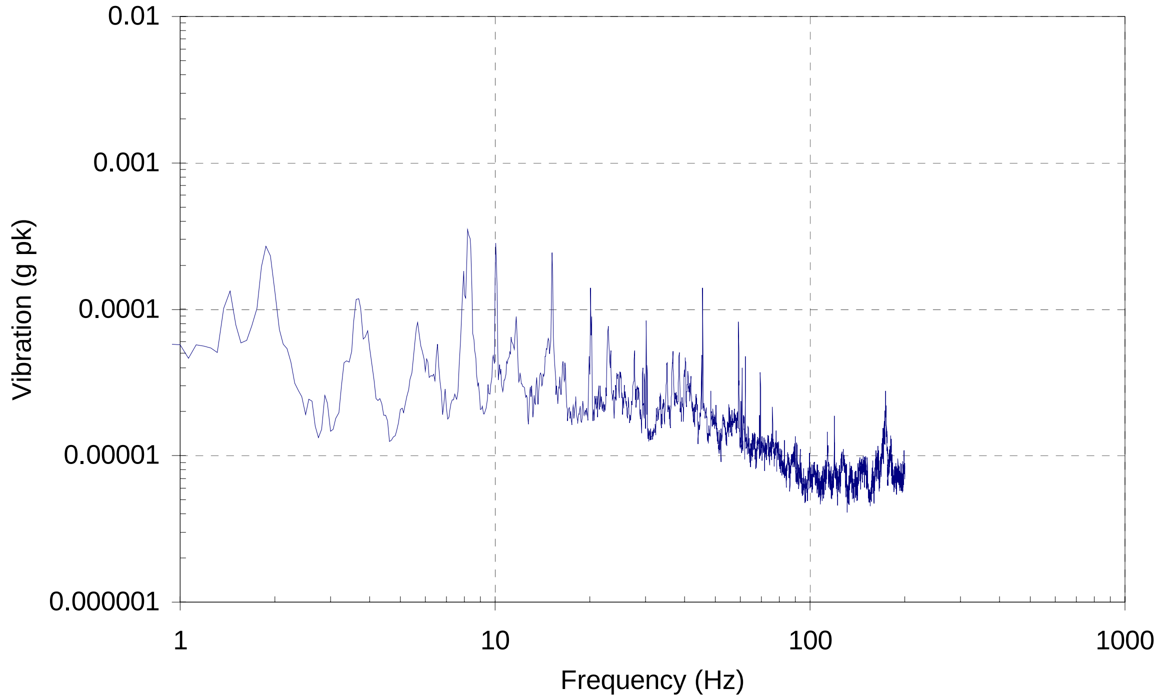
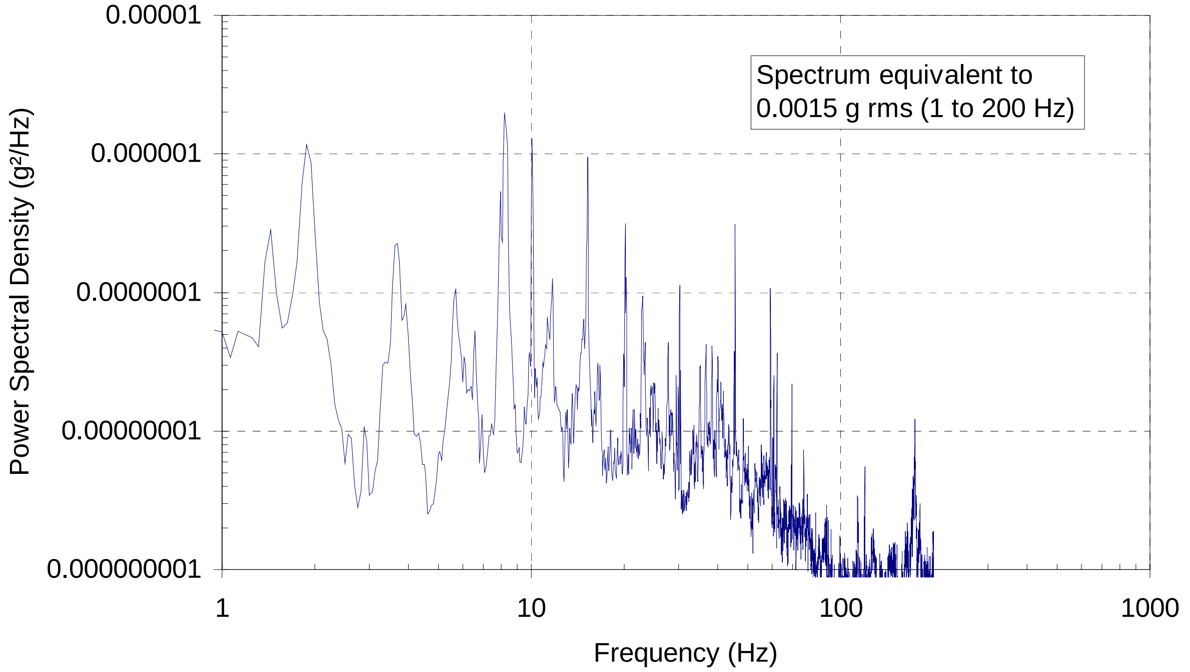


Figure 1: Identification of propeller shaft frequency components in a frigate's vibration spectrum



a: Peak hold (g pk) vibration spectrum



b: Mean power spectral density

Figure 2: Vibration spectrum from an anti-aircraft (F70) frigate

ANNEX A
PARAMETERS INFLUENCING THE MECHANICAL ENVIRONMENTS

A.1 General

A.1.1 Measured vibration data on onboard machinery will rarely be available for all in-service conditions. Therefore it is useful to establish, particularly for sensitive materiel, a working knowledge of the effects of various parameters on vibration severity. This is usually achieved by the derivation of empirical predictive models from the measured data acquired from a well planned programme.

A.1.2 Vibration amplitudes on small ships, such as motor torpedo boats, can be relatively high because of their high performance. Also, being small means that transmission paths will be short from machinery to installed materiel and so the attenuation of vibration will be limited. While larger ships would be expected to give rise to a more benign vibration environment than small ships, aircraft carriers are a special case. This arises from the requirement to accommodate high performance and from the installation of the necessary powerful propulsion systems. Aircraft operations, such as take-off and landing, can also induce vibration and shock loads into the ship's structure.

A.1.3 Due to the relatively benign environments arising from the conditions addressed in this sub-section, the following parameters are limited to those relating only to the transmission of vibration from on-board machinery, whether or not anti-shock mountings are used on the installed materiel.

A.2 On-board Machinery

A.2.1 Speed: Vibration can be expected to increase with increasing speed, although maximum vibration may not necessarily coincide with maximum speed. Rather than speed, a better parameter here might be power demand, or the position of the Power Control Lever (PCL). Some ships respond to power demands by altering both engine speed and propeller pitch according to pre-set control laws. Figure A1 presents data obtained from a frigate which illustrates how vibration can vary according to PCL setting; corresponding ship speeds are also indicated on the figure.

A.2.2 Asynchronous Running: Some ships are fitted with multiple propulsion lines and sometimes run with only one line powered and one line "training", called asynchronous running. Differences in vibration severity between asynchronous and synchronous running can occur.

A.2.3 Engine Configuration: Some ships are fitted with multiple engines per propulsion line. Differences in vibration severity can be expected according to which engine configuration is in use.

A.2.4 Turns: Turns to port and starboard can be expected to be equally severe and of greater severity to the equivalent ahead condition, as illustrated in Figures A2 and A3.

A.2.5 Emergency Stop: This condition can be expected to give rise to relatively severe vibration, albeit for only short durations. An acceleration (g rms) time history for an emergency stop is presented in Figure A4.

A.2.6 Astern: Vibration associated with this condition can exceed that of full ahead, although as for the emergency quick-stop, vibration tends to be non-stationary in character.

A.2.7 Sea Depth: For a given condition vibration is likely to be more severe in shallow compared to deep water because of reflections from the sea bed. Shallow water is generally regarded to be of depth less than five times the draught of the ship.

A.2.8 Sea State: The general vibration environment onboard ship can be expected to become more severe with increasing sea state. This can arise as a result slamming, wave slap and increased demands on the propulsion system.

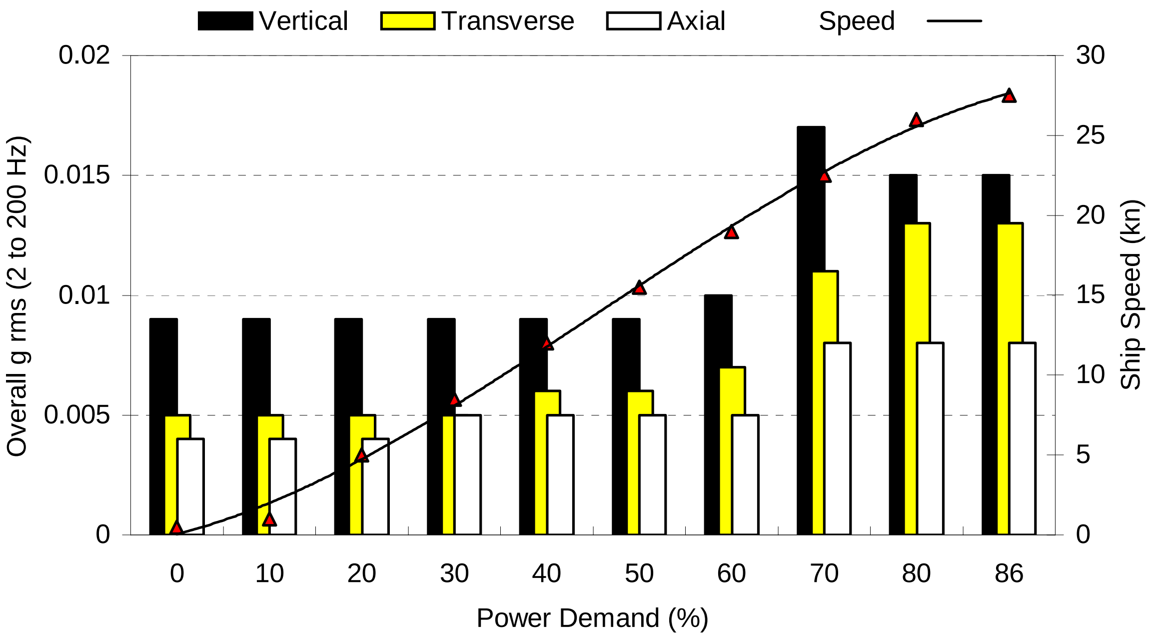


Figure A1: Vibration severity (g rms) versus power demand

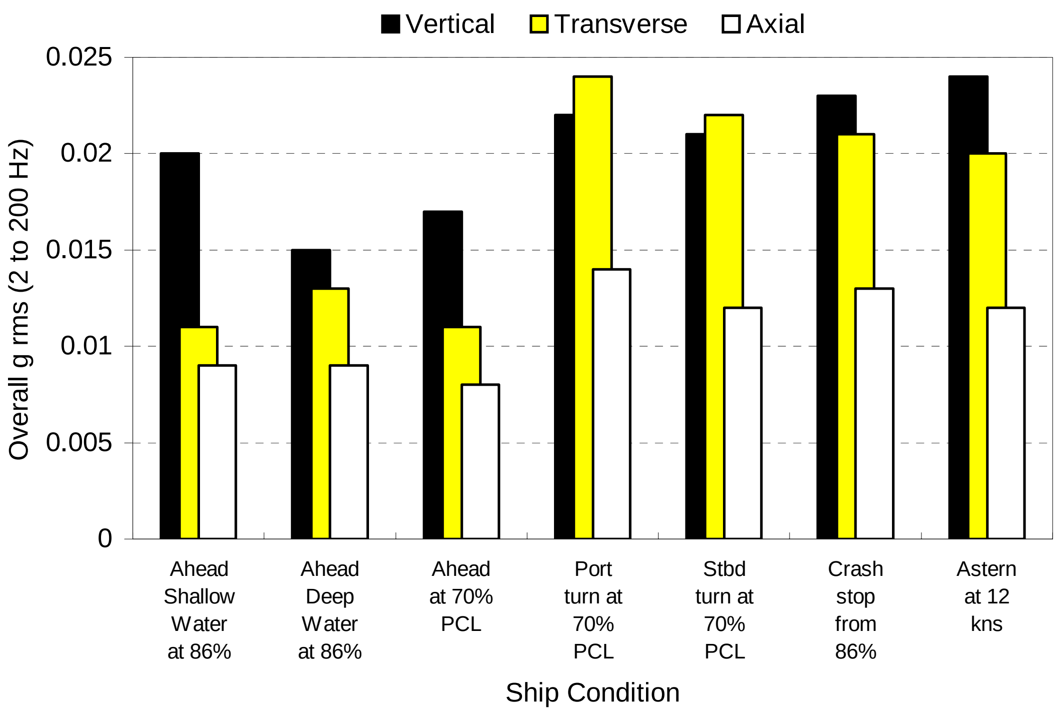


Figure A2: Comparison of the effects of various ship conditions

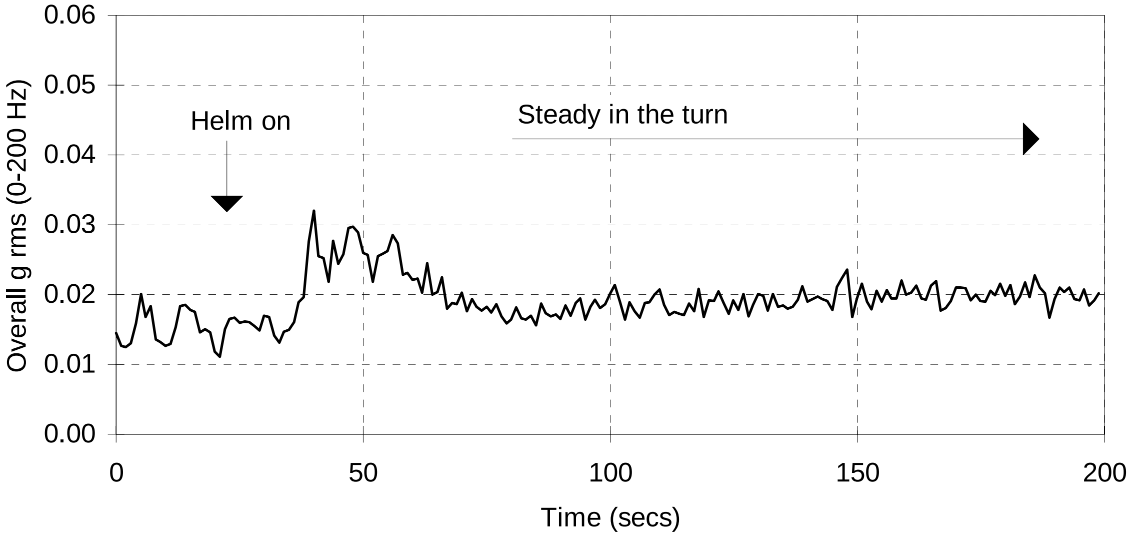


Figure A3: Ship structural vibration response for a starboard turn

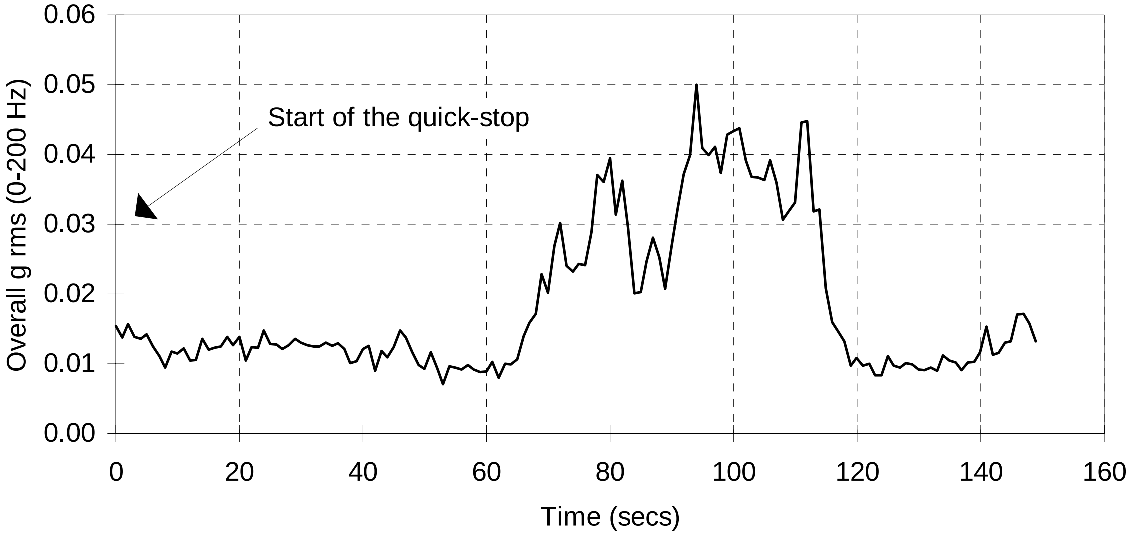


Figure A4: Ship structural vibration response for a quick-stop

ANNEX B
DERIVATION OF TEST SEVERITIES FROM MEASURED DATA

B.1 General

B.1.1 This section explains how vibration test severities can be derived from measured data. The severities are themselves based upon an environment description, the derivation of which is explained first.

B.2 Derivation of an Environment Description

B.2.1 An environment description for materiel deployed on or installed in a ship should generally include for that materiel, and for each relevant ship operating condition, frequency response characteristics and amplitudes and time histories of any transients. This information can form the basis of an examination of trends, eg: on how severity is influenced by speed. The ideas outlined below can be used to derive an environment description from measured data. Procedures utilising the elements of the environment description to produce test spectra and durations are also discussed.

B.2.2 Regarding spectral characteristics two parts of the spectrum need to be considered, ie: the broad band background vibration and the narrow band peaks associated with rotating machinery.

a. Broad Band Component: In general, it can be expected that the broad band component spectral characteristics, ie: the shape of PSD plots, will be stable with respect to many parameters.

b. Narrow Band Components: The frequency of the dominant narrow band components are likely to correspond to the propeller blade passing frequency and its harmonics. Derivation of the amplitudes for these components can be a problem if their frequency changes with speed. This can lead to an under-estimation of severity because of averaging effects implicit in a PSD analysis. One solution is to gather data at a number of constant speeds which can then be analysed separately. Alternatively, if the speed is not constant throughout a record, evolutionary spectra (waterfall plots) can be used. Another approach is to use a tracking filter locked on to a shaft revolution signal. In either case, the severity should be associated with the resolution bandwidth to make the definition unambiguous. In extreme cases, the severity associated with these components could be based on peak-hold spectra to avoid their severity being subject to averaging processes.

B.3 Derivation of Vibration Test Amplitudes

B.3.1 To transform an environment description compiled from measured data into test severities, the elements described above need to be modified to represent an acknowledged severity level of an anticipated in-Service condition. While in principle it is desirable that test amplitudes representing such limit conditions are expressed in terms of a probability of occurrence, eg: 1 in 500 case or 2.88 level, it is rarely practicable to do so rigorously because of the large amount of data required to establish the statistics. Therefore, in most circumstances, recourse must be made to engineering judgement when establishing limit conditions from the measured data. As a guide, only in exceptional circumstances would test severities exceed those presented above as fall-back severities.

B.3.2 The transformation of the background random vibration and the propeller blade passing frequency related elements of the environment description into test spectra is accomplished separately. The procedure comprises the following stages:

a. The background random element of the environment description often needs to be simplified to provide a practicable test spectrum. This can be achieved by enveloping the measured spectra by a number of straight line segments which follow the basic trend of the PSD characteristic. The resulting g rms should represent the limit condition or the nominated predicted probability of occurrence, eg: the 1 in 500 level.

b. The amplitudes measured at the propeller blade passing related frequencies are considered separately for the steady state and transient flight conditions. For both sets of conditions, amplitudes corresponding to the limit condition or the nominated probability of occurrence, should be established. For some ships, the frequencies may change according to speed. To recognise in a test spectrum that the frequency of these components is speed dependent, the narrow bands should be swept over an appropriate frequency range. Alternatively, the broad band spectrum could simply be shaped to accommodate these peaks, rendering the narrow bands unnecessary at the cost of a degree of over-testing.

c. The values derived in (a) for the background random element and (b) for the steady state flight conditions of the blade passing related element should then be reconsidered to determine whether any further enhancement of the levels is necessary to cover the following parameters:

- Ship condition
- Ship variations, both within and across types, as appropriate
- Alternative installation schemes
- Measurement position and axis

In practice, it is unlikely that the background random element will require further enhancement to cover these parameters, but the propeller blade passing related components may well need consideration.

