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U.S. AIR FORCE GUIDE SPECIFICATION

INSTRUMENT SYSTEMS, AIRBORNE

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INSTRUMENT SYSTEMS, AIRBORNE

1. SCOPE

1.1 **Scope**. This specification establishes the development requirements and verifications for airborne instrumentation used in an entire weapons system or for an individual instrument or piece of equipment.

1.2 **Use**. This specification cannot be used for contractual purposes without supplemental information relating to the performance requirements of the particular weapons system or instrument/equipment for which the specification is being prepared.

1.2.1 **Structure**. The supplemental information required is identified by blanks within the specification.

1.2.2 **Instructional handbook**. The instructional handbook, which is contained in the appendix herein, provides the rationale for specified requirements, guidance for inclusion of supplemental information and a lessons learned repository.

1.3 **Deviation**. Any projected design for a given application which will result in improvement of system performance, reduced life cycle cost, or reduced development cost through deviation from this specification or where the requirements of this specification result in compromise in operational capability shall be brought to the attention of the procuring activity for consideration of change.

2. APPLICABLE DOCUMENTS

2.1 There are no applicable documents.

3. REQUIREMENTS

3.1 **System description**. The air vehicle instrumentation shall provide the functions necessary to meet the overall air vehicle requirements and the mission to be accomplished. Instrumentation and equipment fall into four general groups: panel- and console-mounted indicators, airframe-mounted sensors/transducers, engine-mounted sensors-transducers, and flight management systems.

3.2 **Performance**

3.2.1 System characteristics

3.2.1.1 **Physical characteristics**. The physical characteristics of the instrument system shall be _____.

3.2.1.2 **Display characteristics**. Visual display characteristics shall be as follows: _____.

3.2.1.2.1 **Readability**. The display shall be readable under the following conditions: _____. The minimum contrast between pointers, characters, and indices, and the background shall be _____.

3.2.1.2.2 **Lighting**. Lighting shall be as follows: _____.

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3.2.1.2.3 **Units of measurement**. The units of measurement for display parameters shall be as follows: _____.

3.2.1.3 **Input signals**. The format of the signal input to the equipment shall be _____.

3.2.1.4 **Output signals**. The output signal format shall be as follows: _____.

3.2.1.5 **Interface connections**. Electrical or other interface connections shall be as follows: _____.

3.2.1.6 **Operational readiness**. After power has been applied for not more than _____ minute(s), the equipment shall operate within _____ percent of the normal operating tolerance.

3.2.1.7 **Electrical characteristics**

3.2.1.7.1 **Input voltage and frequency**. Equipment requiring aircraft electrical power shall be designed to operate from _____.

3.2.1.7.2 **Power available**. The power available for use by the equipment is _____.

3.2.1.7.3 **Electrical grounds**. Equipment using electrical power shall be grounded. Case grounding or use of external straps or jumpers is not acceptable.

3.2.1.8 **Environmental conditions**. The equipment shall withstand the following environmental conditions: _____. Performance shall be as follows: _____.

Environment	Requirement	Performance
Temperature		
Temperature Shock		
Humidity		
Fungus		
Vibration		
Dust		
Salt Fog		
Rain		
Acoustical Noise		
Explosive Atmosphere		
Shock		
Gunfire Vibration		
Acceleration		
Solar Radiation		
Nuclear Exposure		

3.2.1.9 **Electromagnetic interference**. Electromagnetic interference shall meet the following: _____.

3.2.1.10 **Magnetic effect**. The display shall not cause a magnetic compass to deflect more than _____ under the following conditions: _____.

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3.2.1.11 **Self-test**. The equipment shall be capable of self-test as follows: _____.

3.2.2 **Functional instrumentation characteristics**

3.2.2.1 **Acceleration display**. The acceleration display shows an instantaneous normal (Z axis) acceleration of the air vehicle in units of gravity ("g"). It shall have the following characteristics: _____.

3.2.2.2 **Attitude display**. The attitude display indicates the air vehicle pitch and roll attitude with respect to the gravity vector and shall have the following characteristics: _____.

3.2.2.3 **Attitude director indicator (ADI)**. The attitude director display shall provide attitude information combined with action director information superimposed on the attitude display. It shall have the following characteristics: _____.

3.2.2.4 **Clock/timer**. The clock or timer shall include a display of real time. The following characteristics shall be provided: _____.

3.2.2.5 **Flight data recorder**. A flight data recorder (FDR) shall be provided to aid in mishap investigations. The following parameters shall be recorded: _____.

3.2.2.6 **Engine pressure ratio system (EPR)**. The EPR display shall receive signals from an EPR sensor and display EPR values to the aircrew. The EPR sensor shall sense the engine inlet total pressure, the turbine exhaust total pressure, divide the exhaust pressure by the inlet pressure, and provide a signal proportional to this nondimensional ratio for use in a display or in control of an aircraft. The performance of the system shall be as follows: _____.

3.2.2.7 **Engine temperature display**. The engine temperature display shall receive signals from an engine temperature sensor and shall display temperature in degrees celcius to the aircrew. The indicator shall have the following features: _____.

3.2.2.8 **Flight director system (FDS)**. The FDS shall display the air vehicle interception and tracking of course, heading, attitude, and glideslope, based on present position, heading, desired position and rate of convergence. The FDS will continuously calculate the proper pitch, bank, and power to perform the desired maneuver. It shall conform to the following: _____.

3.2.2.9 **Rate of fuel flow system**. The rate of fuel flow system consists of one indication used in conjunction with a flow sensor. One display is used for each engine to indicate rate of fuel flow in _____ (units). The system requirements shall be as follows: _____.

3.2.2.10 **Fuel savings advisory system (FSAS)**. The fuel savings advisory system shall display optimum flight profiles for minimum fuel consumption. The system shall be compatible with the aircraft and the missions to be accomplished. The system shall have the following characteristics: _____.

3.2.2.11 **Fuel quantity system**. The fuel quantity gaging system shall indicate the amount of fuel in _____. The system shall measure and display the fuel quantity in _____ (units) and shall be in accordance with _____.

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3.2.2.12 **Horizontal situation indicator (HSI).** The HSI shall provide a pictorial display of the navigational relationship of the aircraft to the earth including other information as follows: _____. It shall be compatible with _____.

3.2.2.13 **Hydraulic pressure indicator and sensor.** The hydraulic pressure indicator is used in conjunction with a hydraulic pressure sensor and is used to display pressure of each hydraulic system on the aircraft. The following requirements apply: _____.

3.2.2.14 **Magnetic compass.** The magnetic compass provides an indicator of aircraft magnetic heading for use as a backup heading reference and for cross-checking the primary heading reference system. The following requirements shall apply: _____.

3.2.2.15 **Structural integrity recorder.** The structural integrity recorder shall record certain data for use in determining the stresses to which aircraft structures have been subjected for the purpose of predicting when certain parts require repair or replacement. The following parameters shall be recorded: _____. Other requirements shall include: _____.

3.2.2.16 **Engine oil quantity indicating system.** The oil quantity indicator shall receive signals from an oil quantity sensor and display to the aircrew the oil quantity in _____ (units) remaining in each tank associated with each engine. The characteristics of the system shall be as follows: _____.

3.2.2.17 **Oil pressure indicating system.** The oil pressure display shall indicate the pressure of the engine oil to each engine in _____ (units) using signals from a remote sensor. The oil pressure sensor shall measure the pressure of the oil supplied to each engine and provide a signal proportional to the pressure for use by a display or other equipment. The following requirements shall apply: _____.

3.2.2.18 **Position indicating system.** The position display is used to indicate the position of certain elements of the aircraft such as flaps, wings (sweep), pitch trim, nozzle, etc. The requirements outlined below apply to continuously variable indications rather than two-position indications such as landing gear, speed brakes, etc.

3.2.2.19 **Tachometer indicator system.** The tachometer display shall indicate the rotational speed of _____ in _____ (units). It shall have the following characteristics: _____.

3.2.2.20 **Thrust computing system.** The system shall display actual gross thrust divided by reference thrust as a percentage. Rerating of the engine shall not require changes to the gross thrust computation algorithm. The system will receive information (pressures, temperatures, etc.) from the following aircraft systems: _____. The system shall have the following performance: _____.

3.2.2.21 **Turn-and-slip display.** Turn-and-slip displays provide an indication of aircraft rate of turn-and-slip information. It shall have the following characteristics: _____.

3.2.2.22 **Warning system.** The warning system shall warn the aircrew of a dangerous situation or an impending dangerous condition using an aural tone and/or voice warning. A warning of the following conditions shall be provided: _____. The warning system shall have the following characteristics: _____.

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3.3 **Reliability**. The instrumentation reliability requirements shall be as follows: _____.

3.4 **Maintainability**. The instrumentation maintainability requirements shall be as follows: _____.

3.5 **Safety**. The instrumentation safety requirements shall be as follows: _____.

3.6 **Human engineering**. Human engineering shall be in accordance with _____.

3.7 **Interface requirements**

3.7.1 **Related systems**. The instrument system shall interface with other air vehicle systems as follows: _____.

3.7.2 **Ground support equipment**. The instrument(s) shall interface with the following ground support equipment: _____.

3.8 **International standardization**. International standards, including NATO STANAGS, ASCC Air Standards, and ISO documents, shall be used as follows: _____.

4. VERIFICATIONS

4.1 **General**. The verifications specified herein shall verify the ability of the instrument systems to meet the requirements of section 3 herein. Verifications shall include visual examinations, laboratory tests, demonstrations, and flight tests. All verifications shall be the responsibility of the contractor; the Government reserves the right to witness any verification.

4.2 **Performance**

4.2.1 **System characteristics verification**

4.2.1.1 **Verification of physical characteristics**. The physical characteristics of the instrument system shall be verified by _____.

4.2.1.2 **Verification of display characteristics**. The display characteristics shall be visually verified as follows: _____.

4.2.1.2.1 **Verification of readability**. The display readability and contrast ratio shall be verified in the laboratory as follows: _____.

4.2.1.2.2 **Verification of lighting**. Lighting shall be verified in the laboratory as follows: _____.

4.2.1.2.3 **Verification of units of measurement**. The units used for measurements and display shall be verified in the laboratory as follows: _____.

4.2.1.3 **Verification of input signals**. Proper input signal format shall be determined in the laboratory as follows: _____.

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4.2.1.4 **Verification of output signals**. Output signal format shall be verified by test in the laboratory and confirmed by compatibility tests on the air vehicles as follows: _____.

4.2.1.5 **Verification of interface connections**. Interface connections shall be verified in the laboratory by: _____.

4.2.1.6 **Verification of operational readiness**. To verify that the time required for operation is within the tolerance specified, the following laboratory tests shall be used: _____.

4.2.1.7 **Electrical characteristics verification**

4.2.1.7.1 **Verification of input voltage and frequency**. Proper equipment operation using the specified voltages and frequencies shall be verified in the laboratory as follows: _____.

4.2.1.7.2 **Verification of power available**. Verification that the instrument does not require more power than that available shall be determined in the laboratory as follows: _____.

4.2.1.7.3 **Verification of electrical ground**. Proper electrical grounding shall be determined visually and by testing in the laboratory as follows: _____.

4.2.1.8 **Verification of environmental conditions**. Environmental testing shall be conducted in the laboratory to verify the requirements of 3.2.1.8 as follows: _____.

4.2.1.9 **Verification of electromagnetic interference**. Compliance with electromagnetic interference requirements shall be verified in the laboratory as follows: _____.

4.2.1.10 **Verification of magnetic effect**. The display shall not deflect a magnetic compass by more then the value specified in 3.2.1.10 when it is tested in the laboratory as follows: _____.

4.2.1.11 **Self-test verification**. Self-test features shall be verified by tests in the laboratory as follows: _____.

4.2.2 **Functional instrumentation/equipment**. The number and type of instrumentation provided by the contractor shall be verified by visual inspection.

4.2.2.1 **Verification of acceleration display**. The characteristics of the acceleration display shall be verified in the laboratory as follows: _____.

4.2.2.2 **Verification of attitude display**. Attitude display characteristics shall be evaluated in the laboratory by _____.

4.2.2.3 **Verification of attitude director indicator (ADI)**. The ADI characteristics shall be verified in the laboratory as follows: _____.

4.2.2.4 **Clock/timer verification**. The requirements specified for the clock/timer shall be verified in the laboratory as follows: _____.

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4.2.2.5 **Verification of flight data recorder**. Performance of the flight data recorder shall be verified in the laboratory by _____.

4.2.2.6 **Verification of engine pressure ratio system**. The engine pressure ratio system shall be evaluated in the laboratory as follows: _____.

4.2.2.7 **Verification of engine temperature display**. The characteristics provided in the engine temperature display shall be verified in the laboratory as follows: _____.

4.2.2.8 **Verification of flight director system (FDS)**. The performance of the FDS shall be evaluated in the laboratory by _____.

4.2.2.9 **Verification of rate-of-fuel-flow system**. The system requirements shall be verified in the laboratory as follows: _____.

4.2.2.10 **Verification of fuel savings advisory system (FSAS)**. Characteristics and performance of the FSAS shall be verified in the laboratory and by flight test as follows: _____.

4.2.2.11 **Verification of fuel quantity system**. Accuracy and characteristics of the fuel quantity system shall be evaluated in the laboratory and in the aircraft as follows: _____.

4.2.2.12 **Verification of horizontal situation indicator (HSI)**. The HSI characteristics shall be evaluated in the laboratory as follows: _____.

4.2.2.13 **Verification of hydraulic pressure indicator/sensor**. Verification of the requirements for hydraulic pressure sensors and indicators shall be accomplished in the laboratory as follows: _____.

4.2.2.14 **Verification of magnetic compass**. Requirements for the magnetic compass shall be verified in the laboratory by _____.

4.2.2.15 **Verification of structural integrity recorder**. Recorded parameters and other requirements specified for the recorder shall be verified in the laboratory as follows: _____

4.2.2.16 **Verification of engine oil quantity indicating system**. To evaluate the performance of the engine oil quantity indicating system, tests shall be conducted in the laboratory as follows: _____.

4.2.2.17 **Verification of oil pressure indicating system**. The accuracy and requirements for the oil pressure indicating system shall be verified in the laboratory as follows: _____.

4.2.2.18 **Verification of position indicating system**. The position indicating system requirements are verified in the laboratory as follows: _____.

4.2.2.19 **Verification of tachometer indicating system**. The tachometer display and sensor shall be verified by testing in the laboratory as follows: _____.

4.2.2.20 **Verification of thrust computing system**. The requirements for the thrust computer system shall be verified in the laboratory as follows: _____.

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4.2.2.21 **Verification of turn-and-slip display**. Turn-and-slip display characteristics shall be evaluated in the laboratory as follows: _____.

4.2.2.22 **Verification of warning system**. The characteristics and performance of the warning system shall be confirmed in the laboratory as follows: _____.

4.3 **Reliability verification**. The reliability requirements of 3.3 shall be verified in the laboratory as follows: _____.

4.4 **Maintainability verification**. The maintainability requirements of 3.4 shall be verified as follows: _____.

4.5 **Safety verification**. The safety requirements of 3.5 shall be verified as follows: _____.

4.6 **Verification of human engineering**. Human engineering requirements shall be verified by inspection.

4.7 **Verification of interface requirements**

4.7.1 **Verification of related systems**. Characteristics of the instrumentation interface with other air vehicle systems shall be verified by _____.

4.7.2 **Verification of ground support equipment**. The instrument(s) interface with specified ground support equipment shall be evaluated by _____.

4.8 **Verification of international standardization**. Requirements of NATO, ASCC and ISO standards shall be verified by _____.

5. PACKAGING

5.1 All deliverable items shall be prepared for shipment as directed by the procuring activity.

6. NOTES

6.1 **Intended use**. This specification is intended for use in developing instrumentation and flight management systems for Air Force air vehicles. It may be used to specify equipment for entire weapons systems or one or more instruments or flight management systems used on new or modified air vehicles.

6.2 **Responsible engineering office**. The office responsible for development and technical maintenance of this specification is ASD/ENASI, Wright-Patterson AFB OH 45433-6503. Requests for additional information or assistance on this specification can be obtained from Mr. James R. Andres, ASD/ENASI, Wright-Patterson AFB OH 45433-6503; AUTOVON 785-4130, Commercial (513) 255-4130. Any information required relating to Government contracts must be obtained through contracting officers.

Custodian:
Air Force - 11

Preparing Activity:
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APPENDIX

INSTRUMENT SYSTEMS, AIRBORNE

HANDBOOK FOR

10. SCOPE

10.1 **Scope**. This appendix provides rationale, background criteria, guidance, lessons learned, and instructions necessary to tailor Sections 3 and 4 of the basic specification (MIL-I-87216) for a specific application.

10.2 **Purpose**. This appendix provides information to assist the Government procuring activity in the use of MIL-I-87216. Specifications written using this document should follow MIL-STD-961 format.

10.3 **Use**. This appendix is designed to assist the project engineer in tailoring MIL-I-87216. The blanks of the basic specification shall be filled in to meet operational needs of the equipment being developed.

10.4 **Format**

10.4.1 **Requirement/verification identity**. Section 30 of this Appendix parallels Section 3 and Section 4 of the basic specification; paragraph titles and numbering are in the same sequence. Section 30 provides each requirement (Section 3) and associated verification (Section 4) as stated in the basic specification. Both the requirement and verification have Sections for rationale, guidance, and lessons learned.

10.4.2 **Requirement/verification package**. Section 30 of this Appendix has been so arranged that the requirement and associated verification is a complete package to permit addition to, or deletion from the criteria as a single requirement. A requirement is not specified without an associated verification.

10.5 **Responsible engineering office**. The responsible engineering office (REO) for this Appendix is ASD/ENASI, Wright-Patterson AFB OH 45433-6503. The individual who has been assigned the responsibility for this handbook is Mr. James R. Andres, ASD/ENASI, Wright-Patterson AFB OH 45433-6503, AUTOVON 785-4130, Commercial (513) 255-4130.

20. REFERENCE DOCUMENTS

20.1 Unless otherwise indicated, the documents specified herein are referenced solely to provide supplemental technical data.

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20.1.1 Government documents

SPECIFICATIONS

MILITARY

MIL-L-5020	Liquid, Compass, Aircraft
MIL-E-5400	Electronic Equipment, Airborne, General Specification for
MIL-C-5604	Compass, Magnetic, Pilot S Standby
MIL-I-7627	Indicator, Turn and Slip, 28V DC
MIL-C-7762	Compass Installation of
MIL-P-7788	Panel, Information Integrally Illuminated
MIL-L-7808	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
MIL-G-7940	Gage Liquid Quantity, Capacitor Type, Installation and Calibration of
MIL-F-8615	Fuel System Components, General Specification for
MIL-C-14806	Coating, Reflection Reducing, for Instrument Coverglasses and Lighting Wedges
MIL-L-23699	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
MIL-L-25467	Lighting, Integral, Red, Aircraft Instrument, General Specification for
MIL-F-26685	Flight Director System, Design, Installation and Test of
MIL-G-26988	Gage, Liquid Quantity, Capacitor Type Transistorized, General Specification for
MIL-L-27160	Lighting, Instrument, Integral, White, General Specification for
MIL-A-27261	Accelerometer, Aircraft
MIL-B-27497	Bearing, Jewel, Sapphire, or Ruby, Synthetic
MIL-I-27619	Indicator, Attitude Director
MIL-T-38230	Transmitter, Pressure TRU-66/a Oil Variable Reluctance
MIL-G-81704	Glass, Aircraft Instrument, Lighting Wedge and Cover
MIL-B-81793	Bearing, Ball, Precision, for Instruments and Rotating Components
MIL-I-83034	Indicator, Horizontal Situation AQU-6/A
MIL-L-85762	Lighting, Aircraft, Interior, AN/AVS-6 Aviators Night Vision Imaging System (ANVIS) Compatible
MIL-F-87154	Fuel Systems
MIL-A-87211	Air Data Systems and Equipment
MIL-D-87213	Displays, Airborne, Electrically/Optically Generated

STANDARDS

FEDERAL

FED-STD-595	Colors

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MILITARY

MIL-STD-210	Climatic Extremes for Military Equipment
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Interference for Equipment
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-470	Maintainability Program Requirements (for Systems and Equipments)
MIL-STD-471	Maintainability Demonstration
MIL-STD-704	Aircraft Electrical Power Characteristics
MIL-STD-756	Reliability Predication
MIL-STD-757	Reliability Evaluation and Demonstration Data
MIL-STD-765	Compass Swinging, Aircraft, General Requirements for
MIL-STD-781	Reliability Design Qualification and Production Acceptance Tests Exponential Distribution
MIL-STD-785	Requirements for Reliability Programs (for Systems and Equipments)
MIL-STD-794	Parts and Equipment Procedures for Packaging, and Packing of
MIL-STD-810	Environmental Test Methods
MIL-STD-882	System Safety Program Requirements
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-STD-1553	Aircraft Internal Time Division Command/Response Multiplex Data Bus
MIL-STD-1587	Materials and Process Requirements for Air Force Systems
MIL-STD-1776	Crew Stations and Passenger Accommodations
MIL-STD-2124	Flight Incident Recorder/Crash Position Locator, Minimum Performing Standards for
MS-28042	Clamp, Mounting, Aircraft Instruments
MS-33558	Numerals and Letters, Aircraft Instrument Dial, Standard Form of
MS-33636	Measurement, Units of for Aircraft Instruments
MS-33639	Case, Instrument, Clamp-mounted, Aircraft
MS-33649	Boss, Fluid Connection, Internal, Straight Thread

PUBLICATIONS

Federal Aviation Agency

FAA Advisory Circular 120-29	Criteria for Approving CAT I and II Landing Minima for
	FAR 121 Operation

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National Bureau of Standards

NBS Monograph 125 Thermocouple Reference Tables

AFSC Design Handbook

AFSC DH 1-3 Human Factors Engineering

International

STANAG-3224 Aircrew Station Lighting

STANAG-3319 Dimensions for Instrument Cases

STANAG-3322 Turn and Slip Indicators

STANAG-3329 Numerals and Letters in Aircrew Stations

STANAG-3330 Accelerometers

STANAG-3436 Colors Used to Denote Operating Ranges of Aircraft Instruments

STANAG-3637 Attitude Indicators, Self Contained and Remote Driven

STANAG-3691 Circular Dial Tachometers (non servoed). Compatible with Two-Pole Three Phase Generators

STANAG-3705 Principles of Presentation of Information in Aircrew Stations

STANAG-3741 Horizontal Situation Indicator

AIR STD 10/2 Units of Measurement

ASD Exhibits

ASD/ENAID 79-1 Fuel Savings Advisory System (FSAS), General Requirements for

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

20.1.2 **Other publications.** The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

ARINC
Specification 404 Air Transport Equipment Cases and Racking

(Application for copies of ARINC specifications should be addressed to ARINC, 2551 Riva Road, Annapolis, MD 21401. Copies of exhibits can be obtained from ASD/ENASI, WPAFB OH 45433-6503.)

T.O. 5.1.2 Method of Marking Instruments and INterpretation of Markings

(Application for copies of T.O.s should be addressed to OC-ALC/MMEDU, Tinker AFB OK 73145.)

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30. REQUIREMENTS AND VERIFICATIONS

3.2 Performance

3.2.1 System characteristics

3.2.1.1 Physical characteristics. The physical characteristics of the instrument system shall be _____.

4.2.1.1 Verification of physical characteristics. The physical characteristics of the instrument system shall be verified by _____.

REQUIREMENT AND VERIFICATION RATIONALE (3.2.1.1 and 4.2.1.1)

REQUIREMENT AND VERIFICATION GUIDANCE

REQUIREMENT AND VERIFICATION LESSONS LEARNED

NOTE: The requirement and verification rationale, guidance, and lessons learned for physical characteristics are included in the following individual subparagraphs that are in parenthesis. Since these subparagraphs tend to be design requirements, they are included in this handbook for information and should only be used in the basic specification when they are specifically needed.

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(3.2.1.1.1 **Size and mounting.** The size of the equipment shall be _____. It shall be mounted as follows: _____.)

REQUIREMENT RATIONALE (3.2.1.1.1)

This requirement is necessary when specifying equipment that is to replace existing equipment or where certain sizes and mounting are known requirements. It would not be used to specify every piece of equipment when equipment for an entire air vehicle is being specified.

