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MILITARY HANDBOOK

SURVIVABILITY ENHANCEMENT, AIRCRAFT
CONVENTIONAL WEAPON THREATS,
DESIGN AND EVALUATION GUIDELINES

DEPARTMENT OF THE NAVY
AIR SYSTEMS COMMAND

FSC 15GP

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
WASHINGTON, D.C. 20361

Survivability Enhancement, Aircraft, Conventional Weapon Threats, Design and Evaluation Guidelines

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1. This Military Handbook is approved for use by the Naval Air Systems Command, Department of the Navy, and is available for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commanding Officer, Naval Air Engineering Center, Engineering Specifications and Standards Department (ESSD) Code 93, Lakehurst, NJ 08733 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter,

FOREWORD

One of the unequivocal elements of design that significantly contributes to effectiveness and availability of USN/USMC aircraft Mission-Essential Weapon Systems (MEWS), operating as part of an integrated whole to fulfill a mission need, is the extent combat survivability is integrated in the earliest acquisition phases and subsequently regarded throughout the development and operational phases. The steadily mounting costs of MEWS, the high attrition of both aircraft and personnel experienced in recent combat, and the essentiality of realizing high force readiness and operational effectiveness require utmost attention be given to combat survivability. The capability to survive the conventional weapon threat environment depends on the accuracy with which the expected threat is predicted and the thoroughness with which combat survivability is integrated into the aircraft design and into the tactical employment doctrine to meet this threat. Each component of every subsystem must receive dedicated survivability considerations to ensure highest combat survivability is indeed achieved at acceptable levels in cost, weight, and performance in the integration and design of aircraft MEWS. Significant advances in survivability enhancement technologies and evaluation methodologies have been made which provide the potential to substantially (and efficiently] enhance the survivability of existing and future aircraft MEWS.

This handbook has been prepared in recognition of the need by aircraft designers for uniform guidelines in design techniques and evaluation methodologies to be used in the process of enhancing the combat survivability of aircraft MEWS. The Naval Air Systems Command views combat survivability as a dynamic design discipline. In keeping with evolving needs and threat changes, this handbook will require periodic update to reflect state-of-the-art improvements in design and evaluation techniques, to maintain and enhance its serviceability. Comments and recommendations from users of this handbook are solicited.

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TABLES

1. SCOPE

1.1 General. This handbook is a reference document providing uniform design and evaluation guidelines for the survivability enhancement of aircraft Mission-Essential Weapon Systems (MEWS) for the Naval Air Systems Command, to ensure that effective combat operations are achieved when operating in a conventional weapon threat environment. The design guidelines encompass signature suppression (or its control) and vulnerability reduction. Those elements and design activities that are related to survivability enhancement, but are derived from the degradation of threat subsystem functions (e.g., electronic warfare) or from the ways that the aircraft can be utilized in a hostile environment (e.g., tactics) are not included. The evaluation guidelines, for the purpose of achieving systematic quantification and evaluation of combat survivability, include definition of mission scenario and associated threat environment, vulnerability to threat damage mechanisms, encounter survivability, and survivability enhancement trade-offs.

1.2 Application. These guidelines are applicable to the procurement of all Navy/Marine Corps aircraft MEWS, including remotely piloted vehicles, but excluding systems designated solely for research and training.

1.2.1 New MEWS programs. It is intended that this handbook be applied throughout the materiel acquisition process beginning with the reconciliation of alternative concepts (e.g., conceptual phase) to fill a mission need, as may be set forth in the Mission Element Need Statement (MENS), and extending through the entire life span of aircraft MEWS.

1.2.2 Existing MEWS programs. It is intended that this handbook be applied to aircraft MEWS which have already begun full-scale engineering development, production, modernization, improvement, and retrofit programs.

1.3 Implementation. This handbook should be used in conjunction with aircraft detail specifications and other implementing documentation (e.g., NAVMATINST 3900.16, NAVAIRINST 3920.1) in preparing combat survivability requirements. It may be included in requests for proposals, contract statements of work, survivability program plans, and other contractual documents. It is intended that this handbook be applied in whole, or in part as specified in the implementing documentation, and used as a supplement to MIL-STD-2069, and General Specification for Design and Construction of Aircraft Weapon Systems, SD-24.

2. REFERENCED DOCUMENTS

2.1 Issues of documents. The following documents of the issue in effect on date of invitation for bids or request for proposals, form a part of this handbook to the extent specified herein.

SPECIFICATIONS

MILITARY

MIL-A-8806A -	Acoustical Noise Level in Aircraft, General Specification for.
MIL-A-8860 - (-8861 and -8863 through -8870)	Airplane Strength and Rigidity, General Specification for (Flight Loads and Ground Loads for Navy Procured Airplanes through Vibration, Flutter, and Divergence)..
MIL-A-19879	Armor, Body, Fragmentation Protective, Lower Torso.
M1L-A-46103	Armor, Lightweight, Ceramic-Faced Composite, Procedure Requirements.
MIL-A-46108	Armor, Woven Glass Roving Fabrics.
MIL-A-46165	Armor, Woven Glass Roving Fabrics.
MIL-A-46166	Armor, Glass Reinforced Plastic Laminates.
MIL-B-43366	Body Armor, ‘Fragmentation Protective, Groin.
MIL-B-81365	Bleed Air Systems, General Specification for.
MIL-B-83054	Baffle and Inerting Material, Aircraft Fuel Tank.
MIL-C-675	Coating of Glass Optical Elements (Antireflection).
MIL-C-12369	Cloth, Ballistic, Nylon.
HIL-C-18491	Curtain, Flak Protective.
MIL-C-22285	Extinguishing System, Fire, Aircraft, High-Rate Discharge Type, Installation and Test of.
MIL-C-83291	Covers, Self-Sealing, Fuel Line, Aircraft.
MIL-C-85285	Coating: Polyurethane, Aliphatic, Weather-Resistant, Low Infrared (IR) Reflective.
MIL-D-19326	Design and Installation of Liquid Oxygen Systems in Aircraft, General Specification for.
MIL-D-27729.	Detecting System, Flame-Smoke, Aircraft and Aerospace Vehicles, General Performance, Installation and Test of.
MIL-D-81980	Design and Evaluation of Signal Transmission Subsystems, General Specification for.
MIL-E-5007	Engines, Aircraft, Turbojet and Turbofan, General Specification for.
MIL-E-8593	Engines, Aircraft, Turboshaft and Turboprop, General Specification for.

MIL-E-9426	- Escape System, Requirements Conformance Demonstrations and Performance Tests for, General Specification for.
NIL-E-18927	Environmental Systems, Pressurized Aircraft, General Requirements for.
MIL-E-25499	Electrical System, Aircraft, Design and Installation of, General Specification for.
MIL-E-38453	Environmental Control, Environmental Protection, and Engine Bleed Air Systems, Aircraft and Aircraft Launched Missiles, General Specification for.
MIL-F-7872	Fire and Overheat Warning Systems, Continuous, Aircraft, Test and Installation of.
MIL-F-8785	Flying Qualities of Piloted Airplanes.
MIL-F-9490	Flight Control Systems - Design, Installation and Test of, Piloted Aircraft, General Specification for.
MIL-F-18372	Flight Control System Design, Installation and Test of, Aircraft, General Specification for.
MIL-F-23447	Fire Warning Systems, Aircraft, Radiation Sensing Type, Test and Installation of.
MIL-F-38363	Fuel System, Aircraft, General Specification for.
MIL-F-83300	Flying Qualities of Piloted V/STOL Aircraft.
MIL-G-5485	Glass; Laminated, Flat, Bullet-Resistant.
MIL-G-83363	Grease, Transmission, Helicopter.
MIL-H-5440	Hydraulic Systems, Aircraft Types I and 11, Design, Installation, and Data Requirements for.
MIL-H-5606	Hydraulic Fluid, Petroleum Base, Aircraft, Missile, and Ordnance.
MIL-H-7061	Hose, Rubber, Aircraft, Self-Sealing, Aromatic Fuel.
MIL-H-8501	Helicopter Flying and Ground Handling Qualities, General Requirements for.
MIL-H-8890	Hydraulic Components, Type 111 (-65 Deg to Plus 450 Deg F), General Specification for (Asg).
MIL-H-8891	Hydraulic Systems, Manned Flight Vehicles, Type 111, Design, Installation, and Data Requirements for.
MIL-H-18288	Hose and Hose Assemblies, Aircraft, Self-Sealing, Aromatic Fuel.
MIL-H-18325	Heating and Ventilating Systems, Aircraft.
MIL-H-83282	Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft.
MIL-I-8675	Installation, Aircraft Armor.
MIL-I-8700	Installation and Test of Electronic Equipment in Aircraft, General Specification for.

MIL-I-83294	Installation Requirement, Aircraft Propulsion Systems, General Specification for.
MIL-L-7808	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base.
MIL-L-21058	Lubricating Oil, Gear, Multi-purpose.
MIL-L-23699	Lubricating Oil, Aircraft Turbine Engines, Synthetic Base.
MIL-M-12218	Monobromotrifluorornethane (Liquefied) Technical Grade for Fire Extinguishers.
MIL-P-5518	Pneumatic Systems, Aircraft, Design, Installation, and Data Requirements for.
MIL-P-8045	Plastic, Self-sealing and Non-self-sealing Tank Backing Material,
MIL-P-8564	Pneumatic System Components, Aeronautical, General Specification for.
MIL-P-23377	Primer, Coating, Epoxy, Polyamide, Chemical and Solvent Resistant.
MIL-P-26366	Propeller Systems, Aircraft, General Specification for.
MIL-P-46111	Plastic Foam, Polyurethane (for Use in Aircraft).
MIL-P-83126	Propulsion System, Aircraft Crew Emergency Escape, Ejection Seat Type, General Design Specification for.
MIL-S-8698	Structural Design Requirements, Helicopters.
MIL-S-8802	Sealing Compound, Temperature-resistant, Integral Fuel Tanks and Fuel Cell Cavities, nigh-adhesion.
MIL-S-9479	Seat System, Upward Ejection, Aircraft, General Specification for.
MIL-S-18471	System, Aircrew Automated Escape, Ejection Seat Type, General Specification for.
MIL-S-46099	Steel, Armor Plate, Roll-Bonded, Dual Hardness.
MIL-S-58095	Seat System, Crashworthy, Non-Ejection, Aircrew, General Specification for.
MIL-S-81771	Seat, Aircrew, Adjustable, Aircraft General Specification for.
MIL-T-5578	Tank, Fuel, Aircraft, Self-Sealing.
MIL-T-5624	Turbine Fuel, Aviation, Grades JP-4 and JP-5.
MIL-T-5955	Transmission System, VTOL-STOL, General Requirements for.
MIL-T-25783	Tank, Fuel, Aircraft and Missile Non-Self-Sealing, High Temperature.
MIL-T-27422	Tank, Fuel, Crash-Resistant, Aircraft.
MIL-T-83133	Turbine Fuel, Aviation, Kerosene Type, Grade JP-8.
MIL-W-81752	Windshield Systems, Fixed Wing Aircraft - General Specification for.

STANDARDS

MILITARY

MIL-STD-461	- Electromagnetic Interference Characteristics Requirements for Equipment.
MIL-STD-462	- Electromagnetic Interference Characteristics, Measurement of.
MIL-STD-1288	- Aircrew Protection Requirements Nonnuclear Weapons Threat.
MIL-STD-1290	- Light Fixed- and Rotary-Wing Aircraft Crashworthiness.
MIL-STD-1629	- Procedures for Performing a Failure Mode, Effects and Criticality Analysis.
MIL-STD-1648	- Criteria and Test Procedures for Ordnance Exposed to an Aircraft Fuel Fire.
MIL-STD-2069	- Requirements for Aircraft Nonnuclear Survivability Program.
MIL-STD-2089	- Aircraft Nonnuclear Survivability Terms.

(Copies of specifications and standards should be obtained from the DOD Single Stock Point, Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120).

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

Chief of Naval Material, NAVMATINST 3900.16 “Combat Survivability of Naval Weapon Systems.”

Chief of Naval Material, NAVMATINST 2410.1B “Electromagnetic Environmental Effects (E3) Policy within the Material Command.”

Naval Air Systems Command, NAVAIRINST 3920.1 “Establishment of Naval Air Survivability Program (NASP)."

Department of the Navy, Naval Air Systems Command SD-24 (Volume I Fixed Wing Aircraft; Volume II, Rotary Wing Aircraft) “General Specification for Design and Construction of Aircraft Weapon Systems.”

Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) SECRET Report NO. JTCG/AS-76-CM-001(1) “Countermeasures Handbook for Aircraft Survivability (U),” Volumes I and II of February 1977.

Department of Defense (DOD) Military Handbook MIL-HDBK-XXX-1 “Survivability/Vulnerability, Aircraft Nonnuclear, General” - Volume 1.

DOD Military Handbook MIL-HDBK-XXX-2 “Survivability/Vulnerability, Aircraft Nonnuclear, Airframe” - Volume 2.

DOD Military Handbook MIL-HDBK-XXX-3 "Survivability/Vulnerability,~ Aircraft Nonnuclear, Engine” - Volume 3.

DOD Military Handbook MIL-HDBK-XXX-4 "Sumivability/Vulnerability, Aircraft Nonnuclear, General Classified" - Volume 4.
DOD Military Standardization Handbook MIL-HDBK-221(WP) "Fire Protection Design Handbook for U.S. Navy Aircraft Powered by Turbine Engines."
DOD Military Handbook MIL-HDBK-235 "Electromagnetic (Radiated) Environment Considerations for Design and Procurement of Electrical and Electronic Equipment" - Part 1; Part 2, Confidential.
DOD Military Handbook MIL-HDBK-238 "Electromagnetic Radiation Hazards."
U.S. Army Air Mobility Research and Development Laboratory Confidential Technical Report No. USAAMRL-TR-72-64 "Design Study of Low-Radar-Cross-Section Expendable Main Rotor Blades (U)" of March 1973.
U.S. Army Materials and Mechanics Research Center Confidential Technical Report No. AMMRC TR 81-20 "Ballistic Technology of Lightweight Armor - 1981 (U)" of May 1981.

Evaluation

OPNAVINST 3811.1A "Threat Support to Weapon Systems Selection and Planning."
Applied Technology Laboratory, Research and Technology Laboratories (AVRADCOM) Report No. USARTL-TR-78-8A "Aircraft Radar Cross Section Analysis," Volume 1 - User's Guide of May 1978.
AVRADCOM Report No. USARTL-TR-78-8B "Aircraft Radar Cross Section Analysis," Volume II - Computer Program Listings of May 1978.
Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) Report No. JTCG/ME-71-5-l "SHOT GENERATOR Computer Program," Volume I, User Manual of July 1970.
JTCG/ME Report No. JTCG/ME-71-5-2 "SHOT GENERATOR Computer Program," Volume II, Analyst Manual of July 1970.
Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) Report NO. JTCG/AS-78-V-002 "FASTGEN II Target Description Computer Program" of January 1980.
JTCG/ME Report No. JTCG/ME-71-7-1 "MAGIC Computer Simulation," Volume I, User Manual of July 1970.
JTCG/ME Report No. JTCG/ME-71-7-2-1 "MAGIC Computer Simulation," Volume II, Part 1, Analyst Manual of July 1970.
JTCG/ME Report No. JTCG/ME-71-7-2-2 "MAGIc Computer Simulation," Volume II, Part II, Analyst Manual of July 1970.
U.S. Army Ballistic Research Laboratories (BRL) Report No. BRL R 1802 "The GIFT Code User Manual;" Volume I, Introduction and Input Requirements, of July 1975.
U.S. Army Armament Research and Development Command (ARRADCOM), Ballistic Research Laboratory Technical Report No. ARBRL-TR-02189 "The GIFT Code User Manual;" Volume II, The Output Options of September 1979.

JTCG/AS Report No. JTCG/AS-76-V-004 (also JTCG/ME-76-13) “Aircraft Vulnerability Assessment Methodology,” Volume 1 - General of July 1977.

JTCG/ME Report (Unassigned Report No.) "COVART, A Simulation Program for: Computation of Vulnerable Areas and Repair Times,” Volume I, User Manual of August 1970.

JTCG/ME Report (Unassigned Report No.) "COVART, A Simulation Program for: Computation of Vulnerable Areas and Repair Times,” Volume II, Analyst Manual of August 1975.

JTCG/ME Report No. JTCG/ME-71-6-1 "VAREA Computer Program,” Volume I, User Manual of February 1971.

JTCG/ME Report No. JTCG/ME-71-6-2 "VAREA Computer Program," Volume 11, Analyst Manual of February 1971.

JTCG/ME Report No. JTCG/ME-73-3 “Internal Blast Damage Mechanisms Computer Program” of 10 April 1973.

Air Force Systems Command Aeronautical Systems Division (ASD) Report No. ASD/XR 72-8 Computer Program for the Prediction of Nonnuclear Blast Effects on Flying Aircraft - Users Manual” of February 1972.

ASD Report No. ASD-TR-77-23 “Preliminary Design External Blast Vulnerability Assessment Procedure,” Volume II, User Manual of April 1977.

JTCG/ME Report (Unassigned Report No,) “Antiaircraft Artillery Simulation Computer Program - AFATL Program POO1," Volume 1, User Manual of September 1973.

JTCG/ME Report (Unassigned Report No,) “Antiaircraft Artillery Simulation Computer Program - AFATL Program POO1," Volume 11, Analyst Manual of September 1973.

JTCG/AS Report (Unassigned Report No.) “Antiaircraft Artillery Simulation Computer Program - AFATL Program POO1," Program Update of April 1976,

JTCG/ME Report No. JTCG/ME-79-8 “Mathematical Model for the REFMOD Computer Program” of 1 May 1979.

JTCG/ME Report No. JTCG/ME-79-8-2 "REFMOD-1 Computer Program,” User Manual of 1 December 1979.

JTCG/ME Report (Unassigned Report No.) “ATTACK Computer Program,” Volume I, User Manual of June 1974.

JTCG/ME Report (Unassigned Report No.) “ATTACK Computer Program,” Volume II, Analyst Manual of June 1974.

JTCG/AS Report No. JTCG/AS-78-V-007 “Simplified Techniques for Vulnerability Tradeoff Analyses” of August 1979..

JTCG/AS Report No. JTCG/AS-76-S-001 “The Mission Trade-Off Methodology (MTOM) Model: Model Description” of December 1977.

a. Copies of NAVMATINST 3900.16, NAVAIRINST 3920.1 and DOD Handbooks should be obtained from the procuring activity; DOD Single Stock Point, Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120; or as directed by the Contracting Officer.

3. DEFINITIONS

3.1 Definitions of key terms. The terms and definitions set forth below provide a selected set of terms which offers concise definitions for use of the Military Handbook. These and other definitions included in the referenced documents of Section 2, particularly MIL-STD-2089, shall apply.

3.1.1 Survivability. The capability of an aircraft to avoid and withstand a man-made hostile environment without sustaining an impairment of its ability to accomplish its designated mission.

3.1.2 Vulnerability. The characteristics of a system which cause it to suffer a definite degradation (incapability to perform the designated mission) as a result of having been subjected to a certain level of effects in an unnatural (man-made) hostile environment.

3.1.3 Detection reduction. The use of techniques that reduce the target aircraft signatures (i.e., infrared, radar, visual, etc.) that are used by threat systems for acquisition, tracking, and warhead guidance/homing.

3.1.4 Vulnerability reduction. Any technique that enhances the aircraft design in a manner that reduces the aircraft's vulnerability when subject to threat mechanisms.

3.1.5 Survivability enhancement. The use of any tactic, technique, or survivability equipment, or any combination thereof, that increases the probability of survival of an aircraft when operating in a man-made hostile environment.

3.1.6 Survivability evaluation. Systematic description, delineation, quantification, and statistical characterization of the survivability of aircraft in encounters with hostile defenses.

3.1.7 Threats. Those elements of a man-made environment designed to reduce the ability of an aircraft to perform mission-related functions by inflicting damaging effects, forcing undesirable maneuvers or degrading system effectiveness.

3.1.7.1 Threat mechanisms. Mechanisms, embodied in or employed as a threat, which are designed to damage (i.e., to degrade the functioning of or to destroy) a target component or the target itself.

3.1.7.2 Conventional weapon, Any weapon whose damage mechanisms do not include nuclear effects, biological agents, or chemical agents other than incendiary and tracer materials. "Conventional weapon" is used to represent all classes and types of nonnuclear threats such as small arms, antiaircraft artillery and cannons, surface-to-air and air-to-air guided missiles with blast or fragmentation warheads, and high-energy lasers (HEL).

3.1.8 Mission-essential weapon systems (MEWS). Aircraft weapon systems, subsystems, or components that perform a combat mission or are essential to a mission capability.

3.2 Definitions of acronyms and abbreviations used in this handbook. The following acronyms and abbreviations used in this Military Handbook are defined as follows:

A	Attrition kill level designator; damage that causes an aircraft to fall out of control within 5 minutes after being hit.
AA	Antiaircraft.
AAA	Antiaircraft Artillery.
AAES	Advanced Aircraft Electrical Subsystem.
ABLE	Advanced Blown Lift Enhancement.
ACS	Assistant Chief of Staff.
ADEN	Augmented Deflector Exhaust Nozzle.
AFAM	Air Force Armament Test Laboratory.
AIT	Autogenous Ignition Temperature.
AMMRC	Army Materials and Mechanics Research Center.
AP	Amor-Piercing.
ARBRL	Armament Resource Ballistic Research Laboratory.
ARRADCOM	Armament Research and Development Command (U.S. Army).
(AS)	Suffix to handbook number indicating limited military handbook coordination within the Naval Air Systems Command.
ASD	Aeronautical Systems Division (U.S. Air Force).
ATTACK	Designator for Terminal Encounter Simulation Computer Program.
AUSEX	Aircraft Undersea Sound Experiment.
AVWADCOM	Aviation Readiness and Development Command (U.S. Army) .
B	Attrition kill level designator; damage that causes an aircraft to fall out of control within 30 minutes after being hit.
BLISK	One piece (integral) blade and disk design of engine rotors.
BRL	Ballistic Research Laboratory (Laboratories).
BUFCS	Backup Flight Control System.
C	Attrition kill level designator; damage that causes an aircraft to fall out of control before completing its designated mission (commonly referred to as a "mission kill").
CCR	Circulating Control Rotor.
CI	Combustion Improver.
COVART	Computation of Vulnerable Area and Repair The computer program.
CVA	Conceptual Vulnerability Assessment.

DMEA	-	Damage Mode and Effects Analysis.
DOD	-	Department of Defense.
DNA	-	Defense Nuclear Agency.
E	-	Kill level designator; a measure of the degree of damage that will cause an aircraft to be structurally damaged upon landing, given it survives to the point of landing.
E3	-	Electromagnetic Environmental Effects.
ECM	-	Electronic Countermeasures.
ECS	-	Environmental Control Subsystem.
EMP	-	Electromagnetic Pulse.
ESSD	-	Engineering Specifications and Standards Department.
FASTGEN	-	Designator for an improved (e.g., run-time efficiency) SHOTGEN Target Description Computer Program.
FBL	-	Fly-By-Light.
FBW	-	Fly-By-Wire.
FMEA	-	Failure Mode and Effects Analysis.
FORTRAN	-	Formula Translation (computer technology coding system).
FSC 15GP	-	Federal Supply Classification Aircraft and Airframe Structural Components Group.
GIFT	-	Geometric Information for Targets computer program.
HE	-	High-Explosive.
HEI	-	High-Explosive Incendiary.
HEL	-	High Energy Lasers.
HELISCAT	-	Helicopter Radar Scattering computer program.
HQ USAF	-	Headquarters United States Air Force.
IAP	-	Integrated Actuator Packages.
ID	-	Identification.
IR	-	Infrared.
JP	-	Jet Propulsion (prefix designator for grades of aviation turbine fuel).
JTCG/AS	-	Joint Technical Coordinating Group on Aircraft Survivability.
JTCG/ME	-	Joint Technical Coordinating Group for Munitions Effectiveness.
K	-	Attrition kill level designator; damage that will cause an aircraft to fall out of control within 30 seconds after being hit.
KK	-	Attrition kill level designator; damage that will cause an aircraft to disintegrate immediately upon being hit.

LHS - Lightweight Hydraulic System.
Little SAM - Designator for shoulder-launched IR missile computer model.
LOS - Line of Sight.

MAGIC - Mathematical Applications Group, Inc. (computer simulation).
MENS - Mission Element Need Statement.
MEWS - Mission-Essential Weapon Systems.
MICE - Missile Intercept Capability Evaluation model.
MIL-(A thru W) - Military Specification.
MIL-HDBK- - Military Handbook.
MIL-STD- - Military Standard.
MTO/C - Mission Trade-off/Cost model.
MTO/E - Mission Trade-off/Effectiveness model.
MTOM - Mission Trade-off Methodology model.

NACA - National Advisory Committee for Aeronautics.
NACSP - Naval Air Combat Survivability Program.
NADC - Naval Air Development Center.
NAVAIRINST - Naval Air Systems Command Instruction.
NAVMATINST - Naval Material Command Instruction.
NOL - Naval Ordnance Laboratory.

OATS - Optical Acquisition and Tracking System model.
OBOGS - Onboard Oxygen Generating System.
OCR - Optical Contrast Reduction.
OPN - Operation.

PCB - Plenum Chamber Burning.
PMA - Project Management Air (Naval Air Systems Command).

RADAR - Radio Detecting and Ranging.
RALS - Remote Augmented Lift System.
RAM - Radar Absorbent Materials.
RCS - Radar Cross Section.
RDT&E - Research, Development, Test and Evaluation.
REFMOD - Reference Model digital computer program.
RF - Radio Frequency.
RLS - Reservoir Level Sensors.

SCAN - Survivability by Computer Analysis computer program.
SD - Standardization Document.
SHOTGEN - Shot Generator computer program.
SONAR - Sound Navigation Ranging.
SUDIC - Survivability through Use of onboard Digital Computers.

TAW - Thrust Augmented Wing.

USARTL	United States Army Research and Technology Laboratory.
USN/USMC	United States Navy/United States Marine Corps.
UV	Ultraviolet.
V	Kill level designator; a measure of the degree of damage that will cause a vertical takeoff or landing (VTOL) aircraft to be incapable of vertical flight, vertical takeoff, or vertical landing.
VAREA	Vulnerable Area computer program.
VRS	Visual Radiation Source.
V/STOL	Vertical or Short Takeoff and Landing.

4. DESIGN GUIDELINES TO REDUCE DETECTION SUSCEPTIBILITY

4.1 Detectable signatures. The emissions emanating from aircraft MEWS can be used by enemy defensive weapons systems to detect, acquire, track, and provide missile guidance to the target. These emissions result in radar, infrared, optical, and acoustic signatures and may include inadvertent electromagnetic radiations (e.g., stray radio frequency (RF) sources).

4.1.1 Signature suppression or control. Signature suppression (or its control) can be achieved by the use of passive techniques to reduce signatures and electromagnetic radiations resulting in induced delays in reaction and response time of the threat, or in reduced detection susceptibility of the target to threat weapons systems. Suppression or control of any one detectable signature should be considered in the context of the entire mission, threat environment, tactics, countermeasures, self-defense systems, and overall effect on all other signatures or emissions. Signature suppression should be a systems consideration that is balanced against all these factors. Detailed, classified discussions on passive signature suppression are contained in DOD Military Handbook MIL-HDBK-XXX-4 and Joint Technical Coordinating Group on Aircraft Survivability SECRET Report No. JTCG/AS-76-CM-001(1) “COUNTERMEASURES Handbook for Aircraft Survivability (U)” of February 1977, Volumes I and II.