B.4 Derivation of Test Duration

B.4.1 Test durations should be based upon the required life of the materiel and the usage profile of the relevant ships.

B.4.2 Test Duration: Test durations should be based upon the required life of materiel and the usage profile of the relevant surface ship. In order to avoid impractically long test durations, it is general practice to invoke equivalent fatigue damage laws such as Miner's Rule. This rule is also known as the "Exaggeration Formula" and is expressed as follows:

$$t_2 = t_1 \left(S_1 / S_2 \right)^n$$

where

t_1	=	the actual duration in the requirements characterised by the measured level
t_2	=	the equivalent duration at the test level
n	=	the exaggeration exponent

For rms level

S_1	=	the rms level of the measured spectrum
S_2	=	the rms level of the test spectrum
n	= b =	the exaggeration exponent; values between 5 and 8 are typically used

For ASD level

S_1	=	the ASD level of the measured spectrum
S_2	=	the ASD level of the test spectrum
n	= b/2 =	the exaggeration exponent; values between 2.5 and 4 are typically used

The exponent ‘b’ corresponds to the slope of the fatigue (S/N) curve for the appropriate material. A value of ‘b’ equal to 8 is adequate to describe the behaviour of metallic structures such as steels and aluminium alloys which possess an essentially linear stress-strain relationship. This expression is used with less confidence with non-linear materials and composites. For electronic equipment and non metallic materials, elastomers, composites, plastics, explosives, a value of 'b' equal to 5 is recommended.

Although the expression has been shown to have some merits when applied to materiel, it should be used with caution, if unrepresentative failures are to be avoided. It is inadvisable for test levels to be increased beyond the maximum measured levels that equipment may experience during in-service life, with a statistically based test factor applied. Furthermore, where there is evidence that the materiel is not fully secured to the vehicle Miner's Rule is totally invalid and should not be used. In such cases the Loose Cargo Test (AECTP 400, Method 406) should be considered as an alternative.

B.4.3 A simplified example of the derivation of a test duration using these ideas is given below.

Condition	**Power (%)**	**Severity Index**	**Time**		
			%	Mins	Equivalent
Ahead	100	0.8	10.0	6.0	2.00
Ahead	70	0.6	47.0	28.2	2.19
Ahead	40	0.4	10.0	6.0	0.06
Turns	100	1.0	5.0	3.0	3.00
Turns	70	0.8	25.0	15.0	4.92
Astern	-	1.0	2.0	1.2	1.20
Emerg.Stop	-	1.0	0.5	0.3	0.30
		Totals:	100.0	60.0	17.67

Notes

1. 17.67 minutes test is equivalent to 60 minutes in-Service.

2. The “Severity Index” for a condition is the overall g rms normalised with respect to the maximum measured overall g rms (associated with astern running and emergency stop in this example).

B.4.4 As stated in paragraph B.4.2, when attempting to accelerate a test as illustrated above, it is held as good practice not to test at levels greater than those seen in-Service. However, as in this case vibration levels can be very low, it may be permissible to further reduce the test duration by adopting a test level higher than that associated with this particular environment. For example, levels associated with road transport may be considered as a basis for testing.

B.4.5 The above method of calculating test durations would normally be applied subject to a maximum of 17 hours per axis.

LEAFLET 248/2

DEPLOYMENT ON SUBMARINES

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LEAFLET 248/2

DEPLOYMENT ON SUBMARINES

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be encountered by materiel when deployed on or installed in submarines (nuclear or conventionally powered). The sources and characteristics of the mechanical environments are presented and where appropriate, information is given on potential damaging effects. Where relevant, advice is given on the selection of the appropriate AECTP 400 Test Methods.

1.2 Aspects relating to deployment or installation of materiel in submarines that are not addressed in this leaflet are:

a. Hostile actions: Even though environments arising from hostile actions such as underwater attack may drive major design parameters, they are outside the terms of reference of this STANAG. For guidance on such actions reference should be made to the procurement authority.

b. Propulsion systems: The environment experienced by materiel on the propulsion raft, induced by the operation of the propulsion system, is excluded. Reference should be made to the propulsion equipment supplier for guidance and data. The environment at the raft/vessel interface is included.

c. Measured Data: The derivation of test severities from measured data for submarines uses identical procedures to that for surface ships. Therefore please refer to Leaflet 248/1, Annex B for information on this subject.

1.3 The operation of submarines gives rise to a range of mechanical environments. The severity of a particular environment is influenced by the location of the subject equipment with respect to a source of the environment. The following paragraphs address a number of generalised sources.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Hydrostatic Effects

2.1.1 Materiel subjected to diving pressure either inside or outside the pressure hull will, during sub surface operation, be subjected to severe hydrostatic pressure. Materiel is expected to survive or operate as required when subjected to the Depth Dependant System Test Pressure. Typically materiel is expected to withstand cyclic stress changes in the order of 2.10^4 cycles.

2.2 Water Motion

2.2.1 Sub-surface Fluid Motion. Fluid motion of the sea in the vicinity of a submarine will cause the vessel to adopt a rigid body cyclical motion at low frequencies in roll, pitch, yaw and heave. These cyclical motions approximate to simple harmonic motion (SHM) with a natural period (of several seconds) depending upon the characteristics of the vessel. To accommodate any variances from SHM, the velocities and accelerations calculated using SHM theory should be multiplied by a factor, typically a value of 1.5 is used. Limit severities are indicated in Table 1.

2.2.2 Wave Slap. During surface transit, wave motion will subject external structures situated above the waterline, eg: rudders, hydroplanes and masts to a severe distributed loading. This loading is usually treated as a quasi-static condition. The choice of the design pressure loading is based on the implications of the potential failure mode under consideration. If the failure would result in a breach of the pressure hull boundary, then the design pressure should normally have a probability of occurrence of less than one in ten thousand. If the failure would result in loss of system function only, then a probability of one in one hundred is usually acceptable. Design pressures of 58.1 and 48.8 kPA respectively can arise from such a rationale. The pressures are assumed to apply to the projected areas of the structures under consideration.

2.3 Submarine Motion - Vibration

2.3.1 Tactical considerations demand that submarines produce extremely low levels of vibration. Moreover, operating procedures are optimised to ensure minimisation of noise. Factors that contribute to limiting such dynamic responses are:

- *Double skin construction*
- *Surface coatings on hull outer surface*
- *Laminar flow hull design*
- *Careful balancing of rotating components*
- *Fine bladed large diameter propellers*
- *Isolation of machinery/equipment from main structure*

2.3.2 Vibration measured during instrumented trials of submarines indicates the dominance of periodic vibration at frequencies associated with the propeller blade passing frequency, ie: the shaft rotation frequency multiplied by the number of propeller blades. Since the speed of submarines is varied by controlling the shaft speed, measured vibration severity will vary with the forward speed of the craft, as illustrated in Figure 1.

2.3.3 For materiel particularly sensitive to vibration, the usual approach for qualification using fallback test severities may not be appropriate. In such circumstances it will be necessary during equipment development to characterise the environment pertaining to the particular installation. Both long term vibration and transient events should be considered when producing such an environmental description.

a. Long Term Vibration: The long term vibration environment at materiel locations will vary with the forward speed of the submarine and will be dominated by the local structural response at the propeller blade passing frequency. Typically, responses will be ± 0.1 g peak and of a periodic nature. Figure 1 illustrates a typical response on a submarine weapon bay structure as a function of the forward speed of the craft. With knowledge of the distribution of forward speed with operational time, a full description of the long term vibration environment may be achieved. The procurement authority should be consulted to provide the speed versus blade passing frequency relationship and the speed versus duration distribution.

b. Transient Events: The effects of transient events such as adjacent weapon release cannot be generalised and therefore specific measurements and/or analyses should be undertaken as appropriate.

2.4 Submarine Motion - Manoeuvres

2.4.1 Tactical manoeuvres adopted by some submarines can cause a "Snap Roll" condition, ie: a sudden and rapid rate of roll about the vessel longitudinal axis, which occurs during the initial transient phase of a submerged high speed turn. Such manoeuvres produce a roll amplitude of up to ± 25 degrees with a period of around 7 seconds.

2.5 Static Tilt

2.5.1 Submarine operations may result in the vessel adopting an angle of heel or trim up to approximately 30 degrees for extended periods. Equipment is normally expected to be capable of satisfactory operation under such circumstances.

2.6 On-board Machinery

2.6.1 The operation of on-board machinery has the potential to cause vibration that could be transmitted to the submarine structure. However, the requirement for silent operation dictates that such machinery is anti-vibration mounted and usually sited on a raft. For information on permissible raft environment severities, reference should be made to the procurement authority.

2.7 Launch, Firing of Weapons and Countermeasures

2.7.1 Materiel may be subjected to the effects of launch and firing of weapons and countermeasures, particularly materiel situated on the outer surface of the submarine, above the waterline, during surface operations. The effects of such actions are specific to the particular location of the materiel and weapon in question.

3. POTENTIALLY DAMAGING EFFECTS

3.1 Failure Modes

3.1.1 Materiel may be susceptible to three possible failure modes, ie: related to displacement, velocity and acceleration. Displacement related failures in materiel can arise through collisions between equipments after relative movement; tension failures after relative movement; connectors becoming loose leading to a break in electrical continuity. Acceleration related failures may arise through the action of inertial loadings. These may be applied once, to produce a threshold exceedance failure, or repeatedly to induce a fatigue failure. Velocity related failures are not as common as those of displacement or acceleration. However, velocity loadings on some electrical equipment, including sensors, could induce spurious voltages, which in turn could lead to functional failure.

3.2 Implications

3.2.1 To protect against the effects of underwater attack, materiel is often fitted with shock mounts. Unfortunately, materiel mounted using these devices can, as a consequence, possess installed natural frequencies in the frequency range associated with onboard rotating machinery. If this coincidence of excitation and response frequencies occurs, then excessive materiel displacements can result. Moreover, such coincidence can lead to a degradation of the anti-shock mount.

3.2.2 Although the vibration environment on board submarines, for most materiel is benign, it should be noted that because of the operational deployment patterns for submarines, materiel can be exposed to the environment continuously for several months. Consequently, the most common failure mechanisms likely to be encountered are of the time-dependent variety such as high cycle fatigue, fretting and brinelling. These types of failure are of particular relevance to flexible and lightly damped components, which may have resonances in the range associated with the vessel's propeller blade passing frequencies.

4. TEST SELECTION

4.1 Options

4.1.1 Sea trials or laboratory tests are possible means of testing materiel for use in this environment.

a. Sea Trials: Sea trials are essential if the materiel interacts significantly with the dynamics of the submarine. Sea trials may be required if the materiel is sensitive and no adequate data are available upon which to base laboratory test severities of adequate precision. An advantage of sea trials is that all units are in their correct relative positions and all mechanical impedances are realistic. Consequently, sea trials can potentially expose materiel to relevant failure mechanisms, which may not be the case for a laboratory test. However, a disadvantage is that practical submarine operating conditions and prevailing sea states dictate the extent to which sea trials can subject items of materiel to their design limit environments. Furthermore, a sea trial is unlikely to be of sufficiently long duration to generate those time dependent failure mechanisms discussed in paragraph 3.2.2 above.

b. Laboratory Tests: The simulation of the environment in a laboratory is usually viable for all but the largest equipments or unit assemblies. The laboratory tests defined in this leaflet are generally applicable to unit testing only, eg: assembled radio sets, measuring instruments or small computers.

4.2 On-board Machinery

4.2.1 The swept frequency sinusoidal test as given in AECTP 400, Method 401 Vibration, Procedure I should be selected for the vibration environments associated with these conditions. This test is applicable for materiel deployed in all regions of a submarine.

4.3 Shocks

4.3.1 The shocks that may be expected to occur during normal ship operation are likely to be encompassed by those associated with handling (see Section 243). Possible severe shocks associated with hostile action are highly specific and any tests considered necessary should be agreed with the procurement authority.

4.4 Other Environments

4.4.1 It is not usually necessary to carry out tests for the remaining conditions addressed in paragraph 2. Any tests considered necessary should be agreed with the procurement authority

.

Table 1: Submarine motion data

Type	Roll		Pitch		Yaw	Heave	
	Period (s)	Amplitude (deg)	Period (s)	Amplitude (deg)	Acceleration under Ship's Motion (deg/sec^2)	Period (s)	Amplitude (deg)
C	6	±25	11	±5	Small - insufficient data	11	3
N	7	±25*	11	±5		11	3

Notes:

(1) C denotes a conventionally powered submarine

(2) N denotes a nuclear powered submarine

(3) All data relates to Sea State 7, significant wave height 6 to 9 m

(4) These statistically significant values are defined as the average of the third highest peaks and there is a 13% probability of exceeding these values

(5) RMS values, which have a numerical value equal to half the significant value, are exceeded 60%

(6) *denotes a snap roll manoeuvre

(Derived from UK Specification NES 1004)

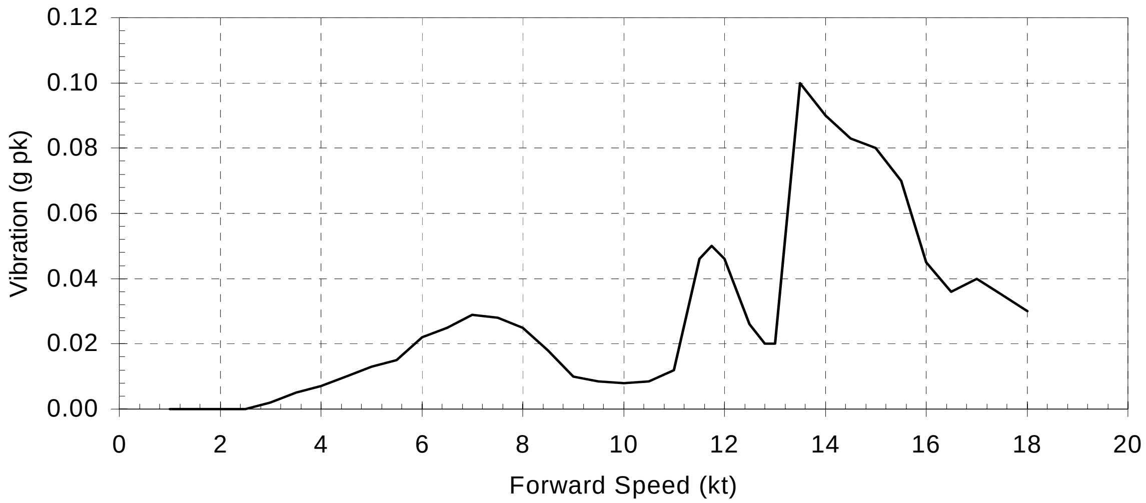

Figure 1: Structural vibration response versus forward speed

LEAFLET 249/1

AIR AND SURFACE WEAPONS

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LEAFLET 249/1

AIR AND SURFACE WEAPONS

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be encountered by air and land weapons, including guided missiles, bombs and projectiles during their separation from the host platform and during their autonomous flight to the target. The sources and characteristics of the mechanical environments are presented, and where available, supplemented by references in Annex A. Where appropriate, information is given on potential damaging effects, treatment options and the selection of the appropriate AECTP 400 Test Methods.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Air Launch - Ejection Transients

2.1.1 Severe transient accelerations are induced in stores during release by cartridge powered ejection release units (ERUs). The purpose of ERUs is to ensure the safe release of stores from high performance aircraft. Other devices, such as the various gravity release units used for releasing stores from helicopters and rail launchers used for releasing some types of guided weapons from aircraft, do not themselves induce significant transient loadings into stores.

2.1.2 Depending upon the particular aircraft/store combination, transients applied to stores by ERUs can attain acceleration levels up to 40 g, while pulse shapes are broadly half sine and durations typically within the range 10 to 40 ms. Ram ejection forces can attain 50 kN. Typical ram force time histories are shown in Figure 1. Further information is referenced in Annex A, paragraph A.1.

2.1.3 The relatively high amplitudes and long durations of these pulses often produce critical design load cases. Consequently, modelling and/or test firings are used to derive project specific, ie: tailored, load-time plots to which materiel is qualified. General purpose fall-back or minimum integrity levels for design are not appropriate for ejection transients.

2.2 Air Launch - Release Disturbance

2.2.1 During release of the store from an aircraft, any asymmetric ERU ejection forces will cause significant store pitching motions, which will result in substantial aerodynamic pressure and acceleration forces being imparted to the store.

2.2.2 Aerodynamic design requirements for stores should ensure that these release disturbance forces are quickly damped out. Nevertheless, the applied forces experienced by the store can attain relatively high amplitudes and long durations, which may result in critical design load cases. Therefore modelling and/or wind tunnel testing are used to establish project specific, ie: tailored, loads to which materiel is qualified. Fall back or minimum integrity levels are not appropriate for this condition.

2.3 Land Vehicle Launch

2.3.1 No additional severe weapon loadings are attributed to this launch mode, other than those associated with materiel deployed on vehicles (see Section 245). However, a detailed knowledge of vehicle motions during launch is usually essential for weapon performance considerations.

2.4 Ground/Silo Launch

2.4.1 During launch, motor efflux reflections from the launch pad/silo surfaces can result in severe transient acoustic and vibration levels throughout the store, which sometimes produce the highest operational vibration levels.

2.4.2 The amplitudes and durations of these transients are, of course, unique to the particular store design, and therefore it is not appropriate to quote fall back levels for these events. Nevertheless, because of the high levels generated it is important to conduct measurements as early as possible to confirm design assumptions.

2.5 Gun Barrel Launch

2.5.1 Very high acceleration forces, say, of the order of 20,000 g, can be induced longitudinally in gun launched stores while traversing the length of the barrel. In addition, they can be subjected to high lateral acceleration forces, often to a similar order of magnitude, and also to a very high spin rate. Therefore, these stores require special, and/or live, firing facilities with which to undertake design proving and equipment qualification trials.

2.6 Other Launch modes

2.6.1 Other launch modes such as the launch of a munition from the deck of a surface ship is addressed in Leaflet 249/2, paragraph 2.4.

2.7 Powered Flight

2.7.1 During the powered flight phase certain missile elements and units, particularly those sited adjacent to the motor system, may be subject to severe vibration arising from propellant combustion and gas dynamics. This vibration often comprises two phases, ie: a high level short duration period arising from the boost phase, followed immediately by a lower level longer duration period arising from the sustain phase. Vibration responses tend to be project specific because of the unique performance characteristics required of each missile/motor combination. Consequently, it is impractical to cover all combinations in this leaflet. However, the basic characteristics of typical vibration spectra are described and typical severities are indicated.

2.7.2 For a missile powered by a solid propellant motor the observed vibration spectra for equipment installed forward of the motor is predominantly broad band random and typically of the form illustrated in Figure 2, but propellant cavity induced resonances may sometimes be evident as sine-like excitations. Liquid propellant motors also produce predominantly broad band random vibration at their nozzles. However, in ramjet powered missiles the observed vibration spectra on similarly sited equipment may be dominated by sine-like excitations arising from the inherent cavities as shown in Figure 3.

2.7.3 For units sited towards the rear of a high speed missile powered by a solid propellant motor, the flight vibration levels can be the most severe which units will experience. Moreover, it should be noted that the measured vibration spectra will also include the responses arising from the turbulent air flow traversing the missile. A typical vibration spectrum for units sited towards the rear of a missile is shown in Figure 4. Acceleration responses (rms g) arising from turbulent airflow are generally proportional to dynamic pressure (q), and are described in Leaflet 246/2. For equipment sited towards the front of a high speed missile the vibration levels arising from the motor may not be particularly severe, and may not differ significantly from those arising from turbulent airflow. A typical vibration spectrum for forward sited equipment is also shown in Figure 4. For equipment located towards the rear of a missile significant vibration levels extend out to frequencies of around 5 kHz, while for forward located equipment the attenuation at the higher frequencies has effectively reduced the frequency range to 2 kHz.