REQUIREMENT GUIDANCE

Air vehicle limitations dictate the size and mounting configuration. Standard indicator sizes are listed in STANAG 3319AI. When specifying retrofit equipment, it must be the same size and mounting as the previous equipment. All dimensions must provide a reasonable tolerance for manufacturing purposes. Equipment to be mounted in equipment bays may be in accordance with ARINC 404. Equipment to be mounted in high vibration areas may require shock mounting. Engine-mounted equipment must be mounted with sufficient rigidity to withstand the vibration and temperature expected to be found in that location. Mounts should withstand the maximum shock anticipated, and equipment should not break loose when subjected to the maximum shock expected.

Certain instrument sizes and mounting configurations have become standardized through multiple usage. Round dial engine instrumentation per MS-3359 for example, have come to be considered as standard. Equipment-bay-mounted instrumentation usually use ARINC-ATR-style, quick-disconnect mounts which facilitate replacement of the equipment. Instrument clamps per MS-28042 are used to mount round case instruments.

REQUIREMENT LESSONS LEARNED

Several lessons have been learned in this area, particularly in mounting equipment on engines or in fuel lines, such as fuel flow transmitters. The F-5 experienced fuel leakage at the connections to the fuel flow transmitter because of expansion and contraction of the fuel lines and subsequent galling of surfaces against which "O" rings were seated. A costly redesign was required. Equipment must be mounted in an area that does not exceed its environmental capability.

(4.2.1.1.1 **Verification of sizing and mounting.** The size and mounting configuration shall be verified by visual examination and measurement.)

VERIFICATION RATIONALE (4.2.1.1.1)

The size and mounting configuration must be verified to make certain the equipment meets the requirements.

VERIFICATION GUIDANCE

Size and mounting configuration can easily be verified by visual examination and measurement.

VERIFICATION LESSONS LEARNED

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(3.2.1.1.2 **Weight**. The weight of the equipment shall not exceed _____.)

REQUIREMENT RATIONALE (3.2.1.1.2)

Weight is an important factor in many weapons systems and may have to be controlled particularly on retrofit equipment.

REQUIREMENT GUIDANCE

When retrofit equipment is specified, the weight in the blank should be the same as the original equipment weight. More or less weight could affect the air vehicle center of gravity. When instrumentation for an entire air vehicle is being specified, the contractor is usually responsible for the overall vehicle weight.

REQUIREMENT LESSONS LEARNED

Aircraft have typically grown in gross weight from 10 percent to 40 percent. While instrumentation is only a small part of the air vehicle gross weight, it must be controlled over their lifetime.

(4.2.1.1.2 **Verification of weight**. The weight of the equipment shall be determined by measurement.)

VERIFICATION RATIONALE (4.2.1.1.2)

The weight of the equipment must be verified to make certain it meets the requirement if one is given.

VERIFICATION GUIDANCE

The use of calibrated scales is the standard procedure for determining equipment weight.

VERIFICATION LESSONS LEARNED

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(3.2.1.1.3 **Standardization.** Standard parts shall be used in accordance with _____.)

REQUIREMENT RATIONALE (3.2.1.1.3)

The use of nonstandard parts creates a costly maintenance problem and should be considered when preparing specifications.

REQUIREMENT GUIDANCE

The use of standard parts depends upon the general procurement and management policy, but in general, standard parts should be used to the maximum extent possible. There are several Military Standards for capacitors, resistors, screw threads, etc. The responsibility for using standard parts is usually placed on the contractor. MIL-E-5400, Appendix A, contains a list of standard part documents for consideration.

Air Force experience with equipment using certain types of capacitors has been very poor. Requirement 2 of MIL-STD-454 was written to exclude those types of capacitors such as paper dielectric molded capacitors and certain electrolytic capacitors which have been known to explode. The requirement lists the approved types and also serves to reduce the number of types of capacitors required for maintenance of the equipment, thereby reducing maintenance cost and the requirement to stock many different capacitors.

Following World War II, the Defense Department established a jewel bearing manufacturing facility in the United States to prevent dependence on Swiss and other foreign jewel bearing manufacturers in event of war emergency. Procurement requirements directed by FAR 7-104.37, Required Source for Jewel Bearings, specifies that instrument manufacturers procure all jewel bearings from the William Langer Jewel Bearing Plant, Rolla, N.D., Specification MIL-B-27497 and its associated MS drawings list the standard jewel bearings that are available and which are to be used in the design of instruments for the DOD when jewel bearings are needed.

Probably the most important mechanical elements in airborne instrumentation are bearings and lubricants. The bearing forms the interface between rotating parts and is subject to wear and deterioration and is most often the limiting factor in reliability and life of the equipment. MIL-B-81793 provides recommendations of bearing types and tolerances for various instrument applications. These types are recommended on the basis of experience from ball bearing and quality instrument manufacturers. It also provides guidance for the selection and standardization of bearing lubricants. There are more than 100 different types of oils and greases available for instrument ball bearings. Instrument manufacturers tend to try different lubricants to solve various instrument problems such as poor low temperature starting, poor reliability, hysteresis, etc. The large number of lubricants creates a very difficult Air Force stocking and maintenance problem. In addition, MIL-B-81793 controls the types of lubricants and restricts the use of silicone compounds which are generally poor lubricants, do not have good corrosion prevention characteristics and tend to revert to silicon compounds (sand) especially if a small electrical current is present. The silicone oils also tend to spread and creep over all adjacent surfaces creating problems on slip rings, potentiometers, etc.

REQUIREMENT LESSONS LEARNED

In the past, many contractors have purposely used special parts to enhance their profits by selling spare parts. Spare parts orders often exceed the original contract price. The proliferation of needless special parts greatly affects maintenance costs. This not only applies to piece parts, but complete assemblies such as instruments when an entire weapons system is being specified. Many instruments on the F-15 were made non-standard by slight modification, such as in the lighting, which resulted in a complete new set of part numbers for instruments that were normally standard inventory items.

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(**4.2.1.1.3 Verification of standardization.** The use of standard parts where specified shall be verified by reviewing the contractor's design and drawings.)

VERIFICATION RATIONALE (4.2.1.1.3)

The use of standard parts must be verified to make certain the requirement is met.

VERIFICATION GUIDANCE

Use of standard parts should be determined during the proposal stage, and design drawings can be monitored during development to ascertain compliance with this requirement.

VERIFICATION LESSONS LEARNED

(3.2.1.1.4 **Finish.** The external surfaces of the equipment shall be finished as follows: _____.)

REQUIREMENT RATIONALE (3.2.1.1.4)

Aircrew station instrumentation has usually been painted lusterless black or grey depending upon mission requirements and desires of the weapons system management and user.

REQUIREMENT GUIDANCE

The blank may be filled in to specify color, luster, and durability. On missions that use night vision goggles, it is very important to have a nonreflective black finish to avoid pickup of reflected light in the goggles. Durability requirements may include resistance to fungus, salt spray, humidity, solar radiation, etc., depending upon mission requirements. In addition, a peel test using adhesive tape may be specified.

REQUIREMENT LESSONS LEARNED

Evaluations have been conducted to determine if finishes, such as paint, could be eliminated on certain equipment, particularly equipment mounted in equipment bays or cargo areas. It was found that the equipment corroded and became poor in appearance after environmental exposure to salt spray, humidity, rain, and fungus. Fungus growth has been a problem with some organic base paints. Synthetic resin paints have proved to be superior in resisting fungus growth and are more durable than organic resin paints. Some finishes which look good initially have cracked and peeled during environmental testing; therefore, environmental durability should be specified and tested.

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(**4.2.1.1.4 Finish verification**. The finish of the equipment shall be verified in the laboratory as follows: _____.)

VERIFICATION RATIONALE (4.2.1.1.4)

The laboratory is the best place to examine and test the finish as may be required.

VERIFICATION GUIDANCE

Visual examination is usually sufficient to determine compliance with this requirement. If reflectivity or color is important, the finish can be compared to approved samples or be measured with a photometer. The finish can be examined after each environmental test such as salt spray, humidity, etc., to determine the degree of degradation.

VERIFICATION LESSONS LEARNED

(3.2.1.1.5 **Markings**. Equipment shall be marked in accordance with _____.)

REQUIREMENT RATIONALE (3.2.1.1.5)

All equipment must be marked so that it can be identified for replacement, stock control, etc. Connectors, fuses and other items used on equipment must also be marked.

REQUIREMENT GUIDANCE

The markings must be as permanent as the normal life expectancy of the equipment. Guidance for marking equipment is contained in MIL-STD-454, Requirement 67.

REQUIREMENT LESSONS LEARNED

In the past, some equipment was poorly marked, and the markings wore off causing much extra work trying to identify the part for replacement and trying to identify the proper nomenclature for overhaul.

(**4.2.1.1.5 Verification of markings**. Equipment marking and nameplate data shall be verified visually.)

VERIFICATION RATIONALE (4.2.1.1.5)

Equipment marking must be verified to make certain it meets the requirements. Visual examination is usually sufficient.

VERIFICATION GUIDANCE

Visual examination before and after environmental testing will determine if the markings are as specified and if they are durable.

VERIFICATION LESSONS LEARNED

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3.2.1.2 Display characteristics. Visual display characteristics shall be as follows: _____ .

REQUIREMENT RATIONALE (3.2.1.2)

It is necessary to specify the display characteristics of panel and console mounted instrumentation which provides visual information to the aircrew to make certain it is compatible with the weapons system and with generally accepted human factors engineering principles.

REQUIREMENT GUIDANCE

The term "display" as used in this document can mean any type of visual indication. It may be a mechanical pointer, drum counter, liquid crystal display, cathode ray tube or other device. Display characteristics for an entire air vehicle may be described in general terms, such as the requirements to provide certain instruments as CRTs and certain instruments as electromechanical displays, etc. When specifying individual indicators, the display characteristics should be more detailed and will be addressed in later paragraphs.

Guidance regarding display characteristics is found in MIL-STD-1472, paragraph 5.2 and in STANAG 3705. The principles of presentation outlined in these documents are internationally accepted standards and should be followed whenever possible.

The use of color has become an important characteristic in many displays. Power failure indicator malfunction flags should be painted with Color No. 38907 of FED-STD-595. Black portions of displays should be Color No. 37038 and white indices and pointers Color No. 37875. Range markings, used mostly on engine instruments, should be in accordance with STANAG-3436 and T.O. 5.1.2.

It is important that all letters and numerals used in displays be uniform in appearance. MS-33558 and STANAG-3329 provide information regarding fonts, stroke width and proportion of numerals and letters for Air Force equipment.

It is important to specify the resolution and accuracy of scales. For each parameter, the resolution must be appropriate for aircrew needs. For example, oil quantity displays can be very coarse, because usually the aircrew is only interested in knowing if the tank is full or close to empty. Increments of 1/4 of a full tank can be used. On the other hand, engine temperature is critical to the aircrew, so the scale must have much greater resolution and accuracy. Sometimes, as with normal operating engine RPM, the accuracy need is greater over certain portions of the range. In such cases, the scale may be expanded over those portions which require close control. Guidance for specifying accuracy can be found under the requirements for individual instruments. In general, the systems application will dictate the accuracy required.

Guidance for specifying cathode ray tube displays can be obtained from MIL-D-87213, Displays, Airborne, Electrically/Optically Generated. Air data display guidance can be found in MIL-A-87211, Air Data Systems and Equipment.

REQUIREMENT LESSONS LEARNED

There have been many lessons in the display field. It has been found that multipointer indicators, such as the three-pointer altimeters, can be confusing to interpret and can be misread under stress conditions. In general, it has also been found that display motion should follow the motion of real-life cues whenever possible. The use of pictorial displays, such as fuel panel flow path displays, have proven to be easily interpreted and should be used wherever possible.

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4.2.1.2 Verification of display characteristics. The display characteristics shall be visually verified as follows: _____.

VERIFICATION RATIONALE (4.2.1.2)

The display characteristics of the instrumentation must be visually examined to determine that they meet the requirements specified.

VERIFICATION GUIDANCE

The most convenient time to verify that display characteristics are as specified would be at cockpit mockup reviews. The final verification would take place during flight testing.

VERIFICATION LESSONS LEARNED

3.2.1.2.1 Readability. The display shall be readable under the following conditions: _____. The minimum contrast between pointers, characters, and indices and the background shall be: _____.

REQUIREMENT RATIONALE (3.2.1.2.1)

The readability requirement of certain displays will vary depending upon their end use and location in the crew station. Readability will also depend upon the design of the display. Display readability under all expected conditions is of the utmost importance.

REQUIREMENT GUIDANCE

The following items should be considered when preparing this requirement:

a. Coverglass and wedge quality and color.

b. Coverglass and wedge reflectivity.

c. Coverglass fogging.

d. Contrast between display elements.

e. Viewing angle.

Coverglass and lighting wedge quality is addressed in MIL-G-81704. Type 1 glass is used for most instruments because the index of reflection is in the range which provides the best anti-reflective properties when the glass surfaces are coated with anti-reflective coatings. Color, scratches, digs, chips, etc., are also addressed and provide a guide for acceptance of instruments using coverglasses.

Anti-reflective coatings are essential to readability of displays. Coatings per MIL-C-14806 are typically used on all Air Force instruments that use a coverglass. Coverglass reflections are particularly troublesome when the indicator is viewed at an angle and at night when various crew station lights can reflect from the surfaces of the glass.

A requirement for prevention of fogging should be included in instrument specifications. Fogging of coverglasses can occur when a warm instrument is suddenly cooled.

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Probably the most important factor for display readability is the contrast between the pointers, scale, and characters and the background. The contrast between these display elements in liquid crystal displays and emissive lighted displays can be marginal. In these displays the contrast is closely associated with lighting and the specification for readability should include a statement that the display shall be readable under all ambient light conditions. For light emissive displays the following paragraph can be used to state this requirement:

"Contrast. While at maximum intensity, which shall not exceed the light source rated voltage, the lighted display segments shall provide a contrast of not less than 4.0 against the darker display background, in a diffuse ambient environment of 108,000 lux (10,000 footcandles) measured at the face of the display. Unlighted display segments that are not to be used shall be demonstrated to have a contrast no greater than 0.1. Contrast is defined as:

$$\text{Contrast} = \frac{L_1 - L_b}{L_b}$$

Where L_1 = Luminance of display segment
L_b = Luminance of background"

Off-center viewing of certain instruments is required in some crew stations. This is particularly true of side-by-side cockpits where the crew members must read some of the indicators across the cockpit. The viewing angle is specified from the display horizontal centerline and is typically specified as 30 degrees, which would provide a conical viewing cone of 60 degrees included angle. The viewing angle equipment will vary depending upon the location of the indicator in the cockpit.

REQUIREMENT LESSONS LEARNED

Many lessons have been learned in this area. It has been found that under some conditions, reflections on uncoated coverglasses render a display unreadable. A triple-layer coating was developed and is specified in MIL-C-14806 and has become virtually standard on all aircraft instruments. It also has been found to be durable when properly applied.

Fogging of the inside of the coverglass on aircraft instruments has been a recurring problem. Fogging can be caused by excess moisture in the filling gas, by evaporation of lubricating oil, or by outgassing of varnishes or plastics used in the construction of the indicator. Fogging is most likely to occur when the indicator is warm from a long period of operation and when the coverglass is cool due to a low ambient temperature. Low moisture content materials and dry filling gas must be used in hermetically-sealed indicators. Vacuum baking of assemblies before sealing if often required to prevent fogging.

Under bright sunlight conditions, equivalent to 108,000 lux shining directly on the display, it has been found that many light-emitting displays are nearly washed out, providing very poor readability. Through experimentation, a contrast ratio of four to one has been found to be readable under most conditions.

3.3.3 Metal conditioners.

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4.2.1.2.1 **Verification of readability**. The display readability and contrast shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.1.2.1)

The best place to verify that a display is readable in all ambient lighting conditions is in the laboratory. The ambient and instrument lighting can be controlled, and the display can be observed from all angles.

VERIFICATION GUIDANCE

Color and brightness measurements can be made using various laboratory equipment. Whole panel display readability must be accomplished in the air vehicles using visual examination under various ambient conditions.

VERIFICATION LESSONS LEARNED

3.2.1.2.2 **Lighting**. Lighting shall be as follows: _____.

REQUIREMENT RATIONALE

Display lighting may be required to be specified for compatibility with other weapons systems requirements such as the use of night vision goggles. When specifying an individual display, it is necessary that it be visually compatible with the other surrounding displays.

REQUIREMENT GUIDANCE

This is a complex requirement when specifying instruments for an entire crew station. Some displays will be light-emitting and some will probably be lighted by transillumination or by front lighting. The following factors should be considered for lighting:

a. Color.

b. Uniformity.

c. Intensity and dimming.

Mission requirements, user preference, and procurement policy will dictate the lighting color. There are three basic lighting colors used in USAF air vehicles. They are: red per MIL-L-25467, blue-filtered white per MIL-L-27160, and incandescent white which is used on most commercial aircraft. STANAG-3224 also addresses lighting colors and limits. Red lighting may be preferable for some missions requiring night vision, but generally, blue-filtered white is the preferred Air Force lighting.

Uniformity of night lighting is vital to display readability. Uniformity limits of plus and minus 1.72 cd/m2 (plus and minus 0.5 ft-L) have been found to be satisfactory for most lighting systems. Limits tighter than these are costly to achieve and are of doubtful value.

Intensity and dimming properties are important particularly on missions requiring night adaptability. A full voltage intensity of 3.43 cd/m2 (1.0 ft-L) has been used. Dimming properties should be uniform to near extinction. Certain display elements must not become indistinguishable before others.

Guidance for specifying requirements for lighted panels can be found in MIL-P-7788 to provide compatibility with other lighted instruments.

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Special consideration must be given to lighting instrumentation when the mission requires the use of night vision goggles (NVG). This is a rapidly changing field and the latest information from various sources, including the Army, should be consulted before specifying lighting details for these missions. The use of electroluminescent lighting also should be considered because of its low red emissions, low power requirements and long life. MIL-L-87562 outlines requirements for NVG-compatible lighting.

REQUIREMENT LESSONS LEARNED

Much effort and study has been expended in the area of night lighting. In the early 1940s ultraviolet lighting used in conjunction with fluorescent-marked indicators was predominately used but was found to be fatiguing to the aircrew. Some older aircraft still use this type of lighting. In the late 1940s and early 1950s, red lighting was widely used in military aircraft because studies showed that red lighting does not affect night vision. It is still used in many Army and Navy air vehicles where night vision is critical.

In the late 1950s the USAF began an extensive study of red versus white lighting and it was found that white light was best suited to Air Force missions. The low, white light brightness levels normally used did not seriously affect night vision, which was easily destroyed by other sources of light anyway. The use of white light provided much better display readability and allowed use of colors. Studies showed that the blue-filtered white was best because it did not turn to yellow as much when dimmed and it provided the best color rendition under dim conditions.

Commercial aircraft have adopted an incandescent white color which supposedly does not require filters. However, yellow filters are often required to match the different color temperatures of various lamps. It has been found to be as difficult to provide a uniform incandescent white color as it was to provide the blue-filtered white during the early development of that lighting system. Color tolerances for incandescent white have not been completely agreed upon by all contractors.

Care should be taken not to specify tolerances tighter than necessary or arbitrarily accept contractor's specifications which have tighter limits that promise better uniformity of displays. Experience has shown that tighter limits are costly to achieve and are not necessary. Tighter limits were tried for the F-15, and they could not be met, requiring relaxation to standard USAF limits.

Dimming properties have been found to be difficult to control and match from instrument to instrument. The USAF has achieved some degree of success in controlling dimming characteristics by using a group of common lamps whose filaments are similar, and therefore, have uniform dimming characteristics.

4.2.1.2.2 Verification of lighting. Lighting shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.1.2.2)

The most appropriate place to evaluate lighting characteristics is in the laboratory where various ambient lighting conditions can be simulated and where lighting can be adjusted with test equipment.

VERIFICATION GUIDANCE

VERIFICATION LESSONS LEARNED

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3.2.1.3 Input signals. The format of the signal input to the equipment shall be _____.

REQUIREMENT RATIONALE (3.2.1.3)

This requirement is needed to make certain the equipment will operate from the signals provided. In some cases, the equipment will contain its own sensor and will not use an input signal. In new weapons systems, the MIL-STD-1553 data bus may carry most of the signals, and the equipment must be compatible with this signal format.

REQUIREMENT GUIDANCE

In general, the input signal will either be an analog or digital type. Analog signals can be either voltage, frequency, capacitance, synchro, resistance, etc. If both the display and sensor are specified as a system, and there is no desire to ever procure them separately, the input signal transmitted between the sensor and the display may be left to the option of the contractor. In the case of digital signal inputs, the proper code must be specified. If the equipment is to be used on a MIL-STD-1553 data bus, this requirement must be stated.

REQUIREMENT LESSONS LEARNED

In the past, when the signal format between sensors and displays was left to the contractor, very often special formats were used, and it was virtually impossible to procure either item separately from the other contractors because of the lack of data on very specialized signals. The F-5 fuel flow transmitter and indicator are examples. Both pieces must be procured from one vendor with no competition because of unusual signal formating.

4.2.1.3 Verification of input signals. Proper input signal format shall be determined in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.1.3)

Laboratory tests can easily be peformed by applying the specified voltage, frequency, pressure, etc., and observing the performance of the equipment.

VERIFICATION GUIDANCE

In most cases, laboratory test equipment will be designed to properly test this requirement. The final verification is the performance in the air vehicle as determined by flight testing.

VERIFICATION LESSONS LEARNED

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3.2.1.4 Output signals. The output signal format shall be as follows: _____.

REQUIREMENT RATIONALE (3.2.1.4)

Where applicable, the output signal format must be specified to make certain the equipment will properly interface with other equipment which may require this signal.

REQUIREMENT GUIDANCE

This requirement applies mostly to sensors/transmitters. In some cases, indicators will have auxilliary output signals, such as a switch on a temperature indicator to actuate a warning light when a certain temperature is reached or a voltage proportional to the display value to be used for computational purposes. The blank is to be filled in with the required signal format to be compatible with the using equipment whether it be a display, computer, or perhaps for telemetry. If the signal is to be placed on the MIL-STD-1553 data bus, this fact must be stated.

REQUIREMENT LESSONS LEARNED

(See Lessons Learned under 3.2.1.3.)

4.2.1.4 Verification of output signals. Output signal format shall be verified by test in the laboratory and confirmed by compatibility tests on air vehicles as follows: _____.

VERIFICATION RATIONALE (4.2.1.4)

Output signals can usually be measured using common laboratory equipment including voltmeters, frequency counters, recording equipment, etc.

VERIFICATION GUIDANCE

In most cases, special laboratory test equipment will be designed to properly test this requirement. Final verification is performance in the air vehicle.

VERIFICATION LESSONS LEARNED

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3.2.1.5 Interface connections. Electrical or other interface connections shall be as follows: _____.

REQUIREMENT RATIONALE (3.2.1.5)

With few exceptions, aircraft indicators and equipment must interface with other equipment to obtain power, receive signals, transmit signals, connect to fuel and oil lines, attach in fuel tanks, etc. The interface requirements must be specified to insure that the equipment is compatible with the airframe.

REQUIREMENT GUIDANCE

An air vehicle will usually have a common series of electrical connectors that should be specified for all equipment. If a single piece of equipment is being specified guidance can be obtained from MIL-STD-454, Requirement 10. Connections other than electrical plugs must be compatible with other existing equipment and with the associated airframe systems. Guidance for the specification and design of pipe and tube connections can be obtained from MS33649. The Society for Automotive Engineers (SAE) has also published many documents from which guidance for the specification of pipe and tube fittings can be obtained, however, MS33649 is preferred.

REQUIREMENT LESSONS LEARNED

Interface connections have a history of being troublesome. Electrical connectors corrode, pins bend, and often maintenance personnel attempt to mate the wrong connector to a piece of equipment. In the case of pressure connections, leakage is the major problem. Fittings similar to MS33649 have been found to be satisfactory. Tapered pipe threads are very susceptible to leakage and should not be used.

Several years ago, the Navy used a rubber-like potting compound around the wires going into electrical connectors. The potting material deteriorated into a soft, sticky compound in a few months, and the connectors had to be replaced at great expense. Any such potting compounds should be carefully checked before their use is specified.

4.2.1.5 Verification of interface connections. Interface connections shall be verified by visual examination and compatibility testing in the air vehicle.

VERIFICATION RATIONALE (4.2.1.5)

Visual examination is required to determine that the interface connection design is as specified.

VERIFICATION GUIDANCE

Usually a check of part numbers is sufficient to verify that the requirement has been met. In the case of some pipe and tube connections, it may be necessary to physically measure the dimensions and try a mating part. The final verification is in the air vehicle to make certain the equipment fits and performs as required.

VERIFICATION LESSONS LEARNED

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3.2.1.6 Operational readiness. After power has been applied for not more than _____ minute(s), the equipment shall operate within _____ percent of the normal operating tolerance.