4.1.1.1 Radar cross section. Radar cross section (RCS) influences aircraft MEWS survivability when operating in a hostile environment. It governs the range and size of the volume within which the hostile radar can detect or track the target, and it influences the burn-through range below which the amplitude of skin echo exceeds that of a jammer signal received at the radar. The RCS level serves as a basis to determine the required size, weight, complexity, and cost of complementary electronic countermeasures (RCM) for supplementary survivability enhancement. The penalties and effectiveness of ECM are directly related to the magnitude of the radar echo emanating from the aircraft for which the protection is intended.

4.1.1.1.1 Radar cross section reduction. In minimizing RCS, the major scattering centers contributing to overall RCS shall be identified. Greatest concern should be given to large amplitude echoes which occur over broad angular regions rather than to isolated narrow peaks. Echo sources to be controlled and treatment methods should be broadband to minimize possibilities for enemy negation of the echo reduction by simply changing radar frequency a small amount. For fixed wing aircraft from the frontal aspect, emphasis shall be placed on the engine inlet cavities, cockpit, antennas and antenna compartments, leading edge of the wings, external stores and associated suspension equipment, and any other cavities and corner reflectors. From the broadside aspect, emphasis shall be placed on the fuselage, fuselage-wing-empennage interfaces and the vertical tail. For the aft aspect, emphasis shall be placed on the engine exhaust cavities, the external stores and associated suspension equipment, and any other cavities or corner reflectors. For rotary wing aircraft, additional emphasis shall be placed on main rotor mast, hub, and blades; tail rotor drive, hub, and blades; and landing gear. Techniques that reduce the reflectivity of critical surfaces include shaping to maximize signal scatter in a direction away from the threat receiver, shielding of major scatterers, and the application of radar absorbent materials (RAM) to absorb transmitted electromagnetic energy. A number of RAM types have been developed which provide a selection of weights, thicknesses, and structural properties. These include the dielectric gradient, magnetic absorbing coating, and circuit analog and hybrid absorbers. For main rotor blades of rotary wing aircraft, the shaping of the main spar and the use of absorbers provides reduced RCS signatures for certain radar wave bands (see Confidential U.S. Army Air Mobility Research and Development Laboratory Report No. USAAMRL-TR-72-64 “Design Study of Low-Radar-Cross-Section Expendable Main Rotor Blades (U)" of March 1973). Low RCS tail rotor blades have been developed by using a wet filament winding process on Revlar 49 Aramid fibers and epoxy materials, one of many techniques that can be used. It consists of an inner Kevlar 49 core, a layer of microwave absorbent material, and an outer Kevlar 49 spar and skin. There are other designs that may yield greater reductions in RCS.

4.1.1.2 Infrared radiation.

a. Electromagnetic radiation that propagates in the wavelength region from 0.75 to 1000μ is defined as infrared (IR) or thermal radiation. Subdivisions of the IR spectrum include the following:

(1) near IR (0.75 to 3μ)

(2) middle IR (3 to 6μ)

(3) far IR (6 to 15μ)

(4) extreme IR (15 to 1000μ)

b. The principal sources of IR radiation associated with an aircraft platform include:

(1) engine hot metal and plume emission

(2) airframe surface reflection

(3) airframe surface emission

c. The engine hot metal and airframe surface emissions exhibit spectral IR continuum characteristics which are dependent on the temperature and emissivity-area of the radiating surface. These IR sources radiate in a relatively broad wavelength interval with a spectral shape in accordance with Planck's Law (i.e., with a blackbody spectral shape). The surface-reflected IR radiation will also appear as a continuum based on the equivalent blackbody temperature of the incident radiation (e.g., the sun has a spectral shape characteristic of a 5527°C blackbody). Both the direct (specular) as well as the diffuse (Lambertian) reflected IR radiation components, which are a function of the surface texture and the relative orientation of the surface to the source, must be included. The remaining IR source, engine plume emission, is a composite primarily of CO_2 and H_2O molecular emission spectra. The spectral strength and linewidth of these emissions are dependent on the temperature and concentration of the hot gaseous species in the plume which are a function of the aircraft altitude, flight speed, and power setting. When large rotary wing aircraft approach a landing zone, IR radiation will increase (extent of increase dependent upon power setting, speed and gross weight) due to swirl action of hot exhaust gases about the airframe. This situation affects the engine hot metal emission, airframe surface emission, airframe surface reflection, and engine plume emission. In addition to the spectral nature of the individual IR sources, their spatial distribution must also be considered. A summary of the spatial considerations associated with each of the IR radiation sources is provided below:

(1) Engine hot metal emission is derived from the last turbine stage, tailpipe inner liner and nozzle surfaces, and hence is generally confined to rear hemisphere aspects.

(2) Airframe surface emission is generally largest when viewing the top or bottom of the aircraft where the maximum projected area normal to the sensor line of sight (LOS) occurs. The remaining spatial distribution will be dependent on the change in total surface temperature and projected area as a function of viewing angle.

(3) Airframe surface reflection is maximum when the direction of the incident source radiation is collinear with the sensor LOS and the maximum airframe projected area is normal to the LOS. The spatial distribution will be dependent on the complexity in shape and size of the aircraft as well as on the reflectance characteristics of its surface coatings.

(4) Engine plume emission extends at least 10 tailpipe diameters to the rear of' the exit plane of the aircraft engine(s). Hence, it may generally be viewed from

any aspect angle with the maximum radiation occurring at broadside aspects where radiation from the entire length of the plume may be detected.

4.1.1.2.1 Infrared radiation reduction. General methods that should be applied to reduce the primary sources of aircraft IR signature include the reduction of temperature, area, and emissivity (or reflectivity). These techniques apply to both continuum and band/line emissions. The order of priority in which reduction of these source contributors is incorporated should be integrated into considerations of the aircraft mission, flight profile, and expected threat encounter. As the first order signature source is reduced, the remaining orders of priority increase accordingly. Most IR reduction techniques also reduce engine cavity RCS or enhance the application of RAM by virtue of redaction in wall temperatures.

4.1.1.2.1.1 Engine IR emission reduction. Efficient utilization of advances in specific technologies to reduce or control IR emissions is contingent upon the aircraft/engine application of these techniques and must be incorporated with a minimum penalty in weight and performance. This utility is uniquely related to the engine cycle type - turbojet, turboshaft/turboprop, or turbofan. In comparison to the turbofan, neither the turbojet nor the turboshaft/turboprop has an inherent coolant source for IR reduction. Since shaft horsepower is the primary output of the turboshaft or turboprop cycle engine, derived by incorporating a power turbine behind the main turbine to extract maximum energy from the gas stream, its power turbine exhaust gas temperature is lower than that from a turbojet. Therefore, for a given technology limit of turbine inlet temperatures, the turboshaft/turboprop would typically be expected to have a lower IR radiation level than turbojets. Although the potential for reducing IR emissions from existing turbojets is considered poor - virtually impossible for existing augmented turbojets - coolant sources (-e.g., cooling air pumped by ejectors) have been developed that appear to have a high potential in reducing the IR radiation from turboshaft or turboprop engines’. The ejector pump technique utilizes the residual energy of the engine exhaust gases to pump large volumes of ambient air to reduce the temperature of the plume gases. On the other hand, the advantage of the turbofan is the inherent availability of cool bypass air for the reduction or control of the IR signature. of the two bypass ratio wariants of the turbofan, mini-bypass and medium-bypass, the medium-bypass variant with a bypass ratio of 0.5 to 3.0 will logically have higher potential for IR suppression. Reduction of the IR signature is possible because of the availability of bypass air to cool engine hot parts (e.g., exhaust frame center-body, flameholders, tailpipe, and nozzle walls) and mix with the hot core gas to cool the plume. An integrated mixer/augmentor nozzle/IR suppressor exhaust system can be used to achieve additional IR suppression without severely compromising the performances of both augmented and unaugmented turbofan cycle engines. for components such as turbine blades, cooled shields (or plugs) which block the view of the blades can Be used.

Further IR radiation reduction may be accomplished by coating the cooled surfaces with an IR radiation absorbent material, or by modifying the cross-sectional exhaust duct shape. IR absorbent material should ideally convert the surface characteristics of the material to those of a diffuse reflector which returns approximately one-half of the radiation towards the turbine and reflects little of the remaining portion in the direction of the exhaust exit plane. In this way, the radiation from the turbine will have a larger number of reflections from the absorbent surfaces and, thus, a higher probability of IR absorption occurs before leaving the exhaust duct. The second IR reduction technique entails a transition from a round, cross-sectional, exhaust duct shape at the turbine discharge plane to an elliptical or rectangular shape ($L/W \geq 2$) at the exhaust gas exit plane. Either exit shape provides more perimeter for the engine exhaust flow to mix with the surrounding ambient air; hence, it reduces the optical depth of the plume across the narrow dimension and enhances mixing of, for instance, the plume core flow with the bypass flow for a mixed flow turbofan installation.

4.1.1.2.1.2 Airframe emission/reflection reductions. IR emissions from aerodynamically heated airframe sources are virtually insignificant for small aircraft operating at subsonic flight speeds. Significantly high emissions result from supersonic flight speeds of most interceptors and bombers and from low altitude, high subsonic speeds of large aircraft. At supersonic speeds, the emissions are caused by high airframe skin recovery temperatures. In the case of large aircraft operating at high subsonic speeds, the emissions are due to moderate airframe skin temperatures combined with large skin areas. Although no efficient techniques exist to reduce aerodynamic heating effects, MIL-P-23377 (Type II) primer and MIL-C-85285 IR reflective coatings are available to reduce continuum emissions emanating from airframe surfaces. IR radiation from "hot spots," caused by other than the propulsion system and aerodynamic heating such as rotary wing aircraft main rotor transmissions and power trains and heat exchangers, can be reduced by the use of insulation, masking, or cooling flow techniques; however, the use of these techniques generally results in a weight penalty that can be minimized by judicious placement of these components during the conceptual design phase. The highly specular solar reflections from aircraft transparencies (sometimes referred to as sun glint) and other highly reflective surfaces can be reduced by using flat surfaces to the extent practical or, in the case of transparencies, the use of baffles or fences and flat transparencies can reduce the incidence of reflection from certain aspects used by some IR-guided missiles for target acquisition. Glint intensity is influenced by surface shape and surface material reflectivity, diffuseness, and absorptiveness. Techniques, provided in 4.1.1.3, to control the optical signature may also be used to reduce airframe reflections.

4.1.1.3 Optical signature. Four contrast mechanisms influence optical detectability - luminance, chromaticity, clutter, and movement. Of these, the most dominant (in most cases) is aircraft luminance contrast ratio - ratio of the difference between the luminance of the aircraft and background to the luminance of the background. Luminance is the radiance (i.e., power/solid angle/projected area) of an object as weighted by the luminosity function of the standard observer which varies with viewing and target conditions. The aircraft luminance is the sum of any onboard luminance sources and luminous reflectance from the aircraft exterior surfaces. Interior and exterior lighting systems should be considered as significant sources of potential visual cues to enemy ground forces during nighttime combat operations. In addition to the basic structure of the aircraft itself, a variety of aircraft attributes produces significant luminance contrast detection cues; for example, engine exhaust smoke, contrails, and glow (at night) and canopy glint. Glint is due to specularly reflected sunlight from canopies, windows, and other types of transparent enclosures and from metallic surfaces. When efforts are taken that significantly reduce the luminance contrast of aircraft relative to that of the background, residual chromatic contrast between the aircraft and its background can become the dominant detection cue. Since color sources may differ in their hue (a chromatic characteristic) , as well as in their luminance, the term color encompasses both luminance and chromatic contrast attributes. As the background of a number of engagement situations may not be uniform, clutter contrast can affect visual detectability. Examples of clutter contrast include helicopter nap-of-the-earth flight profiles and low altitudes of flight of fixed wing aircraft. Under these conditions of flight, the observer must fixate with a foveally centered lobe to detect and discriminate the aerial target from the background clutter of confusing forms rather than rely on his peripheral contrast thresholds for target acquisition. For many “detection in clutter” tasks, detection is immediately achieved once fixation is achieved. This occurs because the target still has a very high luminance contrast relative to the clutter contrast. Another attribute that can have a significant cueing effect on detectability is any discernible movement of the aircraft. Discernible movement is conditional upon some degree of luminance or chromatic contrast between the aircraft and background and distance from the observer to the target. The eye is sensitive to movement over a very large range of angular frequencies (from 5.8 x 10^{-4} rad/s to 87,3 x 10^{-} rad/s). A significant factor influencing movement contrast is the amount of variation in the background luminance, since this will lead to contrast fluctuations as the aircraft moves. In the case of rotary wing aircraft, a movement that may be discernible to detection is the rotation of the rotor blades. Against a background of relatively high luminance (e.g., the sky), the rotating blades present a negative contrast - a flickering stimulus. Under some illumination conditions, the rotating blades yield glint-flicker which is a highly detectable cue due to the inherent high luminance associated with the glint combined with the temporal enhancement due to flicker.

4.1.1.3.1 Optical signature reduction. Techniques to suppress or control the optical signature include engine exhaust/glow suppression, canopy glint reduction, paints and coatings, YEHUDI camouflage, and lighting system suppression.

4.1.1.3.1.1 Engine exhaust/glow suppression. Engine exhaust contributors to optical detection include smoke, contrails and, at night, exhaust glow, Until recently, methyl-cyclopentodienyl+manganese-tricarbonyl (commonly referred to as CI-2 combustion improver] was used as a catalytic chemical additive to catalyze the oxidation of carbonaceous particles by lowering the fuel ignition temperature. The use of chemical additives (e.g., CI-2) has since been abandoned, because it shortened engine life, was ineffective at altitudes of flight below 2000 ft (610 m), and toxic. Current emphasis is directed towards improved (smoke free) combustor design. These techniques include increasing the primary airflow to the fuel-rich burner dome, employing high density/multisource fuel injection, increasing the pressure loss across the combustor, minimizing the amount of dilution air, pre-vaporizing the fuel prior to injection in the combustor zone, and injecting the fuel in the dome inlet diffuser region. To minimize hot parts glow, hide or cool the hot parts and, as delineated in paragraph 4.1.1.2.1, an asymmetric or turned exhaust nozzle can be utilized. Hot parts glow reduction is an inherent fringe benefit of an IR engine suppressor.

4.1.1.3.1.2 Canopy glint reduction. Canopy glint reduction has been applied to rotary wing aircraft only, since their relatively slow speeds readily allow this application and possibly account for detection of the glint signature (or glare) more readily than other visual cues. The only specification coating that reduces glint somewhat is MIL-C-675 which acts as an interference filter. However, the remaining solar glint is so intense that it still remains a significant detection contributor. Even with multilayering of this coating, overall detection by the naked eye was not significantly reduced even though, in one test, a three-to-one reduction in reflected solar energy was achieved. For this reason, reflection reduction coatings have not been adopted as an acceptable technique for controlling solar glint. However, during overcast illumination, coatings may be of value by optimally reflecting the amount of sky light necessary to minimize detection. A more effective method is to replace the canopy’s current surfaces with an optimal number of flat surfaces - optimization dependent upon scenario-related conditions. Elements of the expected engagement conditions that must be considered include aircraft mission, threat observer’s threshold mechanisms, and ambient optical environment. Mission operating profile of the aircraft will determine the associated viewing geometry and background, define viewing ranges to establish angular size of the target and its resolvable structure, and define the region of engagement to provide a basis for bounding the ambient operating environment. The observer’s performance will be dependent on his optical state (optical state includes adaptation luminance, field of view, number of observers, and manner of search), the use of any magnification aids, psychological factors, and physiological induced detriments. Ambient optical environmental considerations (e.g., frequency and amount of cloud cover, terrain) include reflectance, sky luminance, visibility ranges, and other pertinent optical parameters. The use of flat transparencies reduces the frequency of glint occurrence to the threat observer. Since the flat surfaces will act like a mirror, the sun will be reflected at angles equal to the domain of incident angles which is small - sun subtends a planar angle of only 93.4 x 10^{-4} arc rad. Curie surfaces will diverge the reflected sunlight into a much larger angle, thereby allowing glint to be observable at more locations simultaneously. The objective of optimum glint reduction is not to reduce it to zero necessarily, but to reduce it to the level of the next most dominant visual cue. However, glint observability does not necessarily lead to glint detectability, and glint detection does not necessarily assure acquisition. For accurate weapon pointing and firing, the aircraft in most cases would need to be almost continuously (not momentarily) discernible to the naked eye.

4.1.1.3.1.3 Paints and coatings. The techniques to control the optical signature involve preponderantly the application of some form of paint or coating. -Its effectiveness as a technique is dependent upon the successful suppression of visible cues from engine smoke and canopy glint. For inflight visual signature control of aircraft, paint application categories include glint suppression, luminance contrast minimization, countershading, pattern matching to structured backgrounds, searchlight suppression, and new developments in paint/coating and mechanical concepts.

a. Glint suppression. See 4.1.1.3.1.2; classified information on paints and coatings to reduce solar glint can be found in the references cited in 4.1.1.

b. Luminance contrast minimization. When the aircraft's background is generally uniform, minimizing luminous contrast of the aircraft minimizes its detectability. Since the optical environmental parameters will usually encompass a range of luminous reflectance values, no one paint reflectance can be optimum. Therefore, the reflectance value should be so chosen which will minimize, on a frequency of occurrence basis, the possibility of large contrasts. For low altitude flight profiles, generally associated with rotary wind aircraft, considerations other than luminance matching to sky backgrounds dominate. Most helicopter flight profiles include either discernible terrain as the background or are so low as to preclude any significant illumination on the aircraft undersides. In such cases, select paints with reflectance simulating foliated terrain rather than using high reflectance paint for sky background camouflage. As altitude of flight increases, there will be more upwelling illumination from the atmospheric scattering of the sky light and a decrease of the sky background luminance. These effects require that the reflectance of the aircraft’s bottom be less than that required for lower altitude camouflage. In air-to-air engagements at 3 to 10 km altitude, the aircraft will be viewed against terrain backgrounds of increased luminance caused by scattering of the sky light. Thus, the reflectance of the upper surfaces of the aircraft should be higher than the inherent reflectance of the terrain.

c. Countershading. Countershading is a painting technique for controlling the overall luminance (or brightness) of aircraft by removing internal contrasts or by achieving the desired average apparent brightness of the overall surface. It consists, generally, of specifying paints darker than the overall paint for normally highlighted surfaces and specifying lighter paints for surfaces normally in shadow. The extent to which the shadow and the highlight paints should differ in reflectance from the overall paint increases with the overall level of illumination falling upon the aircraft. It is more important to correct for light directionality than for light level, since the location of the shadow and highlight paints is determined by light directionality.

d. Pattern matching. The objective of pattern painting is to reduce aircraft detectability against structured backgrounds, a condition encountered primarily during low level flight. By using a disruptive pattern, the aircraft will be indistinguishable from some background clutter and, thus, less acquirable. The use of several different paints increases the likelihood that, at least, part of the aircraft will be of negligible luminance or chromatic contrast to its immediate background; the effective area-to-contrast to the aircraft is reduced which, in turn, reduces its detectability. Patterns, either natural or painted, will be discernible only at certain ranges due to atmospheric attenuation of detail and limits to visual resolution. It must be cautioned that detrimental effects (ie., visual acquisition enhancement) can occur, if a patterned aircraft operates in scenario above ground level, over haze, over wrong terrain pattern/color, etc.).

e. Searchlight suppression. To reduce the nighttime detectability of aircraft encountering searchlight illumination, paints of low luminance reflectance must be used to reduce its high contrast relative to the night sky.

f* New developments in paint/coating and mechanical concepts. New paint concepts include paint formulations with seasonal adaptive and photochromic properties and paint schemes to give a false perception of the aircraft as to its type or its course of movement. Thermochromic coatings have been under development that allow simultaneous sea and terrain matching - color change controlled by aircraft skin temperature. Use of mechanical devices such as form filler and dimension distorters has been considered.

4.1.1.3.1.4 YEHUDI camouflage. The YEHUDI camouflage technique has application to those viewing engagements in which the aircraft ordinarily would appear as a dark silhouette, but the use of external lights on the aircraft minimizes its contrast to the surrounding sky background. When the aircraft is at low-to-medium altitudes, the dark aircraft silhouette occurs when viewed from below against a sky background. If the intensity of the lights is appropriately controlled, the visual detectability of the aircraft will thus be greatly reduced. Variable intensity lights allow maintenance of the low luminous contrast against a background of dynamic brightness, an advantage over paints or coatings which control the luminous contrast against a background of limited brightness. Advances in lamp, electronic, and electrical technologies may make the YEHUDI camouflage technique a more viable concept, in terms of power requirements. Use of Xenon or other higher efficiency lamp sources, beam shaping, and consideration of atmospheric contrast attenuation are factors that can further reduce the power required. On the other hand, camouflage coverage over larger solid angles and higher sky brightness levels may require additional power. A modern YEHUDI camouflage technique is the Visual Radiation Source (VRS) system using Xenon lamps controlled by a backward- and downward-looking sensor that provides control of the color and intensity of the required illumination relative to the ambient luminous environment. Chromaticity matching by the VRS system has been accomplished by a set of "white" and “blue” detectors as part of a backward-looking sensor. Another recent YEHUDI technique is the Optical Contrast Reduction (OCR) system developed for a rotary wing aircraft.

4.1.1.3.1.5 Lighting system suppression. Nighttime visual cues from the aircraft” lighting system should be minimized to the greatest degree practical while-maintaining adequate safety for formation flying. The capability of anti-collision light installations to reflect moonlight or any other light source should be minimized, when not in operation. Care should be exercised to minimize the direction and intensity of instrument lighting as well as reflections from cockpit interior surfaces. Tactical aircraft should be equipped with an easily accessible switch for the pilot to turn off all external lights and all nonessential cockpit lighting.

4.1.1.4 Acoustic signature. The factors which determine aural detectability include the intensity and radiation pattern of the inherent noise generated by the aircraft; spectrum and real time character of the generated noise; distance and propagation media separating the noise source(s) and the receiver; atmospheric absorption; refraction and scattering effects due to atmospheric wind velocity, temperature gradient, and turbulence; attenuation (absorption and scattering) due to terrain; level and frequency of the background noise in the vicinity of the receiver's environment; and sensitivity of the receiver to the noise. Although these factors have been identified as significant contributors to aural detection by enemy ground observers, they also influence undersea detection of aircraft propagated far-field noise through the atmosphere, atmosphere-to-water interface, and ocean {bottom-reflected and bottom-refracted noise paths). Together with the sensitivity of the enemy sonar and its surrounding background noise, the detectability of the maneuvering aircraft can be successfully accomplished. This detectability can be used to successfully launch, for example, an air defense missile or exercise evasive maneuvers to reduce effectiveness. The noise spectrum from an aircraft is composed of many sources which may include propeller (or rotor blade) rotational and vortex noises; engine inlet, exhaust, and rotary combustion noises; airframe aerodynamic laminar flow noise; and turbulent flow. For turbine-powered rotary wing aircraft, rotors are the principal noise source. In the case of propeller-driven aircraft, boundary layer noise may exceed noise from propellers. Engine cycle type is a significant factor that determines the percentage of engine noise to total aircraft noise. Aircraft utilizing high bypass turbofan engines have a reduced noise level over that of turbojet engines of equivalent thrust and aircraft type.

4.1.1.4.1 Acoustic signature reduction. The approaches that should be used to suppress detectable noise levels include reducing acoustic power; modifying the noise spectra (amplitude and frequency) of the radiated noise to increase the excess attenuation through the atmosphere, atmosphere-to-water interface or ocean, and to reduce the acoustic power in the audible frequency range; and shielding and absorption.

4.1.1.4.1.1 Acoustic power reduction. Fan inlet radiated noise may be reduced by the use of an accelerating inlet with a high subsonic throat Mach number. Propeller radiated noise can be reduced by increasing the diameter and number of blades, decreasing tip velocity, decreasing shaft horsepower, or synchrophasing optimization of propellers of a multipropeller aircraft to minimize noise through phase cancellation of the noise from each propeller. Blade changes to reduce propeller noise include variations in sweep, spanwise loading distribution, airfoil section thickness, and use of unsymmetrical blading concepts including unequal circumferential or axial blade positioning and unequal blade angles (reduces tone levels at harmonics of blade passage frequency at the expense of added noise at harmonics of shaft speed frequency). Since the jet engine exhaust radiates noise to approximately the eighth power of the jet velocity, a small reduction in velocity results in large reduction in acoustic power. With respect to aerodynamic noise, air turbulence and vibrations due to the motion of the wing and fuselage, rotating propellers, and air movement across a cavity or other airframe protuberances should be kept to a minimum.

4.1.1.4.1.2 Spectrum shaping of noise. During the conceptual design phase, spectrum shaping of noise to where the human ear is less sensitive should be a consideration. This concept does not necessarily result in reduced acoustic power, but it does result in redistribution of total acoustic power to lower and higher frequency bands (i.e., to below 125 Hz and above the 4 kHz one-third octave bands, respectively). Below 125 Hz, the basic hearing threshold rises at a rate of 5.db per one-third octave band; above 4 kHz, hearing threshold rises at a rate that is even higher. At the higher frequencies, additional reduction in noise is achieved through excess atmospheric attenuation and, below 125 Hz, background noise levels may mask the aircraft free-field (or far-field) noise. Another possible concept, using spectrum shaping as the primary aural reduction principle, is directing the engine exhaust through a number of small diameter, remotely placed nozzles to produce a much higher noise frequency (above 20 kHz) than that of a single exhaust pipe with minimal effect on thrust. This high frequency band results in an atmospheric attenuation coefficient of 20 to 30 db per 0.3 km. Although no undersea detection criteria have been established, such criteria may allow high tone levels at some frequencies, while requiring very low tone levels at other frequencies. Therefore, it is important to consider trade-offs between amplitude and frequency of tones in the development of undersea detection criteria.

4.1.1.4.1.3 Shielding and absorption. The application of shielding techniques or absorbing panels can result in significant reductions in aural detectability. Shielding methods involve a physical barrier in the path of the noise so that a lower intensity of noise is propagated to the receiver (e.g., the placement of engines or engine exhaust nozzles above the wing). The effectiveness of shielding is greater for shorter wavelength (higher frequency) tones and when shielding is located closer to the noise source. Absorbing materials involve the use of sound absorbent materials (or resonators) which absorb the incident acoustic energy. These materials include fiberglass batting and open cell polyurethane. Engine cowling can be designed to form a labyrinth for the cooling air and noise. Fan inlet-radiated noise may be reduced by the application of acoustic materials on a conventional inlet. Likewise, exhaust noise can be reduced by using acoustic absorbent panels. Panels, when installed in series, can have a greater combined effectiveness in reducing noise than the sum of the reduction from two separate panels not installed in series. Rotary combustor and turbine engine noise reduction can be achieved by the use of acoustic treatment just downstream of the low pressure turbine stage. Properly designed mufflers or resonators may be used as a combination mechanism for shielding and absorbing noise in duct walls of turboprop and turbofan engines.