2.8 Flight Manoeuvres

2.8.1 While manoeuvring after launch a missile can be subjected to severe acceleration loads. Some intelligent submunitions may also incur such loads. The duration of a manoeuvre is relatively long and therefore its maximum acceleration value can usually be treated as a quasi-static load condition. Because these manoeuvres are unique for a missile type, no fall-back severities are suggested for these conditions.

2.8.2 Where novel thrust devices are used to induce missile manoeuvres, the forcing actions should be evaluated for any significant transient accelerations.

2.9 Unpowered Flight

2.9.1 Few data are available on vibration levels during the unpowered flight phase of a missile or store. Nevertheless, it is usually assumed that unpowered flight vibration levels will not exceed those during powered flight, discussed above, or those during flight carriage, provided that the dynamic pressure when unpowered does not exceed that for powered flight or flight carriage.

2.10 Separation and Staging

2.10.1 During missile separation and staging events the initiation of pyrotechnic devices, such as explosive bolts and line cutting charges, often result in severe shock loadings, which can take the form of stress waves and/or oscillatory acceleration transients.

2.10.2 Materiel sited close to a pyrotechnic source may be subject to high amplitude stress waves. This situation is likely where the measured acceleration data appear to be dominated by high frequency peaks, such as those shown in Figure 5. In these cases test methods that subject equipments to acceleration transients are inappropriate; and consequently, special purpose test apparatus is usually necessary. One solution is to use a gas gun facility to fire projectiles at a platform on which is mounted the equipment for testing. The test severity may be controlled by monitoring strain histories on the platform. The preferred solution is to conduct a number of live firings, and to compensate for actual rather than factored test levels by analysing the monitored test severities and the performance of the materiel on a statistical basis.

2.10.3 Materiel sited some distance from a pyrotechnic source will be subject to the effects of the structure responding to the excitation. This situation is identified from measured data where the responses appear to be dominated by structural resonances, as is shown in Figure 6.

2.10.4 Comprehensive information on many aspects of pyrotechnic shock, including shock levels, their measurement, attenuation and simulation, is referenced in Annex A, paragraph A.2. Nevertheless, due to the diverse nature of the shock mechanisms associated with pyrotechnic devices it is inappropriate to quote generalised fall back severities for design or test purposes.

2.11 Spin

2.11.1 To increase stability some projectiles or submunitions are subjected to spin during release. Spin rates vary considerably depending upon performance requirements. Therefore, it is inappropriate to recommend general purpose test methods or spin rates. Special purpose test facilities, such as using a motorised device to induce spin, may be required to induce high rates.

2.12 Parachute Retardation

2.12.1 Parachute retarded projectiles are usually subjected to two significant acceleration transients during parachute deployment. The first transient is a snatch condition that occurs when the uninflated canopy is arrested by the rigging lines at the instant of full deployment. The second transient arises from the rapid increase in deceleration force during the inflation of the canopy. Both transients are illustrated in Figure 7 and comprise, in the main, relatively low frequency components. Therefore these transients can often be treated as quasi-static load conditions.

2.12.2 It should be noted that transverse load components can be induced in a store from both snatch and inflation events. Comprehensive information on parachute snatch and inflation loads is referenced in Annex A, paragraph A.3. Due to the wide range of operational uses for parachute systems, it is inappropriate to quote generalised fall back test severities.

2.13 Water Entry

2.13.1 These conditions are addressed in Leaflet 249/2.

2.14 Submunition Ejection

2.14.1 To achieve the required deployment patterns, submunitions may be ejected from their host store by explosive devices. Typically such devices comprise cartridge powered launch tubes or piston assemblies. The acceleration transients arising from these devices can be severe, typically around 1000 g. Pulse durations are of the order of 10 ms, while pulse shapes are broadly of half sine format. Since these ejection devices are tailored to suit specific performance requirements, it is inappropriate to quote generalised fall back design and test severities. However, severities can usually be derived from theoretical predictions, and where necessary supported at a later stage by experimental data.

2.15 Submunition Impact

2.15.1 Submunitions required to survive ground impact after deployment from a dispenser are likely to experience high accelerations and fast acceleration rise times during such an event. A typical example of an acceleration time history for a submunition during impact and penetration of concrete is shown in Figure 8, where levels of 60,000 g are experienced within 0.0001 seconds.

2.15.2 Considerable development testing may be necessary to produce a satisfactory design. This testing may require a purpose built gas gun or catapult device which can in many cases provide a very realistic environment at a relatively low cost. Consequently, special purpose test apparatus, rather than standardised test procedures, are usually more appropriate for testing equipment to impact conditions.

2.16 Novel Approaches

2.16.1 It is not possible within this Leaflet to address all the environmental conditions and particularly those that arise from novel approaches to weapon design. Moreover, it is usually necessary to conduct particular data acquisition programmes and to devise special test facilities for the conditions arising from novel approaches.

3. POTENTIAL DAMAGING EFFECTS

3.1 General

3.1.1 The mechanical environments arising during the progression of a munition to its target may induce a number of potential damaging effects. The most significant are those that induce large acceleration loadings or relative displacements into equipment.

3.1.2 Only those conditions that could be expected to produce critical loading cases are considered under this heading.

3.2 Air Launch/Manoeuvres/Parachute Retardation

3.2.1 The severe transient accelerations induced during ejection, release disturbance, flight manoeuvres or parachute retardation often provides munition critical design load cases. Therefore, should these design loads be exceeded it is likely that a primary structural failure of the munition will result.

3.3 Ground Launch/Powered Flight

3.3.1 The severe vibration and acoustic environments from a ground launch or powered flight phase, although usually of relatively short duration, can be a major cause of the mechanical failures of PEC boards and other small electrical and mechanical devices.

3.4 Barrel Launch/Separation/Impact

3.4.1 High acceleration, fast rise time shock environments induced by events such as gun barrel launch, stage separation, submunition ejection, or munition impact can result in serious structural failures caused by stresswave effects, and can result in electrical component failures due to excessive inertia loadings.

4. TEST SELECTION

4.1 Air Launch - Ejection Transients

4.1.1 These conditions are usually dealt with using quasi-static structural analysis and test methods, because the relatively long duration of the pulse usually ensures that there is no coupling of the pulse with the dynamics of the store structure. However, should it prove necessary to test dynamically for these transients then AECTP 400, Method 403 - Shock is applicable. The shock spectrum test procedure is preferred, but the basic pulse shock procedure may be suitable in many cases, ie: where the application of the exact pulse shape is unnecessary.

4.2 Air Launch - Release Disturbance

4.2.1 This condition is usually dealt with using quasi-static analysis and testing methods, as discussed above for ERU ejection transients.

4.3 Powered Flight

4.3.1 When selecting a vibration test to simulate the powered flight condition, care must be taken not to over specify the test level. In view of the very limited quantity of flight trials data available on which to base vibration test levels there may be a tendency for the specification compiler to envelop any spectrum peaks over the frequency bandwidth of interest, typically 100 Hz to between 2 kHz and 5 kHz. Enveloping spectrum peaks will inevitably result in excessive rms g values, and hence in an indefensible over-test should the specimen fail. Therefore, when compiling a test spectrum careful consideration should be given to balancing g^2/Hz levels with rms g values with the aim of producing reasonable levels for both quantities.

4.3.2 Suitable test procedures to accommodate this vibration environment can be found in AECTP 400, Method 401 - Vibration. Flat or shaped wide band random excitation should be acceptable for many applications, but alternative excitations such as fixed sine on wide band random may be preferable where sine-like excitations are identified.

4.3.3 Where particularly severe vibration levels are required the test described in AECTP 400, Method 402, Acoustic Noise could be applied using the Progressive Wave Tube procedure to excite acoustically the mechanical vibration responses within the missile units. Where close simulation for sensitive units is necessary the test described in AECTP 400, Method 413 - Combined Vibration Acoustic Temperature could be applied. In addition an acoustic test, such as that described in AECTP 400, Method 402 - Reverberant Chamber or Progressive Wave Tube procedure may be necessary over certain rear sections of the missile to cover the acoustic excitation emanating from the nozzle.

4.3.4 If the duration of the powered flight condition is relatively short, say less than 30 seconds, then the statistical random sampling error should be checked to ensure that it is acceptable for the purpose of the test. This error should not normally exceed 15%, which is equivalent to a bandwidth/sampling time product of 50, or 100 degrees of freedom. This check is important for qualification and production conditioning tests where the severities applied need to be repeatable to close tolerances.

4.3.5 The particular characteristics of the severe vibration level and short duration generally associated with missile powered flight generally precludes test tailoring of the form that increases other lower level severities, using power laws, to these severe levels for the purpose of drastically reducing test durations.

4.3.6 The high flight speed attained by a powered missile may cause a rapid increase in temperature, particularly at the skin. Therefore, to ensure an adequate simulation it may be necessary to conduct a combined vibration /temperature test, where the temperature aspects of the test cover any required thermal shock conditions. AECTP 400, Method 413 - Combined Vibration Acoustic Temperature is designed to fulfil such requirements.

4.4 Separation and Staging

4.4.1 Although the pyrotechnic conditions resulting from separation and staging events may produce complicated acceleration response histories, simulations are possible in most cases using the test described in AECTP 400, Method 415 - Pyrotechnic Shock.

4.5 Parachute Retardation

4.5.1 Where some coupling occurs of one of these transients with the dynamics of the structure a close simulation of the pulse may be justified, in which case AECTP 400, Method 403 - Shock is applicable. The shock spectrum procedure is preferred but the basic pulse procedure should prove adequate for most cases.

4.6 Submunition Ejection

4.6.1 With regard to the selection of test procedures AECTP 400, Method 403 is applicable. The basic pulse procedure should suffice for most applications, but where a closer simulation is required the shock spectrum procedure is recommended.

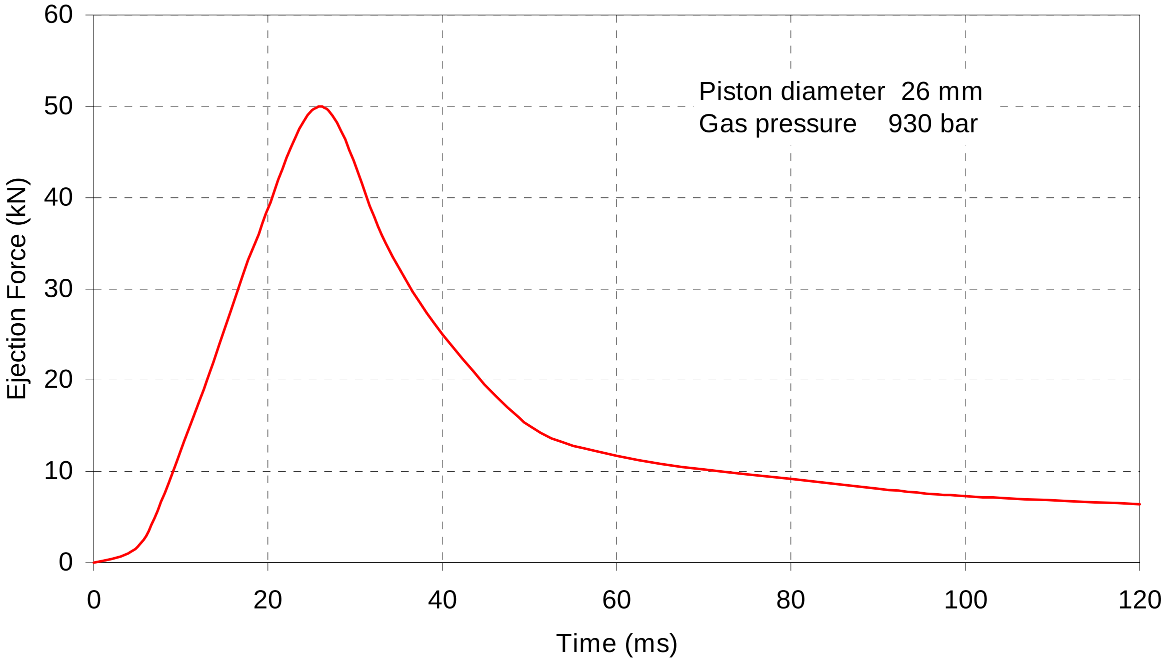


Figure 1: ERU ejection transient

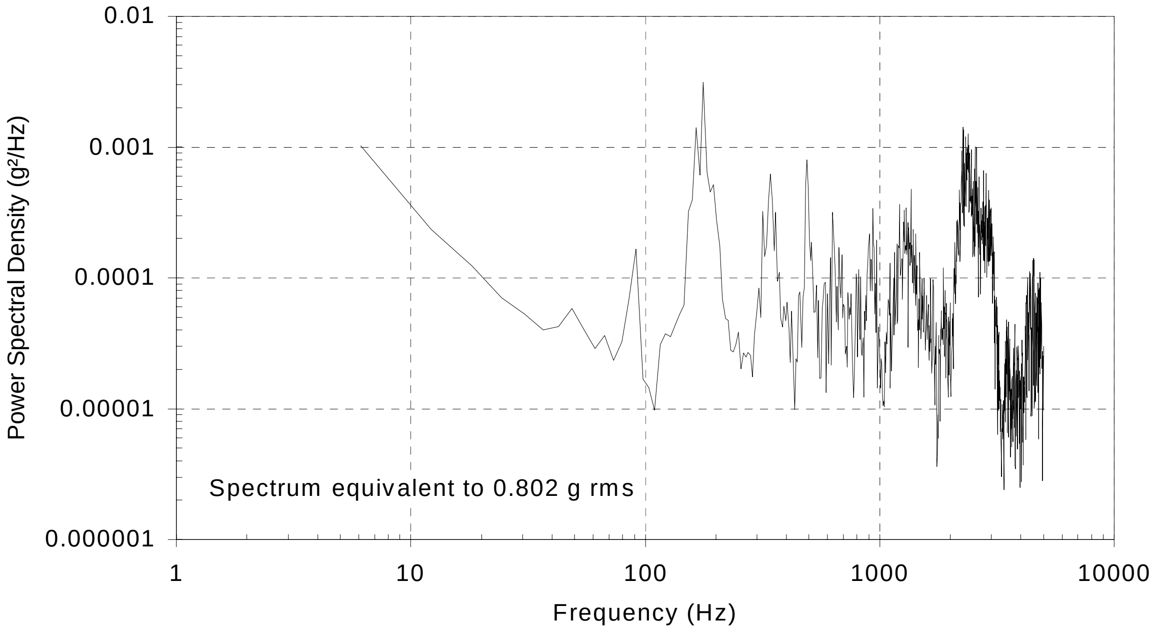


Figure 2: Spectral response of missile equipment installed forward of a solid propellant rocket motor

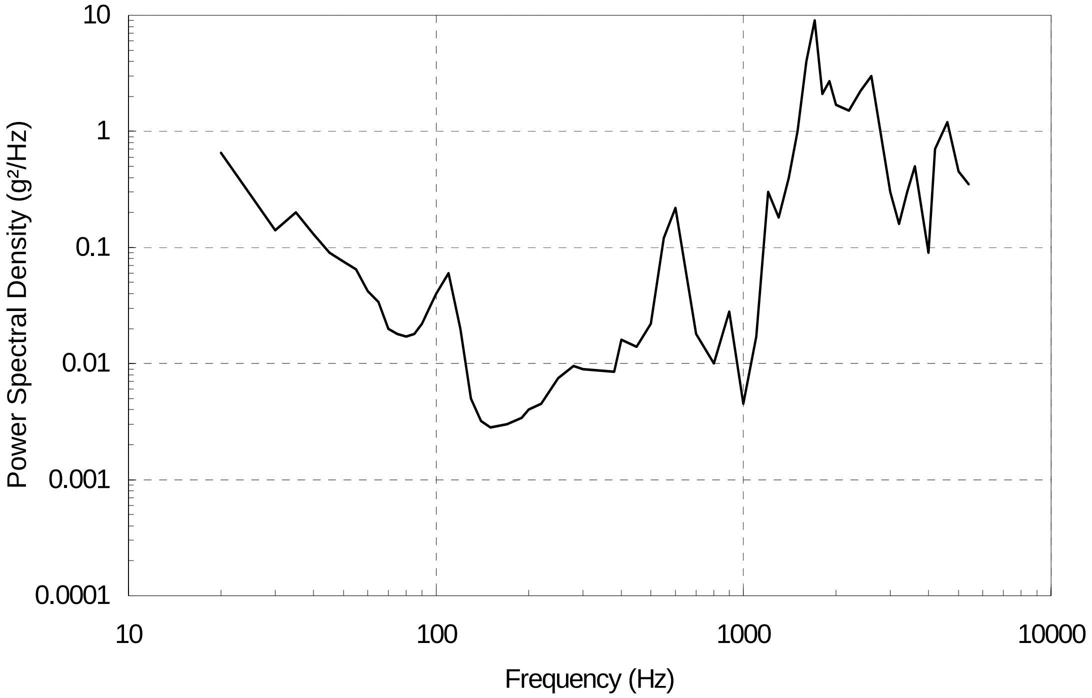


Figure 3: Spectral responses of missile equipment adjacent to a ramjet motor

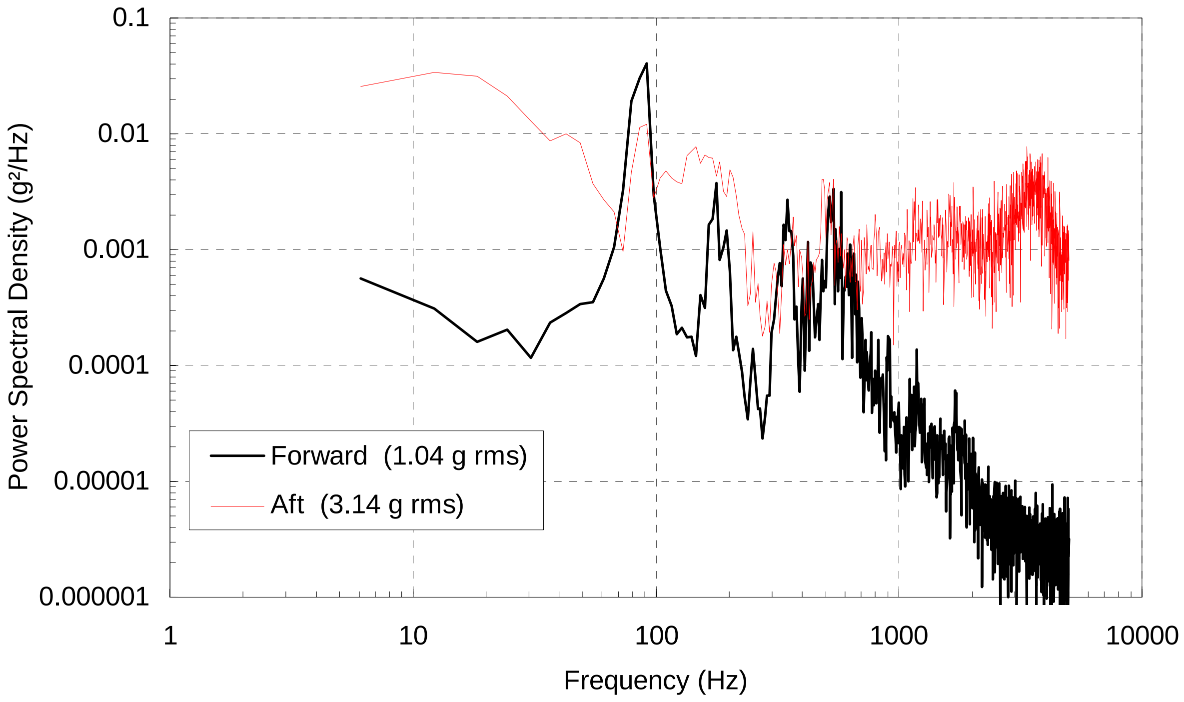


Figure 4: Comparison of spectral responses of missile equipment at forward and aft locations within a solid propellant powered missile