REQUIREMENT RATIONALE (3.2.1.6)

Most USAF missions require rapid operational readiness, such as fighter aircraft scrambles. Many types of equipment require a warmup period to reach operational readiness. It is, therefore, necessary to specify the maximum warmup time allowed.

REQUIREMENT GUIDANCE

The mission requirements will dictate values to be inserted in the blanks. It may also be necessary to specify different times under environmental extremes. If some degradation can be tolerated for early readiness, it should be specified. In general, the maximum allowable time should be specified since the instruments can be designed for lower power consumption which usually results in longer MTBFs. Most indicators can be operational within a few seconds.

REQUIREMENT LESSONS LEARNED

Interface connections have a history of being troublesome. Electrical connectors corrode, pins bend, and often maintenance personnel attempt to mate the wrong connector to a piece of equipment. In the case of pressure connections, leakage is the major problem. Fittings similar to MS33649 have been found to be satisfactory. Tapered pipe threads are very susceptible to leakage and should not be used.

Several years ago, the Navy used a rubber-like potting compound around the wires going into electrical connectors. The potting material deteriorated into a soft, sticky compound in a few months, and the connectors had to be replaced at great expense. Any such potting compounds should be carefully checked before their use is specified.

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VERIFICATION RATIONALE (4.2.1.5)

Visual examination is required to determine that the interface connection design is as specified.

VERIFICATION GUIDANCE

Usually a check of part numbers is sufficient to verify that the requirement has been met. In the case of some pipe and tube connections, it may be necessary to physically measure the dimensions and try a mating part. The final verification is in the air vehicle to make certain the equipment fits and performs as required.

VERIFICATION LESSONS LEARNED

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3.2.1.6 Operational readiness. After power has been applied for not more than _____ minute(s), the equipment shall operate within _____ percent of the normal operating tolerance.

REQUIREMENT RATIONALE (3.2.1.6)

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REQUIREMENT GUIDANCE

The mission requirements will dictate values to be inserted in the blanks. It may also be necessary to specify different times under environmental extremes. If some degradation can be tolerated for early readiness, it should be specified. In general, the maximum allowable time should be specified since the instruments can be designed for lower power consumption which usually results in longer MTBFs. Warmup times for some gyro equipment are from 1 to 1.5 minutes at 20°C to 30°C. Other indicators can be operational within a few seconds.

REQUIREMENT LESSONS LEARNED

4.2.1.6 **Verification of operational readiness.** To verify that the time required for operation is within the tolerance specified, the following laboratory tests shall be used _____.

VERIFICATION RATIONALE (4.2.1.3)

The laboratory is the best place to verify this requirement because various environmental and operational situations can be simulated.

VERIFICATION GUIDANCE

This test is usually conducted during startups when other tests are to follow, for example, startup after a cold soak prior to low temperature tests of scale factors, etc.

VERIFICATION LESSONS LEARNED

It has been found that startup times at low temperature are often very long and special attention to the design and test of the equipment under these conditions is important.

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3.2.1.7 Electrical characteristics

3.2.1.7.1 Input voltage and frequency. Equipment requiring aircraft electrical power shall be designed to operate from _____.

REQUIREMENT RATIONALE (3.2.1.7.1)

Nearly every instrument or piece of equipment requires some sort of electrical power for operation and it must be specified to insure proper operation in the weapons system.

REQUIREMENT GUIDANCE

Depending upon the air vehicle, only certain types of power may be available and, if appropriate, may be specified for this requirement. If the equipment is to be operable from battery power during startup or standby use, dc power requirements should be specified. Air vehicle power supplies often experience overvoltages of various magnitudes. To make certain, the equipment is not damaged by these overvoltages, the equipment should be subjected to a series of applications of higher-than-normal voltage for a short period of time. The voltage may be ac or dc depending upon the air vehicle power supply and the equipment input power. If the air vehicle power has a normal variation, the equipment should be specified to operate within normal tolerance for this range of voltage and frequency. If there are emergency ranges of power, consideration should be given to allowing reduced performance at the extremes. Commonly available power includes 115V, 400 Hz, three phase, three wire, and 28V dc power. Single phase, 115V, 400Hz power is available by using one phase of the three phase system.

REQUIREMENT LESSONS LEARNED

Some aircraft such as the F-5 aircraft have a wider range of voltage and frequency variation than specified in MIL-STD-704. It was found that certain equipment would not operate properly when the extreme high voltage and the extreme low frequency was applied to the equipment. An investigation of the aircraft power supply showed that this combination could not exist; so, the requirement was removed from the specification. If the equipment is designed to be used on only one aircraft, it should not be required to meet different conditions found on other air vehicles, but should include all extremes of voltage and frequency expected on the particular weapons system.

Frequent failures of some equipment have occurred on several aircraft. The failures were analyzed, and it was found that certain transistors were destroyed by high voltage. The equipment could not withstand the momentary high voltage transients found on most aircraft. It is important, particularly for electronic equipment to specify the voltage transients to be withstood. Some electronic equipment is subjected to 100 applications of high voltage transients to ensure that failure does not occur in the air vehicle. If high voltage transients are expected in the weapons system, a requirement to withstand a certain number of overvoltages should be specified. The peak voltage and duration should be stated.

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4.2.1.7 Electrical characteristics verification

4.2.1.7.1 Verification of input voltage and frequency. Proper equipment operation using the specified voltages and frequencies, shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.1.7.1)

The laboratory is the logical place to verify this requirement because equipment is available to apply various voltages and frequencies.

VERIFICATION GUIDANCE

The blank may be completed by stating that the equipment must operate using MIL-STD-704 power variations or other power variations depending upon the air vehicle power supply. If degraded performance can be tolerated during voltage and frequency power extremes, it should be so stated both in the requirement and verification paragraphs. Proper operation can be easily tested in the laboratory using variable voltage and frequency power supplies. Combinations of extreme voltage and frequency expected on the air vehicle are applied to the equipment, and it should operate within the tolerances specified. The specified number and level of voltage transients should be applied to susceptible equipment to ascertain that the equipment will withstand the transients that could occur in service.

VERIFICATION LESSONS LEARNED

Applications of 100 transients on certain equipment has been used successfully and no in-service failures due to voltage transients occurred.

3.2.1.7.2 Power available. The power available for use by the equipment is _____.

REQUIREMENT RATIONALE (3.2.1.7.2)

This requirement is necessary to make certain the equipment is designed to operate from the amount of power available from the weapons systems power source. It is directed at the specification for a single piece of equipment for modification of air vehicles to maintain or reduce overall power requirements.

REQUIREMENT GUIDANCE

If the power (VA or watts) available is large, it may not be desirable to allow the full amount to be used by the instrument. This would generally be the case because the use of excess power could overheat the instrument or overtax the cooling system. In general, the power requirements of a new instrument should not exceed that of the one it replaces and should be specified as a maximum value. Some equipment requires higher starting power. This may have to be specified if the power source is limited or does not have overload capability.

REQUIREMENT LESSONS LEARNED

Reduction of input power requirements by use of transistorized circuits has increased the reliability of many items. In addition, a reduction in power reduces overall power required from the air vehicle and reduces cooling loads. The operating temperature of instruments has been found to be inversely proportional to the reliability--the higher the temperature the lower the reliability. High power consumption results in high internal heating.

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4.2.1.7.2 Verification of power available. Verification that the instrument does not require more power than that available shall be determined in the laboratory by _____.

VERIFICATION RATIONALE (4.2.1.7.2)

The instrument power requirements are easily determined in the laboratory using ammeters, voltmeters, and wattmeters as required.

VERIFICATION GUIDANCE

The power consumption of the instrument can be compared to that which is available to make certain it does not exceed the amount specifed as available.

VERIFICATION LESSONS LEARNED

3.2.1.7.3 **Electrical grounds.** Equipment using electrical power shall be grounded. Case grounding or use of external straps or jumpers is not acceptable.

REQUIREMENT RATIONALE (3.2.1.7.3)

An electrical ground is required to minimize electromagnetic interference and electrical shock hazards.

REQUIREMENT GUIDANCE

Most equipment is grounded through a separate pin in the electrical connector which is the preferred means of grounding. Grounding through the case only is not acceptable because it is not reliable due to paint or other surface contamination and presents a shock hazard when handling the equipment. Signal lead grounds in particular must be low in resistance. Common grounds, particularly signal and power ground combinations, are troublesome because changes in ground current may affect the electrical signals and cause undesirable display movement. Guidance for grounding requirements can be found in Requirement 1 of MIL-STD-454.

REQUIREMENT LESSONS LEARNED

Improper equipment grounding has resulted in electrical shocks to personnel either installing or testing the equipment. If the equipment is case grounded and is lifted from its attachment before removing power, the operator is subjected to the ground voltage. Poor case grounding has also resulted in improper equipment operation.

4.2.1.7.3 **Electrical grounds.** Proper electrical grounding shall be determined visually and by testing as follows: _____.

VERIFICATION RATIONALE (4.2.1.7.3)

Verification of the requirement is necessary to insure compliance. Visual examination is usually sufficient.

VERIFICATION GUIDANCE

The equipment can be examined to determine the method of grounding. Electrical tests can be conducted to verify the ground points. There should be no more than 0.002 ohms resistance between the electrical ground lead and the equipment ground.

VERIFICATION LESSONS LEARNED

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3.2.1.8 Environmental Conditions. The equipment shall withstand the following environmental conditions: _____. Performance shall be as follows: _____.

Environment	Requirement	Performance
Temperature		
Thermal Shock		
Temperature-Altitude		
Humidity		
Fungus		
Vibration		
Dust		
Salt Fog		
Rain		
Acoustical Noise		
Explosive Atmosphere		
Shock		
Gunfire Vibration		
Acceleration		
Solar Radiation		
Nuclear Exposure		

REQUIREMENT RATIONALE (3.2.1.8)

Depending upon the weapons system, its mission and theater of operation in the world, the equipment must function under verious environmental conditions.

REQUIREMENT GUIDANCE

The intent of this requirement is to provide a suitable definition of environmental conditions under which the instruments/system must operate periodically and continuously.

Environmental requirements have always been included in the various item specifications. It has not always been possible to accurately determine the environment which each item had to withstand because of lack of information or because of changes in the air vehicle. Some guidance can be found in MIL-STD-210. With the environment defined, the development cycle can be tailored to meet the application. The risk is the ability to accurately assess the true environment.

MIL-STD-810 requirements can be specified for various environmental tests if it is determined that they are applicable to the particular weapons system.

It is generally accepted that the performance of various equipment is degraded at environmental extremes such as high and low temperature. It will be necessary to determine the weapons systems performance requirements at these extremes and specify the performance of the equipment accordingly. Care should be taken not to specify requirements which are not necessary or which the equipment is not susceptible to such as noise on heavy equipment or solar radiation on equipment in bays.

REQUIREMENT LESSONS LEARNED

Typically, the most critical environmental factors for instruments are temperature and vibration. Other factors affect some instruments depending upon their design.

Many contractors have chosen to hermetically seal their instruments which renders them impervious to humidity, fungus, salt spray, dust and rain.

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Some temperature problems are created in crew stations due to sunlight through the canopy and due to self-heating when instruments are mounted closely together. Excessive heat greatly reduces the life of instrumentation.

Vibration is a critical test for most instruments. When possible, a vibration survey should be taken in the air vehicle where the instrument is to be mounted. The vibration test should duplicate the vibration found on the air vehicle as closely as possible.

Accelerations applied in various directions to indicators/displays have uncovered many problems, mostly due to instrument imbalance. An important requirement for displays is that they must operate in all positions--upside-down, etc., particularly if they are to be used in fighter-type aircraft.

4.2.1.8 Verification of environmental conditions. Environmental testing shall be conducted in the laboratory to verify the requirements of 3.2.1.8 as follows: _____.

VERIFICATION RATIONALE (4.2.1.8)

The laboratory is the only place where all environmental conditions can be simulated using various temperature, altitude, humidity chambers and other test equipment.

VERIFICATION GUIDANCE

Depending on the equipment, the environmental tests should be tailored to evaluate its critical characteristics. The classical methods of environmental testing are presented in MIL-STD-810. These should be used whenever they can be determined to be applicable or where they simulate operational conditions.

Some environmental tests are long and costly. Only those tests which are required to ensure compliance with the requirements should be specified. Certain tests such as fungus can be eliminated if the contractor provides certification that no material which supports fungicidal growth has been used. When equipment is hermetically sealed, salt spray, rain, humidity, dust and fungus tests may be conducted on empty equipment cans only to test paint connectors, external hardware, etc. This usually results in a savings of time and money.

VERIFICATION LESSONS LEARNED

Several lessons have been learned during environmental verification testing. Most of the lessons have been included in MIL-STD-810 test procedures.

Mounting of equipment during vibration testing has been found to be critical. It is important that the mounting fixture not amplify or reduce the vibration which the equipment experiences.

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3.2.1.9 Electromagnetic interference. Electromagnetic interference shall meet the following: _____.

REQUIREMENT RATIONALE (3.2.1.9)

Electromagnetic interference affects operation of communications systems and may allow detection by the enemy. Radiation may also affect operation of other equipment which is susceptible to electromagnetic radiation. Some electromagnetic interference from outside sources is a certainty, possibly from external jamming or weapons, and certain instruments could be affected.

REQUIREMENT GUIDANCE

This requirement relates to the necessity of establishing the limits of electromagnetic interference (EMI), which the equipment must meet. It also must state the amount and type of EMI the equipment must be able to withstand and function with (electromagnetic susceptibility). The requirements will vary depending upon the mission of the air vehicle. Certain air vehicles, such as bombers, may require very high tolerance to electromagnetic radiation in addition to having low levels of external radiation to avoid detection by an enemy. Guidance to specification of requirements can be obtained from MIL-STD-461. There would be no need to specify EMI requirements for purely mechanical devices or certain other equipment which may only use ac induction electrical motors.

REQUIREMENT LESSONS LEARNED

Through the years, there have been many lessons learned regarding the control of and susceptiblity to electromagnetic interference. It has been found that radiation can usually be controlled by making certain the equipment is properly shielded by chassis, "RF" gaskets, shielded wire, etc. Conducted radiation can be controlled by using filters. Radiation through coverglasses can be prevented by transparent conductive coatings. Some equipment which is susceptible to conducted radiation must be equipped with filters or be designed to be insensitive to the range of radiation specified.

4.2.1.9 Verification of electromagnetic interference. Compliance with electromagnetic interference requirements shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.1.9)

The laboratory is the only practical place to determine compliance with this requirement where screen rooms and test equipment are available.

VERIFICATION GUIDANCE

Testing procedures are specified in MIL-STD-462. Appropriate methods can be selected depending upon the specified requirements.

VERIFICATION LESSONS LEARNED

In the past, DOD services used a variety of documents to specify the requirements and tests for EMI. This created much confusion and duplication in EMI testing and MIL-STD-461 and -462 were written to consolidate the requirements and standardize on test methods, thereby reducing testing costs.

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3.2.1.10 Magnetic effect. The indicator shall not cause a magnetic compass to deflect more than _____ degrees under the following conditions: _____.

REQUIREMENT RATIONALE (3.2.1.10)

This requirement is intended for indicators or equipment which is to be mounted near a magnetic compass or other magnetic sensitive sensor elements. Excessive magnetic influence, with power on or off, would create error in the magnetic sensor which may be too great to be compensated.

REQUIREMENT GUIDANCE

General practice is to restrict magnetic effect to a certain maximum compass deflection when the indicator is revolved around a compass in an east-west vertical plane with the nearest part of the indicator a certain distance from the center of the compass. The specified limits range from one degree to five degrees of compass deflection when tested at a distance of 12 inches to five inches from a compass.

The exact amount of magnetic effect allowable probably cannot be determined for any one instrument. Historically, an allowance of three degrees deflection at 5 1/2 inches has not resulted in compensation problems.

REQUIREMENT LESSONS LEARNED

All magnetic compasses and compass systems using magnetic azimuth detectors have compensation features. It is sometimes difficult to compensate the element if there is too much magnetic influence of equipment or structure around the element.

4.2.1.10 Verification of magnetic effect. The indicator shall not deflect a magnetic compass by more than the value specified in 3.2.1.19 when it is tested in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.1.10)

The laboratory is the best place for this test because controlled magnetic fields can be provided and test equipment is available.

VERIFICATION GUIDANCE

The most commonly used test to verify this requirement is to place a magnetic compass in a north direction and revolve the instrument around the compass a given distance in an east-west plane. The test is conducted with power on and power off. A convenient method of conducting this test is to place a magnetic compass at the center of a non-magnetic disk the radius of which is equal to the desired test distance. The equipment to be tested is then slowly revolved around the periphery of the disk while watching for compass deflections.

VERIFICATION LESSONS LEARNED

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3.2.1.11 Self-test. The equipment shall be capable of self-test as follows: _____.

REQUIREMENT RATIONALE (3.2.1.11)

The capability for self-test of equipment, either from a central location or by individual interrogation of a single instrument, can be a valuable means of determining the condition of the equipment. With this knowledge, mission completion can be enhanced and maintenance and turnaround times can be reduced by knowing which equipment to replace.

REQUIREMENT GUIDANCE

The specification of this requirement will depend upon weapons system requirements, management policy and user preference. If the self-test system is centralized, it will require a listing of those equipments to be monitored, and the method of monitoring will have to be specified. User preference may dictate the use of self-test features. The C-5 and B-1 have centralized test systems. Individual pieces of equipment on other air vehicles have self-test capabilities. Use of self-test is an optional design feature and, in general, will cost more to provide.

REQUIREMENT LESSONS LEARNED

Design complexity and poor reliability have been experienced with some central test systems. High cost is another consideration. Self-test on certain individual instruments has been successful. Maintenance of the test systems has been a problem.

4.2.1.11 Self-test verification. Self-test characteristics shall be verified by tests in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.1.11)

The laboratory is the logical place to verify self-test characteristics.

VERIFICATION GUIDANCE

Self-test capability is readily verified before, after, or during other testing by actuating the self-test circuit and observing equipment response.

VERIFICATION LESSONS LEARNED

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3.2.2 Functional instrumentation/equipment

The following equipment may be chosen and specified for weapons systems. In addition, equipment in accordance with MIL-D-87213 Display, Airborne, Electrically/Optically Generated and MIL-A-87211 Air Data Systems and Equipment may be chosen to complete the weapons system complement of equipment related to aircraft flight control and crew interface with the aircraft. MIL-STD-1776, Aircrew Stations and Passenger Accommodations, provides information regarding integration of instrumentation into aircrew stations.

A specification for a single instrument or piece of equipment may be prepared using the guidelines contained herein. These requirements can be used in conjunction with the general requirements previously stated to define an individual instrument or equipment. The paragraph numbering carries the same numerical identification found in the specification.

Obviously, small aircraft performing simple missions will not require as much or as sophisticated equipment that larger aircraft would need. Careful consideration should be given to selecting an existing instrument before initiating development of a new one. AFSC/AFLC Regulation 800-31 has been issued to provide lists of preferred Air Force equipment to be considered for use on new or modified weapons systems. It should be realized that it would generally be more cost effective to use an existing piece of equipment, which may have a greater capability than needed, rather than develop new equipment which is only as good as needed. Savings would also result from fewer parts in the USAF inventory, lower maintenance costs, fewer T.O.s, more effective procurement due to larger buys, etc.

The following list of instruments/equipment are covered in this document and can be chosen and specified as required.

Equipment	Paragraph
Acceleration Sensors and Indicators	3.2.2.1
Attitude Indicators	3.2.2.2
Attitude Director Indicator	3.2.2.3
Clocks/Timers	3.2.2.4
Flight Data Recorder	3.2.2.5
Engine Pressure Ratio (EPR) System	3.2.2.6
Engine Temperature Indicator (EGT/TIT)	3.2.2.7
Flight Director System	3.2.2.8
Fuel Flow Systems	3.2.2.9
Fuel Savings Advisory System (FSAS)	3.2.2.10
Fuel Quantity System	3.2.2.11
Horizontal Situation Indicator (HSI)	3.2.2.12
Hydraulic Pressure Indicator & Sensor	3.2.2.13
Magnetic Compass	3.2.2.14
Structural Integrity Recorder	3.2.2.15
Engine Oil Quantity Indicating System	3.2.2.16
Oil Pressure Indicating System	3.2.2.17
Position Indicators	3.2.2.18
Tachometer Indicator System	3.2.2.19
Thrust Computer System	3.2.2.20
Turn and Slip Display	3.2.2.21
Warning Systems	3.2.2.22

In some cases the main paragraph covers both sensors and indicators, but they can be specified individually by tailoring the requirements to specify the component desired.

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3.2.2.1 Acceleration display. The acceleration display shows an instantaneous normal (z axis) acceleration of the air vehicle in units of gravity ("g"). It shall have the following characteristics: _____.

REQUIREMENT RATIONALE (3.2.1.1)

An acceleration indicator is usually provided on those aircraft which are limited in positive or negative g loading capability. It is also used in combat and to record maximum and minimum g levels the airframe has experienced.

REQUIREMENT GUIDANCE

Most of the devices currently in use are mechanically operated from an acceleration sensitive spring/mass sensor located within the indicator itself. The sensor mechanism on these devices is geared directly to a pointer which will indicate the g-loading on a round dial display. Most of these devices also have a mechanism including two additional pointers which will allow the maximum positive and negative g reading to be retained after the aircraft has encountered those maximum load factors. A typical display would show the instantaneous pointer, maximum positive acceleration memory pointer, maximum negative acceleration memory pointer, and reset button. The reset button is provided for the purpose of allowing the memory pointers to be reset to the 1 g indication during or after each flight.

Some form of internal protection against acceleration forces incident to shipping is often necessary, particularly for mechanical accelerometers. A locking device can be incorporated in the mechanism which will prevent damage to the instrument if it is dropped or severely jolted in shipment.

Acceleration indicators for those air vehicles which require them may be provided in several forms. They may be round dial, self-contained mechanical instruments; vertical scale displays with remote sensors; or any form of electro-optical display with appropriate sensors. The following factors must be considered together with the common requirements already listed in previous paragraphs:

a. Range. The range of the accelerometer should be specified based on the mission and type of the aircraft. Typically, a high performance fighter aircraft has a range of g loading from approximately -2.0 to +8.00 g's, and therefore, a range of -4 to +10 g's on the accelerometer is reasonable. For a cargo/ transport aircraft which has a mission with no high g loading, an accelerometer with a range of -2 to +4 g's could be used.

b. Accuracy. The limiting factor on most g meters is the design of the sensor. With a mechanical device like that installed on most aircraft, D+0.2 g's accuracy is considered to be the state-of-the-art. Electrically driven indicators with remote transducers can be designed to be more accurate; however, it is questionable whether or not an accuracy better than D+0.2 g's is required.

c. Response. The purpose of the g meter is to sense steady-state g loading on the aircraft. Acceleration loading due to vibration of the aircraft also exists. This g loading is a function of the frequency of vibration, and therefore, the g meter should be damped so as not to sense this portion of the aircraft g loading. Most accelerometers damp out any g loading due to vibration at frequencies above 5 Hz. This damping is critical in the design of the g meter, and any vibration above 5 Hz that is not damped out will be displayed by the pointer and make the display unacceptable.

d. Display. A typical display proven acceptable in USAF aircraft is shown in MIL-A-27261 and STANAG-3330. As noted, the g meter should read 1 g when in a normal position with no g loading on the instrument since the mechanism should sense the earth's normal g force acting on the aircraft. Other displays such as head-up displays (HUDs), etc., may be considered if it can be shown that the display will be operationally acceptable. The maximum positive and negative memory feature should

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be incorporated in any considered display due to the fact that during aircraft maneuvering the pilot may exceed his allowable g loading limits without reading his accelerometer and will not know that he has exceeded the limit. The memory capability will provide the crew (pilot and ground crew) that information.

REQUIREMENT LESSONS LEARNED

Design complexity and poor reliability have been experienced with some central test systems. High cost is another consideration. Self-test on certain individual instruments has been successful. Maintenance of the test systems has been a problem.

4.2.2.1 **Verification of acceleration display**. The characteristics of the acceleration display shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.1)

Laboratory testing is the easiest method for confirming specified characteristics. Test equipment is available which can apply various g loadings in all directions.

VERIFICATION GUIDANCE

A centrifuge and vibration table can be used to confirm the calibration and accuracy of the indicator and sensor.

Drop-testing the packaged acceleration indicator in the laboratory is the most practical means of testing the locking mechanism and damage to the indicator. Tests per MIL-STD-794 may be conducted.