5. DESIGN GUIDELINES TO, REDUCE VULNERBILITY

5.1 General design principles. During the initial stages of the design of aircraft MEWS, general design principles to reduce vulnerability should be exercised to the maxinum extent possible (due consideration should be given to other desin constraints such as reliability, safety, maintainability> and repairability) to ensure a most effective configuration results that has been balanced against all these considerations with minimum incurrence of penalties in performance and cost. Since maintainability and repairability considerations may not complement (or be compatible with]. survivability enhancement, special considerations may be required to minimize compromise of these factors while, at the same time, maximize vulnerbility reduction. New or modified troubleshooting procedures may be required to ensure diagnosis of malfunctions (or false indication of malfunctions) of components located behind ballistic shields. General design principles include provisions for redundancy and adequate separation of redundant subsystems to maintain the performance of essential functions> isolation of critical subsystems from areas of potential hazards (or potential hazards from critical subsystem) and localization and shielding of critical subsystems The application of these general design principles and other vulnerability reduction techniques to specific subsystems is addressed in 5.2.

5.1.1 Redundancy and separation The potential incurrence of losses in combat can be reduced substantially by providing duplicate or redundant subsystems to perform essential functions. This principle is also used to enhance safety or reliability. For combat survivability purposes, however, the effectiveness of redundancy is optimized only when redundancy is complemented by adequate separation of the redundant subsystems. This separation distance should be sufficient to preclude damage by a threat mechanism on more than ae subsystem of a redundant set. Separation should be judiciously evaluated for each application, and advantage should be taken of the most beneficial amount of natural shielding from structural elements and shieding afforded by less critical components to further combat surviability enhancement. Examples of the redundancy principle are mutiple engines, dual pilots, multiple fuel transfer, multiple flight control power systems, and multiple load-carrying structures. An example of separation in a multiengined aircraft MEWS is the location of individual engine nacelles outboard of the fuselage. Another example is the machining of a groove on the outer surface of the body of a dual hdraulic actuator for crack arrestment; this minimizes crack propagationto the undamaged side when only one side of the actuator has been impaced. In those areas where a catastrophic failure from a single hit of a redundant subsystem is likely (e.g., the proximity of the primary and secondary flight control lines to the servomechanism of a dual hydraulic actuator), passive protection may be the only recourse.

5.1.2 Isolation. Critical subsystems should be isolated from areas of potential hazards that may be readily generated by a threat mechanism impact. However, it may be more feasible to isolate hazardous materials such as fuel, coolant, hydraulic fluid, toxicants, and high-pressure or high-temperature components from critical subsystems. For example, the fuel storage or transfer lines should be isolated from areas where high-temperature gases could be liberated from the ballistically damaged engine combustor. A converse example is the location of combustibles in areas where leakage or release of vapors caused by ballistic impact will not readily propagate to high temperature regions, ignition sources, or oxygen compartments.

5.1.3 Damage tolerance or resistance. Design for tolerance or resistance to combat damage can provide a significant degree of survivability enhancement for low weight and cost penalties. Damage tolerance is a vulnerability principle which can be implemented by designing into essential components and structure an inherent. capability to withstand a degree of damage without impairing functional performance. Increased tolerance to threat damage mechanisms can be achieved by providing redundant load-carrying features in the design of critical structural elements, using materials of high fracture toughness (e.g., to reduce hydrodynamic ram effects), designing push rods of larger diameter and thinner wall, using ballistically tolerant (nonmetallic) bellcranks and cable sectors, and incorporating high-temperature tolerant features (e.g., highly polished exterior surfaces where the existing skin gauge provides an adequate heat sink to reflect the high energy laser threat). Damage resistance is a vulnerability reduction principle which can be implemented by designing critical components to withstand penetration by material selection and construction. An example of this principle is the possible fabrication of a hydraulic actuator body or transmission oil sump from MIL-S-46099 dual hardness steel amor.

5.1.4 Fail-safe features. Fail-safe features should be incorporated so that the subsystem can transfer from a high loss mode to a low loss mode upon occurrence of failures caused by a threat damage mechanism. These features do not necessarily reduce the probability of occurrence of subsystem failure as do redundancy and separation, but they can alter the nature or magnitude of the loss. Some examples of fail-safe features include the design of an engine variable exhaust nozzle actuation system to fail in a closed position (typically, failure results in opening of the nozzle with attendant thrust loss); the incorporation of an engine fuel control that will automatically position itself to a predetermined power setting when the throttle linkage is severed; the provision of an automatic, reconfigurable flight control capability (sometimes referred to as a digital surface management system of flight control resources) to change the flight control laws sufficiently so that flight can be maintained after damage has caused functional loss of a primary control surface; and the application of the redundancy and separation principle (e.g., the separated, multispar construction of the wing or empennage).

5.1.5 Localization and shielding. The grouping of critical components should be localized to reduce overall subsystem vulnerable area and hit probability. Less critical components should be located to shield more critical components within the group from likely aspects of approach of threat damage mechanisms, and the location of the group should take advantage of any natural shielding. Localization or compact grouping should consider ease of access for maintenance. An example of localization is the use of an integrated 'hydraulic actuator package comprised of the pump, filter, control valve and reservoir, located near the aerodynamic surface requiring actuation. The conventional dispersion of hydraulic components throughout the airframe, resulting in exacerbation of vulnerability and increased hit probability of critical hydraulic components, is thus reduced. In addition to natural (or inherent) shielding, as interspersed throughout the discussions on general design principles, another form of shielding is armor. The use of armor can be minimized by practicing to the hilt the general principles of design for vulnerability reduction. However, there may remain critical items for which the use of armor may be the most efficient recourse. In such a case, the areal density of armor should be as low as the state of the art of armor technology will allow for protection against a specified threat, and its installation should afford maximum coverage and minimize weight penalty. Localization lends itself to reduced requirements for armor. In the case of the relatively small servomechanism of a dual hydraulic actuator, where the single point failure of the primary and secondary hydraulic flight control subsystems is likely from a threat mechanism impact, the use of armor may be most efficient.

5.2 Design of specific subsystems. Once general design principles have been applied to each critical subsystem, other techniques should be used in the design of each critical subsystem to further reduce vulnerability. Additional details, over and above those provided in this handbook, are given in DOD Military Handbooks MIL-HDBK-XXX-2 and MIL-HDBK-XXX- 3. Short of combat experience, the combat worthiness of any design technique should be validated by testing. To effectively design a specific subsystem for low vulnerability, the response of this subsystem to impacts from conventional weapon threat mechanisms should be fully explored and understood. Responses to threat mechanisms will wary from subsystem to subsystem. The critical subsystems include fuel storage and transfer, propulsion, flight control, fluid power, aircrew and other personnel, power train, rotor, environmental control, electrical power, avionics, armament, and structure.

5.2.1 Fuel storage and transfer. Fuel vulnerability reduction consi-derations, in concert with meeting the general specification for aircraft fuel systems (MIL-F-38363) during preliminary design, will produce a significant payoff in terms of total system effectiveness while avoiding costly and inefficient retrofit modifications after the aircraft MEWS have been developed and become operational. Combat experience has shown that the fuel storage and transfer subsystem is the primary contributor to aircraft losses. Analytical evaluations and controlled firing tests have further substantiated this high contribution which is due to the large area presented to the threat, the dispersion of the subsystem throughout the airframe, and the instrument of destruction (fire). that is inherent in fuel. To minimize the amount of fuel that can be lost by ballistic damage, the fuel tanks should be compartmented; fuel lines should be isolated from the fuel supply upon leakage detection; and redundancy in fuel transfer should be provided, automatically (or manually). With respect to fire and explosion, the flammability data given in MIL-T-5624 (JP-4 and JP-5) and MIL-T-83133 (JP-8) for turbine, aviation fuel should be tempered by the following considerations: flammability limits are bands which can vary for individual fuel grades within their specification limits; flammability limits shift toward higher temperatures when fuel has been aged or weathered sufficiently to reduce volatility through evaporation; under operational conditions, fuel in tanks does not normally reach equilibrium vapor distribution states - fuel vapor-to-air ratios may vary from lean through explosive-to-rich in different portions of a given fuel cell, and this variation can exist as potential explosive pockets or as stratifications depending upon vent design, tank configuration, vibration, sloshing, and duration from launch to (and at) operational altitude. Empty tanks are more susceptible to explosion but filled tanks (particularly, integral tanks) are more susceptible to hydrodynamic ram damage. Actual ignition of a combustible fuel-to-air mixture by a given high-energy ignition source may shift from the lean flammability temperature limit by as much as 25°F (-4°C) - for example, fuel tank slosh and vibration can cause a considerable extension of the lean flammability limit of fuel due to the formation of fuel mist.

5.2.1.1 Primary responses from threat weapon effects. Responses of the fuel subsystem components to threat mechanisms include the following: perforation, distortion, rupture, or shattering from impacts by projectiles or fragments; internal or external blast effects from high-explosive projectile or guided missile warheads (a synergistic effect of the blast impulse loading on the structure and damage to adjacent fuel system components, when impacted by high-velocity fragment impacts, may be experienced); and ignition of fuel vapors (or mists) by incendiary projectiles, sparks (depending upon the material perforated) from high velocity fragment penetrations (sometimes identified as "vaporific flash”), and burn-through of structures supporting the fuel subsystem and fuel components from HEL weapons (complete burn-through may not be necessary to cause a fuel fire or explosion, if sufficient thermal energy is transmitted through the wall material to produce a “hot plate” effect).

5.2.1.2 Secondary damage effects. When primary weapon effects damage other than fuel subsystems and components, which in turn can be potentially capable of adversely affecting the operation and integrity (or create undesired responses) of fuel system elements, consideration should be given to the secondary damage effects. These effects include: spallation from structures or nearby components; liberation of hazardous contributors such as oxygen and hydraulic fluids; explosive disintegration of hydraulic accumulators; -release of high-temperature gases such as when hot bleed air lines or ducts are damaged and "torching" from a ruptured engine combustor; and sparks from damaged electrical systems.

5.2.1.3 Combat failure modes. Either (or both) primary and secondary weapon effect(s) have resulted in five basic failure modes of the fuel subsystem - engine fuel starvation; fuel storage destruction resulting in internal fire, explosion, or hydrodynanmic effects; “dry bay" fire or explosion; fuel transfer fire or explosion; and engine ingestion of leaking fuel.

5.2.1.4 Protective techniques. Significant progress has been made through various programs under the auspices of each of the military services and the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) in developing efficient techniques to protect the fuel subsystem to threat damage mechanism impacts. This progress is expected to continue, and the designer is urged to contact cognizant individuals to ensure that state of the art techniques have been deliberatively considered in the design of the fuel subsystem at all acquisition phases. A listing of these individuals can be found in the JTCG/AS “Directory of Aircraft Survivability Specialists and Their Affiliations.”

5.2.1.4.1 Fuel cell arrangement. The types of internal fuel cell construction include integral, bladder, or combination integral and bladder. A bladder type is either MIL-T-25783 non-self-sealing, MIL-T-5578 self-sealing (partial or complete)., or MIL-T-27422 crash-resistant. Although the type of fuel cell is generally established by the detailed requirements, the arrangement of fuel cells is a primary consideration in reducing the inherent vulnerability of the fuel subsystem. This arrangement should be based on the type of fuel cell and expected threat exposure. Other considerations should include locating the fuel cells to minimize presented area to primary threat directions; maximizing protection of fuel cells and transfer lines by taking advantage of structural masking and masking afforded by less critical fuel masses (e.g., masking by self-sealing fuel cells). and less critical components; locating fuel cells away from potential ignition sources or exercising its converse; locating fuel cells to minimize lengths of transfer lines; submerging critical fuel components within the fuel cell; providing redundancy in fuel transfer, adequate separation of redundant components, and minimal exposure of single point failures of redundant lines (e.g., crossover valve where redundant transfer lines meet); installing fuel cells to minimize ingestion of leaking fuel by the engine(s) (e.g., away from engine inlet ducts) and reduce void volumes (“dry bays”) between cell wall and airframe skin; locating fuel cells to reduce the likelihood of leaking fuel or vapors being drawn into areas where fire or explosion could occur and, if fire has initiated, the propagation of this fire to other areas or compartments; and providing rapid drainage of all compartments containing fuel from a leaking cell or line.

5.2.1.4.2 Fuel flow distribution and management. The sequence of the distribution and management of fuel flow should be designed so that the maximum amount of fuel is available to the propulsion subsystem by gravity feed. Fuel management should be designed to use fuel from most vulnerable tanks first, proportioned so that no cell is completely full or completely empty during combat, proportioned between wing and fuselage cells to take advantage of lower surface area-to-volume ratio of fuselage fuel cells to reduce overall fuel vulnerable area and hydrodynamic ram effects, and designed to minimize adverse shift in aircraft center-of-gravity and provide fuel management options when primary management of fuel has been thwarted. Fuel transfer should be designed to provide bypass of damaged fuel cell (or compartments within a fuel cell), isolation of damaged fuel line, and automatic positive shutoff of fuel to an inoperative or damaged engine of a multiengined aircraft MEWS for purposes of conserving remaining fuel supply and minimizing fire and explosion hazards.

5.2.1.4.3 Leakage prevention (or suppression) and control. To ensure an adequate supply of fuel to the propulsion subsystem and to minimize the hazards of fire and explosion, the prevention (or suppression} and control of fuel leakage is indispensable. Given the occurrence of leakage, its control is essential to the minimization of Vulnerability.

5.2.1.4.3.1 Leakage prevention (or suppression) techniques. Techniques to prevent or suppress leakage and enhance self-sealing capability include the application of self-sealing concepts and appropriate backboard materials (e.g., high modulus fiberglass epoxy and low modulus BBC-8 and ARM-62 per MIL-P-8045, honeycomb panels with aluminum core and glass reinforced plastic face, and semirigid plastic foam) to critical fuel tanks, self-sealing hoses (e.g., MIL-T-5578 and MIL-H-7061 or MIL-H-18288 self-sealing, respectively). and self-sealing covers (MIL-C- 83291); reduction of tank/vent pressures to leSS than 2 psi (13.8 x 10^3 Pa; Pa; 1 psi = 6.89 x 10^3 pascal (Pa)) and line pressure to less than 15 psi (103.4 Pa) to further self-sealing effectiveness and lower weight requirements for self-sealing materials; increase in tolerance to hydrodynamic ram and cavitational effects in tanks and lines containing fuel; use of an engine suction feed system with engine-mounted boost pumps in lieu of a pressure system with pumps submerged in fuel cells; minimization of lengths of external lines; and provisions for leak detection and fuel shut off or alternative transfer capability (automatic or manual).

5.2.1.4.3.2 Leakage control techniques. The number and length of potential leakage paths should be minimized by strategically locating all fuel system elements. These leakage paths should be identified, located, and directed to avoid autogenous ignition sources which are normally and potentially present in aircraft MEWS and to minimize areas for the accumulation of fuel (e.g., to avoid long leakage paths and reentry of fuel or vapor into hazardous areas, sufficient drain holes of 3/8 in. (0.95 cm) minimum diameter should be provided along potential leakage paths)., Leakage paths should be coordinated with venting air to flow in the same direction to increase the overboard movement of the leaking fuel and vapor. The combined use of leakage diverters and' sealants (e.g., MIL-S-8802 sealing compound). will provide a capability to confine and prevent, respectively, the leakage of fuel and vapor to minimum hazard compartments with drain-safe provisions and its entry or migration to ignition source compartments.

5.2.1.4.4 Fire/explosion prevention and suppression. Fuel or fuel vapor in proper proportion with air/oxygen and an appropriately timed ignition source can result in fire or explosion (explosion is sometimes considered a “fast” fire); its prevention and suppression is imperative. In aircraft MEWS, combustible fuel vapor-to-air mixtures may exist within fuel tanks (ullage volumes) and vent systems, void or “dry bay" areas surrounding tanks, compartments adjacent to tanks, and any other areas where leaking fuel or resulting fuel vapor can accumulate. When a penetrator impacts a fuel cell below the ullage volume, a pressure wave is created in the fuel that can generate a substantial spurt of fuel out of the entrance and exit perforations. This spurt can produce a combustible mixture surrounding the perforation and, in the presence of an ignition source, may result in fire or explosion. In a near-filled tank, the pressure wave and cavitational effect may be sufficient to cause complete rupture of the tank through hydrodynamic ram. High temperature ignition sources normally found in aircraft (temperature of the sources higher than the autogenous ignition temperature (AIT) of fuel) hot engine parts (e.g., combustor, turbine, or exhaust pipe); high temperature bleed air ducts; overheated or high temperature electronic components; friction sparks; and sparks or arcs from electrical/avionic connections, wiring, and equipment shorts. Combat-induced effects which can ignite combustible fuel-to-air mixtures (e.g., non-inerted ullages of fuel tanks) include incendiary or high-explosive incendiary (HEI) projectiles whose incendiary has been activated, vaporific flash from hypervelocity fragment and secondary span fragment impacts, and HEL.

5.2.1.4.4.1 Fire/explesion prevention and suppression techniques. State of the art techniques are available to prevent the occurrence of combat-induced fire/explosion and, given occurrence, to suppress these hazards. The designer should make every effort towards prevention before addressing suppression. Although a number of variables (e.g., absolute pressure, temperature, humidity, etc.) influence the ease of ignition, modification of the character of any one ingredient that directly contributes to the occurrence of fire/explosion will prevent or, at least, minimize such occurrences. The constituent elements that can be modified include fuel, incendiary source, and oxygen required to support the process of combustion or explosion. However, preliminary test data indicate, and is supported by ongoing research efforts, that improved fire/explosion prevention at reduced penalties in weight and problems in logistics can be achieved by combining the best characteristics of each of the techniques, discussed below, for modifying the character of the principal elements contributing to fire/explosion. An example of an effective fire/explosion suppression combination concept Is the gross-voided foam/nitrogen diluent systems.

a. Prevention techniques

(1) Incendiary source quenching. The interaction of the fuel with the large, complex surface area of MIL-B-83054 reticulated polyester foam (also known as red or yellow foam), when installed inside the fuel cell, creates a locally rich zone which prevents passage of the flame front, thus reducing the occurrence of fire. A hybrid polyester urethane reticulated foam (also known as blue foam) has been developed which ballistically performs as well as the polyester foam and is far less prone to chemical degradation effects in a high temperature/humidity environmen t. The use of these foams can also reduce the occurrence of explosion. Filling spaces and voids in airframes with MIL-P-46111 flexible polyurethane foam keeps ignition sources away from fuel and, if the projectile passes through fuel, any remaining incendiary will likely be quenched by the fuel. The maximum density of these foams is 1.5 1b/ft3 (24.0 kg/m^3) with a fuel denial of approximately 7 percent. Polyamide polymer in-tank baffling materials have been under development by the United Kingdom at less than one-half the weight penalty and a fuel denial of only 3 percent, as well as void fillers. For “dry bay” protection, a weight penalty of as low as 0.15 1b/ft3 (2.4 kg/m^3) is possible.

(2) Oxygen reduction. Inerting, the dilution of a flammable atmosphere with a noncombustible gas (e.g., nitrogen) to reduce the oxygen content of the fuel-to-air mixture is an effective technique in preventing fire and explosion in the ullage of aircraft fuel tanks when impacted by HEI projectiles up to caliber 23 mm. It has been demonstrated that flame propagation does not occur if the oxygen concentration in the ullage space can be reduced to less than 12 percent by volume. State of the art nitrogen inerting systems include closed vent (nitrogen fed into tank ullage as fuel is consumed), open vent (sweeping action to reduce oxygen concentration in the ullage space), and scrubbing (fine bubbles are formed in the bottom of the fuel tank to remove the dissolved oxygen).

Of the two nitrogen storage and supply systems, cryogenic liquid is preferred over high pressure - a low temperature liquefied nitrogen system is considerably lighter in weight. To overcome the logistic requirements (one of a number of disadvantages of a remotely supplied liquid nitrogen system], two candidate onboard nitrogen generating systems have emerged - absorption (Oxygen absorption by a molecular-sieve) ; diffusion (oxygen preferentially removed from the primary gas stream by a polymeric permeable membrane).

b. Suppression techniques

(1) Metal arrester (Explosafe). An explosion suppression technique consisting of multisheet bundles of 0.003 in. (0.076 mm) thickness aluminum sheets. Each sheet having several short cuts at regular intervals forms an expanded metal mesh. Limited test data indicate that the metal arrester can suppress explosion.

(2) Intumescent coatings/ablator materials. When exposed to heat, the intumescent coating expands to many times its original thickness and forms a carbonaceous porous matrix char which functions as a thermal barrier for the surface underneath. At the surface of this char, flame-quenching gaseous products are generated at block convective heating by forming an outflowing front of gas which chemically interferes with the flame. Although the ablator barrier (insulation) principle of intumescent coatings provides the greatest amount of protection for a given weight penalty against HEL radiation, toxicity of gases formed should be an important consideration when ablative materials are contemplated as a countermeasure. Consideration should also be given to integrate HEL protection with ballistic protection schemes to achieve the most effective combined protective system. Less effective protective techniques against HEL include reflection or mass ingestion. However, some combination of these techniques might be best for HEL radiation protection.

(3) Extinguishment systems. Fire or explosion extinguishment systems (MIL-C-22285) operate on the principle of detecting the initiation of a flame front (MIL-D-27729) or warning of fire (MIL-F-7872 and MIL-F-23447) by -means of an IR-sensitive lead sulphide photoelectric cell, an ultraviolet (W)-sensitive tube, or by means of a piezoelectric sensor, and using this detection to trigger the’ explosive or nonpressurized release of an extinguishing agent (e.g., MIL-M--l22l8 liquefied monobromofluoromethane or, in order of increased toxicity, Halons 1301, 1211, 1011, 2402, and 1202), Of these Halon agents, Halon 1303 is predominantly used. However, in “dry bay” compartments

with high air flows, the use of a lightweight thermal barrier system may be more efficient, in terms of reduced weight penalty and increased effectiveness, to prevent (or delay) the migration of fire to compartments containing flight or mission critical components or sources of ignition. For a detailed discussion on fire extinguishing, see DOD Military Standardization Handbook MIL-HDBK-221 (WP) ,

5.2.2 Propulsion. Since the propulsion subsystem is a major contributor to the combat survivability of aircraft MEWS, special attention should be devoted to the design, selection, and installation (MIL-I-83294) of gas turbine engines (reciprocating engine-driven military aircraft virtually nonexistent). While the design of an engine to a type specification resides with the engine manufacturer, this specification is derived from general turbine engine military specification MIL-E-5007 or MIL-E-8593. Although the propulsion subsystem installation and inlet design responsibilities rest with the airframe manufacturer, it is a responsibility that should be shared by the engine manufacturer.

5.2.2.1 Primary responses from threat weapon effects. Responses of the engine to ballistic, HEL, or foreseeable EMP threat damage mechanisms include the following: uncontained release of high-energy parts; uncontrolled fires; ingestion of fuel or foreign objects; power loss through damage of engine sections, fuel starvation, or lubrication failure; HEL burn-through; and EMP-induced operational or functional damage to electronic controls. Hits on propeller systems result in out-of-balance operation or blade throwing. These responses not only affect propulsion subsystem performance adversely but also threaten the combat survivability of aircraft MEWS. Therefore, the propulsion subsystem should be designed not only for performance but also for low Vulnerability.

5.2.2.2 Low vulnerability engine design techniques. The gas turbine engine is an assemblage of a number of functional sections or systems, as follows: inlet frames, struts, and guide vanes; fan and compressor (or compressor); combustor; turbine; afterburner and exhaust; fuel; lubrication and accessory gearbox; bearing and seals; bleed air; and propellers. Design techniques to achieve low vulnerability for each of these engine sections or systems are provided in 5.2.2.2.1 through 5.2.2.2.10. Overall engine performance is dependent upon the functional and operative capabilities of each engine section or system. For a detailed discussion on reducing engine vulnerability, see DOD Military Handbook MIL-HDBK-XXX-3.

5.2.2.2.1 Inlet frames, struts, and guide vanes. The inlet frames and struts should be sufficiently strong to take maximum expected foreign object impacts and damage vibration loads without breakup or release of engine material into the flow path. Cast or welded construction is preferred over bolted or riveted designs. Inlet guide vanes tend to entrap foreign objects in the flow path; however, when used, vanes should be securely supported at both ends and substantial axial spacing provided between the vane trailing edges and rotor blade leading edges to minimize contact under damaged conditions. The use of relatively soft materials (e.g., aluminum instead of steel) should be tempered by considerations of overtemperature and explosive effects due to ignition of ingested fuel - turbomachinery is more tolerant to the release of softer particles without suffering crippling damage.

5.2.2.2.2 Fan and compressor (or compressor).. The fan (low pressure) and remaining compressor sections of a turbofan engine (or the compressor of a turbojet) present relatively large areas that are sensitive to threat damage mechanism impacts. Upon casing penetration, engine performance and structural effects depend on stall margin, blade and vane size and their resistances to the penetrator, and structural soundness of the design. Internal damage to turbomachinery, if the engine continues to run, may result in loss of thrust and create excessive vibration which, in turn, can cause fuel line rupture, engine mount failure, or uncontained release of high-energy parts. To reduce vulnerability, the following techniques should be implemented insofar as possible:

a. Design disc burst speed to a minimum of 122 percent of maximum allowable steady-state speed.

b. Increase stage loading to reduce the number of stages required and presented area.

c. Design pressure vessel/case for rupture resistance to at least twice the maximum operating pressure.

d.. Centrifugal compressors are preferred over axial flow compressors.

e. Blades and vanes should be large, widely spaced, and low in aspect ratio (i.e., span-to-midchord ratio).

f. Hollow vanes are preferred over solid vanes.

g. Connection between blade and disk should be rugged; integral, one-piece blade and disk (blisk) design is preferred.

h. Integral multiple vane segments with two or more vanes are preferred over individual vanes.

i. Minimize the use of variable pitch stator vane stages and, where used, design for actuation by mechanical links.

j. Unshrouded blades are preferred over tip-shrouded blades; tip-shrouded blades provide potential ease of containment but at the expense of higher blade kinetic energy at release.

k. Design blade leading edges to be damage- and erosion-tolerant.

1. Thicken casings to contain maximum rotor speed release of blades.

5.2.2.2.3 Combustor, The combustor section is a contributor to engine vulnerability. Modem engines are designed with either through-flow or reverse-flow annular liners within which combustion of the fuel. to-air mixture occurs. Combustor casings are easily perforated. When perforated, excessive gas leakage may occur and hot plumes can be emitted. In addition, energy to drive the turbines is reduced, and engine rollback and significant thrust loss are likely occurrences. For a given hole sizes leakage flow of gases is greater for higher pressure ratio engines. Even high obliquity hits from small caliber projectiles or fragments make holes sufficient to cause rollback in high-pressure engines and low probability of a destructive hot plume occurring. Hits on high-pressure fuel manifolds and nozzles can result in immediate power loss and mommentary fires. To reduce vulnerability, the following techniques should be implemented insofar as possible:

a. Minimize combustor size. Through-flow combustors permit reduced engine diameter and result in reduced combustor section surface area. On the other hand, the reverse-flow combustor reduces engine vulnerability via its shielding of the turbine.

b. Locate high-pressure fuel manifolds internally.

c. Select burner materials of high fracture toughness for elevated operating temperatures and burner shell materials of high ductility to minimize hole size and torching effects.