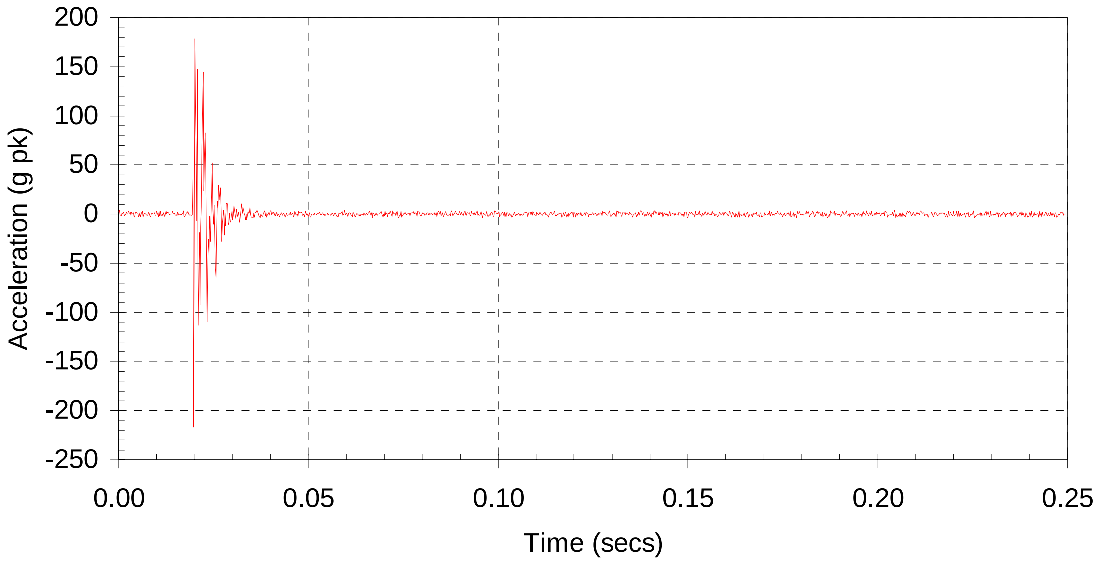


Figure 5: Shock response history from close to the source

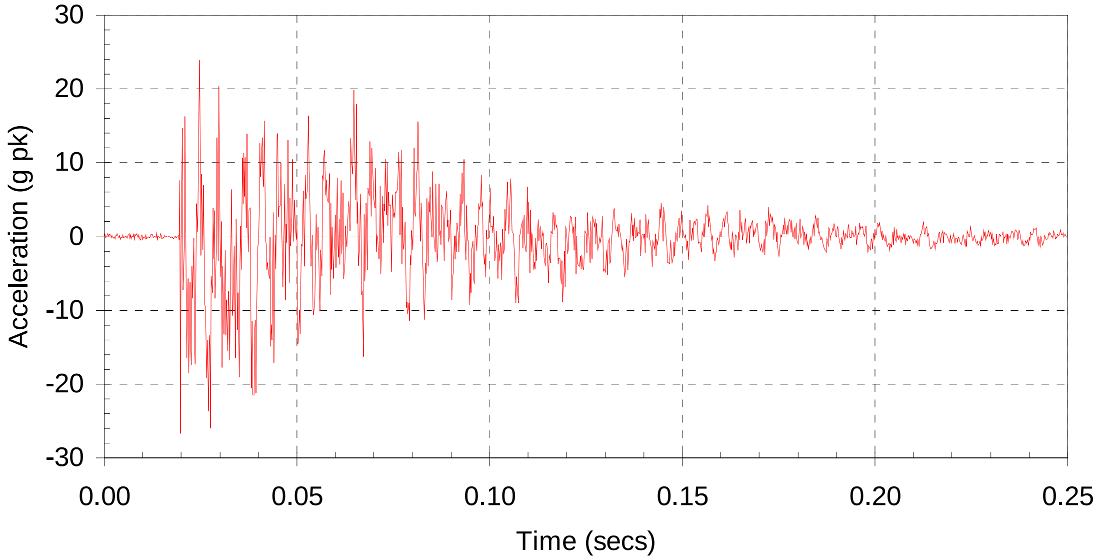
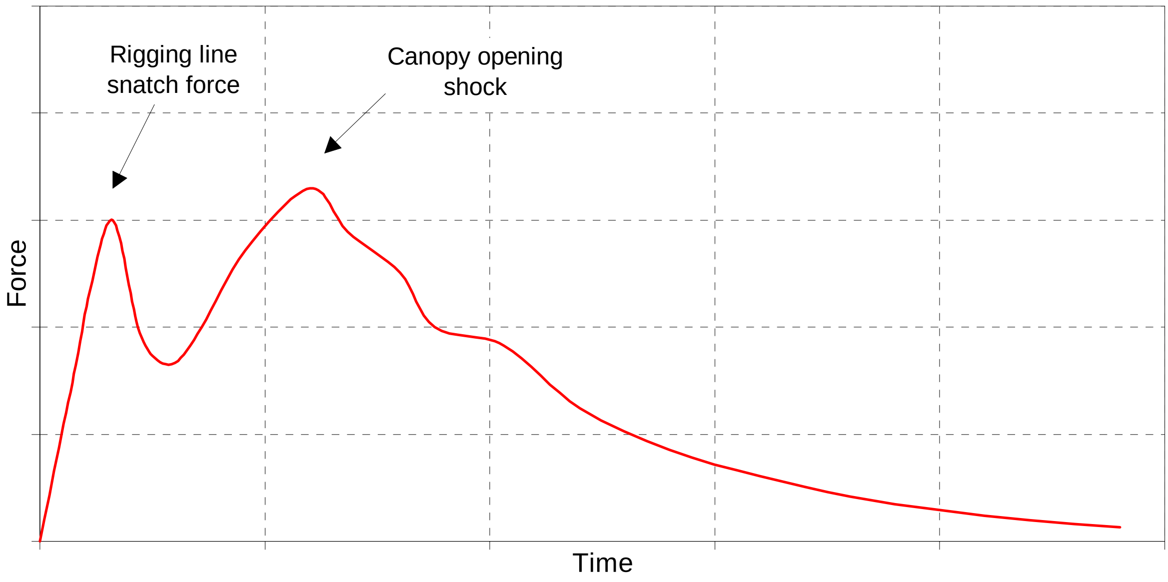
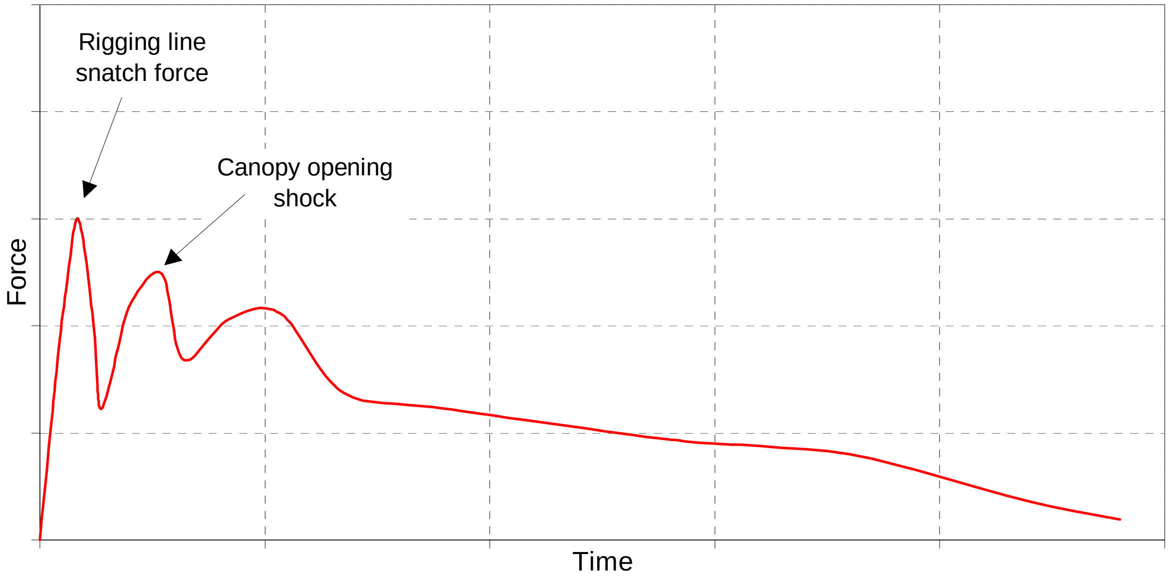


Figure 6: Shock response history distant from the source



a: Large canopy and short lines



b: Small canopy and long lines

Figure 7: Parachute inflation force histories

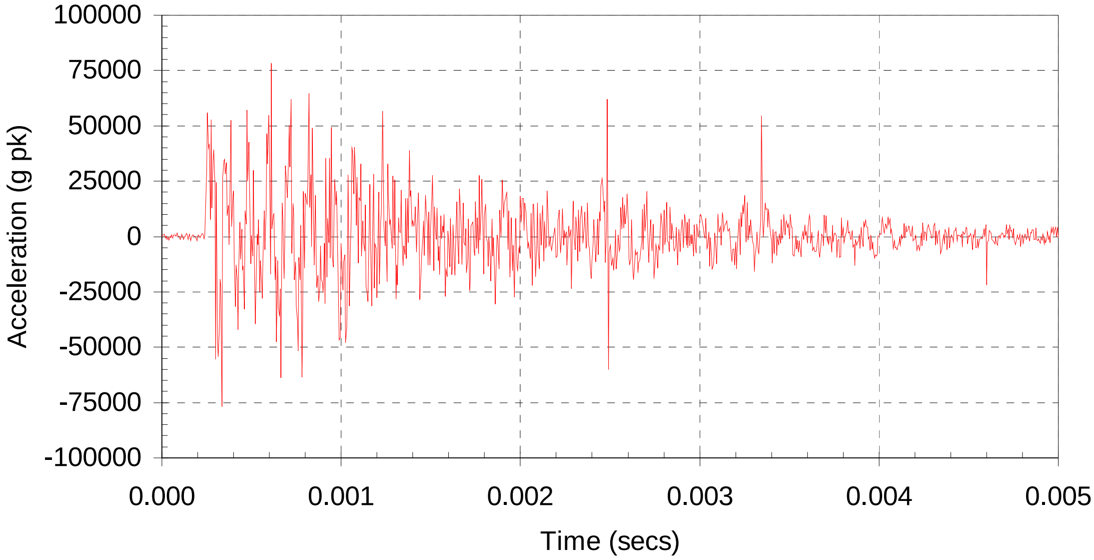


Figure 8: Munition impact and penetration of concrete

ANNEX A
REFERENCES

A.1 EJECTION TRANSIENTS

A.1.1	Title:	Evaluation of the Harpoon shock environment during ejection l aunch by aircraft launchers
	Author:	AG Piersol
	Source:	US NWC China Lake CA
	Ref No:	NWC TP 5881 - ADA 037 067
	Date :	February 1977
	Pages :	41

A.1.2 Mission/Platform

Aircraft launchers

A.1.3 Summary of Technical Data

Environment descriptions of ejection shock transients are presented, in various formats.

Information is also included on the following:

Test configurations and procedures
Parametric assessment of the results
Design principles
Data acquisition and analysis

A.2 PYROTECHNIC SHOCK

A.2.1	Title :	Pyrotechnic shock - A tutorial
	Author:	Document comprises 9 separate papers
	Source:	US The Institute of Environmental Sciences
	Ref No:	IS BN 0-915414-90-2
	Date :	1990
	Pages :	289

A.2.2 Mission/Platform

Various

A.2.3 Summary of Technical Data

Many environment descriptions of pyrotechnic shock sources are presented, mostly in shock spectra formats.

Considerable information is included on the following:

Equipment failure modes
Attenuation techniques
Data acquisition and analysis

A.3 PARACHUTE SHOCK

A.3.1 Document details

Title:	Performance and design criteria for deployable aerodynamic decelerators
Author:	Document is in handbook form
Source:	US AFFDL-RTD-AFSC-WPAFB, Ohio
Ref No:	ASD-TR-61-579
Date :	1963
Pages :	535

A.3.2 Mission/Platform

Various

A.3.3 Summary of Technical Data

Several environment descriptions of parachute deployment and inflation shocks are presented, mostly in load versus time formats.

Considerable information is included on the following:

Operational characteristics
Parachute materials
Design principles
Test simulation
Theoretical analysis

LEAFLET 249/2

UNDERWATER WEAPONS

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LEAFLET 249/2

UNDERWATER WEAPONS

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be encountered by underwater weapons, such as torpedoes and mines, whose targets are predominantly below the surface of the sea, during their separation from the host platform and their autonomous progression to the target. The sources and characteristics of each environment are presented and where appropriate, information is given on potential damaging effects. Advice is given on treatment options and where relevant the selection of the appropriate AECTP 400 Test Methods.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Air Launch - Ejection Transients

2.1.1 Severe transient accelerations are induced in stores such as torpedoes during their release by cartridge powered ejection release units (ERUs). The purpose of ERUs is to ensure the safe release of stores from high performance aircraft. Other devices, such as the various gravity release units used for releasing munitions from helicopters, do not themselves induce significant transient loadings into stores.

2.1.2 Depending upon the particular aircraft/store combination, transients applied to stores by ERUs can attain acceleration levels up to 40 g, while pulse shapes are broadly half sine and durations typically within the range 10 to 40 ms. Ram ejection forces can attain 50 kN. Further details and a reference is given in Leaflet 249/1.

2.1.3 The relatively high amplitudes and long durations of these pulses often produce critical design load cases. Consequently modelling and/or test firings are used to derive project specific, ie: tailored, load-time plots to which equipment is qualified. General purpose fall back levels are not appropriate for ejection transients.

2.2 Air Launch -Release Disturbance

2.2.1 During release of a munition from an aircraft any asymmetric ERU ejection forces will cause significant pitching motions, which will result in substantial aerodynamic pressure and acceleration forces being imparted to the weapon.

2.2.2 Aerodynamic design requirements for weapons should ensure that these release disturbance forces are quickly damped out. Nevertheless, the applied forces experienced by the weapon can attain relatively high amplitudes and long durations, which may result in critical design load cases. therefore modelling and/or wind tunnel testing are used to establish project specific, ie: tailored, loads to which a weapon is qualified. Fall back levels are not appropriate for this condition.

2.3 Tube Launch

2.3.1 Munitions such as torpedoes launched from a submarine are likely to be subjected to the shock arising from compressed gas effects within the launch tube. Typically, acceleration severities along the longitudinal axis can attain peak values of around 25 g with durations around 20 ms. Peak values in the transverse axes can reach 32 g with durations around 15 ms.

2.4 Deck Launch

2.4.1 Munitions launched from the deck of a surface ship may be subjected to shock loadings in the longitudinal axis of up to 60g. The durations of these loadings are typically of the order of 8 ms.

2.5 Other Launch Modes

2.5.1 Other launch modes such as Land Vehicle, Ground/Silo, and Gun Barrel are addressed in Leaflet 249/1, paragraphs 2.3, 2.4, and 2.5 respectively.

2.6 Powered Underwater Motion

2.6.1 During powered underwater motion munitions such as torpedoes will experience vibration induced by water traversing the external surfaces, and also self induced vibration arising from out of balance motors and drive gear. However, tactical considerations dictate that acoustic propagation from such munitions is extremely small, and therefore significant design effort is expounded to minimise all vibration sources. The vibration characteristics are expected to be predominantly sinusoidal, while acceleration amplitudes are likely to be within 1 g and over the frequency range 20 to 500 Hz.

2.7 Underwater Manoeuvres

2.7.1 While manoeuvring after launch a munition such as a torpedo can be subjected to sustained acceleration loads. The severity of such loads is determined by tactical considerations, but in general they are unlikely to exceed 15 g.

2.8 Unpowered Motion

2.8.1 For tactical reasons munitions such as mines or torpedoes may spend extended periods during which they are unpowered and undergo only subsidiary motion arising from previous powered or deployment phases. Any sources of vibration will be shut down to minimise acoustic propagation and detection. Therefore, the mechanical environment can usually be assumed to be limited to that of hydrostatic pressure, which is generally covered by static analysis.

2.9 Separation and Staging

2.9.1 During munition separation and staging events the initiation of pyrotechnic devices, such as explosive bolts and line cutting charges, can result in severe shock loadings, which can take the form of stress waves and/or oscillatory acceleration transients.

2.9.2 Further information and a reference on this subject is contained in Leaflet 249/1, paragraph 2.10.

2.10 Spin

2.10.1 To increase stability some projectiles or submunitions are subjected to spin during release. Spin rates vary considerably depending upon performance requirements. Therefore, it is inappropriate to recommend general purpose test methods or spin rates. Special purpose test facilities, such as using a motorised device to induce spin, may be required to induce high rates.

2.11 Parachute Retardation

2.11.1 Parachute retarded munitions such as mines or torpedoes may be subjected to two significant acceleration transients during parachute deployment. The first transient is a snatch condition that occurs when the uninflated canopy is arrested by the rigging lines at the instant of full deployment. The second transient arises from the rapid increase in deceleration force during the inflation of the canopy.

2.11.2 Further information and a reference on this subject is contained in Leaflet 249/1, paragraph 2.12. However, as underwater munitions are not normally deployed from high performance aircraft, loadings arising from parachute inflation are unlikely to exceed those arising from submarine launch tubes, ie: less than 25 g.

2.12 Water Entry

2.12.1 It is to be expected that response accelerations of torpedoes during water entry are dependant on parameters such as impact velocity, impact angle and nose geometry. As an indicator, at a store nose, peak acceleration levels of around 3000 g have been measured for water impact velocities of 80 m/s. A typical water entry time history and shock spectrum is shown in Figure 1, both of which demonstrate the high frequency acceleration components usually observed from measurements for this condition.

2.13 Submunition Ejection and Impact

2.13.1 These conditions are addressed in Leaflet 249/1, paragraphs 2.14 and 2.15 respectively.

2.14 Novel Approaches

2.14.1 It is not possible in this document to address all the environmental conditions and particularly those that arise from novel approaches. Moreover, it is usually necessary to conduct particular data acquisition programmes and to devise special test facilities for the conditions arising from novel approaches.

3. POTENTIAL DAMAGING EFFECTS

3.1 General

3.1.1 The mechanical environments arising during the progression of a munition to its target may induce a number of potential damaging mechanisms. The most significant of these mechanisms are those that induce large acceleration loadings or relative displacements into equipment.

3.1.2 Only those conditions that could be expected to produce critical loading cases are considered under this heading.

3.3 Air/Tube Deck Launch, Manoeuvres, Parachute Retardation

3.2.1 The severe transient accelerations induced during launch, manoeuvres or parachute retardation often provides munition critical design load cases. Therefore, should these design loads be exceeded it is likely that a primary structural failure of the munition will result.

3.3 Powered Underwater Motion

3.3.1 The vibration environment during powered underwater motion can be a cause of mechanical failures of PEC boards and other small electrical and mechanical devices.

3.4 Separation, Water Energy, Impact

3.4.1 High acceleration, fast rise time shock environments induced by events such as separation, water entry or impact can result in serious structural failures caused by stress wave effects, and can result in electrical component failures due to excessive inertia loadings.

4. TEST SELECTION

4.1 Air Launch - Ejection Transients

4.1.1 These conditions are usually dealt with using quasi-static structural analysis and test methods, because the relatively long duration of the pulse usually ensures that there is no coupling of the pulse with the dynamics of the store structure. However, should it prove necessary to test dynamically for these transients then AECTP 400, Method 403 - Shock is applicable. The shock spectrum test procedure is preferred, but the basic pulse shock procedure may be suitable in many cases, ie where the application of the exact pulse shape is unnecessary.

4.2 Air Launch - Release Disturbance

4.2.1 This condition is usually dealt with using quasi-static analysis and testing methods, as discussed above for ERU ejection transients.

4.3 Tube Launch

4.3.1 The pulse shape associated with tube launch can sometimes be covered by two separate half sine pulse tests having different amplitudes and durations, for example, 25 g for 20 ms plus 10 g f or 200 ms. In these circumstances the related tests should be conducted using the basic shock procedure contained in AECTP 400, Method 403 - Shock. However, in view of the magnitude of these pulses it is preferred that measured values are used as the basis for munition qualification. Moreover, it is possible that the pulse durations may be considered long enough to allow a quasi-static analysis for this condition, which could obviate the need for shock tests.