VERIFICATION LESSONS LEARNED

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3.2.2.2 Attitude display. The attitude indicator (AI) displays the air vehicle pitch and roll attitude with respect to the gravity vector and shall have the following characteristics: _____.

REQUIREMENT RATIONALE (3.2.2.2)

Attitude indicators are used to determine, achieve, and maintain aircraft pitch and roll attitude in all phases of flight. The most critical use is during flight in IFR (Instrument Flying Rules) conditions. As such, it is a primary safety-of-flight display, and a minimum of two independent attitude references per aircraft are usually required.

REQUIREMENT GUIDANCE

There are two basic types of attitude indicators: (1) self-contained AIs which contain a vertical sensor coupled to the display; and (2) the remote AI which is driven electrically by a separate attitude reference system. Electro-optical displays may be used, providing they meet the requirements of contrast ratio, etc., previously stated.

Self-contained AIs are frequently specified for use to provide standby attitude information when the primary attitude display fails. In the case of gyroscopic instruments, the gyroscope wheel has a certain coast-down time which provides a usable attitude display for several minutes in the event of a power failure. Self-contained attitude indicators have proven to offer size and weight advantages over remote standby attitude indicating systems. The following items must be given consideration when specifying attitude indicators:

a. Display. The common element of attitude indicators is that they all display aircraft pitch and roll attitude by means of a two-colored display (normally a spheroid or drum on some self-contained AIs). The upper half of the spheroid simulates the sky or above the horizon and is colored a light gray or light blue (blue is preferred in white-lighted applications). The lower half simulates the ground or below the horizon and is colored black or brown (brown is preferred in white-lighted applications). The intersection of the two colors represents the horizon line or zero pitch-and-roll reference. A fixed miniature aircraft symbol in the center of the display is the reference to which attitude is displayed. Upward movement of the horizon line indicates a dive maneuver and downward movement indicates a climb maneuver. Roll attitude is displayed by rotation of the horizon line, spheroid, and roll pointer which should be at the bottom of the display. Clockwise rotation indicates left wing down and counterclockwise rotation indicates right wing down. This attitude display convention simulates what the pilot would see if he were flying visually and observing the earth's horizon through the cockpit window. It is safety-of-flight critical that all attitude displays operate in this manner. Examples can be found in MIL-I-83336 and STANAG-3637.

b. Range. The range of the AI must be compatible with the air vehicle in which it is to be used. The range is typically 85° in climb and 85° in dive with an unlimited range of 360° in roll. The pitch range is usually limited by the vertical sensor. If loop maneuvers are to be flown, it may be desirable to specify maximum errors allowed during and after loops.

c. Pitch trim. Most attitude indicators used by the USAF incorporate a pitch trim adjustment to align the horizon line with the miniature aircraft symbol. This allows the pilot to "zero" the display when conditions require maintaining a relatively large angle of attack due to a heavy load or low airspeed for long periods. The zero index mark shows the pilot that some trim has been put in. Certain users, including some NATO nations, do not favor the incorporation of pitch trim for safety reasons. The range of pitch trim is typically 5° to 10° down to 10° to 20° up. These values are not critical and can be specified based on the normal angle-of-attack range of the aircraft.

d. Self-contained indicator. When a self-contained AI (vertical sensor and display combined) is to be specified, the following items must be considered:

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(1) Static accuracy. The static accuracy of self-contained attitude indicators is usually specified at 0.5° in pitch and roll. An accuracy better than this is very difficult to measure and would simply be a matter of judgment on the part of the tester.

(2) Dynamic accuracy. Dynamic accuracy is that accuracy which can be expected to be maintained during various flight maneuvers. It is virtually impossible to test in the laboratory, and other means of specifying this requirement have been used in the past (see lessons learned).

(3) Caging. Self-contained AIs usually require a caging mechanism to bring the display to 0° in pitch and roll during start up or if the vertical sensor has deviated from vertical for some reason or another. It will be necessary to specify the panel tilt angle for self-contained AIs because it must be taken into account when designing the vertical sensor in the case.

(4) Power warning flag. The power warning flag tells the aircrew when power to the AI has been discontinued. It is desirable to have the flag remain from view as long as a usable attitude reference is maintained, such as in the coast-down mode of the gyroscope wheel, if used. If the flag does come in view immediately upon power failure, it must not obscure the display if the AI design provides attitude information for a limited time after power failure.

e. Remotedriven indicator. The following factors must be considered when specifying AIs that are driven from a remote vertical sensor:

(1) Compatibility. The indicator must be designed to be compatible with the vertical sensor planned to be used. If the vertical sensor has an all-attitude capability, the indicator should also have this capability.

(2) Accuracy. An accuracy of ±0.5° within ±30° of zero pitch and roll is necessary and is easily attained. Precise aircraft attitude control and manual dive bombing accuracy are dependent on the accuracy of the attitude indicator. Accuracy at higher attitudes becomes less critical, but it is typically ±1°.

(3) Sensitivity. A sensitivity of ±0.25° or better is necessary to provide detection of minute attitude changes. Sensitivities greater than ±0.25° are not desirable, as undetected attitude changes, especially at high speeds, can cause difficulty in maintaining constant altitude.

(4) Follow-up operation. The pitch and roll follow-up rates should be compatible with the maximum pitch and roll rates of the aircraft without excessive lag. Typical rates for high performance aircraft would be 60°/second in pitch and 300°/second in roll. Typical AIs have 90°/second pitch capability and 300° second roll capability with lag no greater than 3° and 10°, respectively.

(5) Hunting and jumping. It is very important that the attitude display operate smoothly with no noticeable sticking, hunting or jumping, as these conditions are generally accepted as indications of a malfunctioning indicator. In addition, nonsmooth operation would be distracting and annoying to the pilot.

(6) Pitch scaling. For 3-inch case size primary attitude indicators, the pitch display may be expanded to provide the necessary resolution to easily detect small attitude changes. The expansion ratio is typically 1.5 to 1. Expanded pitch displays may be provided in larger AIs if the flight characteristics of the aircraft dictate the need to be able to detect very small pitch attitude changes. Too much expansion could be undesirable as it could result in a noisy display (too much sphere motion). Expansions in the range of 1.5 to 1 to 2.0 to 1 have generally proved acceptable.

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(7) Malfunction warning flag. The AI is a primary safety-of-flight instrument, and if it fails and gives erroneous information without the pilot's knowledge and he continues to assume it is right, the aircraft could be put into a hazardous and possible nonrecoverable attitude. For this reason it is mandatory that the AI contain maximum self-monitoring capability.

The following are conditions which should actuate the warning flag:

(a) Loss of power to the indicator or sensor.

(b) Invalid pitch or roll attitude signals.

(c) Internal failure of the AI display mechanism, such as amplifier failure, servo-motor failure, etc.

REQUIREMENT LESSONS LEARNED

Dynamic or flight accuracy of gyroscopic-type self-contained attitude indicators is difficult to verify. It can only be accomplished under actual flight conditions and the AI compared to an accurate reference, such as an inertial navigation system.

It has been found from experience that dynamic errors can be held to within reasonable limits if certain characteristics of the gyroscope are maintained. These characteristics are:

a. Drift rate. The free gyroscope should not drift more than 0.75° per minute in either axis when tested on a 3-axis motion table (Scorsby).

b. Erection rate. The erection rate of the gyroscope is usually specified at 1.9° to 3.1° per minute in both pitch and roll. The typical value is approximately 2.5° per minute. If the specified erection rate is too high, significant errors will result from accelerations and turns. If the erection rate is too low, the gyroscope will not remain erect.

c. Erection cutout angle. The erection cutout angle is usually specified at 6° to 8.5° in pitch and roll for 2-inch indicators. The typical value is approximately 7°. The cutout angle for 3-inch indicators is usually specified at 7° to 10° in pitch and roll. Indicators with electrical erectors will have a smaller erection cutout angle in the roll axis and may have no erection cutout in the pitch axis.

The performance of remote attitude indicators is based on the accuracy of the remote vertical sensor. However, the AI must smoothly follow the output of the sensor. Experience has proven that hunting and jumping magnitudes less than 0.04 inch total amplitude provide the degree of smoothness that pilots will accept. The rates at which this tolerance is most critical and must be adhered to are the lower rates between 0° and 20°/second.

4.2.2.2 **Verification of attitude display.** Attitude indicator characteristics shall be evaluated in the laboratory by: _____.

VERIFICATION RATIONALE (4.2.2.2)

The laboratory provides the best conditions to confirm specified requirements.

VERIFICATION GUIDANCE

Special test equipment in conjunction with standard pitch, roll and yaw tables are used to determine performance characteristics. Flight testing with comparison to a known vertical reference is the final verification of accuracy but is too costly to do on a routine basis.

VERIFICATION LESSONS LEARNED

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3.2.2.3 **Attitude director indicator (ADI).** The attitude director indicator shall provide attitude information combined with action director information superimposed on the attitude display. It shall have the following characteristics: _____.

REQUIREMENT RATIONALE (3.2.2.3)

Attitude director indicators perform the same function as the attitude indicator in addition to displaying additional flight control information, such as steering commands, rate of turn, slip, etc. These additional functions, incorporated into one display, reduce pilot cross-check workload, which is very important during high workload flight, such as during instrument approaches.

REQUIREMENT GUIDANCE

The information and requirements for attitude indicators apply to the ADI. In addition to attitude information, the ADI provides pitch and bank steering command displays which are controlled by a flight director computer. The steering command display typically consists of two bars. A vertical bar provides roll steering commands and a horizontal bar provides pitch steering commands. The flight director computer which drives the bars is mechanized such that the bars will be centered on the miniature aircraft symbol when the aircraft is on a flight path that will either result in the aircraft flying to the desired flight path or will maintain the aircraft on the desired flight path. The command bars are typically used during ILS approaches and in intercepting and flying a desired heading or TACAN radial. The command bars are biased out of view when not in use. A warning flag is provided to warn the pilot of an invalid or failed flight director computer. The ADI display also incorporates a glideslope deviation scale and pointer, a rate-of-turn needle, and a slip indicator. The glideslope pointer indicates aircraft position relative to the ILS glideslope centerline and receives its input signal directly from the ILS glideslope receiver. The rate-of-turn indicator indicates turn rate of the aircraft where full scale (two needle widths) is normally equivalent to a standard 2-minute turn. The rate-of-turn needle receives its input from a rate-transmitting gyro or a derived rate-of-turn output (heading rate) from an attitude heading reference system.

Like the attitude indicators, the ADI should have a malfunction warning flag for the attitude portion of the indicator.

A pitch trim control knob may be provided. If used, it shall be in the lower right side of the indicator (see paragraph 3.2.2.2 for details). The ADI can incorporate other displays depending on the type and mission requireents of the aircraft. Typical ADI functions include the following:

a. Rising runway symbol. This symbol displays the main landing gear radar altitude above the runway. It comes into view normally at 200 feet radar altitude and moves up towards the miniature aircraft symbol as the aircraft descends. The symbol will coincide with the bottom of the miniature aircraft when the main landing gear wheels touch the ground. The rising runway display should be included in ADIs intended for use on aircraft that will be required to make Category II (1200-foot runway visual range and 100-foot decision height) landings. The symbol receives its input from a radar altimeter.

b. Expanded localizer display. Localizer deviation is displayed with a full-scale range of one dot. The localizer signal is received directly for the ILS localizer receiver. Ideally, this display should be combined with the rising runway symbol although a separate scale and pointer in the lower part of the ADI can be used. Incorporation of a localizer display in the ADI will minimize cross-check workload during the final phases of an instrument approach. This function should be incorporated in ADIs intended for aircraft that will land in weather minimums lower than Category II. An associated failure warning flag is required.

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c. Speed command display. This display consists of a pointer that moves in a vertical path normally located on the left side of the ADI display. The operation of the pointer is such that if it is above center, the aircraft approach speed is fast and if it is below center, the aircraft approach speed is slow. With the pointer centered, the aircraft is on the proper approach speed. The input for this display is an angle-of-attack based signal. This display should be included in ADIs intended for aircraft that will land in weather minimum lower than Category II. An associated warning flag to warn of invalid inputs is required.

d. Heading. Some ADIs incorporate a 3-axis sphere. The third axis is used to display aircraft heading using appropriate markings. An example of this ADI can be found in MIL-I-27619.

e. Attitude display configuration. Generally, the attitude display will conform to that described in 3.2.2.2.

f. Pitch and bank command characteristics. Deflection of the command symbol or symbols should be linear in degree with respect to the input signal. Damping and response should be such as to minimize lag and overshooting. The display must be stable as practical under rough air and vibratory conditions. Accuracy and scale factors shall be sufficient to allow the pilot to maintain the desired flight path without excessive overshooting or snaking. The effect of acceleration on the display accuracy must be negligible.

g. Glideslope deviation scale factor. The scale factor should be such that one-dot deflection is equivalent to a 0.25° deviation from glideslope centerline and shall require an input of _____. Two-dot deflection shall be equivalent to 0.5° deviation and shall require an input of _____. Pointer deflection must be linear with respect to the input signal. The pointer mechanism must be overdamped. The effect of acceleration on pointer accuracy must be negligible.

NOTE: The input signal depends upon the characteristics of the flight director computer (see 3.2.2.8).

h. Turn and slip sensitivity. The rate-of-turn and slip indicator should meet the requirements necessary to control the air vehicle. Guidance can be found in 3.2.2.27.

i. Auxiliary attitude outputs. Outputs of the pitch-and-roll display position can be provided if necessary for use by an external attitude comparator monitor.

REQUIREMENT LESSONS LEARNED

The characteristics of the ADI depend upon the flight characteristics of the air vehicle. Typical values of accuracy, response, and damping, which have proven acceptable for the pitch-and-roll steering commands, are a linear response within 7.5 percent of the proportionate full-scale value of the input, damping such that overshoot is held to less than 1.5 percent and response time of 1/3 second.

It has been found that the use of "raw" deviation data applied to the steering commands is unacceptable.

If the air vehicle has redundant pilot and copilot attitude displays and reference systems, it is recommended that an attitude comparator monitor be installed. The comparator monitor compares the two attitude display systems, and if they differ, a failure warning is annunciated. The ADIs must be mechanized to provide signals at the indicator connector suitable for use with a comparator monitor. The signal characteristics are typically a synchro resolver stator and rotor. Two sets are required--one provides roll-axis position and the other provides pitch-axis position.

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4.2.2.3 Verification of attitude director indicator (ADI). The ADI characteristics shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.3)

Most of the verification can readily be accomplished in the laboratory using simulated input signals to test sensitivity, damping, linearity, etc.

VERIFICATION GUIDANCE

Special test equipment is usually used to verify performance of the ADI. Final performance characteristics will require simulator or flight tests to make certain that the ADI has the proper response and damping characteristics for the particular air vehicle. (See 3.2.2.8, Flight Director Systems.)

VERIFICATION LESSONS LEARNED

3.2.2.4 Clock/timer. The clock or timer shall include a display of real time. The following characteristics will be provided: _____.

REQUIREMENT RATIONALE (3.2.2.4)

The provision of a clock is basic to any air vehicle. In addition to providing real time, most clocks provide elapsed-time measuring features which are required for many functions.

REQUIREMENT GUIDANCE

The clock may be either mechanical or a numeric solid-state electronic type which displays time of day in hours, and minutes and has an elapsed-time capability in seconds. When the mission requires a bomb timer, it should be a solid-state electronic design.

a. Clocks. The following characteristics should be considered when specifying clocks and timers:

(1) Display. The display may be an analog, numeric, or a combination of analog and numeric displays. In addition to a display of time of day, elapsed-time and countdown displays may be specified. Historically, clock displays have consisted of hour, minute and second hands, 12 hours being used for one revolution of the hour hand. Straight numeric readout clocks have been tested by the Air Force, and most of the pilots accepted the display. If a numeric display is desired, it should be carefully evaluated for acceptance by the users, including possible foreign buyers/users, before it is specified. Numeric readouts should display real time from 00:01 to 24:00. Elapsed time and countdown time may be analog or numeric. The time period capability must satisfy mission requirments.

(2) Accuracy. The accuracy must be sufficient to meet mission requirements. It may be necessary to specify accuracies at high and low temperature as well as ambient temperature, depending upon the clock design and its characteristics.

(3) Elapsed-time actuator. If equipped with an elapsed-time display, a push button must be provided to start, stop, and reset or obliterate the display. When the button is pushed, the display should start to count up. When the button is pushed again, the display should freeze. When the button is pushed a third time, the display should reset or disappear from view.

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(4) Countdown mode actuation. If a countdown mode is required, a push button should be provided to initiate the countdown mode of the clock. A second actuation of the countdown push button should zero the countdown mode.

(5) Time set. A suitable means must be provided for resetting the time of day display when it does not correspond to actual time.

(6) Power. Mechanical clocks have been spring-wound types since their inception. New technology permits the use of a self-contained battery or external power, but the use of self-contained batteries in instruments has not received wide approval in the Air Force due to logistics problems.

(7) Power interrupts. If an electrical input clock is specified, the clock should be capable of operation during power interrupts of the longest duration anticipated.

(8) Running time. Running time will depend upon the clock design. Spring-wound clocks will normally run for eight days.

(9) Self-test. If numeric light-emitting display is used, a push-to-test switch should be provided which shall cause all digits to appear.

(10) Case size. A 2-inch nominal case size is normally specified for clocks. Special purpose clocks may have to be larger.

b. Bomb timers. When specifying bomb timers which are sometimes used on a backup system to a primary weapons delivery system, the following modes of operation require consideration:

(1) Clock mode. Controls and mode select capability may be used to provide a time-of-day readout.

(2) First and second stopwatch modes. Controls and mode selection capability may be specified to provide stopwatch modes capable of counting up to the time required for the bomb delivery.

(3) Single countdown timer mode. Controls and a mode select capability may be provided to allow a preset time to be selected. The bomb/timer, upon being started, will count down to zero. An output signal and a visual indication of zero time should be provided.

(4) Dual countdown time mode. In this mode, the timer functions as a bombing pullup and release timer. Controls and mode selection capability must be made available to allow two preset timers to be selected. Upon initiation the bomb/timer counts down to zero on the first present time. At zero an output signal is provided. When the first preset time reaches zero, the timer automatically switches and starts to count down the second preset time to zero. Again, when zero is reached, a separate output signal is provided. Visual cues are provided when each time reaches zero.

REQUIREMENT LESSONS LEARNED

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4.2.2.4 Clock/timer verification. The requirements specified for the clock/ timer shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.4)

The laboratory is the only suitable place to verify clock/timer compliance with requirements because it provides the means and the equipment which are necessary for the verification.

VERIFICATION GUIDANCE

Accurate laboratory time standards can be used to determine accuracy of the clock/timer. Various environmental conditions can be imposed as required in the specification.

VERIFICATION LESSONS LEARNED

3.2.2.5 Flight data recorder. A flight data recorder (FDR) shall be provided to aid in mishap investigations. The following parameters shall be recorded: _____.

REQUIREMENT RATIONALE (3.2.2.5)

A flight data recorder (FDR) records data for mishap investigation purposes. Prerecorded data can serve the dual purpose of flight path reconstruction and equipment failure identification so that corrective action can be taken to prevent future accidents.

REQUIREMENT GUIDANCE

The recorder data must survive crash conditions of high shock and fire. One solution to crash survivability is an ejectable recorder although such systems have disadvantages of criticality of mounting location, unintentional ejections, and location after crash. Ejectable FDR are often combined with a Crash Position Indicator (CPI). Concepts in FDR development are in a state of flux; therefore, this handbook entry cannot offer the latest information. MIL-STD-2124 provides information regarding Navy equipment. The following items must be considered when specifying crash data recorders:

a. Survivability. A draft Federal Aviation Standard defines FDR survivability testing for impact, penetration resistance, static crush, fire protections, and water protection tests and is reproduced below. This testing is required in the order listed and without repairs during or between tests. On completion of the testing it must be possible to retrieve previously recorded data. The recommended tests are as follows:

(1) Impact. Apply to the recorder, at each of its three main orthogonal axes, an impact shock having the characteristics of a half-size wave with a peak amplitude of 1000 g and of five milliseconds duration.

(2) Penetration resistance. Apply an impact force equal to that produced by a 500-pound weight that is dropped from a height of ten feet to each side of the recorder in the most critical plane. The impact force must be applied through a straight steel circular bar having a cross-sectional area of no more than 0.05 square inches and a length of not less than 1 1/2 inches. The direction of the load must be along the longitudinal axis of the bar. Following impact, the steel bar must be whole, and the end which first contacted the recorder must not have laterally deflected, relative to the bar's longitudinal axis of symmetry prior to the test, more than 0.265

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inch. The recorder must be positioned on a square bed of 65 mesh sand 3 to 6 feet on a side and 185^{+0} inches deep. At the moment of impact, the longitudinal axis of the bar must be within 5° of the vertical.

(3) Static crush. Apply a uniform distributed load of not less than 5000 pounds to the recorder in the most critical direction for a minimum of 5 minutes.

(4) Fire protection. Expose the recorder to flames of 1100°C for 30 minutes. The flames must envelope at least 50 percent of the recorder surface area. Except for small parts (such as knobs, fasteners, seals, grommets, and small electrical parts) that would not contribute significantly to the spread of a fire, all combustible materials must be self-extinguishing. When tested in an approved method, the average burn length must not exceed three (3) inches and the average flame time after removal of the flame source must not exceed 30 seconds. Drippings from the test specimen must not continue to flame for more than an average of (3) seconds after falling.

(5) Water protection. Immerse the recorder in sea water at a simulated depth of 15,000 feet for 30 days.

b. Recorded parameters. The capabilities of the aircraft must be considered in the selection of the parameters to be recorded, the update rate of recording, and the resolution of the data. The Air Force Safety Center may be able to offer recommendations for a given aircraft type. These recommendations must be weighed against the availability of that data or the cost and weight penalties of adding additional sensors to provide the data. To aid in the system planning process, a list of recommended parameters from various sources is offered.

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KEY TO FOLLOWING LIST

1. ARINC 542
2. ARINC 573
3. PROPOSED 573 EXPANSION
4. RECOMMENDED FOR FIGHTER/FIGHTER TRAINER BY USAF SAFETY CENTER

KEY	PARAMETER
1, 2, 3, 4	Altitude
1, 2, 3, 4	Airspeed
1, 2, 3, 4	Heading
1, 2, 3, 4	Vertical Acceleration
1, 2, 3, 4	Time
2, 3, 4	Pitch Attitude
2, 3, 4	Roll Attitude
2, 3, 4	Pitch Command (Stick or Control Column)
2, 3, 4	Bank Command (Stick or Control Wheel)
2, 3, 4	Yaw Command (Rudder pedal position)
2, 3, 4	Trim Position
3, 4	Lateral Control Surface (Aileron Position)
3, 4	Yaw Control Surface (Rudder Position)
3, 4	Flap Position (Leading and Trailing Edge)
3, 4	Spoiler and Speed Break Position
3, 4	Fire and Overhead Detection Discretes
3, 4	Hydraulic Pressure Fault Warning Light
3, 4	Electrical Bus Fault Warning Light
3, 4	Outside Ambient or Total Air Temperature
4	Angle of Attack
4	Yaw Angle
4	Throttle Position
4	Engine Output Measurements
4	Fuel pressures, flow supply
4	Flight control/fly-by-wire fault discretes
4	Oil Quantity
4	Aircraft unique items, e.g., wingsweep, TFR switches
4	Fault warning light discretes, such as air data computer
4	Autopilot position
4	Cabin pressure
4	Aircraft bus voltage
2, 3	Lateral Acceleration
2, 3	Engine Thrust

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2, 3	Thrust Reverse Position
2, 3	VHF and HF Keying
3	Selected Flight Director Mode
3	Localizer and Glideslope Deviation
3	Greenwich Mean Time
3	Longitudinal Acceleration
3	Radio Altitude
3	Position of the strut expansion retract switch
3	Indication of outer-, middle-, and inner marker passage

NOTE: A cockpit voice recorder is required by FAA. Often the voice recorder is separate from the FDR. Voice recording is recommended if the recording medium will accept voice information. Update rate and resolution of each parameter should be addressed.

c. Interface. The largest expense of the FDR may result from obtaining the data; most parameters desired are available from existing systems. If foresight is used in making these signals easily accessible and in an convenient format, cost savings will result.

d. Recording time. The FAA requires 25 hours of recording time before self-erasure. This requirement is achievable for magnetic tape systems. It is now feasible to store data in nonvolatile, solid-state memory. The solid-state memory recording time before self-erasure would be limited to accident analysis.

e. Operational factors. The recorder container must be colored either bright orange or bright yellow and marked with reflective patches. The recorder shall be automatically powered and shall not require crew action.