5.2.2.2.4 Turbine. The turbine section constitutes one of the smaller engine target areas. As mentioned in 5.2.2.2.3, the use of reverse-flow combustor design provides some shielding of the turbine. Hits on the turbine section typically cause damage to blades and vanes which, in turn, results in released material at high energy levels, mechanical interference, jamming, hit-induced turbomachinery imbalance, and secondary damage (e.g., engine mount failure due to excessive vibration). To reduce vulnerability, the following techniques should be implemented insofar as possible:

a. Design disc burst speed to a minimum of 122 percent of maximum allowable steady-state speed.

b. Blades and vanes should be large, widely spaced, and low in aspect ratio (i.e., span-to-midchord ratio).

c. Hollow vanes are preferred over solid vanes using very ductile materials which will perforate without shattering into chunks.

d. Connection between blade and disk should be securely retained; integral, one-piece blade and disk (blisk) design preferred.

e. Integral, one-piece stages are desired (except for the final stage); alternatively, multiple vane segments with two or more vanes are preferred over individual vanes.

f. Unshrouded blades are preferred over tip-shrouded blades; however, static honeycomb, abradable blade tip shrouds which release small particles with minimum blade tip damage are desirable.

g. Design blade leading edges to be damage- and erosion-tolerant.

h. Route turbine cooling air passages deeply within the engine to reduce cooling air deprivation due to low-energy impacts; single pass cooling passages are preferred over multiple pass cooling passages.

i. Thicken casings to contain maximum rotor speed release of blades.

5.2.2.2.5 Afterburner and exhaust, The addition of an afterburner section to the exhaust system increases engine thrust and vulnerability. Afterburner casings can be easily perforated. When penetrated, gas outflow into the surrounding engine bay occurs. This leaking gas may consist of cool fan air flow between the liner and casing and, for large holes during afterburner operation, may include hot exhaust gases which can potentially damage the aircraft MEWS. Since afterburner fuel lines are normally retained full during nonafterburner operation, hits on these lines may result in significant fuel leaks and fire. Afterburners are designed with variable-area exhaust nozzles that are often hydraulically or fuel actuated. A hit on the nozzle actuation system typically results in the nozzle failing in the open position, and a significant loss in thrust occurs. Since fuel or hydraulic fluid is usually the working fluid, the potentiality for the occurrence of fire exists. To reduce vulnerability, the following techniques should be implemented insofar as possible:

a. Reduce afterburner length.

b. Pneumatic nozzle actuation is preferred over fuel or hydraulic fluid actuation.

c. Design nozzle actuating systems to be mechanically irreversible and to fail in the closed position.

d. Provide quick response overheat detectors in afterburner section of engine bay.

5.2.2.2.6 Fuel. The engine fuel system components include the pumps, filters, control unit, fuel-powered actuator, fuel-to-oil heat exchangers, flowmeters, pressurizing valves, lines, etc. The afterburner system typically taps fuel off the main fuel filter from which fuel is routed through lines to a pump, control unit, fuel-to-oil heat exchanger, and the afterburner manifold. All fuel components and lines can be easily perforated, and perforation can lead to engine fuel starvation or fire/ explosion. To reduce vulnerability, the following techniques should be implemented insofar as possible:

a. Minimize fuel system area by reducing, integrating, and combining functions.

b. Reduce the number of fuel components and minimize their sizes.

c. Size the pump to supply only as much fuel as engine is designed to use.

d. Use electrical and electronic controls to schedule fuel in lieu of mechanical controls; however, the control of electromagnetic environmental effects (E^3), including EMP, must be a design consideration in accordance with MIL-STD-461, MIL-STD-462, and NAVMATINST 2410.1B.

e. Use mechanical linkages or pneumatics for power transmission, and use air for cooling purposes.

f. Minimize the volume of engine-stored fuel.

g. Use fire-resistant or fireproof fuel lines and components.

h. Use suction engine fuel feed backed up, as required, by boost assist to reduce fuel line pressure and risk of fire.

i. Locate accessories such that highly vulnerable fuel components are masked by lower vulnerability components (e.g., starters, lubrication components, and the necessary gearbox),

j. Locate fuel components to safeguard against ingestion and autogeneous ignition of leakage fuel.

k. Minimize the number of connections, covers, and panels that are removable, consistent with maintainability goals and design criteria.

1. Minimize the number, length, diameter, and standoff distance of lines to functional components.

m. Avoid routing of fuel lines or locating fuel components in planes of rotor revolutions.

n. For fuselage multiengined installations, provide isolation barriers between engines, bay drainage, cooling air for engine driven components and accessories, positive shut off capability, and a combination fire warning and fire extinguishing system.

o. Provide fail-safe engine power controls should pilot-actuated or automatic controls fail.

5.2.2.2.7 Lubrication and accessory gearbox. The engine lubrication system components include the reservoir tank, filter, supply and scavenge pumps and lines, jets, and coolers. The accessory gearbox provides mechanical drives for engine and aircraft driven accessories including the starter. All lubrication lines and components can be easily perforated, and perforation can lead to oil (MIL-L-7808 and MIL-L-23699). deprivation which, in turn, will lead to failure of main bearings. Small threat impacts on the accessory gearbox may cause its malfunctioning through oil deprivation or jammed gears; oil deprivation will likely result in bearing damage before the occurrence of gear damage. Although the risk of lubricant fires is small relative to fuel fires (autogenous ignition temperature of lubricating oil is approximately 300°F (149°C) higher than that of fuel), the probability of an oil fire is nonzero. To reduce vulnerability, the following techniques should be implemented insofar as possible:

a. Use integral engine-mounted lubrication systems.

b. Shape and locate reservoir tanks to reduce presented area, and locate reservoir tank to minimize risk of engine ingestion of leakage oil.

c* Integrate pump and filter into a single component and miniaturize the resulting component.

d. Locate lubrication components to take advantage of shielding afforded by less critical components [e.g., lube lines located within engine shafting)_.

e. Use cored passages; group and join external lines into a single cluster; and minimize the number of connections, length, diameter, and standoff distance of lines to functional components.

f. Use fire-resistant or fireproof lines and components.

g. Reduce the number of sumps, lube flow rates, and reservoir capacity to minimum required.

h. Incorporate emergency or redundant lube system.

i. Provide automatic bypass of oil cooler in the event of damage resulting in leakage of oil from cooler.

j. Minimize use of fuel for oil cooling.

k. Consider the use of oil additives and advanced synthetic lubricants to improve lubrication performance.

5.2.2.2.8 Bearings and seals. Anti-friction ball and roller bearings are generally used for the engine and accessory gearbox. Carbon and labyrinth air seals are used. Although the greatest cause of combat-induced bearing damage results from damage to the lubrication system, discussed in 5.2.2.2.7, direct hits on bearings and bearing supports can cause quick engine kills through excessive bearing stress and vibration and the possible release of uncontained parts. Hits on seals result in air leaks or leakage of oil into cavities where secondary effects may result in kill of the engine or the aircraft MEWS. Other possible effects include venting hot air into bearing cavities and other relatively cool cavities within the engine where this extraneous heating of already highly loaded rotating parts may result in reduced structural integrity and catastrophic failure. To reduce vulnerability, the following techniques should be implemented insofar as possible:

a. Minimize the number of bearings to reduce presented area.

b. Locate bearings to take advantage of inherent shielding and in relatively cool cavities.

c. Use M50 vacuum melt, high strength steel bearing material and steel separators.

d. Use solid lubricant technology to extend operational life when conventional lubricant is depleted.

e. Use squeeze film bearings to increase tolerance to imbalance.

f. Minimize size of sumps.

g. Use metallic seals in lieu of commonly used elastomer seals.

5.2.2.2.9 Bleed air. Air bled from the compressor is used for anti-icing, cabin pressurization, heat and ventilation, turbine cooling, oil cooling, engine seal pressurization, and, in the case of vertical or short takeoff and landing (Y/STOL) type of aircraft, aerodynamic lift. The temperature of the bleed air duct is, in general, not sufficiently high (less than 700°F (370°C)) to ignite fuel. However, as the trend in new engine designs results in higher bleed air temperatures, these increases may become sufficient for concern that heretofore was not a cause for concern in older engine designs. Hits on cooling lines to the turbine or oil cooler can result in overheating of turbine blades or oil, respectively. Hits on other lines will affect the functional performance of compressed air systems or components. To reduce vulnerability, the following techniques should be implemented insofar as possible:

a. Duct required air through the engine (e.g., internally).

b. Provide cored passages and minimize lengths and diameters of external ducting.

c. Locate valves as close as possible to bleed air sources to minimize air leakage downstream of ducts when valves are closed.

d. Provide designs to bypass hit-induced leaks to ensure cooling air to the turbines and oil coolers, to minimize gas leakage, and to reduce engine rollback.

e. Insulate bleed air ducts when the temperature of external surfaces exceeds 700° F (370°C),

5.2.2.2.10 Propellers. The propeller system (MIL-P-26366) includes propeller blades, gearbox, and pitch controls. To reduce vulnerability, the following techniques should be implemented insofar as possible:

a. Select materials to provide maximum toughness and fracture resistance (e.g., steel spar with fiberglass composite blade propeller).

be Design components to minimize crack propagation, maximize tolerance to damage, and maximize resistance to dynamic forces from out of balance operations.

c. Design the propeller with a strong structural box core to minimize blade release when impacted.

5.2.2.2.10.1 Gearbox. The vulnerability reduction techniques provided in 5.2.2.2.7, 5.2.2.2.8, and sections under 5.2.6.2.1, as applicable to the propeller gearbox, should be applied insofar as possible.

5.2.2.2.10.2 Pitch control. The vulnerability reduction techniques provided in 5.2.2.2.7 and 5.2.2.2.8, as applicable to the pitch control, should be applied. In addition, the following vulnerability reduction techniques should be implemented insofar as possible:

a. Provide fail-safe blade positioning.

b. Integrate propeller control with the gearbox in a position to obtain the most beneficial shielding of the critical components.

5.2.3 Flight control. As the performance of aircraft MEWS increases, flying qualities and flight control design-requirements (MIL-F-8785, MIL-H-8501, MIL-F-9490 and MIL-F-18372, respectively) become more critical. Unfortunately, this increase in performance has resulted in an increase in power and response requirements to meet flying qualities of modern day aircraft and those in the future. The addition of V/STOL types of aircraft will add another critical dimension to flight controls. In turn, this has resulted in flight controls of greater complexity and vulnerability to the damage mechanisms from enemy systems. Therefore, a deliberative consideration must be given to the specific hostile effects expected to be encountered over the full range of missions and threat deployments, to ensure optimal combat survivability and operability of the flight controls.

5.2.3.1 Flight control elements. Two basic elements of the flight control subsystem are the nonautomated, mechanical (unpowered) and powered systems. A reversible load control, mechanical system is one through which pilot actuation of the movable aerodynamic surfaces is accomplished by means of mechanical linkages consisting of cables and fairleads, pulleys, gears, sectors, push-pull rods, torque tubes, bellcranks, levers, tension-compression links, and bearings. Powered systems are either boost or full power. A boost power, reversible system is one in which pilot effort is exerted through mechanical linkages to some point at which pilot effort is finally boosted hydraulically to activate the movable aerodynamic surfaces. A full power, irreversible system, used in high performance aircraft, is one in which the pilot actuates a power control servomechanism through a mechanical linkage system, an electrical/ electronic system (fly-by-wire (FBW)), or a combination system of mechanical and electrical devices. Automatic flight control systems (AFCS) are those combinations of mechanical, electrical, and powered components (MIL-H-8890) which generate and transmit automatic control commands which provide pilot assistance through automatic or semiautomatic flight control of airframe disturbances.

5.2.3.2 Primary responses from threat weapon effects. The primary damage mechanisms from threat weapons include: penetration by projectiles and fragments, internal and external blast effects from detonating high-explosive projectiles or guided missile warheads, incendiary activation of incendiary type projectiles and impingements by HEL and EMP. These impacts may cause failure or degradation of flight control functions by severing, shattering or jamming of mechanical linkages and components; loss of hydraulic pressure; leakage of hydraulic fluid; fire when petroleum base hydraulic fluid is used; HEL burn-through or high-temperature heating of flight control components; and electromagnetic interference (e.g., EMP) damage to electrical connections, wiring, and functional damage to electronic devices. Primary damage mechanisms may also generate structural span fragments; fire or explosion; structural deformation; liberation of hot gases, fuel, or oxygen; and electrical sparks. These secondary damage mechanisms can produce detrimental effects on the flight control subsystem.

5.2.3.3 Low vulnerability flight control design principles. In general, three basic design principles should be considered to reduce the vulnerability of flight controls - reduce vulnerable area, provide redundancy and adequate separation of redundant components, and isolate damage effects. A reduction in vulnerable area, in effect, results in a reduction in damage probability of the flight control subsystem. For rotary wing aircraft, the introduction of the elastomeric rotor head will reduce moving parts by as much as 50 percent and the number of vulnerable hydraulic lines. Redundancy is a practice of adding components to provide alternate functional continuity; redundancy should be complemented by separation to preclude single impact kill of critical, redundant components. Isolation is a principle dedicated to containing damage effects such that damage to one component will not propagate to disable the affected subsystem. The ultimate choices of the design principle (or a combination of design principles) and the flight control subsystem concept to be used should be those where combat survivability has been optimized against mission/performance requirements within the entire spectrum of intended operational usage of the aircraft MEWS; expected threat encounter; and subsystem complexity, weight, cost, reliability, safety, maintainability, replaceability, and repairability.

5.2.3.3.1 Vulnerable area reduction. To reduce vulnerable area, either or both presented area and kill probability conditional upon impact should be reduced. Although simplifying the flight control may reduce presented area, the use of a lightweight hydraulic system (LHS) can also reduce presented area. Conventional hydraulic systems operate at 3000 psi (20.7 x MPa), but the smaller diameter lines of the LHS (operating at 8000 psi (55.2 x MPa)) will result in reduced hydraulic line presented area. Miniaturization can also be accomplished by replacing the mechanical signal transmission system with a FBW electrical signal transmission system. Furthermore, electrical bundles of an FBW system can be more easily routed to take advantage of inherent structural shielding. Another method to reduce presented area is to use integrated actuator packages (IAP) where the flight control actuator and the hydraulic power supply (and reservoir) are combined into a compact unit, thus eliminating the maze of hydraulic lines connecting the hydraulic supply to the actuator. Shielding of the IAP is more efficient than is the shielding of conventional hydraulic systems. There are several ways in which the conditional kill probability on flight control components can be reduced. Inasmuch as the mechanical components are concerned, damage-tolerant composite rods and laminated bellcranks are examples that should be used. Hydraulic actuator damage probability can be reduced by designing the dual actuator to resist crack propagation from one side to the other side (split-barrel design) of the actuator or by fabricating the entire actuator body out of a lightweight armor material. To reduce petal-like effects caused by ballistic impacts of the actuator body that prevent piston movement, the actuator should be designed for jam resistance. This can be accomplished by replacing the current steel actuator body with a thinner steel outer housing, a frangible graphite epoxy liner, and a wearproof nickel or chrome bore. Petals or perforations resulting from outer housing impacts will intrude into the area of the frangible graphite epoxy liner, thus, allowing unimpeded movement of the piston.

5.2.3.3.2 Redundancy and separation. Duality of mechanical systems is a requirement specified in MIL-F-9490 for aircraft MEWS exposed to conventional threat weapons. Duplication of powered systems, originally in compliance with safety requirements, is a design principle that also reduces vulnerability to threat damage mechanisms. Redundancy in an FBW control system is achieved through multichannel signal transmission paths. Another redundancy concept, known as functional redundancy, consists of providing a backup flight control system (BUFCS) capability using a functional equivalent but physically different system. Examples of this type of redundancy are use of an FBW system to back up a mechanical control signal transmission system (or vice versa) or the use of flutdic/optic advanced technology backup control concepts. The most important consideration in using redundancy techniques is the means employed to ensure that the redundant components and systems are sufficiently separated and mutually protected or shielded from each other to minimize simultaneous damage and failure from a single threat damage mechanism. Recently, the concept of functional redundancy has been extended to two new areas - analytical redundancy and surface management redundancy. Analytic redundancy utilizes a digital filter to increase the redundancy of the aircraft sensor complement. Surface management is a functional redundancy technique (sometimes referred to as flight control survivability through use of onboard digital computers (SUDIC)) in which the undamaged control surfaces on an aircraft are reorganized within a hierarchy of control laws by digital computers to automatically revert to the most appropriate reversion mode remaining.

5.2.3.3.3 Damage isolation. Although this principle may not be as effective as vulnerable area reduction or redundancy and separation, modest reductions in vulnerability can be obtained. Logic elements can be added to hydraulic systems to detect and isolate hydraulic fluid leaks before catastrophic loss of fluid occurs, and the fluid in other branches of the hydraulic system is preserved to permit operation of the actuators without the isolated portion. The two most common types of logic elements are hydraulic fuses and reservoir level sensors. Hydraulic fuses (currently known as flow difference sensors) operate on the principle that return flow varies in direct proportion to supply flow in an undamaged or correctly functioning hydraulic system. When a difference from the normal ratio between return flow and supply flow is detected by the flow difference sensor indicating the occurrence of a possible leak, that part of the system is disconnected. Although continued leakage is checked, the affected system becomes functionally inoperative. On the other hand, the reservoir level sensor (RLS) is not a leak detector per se; it monitors reservior fluid level. When the fluid reservoir reaches a predetermined low level, the RLS can isolate hydraulic components nonessential to flight, thereby conserving remaining hydraulic fluid to maintain flight integrity or, alternatively, activate a backup system. A more complex arrangement might include return line pressure sensors connected to the RLS to determine and isolate the branch of the system that contains the leak.

5.2.3.4 Low vulnerability flight control design techniques. Specific design techniques that should be applied to ensure low vulnerability of mechanical/electrical and electronic components and powered components of the flight control subsystem are provided in 5.2.3.4.1 and 5.2.3.4.2, respectively.

5.2.3.4.1 Mechanical/electrical and electronic system components.

a. For full flight control operation through one of the redundant paths when the other redundant path has been severed or jammed, provide a dual hydraulic control valve arrangement on an actuator that will permit operation of either control valve independently of the other and that bypasses the jammed system for free piston operation. In the event of a severed control linkage, normal operation of both valves may be achieved to the extent of travel available in the severed linkage and, when restricted travel is encountered, the override of the restricted valve would be accomplished. One anti-jam technique that can be applied to one side of a redundant mechanical system is spring preloaded, anti-jam capsules that will disengage the jammed system under moderate pilot effort.

b. Design to permit simple disengagement of the control interconnect when one of the dual mechanical controls, used for pilot or copilot actuation, is jammed.

c. Push-pull control rods and sectors, constructed from composite materials, are preferred over cables and pulleys; use of composite materials strengthened with-sheet metal build-up provides most beneficial multiload path damage capability to afford continued functional performance of the component when damaged.

d. To reduce the susceptibility of long push-pull rods to jamming caused by nearby structural deformation or component damage, use short length composite/sheet steel build-up push-pull rods with swing arm, laminated bellcranks or idler links.

e. Provide frangible or pull away type fairleads to prohibit jamming due to a nicked cable or a damaged push-pull rod.

f. Use self-aligning bearings for torque tubes to minimize misalignment jamming caused-by torque tube or supporting structure deformation.

g. Incorporate redundant tri-pivot concepts in critical bellcranks and rod end attachments.

h. Use heat-resistant materials for control elements in proximity to hot temperature areas or potential sources of fire.

i. For protection against laser burn-through, surround critical and relatively exposed components with thermal barriers and ablative materials.

j. For FBW control systems, use EMP-tolerance, electromechanical servo valves (e.g., high signal-to-noise ratio (1000 to 1) electric servo valves currently under development); design electric or electronic circuits to minimize inductive and capacitive cross-coupling, and position wires in connection cables to reduce cross-coupling; and fuse circuits containing EMP-sensitive components (e.g., use of a spark gap, filter, or other disconnect mechanism between the energy collector and the sensitive component).

5.2.3.4.2 Powered components.

a. Design fail-safe boost systems so that a degree of manual control is available to the pilot.

b. Consider the possible use of packaged hydraulic power system concepts (e.g., IAP, see 5.2.3.3.1).

c. Engine or power transmission sources of power with clutches to engage and disengage revolving mechanical drive shafts for secondary flight control functions are preferable to hydraulic power sources.

d. Use damage-tolerant materials for the actuator housing (e.g., jam-proof actuator (5.2.3.3.1) or housing constructed from MIL-S-46099 dual hardness, rolled steel armor or from electroslag remelt steel).

e. Machine actuator body to reduce the propagation of cracks from one side of a dual-powered actuator to the other side when impacted by ballistic threat damage mechanisms ("rip-stop" actuator body design).

f. For protection against laser effects, metal seals are preferred over elastomer seals; for protection against laser burn-through and potential fires, surround critical and relatively exposed hydraulic components with thermal barriers and ablative or intumescent materials.

g. Pending successful development of a silicone base hydraulic fluid, use MIL-H-83282 synthetic hydrocarbon base fluid in lieu of MIL-H-5606 petroleum base fluid to reduce hydraulic fluid fires (Note: Candidate Nadraul MS-6 tetrachlorophenylmethyl siloxane fluid, offering higher fire resistance than MIL-H-83282 oil and incorporating dibutyl chlorendate anti-wear additive, is not compatible with existing designs of hydraulic systems.)

h. Use steel or other fire/heat-tolerant materials for pressure and return hydraulic lines in high-temperature areas or where potential fires are likely.

i. Use flow difference sensors and RLS for leak detection and isolation, respectively.

j. Consider integration via the use of IAP to reduce vulnerable area.

k. Consider miniaturization via the use of higher pressure hydraulic systems (e.g., LHS) to reduce vulnerable area.

l. Provide a BUFCS that is functionally equivalent but physically different and completely independent of the primary and secondary flight control systems.

5.2.4 Fluid power. Fluid power is embodied in hydraulic (MIL-H-5440 and MIL-H-8891) and pneumatic (MIL-P-5518 and MIL-P-8564) systems. Power augmentation through hydraulics has been almost exclusively used for aircraft-essential subsystem operation, and its use increases directly with increases in size, weight, and performance requirements of aircraft MEWS. Low vulnerability design techniques for hydraulic flight control powered components (see 5.2.3.4.2) should be applied to any other subsystems requiring hydraulic power augmentation. Pneumatic power has been generally confined to secondary subsystems requiring only two-positional actuation (i.e., extension and retraction] or as emergency backup systems to secondary, hydraulically powered subsystems (e.g., landing gear and wheel brake systems). The pneumatic -medium is generally limited to compressed atmospheric air, nitrogen, or engine bleed air. Basic aircraft considerations usually dictate the choice of the pneumatic medium, unless the high temperature of engine bleed air is found to be sufficiently hazardous for its elimination.

5.2.4.1 Primary responses from threat weapon effects. Aside from functional failure of pneumatically powered subsystems, damage to high-pressure pneumatics can result in potential secondary hazards and adverse synergistic effects. Penetration of the pneumatic power subsystem by ballistic threat mechanisms may cause the release of high-energy damage agents (e.g., span fragments). Besides possible damage to the aircrew, airframe, and other critical subsystems and components, high-energy span fragment penetrations may cause release of combustible gases or liquids or oxygen to result in catastrophic fire/explosion.

5.2.4.2 Low vulnerability pneumatic power design techniques.

5.2.4.2.1 The following techniques shall be implemented insofar as possible:

a. Design basic pneumatic circuits to minimize size and complexity for reduced vulnerable area (e.g., lengths of critical lines as short as possible).

b. Provide pressure-line shutoff valves or circuit breakers to isolate less essential circuits from those that are critical.

c. Provide an automatic failure and shutoff capability to prevent or limit secondary failures and detrimental synergistic effects.

d. Construct high-pressure components to resist explosive disintegration damage to other critical components of aircraft MEWS.

e. Design component attachment points to fail before component critical section failure.

f. Select materials for rigid lines and flexible hoses to resist deformation, fire, or other high-temperature effects.

g. Provide pull-away clips or frangible clamps to allow lines to remain intact upon detonation of the structural elements supporting these lines.

h. Use frangible structural sections for bulkhead fitting attachments.

i. Use lower pressure, larger size lines (or ducts) to minimize failure from laser burn-through and secondary hazards from high-energy release of span fragments.

j. Use ablative barriers or materials in compartments containing critical pneumatic components for protection against HEL and fire.

5.2.5 Aircrew and other personnel. The performance and survivability of personnel in aircraft MEWS, when exposed to hostile, nonnuclear threat damage mechanisms, is a major design consideration. While protection of the pilots and other crew members is of primary importance, consideration must also be given to other personnel (e.g., assault troops and litter patients) whose survival contributes to successful mission performance. The design of systems to protect aircrews from the threats posed by conventional weapons is established in MIL-STD-1288. Personnel are susceptible to all direct and secondary injury mechanisms (e.g., span fragments and other debris) emanating from threat weapon effects, as well as from other causes (e.g., explosion of ejection seat propulsion system (MIL-P-83126) rockets, explosive decompression, toxic fumes, smoke, and adverse effects resulting from failure or loss of environmental control system functions and life support systems). Critical personnel areas include the head, primary organs within the chest and abdomen, and the larger arteries and veins of extremities. As opposed to hardware items of the aircraft, the designer is restricted to providing protection external to personnel. Another area that has been given some emphasis, the results of which will likely contribute to combat survivability enhancement of aircraft MEWS, is improved man-to-machine interface to relieve the pilot(s) to the extent of being able to control an aircraft that otherwise might be uncontrollable.

5.2.5.1 Responses from primary and secondary threat weapon effects. Actual data on wound ballistics provide a generalized set of personnel vulnerability characteristics to penetrators as follows: a 5.56 mm projectile fragments upon bone impact; a 5.56 mm (caliber) x 45 mm projectile, fired from 100 ft (30.5 m) range, pierces the chest cavity near the heart; a 7.62 mm (caliber) x 39 mm projectile, fired at a range of 150 to 225 ft (45.7 to 68.6 m), pierces the chest cavity, perforates a lung, and fractures a rib; projectile wounds of the vital chest structures are more severe than fragments; injuries to the vital structures of the thorax occur in direct proportion to the amount of space occupied by the structures; lungs are injured more than any other chest structure, followed by the heart and the thoracic blood vessels; penetration of the heart and major blood vessels is most likely to be fatal; ribs are injured in approximately 50 percent of fatalities; and in thorax-abdominal injuries, the liver and spleen are most frequently injured followed by the stomach and kidneys. Although vulnerability data on personnel to high-explosive blast overpressure are limited, the fast pressure rise occurs within the 3 to 5 ms range. Personnel lethality lies between a threshold fatality of 112 to 156 psi (772 x 10^3 to 1076 x 10^3 Pa) to near 100 percent fatality of 217 to 302 psi (1496 x 10^3 to 2082 x 10^3 Pa). Secondary weapon effects of concern are those that affect the cockpit environment in which personnel are required to operate. Ignition of combustibles (e.g., coolant used to cool avionics) within or near the cockpit area, either by the direct action of an incendiary projectile or the liberation of hot gases (smoke and the release of toxic gases (e.g., carbon monoxide). is a most common contaminant of sealed spaces), from burning materials are some examples of secondary weapon effects. In addition to these effects, the possible explosion of the ejection rocket motor poses a hazard to the pilot(s). Crashworthiness of the seats and the fuel system is of particular concern to personnel survival for both rotary ring and Y/STOL aircraft (see MIL-S-58095 and MIL-T-27422, respectively, for light fixed and rotary wing aircraft crashworthiness) . HEL is another primary weapon damage mechanism causing skin burns and eye damage.