4.4 Deck Launch

4.4.1 The pulse shape associated with deck launch can sometimes be represented by a half sine pulse test. In these circumstances the related tests should be conducted using the basic shock procedure contained in AECTP 400, Method 403 - Shock. The tests should be conducted in all three major axes. However in view of the magnitude of these pulses, which can reach 60 g, measured values should be used for munitions qualification.

4.5 Powered Underwater Motion

4.5.1 A test to cover this environment is not always warranted. However if it is, then it should be a sine sweep test conducted in accordance with AECTP 400, Method 401 - Vibration.

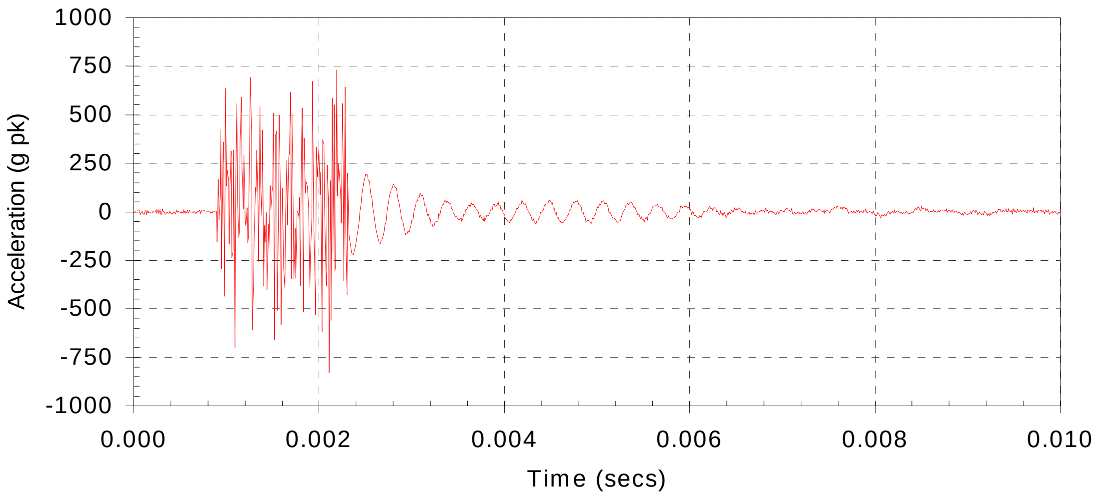
4.6 Underwater Manoeuvres

4.6.1 These conditions are usually covered by static analysis. However, should an acceleration test be warranted then it should be carried out in accordance with AECTP 400, Method 404 - Constant Acceleration. However in view of the possible high magnitude of the accelerations, it is preferred that measured values are used as the basis for munition qualification.

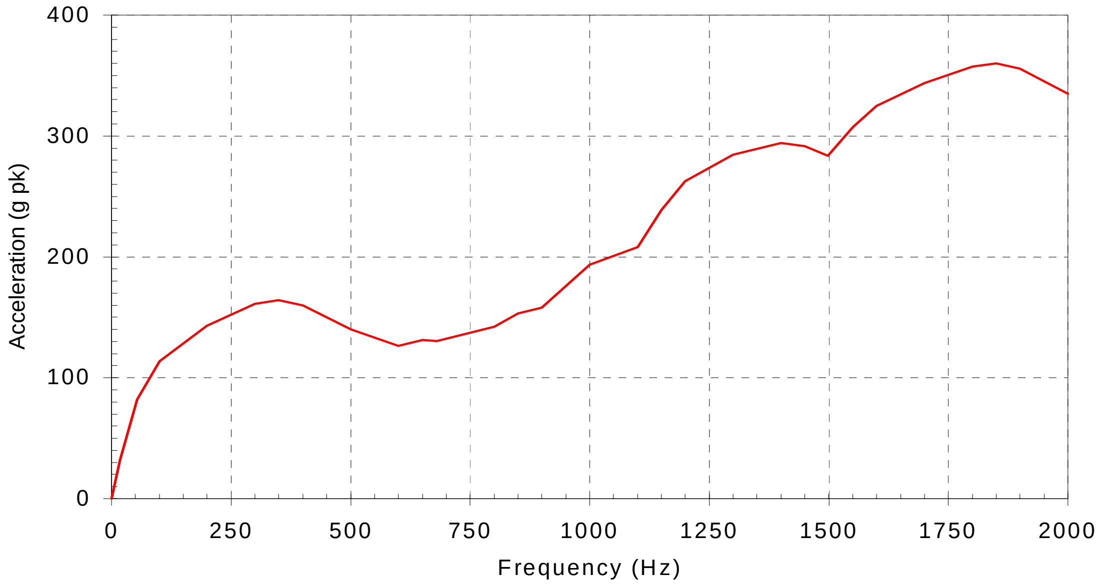
4.7 Water Entry

4.7.1 It is not feasible to quote generalised fall back levels for this event. Nevertheless for initial design purposes, a half sine shock level of 1000 g for 1 ms in all three axes has been adopted in the past for nose section design confidence tests. A value of 250 g has often been adopted for the remainder of the munition. Such tests should be conducted using the basic shock procedure contained in AECTP 400, Method 403 - Shock.

4.7.2 Tests leading to munition qualification should be based on measured values and preferably should be carried out in accordance with the shock spectrum test procedure contained in AECTP 400, Method 403 - Shock.



a: Shock history



b: Shock response spectrum (Q = 10)

<u>Note</u>: The shock response spectrum in (b) has not been derived from the shock history in (a).

Figure 1: Typical water entry shock

LEAFLET 2410/1

THE PROCESS FOR THE VALIDATION OF MECHANICAL ENVIRONMENTAL TEST METHODS AND SEVERITIES

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LEAFLET 2410/1

THE PROCESS FOR THE VALIDATION OF MECHANICAL ENVIRONMENTAL TEST METHODS AND SEVERITIES

1. GENERAL

1.1 The purpose of this leaflet is to provide guidance on the principles that should be used to validate mechanical environmental test methods and severities for their intended application. It is intended to develop this process further for Edition 4.

1.2 The validation process is designed to provide confidence that:

- the environmental characteristics and values, from which the test severities are to be derived, reflect the actual environmental conditions
- all identified potential failure modes are accommodated
- the resulting test severities will not generate an undertest or a significant overtest
- the environmental conditions have been merged wherever possible to minimise the number of tests

1.3 The validation process should be conducted when environmental descriptions comprising characteristics and values are available in project specific documents such as the Life Cycle Environmental Profile (LCEP), sometimes known as the Manufacture to Target and Disposal Sequence (MTDS) coupled with the Environment Requirement document. Consequently, this task is usually undertaken near the beginning of a materiel development programme and should be defined in the Environmental Management Plan. The interaction of the validation process with project specific documentation and environmental design activities is shown in Figure 1. The output of the validation process is the mechanical environmental tests contribution to the (overall) Environmental Test Specification document. Further information on these project specific documents is given in AECTP 100.

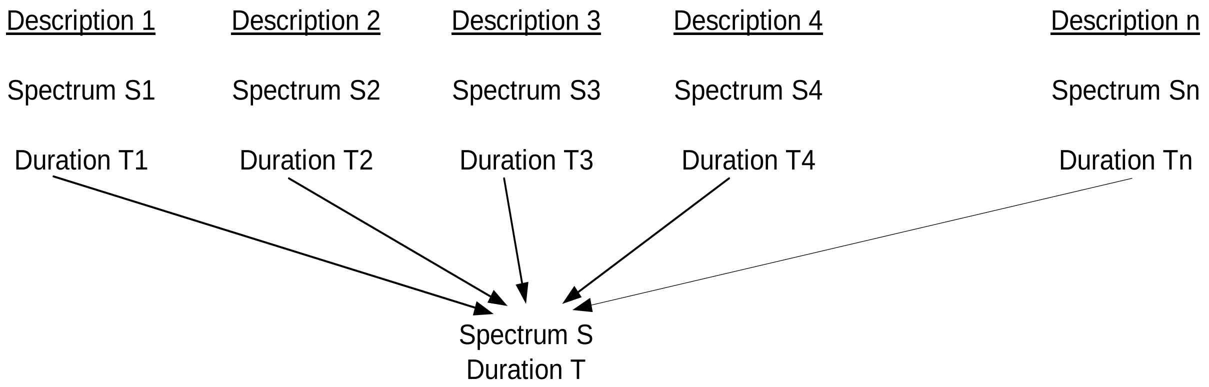
2. STATEMENT OF THE PROBLEM

2.1 The complete life cycle for an item of materiel is defined in the Life Cycle Environment Profile (LCEP). The life cycle will include many different types of induced mechanical environments which may occur while the materiel is being handled, transported, deployed and operated. Although all the induced mechanical environments are not critical in terms of generating potential damaging response amplitudes, they contribute in varying degrees to the materiel’s fatigue damage.

2.2 It is impractical, because of cost and programme constraints, to test for the real life cycle duration of each induced mechanical environment and therefore it is customary to resort to some form of accelerated testing. Unfortunately, the application of accelerated testing for materiel has often involved exceeding the limits for which the principles and data have been validated. Therefore, the objective of this leaflet is to present a process which, when applied, should minimise potential abuses to the principles of accelerated testing through a process that validates materiel maximum responses and fatigue damage.

2.3 In view of the significant costs associated with setting up environmental tests, it is necessary to ensure that compliance with the environmental descriptions in the LCEP is achieved with the minimum of tests. Consequently, there is a need to consider maximising the number of environmental descriptions that can be accommodated within one test. The concept is summarised as a diagram below. However, combining environmental descriptions into a reduced series of tests needs to be undertaken with extreme caution to ensure that the results from the tests provide the necessary evidence for compliance. Guidance on the combination of environmental descriptions into a reduced number of tests is provided in this leaflet.

The concept of incorporating a number of environmental descriptions into one test is illustrated simplistically below for acceleration spectra density formats and associated durations.



3. APPLICATION OF THE PROCESS

3.1 The process is applicable to all materiel, but is particularly applicable to relatively sensitive materiel, eg: electronic equipment and to missile structures.

3.2 It is important to establish that a fully developed LCEP document is available before embarking on the steps of the process detailed in Paragraph 4 - The Validation Process. That is to say, that full descriptions of the environmental characteristics and values are defined for each event. The validity of the descriptions should be checked by comparison with descriptions from earlier data for similar categories of materiel, together with the characteristics and data presented in the relevant leaflets of this AECTP.

3.3 In some cases the character of the data needs to be confirmed through the acquisition of project specific measured data. The initial processing of such data to provide environmental descriptions for specific platforms is presented in several leaflets of this AECTP and consequently is not presented in detail as part of this validation process.

3.4 The vibration process is designed to be applied to project specific measured data. Nevertheless, the process can also be applied to the ‘generic’ initial test levels presented in the annexes of test methods contained in AECTP 400, where these ‘generic’ test levels can be associated directly with the appropriate induced mechanical environmental characteristics stated in the LCEP. Moreover, the process should only be applied to the ‘generic’ test levels when the user is confident that the levels and associated characteristics will excite the relevant potential failure modes for the materiel.

Information on failure modes can be found in STANAG 4570, AECTP 600, Leaflet 604. Further advice on the characteristics of mechanical environments is given in relevant leaflets of this AECTP.

3.5 The process requires close attention to potential failure modes through detailed assessment of the materiel design. The maximum response spectra (MRS) and the fatigue damage spectra (FDS) techniques described in Annex A of this leaflet only address potential failure modes associated with ‘limit’ loads (tensile, shear and bending) and ‘classic’ fatigue failure modes. They do not address, for example, buckling conditions, strain rate effects and fretting fatigue. The advantages and limitations of the MRS and FDS techniques are covered in Annex B of this leaflet.

4. THE VALIDATION PROCESS

4.1 STEP 1

4.1.1 Identify test methods and appropriate procedures from AECTP 400 that appear, provisionally, to accommodate the environmental description for a particular mechanical condition. Environmental descriptions are defined in the Life Cycle Environmental Profile (LCEP) document. The environmental descriptions defined in the LCEP will probably have been derived from data read across from those acquired on previous similar types of materiel, and/or the characteristics and data contained in the relevant leaflet of this AECTP. Ideally, environmental descriptions should be derived from measured data, using a process similar to that detailed in Leaflet 245/1 Annex A for deployment on tracked vehicles, but measured data are only usually available at a later stage in the materiel development programme where they are used primarily to confirm the adequacy of test specifications.

4.2 STEP 2

4.2.1 Identify all the relevant potential failure modes through detailed assessment of the materiel design, e.g.: those resulting from ultimate bending conditions, fatigue, strain rate, etc. Check that the provisionally identified test methods in STEP 1 can realistically excite the failure modes. If they cannot, substitute and/or add other test methods. At this stage any requirements for combined environment testing should also be identified where significant amplitudes of different environmental parameters, such as vibration and temperature, may be expected to act simultaneously. Any potential requirements identified should be assessed and, where confirmed, provisional test methods selected.

4.3 STEP 3

4.3.1 Derive provisional test severities that are compatible with the test methods identified in STEP 1 and could be expected to excite satisfactorily the potential failure modes identified in STEP 2. A typical procedure for deriving test severities from project specific measured data is given in Leaflet 245/1 Annex A. In addition, a process for statistically combining ASD is given in Annex C. Measured data are the preferred choice, but because they are usually unavailable at the early stages of a materiel development programme, the process is designed to accommodate the 'generic' initial test levels contained in the annexes of the test methods in AECTP 400. However, it is for the user to ensure that any selected 'generic' levels both represent the environmental descriptions defined in the LCEP (STEP 1) and excite identified potential failure modes (STEP 2).

4.3.2 Ensure that uncertainty factors are accommodated, whether measured or generic levels are used for testing. The dynamic response characterising an event does not repeat itself identically when the event recurs, or when several measurements of the same event are made. Its variability is characterised by a distribution law, for which the statistical parameters (average and standard deviation) may be determined by on-site measurements. The limiting resistance (or failure stresses) of materiel to this dynamic response also varies randomly between one sample and another. In the absence of any measurements characterising this variability, it is usually possible to estimate the standard deviation (but not the average value) of the corresponding distribution law. Annex D gives additional information concerning uncertainty factors.

4.4 STEP 4

4.4.1 Assess the prospects for combining more than one significant mechanical condition within a single test. This assessment must ensure that any adverse effects of a combination do not undermine the ability of the resulting test to provide the necessary evidence to demonstrate compliance with the relevant environmental descriptions. It must also ensure that the test arising from the combination possesses the ability to exercise satisfactorily the identified potential failure modes. It is important to note that mechanical conditions cannot be combined where a 'change of state' of the materiel occurs. A 'change of state' could arise from a difference in the packaged configuration, in the readiness configuration (particularly where the materiel is structurally supported differently), in its arming or functional state, etc. Moreover, any combination should not unduly prejudice the concept of conducting tests in a sequence that is compatible with the LCEP. Further information on these aspects is given in Annex E.

4.4.2 Two main approaches can be used to combine more than one mechanical condition within a single test.

a. Envelope Method:
Based on comparing directly a parameter that is descriptive of the environment without any reference to the materiel. Hence, this approach is applicable whatever the materiel to be tested.

b. Equivalent Damage Method:
Based on the use of a criterion of equivalence. In this case, it assumed that two environments which have the same damage effect on a particular item of materiel are equivalent. The best known methods use techniques such as maximum response spectra (MRS) and fatigue damage spectra (FDS). These methods require knowledge of the materiel failure process and are applicable where the failure process is linked to classical fatigue. Theoretical aspects of the MRS and FDS techniques are provided in Annex A, while the advantages and limitations are addressed in Annex B.

4.5 STEP 5

4.51 Validate the selected test severities to check that test amplitudes and durations are reasonable with respect to the maximum materiel responses and fatigue damage generated during the test. A test factor may need to be added to reflect the limited number of test specimens and/or the limited number of tests conducted. Further information on the test factor is provided in Annex F. It is advisable to re-visit the relevant data in time history format at this stage to ensure that all their significant characteristics are covered within the test severities. It is also important to check that the potential failure modes not covered by such techniques as the MRS and FDS, e.g.: those arising from brinelling or high strain rates, are also suitably accommodated in terms of realistic test methods and severities.

4.6 STEP 6

4.6.1 Document the results of the activities undertaken as part of the validation process. The series of tests that emanate from the process usually form the mechanical testing section of the (overall) Environmental Test Specification.

4.7 Summary

4.7.1 The validation process is summarised as a flow diagram in Figure 2.

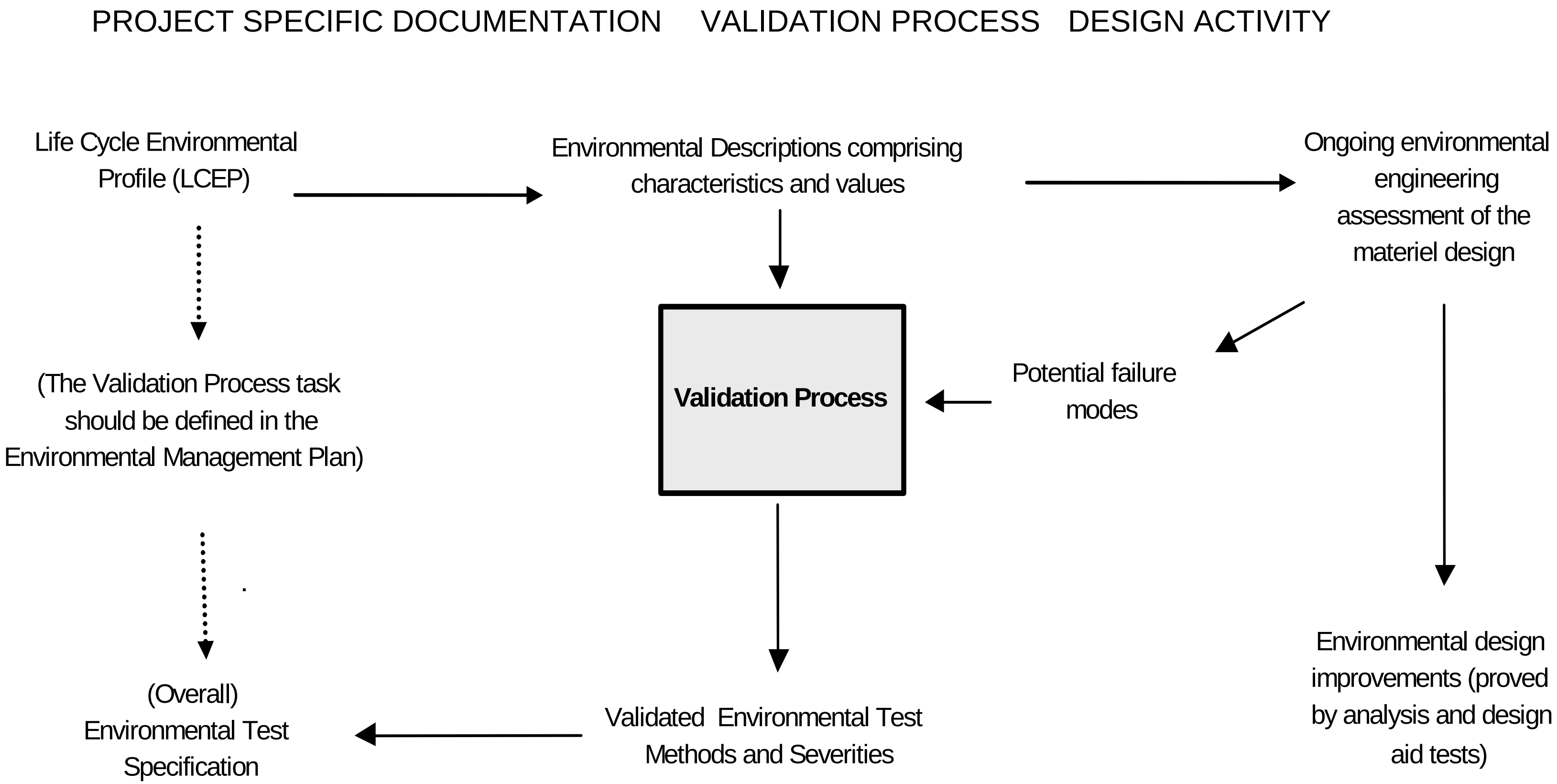


Figure 1: Interaction of the Validation Process with project specific documentation and environmental design activity