There shall be a malfunction indication if the recorder ceases to function.

REQUIREMENT LESSONS LEARNED

There have been several aircraft accidents, the cause of which has not been able to be determined. It is believed that a flight data recorder would have helped to find the cause of most of the accidents.

4.2.2.5 **Verification of flight data recorder**. Performance of the flight data recorder shall be verified in the laboratory by _____.

VERIFICATION RATIONALE (4.2.2.5)

The laboratory is the best place to verify the performance of flight data recorder because controlled environmental conditions can be applied to the equipment.

VERIFICATION GUIDANCE

Crash conditions are simulated in the laboratory by instrumenting the recorder and dropping it from various heights on different surfaces to obtain the g force and duration specified. Other crash conditions are simulated as outlined in the requirements section. Recorded parameters can be read out after the environmental conditions are imposed on the recorder to determine if they survived.

VERIFICATION LESSONS LEARNED

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3.2.2.6 **Engine pressure ratio system (EPR).** The EPR display shall receive signals from an EPR sensor and shall display EPR values to the aircrew. The EPR sensor shall sense the engine inlet total pressure, the turbine exhaust total pressure, divide the exhaust pressure by the inlet pressure, and provide a signal proportional to this nondimensional ratio for use in a display or in control of an aircraft. The performance of the system shall be as follows: _____.

REQUIREMENT RATIONALE (3.2.2.6)

Depending upon the type of engine used in the weapons system it may be necessary to provide an indication of EPR to indicate the amount of thrust being operated by the engine.

REQUIREMENT GUIDANCE

Engine pressure ratio (EPR) is the ratio of the total pressure in front of the engine compressor divided into the total pressure behind the turbine. EPR is a dimensionless number normally in the range of 1.0 to 3.5. Turbofan engines tend to have lower EPRs because of the power extracted by the turbine to drive the fan. Some commercial EPR systems have the ability to compute and display an EPR of less than 1.0. This condition may be encountered on a large fan engine that is throttled back to flight idle for descent. An EPR of 1.0 or less means that even though the engine is running, the net effect on the aircraft is a negative thrust. It is recommended that the military not require the capability to compute display EPR less than 1.0 as it increases the complexity of the system more than it increases the usefulness of the system.

Related to EPR is FPR (fan pressure ratio). On large fan engines some commercial users require a display of the fan pressure ratio. While FPR gives a good indication of the thrust being produced by the fan, it is difficult to compute because of the small differences (low ratio) between the two pressures being divided. Additionally, the plumbing requirements impose a much greater weight penalty than does an EPR system. The use of FPR by the military is not recommended.

EPR is applicable to any fixed nozzle engine. EPR is not suitable for use on any variable nozzle engine, even if the engine employs a two position nozzle. This is because of variations in nozzle geometry and control. It would be possible for two engines to have the same EPR but be producing quite different levels of thrust. For variable nozzle engines, use of a thrust computing system is recommended (see paragraph 3.2.2.26 for a thrust computing system).

The following requirements should be specified in procurement documents:

a. Range. Generally speaking, the EPR transmitter is designed specifically for the engine it is to be used with. An off-the-shelf transmitter may be used only if it very closely matches the requirements of the engine. This is because an unused range is extremely costly in terms of accuracy. Normally, a 0.08 percent unused range is adequate to provide for engine growth.

b. Accuracy. Traditionally, accuracy requirements are driven by the capability of the EPR transmitter manufacturer. EPR accuracies are always expressed in terms of thousands of an EPR unit. Different tolerances are required for different pressures. The larger tolerances are allowed at the lower pressures. The 1.000 point is significant because it provides an operational point that can be checked prior to engine starting. A typical accuracy requirement would be D+0.020 EPR units.

c. Response. The system should be able to respond just slightly faster than the engine can change its pressure output. Many times when a new EPR system is flight tested, there is a noticeable "jitter" in the pointer and counter. This problem can usually be solved by installing pressure dampers in the high pressure line where it enters the transmitter.

d. Sensitivity. At higher pressures more liberal tolerances for sensitivity are allowed. Sensitivity requirements are normally in the range of 0.0008 to 0.15 inches of mercury. Essentially, sensitivity is a measurement of the internal "stickiness" and "looseness" within the transmitter and indicator.

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e. Attitude operation. Even if the aircraft is not intended to operate at all attitudes, the transmitter should be capable of operating at all attitudes. This is really a test (which becomes a requirement to the manufacturer) to assure that internal moving parts are kept in good mechanical balance. A well-balanced system will be more immune to wear due to vibration.

f. EPR limit or command. Many EPR indicators incorporate manual or automatic command "bugs" or limit markers. These markers are useful during takeoff and other flight modes. EPR command "bugs" are used with some fuel savings advisory systems to direct the pilot to the most efficient EPR range.

REQUIREMENT LESSONS LEARNED

It is advisable to make the pressure lines and the transmitter connections two different sizes. A one-fourth-inch line and a five-sixteenth-inch line are sometimes used. There may well be twelve or more connections in the lines between the engine and EPR transmitter. If the lines are made the same size, sooner or later someone will cross-connect the lines and destroy a transmitter.

4.2.2.6 Verification of engine pressure ratio system. The engine pressure ratio system shall be evaluated in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.6)

Laboratory testing is the best method of verifying range, accuracy, and general performance of the EPR system. Accurate pressure changes and measurements can be readily achieved using standard equipment. Environmental changes can also be controlled.

VERIFICATION GUIDANCE

Special, automatic, test equipment is usually used to test production quantities. Environmental conditions are imposed as required.

VERIFICATION LESSONS LEARNED

3.2.2.7 Engine temperature display. The engine temperature display shall receive signals from an engine temperature sensor and shall display temperature in degrees Celcius to the aircrew. The display shall have the following characteristics: _____.

REQUIREMENT RATIONALE (3.2.2.7)

The temperature indication is used to avoid high temperature damage to the engine, determine proper engine operation, and detect or avoid hot starts during engine startup.

REQUIREMENT GUIDANCE

An engine temperature display is provided for each engine and gives an indication of the engine operating temperature. The display receives a temperature signal from the engine. This is normally, but not necessarily, a thermocouple signal generated by a harness of thermocouples located in the engine gas stream. The thermocouples should be Type K (chromelalumel). When other types of engine temperature sensors are used (such as the optical pyrometer), the indicator must be tailored to the specific output of the sensor.

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The following requirements need to be addressed when specifying engine temperature display:

a. Range. The range of the display shall be expressed in degrees Celcius. The range specified should be such that the lowest operating engine temperature at any operating condition (e.g., altitude, airspeed, throttle position, etc.) and the highest possible temperatures are included. The range should be limited to these levels to maintain the smallest usable span between the lowest and highest temperatures. The highest temperature should also be limited by the useful range of the sensor employed in the indicator system.

b. Accuracy. The accuracy requirements specified should be no greater than needed--normally ± 5°C in the most accurate region of the display. The display may be broken into regions of differing accuracies which are dependent upon the need for such accuracies. Accuracies should be specified for both normal room temperature operation, operation at the extremes of ambient operating temperature, and operation during reliability testing.

c. Warmup response. The response requirement specified should be in the form of response to a step change of the input temperature signal. The size of the step change may be specified by defining the starting and ending indication input temperatures of the step change. The tolerance (settling-out characteristics) of the final indication and the time within which this final indication is reached should be specified. These requirements are dictated by the need to detect abnormally high temperature rise within the engine during a hot start condition. A suggested adequate response is 6 seconds to a 1000°C step change within ± 20°C.

d. Display. The display may be either round dial or vertical scale. Round-dial displays are normally of the 2-inch diameter type. Greater accuracies are obtained by use of supplemental counters or expansion of the scale in ranges of greater needed accuracies. The normal operating position during cruise should be approximately at the 9 o'clock position of the round dial.

e. Thermocouples. The display must be compatible with and calibrated for use with the specific type of thermocouples to be used on the engine. Standards (NBS)125. Monograph Thermocouple characteristics are given in the National Bureau of Standards (NBS) Monograph 125.

f. Grounding of thermocouple extension wires. A maximum shift of indication when either thermocouple lead is connected to the ground or low potential side of the input power supply should be specified. The grounding may be at any point between the thermocouple and the interior of the display. Typical limits are ± 2.0°C.

g. External thermocouple circuit resistance. The display shall be designed such that a change in thermocouple circuit resistance between the hot junction and the indicator produces a negligible or small change in indication. A suggested adequate tolerance is 5°C.

h. Thermocouple cold junction compensation. The display should be designed such that the thermocouple circuit cold junction is located within the display. Electronic compensation for the cold junction ambient temperature must be provided. Temperature control or standard cells must not be used in the cold junction circuitry. The compensation must be such that the indication accuracy is as specified regardless of the temperature of the cold junction.

i. Optional features. The display may include a settable maximum temperature recording pointer or a set of contacts which close at a certain temperature to energize a remote overtemperature warning light.

REQUIREMENT LESSONS LEARNED

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4.2.2.7 **Verification of engine temperature display**. The characteristics provided in the engine temperature display shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.7)

Thermocouple or other temperature sensor outputs can readily be produced in the laboratory, together with environmental condition variations required to evaluate the indicator.

VERIFICATION GUIDANCE

When testing temperature displays designed to operate from chromel-alumel thermocouples, temperature-voltage characteristics can be obtained from NBS Monograph 125. Other conditions can be imposed as required using standard laboratory equipment.

VERIFICATION LESSONS LEARNED

3.2.2.8 **Flight director system (FDS)**. The FDS shall display the air vehicle interception and tracking of course, heading, attitude, and glideslope, based on present position, heading, desired position, and rate of convergence. The FDS will continuously calculate the proper pitch, bank, and power to perform the desired maneuver. It shall conform to the following: _____.

REQUIREMENT RATIONALE (3.2.2.8)

When crew workload associated with operation of an aircraft is very high, flight director systems may be employed to provide relief. Factors bearing upon the decision to employ the flight director shall include aircraft speed (and associated aircraft control ability), complexity of aircraft systems and/or subsystems, and the operating environment. In certain applications flight director systems may not provide sufficient relief, and the use of automatic flight control systems must be considered (e.g.,: all-weather landing and high-speed terrain-following).

REQUIREMENT GUIDANCE

a. General. If a flight director is to be employed, components of the system must be specifically identified, including:

(1) Attitude Director Indicator (ADI) and/or Head-up Display (HUD).

(2) Horizontal Situation Indicator (HSI).

(3) Flight Director Computer (FDC).

The FDC may be analog, digital, or hybrid and may be dedicated equipment or part of a central computer/processor. Regardless, the control algorithms must be carefully specified to assure satisfactory system performance.

(4) Flight Director System Control Panel.

The control panel must provide a means for crew selection of navigation modes, manual heading mode, and OFF (or standby) mode. Positive indication of the operating mode must be provided. When automatic switching between manual heading submode and other navigation modes is employed, indication of the operating submode must be provided at the control panel or on the primary flight instruments.

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b. System interface. Specific equipment which comprise the flight director system must be identified to establish system interface requirements. In addition, applicable equipments in the following list (if they provide input to the FDC) must also be identified (see 3.8):

(1) Attitude and Heading Reference (AHRS, DG/VG, or INS).

(2) Navigational Radio Receivers.

(a) Tactical Air Navigation (TACAN)

(b) VHF Omnidirectional Range (VOR)

(c) Instrument Landing System (ILS)

(d) Microwave Landing System (MLS)

(3) Radar Altimeter

(4) Air Data Computer

(5) Data Link Receiver

c. Flight director system (computer) logic. The flight director system may be utilized to reduce pilot workload in intercepting and tracking course, heading, altitude, or glideslope. Based upon present position, desired position, and the rate of convergence, the flight director computer continuously calculates the proper pitch, bank, or power to perform the desired maneuver (the commands are presented on the control displays/indicators). One of the following methods of displaying commands can be used:

(1) Pitch and bank cross pointers (in the ADI). When the aircraft is not properly positioned for course intercept, the vertical steering pointer is offset. By banking the "miniature aircraft" toward the pointer, the pointer moves toward the center of the ADI. By maintaining the pointer at center, the computed steering commands are satisfied. The computer will recognize proximity to and rate of convergence on the desired course and will supply appropriate commands to permit asymptotic intercept and stable tracking of the desired course. The above method of operation is equally applicable to vertical steering. When steering commands displayed on the horizontal pointer are satisfied, the aircraft will intercept and track the desired vertical path.

Power commands may also be displayed on ADIs containing a Fast-Slow display. The above system description is identified as the "conventional FDS" or the "2-cue system." A variation of this system is the integrated cue system in which a single cue is utilized; it is analogous to a pivoted horizontal pointer--when the cue pivots, the pilot must introduce bank to satisfy roll commands and as the cue transitions vertically the pilot must introduce pitch to satisfy steering commands.

(2) Three-cue flight director system (3-Cue FDS). This type of system is used primarily for V/STOL aircraft. AS in the conventional system, the vertical pointer furnishes guidance for lateral steering. However, the horizontal pointer is utilized to maintain reference airspeed by controlling pitch. The third cue (normally a scale and pointer similar to the glideslope display in the ADI) is utilized for vertical path control (ILS glideslope tracking, altitude hold, or climb/descent rate).

(3) Electro-optical displays (HUD, VSD, EADI). These types of displays utilize electronically-generated symbols to display flight director steering commands. The control logic associated with these displays is identical to conventional displays. In some aircraft the outputs from the FDC are scaled such that flight director steering commands are displayed on both HUD and ADI simultaneously.

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d. Modes of operation. There are several modes of operation for flight director systems. Accordingly, specific modes of operation for a particular flight director system/weapons system must be specified. In addition, many modes are comprised of two or more submodes and depend upon automatic beam sensing and switching to effect submode changing. These submodes and operating regimes must also be specified, as well as automatic switch functions. The following modes (which may also be submodes) are provided:

(1) Manual heading mode. The pilot must select the desired reference heading (setting HDG on the HSI or similar control/display/flight control panel). The flight director system uses preset heading and reference heading to generate the proper steering commands to turn to and maintain the reference heading. The standard rate of turn is 3 degrees per second.

(2) Data link mode. This mode is most often an adaptation of the manual heading mode except that the heading set function is remotely controlled by a ground station/mission controller.

(3) Inertial navigation system (INS) mode. Desired course is established by a central navigation/mission computer by way-point identification. Deviation from course, as measured by an INS, provides a course error reference upon which to base lateral steering commands.

(4) Radio navigation mode(s). The desired radio reference (VOR/TACAN/ILS/MLS/etc.) must be selected, and reference course identified by setting the CRS on the HSI or similar control/display/flight control panel. The FDS senses present position (heading and course error), desired course, and rate of convergence to generate the proper steering commands to capture and track desired course. Some flight director systems employ submodes and automatic submode selection in this major mode of operation. When course error is great, the manual heading submode is used and the pilot must set reference heading to initiate course capture. When approach to course is sensed, the FDS will automatically switch to the course capture (radio navigation) submode. When submodes are not employed, the course intercept angle must be limited (normally to 45 degrees) and the FDS will command a turn to the 45 degree course intercept angle (when course error is great) immediately upon selection of the radio navigation mode.

(5) Approach mode. In this mode, the FDS (or operator) first assures that ILS/MLS course capture has been effected (per paragraph "b" above). After course is attained, the operator or system will select the vertical path (glideslope) submode. Automatic systems will sense approach to glideslope and will select the approach mode at the proper time. In some systems, radar altitude is also utilized to control glideslope steering sensitivity to desensitize steering commands as the glideslope beam narrows near the decision height. If altitude-hold mode is active prior to the approach, glideslope steering shall override altitude-hold upon sensing approach to glideslope.

(6) Altitude-hold mode. In most applications, the pilot must manually fly to the desired (reference) altitude. Upon reaching this altitude, he will select the altitude-hold mode. In more sophisticated systems, the pilot may select the reference altitude (barometric or radar altitude) before reaching it. The FDS will command proper pitch and obtain and maintain the reference altitude.

(7) Climb-descent modes. This mode is generally used in conjunction with the airspeed-hold mode. The pilot must set reference vertical speed in addition to airspeed. The control parameter is power (i.e., a 3-cue FDS). As in the airspeed mode, the climb or descent speed may be manually selected or the existing rate at the time of mode selection may be the reference speed (the method of selection must be specified).

(8) Airspeed-hold mode. In this mode, a "fast-slow" cue is used in conjunction with manual control of power. Reference speed must be set and employed in conjunction with engine dynamics and control characteristics to determine proper throttle commands. By maintaining the power cue at the command reference point, the pilot will attain and maintain the reference airspeed. Such

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command may be displayed on the FAST-SLOW display on some ADIs or similar display on electro-optical displays. In simpler systems, the airspeed-hold mode will simply maintain that speed which was present at time of mode selection.

(9) Terrain-following mode. This mode is used in conjunction with forward-looking radar. It is normally mechanized as a rate climb/descent mode such that when terrain falls within a predetermined envelope (template) ahead of the aircraft, a climb command is issued; when no terrain is within the specified envelope, a descent command is issued. Capability to track the desired flight path is dependent upon flight performance of the basic air vehicle, but once the appropriate template is defined, the FDS must provide very high probability of meeting required tracking accuracy.

e. FDS performance criteria. Specific performance criteria with respect to course intercept (maximum allowable overshoot, number of overshoots, and time to stabilize) must be tailored to each aircraft. FAA Advisory Circular 120-29 may be used as a guide. In establishing this criteria, pertinent aircraft performance requirements and characteristics must be established (i.e., cruise speed, approach speed, course intercept angle, and distance to station, including expected range of all parameters listed). Course tracking criteria shall also be specified. For most applications deviations from course centerline after course capture is less than 1/2-dot (course deviation scale on HSI); further, there must be no sustained oscillations about course centerline. Crosswind compensation is normally provided such that when operating in crosswinds up to 10 percent of aircraft speed (or 20 degree crab angle), there is no steady-state beam standoff. Navigational radio aids to be employed must be specified; particular attention is directed to tailorable ILS in which localizer width may be as narrow as 3 degrees (standard width is 5 degrees).

NOTE: 1/2-dot deviation has the following real values for a standard ILS:

TACAN -	2-1/2 degrees
VOR -	2-1/2 degrees
ILS-LOC -	5/8 degrees

f. Control algorithms (and associated control parameters). To assure understanding of the control algorithms and mode control logic, simplified diagrams of lateral steering circuits, vertical steering circuits, beam sensor circuits, etc., shall be provided. In addition, tables of values of gains and time constants associated with these diagrams shall be provided. The latter shall be presented as nominal values and allowable tolerances.

g. System safety. The following requirements are provided to assure safe use of the flight director system:

(1) Raw data (course deviation display, glideslope deviation display, etc.) upon which the computed steering commands are based shall be displayed concurrently with flight director data to permit operator assessment of system performance. (e.g., ILS localizer and glideslope deviation shall be displayed whenever ILS approach mode steering commands are displayed.)

(2) Failure warning. The following features shall be considered standard:

(a) Flight director command cues shall be stowed out of view whenever the reference signal source (navigational radio, air data computer, etc.) for the selected mode of operation has failed or whenever the flight director computer has failed. (An acceptable alternative, if an existing ADI design is to be utilized, is the employment of failure warning flags--one for each steering pointer.)

(b) Failure warning flags or symbols shall be provided to assure validity of navigational radio information, air data computer, etc., on which the FDS depends.

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(c) When variable gain features are employed, the system shall be designed to revert to a single nominal value in the event of gain controller failure. In most flight director systems which use variable glideslope gain (in approach mode), the gain is desensitized to the lowest possible gain upon sensing that radar altitude input is invalid.

Basic requirements for a FDS are found in MIL-F-26685.

REQUIREMENT LESSONS LEARNED

Possible disorientation can occur if the HUD and ADI do not agree. For example, the F-16 uses normal flight director data on the HUD but only raw data on the cross pointers in the ADI. This is not a recommended practice because the HUD pointer display may be centered, while the ADIs are not.

4.2.2.8 **Verification of flight director system (FDS).** The performance of the FDS shall be evaluated in the laboratory by: _____.

VERIFICATION RATIONALE (4.2.2.8)

The laboratory provides the most convenient place to verify FDS performance where required test parameters can easily be applied.

VERIFICATION GUIDANCE

Special purpose laboratory test equipment will usually be available for verification of the FDS in conjunction with simulator tests. The final proof of satisfactory operation can only be accomplished by flight test in the air vehicle in which it is to be used.

VERIFICATION LESSONS LEARNED

During calibration of the FDS, it is important to use exact air vehicle simulation rather than a simplified linear simulation to make certain the performance of the FDS meets the requirements of the air vehicle. It was necessary to recalibrate the F-5's FDS for this reason.

3.2.2.9 **Rate of fuel flow system.** The rate of fuel flow system consists of a display used in conjunction with a flow sensor. One display is used for each engine to display rate of fuel flow in _____ (units). The system requirements shall be as follows: _____.

REQUIREMENT RATIONALE (3.2.2.9)

Fuel flow is used for engine starting, calculating flight time remaining, and giving an indication of thrust output. It is also used for engine fuel control trimming and on tankers to display rate of fuel flow transfer.

REQUIREMENT GUIDANCE

Fuel flow measurement systems used on Air Force aircraft are to be of the mass measuring type. Most of the transmitters in current use are of the angular momentum type. Mass flow measurement is required because the heat content of a fuel is measured in heat units per mass and engine output is directly proportional to the heat content of fuel assuming a given engine efficiency. Fuel flow is measured in pounds per hour (PPH) or kilograms per hour (KPH).

The following items must be considered and specified for fuel flow systems:

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a. Range. The lower range should be adequately low to provide an indication of flow for engine start. The lower limit will vary depending upon the overall range of the system. It is difficult to obtain a dynamic range of much greater than 200 to 1 in most mass flow systems; therefore, if a 100,000-pound-per-hour (PPH) maximum range is required the low limit will be around 500 PPH. The upper limit may be the total core engine plus after burner flow or may be limited to core flow only depending upon mission requirements and necessity for afterburner monitoring, fuel-used computations, etc. The highest flow currently used is on the F-15 having a 100,000 PPH capability. The range may be specified in kilograms per hour on aircraft destined for use in countries using the metric system. The range of systems used for refueling can go as high as 600,000 PPH or higher.

b. Accuracy. The accuracy of fuel flow systems is variable depending upon the flow rate. Typically, mass flow transmitters have a "bathtub-shaped" curve with less accuracy at the low and high-flow rates and greater accuracy in the mid-flow range. Indicator accuracies are usually constant over the entire range. Mid-range accuracies of transmitters are usually about +1.0 percent of reading. It will be necessary to prepare a table of accuracies versus flow rates in the detail specification. Accuracies should not be greater than required at each flow rate specified. Tolerances at high and low temperatures will be greater than at room temperature and will have to be specified accordingly depending upon the temperature extremes expected and the accuracies required.

c. Response. Specification of fuel flow system response may be required for two reasons; to follow rapid throttle movements and to calibrate fuel control systems. Typical throttle response times would require the system to respond to a full-scale step input within 1 percent after 3 to 5 seconds. If the system is to be used for fuel control calibration, the response time can be as low as 2 seconds, and the flow rates must be tailored to cover the rates required for calibration. The response time may be specified for the transmitter only assuming the fuel flow readout will be an X-Y plotter or other display.

d. Display. Fuel flow displays are typically 2-inch round dial indicators installed in 2-inch clamp-mounted cases per MS-33639. The scale should be oriented so that the cruise range fuel flow rate is positioned at 9 o'clock. Displays may be varied depending upon mission requirements and the aircraft panel design. Digital numeric readouts, vertical scale indicators or CRTs may be used.

e. Transmitter. The fuel flow sensor/transmitter must be of the true mass flow measuring type. The output signal shall be proportional to the rate of flow and may be analog or digital in format. If a digital signal is specified, it shall be compatible with MIL-STD-1553 or with ARINC standards, depending upon end usage.

f. Pressure drop. Pressure drop is important because it requires pumping force to overcome. In some aircraft pressure drop is critical when the pumps fail and the engine must be fed by gravity flow. A typical pressure drop in a 100,000 PPH transmitter is 2.5 psi at flow. Pressure drop generally increases by a square power of the flow. The pressure drop requirement is based on several factors, such as the requirement for gravity feed, auxiliary pumping equipment, fail-safe considerations, etc.

g. Pressure. The static pressure that the transmitter must withstand without rupture or leakage must be specified. The component should be capable of withstanding a proof pressure of two times maximum operating pressure, an ultimate pressure of three times the maximum pressure, and a negative pressure of approximately one atmosphere. A fuel resistance test similar to that specified in MIL-F-8615 should be conducted.

h. Contaminated fuel. This requirement should be included because it is not always possible to keep fuel from becoming contaminated. A typical contaminant for test purposes is listed in MIL-F-8615.

i. Flame. Some transmitters may be required to withstand a flaming environment, particularly when they are mounted on the engine. If a flame should occur around the transmitter, it is essential that

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there be no damage that could result in leakage. Typical limits for this test are 1093°C flame temperature for a period of five minutes. Depending upon the engine operation, fuel may be flowing or static at a particular pressure. Data from the airframe manufacturer may be required to complete this requirement.

j. Excessive and reverse flow. This requirement may be necessary on some aircraft depending upon how and where the fuel flow transmitter is plumbed into the fuel system. In some installations fuel flow rates may exceed the maximum specified in certain instances when fuel is being transferred from one tank to another through the transmitter. Reverse flow may be required during refueling operations.