5.2.5.2 Ballistic protection design techniques. The general design principles in 5.1 apply and, in the case of multiple pilots, 5.1.1 and 5.1.2 also apply. Unfortunately, the use of an armor system may be the only recourse for personnel protection. Therefore, every attempt must be exercised to ensure that the most optimum system is used and-that the materials used conform to MIL-A-19879, M1L-A-46103, MIL-A-46108, MIL-A-46165, MIL-A-46166, MIL-B-43366, MIL-G-5485, MIL-S-46099, or MIL-W-81752. The installation of armor to protect the pilots fall into three areas: airframe, aircrew seats, and body armor (crew and other personnel). Of these categories, body armor will provide maximum personnel coverage as well as reduced performance with minimum weight of armor, followed-by crew seats and airframe armor. To minimize the areal density of armor required, maximum consideration should be given to natural shielding provided by structure and less critical components.

5.2.5.2.1 Airframe armor. The current state-of-the-art on lightweight armor (see Confidential U.S. Army Materials and Mechanics Research Center Report No. AMMRC TR 81-20) does not provide complete armor protection of aircraft personnel to all possible threats. Regardless of the armor material used, the following design techniques for airframe armor should be implemented insofar as possible:

a. When nonmetallic armor is used, ensure multiple hit capability in an area of impacts greater than 6 inches apart.

b. Use fragment-suppression barriers to absorb span fragments (e.g., ballistic nylon cloth (MIL-C-12369) fiberglass composites, ballistic felt, and Aramid fiber composition).

c. The trunk and torso areas of the crew should be protected from the predominant threat and at angles of hostile fire to the highest level practical up to the horizontal plane passing over the crew's shoulder. Limited protection of the sides and back of the head should be provided.

d. For frontal protection, use a bullet-resistant glass windshield (see MIL-G-5485).

e. Where practical, use integral armor (i.e., armor that is integrated with structure).

f. Except for integral armor, readily removable armor is preferred, and its installation should be in accordance with MIL-I-8675.

g. Maximize coverage by installing armor as close to the crew as possible.

h. For added flak suppression, use MIL-c-18491 flak curtains.

5.2.5.2.2 Aircrew seat armor. Aircrew seat armor should be approached from two aspects, protection capability and crashworthiness. Detailed information on armored and unarmored, crashworthy aircrew seats is given in MIL-S-58095 and MIL-S-81771. The successful development of ceramic armor has resulted in a lightweight molded armor seat (i.e., B_4C, ('boron). The current types are composed of a backup material, fiberglass, Aramid fiber composites, and aluminum, over which a layer of ceramic armor is bonded. The following design techniques for aircrew seats should be implemented insofar as possible:

a. Small section design concepts should be used with ceramic armor. Section sizes should be selected to minimize damage area without degrading ballistic performance.

b. Design torso shield to prevent interference with the crew's capability to function, provide ease of articulation for ingress and egress, be fully supported by the seat but with a single point release mechanism, and be resistant to crash landing, without dislodgement to become an additional mechanism of damage.

c. Use armor panels as structural elements in the seat design. Design side, shoulder, and torso shield panels to be easily removed for repair or replacement and, if damaged, to be completely interchangeable from seat to seat.

d. Side-by-side and tandem armor seat concepts should be considered separately to best take advantage of respective mutual shielding effects.

e. Design an armor seat that is convertible and interchangeable for operation in either a low or high threat environment (multiple protection levels).

f. Aircrew seat armor should be compatible with the general specification for seat (MIL-S-9479, MIL-S-18471, and MIL-S-58095) and escape (MIL-E-9426) systems.

5.2.5.2.3 Body armor. MIL-STD-1288 provides the basic guidance for body armor. Body armor includes protective vests, groin protectors, and helmets. The design of aircrew body armor is a specialized technology that is normally outside the responsibility of specific aircraft MEWS programs. Body armor is usually government-furnished personnel equipment. However, the aircraft designer should consider the availability of candidate state-of-the-art body armor and the impact that any furnished or candidate body armor will have on a proposed armor system together with effects on crew functional performance and the total aircraft weapon system. Body armor can be used by the aircrew as well as by other personnel (e.g., troops transported by assault helicopters). The following design techniques for body armor should be implemented insofar as possible:

a. Use lightweight body armor consistent with desired level of protection (e.g., against caliber 7.62 mm armor-piercing (AP) projectiles), the weight of body armor between 5 to 8 lbs (2.3 to 3.6 kg) is desirable; 5 lbs (23 kg) most desirable.

b. Integrate body armor with life support equipment (i.e., survival vest, life preserver, and other equipment peculiar to the mission/aircraft).

c. Use fire-resistant materials in the manufacture of body armor.

d. Design efficient interface of body armor with related armor systems.

e. Integrate body armor with required crew performance.

5.2.5.3 HEL protection. As indicated in 5.2.5.1, the human body is highly susceptible to skin burns and eye damage from the HEL damage mechanism; flash blindness can occur as a secondary weapon effect, if the person is looking at or near the incident HEL beam. A first degree burn can be experienced with an exposure of 10 J/cm* for a duration of 1 s; second degree bum, 20 J/cm^2 for a duration of $\frac{1}{2}$s. Animal experiments have indicated that a l-second pulse of 20 J/cm^2 is sufficient to cause severe cornea burns and possible blindness. Protection of the aircrew and other personnel against HEL weapon effects includes the consideration of opaque portions, normally comprised of the structure and equipment surrounding the crew, and transparent portions of the personnel stations. To protect opaque and transparent portions against HEL weapon effects, the following design techniques, depending upon the extent of natural shielding to prevent burn-through, should be implemented insofar as possible:

a. Treat fuselage skin to provide a high degree of reflectivity so that less thermal flux density is absorbed.

b. Use ablative materials such as "graphoil" or Teflon (polytetrafluoroethylene) that absorb thermal energy while ablating.

c. Use intumescent materials to react to the initial thermal exposure and, then, form a thick char-like material to resist burn-through. Since the char-like formation is light and fragile, consideration should be given to reduced thickness and effectiveness of this formation by airflow sweep.

d. Due to rapid vaporization, crazing to low micron levels and fractures to low power levels of acrylic transparencies, and the ease of melting and resulting reduced visibility of glass when exposed to HEL beams, the use of advanced materials offering increased resistance to HEL weapons (e.g., epoxy-boroxine-type materials, EXl12 and FX4T9) should be considered.

e. Integrate HEL protection and protection against ballistic fragments and high-explosive blast effects; Aramid (Kevlar). fiber materials are materials with some effectiveness against both HEL and ballistic damage mechanisms.

5.2.5.4 Protection against secondary weapon effects. To protect personnel against secondary weapon effects (See 5.2.5.1), the following design techniques should be implemented insofar as possible:

a. Use stringent care in the selection of materials for the aircrew and passenger compartments to minimize the amount of smoke or toxic products or combustion (e.g., use of nonflammable covers or coatings as for seat upholstery). However, the products from combustion of certain helogenated epoxy resins, used as fire-resistant materials, can produce a critical amount of halogenous acid whose irritant characteristics may sufficiently warn personnel of its presence to allow corrective action.

b. Select materials that will not support combustion and, when ignited, will not continue to burn upon heat source removal.

c. Select materials that will not produce toxic products of combustion in quantities greater than removal capability of the environmental control system.

d. Flame-resistant coatings should be used to coat combustible items .

e. Isolate oxygen system as distant as possible from combustibles.

f. Use an onboard oxygen generating system (OBOGS). to eliminate converters, bottles, and other hardware whose damage may pose a hazard to personnel.

g. Use of fire suppressants should consider the toxicities of their products of pyrolysis resulting from exposure to high thermal conditions (e.g., high-temperature laser effects]. In addition, the threshold of bearable pain is between 108°F to 113°F (40°C to 45°C); and the maximum temperature to which the human respiratory system can be subjected, without severe damage, is 360°F (179°C).

h. Crashworthy seats should be designed with due consideration given to the capability of that portion of the structure to maintain occupant living space throughout a crash and other post crash hazards.

i. Use instruments and equipments that will prevent or minimize the generation of hazardous spallation (e.g., use nonsplintering or nonshattering instrument face).

j. Displays and sensor systems detecting critical malfunctions should be provided to give the aircrew timely and sufficient information as to location and extent of critical subsystem malfunctions to be able to take appropriate, corrective action or to automatically assume corrective action.

k. Provide redundant circuits for the oxygen supply system (see MIL-D-19326).

1. Provide vision protection against flash blindness, a secondary effect from an HEL beam.

5.2.6 Power train. The power train subsystem provides primary responsibility for flight capability in all rotary wind aircraft, propeller-driven fixed wind, and V/STOL aircraft (MIL-T-5955) dependent upon speed reduction gearboxes or transmissions and interconnecting drive shafts and associated coupling mechanisms. The main transmission may provide output drives to intermediate transmissions and shafts to anti-torque rotors, hydraulic pumps, and generators.

5.2.6.1 Primary responses from threat weapon effects, Combat data, substantiated by tests and analyses, indicate that loss of lubrication is the predominant failure mode for current designs of transmissions and gearboxes when operating in a threat environment. Direct projectile or fragment hits on power train components (e.g., bearings, gears, shafts, and couplings) usually result in either immediate loss of the unit's function or failure after some period of extended operation. With increases in gas turbine power and speed, corresponding increases in shaft rotational speeds will be required. Design of such high speed shafting dictates greater consideration of techniques and features to prevent or minimize failures due to threat damage mechanism impacts. Particular attention should be applied to systems where, although they may be designed to operate at or near critical speeds, such speeds can be attained when the centrifugal force due to initial unbalance (unbalance caused by a ballistic impact). exceeds the elastic restoring force or where shaft stiffness “whirl” deflection theoretically increases to infinity. Such “whirl” may cause bending stresses in the shaft which could exceed the strength capability of the shaft. Small diameter, thick wall shafts are more susceptible to failure from ballistic damage than shafts of larger diameter and thinner walls. In general, gears tend to resist damage to a greater extent than bearings. Direct hits on bearings usually cause significant damage, and this damage can be exacerbated by damages to the lubrication system. Chips and debris from either or both projectile and gear teeth can jam the oil pump or clog the filters to cause malfunctioning of the lubrication system; damage to associated oil cooling components can cause excessive buildup of heat. Loss of lubrication results in bearing seizure or breakup through heat build up and thermal imbalance. In some cases, bearing failure can cause misalignment of gear meshes and loss of gear teeth which, in turn, can cause complete gear malfunctioning, cause rupture and fire under extreme temperature build Up.

5.2.6.2 Low vulnerability power train design techniques. Techniques can be applied to the lubrication system, transmission and gearbox design, shaft design, and bearing selection to reduce the vulnerability of the power train subsystem to threat damage mechanisms. Although some of these techniques are more feasible in initial design than in retrofit design, the techniques provided in 5.2.6.2.1 through 5.2.6.2.5 should be implemented, insofar as possible, only after the general design principles in 5.1 have been exercised to the fullest extent.

5.2.6.2.1 Transmission and gearbox lubrication. Damage tolerance techniques to minimize or prevent failure due to combat-induced impairment of the lubrication system of the transmission and gearbox can provide significant benefits at little or no penalties, if incorporated into the initial design. These techniques include the use of: solid lubricants, high-temperature steel bearings, high-temperature greases, steel bearing cages, improved bearing geometry, auxiliary cooling, an emergency backup lubrication system, an oil cooler bypass, an integral cooling system, inherent shielding afforded by heavy housings (e.g., external oil lines relocated inside gearboxes), and an armored sump. Some gearboxes can operate with (MIL-G-83363) grease at all times - no oil system required. Using airflow as a medium to cool oil (e.g., an annular, integral, close-coupled," air-to-oil heat exchanger, etc.), rather than combustible coolants (e.g., ethylene glycol). should be used to minimize the possible occurrence of fire.

5.2.6.2.1.1 Oil cooler bypass system. Bypass lubrication should be considered for applications where oil coolers external to the transmission or gearbox are in use or where its use cannot be avoided in a new design. This technique isolates the oil sump from the oil cooler circuit when a leak is detected or when the oil descends to a predetermined low level. Automatic or manual actuation of the bypass valve diverts the pump output flow through a bypass circuit, bypassing the oil cooler, and directly back to the oil sump. Bypassing the heat exchanger will result in temperature rise of the oil. Tests indicate that the temperature rise will likely be gradual and will stabilize long enough for the aircraft to return to 'base or to an area where a safe, forced landing can be achieved. Approximately 30 minutes will be required to cause a rise in temperature from normal to over 400° F (204° C) at which the temperature is stabilized for at least 70 minutes. Analysis of these test results indicate that bearing velocity dominates temperature rise rates.

5.2.6.2.1.2 Backup oil system. One such system incorporates a small backup sump and pump to provide minimal oil flow to critical areas of the transmission or gearbox. Ideally, auxiliary oil lines, pump, and sump should be located internally.

5.2.6.2.1.3 Solid lubricants, The use of solid lubricant technology can extend operational life when lubricating oil is depleted. Bearings with solid lubricant retainers and gears using solid lubricant idlers will perform satisfactorily during operation with lubricating oil (e.g., MIL-L-21058 lubricating gear oil). Teflon solid-lubricant-filled silver alloy matrix has been found to provide the best long-term operation at a speed of 1000 rpm. However, long-term reliable operation at 2000 rpm has been achieved by the use of tungsten diselenide/gallium-indium composite solid lubricant.

5.2.6.2.2 Transmission and gearbox housings. Although the use of ballistic protection may be the only recourse in a retrofit program, the protection of the oil sump should receive highest attention. The direct fabrication of the oil sump from MIL-S-46099 dual hardness should be considered a possibility. In new designs, housings should be fabricated from materials with high fracture tougliness and ductility. Bearing support structure should be designed for ruggedness and toughness with redundant load paths. Where protection of larger size main bearings is essential, ballistic-resistant steel bearing cages (e.g., cages or sleeves constructed from MIL-S-46099 armor material) and high-temperature resistant steel bearings should be used.

5.2.6.2.3 Drive shafts. Main drive and intermediate shaft design must provide for safe operation after being damaged by single or multiple projectile or fragment hits. Drive shafts should be large in diameter, thin-walled, and constructed from high fracture toughness materials. Shaft couplings and intermediate shaft supports or hangers should be designed for tolerance to ballistic damage.

5.2.6.2.4 Gear train. The load that must be transmitted by the individual gears is dependent upon its functional requirement. To minimize the degradation of gears through destruction or jamming and resulting marginal performance when impacted by a threat damage mechanism, damage tolerance features should be incorporated. Wide section gears are preferred over gears of narrow width. Use of wide section gears permits additional retention of operational capability for a given area of tooth removal. Fracture tough, rather than brittle, gear material should be used.

5.2.6.2.5 Bearings. For critical bearing applications, high-temperature bearings with inherent capability to operate after loss of lubrication or cooling should be used. Depending upon rotational speeds and heat transfer and the load distribution characteristics of a specific installation, a fewer number of larger bearings may be more preferable than a greater number of smaller bearings. Metallic seals are preferred over elastomer seals, particularly when encountering HEL or operating in an over temperature condition for extended periods.

5.2.7 Rotor blade. Satisfactory performance of rotary wing aircraft rotor systems requires that rotor blade structural integrity be maintained following penetration or burn-through (from HEL) by threat damage mechanism impacts or exposure to high-explosive blast effects as well as the maintenance of balance within specific design limits to avoid catastrophic failure or unacceptable vibration levels. Since rotor blades operate under tension, compression, torsion, and bend forces that rapidly change as the blade rotates about its hub, special attention to these forces should be aplied to maintain satisfactory operation of the rotor blade system under realistic operational loads so that, after combat damage, escape from the combat area to land or for safe recovery can be achieved.

5.2.7.1 Primary responses from threat weapon effects. When a blade is damaged, a number of factors contributing to the blades's resulting performance may occur. These factors include rotor unbalance, blade instabilily, loss of track, and loss of lift. Probably the most critical consequance from combat damage is rotor unbalance. Combat experience has indicated that conventional rotor blade designs are relatively tolerant to projectile impacts through caliber 12.7 mm. As the extent of mass loss (spanwise) outboard of the damaged point of a blade increases, higher alternating in-plane hub forces are created. Depending upon the number and diameter of blades, these forces can result in cockpit and control vibrations of sufficient magnitude to cause loss of control of aircraft MEWS. In addition, unusual hub forces may be created to wrench the rotor transmission completely from its mount. Even if the damaged blade does remain intact, a local reduction in blade stiffness could result in either catastrophic flutter or divergent pitch oscillations through blade instability. Reduction in local blade stiffness, caused by 23 mm HEI (or larger caliber) projectile impacts on the spar, can create excessive loss of track and vibration. Although more likely to occur after shutdown, extreme loss of track can cause rotor blade contact with the fuselage during flight, A less likely occurrence is the loss of lift. Loss of lift can be caused either by separation of large blade areas or by a local reduction in blade stiffness which could result in its operating at a lower angle of attack. Depending upon the relationship of the extent of blade loss (usually small) to overweight, altitude, and temperature extremes of MEWS" operations, increasing the pitch on all blades may compensate for the loss in lift.

5.2.7.2 Low vulnerability rotor blade design techniques. The prime design consideration in reducing rotor blade vulnerability is to retain intactness; secondary consideration maintain sufficient stiffness about the flap, chord, and pitch axes to retain stability or track. These considerations can be implemented by designing the blade with separated (spaced chordwise). and redundant, spanwise load paths (e.g., multi. tubular spar concept) to carry the major centrifugal faces and bending and torsional loads. Such a design will reduce the possibility of critical blade section removal and provide sufficient blade residual stiffness when ballistically damaged. The practicability of this technique is dependent upon the availability of space, and some weight penalty can be expected. The cross-sectional area of the blade should be designed sufficiently large to further reduce vulnerability to multiple fragment or projectile impacts. To compensate for interlaminar shear forces developed at the blade root-to-hub interfaces, the highest practical redundancy level of attachments should be provided. For smaller size rotor configurations or restricted areas at which bearings and control linkages attach, passive shielding may be the only efficient recourse. However, the vulnerability of a tail rotor sytem can be reduced by employing a "torsion pitch control" concept. In this concept, a torque tube is bonded to the blade, and a flexible collar is used to permit angular pitch adjustment by a control linkage input to twist the torque tube bonded blade combination. Complete loss of the rotor blade is not likely to occur because of the large area of tube attachment to the blade and the inherent stability that exists upon severance of the control linkage attachment. To limit the extent of damage and the amount of material removal against 23 mm EI projectile

Impacts, crack and rip stoppers together with the incorporation of redundant load paths should be used. Research in new, low vulnerability design concepts indicates that an all-composite material rotor blade can be constructed to achieve high damage tolerance to both nonexplosive and explosive projectile threats. The basic design concept employs the use of a geodesic truss structure box spar composed of many elements forming a redundant grid system covered with an aerodynamic skin. Against an HEI projectile impact, besides its inherent resistance to crack formation or propagation, the structurally expendable skin tears away locally to allow venting of the pressure wave generated by the detonation of the projectile. HEL protection can be incorporated into the blade design by selection of materials that will act as ablators (e.g., advanced development thin film ablative material whose protective capability exploits the characteristic that highly polished aluminum reflects over 95 percent of the energy from an impinging laser beam), insulators, or as reflectors.

5.2.8 Environmental controls, The environmental control subsystem (ECS) is comprised of pressurizing, cooling, heating, ventilating, moisture control, and environmental protection (e.g., contamination control) systems and components. Portions of the ECS are essential for mission completion and aircrew survival.

5.2.8.1 Responses from threat weapon effects. The general specification for ECS is MIL-E-38453; MIL-E-18927 for the pressurized portion. The ECS is rarely listed as the cause of a mission abort because of the complexity of the interface between the ECS and all other aircraft subsystems. The secondary effects, following an ECS failure, are normally entered on the accident and damage reports under the heading of primary cause. The importance of evaluating the effect of the aircraft’s operational environment along with the primary failure that may be caused by hostile weapons should be considered. The altitude, speed, maneuvers, weather, mission objectives, and terrain can be contributing factors to a condition that could cause loss of mission or loss of the aircraft. Such hazards must be considered by the designer early in the design process. The designer should, therefore, identify those portions of the ECS that are essential for mission completion and for aircrew survival. The ECS should be designed to service the mission-essential elements of the other aircraft subsystems in a suitable order of priority to enhance total system survivability and capability when subjected to threat damage mechanisms.

5.2.8.2 Low vulnerability ECS design techniques. The following low vulnerability design techniques for the cooling and heating, 5.2.8.2.1; pressurization, 5.2.8.2.2; ventilation and contamination, 5.2.8.2.3; and moisture control systems, 5.2.8.2.4; and the installation of the ECS, 5.2.8.2.5; should be implemented insofar as is possible:

5.2.8.2.1 Cooling and heating. Environmental cooling and heating systems (MIL-H-18325) are used to maintain the temperature of crew stations or subsystems within the limits required for comfort and proper operating conditions. Design systems to service mission-critical aircrew stations and equipment in order of priority for mission completion and for aircrew and aircraft survivals. Implement the following insofar as possible:

a. Provide redundant or emergency cooling and heating systems that will provide necessary temperature control for time necessary for mission completion or for crew recovery.

b. Provide emergency, automatic, or aircrew-operated shutoff or isolation of high-temperature heating systems; failures or malfunctions caused by weapon effects could result in unacceptable crew discomfort, other subsystem malfunctions or failures, and secondary hazard conditions such as internal fire, smoke and toxic fumes.

c. Locate refrigeration unit components (e.g., heat exchangers, air cycle machine, etc.) so as to provide inherent shielding from weapon effects.

d. Construct components to resist shattering or explosive disintegration that could cause failure of other subsystems or injury to personnel from fragmentation.

e. Keep high temperature gas and air line pressures as low as possible to minimize secondary hazards from penetration of such lines by projectiles or fragments.

f. Route high-pressure and high-temperature gas and air lines to avoid potential fire hazard areas and in channels or other heavy structure to isolate them from other subsystems.

g. Position hot gas and air line connections in areas where their failure from weapon effects will cause least secondary hazards from the release of high-temperature gases.

h. Design high-speed rotating equipment of refrigeration units so that its containment capability following exposure to weapon effects is not lost.

i. Provide a pre-cooler heat exchanger near the source of high-temperature air to reduce the temperature of the air ducted throughout the aircraft to a level that minimizes the hazards resulting from penetration of ducting by projectiles or fragments.

j. Provide a leak detector along high-temperature ducting to warn the crew of a hazardous, high-temperature leak resulting from penetration of ducting by projectiles or fragments.

5.2.8.2.2 Pressurization. Mission requirements for aircraft pressurization systems are, with few exceptions, altitude dependent. The cockpit, canopy/hatch inflatable seals, crew pressure suits, avionics, fuel, and hydraulic systems are the major subsystems that may require pressurization, Implement the following insofar as possible:

a. Provide redundant and separate pressurization sources for essential crew or subsystem operation. Design sensing and control systems to provide pressurization on a priority basis, if aircraft pressurization system capabilities are degraded by threat weapon effects.

b. Design and construct pressurization system elements from materials to resist explosive shattering and complete failure if struck by projectiles, fragments, HEL, or secondary spallation.

c. Design crew station pressurization systems to resist explosive decompression due to sudden loss of pressure source by providing crew station inlet check valves.

d. Use emergency ram-air pressurization for critical subsystems where only single pressurization sources are available or where other trade considerations (e.g., vulnerability, complexity, safety, reliability, or weight) or modification factors are involved.

5.2.8.2.3 Ventilation and contamination control. Proper ventilation and contamination control may be essential for specific subsystem performance needed to achieve mission completion and aircrew and aircraft survivals. These subsystems may include aircrew stations, engine bays, armament functions, and other critical compartments. Provide priorities for subsystem operation, and incorporate these into the basic design phase to direct ventilation to those subsystems whose failure or malfunction would degrade the survivability of aircraft and aircrew and mission completion. Implement the following insofar as possible:

a. Provide positive ventilation to those compartments and areas where flammable vapors or liquids may migrate when their containers have been damaged by threat weapon effects.

b. Design and construct system components to resist cracking and shattering when struck by a projectile.

c. Route ventilation lines to avoid secondary hazard areas where fire, explosion, smoke, or toxic fumes may be ingested into aircrew stations.

d. Use ram-air emergency ventilation for aircrew stations and critical subsystems when the normal system has failed or malfunctioned.

5.2.8.2.4 Moisture control systems. Moisture control is required for the aircrew compartment and electronic equipment. Introduction of moisture into the aircrew compartment caused by control failure from weapon effects could result in poor visibility and discomfort for the aircrew. Excessive moisture can cause failure or malfunction of essential electronic equipment. In applications where moisture control for electronic equipment is accomplished through the use of a coolant liquid, secondary hazards may be caused by the release of coolant liquid or vapor into the aircrew compartment area that would be detrimental to the crew’s performance or health and lead to possible loss of the aircraft or mission failure. In addition, a combat-induced leak in the liquid coolant circuit will result in loss of cooling for the electronic equipment and subsequent failure of the electronic equipment. Implement the following insofar as possible:

a. Use an air coolant system in preference to a liquid coolant system where vulnerability of the latter is greater or would create an unacceptable secondary hazard.

b. If a liquid coolant is used, select one that will prevent or minimize toxic or fire hazards.

c. Avoid locating liquid coolant lines in aircrew stations.

d. Locate moisture controls where they will be provided natural masking from weapon effects.

e. Provide adequate means for windshield defogging should the air-conditioning shut off valve become closed and inoperative.

5.2.8.2.5 Installation. Insure that air flows from cockpit to cabin or aft stations. This is to minimize the cockpit confinement and concentration of fire, smoke, or toxic gas emanations from other parts of the aircraft. Additional installation techniques should be implemented inasmuch as possible:

a. Use materials that minimize the emission of toxic or explosive gases when exposed to HEL or other high-temperature sources.

b. Use materials that are resistant to explosive shattering when impacted by ballistic damage mechanisms.

c. Isolate, pre-cool, or use noncombustible materials on those ECS components in proximity to potential hot air leakage sources to reduce fire hazards.

d. Route lines to prevent or minimize hazards associated with weapon effects.

e. Install mission-critical components to maximize advantage of natural shielding.

5.2.9 Electrical power. The conventional techniques and practices of electrical design (MIL-E-25499) include several elements that enhance the capability to survive in a combat operating environment. For example, the redundancies built in for reliability purposes and efforts to reduce electromagnetic environmental effects (E (see MIL-STD-461, MIL-STD-462, NAVMATINST 2410.1B, MIL-HDBK-235, and MIL-HDBK-238) reduce vulnerability. The power limiting functions built into all electrical distribution systems afford protection against short circuits caused by projectile impacts, and the minimum weight and volume design objectives also minimize the equipment presented area. The technological limitations of conventional aircraft electrical power systems (e.g., load management), with respect to the continued improvements required to meet projected demands of future aircraft MEWS, have necessitated the development of an advanced aircraft electrical subsystem (AAES). Advances in data handling, high-voltage direct current solid-state devices, multiplexing techniques, and logical control of dynamic functions will be used in the development of AAES. Some of these advances, in particular, solid-state devices, will be susceptible to electromagnetic interference via the EMP threat mechanism of damage.