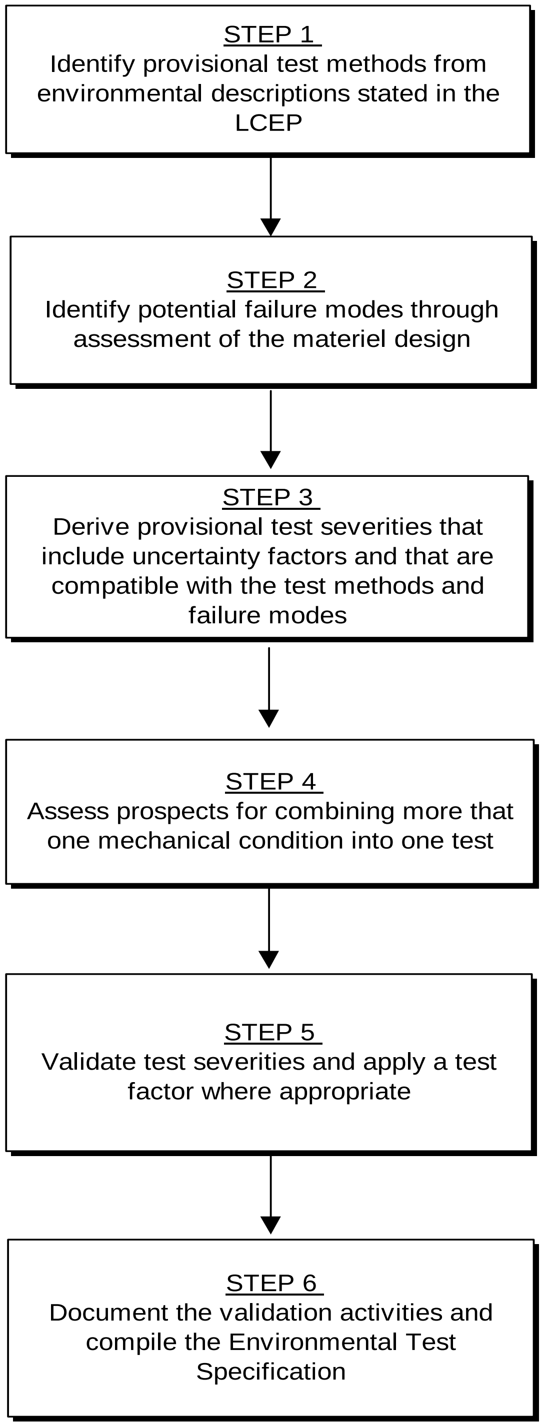


Figure 2: Summary of the Validation Process

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ANNEX A

THEORETICAL ASPECTS OF MAXIMUM RESPONSE AND FATIGUE DAMAGE SPECTRA TECHNIQUES

A1. MAXIMUM RESPONSE SPECTRUM (MRS)

A1.1 When a vibration excitation is applied to a mechanical system with one degree of freedom, the maximum value of the response of this system for a deterministic signal, or the probability of a maximum value for a random signal, can be calculated. This value is called the ‘maximum’ or the ‘extreme’ value. The maximum response spectrum is the curve that represents variations of the ‘maximum’ response value as a function of the natural frequency of the system with one degree of freedom, for a given damping factor ξ.

A1.2 Considering sine excitation:

Given a sinusoidal excitation with the form:

$$\ddot{x}(t) = \ddot{x}_m \sin(2\pi f t)$$

The relative response displacement z(t) of a linear system with one degree of freedom is expressed:

$$z(t) = \frac{-\ddot{x}(t)}{\omega_0^2 \left\{ \left[1 - \left(\frac{f}{f_0} \right)^2 \right]^2 + 4\xi^2 \left(\frac{f}{f_0} \right)^2 \right\}^{\frac{1}{2}}}$$

For given values for f and f_0, z(t) is a maximum when $\ddot{x}(t) = \ddot{x}(m)$:

$$MRS = \omega_0^2 z_m = \frac{-\ddot{x}(m)}{\left\{ \left[1 - \left(\frac{f}{f_0} \right)^2 \right]^2 + 4\xi^2 \left(\frac{f}{f_0} \right)^2 \right\}^{\frac{1}{2}}}$$

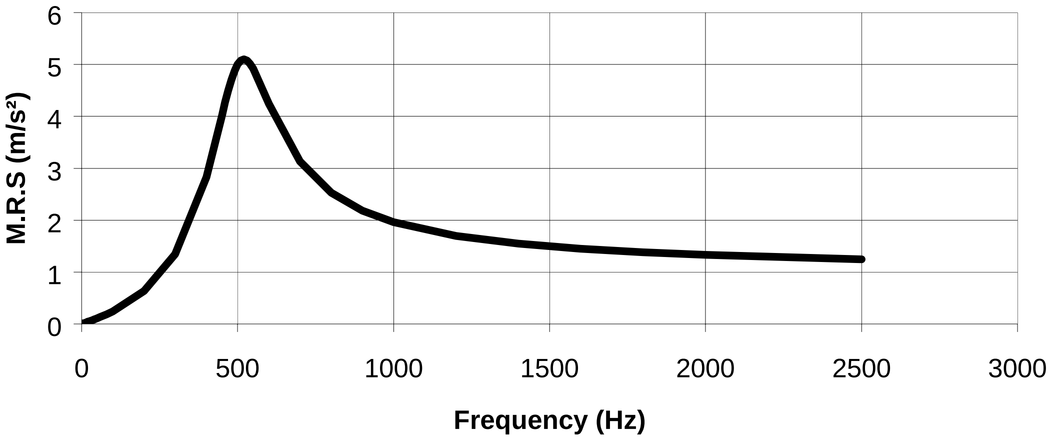
The MRS is the curve representing the variations of $\omega_0^2 z_m$ versus f_0, for given value of ξ. The positive and negative spectra are symmetric. The positive spectrum goes through a maximum when the denominator goes through a minimum, i.e.:

$$MRS = \frac{\ddot{x}_m}{2\xi\sqrt{1-\xi^2}}$$

As an initial approximation, it can be considered that:

$$MRS = Q\,\ddot{x}_m$$

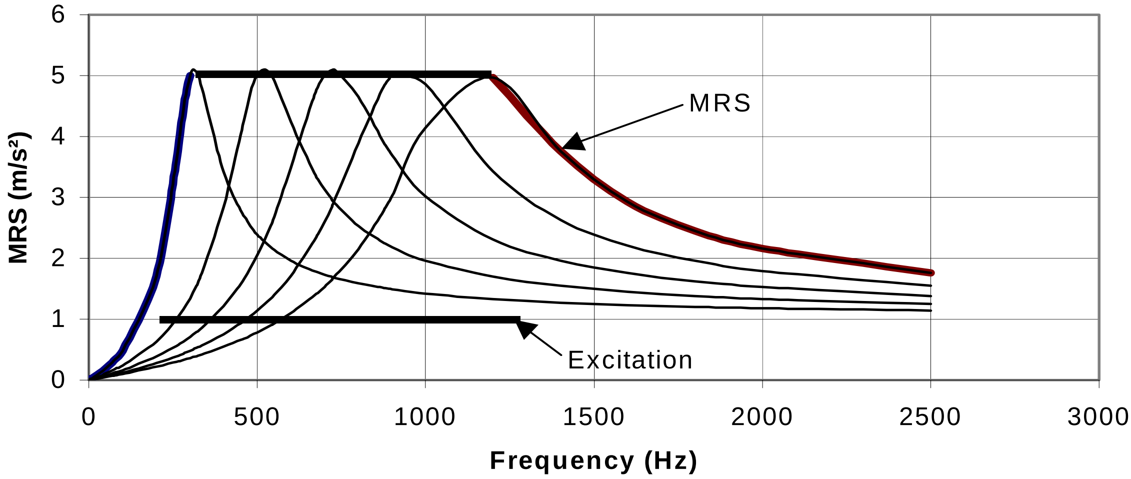
Example: MRS for a fixed sine excitation at 500 Hz with Q=5



1.3 Considering swept sine excitation:

The MRS is extrapolated from the MRS of fixed sines at frequencies corresponding to the limits of the domain of sweeping.

Example: MRS for a swept sine from 300 Hz to 1200 Hz



A1.4 Considering random vibration excitation:

The MRS is calculated by considering the average number of times a threshold of the response z = a is exceeded with a positive slope for a time T. This number is given by the following equation for a Gaussian vibration:

$$N_a^+ = n_a^+ \, T = T \, e^{\frac{a^2}{2\pi_{eff}^2}}$$

Considering a threshold which is exceeded only once on the average, and setting $N_a^+ = 1$

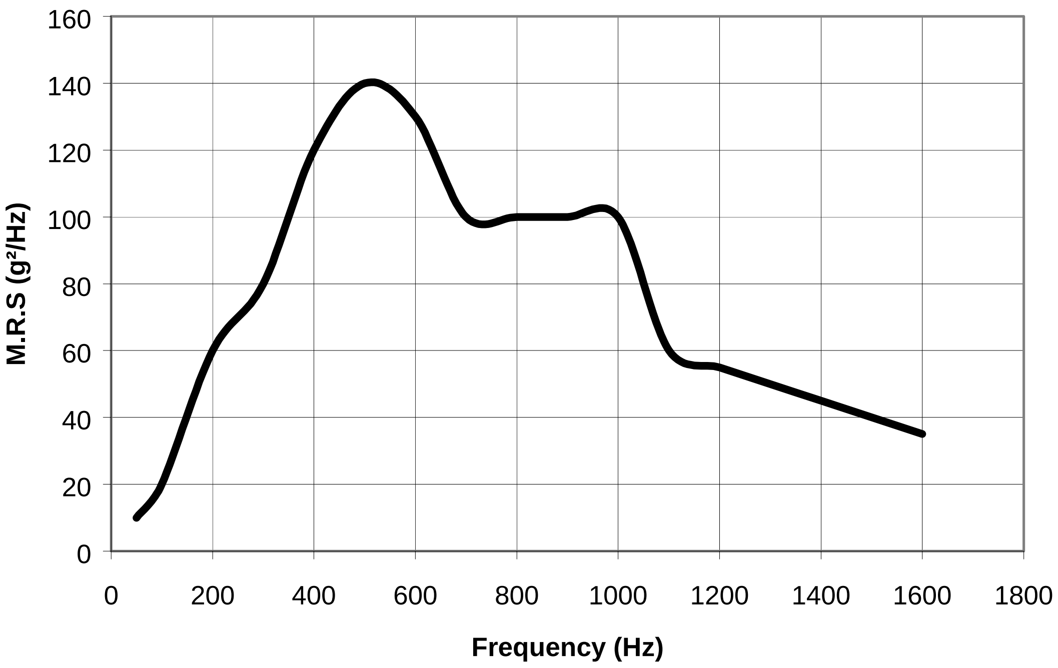
$$a = z_{eff} \sqrt{2 \ln \left(n_0^+ \, T\right)}$$

which provides:

$$R = 4 \, \pi_2 \, f_0^2 \, z_s = 4 \, \pi_2 \, f_0^2 \, z_{eff} \sqrt{2 \ln \left(n_0^+ \, T\right)}$$

Example: MRS for a random vibration defined by

100 – 300 Hz	0.5 g^2/Hz
300 – 600 Hz	1 g^2/Hz
600 – 1200 Hz	0.2 g^2/Hz
Q = 10	



A2. FATIGUE DAMAGE SPECTRUM (FDS)

A2.1 When a vibration excitation is applied to a mechanical system with one degree of freedom, the value 'D' of the fatigue damage for this system for a deterministic signal, as defined by Miner's Law, or the probability of a value D for a random signal, can be calculated. This value is called the 'fatigue' value. The fatigue damage spectrum is the curve that represents variations of D as a function of the natural frequency of the system with one degree of freedom, for a given damping factor ξ.

A2.2 Considering fixed sine excitation:

The amplitude of each half-cycle of the response is equal to

$$|z_m| = \frac{\ddot{x}_m}{\omega_0^2 \left[\left(1 - \frac{f^2}{f_0^2}\right)^2 + \frac{1}{Q^2}\frac{f^2}{f_0^2} \right]^{\frac{b}{2}}}$$

Since n = fT,

$$D = \frac{K^b}{C} f\,T \frac{\ddot{x}_m^b}{\omega_0^{2b} \left[\left(1 - \frac{f^2}{f_0^2}\right)^2 + \frac{1}{Q^2}\frac{f^2}{f_0^2} \right]^{\frac{b}{2}}}$$

If the test is conducted at resonance,

$$f = f_0 \sqrt{1 - \frac{1}{2Q^2}}$$

and finally,

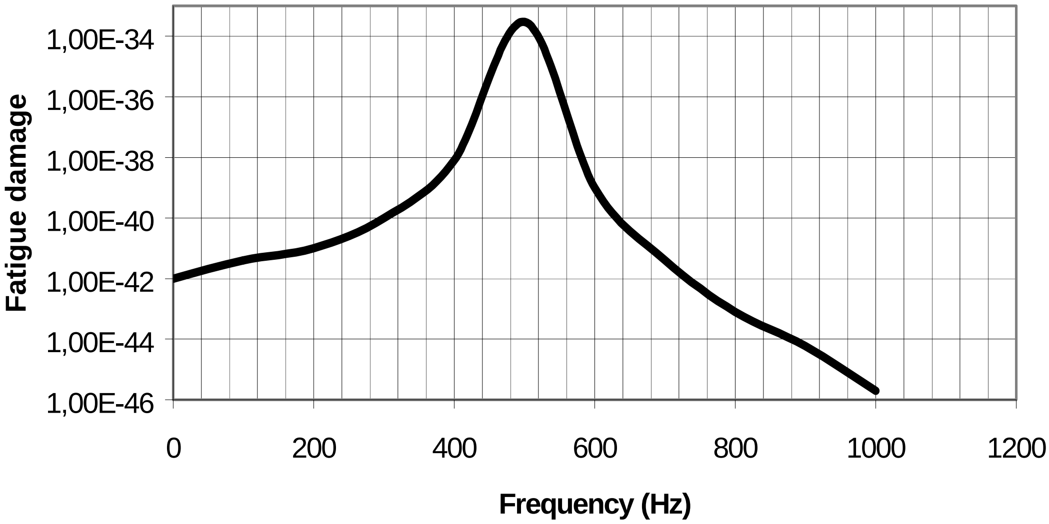
$$D \cong \frac{K^b}{C} f_0\,T \frac{Q^b\,\ddot{x}_m^b}{\omega_0^{2b}}$$

If $f << f_0$, $D \cong \frac{K^b}{C} f\,T \frac{\ddot{x}_m^b}{\omega_0^{2b}}$

Example: FDS for a fixed sine with:

F =500 Hz
$\ddot{x}_m$ =10m/s^2
Q =10
B =8
K =1
C =1

Duration, T = 1 hour



A2.3 Considering swept sine excitation:

If Miner's rule and Basquin's representation $\left(N\ s^b = C\right)$ are used to describe the Whölher curve, the fatigue damage D is expressed

$$D = \sum_i \frac{n_i}{N_i} = \int_0^{t_b} \frac{dn}{N}$$

where

$$N = \frac{C}{s_m^b}$$

(number of cycles to fracture at maximum level s_m)

$$s_m = K\ z_m$$

which provides

$$D = \frac{K^b}{C} \int_0^{t_b} f(t)\ z_m^b\ dt$$

and

$$D = \frac{K^b}{C} \int_0^{t_b} f(t) \left[\frac{\left|\ell_m\right|}{H(f)}\right]^b dt$$

where ℓ_m is the maximum (generalized) excitation and H(f) is the transfer function of the system.

Finally

$$D = \frac{K^b}{C} \int_0^{t_b} f(t) \frac{\left|\ell_m^b\right| dt}{\left\{\left[1-\left(\frac{f}{f_0}\right)^2\right]^2 + \frac{1}{Q^2}\left(\frac{f}{f_0}\right)^2\right\}^{\frac{b}{2}}}$$

For a logarithmic sweep at constant acceleration,

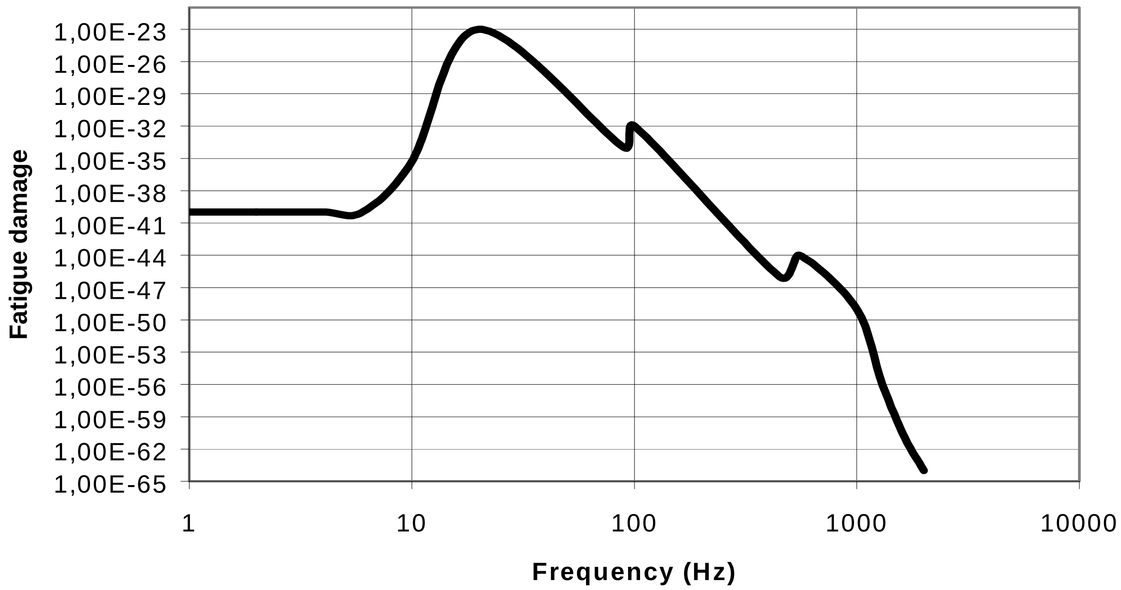
We have

$$\left|\ell_m\right| = \frac{\ddot{x}_m}{4\pi^2 f_0^2}$$

which provides

$$D = \frac{K^b}{C} f_0 \frac{T_1 \ddot{x}_m^b}{\left(4\pi^2 f_0^2\right)^b} \int_{h_1}^{h_2} f(t) \frac{dh}{\left\{\left[1-h^2\right]^2 + \frac{h^2}{Q^2}\right\}^{\frac{b}{2}}}$$

Example of logarithmic sweep with constant acceleration, with:
$\ddot{x}_m = 10\ m s^{-2}$
logarithmic sweep between 10 and 500 Hz
T = 30 min
B = 10
Q = 10
K = 1
C = 1



A2.4 Considering random vibration excitation:

If the distribution of the instantaneous values of excitation $\ddot{x}(t)$ can be assumed to be Gaussian, the distribution of the response as instantaneous stresses is also Gaussian and the distribution of the relative maxima of the response obeys the probability function

$$p(u) = \frac{\sqrt{1-r^2}}{\sqrt{2\pi}}\, e^{\frac{u^2}{2(1-r^2)}} + \frac{u\,r}{2}\, e^{\frac{-u^2}{2}} \left[1 + \mathrm{Erf}\left(\frac{u\,r}{\sqrt{2\left(1-r^2\right)}}\right)\right]$$

During vibration duration T, the average number of peaks of z(t) is $2 n_p^+ T$.