REQUIREMENT LESSONS LEARNED

Past experience has shown that certain materials are not well suited for use in fuel flow transmitters when they come in contact with fuels. Most plastics are unstable and can be affected by fuel additives; magnesium alloys are highly corrosive and react to any moisture in the fuel. Magnesium protective coatings have not proven effective over long periods because of scratches and thin spots in the coatings. Copper alloys and cadmium plating have been found to be attacked by many fuel additives, and copper salts are detrimental to engine oil which could become contaminated through the fuel in the engine. These materials should be prohibited. Fuel seals should be in accordance with MIL-STD-1587.

Fuel flow transmitters are mounted on the engine or airframe. The transmitter should be mounted at a slight angle with the outlet higher in order to purge air from the transmitter. Sharp bends in the inlet and outlet plumbing shall be avoided. This causes turbulance in the fuel and can produce erratic fuel flow measurement. End fittings may be "0" ring clamp-type, screw-on, or flange-type. Mounting designs must take into account plumbing expansion and contraction and vibration and temperature when mounted on the engine.

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4.2.2.9 Verification of rate of fuel flow system. The system requirements shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.9)

Accurate flow measurements can only be accomplished in the laboratory using calibrated weight standards. Other conditions, including environmental, fuel contamination, flame resistance, reversed flow, etc., are all easily accomplished in the laboratory.

VERIFICATION GUIDANCE

Verification of production quantities is best accomplished with the use of automated test equipment. Secondary standards are usually adequate for this use. All requirements specified must be verified on a 100 percent or sampling test basis.

VERIFICATION LESSONS LEARNED

It should be realized that the temperature of the fuel dictates the temperature of the transmitter. If high temperature fuels are to be measured, the fuel temperature should be specified and not merely the temperature around the transmitter.

3.2.2.10 **Fuel savings advisory system (FSAS).** The fuel savings advisory system shall display optimum flight profiles for minimum fuel consumption. The system shall be compatible with the aircraft and the missions to be accomplished. The following characteristics shall be included in the system for display to the aircrew: _____.

REQUIREMENT RATIONALE (3.2.2.10)

The Air Force has strong motivation to consider techniques for fuel conservation. Fuel costs continue to increase, and projected cost increases make fuel conservation even more important.

REQUIREMENT GUIDANCE

The FSAS uses a technology which offers the potential for achieving significant fuel savings through the use of fuel minimizing-optimum flight path and throttle control laws. These control laws are designed to enable a pilot or an automatic flight control/autothrottle system to regulate an aircraft's kinetic and potential energy so that a minimum amount of fuel is expended while meeting the mission objectives. The FSAS should demonstrate mission fuel savings while considering the variability of aircraft performance, the current atmospheric conditions, and the existing air traffic control procedures.

Quantitative fuel savings should be in the range of 3-5 percent with the use of an FSAS as opposed to conventional flying procedures. The system is applicable to both current aircraft as well as future aircraft and offers a rapid return on initial investment costs through fuel savings. A secondary benefit of the FSAS is that it will lessen the flightcrew member's workload by relieving him (them) of the necessity to frequently calculate the aircraft's best altitude and airspeed from the flight manual charts. A typical FSAS is described in Exhibit ASD/ENAID-79-1, Revision 1.

The following paragraphs describe components, interface, and other recommendations for specifying the FSAS:

a. Systems components. The FSAS will generally consist of a computer unit (CU), control display unit (CDU), a flight data storage unit (FDSU), if required, and additional displays such as mode annunciator panel, engine pressure ratio (EPR) indicators with command bugs and indicated airspeed/

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Mach (IAS/Mach) central computing and information processing unit for all fuel saving functions. The computer unit receives all the fuel management related aircraft and propulsion sensor inputs and provides signals for display information as required. The Control Display Unit provides control of the FSAS with mode and function selection and data entry capability via an alphanumeric keyboard. The CDU also displays all the required mode and function information, data entry or recall information and the best flight profile command information via a CRT display. This information is presented in the form of "pages" which are generated and recalled in a logical sequence necessary for proper pilot-system interface and control. Because a FSAS requires versatility, digital technology is mandated for design of this system.

b. Interfaces. The FSAS interfaces with various aircraft flight and propulsion systems and sensors depending on the particular design and application. Generally, the system will interface with the following systems and sensors:

(1) Central Air Data Computer

(2) Fuel Flow or Fuel Totalizing System

(3) Engine Pressure Ratio Systems

(4) Exhaust Gas Temperature Measuring System

(5) Anti-Icing and Air-Conditioning Bleeds

(6) Distance Measuring Equipment

(7) Automatic Flight Control System

(8) Angle of Attack Measuring System

This list is not all encompassing and is provided to give an idea of the type of interfaces that will be required. A particular aircraft may not have all the required systems or sensors available in which case other provisions or design accommodations will have to be provided. It is recommended that an FSAS aircraft system/sensor interface comparison be performed at the time the system is considered for aircraft implementation.

c. Display. The CDU should display to the flightcrew aircraft flightcrew to pilot the aircraft in the most fuel efficient manner. Typical information that should be displayed on the CDU is as follows:

(1) Climb

(a) Cruise altitude	(CRS ALT)
(b) Actual altitude	(ACT ALT)
(c) Required IAS	(REQ IAS)
(d) Required EPR	(REQ EPR)
(e) Actual IAN	(REQ IAN)
(f) Altitude select	(ALT SEL)

(2) Cruise

(a) Optimum altitude	(OPT ALT)

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(b) Cruise altitude	(CRS ALT)
(c) Required Mach	(REQ MACH)
(d) Fuel remaining at end of descent	(E-D FUEL)
(e) Estimated time to beginning of descent	(ETE TO B-D)
(f) Time and distance to step climb	(STEP X:XX/XXKT)
(g) New altitude	(NEW ALT)
(h) New altitude temperature	(NEW ALT TEMP)
(i) Wind at new altitude	(WIND TRADE)
(j) Altitude select	(ALT SEL)
(k) Too close to descent for step climb	(STEP N/A)
(l) Begin descent	(DESCENT)

(3) Descent

(a) End of descent altitude	(E-D ALT)
(b) Distance to end of descent	(DIS TO E-D)
(c) End of descent altitude	(E-D ALT)
(d) End of descent IAS	(E-D IAS)

(4) Incremental Fuel Savings Inquiry

(a) Cruise altitude	(CRS ALT)
(b) Optimum altitude	(OPT ALT)
(c) New altitude	(NEW)
(d) Required Mach at new altitude	(REQ MACH)
(e) Wind at new altitude	(WIND TRADE)
(f) Estimated time to beginning of descent	(ETE TO B-D)
(g) Fuel savings at new altitude and speed	(FUEL SAV ± %)

d. Extended capabilities. FSAS capabilities can be extended to include additional features. A baseline system would consist of a computer and a display unit. The addition of EPR and IAS/Mach

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indicators with manual or remotely adjustable cursors will improve the usability of the system. Integrating the system into an aircraft's automatic flight control system and an auto-throttle system will further improve the usability and also provide additional fuel savings through more precise control of the aircraft flight. If an aircraft has autopilot and autothrottle systems available, it is advisable to integrate them into the FSAS control loop, as this will result in about 1 percent fuel economy improvement. Furthermore, depending on the type of equipment available on an aircraft, dedicated FSAS equipment may not be required. As an example, an existing digital computer with spare capability can be utilized to perform the computations or an existing display can be utilized to display the FSAS functions.

REQUIREMENT LESSONS LEARNED

Flight tests on C-141, B-52, and KC-135 aircraft have confirmed that fuel savings of approximately 3 percent can be realized if an FSAS is used.

4.2.2.10 Fuel savings advisory system (FSAS). Characteristics and performance of the FSAS shall be verified in the laboratory and by flight test as follows: _____.

VERIFICATION RATIONALE (4.2.2.10)

System component accuracy, functional checks, and environmental tolerances can best be verified using laboratory tests. Final system performance in conjunction with the air vehicle can only be accomplished through flight tests.

VERIFICATION GUIDANCE

All specified requirements should be verified by examination and testing. It will not be possible to verify fuel savings except by periodic flight testing.

VERIFICATION LESSONS LEARNED

3.2.2.11 Fuel quantity system. The fuel quantity gaging system shall indicate the amount of fuel in _____. The system shall measure and display the fuel quantity in _____ (units) and shall be in accordance with _____.

REQUIREMENT RATIONALE (3.2.2.11)

The fuel quantity readings are needed by the aircrew member to plan the length of his mission, to control the center of gravity of the aircraft, and to insure that sufficient fuel reserves exist to insure a safe return to base. It also is used as an input to some fuel savings advisory systems.

REQUIREMENT GUIDANCE

The fuel quantity gaging system for use on Air Force aircraft shall measure and indicate the fuel quantity in pounds or kilograms. Most gaging systems are of the capacitance type that sense changes in the dielectric constant of the fuel/air mixture between the cylinders of the capacitance probes brought upon by raising or lowering the fuel level. Compensation is provided to correct for varying tank configurations.

The following items should be considered and specified for fuel quantity measuring systems.

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a. Range. It is important to measure fuel from full to as near empty as possible. If a large unmeasurable amount of fuel exists, it will rob the aircraft of some of its potential range and apply as a weight penalty.

b. Accuracy. The readings must be most accurate when the fuel tanks are near empty to insure sufficient fuel to return to base. Typical accuracies are Class I, MIL-G-26988, ± 4 percent of indication in addition to ± 2 percent of full scale, for older aircraft. Most newer systems specify Class II, ± 2 percent of indication added to ± 0.75 percent of full scale. In rare instances where fuel quantity is extremely critical and is needed to control the center of gravity of the aircraft, such as the B-1 system, a tighter tolerance is used. That tolerance is usually Class III, ± 1 percent of indication and ± 0.5 of full scale. This accuracy requires an attitude correction computer as part of the system and will, therefore, result in much more expense. New weapon systems should be encouraged to utilize Class II systems whenever possible.

c. Provisions. The fuel gage should provide an adjustable signal to close the refuel valves for intermediate fuel loads.

d. Display. Fuel quantity displays take many different forms, including round dial, numeric readout, vertical scale, etc. The configuration of the air vehicle will dictate the best display. In general, a display will be included for each tank. A display of total fuel is also usually provided.

e. Tank units. The aircraft fuels and all their additives (including anti-static additives) and water that condenses out in the tanks should not detrimentally affect the life, reliability, and accuracy of the tank units.

f. Materials. Aircraft fuels and additives should not affect the materials used to construct the tank units so that the fuel gaging system accuracy is not adversely affected and fuel is not contaminated.

g. Installation and calibration: Guidance for installation and calibration of the fuel quantity gaging system is contained in MIL-G-7940 and MIL-F-87154.

REQUIREMENT LESSONS LEARNED

It has been found that tank units should be top-mounted and externally accessible wherever possible for system maintenance.

The use of fuel additives, alternate fuels, and contaminated fuels is causing some concern about the adequacy of capacitance-type gaging systems. These factors should be investigated when specifying a capacitance system.

4.2.2.11 Verification of fuel quantity system. Accuracy and characteristics of the fuel quantity system shall be evaluated in the laboratory and in the aircraft as follows: _____.

VERIFICATION RATIONALE (4.2.2.11)

Some portions of the system such as configuration, materials, etc., can best be verified in the laboratory by examination. Overall accuracy of the system can only be accomplished in the aircraft.

VERIFICATION GUIDANCE

During testing in the aircraft, known quantites of fuel are added to each tank in certain increments, and the accuracy of the system is checked. This is normally accomplished in a level position. Different aircraft altitudes are difficult to achieve, but ramps or jacks may be used to determine system accuracy from small pitch or roll angles.

VERIFICATION LESSONS LEARNED

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3.2.2.12 **Horizontal situation indicator (HSI).** The HSI shall provide a pictorial display of the navigational relationship of the aircraft to the earth, including other information as follows: _____. It shall be compatible with _____.

REQUIREMENT RATIONALE (3.2.2.12)

The HSI is usually the pilot's primary heading reference. It is a navigation instrument whose display was developed to aid pilots in intercepting TACAN or VOR radials, but it is also used with other navigation methods such as Area Nav and INS.

REQUIREMENT GUIDANCE

The HSI shows the aircraft heading with respect to north (magnetic or true) and the aircraft position with respect to a selected ground station and a selected course to the ground station. The aircraft heading is shown on a compass card beneath a lubber line. The display also gives slant range and bearing to a selected ground station and allows the pilot to select a desired course toward the station. The HSI then shows the aircraft position with respect to this selected course. The pilot can select a desired heading which is shown by a marker on the outer edge of the compass card. TO-FROM information with respect to the selected ground station is shown in the center of the HSI. The HSI also has various failure warning flags. The following functional capabilities are considered to be the minimum necessary for an adequate HSI display:

a. Heading. The aircraft heading is the direction the aircraft is pointing. The actual direction of flight may be slightly different depending on crosswinds or aircraft control problems. The heading may be referenced to either magnetic north or true north depending on the directional reference source. Usually a directional gyro output is referenced to magnetic north while an INS output is referenced to true north. The accuracy of the azimuth card (or compass card) is usually specified as 1° minimum, which is readily achieved in any well-designed instrument and is about the limit of readability on a normal azimuth card with 5° between markings. For the larger HSIs (4 x 5 or 5 x 5), an accuracy of 1/2° can be specified with the azimuth card marking spaced at 2°. The heading input signal for the HSI depends upon the directional reference source which probably will have a synchro signal output but which may have a digital output, such as with a MIL-STD-1553 data bus.

b. Command heading. The command heading is a heading the pilot wishes to fly from 0 to 359° and which can be set with a knob on the HSI or can be set remotely, usually by a second HSI.

c. Heading marker. A heading marker is set around the outside edge of the azimuth ring to show the command heading which has been selected. The heading marker (also called heading "bug" or "Captain's Bars") is set manually or remotely depending on the HSI mode (master or slave), which is controlled by the external pin connections. In a two-place cockpit, one HSI will be the master and one the slave so that both HSIs will display the same command heading. Each HSI should be capable of acting as either the master (called "remote device" in specification) or the slave. The signal may be synchro or digital. When choosing a signal format, consideration should be given to the signal format of any equipment which interfaces with the command heading display of the HSI.

d. Command heading rate and accuracy. The maximum rate of change for command heading is usually specified to be 60° per second, as this is about the maximum rate at which the pilot can manually set the master HSI. While the minumum rate of change is 0° per second, the lowest measured rate of change is usually 1-1/2° per second, which corresponds to a 4-minute turn.

e. Remote heading signal. When the HSI is operating in the SLAVED mode, it must receive a commanded heading signal for a remote source. If no signal is available, the heading marker may rotate

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continously around the azimuth card. When an HSI is in the SLAVED mode, rotating the set knob may temporarily move the heading marker; however, the marker must return to the heading of the remote device to preclude having separate command heading values on the two HSIs. After being set manually (only in the master mode) or remotely, the marker must not move with respect to the azimuth card even if the azimuth card is rotating. The accuracy will normally be specified as 1° with an azimuth card having 5° marking or 1/2° with a card having 2° markings.

f. Command course. The command course is a heading the pilot wishes to fly toward a specific point, usually toward a selected TACAN station. The course can be set manually with a knob on the HSI or it can be set remotely, usually by a second HSI.

g. Course marker. A course arrow (marker) is set to the desired heading on the inside edge of the azimuth card to correspond with the course selected. The course arrow may be set manually or remotely depending on the HSI mode (master or slave) which is controlled by the external pin connections. In a two-place cockpit, one HSI will be the master and one the so that both HSIs will display the same command course. Each HSI will normally be capable of acting as either the master or the slave. The signal may be synchro or digital. When choosing a signal format, consideration should be given to the signal format of any equipment which interfaces with the command course display of the HSI.

h. Course readout. In order to aid the pilot in rapidly and accurately selecting a command course, a digital course readout is provided in the upper-right-hand corner of the HSI face.

i. Course rate and accuracy. The maximum rate of change for the course arrow is usually specified to be 60° per second for the same reason as in the command heading. Likewise, the lowest measured rate is usually 1-1/2° per second. The accuracy is usually specified as 1° if the azimuth card has 5° marking and 1/2° if the card has 2° markings.

j. Remote course signal. In the slaved mode, the HSI must receive a remote course signal to preclude continuous rotation of the course arrow. A rotation of the course set knob on the slaved HSI may cause a temporary movement of the course arrow; however, the arrow must immediately return to the value set by the remote device to preclude erroneous readings. After being set to a given value, the course arrow must not move with respect to the azimuth card unless reset to a new command course. The accuracy is usually specified as 1° if the azimuth card has 5° markings or 1/2° if the card has 2° markings.

k. Course deviation bar. The command course is a specific direction toward a specific point and can be represented by a signal line on a map or by an imaginary line on the earth. If the aircraft is flying on course, it should be flying directly above and along this imaginary line. The deviation bar (D bar) shows the relationship of the aircraft to this imaginary line, which represents a command course. If miniature airplane in the HSI is to the right of the deviation bar, then the actual aircraft is to the right of its commanded course. The impedance of the D bar input is usually specified as 1000 ohms for compatibility with existing equipment. Likewise, the current required for one-dot displacement usually specified to be 75 uA, with two dots requiring 150 uA. In most aircraft one dot on the D bar represents 5° off course with two dots for 10°. One degree off course is defined as a 1° difference between the command course and the bearing to the selected station.

l. Deviation bar alarm flag. The primary purpose of the deviation bar alarm flag is to indicate whether the deviation bar input signal is usable or not; however, when in the TACAN mode, it also shows whether the bearing signal is usable or not. The suppress zero-type of meter movement holds the flag tightly against its stop until the input current is a substantial fraction (about 1/3) of the maximum rated current. This prevents the flag from moving off its stop during high vibration or high

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"g" loading environments. In order to be compatible with existing equipment, the flag is normally required to leave its stop at no less than 180 uA and be fully out of view at not more than 245 uA. For reasons of compatability, the input impedance is usually required to be 1000 ohms. With a digital interface the flag operation may be a function of a status bit rather than a function of an input current.

m. TO-FROM arrow. The TO-FROM arrow is used in making TACAN or VOR intercepts. The arrow shows whether the aircraft would fly toward or away from the station if the selected course were intercepted and flown. The signal is usually generated in the TACAN or VOR coupler; however, the HSI can be designed to generate the signal internally if the TACAN or VOR coupler is to be deleted. For compatibility with existing TACAN and VOR couplers, the TO-FROM arrow should have 200 ohms input impedance and should come into view with +225 uA.

n. Display movement. The central portion of the display contains all of the information pertaining to the selected course and rotates as a unit with the azimuth card in order to present the desired information in a usable and coherent manner.

o. Bearing pointer. The bearing pointer indicates the direction toward a selected radio station or other target. Because a pilot may wish to track a TACAN station plus another radio station in the direction finding (DF) mode or may need to find his position by triangulation, it is desirable to have two bearing pointers on the HSI. If this is not possible because of size constraints or other reasons, one bearing is considered to be the minimum acceptable. The maximum rate of change for the bearing pointer is usually specified to be 60° per second, as this is adequate for navigation purposes and is relatively easy to achieve. It also keeps the test requirements uniform when compared to the other servos on the HSI. The lowest measured rate of change for the bearing pointer is usually taken to be 1-1/2° per second, as this corresponds to a 4-minute turn. This low rate is often more difficult to achieve satisfactorily because of problems with jumpiness and erratic movement at the low rates of movement. The accuracy is usually specified as 1° if the azimuth card has 5° markings and 1/2° if the card has 2° markings.

p. Distance display. The distance (range) to a selected station is presented in the upper-left-hand corner of the HSI in order to standardize the display features. The distance is usually the slant range but could be some other value received from a computer. The normal display consists of three digits, each operated by a separate synchro receiver with separate three-wire inputs. The display may also have a separately controlled thousands' flag to increase the range of the display from 999 to 1999. If the distance display is intended to interface only with a TACAN, a range of 999 miles would be sufficient. The distance display can be designed with a digital interface, for use with a digital TACAN, or with a digital multiplex bus; however, the range of the display will still be a function of the interfacing equipment which supplies the distance signal. If the signal is available to accuracies of one-tenth of a mile, it would be advantageous to display to that accuracy. This can be done by adding an additional digit or by using a movable decimal point. If a movable decimal point is used, the typical accuracy would be one-tenth of a mile from 0 to 999 miles and one mile from 100 to 999 miles.

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4.2.2.12 Verification of horizontal situation indicator (HSI). The HSI characteristics shall be evaluated in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.12)

The HSI characteristics can be easily verified by laboratory testing. Known signals can be generated, and the performance of the HSI can be observed.

VERIFICATION GUIDANCE

Typical verification practice can be found in MIL-I-83034. Many of the performance requirements specified will require 100 percent testing others may be verified on a sampling basis.

VERIFICATION LESSONS LEARNED

3.2.2.13 Hydraulic pressure indicator and sensor. The hydraulic pressure indicator is used in conjunction with a hydraulic pressure sensor and is used to display pressure of each hydraulic system on the aircraft. The following requirements apply: _____.

REQUIREMENT RATIONALE (3.2.2.13)

Hydraulic pressure measurement is used to monitor the hydraulic systems on the aircraft. Hydraulic pressure measurement is necessary to insure operational and functional system capability on those aircraft which use hydraulic power for flight control, landing gear actuation, etc.

REQUIREMENT GUIDANCE

Most of the hydraulic pressure measurement systems in current use are of the basic synchro type.

The following requirements should be specified.

a. Range. Most of the hydraulic pressure systems in Air Force aircraft require a 0-4000 psi range. A few aircraft have higher hydraulic pressure systems where a 0-5000 psi range is required. The vehicle system requirement will dictate the range.

b. Accuracy. The accuracy of the hydraulic pressure indicating system is approximately 5.0 percent of full-scale reading. The indicator and transmitter accuracies are approximately 2.5 percent of full-scale reading and are fairly constant over the entire range. Accuracies at high and low temperatures will be greater than at room temperature and will have to be specified accordingly depending upon the temperature extremes expected and the accuracies required.

c. Response. Requirement of hydraulic pressure indication response time may be required for two reasons: (1) to follow rapidly dropping hydraulic pressure or system fluctuations and (2) to follow not-so-rapidly dropping hydraulic pressure or system fluctuation so as to cause oscillations or erroneous readings. Typical response time of a pressure drop from 4000 psi to 500 psi is 1 second to 3 seconds for the transmitter and not more than 2 seconds for indicator response time.

d. Display. Hydraulic pressure displays are typically installed in 1-inch round dial clamp-mounted cases per MS-33639. The scale should be oriented so that the normal hydraulic pressure indication is positioned in the 11 o'clock to 1 o'clock position. Any other display may be used depending upon panel space and application.

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e. Transmitter output signal. Depending upon the indicator, the transmitter may use a synchro signal, voltage output, or other analog signal. If a digital signal is specified, it shall be compatible with MIL-STD-1553 or with ARINC standards depending upon end usage.

f. Overpressure. The transmitters are usually required to withstand an operating overpressure of 1000 psi (500 psi applied) without degrading the performance. The 1000 psi overpressure is considered adequate to meet the most severe overpressure fluctuations in the hydraulic pressure system. An upper limit of 3500 psi over max normal (7500 psi applied) is usually specified for rupture or leakage tests. Some loss of performance or permanent damage is allowed after this test.

REQUIREMENT LESSONS LEARNED

The transmitter should be mounted as near to the hydraulic fluid reservoir as possible. This minimizes the possibility of line ruptures and leakage due to exposure of long lines to excessive vibration or wear against sharp edges or protuberances. Pipe connections to transmitters are prone to leakage. Fittings per MS-36649 are preferred.