5.2.9.1 Responses from primary and secondary weapon effects. Electrical power systems are particularly sensitive to the primary and secondary damage mechanisms associated with conventional weapon effects. Primary effects are those that are the result of penetration and impact from ballistic threats and interference or burnout from EMP. These effects can cause severance of electrical wires and shorting of electrical circuits; functional obliteration from EMP. Secondary weapon effects are those hazardous effects created by projectile impacts that, in turn, can adversely affect electrical elements. These include fires, explosions, high-temperature conditions, and liberation of hazardous materials. Failure modes of electrical elements are disruption and shorting of circuits and malfunctioning of equipment.

5.2.9.2 Low vulnerability electrical power design techniques. The following circuit design techniques should be implemented inasmuch as possible to prevent or minimize loss or degradation of electrical generation, storage, conversion, and distribution for systems essential to mission accomplishment and survivability of aircraft MEWS:

a. Provide multiple redundancies in circuits so that failure of a circuit or component due to conventional weapon effects will not result in serious degradation or loss of essential electrically powered equipment. Redundancy should also encompass drive mechanisms for single-engine aircraft electrical generators so that redundant power sources are not dependent on a common drive mechanism such as the engine accessory drive or aircraft hydraulic subsystem.

b. Use multiple-wire feeder lines to minimize or eliminate the possibility of complete system loss.

c. Provide an emergency power source that supplies power to bus or that bypasses normal feeder circuits providing power directly to essential equipment. Employ sensing devices to provide rapid and automatic actuation of emergency systems whenever primary system loss occurs for a specified time duration.

d. Provide parallel or redundant power conversion units or systems for operation of critical subsystems where adequate protection cannot be provided for a single electrical power conversion system.

e. Avoid controls which use ground circuit switching to preclude inadvertent operation of systems or components (due to grounding by weapon effects). that would reduce aircraft survivability or cause mission failure/degradation.

f. Use circuits that will provide electrical grounding of both sides of activation circuits for critical components or systems. This will prevent inadvertent operation due to a short of electrical energy from combat damage.

5.2.9.3 Installation, If an electrical system is critical to the mission and no redundancy exists, then the installation must consider suitable masking from the ballistic threats or armor provisions. The location of components is critical from a secondary hazard standpoint, if it provides an ignition source when damaged. The installation of some electrical equipment includes a grounding connection to the structure. If this connection is broken, the potential difference can be a highly efficient ignition source. Ignition can occur from voltages of as little as 0.5 volt, from a point contact between the two potential levels. Capacitance-type fuel quantity measurement systems commonly use a potential difference of up to 75 volts. Any possibility that debris or other material from ballistic damage could cause a short circuit in such a system should be carefully scrutinized. Batteries should be designed or procured with ballistic impact tolerance and should provide a degree of power, even when damaged. Battery bays should be sealed to prevent migration of corrosive battery acids to nearby sensitive equipment or components. Provisions should be made to drain or vent corrosive fluids and vapors overboard or to locations that are not sensitive to corrosive fluids. Against HEL, components should be carefully located to take advantage of inherent masking, and materials and coatings should be chosen that exhibit or provide high tolerance to burn-through. The following techniques should be inplemented insofar as possible:

a. Route electrical wiring away from hazardous or hazard-producing areas such as fuel bays and oxygen cylinders. Where hazardous areas cannot be avoided, provide shielding for protection of cabling and for protection of surrounding potentially hazardous equipment from possible electrical arcing caused by damaged wiring.

b. Use pull-away bulkhead fittings to minimize possibility of wire damage due to displacement of, or damage to, supporting structure.

c. Use shortest possible tire runs to provide minimum exposure of circuits to conventional weapon effects.

d. Locate bus bars and essential terminal strips in those areas of the aircraft which are least vulnerable, considering design mission requirements of the aircraft.

e. Design circuits to minimize crew compartment electrical system wiring. Use shielding where crew compartment wiring is unavoidable, and use wire insulation materials and system elements which, when subjected to fire or intense heat, will not produce smoke and noxious or toxic vapors.

f. Use cooling system duct materials which will accept conventional weapon or secondary projectile penetrations without disintegration.

g. Separate as far as practical all redundant wire runs and system elements to avoid total system loss from a single conventional weapon effect and route essential wiring deep within wire bundles, thereby utilizing shielding effect of nonessential wiring.

h. Provide insulated rigid ducts, installed along strong structural sections, to prevent short circuits due to fragment damage. Ducts should be fireproof, smokeproof, and nonabrasive.

i. Provide continuous tire runs as far as practical to avoid or minimize terminal strips, splices, connectors, etc., which are more susceptible to damage or failure from EMP and other weapon effects.

j. Avoid using common connectors or terminal strips for routing control circuits of multiple power sources to prevent total power failure from a single weapon effect.

k. Locate essential components to take advantage of natural shielding offered by less essential components.

5.2.10 Avionics. The avionics subsystem is comprised of components interconnected by cabling. These elements are highly susceptible to damage by threat weapon effects, particularly EMP. Efforts to reduce E^3 (see MIL-STD-461, MIL-STD-462, and NAVMATINST 2410.1B, MIL-HDBK-235, and MIL-HDBK-238) can reduce the effects of EMP. Aircraft and crew survival and mission completion can be highly dependent upon avionics subsystem performance in hostile conventional weapon environments. Some of the most influential factors in aircraft survival are the utilization of electronic warfare equipments to prevent or minimize its detection by hostile forces, to defeat enemy search and weapon homing systems, and to confuse or misdirect hostile weapon systems. Mission completion and aircraft or crew recovery may also be highly dependent upon the effectiveness of aircraft fire control, communications, flight control augmentation, data processing, or navigation systems.

5.2.10.1 Responses from threat weapon effects. The basic conventional threat kill mechanisms that may be experienced by avionics systems are penetration or impact shock by projectiles, fragments, secondary spallation; high-explosive blast effects; and secondary thermal hazards such as fires or hot gas torching effects. Advanced threats and kill mechanisms may include HEL burn-through and EMP burnout resulting in possible transitory damage. Solid-state electronics is the basic configuration of current avionics subsystems. Against. ballistic damage mechanisms, the solid-state electronic systems exhibit higher survivability advantages over vacuum tube systems in terms of smaller presented area, higher shock resistance, and lower cooling requirements’o

5.2.10.2 Low vulnerability avionics design techniques. To provide low vulnerability electronic components cabling, the following techniques should be implemented inasmuch as possible:

a. Design critical system circuit to avoid complete loss of functions if one element or group of elements is damaged or destroyed. For extremely critical systems, separate redundant systems or portions’ of systems that would be exposed to weapon effects.

b. Design circuits to provide long the-to-die features from high-temperature hazards that may occur in specific aircraft design due to nonnuclear weapon effects (e.g., hot gas torching from a damaged engine, internal fires, loss of environmental cooling, etc.) O

c. Provide safety monitoring systems with a "vaild" signal parity check-type circuitry to prevent hazardous, erroneous, or “hard over” signals to critical systems due to damage, malfunction, or destruction of one of the system elements caused by weapon effects. Provide fail-safe system disengagement or backup operation along with pilot warning.

d. Design layout of circuitry or signal transmission systems (MIL-D-81980). to minimize inductive and capacitive cross coupling effects; circuits containing EMP-sensiYive components should be fused (e.g., introducing an amplitude limiting device such as a spark gap, a filter, or other disconnect mechanism). between the energy collector and the sensitive component.

e. Construct components to withstand high shock loads caused by projectile or fragment impact on the component, adjacent units, or structure. Stabilize potential failure areas with adequate mechanical shock mountings to withstand, in addition to normal vibration conditions, weapon effects.

f. Provide support, potting, or lightweight fillers within the electronic equipment to prevent or minimize failures caused by excessive shock loads, with due concern given to ease of maintenance.

g. Separate redundant circuits within components as far as is practicable to minimize possibility of simultaneous failures, structural distortion, or blast effects from projectiles or fragments.

h. Provide breakaway mounting features on equipment where distortion of case by weapon effects would cause malfunction or failure consistent with requirements for crash safety, mechanical shock, boresighting, etc.

i. Use insulating material for exterior wrapping of critical equipment to provide extended operational time where exposure to high-thermal conditions may occur due to weapon effects, with due consideration given to possible deleterious effects on equipment from reduced heat dissipation.

j. Select components and materials/coatings that reduce sensitivities to HEL and EMP effects.

k. Provide heat-resistant wiring, connectors, potting, terminal strips, etc. , for critical avionics circuits operating in high-thermal hazard areas.

1. Provide smokeless cabling in crew stations or locations where smoke or toxic fumes would be introduced into crew stations due to fire or high-thermal conditions caused by weapon effects.

m. Provide ballistic-resistant cable bundle covers for isolation and protection of critical equipment cabling from small (or span) fragments.

n. Arrange components to reduce cable run lengths which, in turn, reduce the percentage of energy collected by the structure and applied to EMP-sensitive components.

o. Shield, as a last resort, critical components and cables.

5.2.10.3 Installation. Consider passive techniques such as separation, concentration, and shielding to minimize malfunction or failure of critical avionics equipment and connecting cables consistent with MIL-I-8700 conventional installation procedures. When possible:

a. Locate equipment to obtain best balance between shielding of equipment and routing of connecting cables to minimize vulnerability of the total avionics subsystem. Where adequate cabling survivability cannot be obtained, use redundant cabling with suitable automatic sensing and switch over capability.

b. Provide equipment shock mounting for maximum practicable protection from blast and shock effects consistent with requirements for crash safety, mechanical shock, boresighting, etc.

c. Isolate and route critical equipment cabling apart from non-essential cabling to minimize hazardous short circuits from weapon damage. Avoid using common connectors where such short circuits are likely.

d. Provide frangible, pull away structural attachments of cabling connectors to prevent or minimize wire breakage, separation, or shorting due to structural deflection resulting from weapon effects consistent with maintaining mission performance capability.

e. Route critical cabling as close as practicable to heavy primary structure to obtain natural shielding from weapon effects and to minimize probability of structural deflection induced damage. Avoid areas where secondary fires, high-thermal effects, or hazardous spallation may occur.

f. Optimize positioning of wires in cable harnesses to reduce cross coupling effects.

5.2.11 Armament. The armament subsystem provides for the carriage, target acquisition, arming, launching, and terminal guidance of weapons. Aircraft weapons include guns, bombs, rockets, missiles, torpedoes, and chemical weapons.

5.2.11.1 Reactions from threat weapon effects. When weapons carried by an aircraft are impacted by ballistic damage mechanisms or impinged by HEL, a range of reaction from burning to detonation may occur. A similar range of reactions may occur, in one to ten minutes, when ordnance is exposed to a sustained fire. Explosion of one or more bombs, missile warheads, or rocket motors will cause a mission or catastrophic kill of the aircraft. A similar range of reactions may occur within one to ten minutes when ordnance items are exposed to burning ordnance or to a jet fuel fire on an aircraft carrier deck. Gun ammunition also presents a potential problem due to reaction of propellant or HEI rounds which is dependent on density of packaged rounds, reaction characteristics of particular rounds, and venting of the ammunition container. Nonvented ammunition containers may be vulnerable to the blast effects of contained ammunition, particularly to HE projectile impacts. The smaller the container, the more likely it is to be structurally damaged. Vented containers have maintained their structural integrity to a higher degree than nonvented containers of similar construction when tested under similar conditions. AP projectiles provide more destructive effects on general-purpose bombs than other types of projectiles. Both armor-piercing projectiles and fragments may cause either low or high order detonation of guided missile warheads as well as detonation or ignition of rocket motors. Threat effects on nonordnance elements are likely to degrade armament subsystem performance.

5.2.11.2 Low vulnerability armament design techniques. Mission-essential armament associated elements, components, hardware, and impact and incendiary-sensitive ammunition and other ordnance should be so located to make sure of inherent shielding and to minimize personnel injury/ fatality as well as damage to essential components from explosion or burning initiated by hostile effects. One of the ongoing efforts is the development of technology and concepts for enhanced munitions survivability. The relative merits of external, conformal, or internal carriage vulnerability should be conducted. To ensure low vulnerability of aiming and sighting systems, arming and release systems, internal gun systems, and internal and external carriages of ordnance, the following design techniques should be implemented inasmuch as possible:

a. Use heat barriers (ablative materials) or fire suppression systems for sensitive ordnance components to limit damage.

b. Use methods to prevent or minimize complete failure of the aiming and sighting systems as a result of damage or failure of one of its elements caused by weapon effects. Provide redundant circuits or elements to insure full or acceptable degraded performance when subjected to hostile damage mechanisms.

c. Provide a “fixed” sight capability, either automatic or selected, that is not dependent upon operation of the normal sighting and aiming systems to permit delivery of guns or bombs in a degraded mode.

d. Locate critical system components to use natural shielding protection. Avoid those locations where secondary hazard effects such as short-term fires, high-temperature environments, or structural deformation caused by hostile weapon effects would degrade or destroy the component functions.

e. Isolate arming and release electrical circuits from other electrical or electronic circuits, and give them priority of protection to prevent failures or malfunctions.

f. Use redundant or backup arming and release systems where basic survival of the normal system is unacceptable. For example, provide a mechanically operated or emergency electrical weapon arming and release systems that will permit delivery of ordnance when the normal electrical system is inoperative due to weapon effect damage.

g. Provide emergency or redundant power sources for essential operation of ordnance arming and launching systems.

h. Where multiple ordnance launchers or stations are used, provide separated and protected arming and launching circuits to avoid complete loss of weapon delivery capability due to a single hit.

i. Air-launched missile and rocket propulsion systems must satisfy AS 4449 Safety Requirements for air-launched guided missiles, target drones, and aircrew escape and rocket propulsion systems.

j. Provide gun gas purging, gun and ammunition compartment venting and cooling, and gun charging (if required) systems that are not dependent upon operation of a highly vulnerable electrical or fluid power system. If this cannot be accomplished, provide emergency backup capability for such an operation. For example, provide an emergency accumulator for a. hydraulically operated gun charging or purge door operation. Automatic operation of the emergency system is preferred along with pilot warning of primary system failure.

k. Design gun ammunition feed systems as compact and transfer chutes as short as practical to minimize the vulnerable area and probability of malfunction or jamming due to hostile weapon effects. Avoid rigid attachment of feed and return chutes to structure where deformation from weapon effects could cause jamming of gun or feed operation.

l. Provide case ejection chute installations that will resist failure or malfunction due to hostile weapon effects. Consider using metallic or nonmetallic materials that will accept minor penetration and blast effects and still allow case retention and/or disposal that will prevent or minimize loss of gun operation.

m. Investigate the use of ordnance designed for enhanced survivability.

n. Design ammunition stowage area to preclude or minimize destructive buildup of pressures within aircraft structure, where hostile projectile impact and ignition of stowed gun ammunition can occur. Provide vented ammunition containers/compartments and a capability for relieving pressure from gun ammunition stowage areas.

o. Design weapon bay door hinges and actuating mechanisms to prevent or minimize jamming from blast or weapon penetration effects.

p. Provide redundant or emergency power sources for weapon bay door and articulated weapon positioning devices such as for missile or rocket launchers. Hydraulic, pneumatic, and electrical systems are the primary types that should be compared to determine which one or combination will provide the greatest survivability for the specific application. The emergency backup system may be hydraulic accumulators, pneumatic pressure bottles, batteries, cartridges, or other energy devices.

q. For installations where weapon bay doors may be jammed or become inoperative from weapon effects, provide a means to jettison doors. Frangible or explosive hinge pins or explosive primer cords are examples of such means; however, this is not recommended as the hazards are high. The damaged doors may not separate properly and may cause additional damage to the aircraft.

r. Concentrate operating linkages and equipment to minimize their vulnerable area and possibility of jamming or malfunctioning from weapon effects.

s. Provide single motion jettison capability for external weapons in case of ignition.

t. Mask weapon arming and actuation of electrical circuitry in external pylons to present the least vulnerable aspect or area to weapon effects. Where this cannot be avoided, use redundant circuits.

u. Select less sensitive high explosives and nondetonable solid propellants for fuze, warhead, and propulsion systems/subsystems. Design components containing energetic materials for minimum response to bullet impact and cook-off in accordance with MIL-STD-1648.

5.2.12 Structure. An aircraft structure subsystem consists of the basic airframe which includes the fuselage, empennage, and fixed (swept or unswept) and rotary wings. Major load attachments for elements such as launch and landing gear, engine pylons, armament, and external stores are also included in this category. An airframe is designed in accordance with Military Specifications MIL-A-8860 through MIL-A-8870 or TIIL-S-8698. There are, however, specific aircraft design considerations (e.g., crashworthiness (MIL-STD-1290), repairability, maintainability, secondary hazards, and operational readiness) that can significantly’ influence the effectiveness of the system. These considerations must be taken into account in the initial design phase to select the basic structural type, or combination of types, that will provide the most survivable and effective system configuration. Three types of construction are used - thin skin and stringer, sandwich, and sculptured plate. The airframe, in general, is susceptible to damage from conventional weapon effects such as ballistic impacts by nonexplosive or explosive projectiles; internal blast effects with or without fragmentation; external blast effects with fragmentation; and HEL weapon effects. Secondary weapon effects such as internal fires and explosions, hydrodynamic ram effects, liberation of corrosive materials and toxic gases, and the release of high-temperature gases must be considered in the selection and design of aircraft structures to ensure the achievement of low vulnerability.

5.2.12.1 Responses from primary and secondary effects. Depending upon the characteristics of the threat damage mechanism encountered, overpressures (i.e., pressures above ambient) generated by the blast wave may be of sufficient magnitude to result in a crushing effect on structural elements; reflected impulse (impulse, the integration of the pressure wave over time). of the blast wave may result in blowout (or area removal] of critical structural sections; ballistic impacts may cause crack propagation or hydrodynamic ram (e.g., severity of hydrodynamic ram proportional to the amount of fluid relative to container capacity), and HEL may cause burn-through and, additionally, in the case of composite structures, delamination. Limited test data indicate that the damage from a blast wave (external or internal blast)- for a given amount and type of explosive varies inversely with altitude. Ambient atmospheric pressure has a larger effect than temperature variations on blast wave parameters; temperature affects peak pressure, but its effect on impulse loading is insignificant.

5.2.12,2 Low vulnerability structure design techniques. An understanding of the responses of structure to basic damage mechanisms and repairability, maintainability, and crashworthiness considerations is essential in the initial structural design efforts. When selecting materials for structural applications, fracture toughness' qualities of the material to-minimize crack propagation or hydrodynamic ram efforts should be considered. The use of composite materials in aircraft structures is ever increasing and, under many conditions, may be. substituted for monolithic metallic materials with comparable structural performance at significant savings in weight. However, nonmetallic structures afford less protection against EMP and lightning effects as compared to metallic structures, and this should also be a design consideration. Current composites include fiberglass, doron, Kevlar, graphite or boron epoxy filament, and graphite or boron epoxy filament/polyamide. Polyamides are used for higher temperature applications. Recent developments in advanced composites include high-strength, high-modulus, and continuous filament graphite and boron; improved matrix materials; concepts of uniaxial, stabilized columnar filament arrays and cross-plied laminates; and hybrid structure (some combination of boron, graphite, and glass fibers in a fiber/epoxy laminate). For additional low vulnerability of fixed or rotaty wing aircraft structures, the following techniques should be implemented inasmuch as possible:

a. Fixed wing.

  (1) High fracture toughness materials when thin skin and stringer construction is used for higher ballistic damage tolerance (e.g., crack propagation) and resistance to secondary hazards.

  (2) Use bonded “doublers” on high-strength stressed skin panels in areas of thin skin and stringer construction where catastrophic failures are likely to occur. A thin layer of fiberglass can be bonded to the skin to provide some resistance to crack propagation.

(3) When sandwich construction is utilized, provide high-strength face sheet to inner core bonding material in areas where fuel or other liquids are carried to minimize delamination of hydrodynamic ram effects; use “planking” construction techniques; and use high-temperature resistant bonding materials in areas where short-term fires or the release of high-temperature air is likely.

(4) When sculptured plate construction is utilized, materials (e.g., 7475 aluminum alloy in lieu of the higher strength, but more brittle, 7075-T6 aluminum alloy) and “planking” construction for areas primarily under tension loads to limit crack propagation should be used; straight lines of fasteners over larger sections subject to high stress loads to limit “zippering” effects should be avoided; and sections with large radii should be used.

(5) Provide multiload path construction for fail-safe response when structure is damaged.”

(6) Wide and large areas are preferred over heavy section, small area stringers, frames, and longerons.

(7) Attachments for the transfer of high loads should be designed for adequate strength following ballistic damage to permit safe recovery of the aircraft under maneuvering conditions.

b. For rotary wing aircraft, additional sensitive structures include rotor blades, main and tail rotor assemblies, and tail boom. The rotor blades operate in a repetitive but variable dynamic environment. Fatigue, strength, and vibration level are of utmost importance in the determination of service life and aircrew (and passenger). comfort/aircraft survivability, respectively. For low vulnerability of main and tail rotor assemblies and the tail boom, the following design techniques should be implemented inasmuch as possible:

(1). To reduce vulnerability to fragmentation and external blast effects:

(a) Use multiple load path design to avoid concentrated load-carrying members, the failure of which would result in significant loss of control or performance.

(b) Utilize multiple shear-type joints for primary load path structural attachments and members, which will permit yield in bearing absorption of blast energy.

(c) Avoid designs that will allow crushing of critical structural areas needed for control or performance when subjected to blast effects that would otherwise have been survivable.

(2) To reduce vulnerability to internal blast effects;

(a) Design those interior compartments that have little possibility of accumulating explosive mixtures from other sources (i.e., fuel, hydraulics) to be as large as possible to give blast gases room to expand with resulting pressure reduction and to reduce the number of shock wave reflecting surfaces.

(b) Eliminate, to the extent possible, all dry bay type of cavities that might develop explosive mixtures due to fuel cell damage, hydraulic line or reservoir damage, etc.

(c) Fill those cavities that cannot be eliminated with rigid foam or provide some other device to reduce. the danger of explosion with special attention given to compartments where liquids such as fuel, hydraulic oil, and water are carried. Internal blast effects are generally considerably more destructive with liquids present that when the compartment is empty.

(d) Where aerodynamic requirements dictate use of countersunk (flush). fasteners for structural skin attachment, use such types- that require a force that equals tensile strength of fastener body to pull fastener head through skin to reduce the probability of large skin area loss due to internal blast effects.

(e) Avoid the use of large continuous skin panels., particularly in critical structural areas', unless pads to limit crack propagation are used to reduce the possibility of large skin area loss from blast effects or slipstream forces.

(f) Since continuous rod impacts are generally more hazardous than penetrations by either fragments or small high-explosive projectiles, use multiple load path structural design to avoid single major load-carrying members whose failure from a Penetration would cause significant loss of control or performance, and use crack arrestment techniques to prevent spread, of penetration damage from aircraft operating loads.

(g) Where fire/explosion suppression techniques cannot be used, consider shrouding or compartmentizing critical areas to limit damage to primary structures.

(h) Avoid the use of magnesium for or near major structural members, particularly in fire or heat-critical areas.

5.3 Design of Y/STOL aircraft. Multiple conceptual V/STOL aircraft are under consideration for introduction into the Navy. The design and evaluation guidelines, addressed throughout this handbook, are equally applicable to future V/STOL aircraft designs discussed in 5.3.1 through 5.3.6. Although a number of subsonic and supersonic V/STOL configurations and their variants have evolved, all fall into one or a combination of two or more of the following six basic concepts - vectored thrust, tilt-rotor, tilt-wing, lift/cruise, stopped rotor, and thrust-augmented wing (TAW). Depending upon the extent of combat damage, all V/STOL aircraft MEWS should be capable of returning to base from a combat mission and be able to perform vertical landing or, at least, conventional or short-field landing. From a combat survivability standpoint, a lift system with three or four “posts” providing the vertical thrust may be most desirable; however, substantiation is required.

5.3.1 Vectored thrust. A number of variants of subsonic and supersonic, vectored thrust V/STOL have evolved. These variants include vectored thrust with plenum chamber burning (PCB), vectored thrust with PCB and an augmented deflector exhaust nozzle (ADEN), and vectored thrust with remote augmented lift system (RALS),

5.3.1.1 Vectored thrust with PCB. The addition of PCB results in growth of the vectored thrust concept. Since the same nozzle system is used for all flight modes, the pilot may be able to detect combat damage to the nozzle system sufficiently early to possibly divert to some land base instead of discovery of a nozzle problem while transitioning from conventional flight to vertical landing on a ship. Engine IR radiation suppression may be difficult to achieve as the cooler fan air is not mixed with the hotter core gases. In addition, the protuberances of the nozzle system may require RCS reduction. From a vulnerability standpoint, fuel tanks in the vicinity of the inlet duct will likely pose a severe problem of fuel ingestion by the engine. Hydrodynamic ram and protection against fire/explosion (e.g., firewall and fire detection/extinguishment protective techniques) may be required, particularly in locations where fuel is in proximity to the engine.

5.3.1.2 Vectored thrust with PCB and ADEN. The discussion in 5.3.1.1 applies. The addition of an ADEN holds some potential for IR radiation reduction through plume mixing and blocking of the view, from some aspects, into the tailpipe and turbine.

5.3.1.3 Vectored thrust with RALS. As in 5.3.1.2, the discussion in 5.3.1.1 applies. The front nozzles may require a long bleed air duct and fuel flow to these nozzles when RALS burning is used. Since the RALS is a gimbal design rather than one that is rotational about a single axis, this added complexity is likely to add to its vulnerability. Since the fuel supply to the RALS is located near the pilot compartment, fire and heat resistance may be required to protect the crew. The use of two-dimensional exhaust nozzles will likely promote cooling of the mixed gases to reduce IR radiation.

5.3.2 Tilt-rotor, The tilt-rotor (sometimes referred to as tilt-engine or tilt-nacelle) concept is an attempt to achieve speeds higher than those associated with rotary wing aircraft. It is generally a two "post" design. To achieve nacelle rotation, an electromechanical or hydromechanical actuation system is used. When damaged by threat damage mechanisms, transitioning from conventional flight to vertical flight may be prevented.

5.3.3 Tilt-wing. Depending upon the number of engines installed on the wing {usually two or four), the two or four "post" wing and engine assembly is tilted through an interconnecting drive system to deflect the slipstream to achieve V/STOL capabilities. Since the "posts" are confined to the wing rotational axis, longitudinal stability may be critical. However, the use of the tail rotor for pitch control reduces this criticality. In the case of the four engine configuration, the transmission system with cross shafting between the four propeller cases can ensure a uniform distribution of torque upon failure of an engine. While the aircraft is at low speed, this cross shafting can provide adequate control throughout the low speed flight regime when the normal aerodynamic control surfaces are ineffective or inadequate. During cruise flight, at least two engines can be shut down to -maintain near optimum fuel consumption Fuel is generally contained in fuselage cells with redundancy in fuel transfer provided.

5.3.4 Lift/cruise fan.. The lift fan concept is one in which as many as four relatively large fans (four "post" design) are driven by inter-connecting shafts or by hot bleed air from the engines (gas generators) via ducts to the fan tips (e.g., turbotip design) with two of the engines and fan tiltable to provide vertical capability. In the case of the-gas generator system, the gas produced by the jet engine is directed by the diverter valve into the scrolls which surround the lift fans. Turbine blades attached to the fan outer diameter (tip turbine) are driven by the engine exhaust gas. An inlet door allows ambient air to enter the fan which accelerates the air flow and exhausts it through exit louvers. A complex valving system is utilized to maintain stability and control in three axes in the event of an engine failure. To eliminate the unnecessary rotation of the shaft system of the interconnecting shaft design during cruise flight, clutches should be located near the engine output drive rather than downstream near the fans. Backup opening of inlet doors and exit louver should be provided in case of failure of the main door or exit louver opening mechanism. Because of the large fans used, a large RCS is expected and its reduction is paramount.