The average number of these peaks with an amplitude between z_p and $z_p + dz_p$ is $p(z_p)dz_p$

This yields

$$n(z_p) = 2\, n_p^+\, T\, p(z_p)\, dz_p$$

The mean damage is therefore

$$FDS = n_p^+\, T \left(\frac{K}{A}\right)^b \int_{-\infty}^{+\infty} z_p^b\, p(z_p)\, dz_p$$

If r = 1, the probability function of the peaks is a Rayleigh function and the mean damage becomes:

$$FDS = \left(\frac{K}{A}\right)^b n_p^+\, T\, \left(\sqrt{2}\, z_{rms}\right)^b\, \Gamma\left(1 + \frac{b}{2}\right)$$

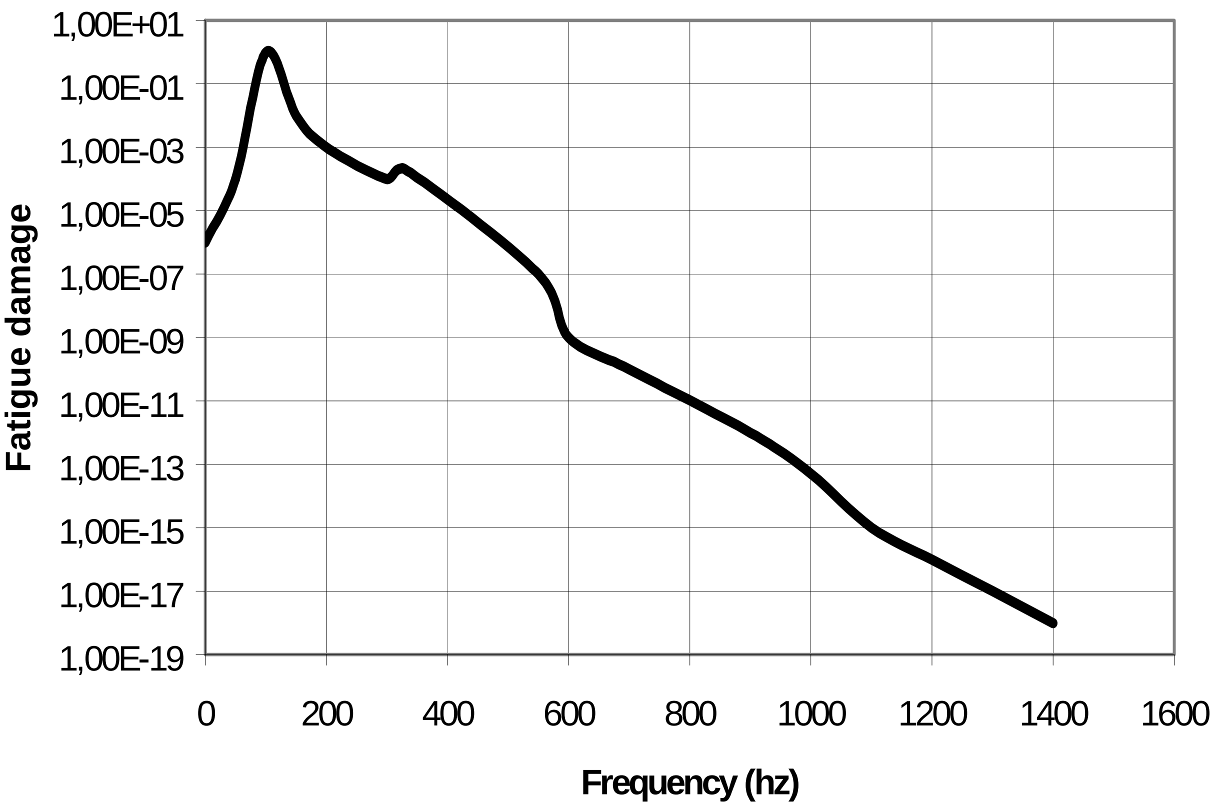
Example of FDS for a random vibration defined by:

Excitation:

100 to 300 Hz	5	$(ms^{-2})^2/Hz$
300 to 600 Hz	10	$(ms^{-2})^2/Hz$
600 to 10000 Hz	2	$(ms^{-2})^2/Hz$

Time = 1 hour

Q =10
B = 8
K = 0.5 10^{12} N/m^3
A = 10^9 N/m^2



Reference Documents

1. GAM-EG13 Annexe générale mécanique Parts 1 to 6
2. Vibrations et Chocs mécaniques. Ch.Lalanne Editions Hermès.
   Tome 4 Dommage par Fatigue
   Tome 5 Elaboration des spécifications

ANNEX B

ADVANTAGES AND LIMITATIONS OF MAXIMUM RESPONSE AND FATIGUE DAMAGE SPECTRA TECHNIQUES

B1. ADVANTAGES:

B1.1. Maximum response spectra (MRS) and fatigue damage spectra (FDS) techniques allow the problem to be handled under the same assumptions as a calculation of a shock spectrum for a transitory event (linear mechanical filter, with one degree of freedom, etc). Analyses of the shocks and vibrations can therefore be performed using the same criteria.

B1.2. These techniques are very simple, making it possible to deal with the classical types of vibratory environment (random vibrations, fixed-frequency sinusoidal vibrations, swept-frequency sinusoidal vibrations, shocks).

B1.3. These techniques take into account the dynamic characteristics (frequency of response, Q-factor) of a (standard) mechanical system.

B1.4. Equivalence between the specification and the real environment is based on mechanical criteria (equality of the maximum stresses and of the fatigue damage generated).

B1.5. There is the possibility of modifying the assumptions of the calculation (Miner's law, in particular, can be replaced by any other better failure model).

B1.6. There is the possibility of reducing the length of time the test takes by using an equivalence of damages.

B1.7. There is the possibility of bringing together into one single test several vibratory environments of arbitrary durations.

B2. LIMITATIONS

B2.1 The analytical assumptions are debatable (proportionality between the stress and the strain, Miner's law, linearly cumulative damages, etc) but could be improved. These drawbacks are especially bothersome for a calculation of life expectancy. However, in this leaflet only two formats are compared, i.e.: the real vibration environment and the test specification.

B2.2 There is a need to make assumptions on the value of the Q factor and on the value of the parameter b for the materiel (see Annex A). Quality factor, Q, is half the inverse of the damping ratio of system at its dominant natural frequency and is often set equal to 10, as in the calculation of shock spectra. The choice of the parameter b, of small importance if the real duration is used, is of great importance if it is required to reduce the duration of the test. This problem is not specific to these techniques, though it does not always arise as clearly as it does here. The problem exists every time one tries to reduce the duration by using a criterion of equality of fatigue damage.

The exponent ‘b’ corresponds to the slope of the fatigue (S/N) curve for the appropriate material. A value of ‘b’ equal to 8 is adequate to describe the behaviour of metallic structures such as steels and aluminium alloys which possess an essentially linear stress-strain relationship. This expression is used with less confidence with non-linear materials and composites. For electronic equipment and non metallic materials, elastomers, composites, plastics, explosives, a value of 'b' equal to 5 is recommended.

Although the expression has been shown to have some merits when applied to materiel, it should be used with caution, if unrepresentative failures are to be avoided. It is inadvisable for test levels to be increased beyond the maximum measured levels that equipment may experience during in-service life, with a statistically based test factor applied. Furthermore, where there is evidence that the materiel is not fully secured to the vehicle Miner's Rule is totally invalid and should not be used. In such cases the Loose Cargo Test (AECTP 400, Method 406) should be considered as an alternative.

B2.3 It is not advisable to combine mechanical environments that are too different in the time or frequency domain (high-level short duration and low-level, long duration).

B2.4 The durations should not be decreased by too large a factor. A general rule is that stresses should not be multiplied by a factor greater than 2 (ratio of the ultimate stress to the endurance limit stress). Unrealistic failure modes may be the result of excessive reduction of time, for several reasons:

(a) Generation of extreme stresses greater than the ultimate stress that would never be attained with the in-service levels.

(b) Generation of shocks in the assemblies which have some free motion, that would not occur in-service or would be of smaller magnitude.

(c) The damage equivalence is obtained by an assumption of linearity of the structure, which may not be confirmed in practice. The resulting error on the exaggeration factor E (E is the ratio of the reduced-duration test level to the in-service level) is greater because the stress level is increased by a higher amount and the duration is consequently reduced by a lower amount.

(d) The two criteria, maximum response and fatigue damage, must always be considered simultaneously.

(e) The choice of parameter b has an influence on the value of the exaggeration factor E. A small error on the choice of b leads to a higher error on E because the time-reduction factor used is greater.

Reference Documents

1. GAM-EG13 Annexe générale mécanique Parts 1 to 6
2. Vibrations et Chocs mécaniques. Ch.Lalanne Editions Hermès.
   Tome 5 Elaboration des spécifications

ANNEX C

STATISTICALLY BASED COMBINATION OF SPECTRA

C1 Vibration time history data are recorded for a series of test conditions known as "runs". A run is defined (for ground vehicles) as operation over a specific uniform terrain, for a specific test item configuration (load, tyre pressure, etc.) at a constant speed. A common form of analysis involves converting the complete time history (of a particular channel) into the compressed frequency domain format of the Acceleration Spectral Density function (ASD) by dividing the time history into equal length data blocks and computing the ASD for each of the data blocks independently. When combining spectra, it is assumed that the spectra being combined represent a homogeneous set. (i.e., overall spectral levels are comparable and the spectra have the same general shape). If this is not the case, combining spectra should be avoided and another "spectra category" should be added to represent the test condition. When computing estimates of these ASD functions, it is desirable to compute the linear average (assuming the number of samples is sufficiently large (N>30), the standard deviation and the peak, all as a function of frequency, over the length of a test run. The standard deviation represents the variation in the spectral data, as a function of frequency, at a given location on the vehicle due to randomness of the test process. Although the data are stationary, excursions about the mean occur in both the time and frequency domains. The average, average plus one standard deviation and peak spectra can be saved for each channel for each data run processed. This process can be shown mathematically as:

$$G_m(f) = 1/N \{\sum_{i=1}^{N} [G_i(f)]\} \qquad \text{equation 1}$$

where:

$G_m(f)$ = average acceleration spectral density value as a function of frequency
$G_i(f)$ = instantaneous acceleration spectral density value
N = number of records (number of time history data blocks, usually > 30) per data run

Statistical confidence bands can be placed around this mean estimate by:

$$nG_m(f)/([\text{chi sq}]_{n,alpha/2}) \leq G_m(f) \geq nG_m(f)/([\text{chi sq}]_{n,\ 1-alpha/2}) \qquad \text{equation 1a}$$

where:

chi sq $_{n,\ alpha/2}$ = value of the chi-square distribution for n degrees of freedom with a 1-alpha confidence coefficient

n = 2BT and is the number of degrees of freedom
B = frequency analysis bandwidth
T = total time of the record

$$G_d(f) = [1/(N-1) \{\sum_{i=1}^{N} [G_i(f) - G_m(f)]^2\}]^{1/2} \qquad \text{equation 2}$$

where:

$G_d(f)$ = standard deviation of acceleration spectral density values as a function of frequency

$$G_s(f) = G_m(f) + G_d(f) \qquad \text{equation 3}$$

where:

$G_s(f)$ = average plus one standard deviation acceleration spectral density value

$$G_p(f) = \underset{i=1}{\overset{N}{\text{MAX}}}\, [G_i(f)] \qquad \text{equation 4}$$

where:

$G_p(f)$ = peak acceleration spectral density value

Note that, statistically speaking, the normalised error for this spectrum could be very high because of the limited number of degrees of freedom available from the peak values of $G_i(f)$. This spectrum is a maximax autospectral density estimate and should be used with caution.

B2 The data from many locations and many test runs can be combined (by axis) using different techniques to produce representative composite spectra. The first technique is a simple linear average of all average spectra (all channels, all runs) to produce an overall average spectra. If the mean and the median of the distribution are the same, this represents approximately the 50th percentile of the spectral data. A second technique is a "standard" conservative schedule development process in which the average plus one standard deviation spectra from each channel and each run (from equation 3) are combined by using the average of these spectra with the addition of one standard deviation. The standard deviation computed during this process represents the spectral variance due to location and test course differences, and is not the same as that computed by equation 2. Mathematically this is shown as:

$$G_a(f) = 1/N \{\underset{i=1}{\overset{M}{\text{SUM}}}\, [G_s(f)]\} \qquad \text{equation 5}$$

where:

$G_a(f)$ = average acceleration spectral density value as a function of frequency
$G_s(f)$ = average plus standard deviation acceleration spectral density values (from equation 3)
M = number of records (data runs and locations)

$$G_e(f) = [1/(N-1) \{\underset{i=1}{\overset{M}{\text{SUM}}}\, [G_s(f) - G_a(f)]^2\}]^{1/2} \qquad \text{equation 6}$$

where:

$G_e(f)$ = standard deviation of acceleration spectral density values due to variations in test courses and instrumentation locations as a function of frequency

$$G_f(f) = G_a(f) + G_e(f) \qquad \text{equation 7}$$

where:

$G_f(f)$ = average plus one standard deviation acceleration spectral density value (final schedule levels based on "standard" technique)

B3. The technique, shown by equation 4 for individual spectra, but used for composite spectra by allowing the $G_i(f)$ (equation 4) to be represented by the previously computed $G_p(f)$, produces a spectrum which represents the 100th percentile of the spectral data and results from enveloping all of the individual (channel and run) peak spectra.

B4 It is often desirable for a vibration schedule to be a conservative estimate of the in-service environment within some credible bounds. Merely enveloping the peak spectra provides conservatism but results in an overtest since the test rms level is generally much greater than the highest individual rms level measured. Using the "standard" technique applies some conservatism but usually yields realistic rms values; however, it can produce a final spectrum which is not sufficiently conservative if the value of M (equation 6) is large. To ensure that the final spectral estimate is at least as large as the in-service measured data, this spectrum can be adjusted (amplified or attenuated) so that its rms value is the same as the largest rms value measured at any location during any data run provided the corresponding spectra are similar in shape.

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ANNEX D

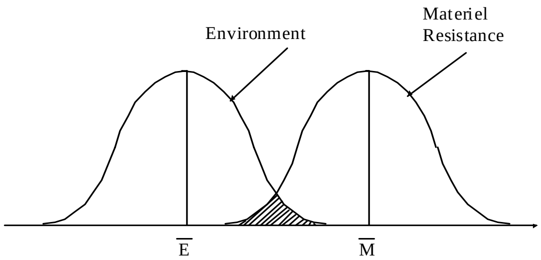
UNCERTAINTY FACTOR

D1 This annex provides an outline for situations where probabilistic analyses need to consider the statistical variations in both the effects of environmental conditions and materiel design and/or manufacturing tolerances. Probabilistic analyses in this context are used to evaluate the risk of failure for probabilistic environmental stresses applied to materiel and the resulting probabilistic response (resistance) of materiel to these stresses

D2 The dynamic response characterising an event is not identically repeatable when the event recurs, or when several measurements of the same event are made. Its variability is characterised by a distribution law, for which the statistical parameters (average and standard deviation) may be determined by on-site measurements.

D3 The limiting resistance (or failure stresses) of materiel to this dynamic response also varies randomly between one sample and another. In the absence of any measurements characterising this variability, it is usually possible to estimate the standard deviation (but not the average value) of the corresponding distribution law.

D4 The existence of these two distributions that characterise the environment and the resistance of the materiel to the environment respectively lead to the existence of a risk of failure for which an indicator may be given by the intersection area of two graphs of probability density functions. The exact value of the risk of failure can be calculated mathematically from the respective probability density functions. A graphic representation is represented by an area within the cross hatched region.



Since the average value of the materiel resistance, $\overline{M}$, is not known, the value of a scalar must be determined. This scalar multiplied by the value representing the environment considered for the current situation, gives the required average value of the materiel resistance that will result in a pre selected failure rate. This scalar is called the uncertainty factor.

Case 1: The specified input value is derived from a single measurement

The environment amplitude value is assigned a fixed uncertainty factor k_1. k_1 will be assumed to be at least 1.2 for all data expressed as a function of time, and 1.4 for all data characterised in ASD.

Case 2: The specified input value is derived from at least two measurements (n > 2)

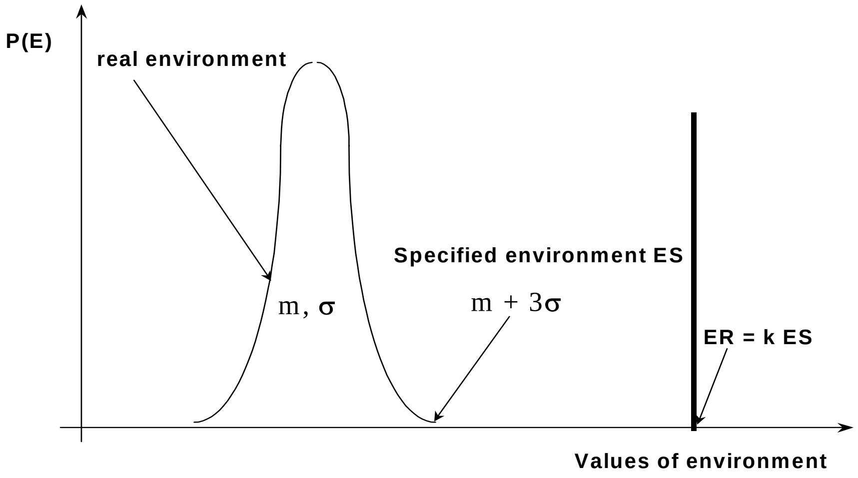
There are two possible approaches.

2.a) The specified value was obtained from the envelope of the measurements;

A fixed uncertainty factor will be applied for which the value will be between 1 (if n is high) and k_1 (if n is equal to 2).

2.b) The specified environment value defines the average value of the environment and the standard deviation.

The uncertainty factor is then determined to set the average strength of the equipment above 3 sigma, for example, more than the value of the real environment used.



Further information can be found in STANAG 4570, AECTP 600, Leaflet 606.

Reference Documents

1. GAM-EG13 Annexe générale mécanique Part 8
2. Vibrations et Chocs mécaniques. Ch.Lalanne Editions Hermès.
Tome 5 Elaboration des spécifications

ANNEX E

THE COMBINATION OF SEVERAL MECHANICAL ENVIRONMENTS INTO A SINGLE TEST

E1. STRUCTURE OF THE APPROACH

Firstly, note that a life profile situation is defined by:

- a platform
- a location in the platform
- a geographic location

Consider the example of a situation: ‘equipment in the nose tip of a fighter aircraft while taxiing before take-off in the United Kingdom’.

A situation is represented by a time signal in which several classes of signals can exist.

For example, the recorded accelerometer signal corresponding to the previously mentioned situation may contain different types of signals (gaussian, pure periodic, stationary or non stationary, deterministic or random, etc.). The part of the situation corresponding to a given class of signal is called an event.

Furthermore, each situation may be represented by one or several measurements. Therefore, starting from these various measurements, it is necessary to make a statistical characterisation of the data in order to determine the estimated average value and its limits for a given confidence level. This characterisation can determine the uncertainty factor to be applied (see paragraph. 7).

- a life profile phase contains several situations, for example the logistic transport phase which can include land transport, sea transport situations, etc.

The approach for obtaining a test severity representative of several situations consists of the following operations:

- Determination of environment values associated with a given event or situation;
- Grouping of events by situations;
- Grouping of situations by phases.

E2. Representation of values

In the case of random or sinusoidal vibrations:

- the maximum response spectrum (MRS) environment value expresses the mechanical stress,

- the fatigue damage spectrum (FDS) environment value expresses the mechanical fatigue damage

In the case of mechanical shocks:

- the shock response spectrum (SRS) environment value expresses the mechanical stress,

- the fatigue damage spectrum (FDS) environment value expresses the mechanical fatigue damage,

- the time signal itself expresses the damage directly sensitive to the time amplitude (unusual case).

E3. Grouping of events by situations

A first group is made between events of a situation as a function of the following elements:

- similar configurations of the equipment,

- similar functions and performances to be provided by the equipment,

- nature of approximately identical environments:
  - stationary phases (ASD),
  - periodic phases (sine),
  - transient phases (shocks).

The selected environment is then calculated in each group

- For stationary phases, take:
  - the arithmetic sum of fatigues representative of each event,
  - the envelope of MRSs.

- For periodic phases, take:
  - the arithmetic sum of fatigues representative of each event,
  - the envelope of MRSs.

- For transient phases, take:
  - the envelope of SRSs, if transients are independent,
  - if successive transients are not independent, the SRS must be calculated on

the entire time signal.

Note: - For transients, the respective durations of the transients will be kept so that this duration is taken into account during the test.