4.2.2.13 Verification of hydraulic pressure indicator/sensor. Verification of the requirements for hydraulic pressure sensors and indicators shall be accomplished as follows: _____.

VERIFICATION RATIONALE (4.2.2.13)

Hydraulic pressure sensors and indicators must be tested to determine if they comply with the specified requirements.

VERIFICATION GUIDANCE

Laboratory testing is the easiest and safest method to verify the specified requirements for pressure transmitters and indicators. Pressures can be accurately controlled and environmental conditions can be imposed as required.

VERIFICATION LESSONS LEARNED

3.2.2.14 Magnetic compass. The magnetic compass provides an indication of aircraft magnetic heading for use as a backup heading reference and for cross-checking the primary heading reference system. The following requirements shall apply: _____.

REQUIREMENT RATIONALE (3.2.2.14)

The magnetic compass indicates the heading of the aircraft with respect to magnetic north. It requires no electrical power for operation other than for lighting. The purpose of the magnetic compass is for a heading source for emergency use and for cross-checking other aircraft heading systems. Most aircraft require a magnetic compass as an emergency heading source.

REQUIREMENT GUIDANCE

The following requirements apply when specifying a typical magnetic compass:

a. Display. The compass mechanization typically consists of two bar magnets attached to a pivoted compass card and float. This mechanism is housed within a case full of fluid in accordance with

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MIL-L-5020. An expansion unit is required to allow for liquid expansion and contraction with temperature changes. A lubber line is installed such that parallax errors are minimum when reading heading from the compass card. The compass card is marked in 5° increments with each 30° increment labeled with the appropriate heading angle and cardinal heading angle and cardinal headings labeled with N, S, E, and W. Increments larger than 5° should not be used as readability errors would become excessive.

b. Compensator. The magnetic compass must be equipped with a compensator for removing errors in north-south and east-west headings due to aircraft magnetic fields. The compensator consists of two permanent magnets that are manually adjustable. A zero index mark is required to indicate the adjustment position where the compensator magnets exert zero effect on the indicator. The range of the compensator must be sufficient to remove errors due to the particular aircraft's magnetic field. Typical ranges that have proven suitable for any aircraft application are between 30° and 40°.

c. Bubble visibility. Air bubbles should not be visible in the usable attitude range of the magnetic compass. This range is typically no more than 18° in pitch. Steeper pitch angels result in larger errors which make the compass unusable.

d. Friction error. Typically, a friction error of 1° maximum has proven acceptable and is easily met.

e. Balance. The compass card must be balanced to provide a readable and accurate display. Deviation of 1° between the compass card plane and the horizontal plane is generally required and has proven to be easily met.

f. Compass error without compensation. The accuracy of the standby compass is typically within ± 1.0° without compensators attached. This requirement has generally proven acceptable.

g. Attitude range. Pitch attitudes of ± 10° should cause no more than 2° change in compass indication. Pitch or roll attitudes of ± 18° should cause no more than 5° change in indication. These attitude errors are characteristic of the typical compass mechanization and should easily be met.

h. Compass swing. Each aircraft standby compass must be calibrated through a compass swing when the compass is first installed, when it is replaced, or when its errors become excessive. MIL-STD-765 defines the magnetic field conditions at the swing site required to perform the compass swing. In addition, it provides the general requirements for a number of acceptable compass swing procedures which include the following: compass rose procedure, sighting compass procedure, magnetic method using a transit, comparison swings, and air swings. Compliance with MIL-STD-765 is a requirement that should be imposed on the airframe contractor to insure an acceptable compass calibration.

REQUIREMENT LESSONS LEARNED

When the magnetic compass is installed in an aircraft, its indications will be affected by magnetic fields in the aircraft such as those due to magnetic materials or lines carrying DC. To provide accurate indications the compass must be located to minimize the effect of aircraft magnetic fields. MIL-C- 7762 defines the requirements for determining the acceptability of a selected location. MIL-C-7762 accomplishes this by specification of the maximum allowable errors due to aircraft climb and glide attitudes, movable and removable magnetic parts, engine operation, landing gear effect, effect of continuously operated circuits, effect of variable circuits, and specification of the maximum allowable uncompensated and compensated compass deviations. Test procedures are defined for measuring these various effects. The requirements of MIL-C-7762 for direct indicating compasses should be imposed on the airframe contractor to insure that errors due to the compass installation can be compensated for and to insure residual errors after compensation are not excessive.

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4.2.2.14 Verification of magnetic compass. Requirements for the magnetic compass shall be verified in the laboratory by _____.

VERIFICATION RATIONALE (4.2.2.14)

Most of the requirements can be verified in the laboratory under controlled magnetic field conditions. Final performance can only be verified after installation in the air vehicle.

VERIFICATION GUIDANCE

The stated requirements should be listed under verification together with any special test procedures or conditions which are to be imposed on the compass. MIL-C-5604 contains typical verification procedures.

VERIFICATION LESSONS LEARNED

3.2.2.15 Structural integrity recorder. The structural integrity recorder shall record certain data for use in determining the stresses to which aircraft structures have been subjected for the purpose of predicting when certain parts require repair or replacement. The following parameters shall be recorded: _____. Other requirements shall include: _____.

REQUIREMENT RATIONALE (3.2.2.15)

A structural integrity recorder is most often used during initial flights of new aircraft to measure and record performance, configuration, and stresses in the aircraft. It can also be used on a continuous basis so that the airframe condition can be monitored and corrective action taken before serious conditions, such as cracked wing spars, occur due to overloads or fatigue.

REQUIREMENT GUIDANCE

The following list of "standard" parameters should be considered for recording. To complete the requirement it will also be necessary to fill in the update rate and resolution.

PARAMETER	UPDATE RATE (SECONDS)	RESOLUTION (Parameter Units)
Time		
Timing word		
Altitude		
Airspeed		
Mach number		
Vertical acceleration		
Lateral acceleration		
Longitudinal acceleration		
Free air temperature		
Pitch rate		
Yaw rate		
Roll rate		
Control surface positions		
Center of gravity		
Landing gear position		
Weight		
Documentary data		
Stress(es)		
Fuel counter		
Refuel counter		

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The blanks are to be filled in depending upon the type of aircraft and the structural elements that require recording. It will be necessary to provide a list of the locations at which the aircraft stresses are to be measured.

Other requirements which must be given consideration include the following:

a. Interface requirements. There are many sensors on board most aircraft whose signals can be used as an input to the recorder. These sensors should be used whenever possible to avoid duplication.

b. Recording time. The recorder should be capable of running for the duration of the longest mission. Recorder times of 20 to 35 hours without changing tapes can be specified if required. The tape speed shall be constant and shall be within +1° of the specified design record speed.

c. Tape. The recording tape should be contained in a cassette/cartridge for ease of handling when changing it and to preclude inadvertent unwinding. The tape should be able to withstand temperatures in the range of -54°C to +71°C. Depending upon the location of the recorder in the aircraft, the temperature requirements can be as severe as -54°C to +100°C.

d. Operating factors. The recorder should be powered automatically with no action required to be taken by the flightcrew. The recorder must have a built-in alert feature which will notify the crew if the recorder ceases to function.

REQUIREMENT LESSONS LEARNED

4.2.2.15 **Verification of structural integrity recorder.** Recorded parameters and other requirements specified for the recorder shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.15)

The requirements of the recorder can most easily be verified in the laboratory where either actual or simulated signal inputs can be applied and recorded. Other specified requirements can be visually inspected and verified.

VERIFICATION GUIDANCE

The recorder should be tested to determine if specified requirements are met. The requirements are restated in the verification section together with any environmental conditions and special test procedures that are to be applied.

VERIFICATION LESSONS LEARNED

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3.2.2.16 Engine oil quantity indicating system. The oil quantity indicator shall receive signals from an oil quantity sensor and display to the aircrew the oil quantity in _____ (units) remaining in each tank associated with each engine. The characteristics of the system shall be as follows: _____.

REQUIREMENT RATIONALE (3.2.2.16)

All aircraft engines require a continuous flow of oil for lubrication and cooling. Each engine is usually fitted with an oil tank, and it is important to know the quantity of oil in each tank. Knowing the oil quantity and the rate of usage as determined by the oil quantity gage, the duration of flight can be determined. This is important in case of an oil leak or excessive oil consumption by a particular engine.

REQUIREMENT GUIDANCE

There are several types of oil quantity systems available. Technical Report ASD-TR-74-39 provides a comprehensive review of these systems and some of the factors that should be considered when specifying an oil quantity system.

The following requirements must be addressed when specifying an oil quantity measuring system:

a. Units of measurement. The engine oil quantity indicating system should display volumetric quantity rather than weight of oil because oil consumption is discussed in terms of quarts or liters per hour. Oil is added one quart at a time, as it is procured only in quart cans to avoid the possibility of an open can being left for future use and becoming contaminated.

b. Range. Full should correspond to minimum oil level which is about 20 percent less than actual tank capacity to allow for oil expansion. Empty should correspond to minimum usable oil in the tank in the event that the tank is designed so that an unusable amount of oil may remain in the tank.

c. Accuracy. There is a tendency to require greater accuracy than is actually needed. Care should be taken in "profiling" the output to the tank it would be if it were mounted in a fully loaded aircraft flying straight and level. This will normally be a different angle than the tank would assume when the aircraft is parked on the ramp.

d. Response time. Rapid response time is not required and is not desirable. Too rapid response time will result in much pointer fluctuation due to oil slosh. Ten to fifteen seconds for a full-scale change is usually adequate.

e. Display. Oil quantity displays can be in many different forms. On large aircraft the oil quantity display is normally a 2-inch diameter round dial display. On fighter-type aircraft, a dual-level system may be considered consisting of two lights in the cockpit for each engine oil tank. One light would indicate that the 1/2 point has been reached; the second light would indicate that the 1/4 point has been reached.

f. Prohibited materials. Because oil samples are used for diagnostic purposes, there are several materials which may not be permitted to come in contact with the oil. Copper is one of these materials, and there are others. Since the list is changing, it should be consulted prior to the issuing of a specification.

REQUIREMENT LESSONS LEARNED

Many oil quantity gaging systems use floats. Historically, the float has always been considered to be a very simple device to build when in reality many failures in several different systems were the result of faulty float design. The float must be designed to withstand two types of pressure cycles. One is the larger change

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of about 6-8 lbs/sq inch which occurs a few times in a flight due to initial startup and a altitude changes. The other cycle is a small change that occurs many times in a flight due to temperature changes in the tank and throttle movement. If a metal float is not properly designed, the sides of the float will move with the pressure changes that will cause fatigue and/or work-hardening which will result in a crack which will sink the float. Nonmetallic floats have encountered problems due to the long-term adverse effects of MIL-L-7808 and MIL-L-23699 oils. Consideration of a metallic float with internal structural honeycomb is recommended.

All but the very shortest tank probe should be retained at each end. A good method is to use a straight-sided socket in the bottom of the tank with a mating part with a groove cut into it mounted on the bottom of the probe. An "O" ring on the groove will provide for differential expansion and tank tolerance variations. The "O" ring is the only part of the probe which comes into contact with the socket. Generally, probes longer than 15 cm should be restrained at each end to prevent fatigue failure of the probe and/or of the tank around the mounting flange.

Nucleonic oil quantity measuring systems should be avoided. Most of these types of systems have been removed from USAF aircraft. The acquisition cost is high, as is the maintenance cost. The systems must be recalibrated every 6 months due to the decay of the radioactive source and it is dangerous for personnel to work around the radioactive source for more than 15 minutes at a time.

4.2.2.16 Verification of engine oil quantity indicating system. To evaluate the performance of the oil quantity indicating system, tests shall be conducted in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.16)

Laboratory testing is the most practical method to verify the requirements and performance of an oil quantity measuring system. The system can easily be tested using different oils and environments as required.

VERIFICATION GUIDANCE

The system would typically be mounted in a duplicate of the tank used on the aircraft. The specified requirements of range accuracy response time, etc., would then be verified using the measured amounts of the proper oils while applying environmental or other conditions on the system.

VERIFICATION LESSONS LEARNED

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3.2.2.17 Oil pressure indicating system. The oil pressure indicator shall display the pressure of the engine oil to each engine in _____ (units) using signals from a remote sensor. The oil pressure sensor shall measure the pressure of the oil supplied to each engine and provide a signal proportional to the pressure for use by a display or other equipment. The following requirements shall apply: _____.

REQUIREMENT RATIONALE (3.2.2.17)

Engine oil pressure is of vital importance to the operation of any aircraft engine. If the oil pressure drops below certain limits, that engine must be shut down or it will be destroyed.

REQUIREMENT GUIDANCE

Each engine oil system is to be provided with an oil pressure transmitter and an associated pressure indicator in the crew station. Oil pressure readings are calibrated in pounds per square inch (psi) in the English system and kilopascals (kPa) in the metric system. Indicator dials are to be provided with colored range markings in accordance with T.O. 5-1-2 and STANAG 3436.

The following requirements should be specified for oil pressure indicating systems:

a. Range. Most oil pressure systems for engine bearing lubrication on Air Force aircraft operate in the 0-100 psi range. There are systems that operate in the 0-200 psi and 0-500 psi range.

b. Accuracy. The accuracy of the oil pressure indicating system is approximately 4.0 percent of full scale reading. The indicator has an accuracy of approximately 1.5 percent, and the transmitter has an accuracy of approximately 2.5 percent of full-scale reading and are fairly constant over the entire range. Accuracies at high and low temperatures will be greater than at room temperature and will have to be specified accordingly depending upon the temperature extremes expected and the accuracies required.

c. Response. Requirement of oil pressure indication response time may be required for two reasons: (1) to respond in a reasonably short time under extreme cold temperatures on engine start and (2) to respond not too rapidly to cause fluctuations or excessive oscillations. Typical response time at cold temperature shall be 1 second to 4 seconds with a pressure change from 100 psi to 10 psi for the transmitter and not more than 1 seconds for the indicator.

d. Display. Oil pressure displays are typically installed in 1-inch or 2-inch round dial clamp-mounted cases per MS33639. The scale should be oriented so that the normal oil pressure indication is approximately at the 9 o'clock position. Other displays may be used.

e. Transmitter. The oil pressure transmitter must be compatible with the indicator or display intended for use. The output signal format may be analog or digital. Synchros and variable reluctance-types are commonly used. If a digital signal is specified, it shall be compatible with MIL-STD-1553 or with ARINC standards depending upon user preference and end use.

f. Overpressure. The transmitter must withstand an overpressure and still operate within specification tolerance requirements. For most aircraft using 0-100 psi oil pressure systems on overpressure of 200 psi (300 psi applied) is considered adequate for covering any severe overpressure fluctuations occurring under most conditions.

g. Burst pressure. An overpressure of 400 psi (500 psi applied) is usually specified for the transmitter to withstand without rupture or leakage to the pressure-sensing element. This test should be run at 70°F with pressure applied to the input oil pressure port.

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h. Mounting. The transmitter should be mounted on the engine although it can be and is mounted on the airframe of some aircraft. Mounting of the transmitter on the engine eliminates extra fittings and oil lines and reduces the chances of oil line rupture on leakage.

i. Mounting torque. A mounting torque test is usually specified for the transmitter to insure that the case of the transmitter can withstand normal torque forces applied during installation without causing distortion or other failures affecting the accuracy.

j. Temperature. Temperature requirements for oil pressure transmitters are greater than most other equipment. Typical temperatures usually specified are from −54°C to +177°C.

k. Materials. As in the case of oil quantity gaging systems, copper and alloys of copper are not to be used in contact with engine oil.

REQUIREMENT LESSONS LEARNED

In the past, many oil pressure transmitters used silicone fluid for damping. Very minute quantities of silicone fluid intermixing with the lubricating engine oil results in a serious foaming problem causing loss of oil pressure and bearing lubrication. This problem has been encountered previously where the oil pressure sensing element in the transmitter ruptured or failed allowing the silicone fluid to mix with the engine lubricating oil. The use of silicone fluids in transmitters should be prohibited.

4.2.2.23 **Verification of oil pressure indicating system.** The accuracy and requirements for the oil pressure indicating systems shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.23)

The accuracy and other requirements outlined for oil pressure indicating systems can best be verified in the laboratory where various pressure levels can be produced and accurately measured. Required environmental condition can also be easily applied.

VERIFICATION GUIDANCE

The specified requirement should be listed under verification together with any testing procedure that may be necessary to make certain the system meets the requirements. Guidance for typical transmitter verification can be found in MIL-T-38230.

VERIFICATION LESSONS LEARNED

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3.2.2.18 Position indicating system. The position indicator system is used to indicate the position of certain elements of the aircraft such as flaps, wings (sweep), pitch trim, nozzle, etc. It shall meet the following requirements: _____.

REQUIREMENT RATIONALE (3.2.2.18)

To provide visual feedback, it is considered necessary to provide a position indicator for any control surface that cannot be seen by the aircrew.

REQUIREMENT GUIDANCE

Generally, surface position indicators do not have to be highly accurate devices except for wing sweep angle. They are generally used to verify that a surface is moving in accordance with a command. Nozzle position indicator systems are used primarily to assure the pilot that the propulsive system is functioning properly. It is not used as a power setting device.

The following factors must be considered when specifying these systems:

a. Display. Position displays are usually 2-inch diameter instruments. The use of symbolic displays consisting of a miniature aircraft or wing cross section should be considered. The effect of control surface trim can be displayed on the miniature aircraft and the position of life control devices, such as spoilers and flaps, can be displayed on the wing cross section.

b. Range. Surface position is usually displayed in degrees. Nozzle position is generally displayed in percent of full open.

c. Accuracy. Surface position is generally displayed to an accuracy of $\pm 3^{\circ}$ of transmitter shaft. Pitch trim indication should be displayed somewhat more accurately. The rigging of the linkage between the transmitter and the control surface can be a source of considerable error, and tolerances should be determined for technical order use.

d. Response. The indication should be capable of moving slightly faster than the surface to which it is attached. Since engine nozzle movement can be extremely rapid, it may not be possible for the indication to follow it.

e. Torque. The torque required to rotate the transmitter should be checked at temperature extremes to insure that differential expansion will not cause internal binding. The transmitter for either an engine nozzle or wing surface can be exposed to a very wide temperature change very rapidly.

f. Anti-freeze-up. Position transmitters for slats and flaps are located in the wing and may be exposed when the surface is extended. In rain they may be exposed to a lot of water which can freeze as the aircraft climbs to altitude. An anti-freeze-up test should be required on transmitters subject to rain and subsequent freezing temperatures.

REQUIREMENT LESSONS LEARNED

It has been found that position transmitters exposed to rain should be as well sealed as possible. The use of drain holes has been detrimental because rain is often driven into the transmitter through the drain holes and is prevented from draining due to air flow.

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4.2.2.18 Verification of position indicating system. The position indicating system requirements are verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.18)

The specified requirements for position indicators and transmitters can easily be verified by laboratory testing. Final installed performance can only be determined during flight test of the air vehicle.

VERIFICATION GUIDANCE

Simple tests equipment is usually provided to verify specified requirements. Environmental conditions can be applied as required.

VERIFICATION LESSONS LEARNED

3.2.2.19 Tachometer indicator system. The tachometer display shall indicate the rotational speed of _____ (units). It shall operate using signals from _____.

REQUIREMENT RATIONALE (3.2.2.19)

Engine rpm is an important parameter which must be displayed to the aircrew for safety and performance reasons. It is used during engine starting and all portions of flight.

REQUIREMENT GUIDANCE

The rpm of gas turbine engines is always displayed as a percent. This is because the numbers tend to be high and vary greatly with the diameter of the engine. For some engines, rpm is the main power parameter. With few exceptions, all USAF aircraft and commercial airlines (and helicopters) use the standard tachometer system. The standard system consists of an engine-mounted tachometer generator and a 2-inch diameter indicator. Basically, the standard system consists of an electric AC 3-phase generator which drives a 3-phase synchronous motor in the indicator. The synchronous motor rotates several magnets within a copper drag cup. The standard tachometer generator consists of a 3-phase winding with a 2-pole permanent magnetic rotating inside the winding. The tachometer generator provides both the signal and the electrical power to drive the indicator. The standard indicator has a four (4) pole permanent magnetic rotor turning in a field, wound to accept the 3-phase output of the generator. The indicator rotor synchronizes at one-half (1/2) of the generator rotor speed. Therefore, the rpm signal is transmitted by the frequency of the 3-phase electrical signal, not the voltage level as is commonly believed. The power (1/3 amp at 21 volts) generated by the generator drives the motor in the indicator. The only external power required is for the indicator lights. A tachometer system should be provided for each engine. On dual spool engines--notably large turbofan engines--a tachometer system may be provided for each spool. The system consists of an engine-mounted transmitter and remote display. Engine rpm shall be measured and displayed as a percentage of the maximum permissible rpm at the maximum continuous nonafterburning power setting. On helicopters, the rotor transmitter may be mounted on the transmission. Rotor speed will be displayed as actual rpm. The rpm of reciprocating engines will be displayed as actual rpm.

The following factors must be considered when specifying tachometer systems:

a. Range. The display range for gas turbine engines should be from 0 to 110 percent to provide for engine growth through rerating. Propeller and helicopter rotor speeds shall be displayed in actual rpm.

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b. Accuracy. Highest accuracy should be required in the 80 percent to 105 percent range. To require an accuracy of plus and minus 0.5 percent in this range is reasonable; even greater accuracy may be desirable. The accuracy below 80 percent could be reduced to plus and minus 2.0 percent or even plus and minus 3.0 percent. At the lower ranges, the tachometer is used during starting to observe the rate of increase of speed to guard against hot starts and hung starts. In the higher ranges, technical orders generally prescribe limits or operating points to one-tenth of a percent (0.1 percent). At temperature extremes, particularly low temperatures, the accuracy tolerances should be relaxed as much as practicable. In some designs, a reduction of low temperature accuracy permits the use of larger amounts of lubricant.

c. Response. The tachometer system should be able to travel up scale slightly faster than the engine can accelerate to 100 percent rpm. Particular attention should be paid to the area between 80 percent and 100 percent rpm to insure that the tachometer indication can keep up with the engine acceleration in this area. This is so that the operator will have the capability of preventing an overspeed in the event of a governor failure.

d. Starting and synchronous operation. In some cases, the operator may want to measure acceleration or coast-down time or perform some operation that can only be done when the engine is not turning. Therefore, the tachometer system should start functioning at a very low rpm, such as 2.5 percent, and with decreasing speed, continue to function down to a low rpm.

e. Display. The display must have the capability of being read to within 0.5 percent. This is usually accomplished using an expanded scale in the critical regions or by the use of a vernier subdial. Displays can be the 2-inch round dial type, vertical scale, or other depending upon user preference, cost considerations, etc.

f. Transmitter. Most systems utilize the standard transmitter which mounts on the standard drive pad located on the engine accessory case. If a magnetic pickup operating from a gear is used, electrical shielding should be considered. In the past, this type of transmitter has proven troublesome because the coil tended to act as an antenna. Efforts to induce and detect eddy currents in titanium fan blades as they pased a sensor have proven less than successful because of clearance variation with wear and temperature changes. References to tachometer indicators can be found in STANAG-3691, and several military specifications found listed in the DOD index of specifications and standards under indicator, tachometer, and generator, tachometer.

REQUIREMENT LESSONS LEARNED

See paragraph 3.2.2.19 - "f" above.

4.2.2.19 Verification of tachometer indicating system. The tachometer display and sensor shall be verified by testing in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.19)

With the exception of some sensors such as blade or gear tooth counters, which must be tested on the engine or air vehicle, tachometer indicators and transmitters can best be verified by laboratory testing.

VERIFICATION GUIDANCE

Displays and transmitters are usually tested separately using specially designed test equipment. Certain requirements are tested on a 100 percent basis while environmental tests are conducted using a sampling plan.

VERIFICATION LESSONS LEARNED

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3.2.2.20 Thrust computing system (TCS). The system shall display actual gross thrust divided by reference thrust as a percentage. Rerating of the engine shall not require changes to the gross thrust computation algorithm. The system will receive information (pressures, temperatures, etc.) from the following aircraft systems: _____. The system will provide information to the following aircraft systems: _____.

REQUIREMENT RATIONALE (3.2.2.20)

The measurement of engine thrust has been a long sought-after achievement. Only recently has it been possible to measure airborne thrust, the most important parameter as far as air vehicle takeoff and performance is concerned. The TCS should be considered for use on any new air vehicle using turbojet, turbofan, or afterburning turbojet and turbofan engines.