5.3.4.1 Lift/cruise fan variants. A variant of the lift/cruise concept is the use of advanced blown lift enhancement (ABLE) to provide lift through fans (compressors driven by shafting from main lift/cruise turbofan engines). Another variant is the use of lift/cruise turbofan engines with ADENS and bleed air from one or more lift engines for reaction controls. In general, the use of lift engines introduces added complexity and vulnerability of controls and fuel supply. Damage to lift engines may remain undetected until the initiation of the transitional phase from airborne flight to vertical operations. Depending upon the configuration, the lift/cruise fan concept is either a two, three, or four "post" design.

5.3.5 Stopped rotor. A two- or four-bladed stopped rotor concept has all the vulnerability problems associated with both rotary wing and propeller systems. Using the principle of circulating control rotor (CCR, the capability to circulate air out of the rotor blades' advancing and retracting edges) would provide a high degree of control and speed whereupon the stopped rotor would function as a wing surface in cruise flight . Due to the relatively large acoustic signature of a two-bladed system, more than two blades should be used but at the possible risk of increased RCS. The use of a large diameter 8 ft (2.4 m) anti-torque 'rotor presents a large area vulnerable to combat damage which, in turn, could destroy its vertical flight capability. Any attempt to develop a foldable, stopped rotor design would only result in added complexity and vulnerability.

5.3.6 Thrust-augmented wing. The thrust-augmented wing (TAW) concept uses ejectors to augment thrust for V/STOL operations. A diverter valve at the engine exhaust forces air through ducts in the aircraft to the wing and canard, where it is expelled downward through the thrust augmenter exit nozzles or fuselage ejectors. Engine thrust is augmented by large quantities of ambient air that are drawn in over the ejector flaps by the ejector nozzle. Propulsion, lift and control will be provided by the primary airflow through the diverter system to thrust augmenters in the wing and canard surfaces. One advantage of this concept is that no lift engine weight penalty is borne for vertical flight. The TAW concept results in a large aircraft presented area and RCS. Although, in effect, TAW is a four "post" design, lift loss due to damage to the ejectors may be critical. Effect of punctures or damages to ducting from the engines to the ejectors may be assessed.

5.3.7 Low vulnerability V/STOL aircraft general design techniques. The design guidelines given under Section 4. to reduce detection susceptibility are particularly applicable to V/STOL aircraft MEWS whose inherent configurations are likely to result in larger radar and IR signatures. The use of ADEN, RALS, or two-dimensional efflux nozzles and low RCS fan and propeller (or rotor) blades could possibly enhance reduction in RCS and IR signatures. To reduce the vulnerability of V/STOL aircraft, the following general techniques, together with those given under 5.1 and 5.2, should be implemented as may be applicable to a specific design concept. Some of these techniques may require further development:

a. Provide a fire detection/extinguishment system and any other techniques for fire/explosion suppression.

b. Harden the full-authority, advanced digital engine control system and FBW flight control system against EMP (see Defense Nuclear Agency (DNA) Confidential report nos. DNA 2114H-1 through DNA 2114H-6 “DNA EMP (Electromagnetic Pulse) Handbook” (U), Volumes I through VI, of 5 July 1979).

c. Provide an automatic reconfiguration of the flight control system (e.g., the use of SUDIC) in keeping with MIL-F-83300 flying qualities of piloted V/STOL aircraft.

d. Provide heat shields to reduce torching effects from a punctured hot bleed air duct surrounding combustible sources and crew.

e. Provide ballistic and, laser damage resistance to all critical components (e.g., fan, rotors, pivot systems, bleed air ducts, interconnecting shafts, RALS gimbal mechanism, etc.) associated with conversion from conventional flight to vertical flight and vice versa.

f. Isolate damaged engine automatically so that the power from the operative engine can maintain drive of the inoperative engine fan.

g. Locate clutch close to power output-to-drive shafts to eliminate unnecessary rotation during cruise flight.

h. Provide a technique to determine the extent of lift engine damage prior to initiation for vertical landing.

i. Provide ballistic and laser damage-tolerance and heat-resistant composite structures (e.g., graphite-polyimide composite materials for high temperature resistance).

j. Provide containment of high energy parts release of lift and lift/cruise engines.

k. Use a three channel per axis digital FBW flight control system and provide a mechanical, fluidic, or fly-by-light (FRL) backup of a full FBW flight control system.

1. Use an advanced seat design for pilot ejection between 0 and 600 kt (0 and 309 m/s). in all attitudes including inverted to as low as 50 ft (15 m). above ground level.

m. Use composite materials for fuel tanks to reduce hydrodynamic ram effects.

6. ANALYTICAL EVALUATION AND INTEGRATION GUIDELINES

6.1 General. Survivability evaluation provides data which permit determinations of specified levels of survivability for aircraft MEWS and effectiveness of proposed survivability enhancement techniques to a variety of expected threats and encounter conditions. The analytical survivability evaluation methodologies specified herein or alternate methodologies as approved by the procuring agency are recommended. The methodologies used must provide effective iterative survivability capabilities during each acquisition phase of the aircraft MEWS (i.e., from conceptual, preliminary, point design to operational phases). The methodology chosen must be suitable for use by the Navy during the operational life of the aircraft MEWS, so that subsequent survivability valuations necessitated by changes in mission, tactics, threat, and aircraft configuration can be readily performed. The analytical survivability evaluation should be accomplished using:

a. The results from the mission-threat evaluation discussed in 6.2 to derive encounter conditions;

b. The results from the susceptibility to detection evaluation discussed in 6.3 including detection, tracking, acquisition techniques and procedures;

c. The results from the vulnerability evaluation discussed in 6.4 including the description of enemy anti-air defense systems specified in the implementing documentation;

d. The combined results from mission-threat, susceptibility to detection and vunerability evaluations, and the derived encounter conditions of scenarios from 6.2 to evaluate the overall engagement outlined in 6.5. The engagement evaluation should at least include individual and multiple weapons of n-types;

e. Each of the above evaluation methodologies to evaluate the effectiveness of recommended survivability enhancement suites as discussed in 6.6; and

f. Survivability trade-off methodologies discussed in 6.7 to evaluate the payoff of recommended survivability enhancement suites.

6.2 Mission-threat evaluation. The missions and threats are those specified by the aircraft MEWS detail specification, operational requirement, and implementing documentation. Mission descriptions include such items as mission objectives, measures of effectiveness, sortie structure and flight profiles. Geographic, physical environment, and force structure. are defined in the scenarios. The threat identification contains a description of each threat and its non-terminal and terminal characteristics, the deployments of the threats, and the deployment doctrine of the specific threat systems. The operational modes of the subsystems cover such items as the sensors, fire control, and countermeasures employed by the aircraft MEWS. The aircraft-threat encounter conditions provide information relative to the operational conditions of the aircraft MEWS such as speed, acceleration or deceleration, altitude, evasive maneuvers, tactics, and configuration variables (fuel, stores, etc.) - see example in Table I - and information relating to the location, range, and aspect and speed of approach of the defensive weapon system projectile or missile. Each mission-threat evaluation performed during the entire life cycle of the aircraft should include:

a. Identifying and describing the mission(s);

b. Defining the scenario(s);

c. Identifying the threat(s);

d. Defining the operational modes of subsystems; and

e. Deriving the aircraft-threat encounter conditions.

6.2.1 Mission element need statement, The MENS describes a mission need and is used to justify the initiation of a major weapon systems acquisition program to meet this need. Usually developed by OPNAV and approved by the Secretary of the Navy, it is submitted to the Secretary of Defense for a decision to proceed. The MENS requires an evaluation of the threat projected through the the frame for which the capability is required. DOD Directive 5000-.2 describes the content of a MENS.

6.2.2 Mission requirements, The mission requirements and essential functions for flight and mission objectives should be determined for each mission phase. The flight and mission essential functions shall be established down to the level that individual aircraft subsystem and major components required to perform the functions can be identified.

6.2.3 Threat evaluation, An evaluation shall be conducted to determine the threats expected to be encountered by the aircraft MEWS in each operational phase (from takeoff through weapon delivery and landing) of its designated mission. The hostile threats should be categorized for each type of mission deployment, and the salient characteristics (e.g., non-terminal and terminal) associated with each threat specified by the procuring agency or as provided in accordance with OPNAVINST 3811.1. These characteristics shall be provided insufficient detail for susceptibility and vulnerability evaluations consistent with the details available for the acquisition cycle of interest. The results from this and the mission evaluations will be used to derive aircraft-threat encounter conditions for each flight profile/phase and threat combination.

6.2.4 Scenarios. The scenarios should provide a variety of conditions describing the design mission for the aircraft MEWS. It should provide information as to the type of enemy forces the aircraft weapon system is expected to encounter. This information should also include the type of climate, weather factors (conditions), and time of day for which deployment is planned.

6.3 Susceptibility to detection evaluation. Susceptibility is defined as the combined characteristics of all the factors that determine the probability of hit on an aircraft, its subsystems, or components by a given threat mechanism. The susceptibility to detection evaluation process consists of non-terminal threat characteristics, performance characteristics of the aircraft weapon system defined by the mission-threat evaluation/ scenario, and the detectable signature(s) of the aircraft to non-terminal threat units. The process of evaluation should follow the following sequence:

a. Scenario. The flight path of the aircraft, the tactics employed by the aircraft, the physical environment, and the deployment of enemy weapons to defeat the aircraft;

b. Non-terminal threat characteristics. The characteristics of enemy weapon systems contributing to overall target detection by radars, infrared sensors, optical or visual detection devices or by the enemy weapon crew, and acoustic sensors; and

c. Aircraft weapon system characteristics. The aircraft may be carrying various countermeasures and may be flying at an altitude and speed (or an evasive maneuvering course) which will degrade the capability of the enemy threat to detect the aircraft.

6.3.1 Scenario definition. Scenarios are derived from the mission-threat analysis. The information in the scenario provides input requirements for the susceptibility evaluation, and the objective of the specific data is to provide flight paths, tactics, physical environment, and threat deployment for specified encounters. The aircraft weapon system flight path shall be defined (e.g., a flight profile shall be given for each mission in accordance with standard procedures), and the tactics to be used by the aircraft should be stated, where possible. When applicable, the physical environment shall be described (e.g., the geographical location, season of the year, and any other characteristics which will provide a realistic setting for the evaluator). The deployment of the defensive threat weapons shall be given in terms of the enemy defense unit(s) which will be used in the evaluation.

6.3.2 Threat characteristics. The threat deployed in the scenario shall be given in terms of its non-terminal characteristics. These characteristics provide information about the enemy defensive weapon system to determine its capability to hit the target. Some of the typical information are type of fire control, type of radar, weapon slew rate, delay times associated with target acquisition or reacquisition, director limitations, alternative modes of operation, etc.

6.3.3 Detectable signatures. Detectable include all observable signatures which can be used by the enemy to detect and track the aircraft as a target. The requirements may specify both signature analysis and signature reduction. A signature analysis shall be conducted to evaluate the radar, infrared, visual, aural, and electromagnetic signatures against specified minimum acceptable levels. The results from this analysis will serve as guidance, as required, for minimizing the aircraft signature through the various acquisition cycles of the aircraft and for establishing a signature reduction program to meet specified levels.

6.3.3.1 Radar cross section. Radar fire control systems are employed by, or are an employment option of, most antiaircraft guns (23 mm or larger) and surface-to-air and air-to-air guided missile weapon systems. The radar cross section (RCS) requirements are mormally specified in terms of both signature analysis and signature reduction. The mission-threat evaluation shall identify the threat weapons to be considered for RCS evaluations. These evaluations shall be conducted to determine the radar reflectivity of the aircraft, to identify the primary sources of reflectivity, and to determine and reflect the further RCS reduction possible and the methods, costs, weight volume, etc., involved in achieving the specified levels of the design specification. Radar signature will be estimated for the frequency levels associated with each of the threat systems identified in the mission-threat analysis. It is desirable to identify the components/subsystems to be emphasized in the RCS analysis. Analytical models used for the determination of RCS are being investigated by JTCG/AS and under individual service programs. Although no model has been officially established for reference purposes, the Army's HELISCAT II and Doppler IT Programs (AVRADCOM Report Nos. USARTL-TR-78-8A/8B) have been used extensively for rotary wing aircraft. However, fixed wing aircraft RCS evaluations are generally performed using models for the determination of detection probability or penetration sill effectiveness (see reference provided in 4.1.1). Both rotary wing and fixed wing aircraft analytical results are validated by laboratory simulations and flight tests.

a. Typical fixed wing aircraft sources of reflectivity are:

(1) Inlet and exhaust cavities,

(2) Antennas and antenna compartments,

(3) Cockpit,

(4) External stores,

(5) Fuselage,

(6) Fuselage-wing-empennage interfaces,

(7) Vertical tail,

(8) Cavities, and

(9) Corner reflectors.

b. Typical rotary wing aircraft sources of reflectivity are:

(1) Cockpit,

(2) Intake and exhaust ducts,

(3) Main rotor hub and mast,

(4) Main rotor blades,

(5) Tail rotor hub and blades,

(6) Fuselage, and

(7) Fuselage-sponson interfaces.

6.3.3.1.1 HELISCAT II program. The HELISCAT 11 (Helicopter radar Scattering program) is used to compute the single-frequency RCS for all nonrotating structures (canopy, tail boom, stabilizers, ducts, etc.]. Each structure may be perfectly conducting or coated with multilayered RAM. If a structure (such as a canopy) is transparent, it is assumed to be metalized. HELISCAT II has the capability of computing single-frequency radar scattering for a wide range of targets, from simple shapes (flat plates, cylinders, spheres, etc.) to complex aircraft geometries. The HELISCAT II program is divided into two passes. Pass 1 is required whenever the scattering from the interior of a duct is to be calculated. It is also required on those rare occasions when Physical optics scattering is to be calculated by the rectangular element integration method, Otherwise, Pass 2 can be used alone. To be more specific, Pass 1 performs the ray trace computations that are necessary to find the field distribution over the aperture of a bare or RAM-lined duct and the surface zoning for the rectangular element integration method. Pass 2 performs the integration over the duct aperture and is used in all field computations for exterior surfaces (fuselage, canopy, tail boom, airfoils and stabilizers).. The engine duct is the only interior surface to which the present HELISCAT 11 program is applicable.

6.3.3.1.2 Doppler 11 program. The Doppler II program is used to compute the RCS (time domain) and frequency spectrum (frequency domain) of the scattered field for all rotating structures (rotor blade and associated hub assembly). The structure may be perfectly conducting or coated with multilayered RAM, and the rotor can have multiple blades. These rotor blades are airfoils of the NACA four-digit series and can be cylindrical or linearly tapered. The hub assembly, which is generally a very complex structure, is represented by the drive shaft, pitch control linkage, hub, and blade housing. Drive shafts and pitch control linkages are modeled using circular cylinders, and the hub and blade housing are modeled using truncated cones. The shadowing of the pitch control linkage onto the drive shaft (and vice versa). is included in the model.

6.3.3.2 Infrared signature. IR signatures are sources for detection and guidance by both air-to-air and surface-to-air guided missile systems. They must be considered in the development of a survivable aircraft. The aircraft weapon system specification for IR signature should state both the analysis requirements and the requirements for signature reduction. The IR analysis requirements shall be to select an engine cycle for the specified level of IR signature. An analytical evaluation of the IR radiation in the specified range(s) of bandwidths shall be performed to establish unsuppressed radiation levels in each of the specified bandwidths for each of the primary and secondary sources (i.e., primary - engine hot parts and exhaust plume; secondary - gearboxes, oil radiations, engine cowls, solar reflectors, etc.) and methods for predicting the radiation of the various sources.

a. The evaluation of the IR signature shall identify the radiation levels of:

   (1) Engine hot parts,

   (2) Tail pipe surfaces heated by exhaust gas,

   (3) Exhaust plume,

   (4) Impingement,

   (5) Gearboxes and transmission, and

   (6) Aerodynamically heated surfaces and solar reflections.

b. Based upon the evaluation of IR radiation levels of the basic aircraft, design data for IR suppression to reduce the radiation levels to those prescribed by the aircraft specification will be developed and information following provided:

   (1) A description of the complete IR suppression system and the total weight (including such components as tailpipes, fans, shields, installation brackets, and cowling) with the location of the system within the aircraft vehicle clearly identified in a phantom three-view drawing. The description shall include the main power plant installation including selected arrangements, shielding, and tailpipe configurations;

   (2) A complete tailpipe description with scale drawings showing geometry, weight, interface, cooling techniques, and materials. Heat transfer data and analysis for the selected cooling technique with a definition of cooling area;

(3) A complete description of the suppressor cooling system including type, size, lines, weight, arrangements, mass flow, pressure rise, and power required; and

(4) Suppression concepts for reduction of IR radiation from the airframe shall be defined by drawings or other techniques. An analysis or surface finishes in relation to bright sun conditions should be performed.

c. Analytical models used for IR evaluations are consistently undergoing revisions and changes. Standardization of these analyses is not firm. Several techniques used throughout the survivability community are suggested for use.

6.3.3.2.1 Little SAM model. Little SAM is a computer model developed by the Assistant Chief of Staff (ACS)/Studies and Analysis, HQ USAF for analyzing shoulder-launched infrared (TR] homing missiles It is written in the FORTRAN programming language for use on the &635 computer. This model simulates the interaction between a single target aircraft and a selected number of missiles fired from designated locations. Target aircraft inputs include:

a. A target flight path file,

b. A six-sided vulnerable area file, and

c. An IR signature and atmospheric attenuation file for two risibilities and five ranges. The missile inputs consist of the launcher location and the desired firing interval and launch restrictions by aircraft aspect angle, and the output of the model is a shot-by-shot history of each launch with a probability of kill (P_K) of each shot. P_K is computed as a function of miss distance and vulnerable area.

6.3.3.3 Optical signature, The optical signature of the aircraft is used for detection and tracking by small arms and machine gun type weapons and alternate tracking by several of the radar-directed weapons. Visual signature evaluations shall be conducted to assure:

a. Maximum use of nonreflective and camouflage paints to minimize visual detection by ground and air observers during low altitude or nap of the earth flight;

b. Engine exhaust (flame, plume, or glowing hot metal parts) is not visible to ground observers at night;

c. The use of window and windshield designs and materials to minimize the detection hazard through reflection of sun or other light sources consistent with the crew's vision in daylight and darkness and minimal use of curved, highly reflective, transparent surfaces; and

d. Minimum visual signature, at night, resulting from either internal or external aircraft lighting. An analytical model that has been used to evaluate aircraft optical signatures is described in 6.3.3.3.1.

6.3.3.3.1 OATS model. The Optical Acquisition and Tracking System (OATS) model is a digital computer code that can be used to determine the detectability of a target by visual or electro-optical, person-in-the-loop sensor systems. This model is capable of representing the dynamic engagement between target and sensor and simulates the optical environment in order to estimate the perceived target characteristics (optical (signatures) used to determine detectability. The comprehensive technical nature and modular construction of the OATS model facilitates its use. The model is based, in large part, upon field test data and widely accepted physical relationships to provide realism. The computer code is written in FORTRAN IV language.

6.3.3.4 Aural signature. The aural signature of the aircraft MEWS is a source of detection by short range, handheld, and crew-served weapons as well as by acoustic sensors (e.g., sonars). Two procedures have been employed in defining the requirements for aural signatures. The general requirement for aural signature shall be minimized to the most effective levels practical as determined by survivability evaluations. A specific requirement applies to a helicopter which operates close to the threat but would also be applicable to any other system (e.g., propeller-driven and fixed wing aircraft). The evaluation shall provide and define concepts for achieving the minimum practical noise signature. External noise shall be reduced as much as possible within the constraints of performance and transportability. The aural signature evaluations shall provide the noise frequency generated by main and tail rotors (particularly that referred to as blade slap), propellers, rotor. rotations, main rotor vortex noise, gearbox noise, turbine engine, and aerodynamic noises for various ranges and altitudes. The noise levels (far field) shall be provided for maximum distance at which the given aircraft can be heard by the unaided ear. The ambient noise level, including meteorological data at the listener location, shall also be included in the evaluation. These noise levels shall be derived from a combination of:

a. The band noise level at the threshold of audibility for maximum hearing distance and the noise level should be increased in intensity to account for the total absorption of sound between the maximum detection distance and some convenient nearby test measurement distance.

b. The allowable noise levels (near field) radiating into aircraft personnel areas as specified in MIL-A-8806A.

c. The noise level actual values should be determined through an evaluation of the mission requirements or specification for the aircraft design.

6.3.3.4.1 AUSEX encounter model. The Acoustic Undersea Sound Experiment (AUSEX) encounter model is a comprehensive, deterministic model which predicts the source level of a target operating under prescribed conditions, and its models the signal's transmission through the air and the air-water interface. It then computes various modes of propagation losses, models the beam pattern of the user specified array, and computes a probability of detection versus time and range for a particular target for the user specified scenario.

6.4 Vulnerability evaluation. Vulnerability is the characteristics of a system which causes it to suffer a finite degradation (incapability to perform the designated mission) as a result of having been subjected to a certain level of effects in an unnatural (man-made) hostile environment. The objective of the vulnerability evaluation is to quantify the air weapon system vulnerability characteristics. This evaluation is a multiparametric function relationship. There are several steps and intervals (secondary evaluations) which must be performed in order to reach a quantifiable vulnerability characteristic, and this evaluation establishes the baseline characteristics for total survivability. Usually, this evaluation will be performed at the request of the project management air (PMA) office.

a. The major elements of the vulnerability evaluation include:

   (1) Aircraft weapon system description,

   (2) FME4,

   (3) Criticality analysis,

   (4) DME4, and

   (5) Vulnerability results (various indices).

b. The vulnerability procedures are performed in a flow sequence using 6.1 as basic input, and these inputs must be carried throughout the evaluation process. The results of the mission-threat evaluation are used as input to the vulnerability evaluation. The terminal threat characteristics and the speed and altitude of the aircraft while performing its mission are used to determine its vulnerability. The critical function analysis will provide information concerning the use of each subsystem/component for each phase of the aircraft flight profile. The failure mode and effects analysis provides the evaluation with a series of paths by which the subsystem/component can or will prevent the component from operating properly. The geometric model provides a mathematical representation of the components described in both the critical and failure mode and effects evaluations. Also provided are components which will serve as shields for components and specified Protection materials. Each component described in the geometric model is evaluated for damage imposed by the threat. This is known as the damage mode and effects analysis. These evaluations provide conditional P_K and is provided for each damage mechanism of the threat being analyzed. The combined effects of this procedure provide the vulnerability indices. Some common indices are vulnerable area and blast contours.

6.4.1 Aircraft weapon system description. The aircraft is described using procedures outlined herein in order that evaluators can conduct the appropriate evaluations. The aircraft weapon system under consideration must be defined, usually by name, model and configuration, in various phases of' the developmental (acquisition) cycle by such items as detailed engineering drawings, operations manuals, maintenance manuals, illustrated parts breakdown, etc. As many of these items as are available should be used in describing the weapon system. An example aircraft weapon system geometric description information is provided as an overview of the various processes in Table II. The aircraft weapon system can be described using the methodologies in 6.4.1.1 through 6.4.1.5. In describing the aircraft weapon system, the following should be included:

a. Methodology used to describe the weapon system;

b. Materials for each system, subsystem or component; and

c. Level of detail of the description.

6.4.1.1 Graphics. The graphics (or manual) procedures are used only when data, time, and resources are limited; it includes only engineering drawings and limited information. It is to be noted that only experienced analysts should use this method. This is not a recommended evaluation process.

6.4.1.2 SHOTGEN. The Shot Generator (SHOTGEN) Computer Program (JTCG/ME Report No. JTCG/ME-71-5-1/2) accepts geometrical model data and produces a series of parallel line penetration descriptions of the target commonly called "shot line" descriptions. Each of these parallel line descriptions specifies (1) the component(s) penetrated, (2) the distance through each component, and (3) the entry points of each shot line with each component in terms of a convenient coordinate system. Entry and exit obliquities are included. The ray line target descriptions may be stored on magnetic tape in compact form for use as input to vulnerability programs. Each component data group contains all the ballistics information necessary to describe the component which is encountered along the ray.

a. The geometrical target model is based on the following considerations:

(1) A target is composed of a group of components;

(2) Each of these components is a volume of material;

(3) Each of these components has interior and exterior surfaces;

(4) Components can be geometrically described if the components' surfaces can be represented;

(5) A sequential group of triangles which completely covers the outside and inside of a component defines the suface of the component; and

(6) A triangle is composed of a group of three distinct points in terms of Cartesian coordinates which are acceptable computer inputs.

b. The program is written in FORTRAN IV language and requires a large scale digital computer, and it offers the following:

(1) The triangle approximation method involves a set of simple, quickly learned rules;

(2) The rules are universal from one target type to another without change;

(3) All degrees of approximation are available depending on the shape of the surface and the desired detail; and

(4) Simple and rapid computations yield the desired output.

6.4.1.3 FASTGEN target description computer program. The "fast" SHOTGEN (FASTGEN) program (JTCG/AS Report No. JTcG/AS-78-V-002) involves projecting a number of rays, from specified point or direction, through a geometric target model. The component encountered along each ray are described in terms of intercept coordinates, entrance and exit obliquity angles, and distance through the component. The FASTGEN computer program generates uniformly distributed shotlines from a particular direction, and computes shotline intercepts with the target model components. Program input allows a target model composed of right truncated cones, spheres, rods, and triangular approximations to describe individual components. The output of the FASTGEN computer program is typically used by other programs such as VAREA or COVART to compute target vulnerable areas for impacting fragments or projectiles.

6.4.1.4 MAGIC. The Mathematical Applications Group, Inc. (MAGIC) computer simulation (JTCG/ME Report Nos. JTCG/ME-71-7-1 and JTCG/ME-71-2-1/2) generates target description data with the detail and completeness required for vulnerability studies. A combinatorial geometry technique is used in the simulation to represent a complex target structure. A large number of parallel rays, randomly located in grid cells, are traced through the target structure to produce item-by-item listings of the components and air spaces. The basic technique for a geometric description consists of defining the locations and shapes of the target physical regions (wall, equipment, etc.) utilizing the intersections and unions of the volumes of 12 simple body shapes. A special operator notation uses the symbols (+), (-), and (OR) to describe the intersections and unions. These symbols are used by the program to construct tables used in the ray tracing portion of the program. The user specifies the type and location of each body used to describe the target, and identifies physical regions in terms of these bodies. Each region is assigned an identification code for use with vulnerability evaluations. A three-dimensional coordinate system is established in relation to the target, which is enclosed by a rectangular parallelepipeds. A grid plane is established according to the angle desired, and parallel rays, starting randomly from each grid cell, are traced through the target. In the normal operating mode, target description data is input by cards. A portion of the routine converts the data to the form required for ray tracing. The input data is checked and, if errors are detected, messages are printed out. Error-free target description data may then be stored on magnetic tape and input in this form on subsequent production mode operations. The basic output is the result of the ray tracing computations. A listing is obtained, for each grid cell, of the line of sight thickness for each geometrical region traversed, the obliquity of the ray with respect to the normal of the first surface of each region encountered, and the normal distance through each region. Three optical routines are available to the user:

a. Special ray tracing used for target data checking.

b. Region volume calculations.

c. Computing target presented area. The simulation, which is programmed in FORTRAN language, requires a large scale digital computer.