- In some special cases, the time signal may be kept entirely, so that it can be restored directly on the test facility.

E4. Grouping of situations by phases

Respect of phases

In general, the generation of severities will respect the main phases of the equipment life profile, for example for a missile.

- Logistics transport or
- Tactical carrier or
- Firing and ejection or
- Free flight

E5. Calculation of test severities

Case 1: situations in series

Produce:
- the envelope of SRSs,
- the envelope of MRSs,
- the envelope of static accelerations,
- the sum of FDSs.

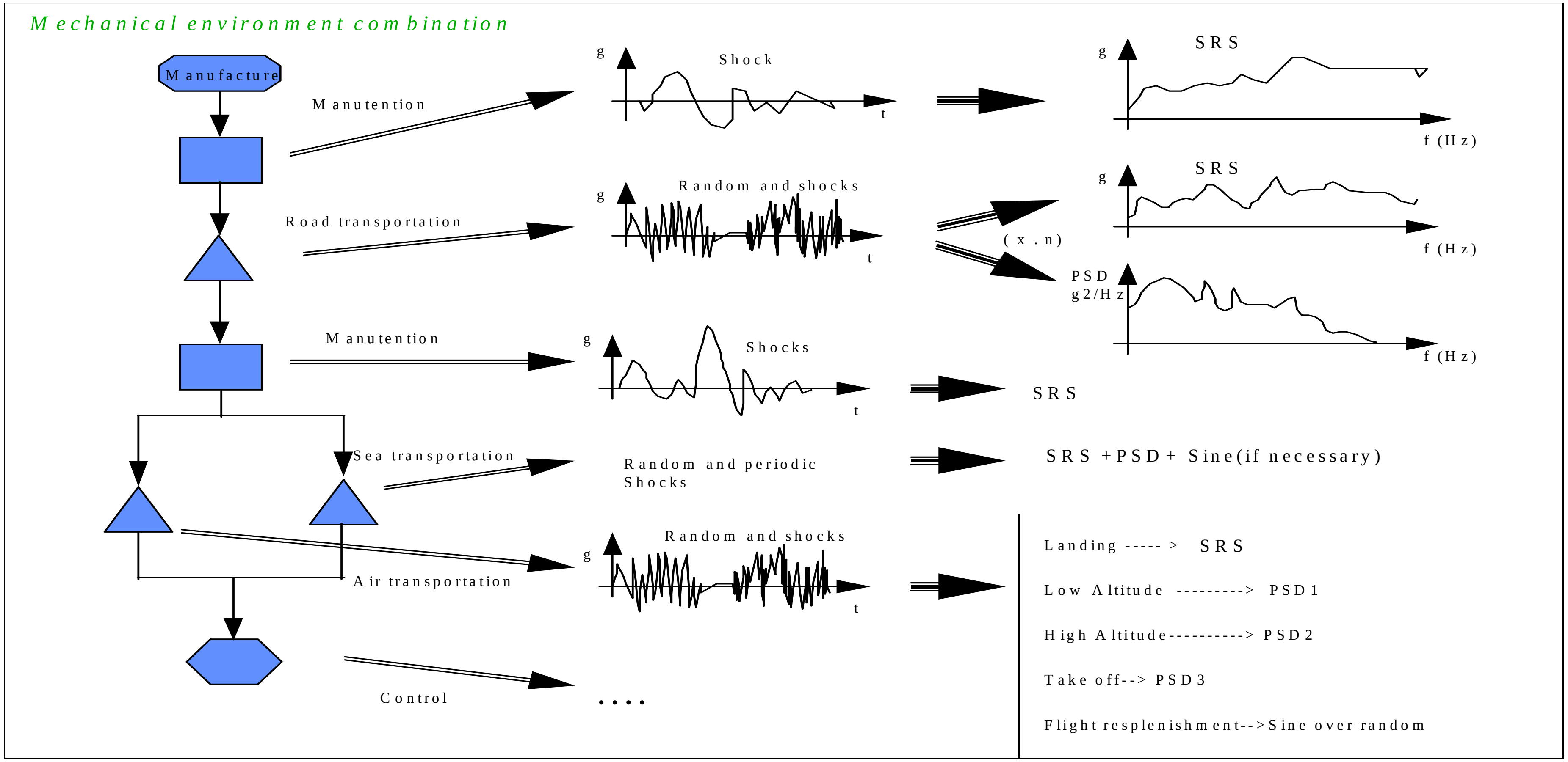
Case 2: situations in parallel at the same life profile level

Produce:
- the envelope of SRSs,
- the envelope of MRSs,
- the envelope of static accelerations,
- the envelope of FDSs.

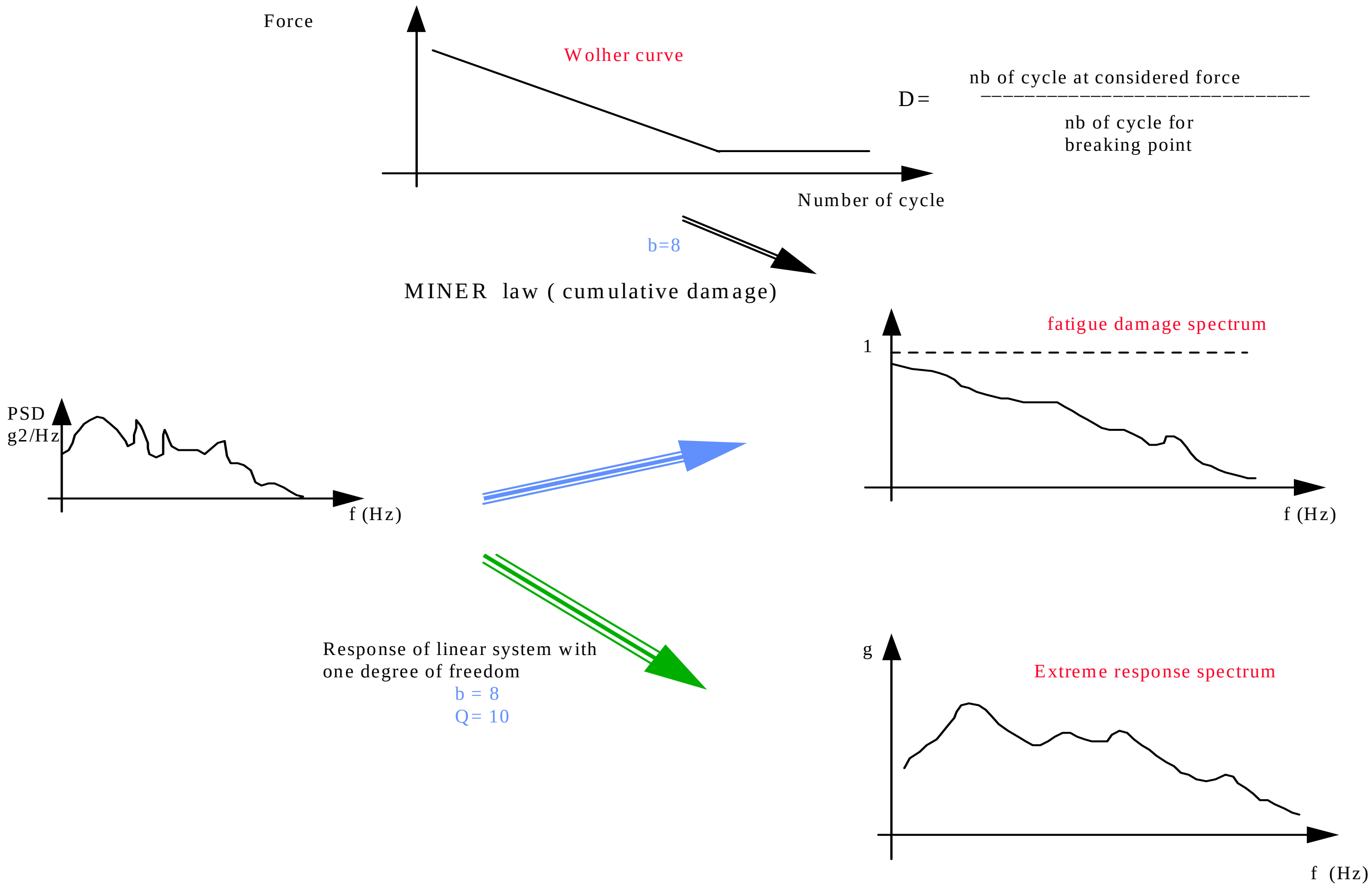
The situations considered will be replaced by a situation characterised by the results (SRS, FDS, ERS and static acceleration) described above.

Reference Documents

1. RE-Aéro 612.10 à 18 Bureau de Normalisation de l'Aéronautique et de l'Espace.
2. Vibrations et Chocs mécaniques. Ch.Lalanne Editions Hermès.
Tome 5 Elaboration des spécifications


Mechanical environment combination
Manufacture
Manutention
Road transportation
Manutention
Sea transportation
Air transportation
Control
g
Shock
t
Random and shocks
Shocks
Random and periodic Shocks
....
SRS
f (Hz)
(x . n)
PSD g2/Hz
SRS +PSD+ Sine(if necessary)
Landing -----> SRS
Low Altitude ---------> PSD1
High Altitude----------> PSD2
Take off--> PSD3
Flight resplenishment-->Sine over random

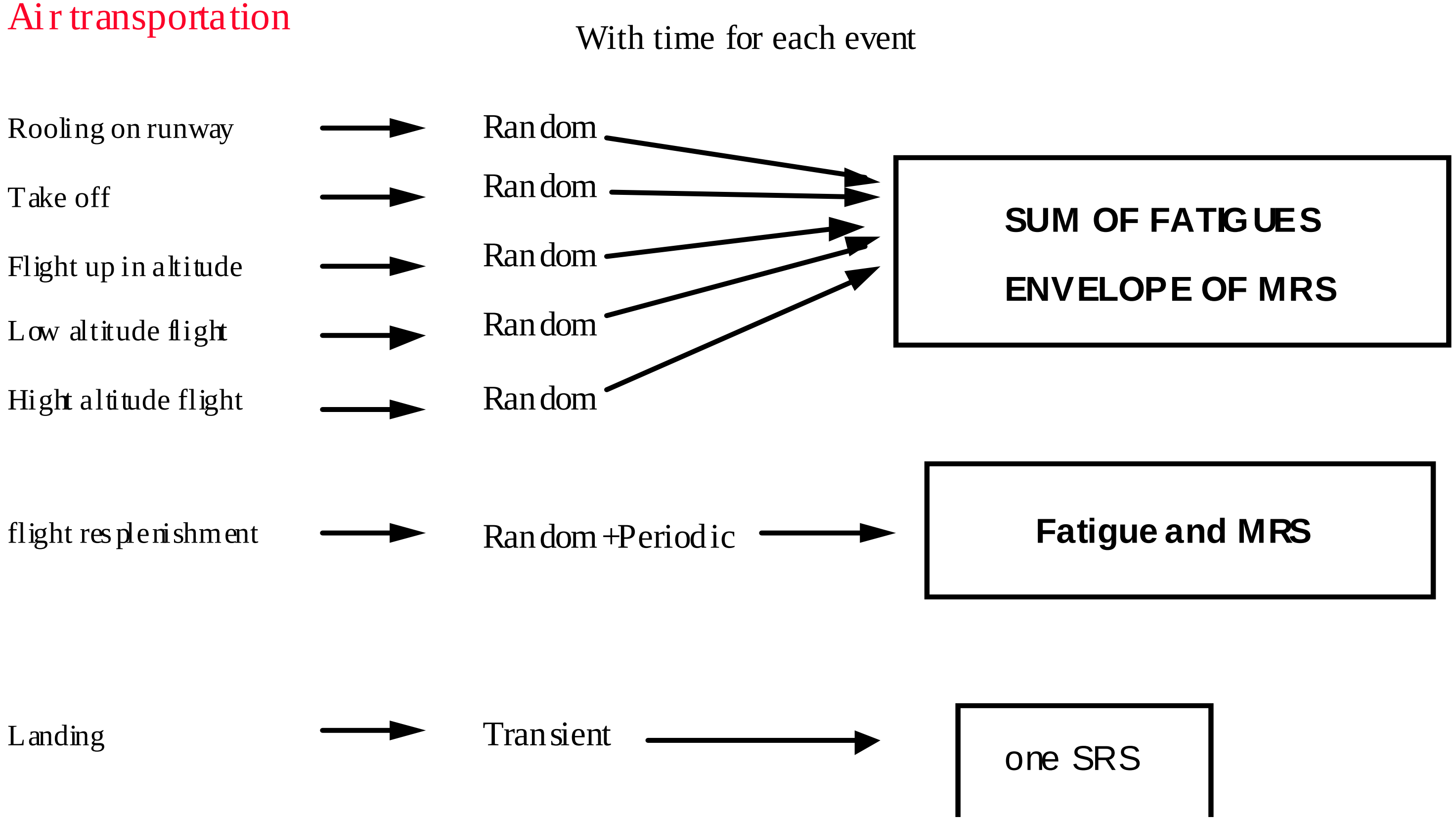
Mechanical environment combination



Mechanical environment combination

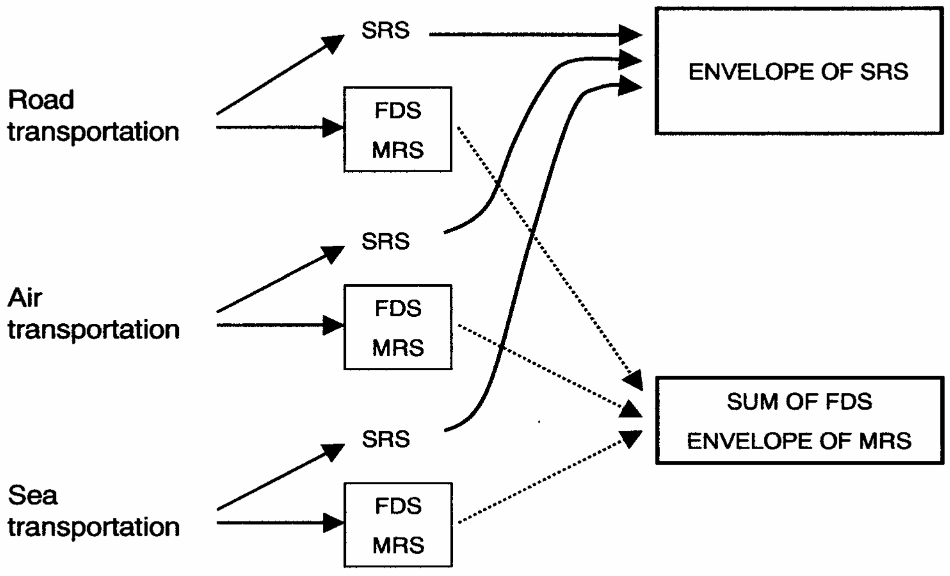
CALCULATION FOR SAME EVENTS BY SITUATION

Air transportation

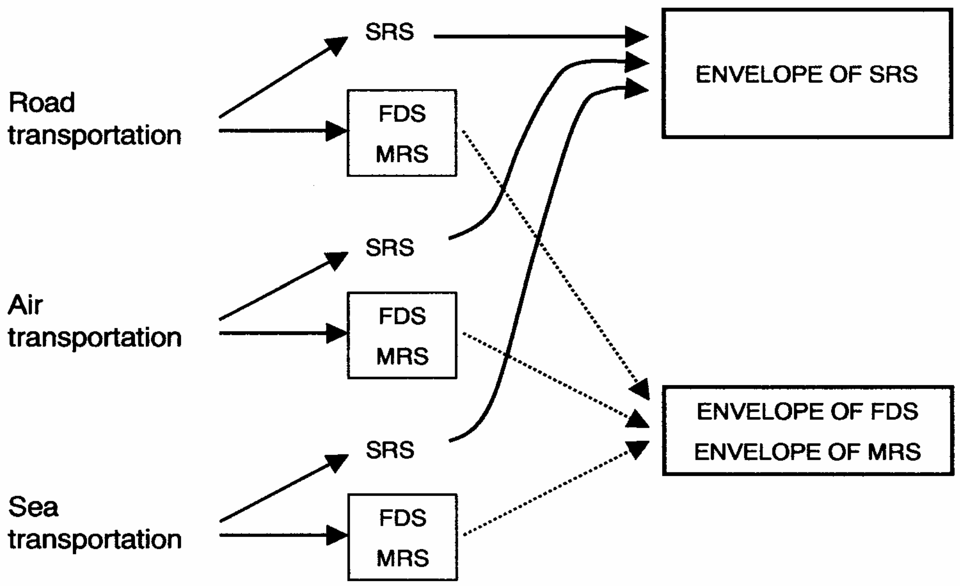


MECHANICAL ENVIRONMENT COMBINATION

CALCULATION FOR SERIAL SITUATIONS



CALCULATION FOR PARALLEL SITUATIONS



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ANNEX F

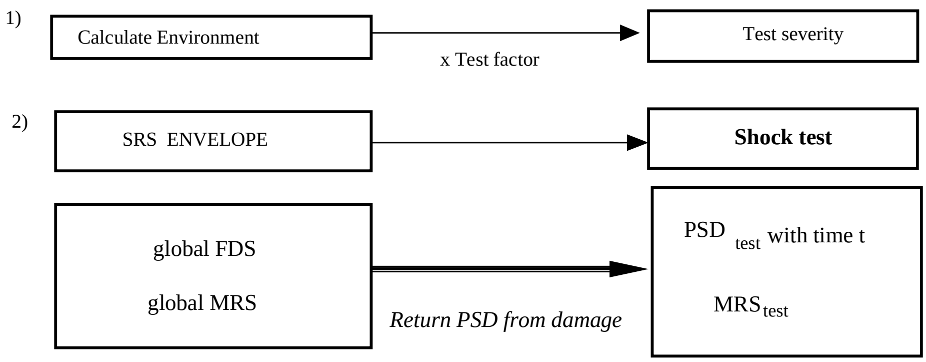
TEST FACTOR

F1 Test Factor allows the calculation of the test severities that will prove whether material has the required mean resistance towards an identified failure mode and its associated environmental stresses.
The introduction of a guaranty coefficient helps in defining the mean resistance of material that has to be proven in order to deal with an acceptable risk of failure. Introduction of a test factor is then used to take into account the limited number of test specimens on which the tests are performed.
The test factor is then defined as a coefficient between the mean resistance to be proven and the test level needed to prove this mean resistance.

Note: Application of a test factor implies acceptance of the fact that the number of tests is limited and that they are carried out on a small sample size (sometimes only one).

Mechanical environment combination

DETERMINATION OF TEST SEVERITY



Level control :

1) If MRS_{test} > SRS envelope, then calculate a PSD_{test} with a longer test duration

2) If MRS_{test} < global MRS then the test time is too long, test time must be adjusted and PSD_{test} must be re-calculate with this new short time

3) If ERS_{test} > global MRS Allowance: MRS_{test} > 2 global MRS

4) If SRS < MRS_{test} the shock severity will be the envelope of the two.

Note: SRS is Shock Response Spectra calculated from a transient (shock) signal, whereas ERS is an Extreme Response Spectra, calculated from a PSD.

Further information can be found in STANAG 4570, AECTP 600, Leaflet 606.

Reference Documents

1. GAM-EG13 Annexe générale mécanique Part 8

2. Vibrations et Chocs mécaniques. Ch.Lalanne Editions Hermès.
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CATERGORY 250

ELECTRICAL/ELECTRO-MAGNETIC CONDITIONS

1. The environmental conditionos within this catergory are under development and it is intended that they will be included in a subsequent edition of this AECTP. The structure and contents of Catergory 250 will be in a similar form to those of Catergories 230 and 240.

2. Related environmental conditions are described in the latest editions of the promulgated STANAGs listed below:

STANAG 1307:	Maximum NATO naval operational electro-magnetic environment produced by radio and radar.
STANAG 4145:	Nuclear survivability criteria for armed forces materiel and installations.
STANAG 4234:	Electro-magnetic radiation (radio frequency) - 200 kHz to 40 gHz environment – affecting the design of materiel for use by NATO Forces.
STANAG 4235:	Electro-static environmental conditions affecting the design of materiel for use by NATO Forces.
STANAG 4236:	Lightning environmental conditions affecting the design of materiel for use by NATO Forces.