REQUIREMENT GUIDANCE

The TCS computes the actual gross thrust (in pounds) being produced and the percentage (based on military power, nonafterburning) of available thrust that is actually being delivered. The TCS is operable on the ground and in all flight modes. While the TCS is applicable to any turbojet or turbofan engine, greatest benefits can be accrued by applying it to variable nozzle engines. On variable nozzle engines, the TCS provides performance information not available from other engine instrumentation. Some potential benefits of utilizing the TCS are as follows:

(1) Single instrument, quickly interpreted.

(2) Provides immediate quantative assessment of malfunction, deterioration, icing, battle damage.

(3) Confirms proper operation of complete propulsion system prior to takeoff.

(4) Reduces unsubstantiated pilot squawks.

(5) Allows more accurate engine trimming which will reduce costs.

(6) Input to energy maneuverability system, flight recorder, etc.

(7) Unchanging performance standard built into each system.

When specifying a TCS, the following requirements must be considered:

a. Range. The percent system should be designed so that 100 percent is equivalent to full military power (nonafterburning for afterburning engines). In this usage, the term "full military power" means the maximum nonafterburning thrust level that the engine can maintain continuously in an operational situation. On an afterburning engine, whenever the afterburner is lit, the percent display will indicate over 100 percent.

b. Accuracy. To be useful, the system should have a gross thrust error of not more than plus and minus 2.5 percent of the point. The accuracy should be greater at the full military power point, especially if the TCS is to be used for engine trimming. The accuracy of the percent function will necessarily be no better than the accuracy of the gross thrust readout.

c. Response. The system should be capable of changing indication slightly faster than the engine is capable of changing the amount of thrust that it is producing.

d. Sensitivity. The system should be capable of responding to the minimum adjustment of the fuel control.

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e. Interfaces. The system will interface with the central air data computer (CADC) and the egine pressure transducers. The CADC will provide ambient pressure and temperature information to the TCS as well as providing a MACH signal. The engine pressure transducers will provide inputs of total pressure behind the turbine, static pressure at the flame holder, and the static pressure at the entrance to the nozzle to the thrust computing algorithm. It is expected that the output of the TCS will operate a cockpit display, a go-no-go indication, play a part in any diagnostic or engine monitoring programs, and provide an input to future energy management or energy maneuverability systems.

f. Display. The display may take any convenient format suitable to the air vehicle. It is anticipated that the thrust display (percent thrust or gross thrust or both) will become the primary engine instrument, thus relegating the traditional engine instrument displays to an area of lesser importance.

REQUIREMENT LESSONS LEARNED

It has been learned by AFLC that J85 engines can be successfully trimmed using a TCS system. The engines are experiencing longer life characteristics because the trimming is more accurately controlled toward the minimum allowable thrust range, thereby maintaining a more uniform, lower operating engine temperature.

4.2.2.20 **Verification of thrust computing system.** The requirements for the thrust computing system shall be verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.20)

Visual inspections and tests to verify that the display and components meet the general requirements can most easily be accomplished in the laboratory. Actual system performance must be verified on an engine running in an engine test cell.

VERIFICATION GUIDANCE

When the measurement parameters and values have been established for a given system, future production systems of the same part number can be verified in the laboratory using simulated pressure and other inputs. All specified requirements should be verified.

VERIFICATION LESSONS LEARNED

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3.2.2.21 Turn and slip display. Turn and slip displays provide an indication of aircraft rate-of-turn and slip information. It shall have the following characteristics: _____.

REQUIREMENT RATIONALE (3.2.2.21)

The turn-and-slip display provides an indication of aircraft rate of turn and slip. It is sometimes considered as a standby indicator in event of failure of the attitude indicator.

REQUIREMENT GUIDANCE

The turn needle can display either a standard two-minute turn for one-needle-width deflection or a four-minute turn for one-needle-width deflection depending on the mechanization of the indicator and system or rate gyro, sensing aircraft rate of turn. Most rate-of-turn displays are mechanized to display a four-minute turn for one-needle-width deflection. The slip indicator or inclinometer indicates aircraft slip or skid by means of a ball free to roll in a curved glass tube. This tube is filled with a colorless fluid which is normally alcohol to provide damping. The preferred color for the ball is white. However, if the slip indicator ball is smaller than 0.20 inches in diameter, a black ball is preferred. The reason for this is that black balls being metal are denser than the white ceramic balls, and as a result, the possibility of sticking is minimized. White ball slip indicators of less than 0.2 inches in diameter have generally proven unacceptable.

The following requirements apply:

a. Rate-of-turn display. The turn-rate display normally appears similar to that contained in MIL-I-7627.

b. Turn-pointer damping. The turn-pointer must have some damping to prevent pointer oscillation. A suitable damping factor of full-scale deflection from one to three seconds has been found to be satisfactory.

c. Turn-pointer accuracy. An accuracy of not more than plus and minus 7.5 percent of the input rate has been found adequate.

d. Slip display. The display of slip is mounted directly below the turn display and usually consists of a ball rolling in a curved glass tube as described above. At least half of the ball must be visible at all times. No part of an air bubble is to be visible in the tube.

e. Slip-indicator damping. The time for the slip ball to roll from the zero mark to the end of the tube should be not less than 0.2 seconds when the indicator is rapidly tipped to an angle of 24 degrees.

f. Full-scale deflecting. The slip ball should travel full scale when the indicator is tipped between 6 degrees and 12 degrees depending upon the sensitivity required for best aircraft control. The ball must travel freely from one end to the other with no sticking. Most of the requirements established for turn-and-slip indicators were generated through trial and error. Damping and sensitivity requirements were determined by flight tests and pilot opinion and have been found to be acceptable in most aircraft. STANAG 3322 outlines international agreements established for the indicator.

REQUIREMENT LESSONS LEARNED

Since most turn-and-slip indicators were and are powered by 28V DC, the original designs used DC commutator motors to turn the gyro motors. The brushes used in DC motors are subject to wear and provide very low reliability. New designs specify the use of inverters and AC motors which greatly increase the reliability of this type of indicator.

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4.2.2.21 Verification of turn and slip display. Turn-and-slip display characteristics shall be evaluated in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.21)

Accurate turn rates are easily produced on laboratory equipment providing ease of verification of turn-and-slip indicator requirements.

VERIFICATION GUIDANCE

Certain of the specified requirements should be tested on a 100 percent basis; these include damping and accuracy. Other verifications, particularly environmental tests, can be accomplished on a sampling basis. MIL-I-7627 contains a typical verification plan for turn-and-slip indicators.

VERIFICATION LESSONS LEARNED

Normally, turn-and-slip indicators are tested on level rate tables with no bank angles applied. This does not represent a true flight condition because there will always be some bank angle, depending upon airspeed, when the aircraft is turning. If very accurate turn-rate indications are required, it is recommended that the bank angle corresponding to the airspeed and rate of turn be applied when testing the indicator. This requirement would mean that the indicator would have to be designed for a certain airspeed. If this were done, the airspeed for which the indicator is intended should be marked on the case.

3.2.2.22 **Warning system.** The warning system shall warn the aircrew of a dangerous situation or an impending dangerous condition using an aural tone and/or voice warning. A warning of the following conditions shall be provided: _____. The warning system shall have the following features: _____.

REQUIREMENT RATIONALE (3.2.2.22)

Warning signals are an inherent part of the operation of any aircraft. During heavy workload periods, the aircrew cannot monitor every system adequately and must be warned of a dangerous or an impending dangerous condition.

REQUIREMENT GUIDANCE

A warning can be presented to the pilot by visual, aural, and/or tactile means. Recommendations concerning intensity, color, aural frequency, and repetition rates of the warnings involve considerable human factor considerations. AFSC DH 1-3 provides guidance in these human factor considerations. The requirement stated here is intended to be for more complex warning systems and does not include simple warning or caution lights for low oil pressure, over temperature, high or low voltage, and other similar warnings.

The following warnings may be considered for the air vehicle:

a. Stall warning. A warning of pending approach to aircraft stall. Refer to Air Data System and Equipment Specification, MIL-A-87211.

b. Gear-up warning. A warning that landing gear has not been lowered while airspeed and altitude are in landing envelope. Refer to Air Data System and Equipment Specification, MIL-A-87211.

c. Barometric altitude warning. A system to aid the pilot by presenting him with: command information prior to capture of a preset altitude, deviation notification upon departure from preset

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altitude, and optional notification just before and at a preset decision height altitude. Refer to Air Data System and Equipment Prime Specification, MIL-A-87211.

d. Ground proximity warning system (GPWS). A system to reduce the number of controlled-flight-into-terrain (CFIT) type accidents. The system monitors outputs of aircraft sensors, such as radar and barometric altitude, glideslope deviation and configuration (gear, flaps, etc.); evaluates these aircraft parameter; and gives a warning if a potentially dangerous situation exists. The aircraft parameters are evaluated in pairs with each pair defining a mode (i.e., radar altitude versus radar altitude rate with gear up). A warning area is defined for each of these two dimensional modes. When the aircraft parameters fall within this area, the warning is given (i.e., when an aircraft is descending at 3000 fpm and descends below 1500 feet, the aircraft is in the Mode 1 warning envelope). The basic GPWS system is defined by five modes:

Mode 1 - Excessive rate of descent with respect to terrain

Mode 2 - Excessive closure rate to terrain

Mode 3 - Excessive sink rate after takeoff or missed approach

Mode 4 - Too great of a proximity to terrain for aircraft configuration

Mode 5 - Glideslope deviation.

Improvements are being made in GPWS by a few manufacturers. One improvement is use of an additional parameter of airspeed which is used to modify the warning area of some modes thereby increasing warning time and decreasing the occurrence of nuisance warnings. Another feature of an improved system is an expanded warning vocabulary. A standard GPWS has only a simulated voice warning "PULL-UP" preceded by a "WHOOP-WHOOP" siren. An improved system could have additional voice warnings such as "SINK RATE," "TERRAIN," "DON'T SINK," "TOO LOW," "GEAR," and "FLAP." These warnings have better pilot acceptance because the warning identifies its cause. A standard GPWS is designed for a 2500-foot range radar altimeter and would use only 2500 feet of higher range altimeters in the USAF inventory. An improved system might use the full range of high- range radar altimeter. In the more distant future, one may see the use of weather radar as an input into GPWS for forward-looking capability. Aural warning generation should be centralized if any of the following features are desired:

(1) When warnings must be prioritized.

(2) When a large vocabulary of simulated voice warnings is desired.

(3) When simultaneous warnings are not allowed.

Tone warnings must be distinct and consistent with established practices. Frequency, period, sweep rate, and volume discussions are found in the Stations and Passenger Accommodations Military Standard, MIL-STD-1776.

Human factor testing has shown that voice warning allows for a more immediate pilot response. The vocabulary can be command or informative. Clarity of simulated voice is a function of technique and alloted memory. Vocabulary discussion will be found in the Crew Stations and Passenger Accommodations Military Standard, MIL-STD-1776.

GPWS is required by Federal Aviation Regulations (FAR) for all large turbine-powered aircraft. The requirement compliance date was extended once to 1 September 1976. The extension was due to resolving problems with unwanted or "nuisance" warnings. The solution was to reduce the protection area of the envelopes. In the discussion of the nuisance warning problem, it was evident that one could make

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the general statement that with larger aircraft, one would notice fewer unwanted warnings. This indicated that one set of envelopes is not ideally suited to all large turbine aircraft in all roles. Flight testing and tailoring the envelope for each aircraft type is recommended. The tailoring must be done by a contractor who has accident data knowledge so that change effects on both warning time and occurrence rate of nuisance warnings can be weighed. One should be cautious if a contractor proposes to provide GPWS capability in some central computer without the aid of a progressive GPWS manufacturer. The governing FAR GPWS TSO is RTCA Document DO-161A, but it does not define all aspects of the warning, such as filtering of signals and delay times. A contractor may take the approach of defining an envelope and then by flight testing keep reducing the protection area until he achieves a satisfactory occurrence rate of nuisance warning with little thought given to the resulting protection against CFIT accidents.

REQUIREMENT LESSONS LEARNED

There are numerous, continuing accident reports on wheels-up landings and on controlled-flights-into-terrain. It is believed that many of these accidents could have been avoided if proper warning systems were used.

4.2.2.22 **Verification of warning system.** The characteristics and performance of the warning system shall be confirmed in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.2.2.22)

Most of the system characteristics can be verified in the laboratory using controlled, simulated inputs. Aural tones and voice simulation can be evaluated.

VERIFICATION GUIDANCE

The verification of the warning system will closely follow the specified requirements. Each requirement should be verified visually, by inspection or test. Some verifications should be accomplished on a 100 percent basis, others, particularly environmental tests can be tested using a sampling plan. Final performance should be verified by flight tests.

VERIFICATION LESSONS LEARNED

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3.3 **Reliability**. The instrumentation reliability requirements shall be as follows: _____.

REQUIREMENT RATIONALE (3.3)

In the early 1960s, the Air Force started placing greater and greater emphasis on reliability of equipment. Prior to this time, instrumentation life was based on endurance testing, usually by merely running the equipment at room environment for a given number of hours. This was found to be unsatisfactory and did not provide assurance that the equipment would have a reasonable reliability when installed in the aircraft.

REQUIREMENT GUIDANCE

Several MIL-STDs are available, including MIL-STD-756, -757 and -785, to provide guidance in predicting, specifying, and testing reliability of equipment. Reliability requirements may be specified in terms of entire instrument systems or in terms of individual indicators depending upon the type of procurement and user preference. Instrument reliability is usually stated in mean time between failures (MTBF). The expected MTBF varies widely between instruments, depending upon the complexity and nature of the instrument. For details of the overall reliability program, consult MIL-STD-785.

REQUIREMENT LESSONS LEARNED

It has been learned that the reliability of equipment is directly related to the quality of the components used in the design and the workmanship used in assembling the equipment. The standard components outlined in paragraph 3.2.10 are selected with reliability in mind. Microelectronics are widely used and are a major factor in the reliability of instrumentation. It has been found that reliability of equipment has been greatly improved by screening microcircuits in accordance with the applicable tests outlined in MIL-STD-883.

Most instrument specifications require a burn-in test of the completed instrument. The test, usually conducted at an elevated temperature for 24 to 48 hours, has greatly reduced the infant mortality rate in the field. Certain procurement procedures, such as failure-free warranty contracts, have been found to create an incentive for contractors to provide equipment with high reliabilities and have been very successful.

Some instrument manufacturers have elected to hermetically seal certain instruments to render them impervious to certain environmental conditions, such as humidity and salt spray. Improved reliability can be realized using good seals but not necessarily hermetic. If a good seal is not used, the non-use of dissimilar metals as found in MIL-STD-454, Requirement 16 must be carefully followed.

High temperature is probably the largest contributor to low reliability in all equipment. Paint on dials rapidly deteriorates as do lubricants and other organic materials in the equipment. Electronic components, capacitors, transistors, etc., also fail rapidly at high temperatures.

Reliability data of equipment in use can be obtained from monthly reports produced by AFLC. Examples of suitable data are the RCS:LOG-MMO (AR) 7170 entitled "Maintenance Actions, Manhours, and Aborts by Work Unit Code," which provides historical information pertaining to each assigned WUC. The work unit code for the particular equipment being investigated must be obtained from the file on each aircraft. The most pertinent data produced is the monthly MTBF and MTBM for each item found in RCS:LOG-MMO (AR) 7220, entitled "Maintainability Reliability Summary." This document provides a 12-months' summary by air vehicle and includes "on" equipment maintenance action occurrences and manhours and "off" equipment units and manhours as reported on AFTO Form 349. These reports are obtainable from AFLC/MMOMA upon request.

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4.3 Reliability verification. The reliability requirements of 3.3 are verified in the laboratory as follows: _____.

VERIFICATION RATIONALE (4.3)

The laboratory is the best place to verify reliability requirements because controlled environmental conditions can readily be applied and performance monitoring equipment is available.

VERIFICATION GUIDANCE

Most instrumentation is tested in accordance with MIL-STD-781 procedures to verify that the specified MTBF has been met. The test plan that most nearly agrees with the planned and use of equipment should be chosen. In service reliability data records are maintained by AFLC.

VERIFICATION LESSONS LEARNED

3.4 Maintainability. The instrumentation maintainability requirements shall be as follows: _____.

REQUIREMENT RATIONALE (3.4)

The cost of maintenance of Air Force equipment is a very important consideration and should be taken into account when specifying any equipment.

REQUIREMENT GUIDANCE

The instrumentation maintainability will be governed by the acquisition policy established for the air vehicle. The overall system maintainability monitor should assist in establishing these requirements. MIL-STD-470 provides information regarding maintainability requirements specifications for individual pieces of equipment generally have not included maintenance requirements.

REQUIREMENT LESSONS LEARNED

It has been found that several equipment contractors have priced maintainability tests so high that maintainability requirements have been deleted from equipment specifications.

4.4 Maintainability verification. The maintainability requirements of 3.4 are verified as follows: _____.

VERIFICATION RATIONALE (4.4)

Maintenance of instrumentation is accomplished at various levels. The task allocation should reflect the overall logistics plan and be consistent with the intended inventory practices. Maintenance times are demonstrated in a repair shop environment.

VERIFICATION GUIDANCE

MIL-STD-471 outlines verification procedures that may be used.

VERIFICATION LESSONS LEARNED

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3.5 **Safety.** The instrumentation safety requirements shall be as follows: _____.

REQUIREMENT RATIONALE (3.5)

Crew member safety is a primary consideration in the dezine of an overall weapons system and the equipment which is to be used.

REQUIREMENT GUIDANCE

Safety requirements for the instrumentation should be consistent with these requirements for the entire air vehicle. Since many of the instruments are located in aircrew stations, a few unique safety considerations are required. They include:

Glass breakage due to explosive decompression.

Glass breakage due to thermal shock.

Release of toxic fumes due to fire or overheating.

Electrical shock.

A safety consideration for equipment mounted in areas where explosive fumes might accumulate would be the requirement of explosion-proofing.

Fuel leakage and flame resistance is a safety requirement for fuel flow measuring sensors.

The instruments and related equipment design must take into consideration the hazards generated by various modes of failure and insure that these failures do not potentially create the Class III or IV hazards listed in MIL-STD-882. MIL-STD-454, Requirement 1, provides some information regarding safety.

REQUIREMENT LESSONS LEARNED

There have been several instances of electrical shock due to improper grounding of equipment (see 3.2.1.7.3).

4.5 **Safety verification.** The safety requirements of 3.5 are verified as follows: _____.

VERIFICATION RATIONALE (4.5)

Instrumentation safety assessment is an integral part of the system safety program for the total air vehicle.

VERIFICATION GUIDANCE

Safety of individual instruments can be verified by analytical methods or by testing. Laboratory tests for explosion, and temperature shock can be conducted in accordance with MIL-STD-810. Release of toxic fumes can be determined by applying heat to the indicator and analyzing the fumes which may be generated.

VERIFICATION LESSONS LEARNED

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3.6 Human engineering. Human engineering shall be in accordance with _____.

REQUIREMENT RATIONALE (3.6)

The human engineering aspects of instrumentation is particularly important because the instrumentation is one of the major man-machine interfaces in the crew station.

REQUIREMENT GUIDANCE

The requirements for human engineering are found in MIL-STD-1472. Recommendations for display details are also found in STANAG 3705. It is important to make certain that any instrumentation procured for use in the U.S. and NATO countries follow accepted human engineering practice for ease of training and consistent operation between different aircraft. If the equipment is large and heavy, it may be necessary to provide handles in accordance with MIL-STD-1422.

REQUIREMENT LESSONS LEARNED

There have been many accidents caused by poorly designed instrumentation. The three pointer altimeter is one example of a display that can be confusing and misread, particularly under heavy workload conditions.

4.6 Verification of human engineering. Human engineering requirements shall be verified by inspection.

VERIFICATION RATIONALE (4.6)

The application of sound human factors engineering can easily be verified by visual inspection of the instrumentation.

VERIFICATION GUIDANCE

Each element of the instrumentation that interfaces with the crew should be inspected to determine if it meets the human factors requirements in MIL-STD-1472 and STANAG 3705, if applicable. Pointer and counter motions, switch actuation direction and other elements should be inspected for proper functioning.

VERIFICATION LESSONS LEARNED

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3.7 Interface requirements

3.7.1 Related systems. The instrument system shall interface with other air vehicle systems as follows: _____.

REQUIREMENT RATIONALE (3.7.1)

Instrumentation must interface with several other air vehicle systems and components. It is essential that all systems work properly together.

REQUIREMENT GUIDANCE

Normally, the interface is accomplished by the air vehicle contractor as part of the air vehicle integration task. In some cases, it may be necessary for the government to define some interface characteristics such as compatibility with MIL-STD-1553 data bus or when modified instruments are retrofitted to an existing air vehicle. In the case of an entirely new development, it may be desirable to include a statement such as: "The instrumentation shall provide the performance required herein without degradation of other air vehicle systems' performance below their specified performance requirements. The instrumentation shall provide the performance specified herein while installed in the air vehicle and operated with interfacing systems as required by all missions defined for the air vehicle."

REQUIREMENT LESSONS LEARNED

4.7.1 **Verification of related systems.** Characteristics of the instrumentation interface with other air vehicle systems shall be verified by _____.

VERIFICATION RATIONALE (4.7.1)

Verification of interface requirements can often be accomplished in the laboratory by mating and testing the two systems together. Some air vehicle requirements can only be verified by functional and flight tests.

VERIFICATION GUIDANCE

Each interface requirement must be verified either in the laboratory, in a mockup, or in the air vehicle. The final proof is in the ability of the air vehicle to perform the required missions.

VERIFICATION LESSONS LEARNED

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3.7.2 Ground support equipment. The instrument(s) shall interface with the following ground support equipment _____.

REQUIREMENT RATIONALE (3.7.2)

Ground support equipment is a costly but essential requirement to properly test and maintain aircraft instrumentation.

REQUIREMENT GUIDANCE

Wherever possible, it is desirable to provide instruments which can be maintained using standard or available ground support equipment. It may be necessary to define permissible modification of standard ground support equipment. This requirement should be completed to state necessary contractual coordination between the air vehicle development and the ground equipment modification. It may also be desirable to identify specific ground equipment to be defined and/or developed by the contractor.

REQUIREMENT LESSONS LEARNED

4.7.2 Verification of ground support equipment. The instrument(s) interface with other air vehicle systems shall be verified by _____.

VERIFICATION RATIONALE (4.7.2)

Compatibility of instruments with ground support equipment can usually be verified by analysis of the documentation and drawings at PDRs and CDRs. Final verification is made when the instrument is actually tested or repaired using the specified ground support equipment. Guidance. The blank shall be filled in to identify the specific verification method to be used for each instrument and associated ground support equipment.

VERIFICATION LESSONS LEARNED

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3.8 International standardization. "International Standards, including NATO STANAGS, ASCC Air Standards, and ISO documents shall be used as follows: _____.

REQUIREMENT RATIONALE (3.8)

Since considerable effort has been expended on developing NATO, ASCC and other standards and participating countries have agreed to use these standards, the Air Force is obligated to conform wherever possible without penalizing the air vehicle.

REQUIREMENT GUIDANCE

With rare exceptions, existing Air Force instrumentation complies with NATO standards. If new instrumentation is to be developed, the guidelines of STANAG 3705 should be followed. When it is anticipated that an aircraft will be sold to and used by NATO or ASCC countries, international standards should be reviewed to determine if they are applicable. A complete listing of NATO STANAGS and ASCC Air Standards can be found in the DOD Index of Specifications and Standards.

REQUIREMENT LESSONS LEARNED

NATO and ASCC countries place much emphasis on international standards. If U.S. aircraft do not comply, loss of foreign sales could result or aircraft could require modification.

4.8 Verification of international standardization. Requirements of NATO, ASCC and ISO Standards shall be verified by: _____.

VERIFICATION RATIONALE (4.8)

Verification that international standards have been followed is necessary, particularly if a foreign nation is buying the aircraft and has specified that they be used.

VERIFICATION GUIDANCE

The verification of the use of international standards can easily be accomplished by examination of drawings and comparison of the equipment with the particular standards specified during cockpit mockups or on the production aircraft.

VERIFICATION LESSONS LEARNED

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(See Instructions – Reverse Side)

1. DOCUMENT NUMBER	2. DOCUMENT TITLE
AFGS-87216A	Instrument Systems, Airborne

3a. NAME OF SUBMITTING ORGANIZATION	4. TYPE OF ORGANIZATION *(Mark one)*
	☐ VENDOR
	☐ USER
b. ADDRESS *(Street, City, State, ZIP Code)*	☐ MANUFACTURER
	☐ OTHER *(Specify)*:

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional	b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional
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