6.4.1.5 GIFT. The Geometric Information for Targets (GIFT) code (BRL Report Nos. BRL R 1802 and ARBRL-TR-02189) is a FORTRAN computer program. The basic input to the GIFT code is data called “target description data” which defines to any degree of accuracy the three-dimensional shape and space of the components of a tank, a building or any physical structure. Some of the GIFT code output options simulate engineering drawings and other graphic illustrations of the components of the physical structure or target as described in the input target description data. These output options document the target description data and are used to validate the accuracy of the input target description data. output options of the GIFT code compute, via analytical techniques, the intrinsic characteristics of the modeled target such as the presented area, the centroids of area and perimeter, the moments of inertia, the center of gravity, the weight and the volume. The GIFT code also computes and outputs the angular and spatial relationships between the modeled components and defined rays. The rays are defined so that they simulate the behavior of projectiles, fragments, or any other physical particle paths. For example, for projectile and fragment target vulnerability analysis, rays are defined which simulate the paths of projectiles and fragments to and through the components of the modeled target. For every projectile or fragment ray, the GIFT code identifies and outputs the following:

a. The components of the target and the order that they are encountered along the ray,

b. The normal and incidence angles between the components encountered by the rays;

c. The distance through and between the encountered components that the projectile or fragment must penetrate.

d. For different analyses, the GIFT code outputs different angular and spatial relationships; the output required for target signature is different from the output for target vulnerability analysis.

6.4.2 Failure mode and effects analysis. The failure mode and effects analysis (FMEA) is a study of the results or effects of single independent component failure in a system. The FMEA is a single failure analysis. Each component, as its effects are studied, is considered to be the only failure in the system. The procedures for conducting the FMEA are provided in MIL-STD-1629. The FMEA provides the framework for the vulnerability evaluation and must be well-defined. An example FMEA matrix is provided in Table III. The extent of the FMEA is dependent upon the stage of the acquisition cycle of the aircraft MEWS. If the aircraft undergoing evaluation is in the point design phase, then as full a treatment as time and resources permit should be provided. On the other hand, if the design is in the conceptual design phase, one can only utilize those elements which are available for the evaluation. In all cases, the following general steps are used in accomplishing the FMEA:

a. Define the system to be analyzed and include all alternative configurations and descriptive information available;

b. Provide block diagrams of the system to be analyzed;

c. Identify all potential failures; and

d. Determine effect of each failure on aircraft, subsystem, and component operations.

6.4.3 Criticality evaluation. This evaluation should determine the flight essential and mission essential functions for each mission and mission phase established in the mission-threat analysis. The subsystems and components required to perform these functions must be identified. The essential functional requirements for aircraft during given stages of the survivability life cycle will require constant evaluation. A list of suggested areas to be investigated is shown in Table IV. The procedures for criticality evaluations shall assign for each component a critical classification as it affects the operation of the subsystem and system. The functional effects of loss or degradation shall be defined so that evaluation can be made. In determining these requirements, the following items should be included:

a. Requirement for continuous flight
   Selected time durations
   Return to base, etc.;

b. Requirement for mission completion
   Delivery of weapons
   Escort other aircraft, etc.; and

c. Special requirements
   Vertical takeoff and landing
   Arrested landing, etc.

6.4.4 Damage mode and effects analysis. The damage mode and effects analysis (DMEA) shall be performed for each specific threat derived in 6.2.3. The FMEA for both flight and mission essential components shall be identified. The effect of each failure mode upon the aircraft weapon system established in 6.4.2, along with the effects upon the aircraft flight and mission completion capabilities, shall be provided. The DMEA shall identify the primary and secondary weapon damage mechanisms to which each component can be exposed. The type of damage mode that each component can experience (i.e. , shatter, jamming, loss of fluid, etc.) shall be identified. The possibility of secondary hazards that may be created by the primary weapon damage modes such as fire, explosions and engine fuel ingestion shall also be identified. Each nonessential component shall be examined to determine if a hazardous environment may be created by its suffering the type/level of damage identified. They shall also include any cascading effects on other subsystems/components from an initial subsystem/component response. The essential components that might be exposed to the hazardous environment shall be identified. The results of the DMEA shall include probability of kill given a hit ($P_{K/H}$) functions for each threat/damage component mechanism combination. These $P_{K/H}$ functions shall be provided for the specified (or expected! spectrum of threat energy levels.

6.4.5 Vulnerability indices. Various indices are used to measure the levels of the aircraft's ability to withstand the threat. These indices are functions of the type of threat damage mechanism. Vulnerable area (A_V) is most commonly used when a projectile or fragment impact is encountered. The level (degree) of degradation may change with type of mission or with phase of a given mission; however, the definitions for "KK,~"K," "A," etc., kill levels remain the same (see 3.2). Aircraft vulnerability evaluations shall be performed using the evaluation procedures in 6.4. It shall be a continuous or iterative process during the total acquisition cycle of the aircraft MEWS. The objectives of this evaluation are:

a. To provide vulnerability data (A_v, $P_{K/H}$, etc.) for specific threats and kill levels;

b. To provide means for identifying soft subsystems and components to which feasible design changes can be made to reduce vulnerability;

c. To provide inputs for survivability evaluations; and

d. To provide inputs for trade-off and cost-effectiveness evaluations.

6.4.6 Vulnerability evaluation methodologies. The indices for vulnerability data and evaluation procedure models shall be provided for various phases of the acquisition cycle of the aircraft weapon system. During the conceptual phase, the evaluation shall use a procedure that is compatible with the available aircraft design data and program resources and shall be responsive to the needs with respect to applicability, validity, and timeliness. The vulnerability evaluation shall be performed using the methodologies in JTCG/AS Report No. JTCG/AS-76-V-004 and those listed in Table V. A brief description of the methodologies used for vulnerability evaluations to the ballistic threat damage mechanism is provided in 6.4.6,1 through 6.4.6.4.

6.4.6.1 COVART. The Computation of Vulnerable Area and Repair Time (COVART) computer program (two JTCG/ME reports on COVART - no report nos. assigned), developed by the Aerial Target Vulnerability Subgroup, Computer Programs Modification and Standardization Panel of the Joint Technical Group for Munitions Effectiveness (JTCG/ME), is used to determine the vulnerable areas and estimate repair times for specific levels of damage caused by single penetrators (fragments or projectiles) against various target types. COVART has been written to accept information generated by tracing parallel shot lines through a geometric description of the target. Therefore, it accepts shot line information which has been generated by SHOTGEN, MAGIC, or the equivalent. This program was designed primarily for aerial targets, including helicopters; however, it also can be applied to ground targets as long as the damage definitions are consistent. Vulnerable area and repair effort are determined for penetrators impacting the target within a preselected weight and speed matrix. Each penetrator is evaluated along each shot line, and the contributions made along that trajectory to the target vulnerable area and repair effort are determined. Target vulnerable area is a function of its presented area, the weight and speed of the impacting penetrator, the target components encountered by the penetrator, and the resistance to penetration encountered by the penetrator. Target repair effort is a function of the target presented area, the probability that the target survives the damage sufficiently to return to a repair area, and the accessibility of a specific component for replacement or repair. The COVART program allows a number of options which, when exercised properly, will allow most targets to be evaluated. The major options available are defeat definition, type of component vulnerable area, repair time selection, and type of line-of-sight data input. Other options available include type of output units, type of weapons, type of slowdown equations, and line-of-sight data trace. The majority of the program data is entered by card input. The shot line description data are entered by card input or tape; however, when a target description is entered via card input, a tape is produced in COVART program format which thereafter may be used for the target description input. Program output can be divided into four types: a record of major input items, input diagnostics, run/error diagnostics, and results. The output is dependent upon the options specified within the input.

6.4.6.2 Point burst. The objective of this computer program is to assimilate the parallel ray line of sight data and the basic target description data in the form of triangle coordinates along with appropriate component identification codes from SHOTGEN. These data are rearranged and sorted to determine which of the rays intersect vulnerable target component centroids and/or surfaces. All duplicate rays are eliminated and those rays whose configurations are such that they may be replaced by other rays are dropped. The final result of this editing process consists of a tape which will become input data for the "Vulnerability" program. This tape contains only data pertinent to those rays which strike either centroids or vulnerable surfaces and which will make meaningful contributions to the vulnerability and kill probability calculations to follow.

6.4.6.3 External blast. The external blast vulnerability assessment program (ASD Report Nos. ASD/XR 72-8 and ASD-TR-77-23) provides traceable and repeatable methodology for prediction of aircraft damage to the entire aircraft due to external blast effects from conventional weapons whose weight of high explosives is greater than 5 pounds. Arrays of reference and surface points reflect size, shape, and position of fuselage sections, wings, stabilizers, engines, etc. Structural properties of the design are automatically selected from pre-coded data for existing example aircraft of similar construction, or are computed from user specified information. Specific damage requirements to achieve the K, A, and Mission Abort levels of flying aircraft defeat are used to designate failure criteria for individual panel sections, cantilever points, and external/internal components evaluated for blast response. The threat warhead is selected from pre-coded descriptions of existing air-to-air and surface-to-air projectile and missile weapon systems, or is specified by the user. Conventional relationships for blast phenomenology are used to establish blast wave properties that interact with the aircraft structure, Dynamic or static intercepts for any combination of weapon orientation and blast wave aimpoint are evaluated at incremental standoffs from the aircraft target. Damage occurrence is predicted for each specified damage criterion, and the results are tabulated for each incremental range. The program is formulated to assess blast damage using limited structural information typically available during preliminary aircraft vulnerability evaluations, as functions of major design and structural properties. Capabilities of the external blast vulnerability assessment program have been validated by comparing computed damage with actual results observed in aircraft tests of the entire aircraft.

6.4.6.4 Internal blast. A computer program has been developed that describes the shock and blast loading characteristics of the detonation of a high-explosive projectile internal to an aircraft structure (JTCG/ME Report No. JTCG/ME-73-3). Both shock wave and confined explosion gas pressure loads are considered. With certain modifications, the program can be made applicable to any internal explosion regardless of the type of confining configuration (e.g. , a naval ship compartment, land vehicle, or building structure). The input options available in the code and the technical aspects of the calculation methods used to determine shock loading functions, confined explosion gas pressure, venting of confined gases, and damage propagation to other areas of the aircraft are included in the program. Comparisons of code results with available experimental data are presented to demonstrate the justifiable confidence in the use of the code on aircraft problems. Complete documentation of the code is given together with the results of sample problems that show the various features of the code and the readily usable form of the resultant loading information..

6.5 End-game evaluation. Several methodologies are available to the analyst to evaluate the threat-aircraft encounter. The threat trajectory and aircraft flight path’s point of closest approach is the point at which this evaluation begins. Two approaches are used depending upon threat type; that is, AA guns or missiles.

6.5.1 Antiaircraft guns and artillery. A number of AA guns and AAA simulation models have been used in the end-game evaluation. The procuring agency should specify the most current methodology to be used. P001 is the most commonly used methodology. This model was developed by Air Force Armament Test Laboratory (AFATL) as program POO1, “Antiaircraft Artillery Simulation Computer Program.” Several updates have been provided to add realism into the simulation by addressing such items as terrain effects and man-in-the-loop. Each shot is accounted for in this simulation. This model will accept all small arms and AA guns through large caliber AAA weapons; that is, 7.62 mm - 23 mm guns through 37 mm - 130 mm AAA. It also accepts both rotary wing and fixed wing aircraft flight information. The model uses vulnerable area as input data and these data may apply in all phases of development; that is, conceptual, preliminary or point designs. Additional information on the P001 model is provided in 6.5.1.1.

6.5.1.1 P001. This program (three JTCG/ME reports on P001 - no report nos. assigned) computes the single shot probability of kill on a target aircraft after consideration is given to various intrinsic errors in predicting the aircraft/projectile intercept point. Computation of target aircraft attrition is performed over an entire flight path, and the probability of kill results for each shot are accumulated and can be presented as a function of various parameters at the option of the user.

6.5.1.1.1 Analysis of errors. The major portion of the program is concerned with the analysis of all sources of random error which influence the effectiveness of the antiaircraft artillery. These errors include prediction of an aim point based on the present behavior of the aircraft, firing process errors, and uncertainties and perturbations which arise externally to the weapon system. All of these sources of random error, uncertainty, or perturbation, which in some way contribute to enlarging the final distribution of projectile trajectories, are assessed by the program to locate the vulnerable area of the aircraft within this total distribution of trajectories and to compute a probability of kill, P_K.

6.5.1.1.2 Aircraft vulnerable area and kill probability. The aircraft vulnerable area data are given in terms of the projectile impact aspect (latitude and longitude) and striking velocity. The actual aircraft attitude with respect to the projectile at the time of intercept determines the latitude and longitude of the impact which with the closing velocity are used to interpolate the aircraft vulnerable area table. Knowing the location of the aircraft on the mean intercept plane with respect to the center of the distribution of projectile trajectories and time of intercept, the probability that the projectile kills the aircraft is then the summation of the probabilities of the projectile being located anywhere within the exposed vulnerable area of the aircraft at the time of mean intercept.

6.5.1.1.3 Input/output, Program data can be entered by card input, tape input, or a combination of both; or, for some parameters, by utilizing the values already given in the block data section of the program. For normal production runs, the majority of the data would be entered from tape. There are seven print control flags that are set during input for the purpose of controlling the type of output desired. Therefore, the user can select the printed output that will best satisfy the particular needs. In addition to the printed output options, the printed output will always contain the ground weapon complex firing data and its P_K against the total flight path, the flight path attrition accrued as a function of time of fire and time of intercept for each ground weapon density factor, total flight path P_K of of the aircraft for all ground weapons as a function of the ground weapon density factors, and the total flight path P_K of the aircraft for unity ground weapon density factor as a function of impact aspect and velocity.

6.5.1.1.4 User options. Since there are nine classes of input data, there exists a large number of possible program uses available to the user. Parameters within these data classes can be varied, such as the flight path, ground weapon location, ground weapon parameters, ground weapon projectile parameters, etc., which results in a very flexible program.

6.5.2 Antiaircraft missiles. An aircraft and missile encounter is referred to as the missile end-game evaluation. This type of simulation is much more complex than AA guns and AAA simulations In that missile fuzing parameters and many other aspects of the simulation, such as guidance and range limitations, are included. The JTCG/AS has been actively involved in seeking out all possible model and methodologies for missile end-game evaluations. A special task was established to develop surface-to-air missile models. Many of these methodologies are currently in the developmental stage and the procedures will, therefore, be in constant update status. The evaluator should rely on the procuring agency to provide the latest procedures to be used. However, the latest methodology approved by JTCG/AS is the Reference Model (REFMOD) digital computer program.

6.5.2.1 REFMOD program.

a. The REFMOD program (JTCG/ME Report Nos. JTCG/ME-79-8 and JTCG/ME-79-8-2) can be used in three types of applications:

   (1) Single encounters and to simulate accurately all physical events which occur when specific missile, fuze, and warhead approach a target aircraft;

   (2) ‘Napped” kill probabilities which result from warhead bursts occurring at specified points around the target along desired trajectories; and

   (3) Statistical sampling model to create means and deviations from probabilistic events which may be specified during the problem encounter.

b. The REFMOD program mechanizes the computer-aided analysis of an encounter between a missile and its target. A substantial number of variables which influence the outcome (probability of target kill, P_K), and which are specified by the user, offer to the analyst great investigative power for evaluating known systems and for providing rational data in support of advanced concepts undergoing formulation and refinement. The REFMOD target P_K results from applying one or more of the following damage mechanisms:

   (1) Direct hit, regardless of warhead detonation against:

      (a) Target composed of truncated elliptical cones;

      (b) Target composed of ellipsoids; and

      (c) Target composed of polygonal surfaces.

(2) Blast, propagating through the air as a pressure wave.

(3) Warhead fragments, striking components which are:

(a) Structural

1. Damaged by area removal; and

2. Cylindrical, damaged by energy density.

(b) Systems' components

1. Cylindrical, cut/sprayed by particles;

2. Critical spherical, sprayed by particles;

3. Critical linear, cut by particles; and

4. Planar, cut/sprayed by particles.

c. A combinatorial description of the target is available to compute the resulting P_K sustained by the target because of damage to its interrelated components and systems. By operating REFMOD using only damage types b.(3)(b)1 and b.(3)(b)4 and specifying only one fragment required to "kill," the probability that the aircraft sustains a detectable hit is yielded. The missile involves descriptions of three systems which define its functional characteristics:

(1) Physical shape, for direct hits;

(2) The fuze, for determining detomation point; and

(3) The warhead, for blast and fragment damage.

6.5.2.1.1 Coordinate systems. The user of REFMOD has available two optional ways of describing the orientation angles of the approaching missile with respect to the target. Although the missile is moving through inertial space, the main concern of the end-game problem is the relative velocity vector of the missile towards the aircraft. For descriptive and computational purposes, seven right rectangular coordinate systems exist within REFMOD.

6.5.2.2 ATTACK program. The ATTACK computer simulation methodology (two JTCG/ME Reports on ATTACK- no report nos. assigned) is used to predict the terminal effectiveness of a missile against an air target. This simulation is capable of treating any warhead/fuze combination for which a terminal encounter can be defined whether it is an air-to-air or a surface-to-air missile. ATTACK is used to determine effectiveness in terms of the missile's lethality which is defined as the probability that a properly deployed and reliable missile will inflict a specific degree of damage on the target (aircraft).

a. Because of the program's flexibility and useful output, the results may be used for a variety of engineering and analysis purposes:

   (1) Weapon system evaluation;

   (2) Warhead design;

   (3) Fuze optimization;

   (4) Aircraft survivability/attrition studies; and

   (5) Trade-off studies.

b. The program's flexibility is derived from its capability to simulate families of trajectories about the target to provide individual lethality, weighted lethality, and lethality fields about the target for a given warhead/fuze type. Moreover, the program will treat a large number of warhead/fuzing combinations. The simulation is structured to provide a logical sequence of computational steps which:

   (1) Establish the encounter situation (velocities, aspect, etc.);

   (2) Establish the family of trajectories;

   (3) Establish influence fuzing burst points;

   (4) Establish warhead/target interaction;

   (5) Evaluate kill type (i.e., direct hit, blast, structural, vital component) and lethality; and

   (6) Summarize results and print output.

c. The output of the ATTACK program is a printed summary of the number of kills as a function of each category of damage interaction, together with a listing of the intercept conditions which prevailed during the missile and target encounter.

6.5.2.2.1 Encounter geometry. Two methods of describing the terminal encounter are provided by the simulation program:

a. The relation of the missile velocity vector to the target.

b. The relation of the missile/target relative velocity vector to the target. The simulation also provides for selection of missile angle of attack.

6.5.2.2.2 Warhead model. The warhead model provides for a variety of kill mechanisms which may be reduced to two general categories of kill mechanisms:

a. Mechanisms which cause structural damage to critical target components.

b. Mechanisms which cause damage to nonstructural components such as the pilot, ordnance, fuel tanks, etc. The structural damage mechanisms include expanding rod, focused gas, linear shaped charge, and annular blast/fragmentation.

6.5.2.2.3 Target vulnerability models. Four target models are used to simulate aircraft vulnerability to the kill mechanisms: direct hit, blast, multiple fragment, and component. The direct hit model uses triangular shaped plates to represent the target. If the missile trajectory intersects one of these plates prior to influence fuzing, a direct hit is assumed to have occurred. The blast model uses cylinders with hemispherical end caps to depict the target relative to blast kills. The multiple fragment model uses cylinders representing major structural components that are vulnerable to fragment structural kills. The component model locates nonstructural components which can be damaged if struck by individual, high energy fragments.

6.5.2.2.4 Fuze models. Optional influence fuzing models are available in the simulation program. Fuze types which may be selected by the user include single and dual fuze cones and fixed angle and doppler designs with a variety of arming devices.

6.5.2.2.5 Computer requirements. The ATTACK program is written in FORTRAN IV language and requires a computer with approximately 54,000 words (152,000 octal) of core storage. Computer time required to obtain results is dependent upon the warhead type, target complexity, and number of trial trajectories.

6.5.2.3 Other end-game methodologies. Other methodologies applicable to missile end-game are Survivability by Computer Analysis (SCAN) and Conceptual Vulnerability Assessment (CVA] models. These methodologies are used in a less detailed evaluation than more detailed evaluations requiring the use of REFMOD and ATTACK simulations. SCANTS output is probability of survival from the effects of missile impact, blast loads, and warhead fragmentation. CVA is an analytical vulnerability assessment of conceptual and preliminary design aircraft to nonnuclear proximity-fuzed guided missile warheads.

6.5.2.3.1 SCAN. An effective program for improving the combat survivability of aircraft MEWS will require that analytical techniques be developed to evaluate survival capabilities from conceptual design to service life termination. Such techniques can additionally be used to provide supporting data for implementation of a particular survivability enhancement feature or to indicate the direction of future research and test programs. The SCAN computer program provides a unique method of analyzing aircraft survivability to missile threats during conceptual design which can provide detailed damage estimates at the component and subsystem levels. It provides the user with multiple options for defining the aircraft geometrical configuration and for specifying the the type of damage criterion to be used. Probabilities of survival from the effects of missile impact or detonation, blast loads, and warhead fragmentation can be computed. Results can be obtained for a single trajectory or for a number of random encounters where the statistical distribution of engagement parameters is specified.

().5.2.3.2 CVA. The Conceptual Vulnerability Assessment (CVA) model is an approach for analytical vulnerability evaluation of conceptual and preliminary design aircraft to proximity-fuzed guided missile warhead detonations. Missile trajectories are considered parallel to an axis of a Cartesian coordinate system or to as many as six distinct axes of approach. The ideal missile trajectory for a given approach aspect of the guided missile is that trajectory which passes through the center of gravity of the aircraft, the location of the origin of the coordinate system. For each approach aspect, missile trajectories are distributed radially and angularly about the aircraft. Their intersections on discrete planes, planes perpendicular to a missile approach aspect, define the location of bursts at which kill probabilities on the aircraft are to be determined. The estimation of the blast envelope about an aircraft target is based on existing blast data and dimensional data of the aircraft with appropriate scaling for altitude, explosive weight, and chemical composition. Its hypothetical shape is spherical, and its volume is equivalent to the volume of the actual blast locus. For all bursts occurring on or within this sphere, a kill probability of unity on the aircraft is assigned. For detonations occurring without the blast envelope, the concept of expected lethal hits is used to determine the probability of kill on the aircraft due to fragments. The basic output of this approach is a conditional kill probability on the aircraft, conditional upon a detonation of the guided missile warhead, at a discrete point in space. This basic output can be extended to encompass a number of parameters and, by employing an appropriate averaging process, a number of singular kill probabilities on the aircraft can thus be obtained. From these discrete kill probabilities on the aircraft, a single measure of vulnerability can be determined which accounts for both blast and fragmentation threat mechanisms of damage for a specific set of engagement conditions. This single measure of vulnerability is in terms of an aircraft kill probability conditional upon a random detonation within its total lethal volume, the limits of this volume set by the location of detonations where the kill probability on the aircraft has just become null. The comparison of respective kill probabilities on candidate aircraft weapons systems provides a measure of the relative vulnerability of each candidate system.

6.6 Survivability/enhancement evaluations, The surviability/enhancement evaluations are processed by the same methodologies as for the basic aircraft. The design guidelines in Section 4 for reducing susceptibility are followed and the appropriate model(s) specified in 6.3 are used to reevaluate the susceptibility of the aircraft to detection. This process may be repeated as many times as is required to reduce specific signatures to specified levels. Likewise, the techniques for vulnerability reduction are handled in the same manner as for reductions in susceptibility to detection. The internal process allows the evaluator to apply any number of reduction techniques (“susceptibility and vulnerability) by repeating the evaluation methodology used during the basic evaluation and define a new susceptibility and vulnerability result. These new inputs are then used in the end-game evaluations.

6.7 Survivability trade-off evaluations. The results of the susceptibility and vulnerability evaluation process can be used to determine the effectiveness of the aircraft MEWS in performing its mission. Two major elements in design for enhanced combat survivability are: (1) the evaluation of the effectiveness of the proposed survivability enhancement measure (e.g., reductions in susceptibility and vulnerability) and (2) the decision as to whether the candidate design measure warrants implementation in view of associated penalties in cost, weight, performance, and feasibility. Although simplified techniques for vulnerability trade-offs per se exist (JTCG/AS Report No. JTCG/AS-78-V-007), the cost effectiveness of survivability enhancement measures directed towards mission accomplishment is most meaningful.. Trade-off decisions are based on the scenario engagement evaluation with their attendant limitations.

6.7.1 MTOM. The mission trade-off model (MTOM), (JTCG/AS Report No. JTCG/AS-76-S-001) is a campaign size model which provides a means for evaluating the relative cost-effectiveness of survivability enhancement features of proposed aircraft designs or modifications of existing designs. MTOM uses detailed cost and survivability inputs that have been determined from associated models, studies, and combat data and integrates them into a broad scope cost-effectiveness analysis. The evaluation of susceptibility/vulnerability improvements is made by using MTOM to compute the total missile cost of aircraft NEWS to accomplish the prescribed mission. The model can also be used without considering costs to calculate the effectiveness of an aircraft, or its modification, to a given scenario. Parameters can easily be varied so that sensitivity and investigation of the effects of uncertainties can readily be conducted. The model is modular, and it can be extended or modified by the addition of or the replacement of submodels.

6.7.1.1 Evaluation procedures of MTOM. MTOM is composed of an effectiveness model and a cost model. Calculations are maae for the baseline aircraft and for all aircraft modifications. The two modules are:

a. MTO/E. The mission trade-off/effectiveness (MTO/E) module determines the impact of susceptibility and vulnerability reduction on mission effectiveness. It is used to compute the impact on sortie effectiveness, maintenance and combines these to determine the overall mission effectiveness. These calculations are made for the baseline aircraft and for all aircraft modifications. Its submodels calculate:

   (1) Sortie effectiveness measures such as survival probabilities, passes delivered to the target, and number of aircraft killed;

   (2) The times required for various types of maintenance, aircraft turnaround time, and sortie rate;

   (3) The number of targets attacked per aircraft during the time of the event, and the general measure of effectiveness, the number (force) of aircraft required to perform the stipulated job during the event; and

   (4) Other submodels act as processors by performing certain calculations for the baseline aircraft and modifications.

b. MTO/C. The mission trade-off/cost (MTO/C) model treats RDT&E, aircraft modifications or acquisition, and peacetime and wartime operating costs. This model is used to calculate absolute dollars. Incremental dollars associated with survivability improvements can be found by taking the difference between the costs for the basic aircraft and those for the modified aircraft. The model calculates the life cycle cost associated with a group of aircraft necessary to accomplish a prescribed mission. The costs include all aircraft losses and damage repairs, as well as life cycle cost expenditures (i.e., RDT&E, procurement, training, operations, and maintenance). Evaluations to survivability improvements are made by using the model to compute the total mission costs to accomplish the prescribed event.

Preparing Activity:
Navy - AS
(Project Number 15GP-N040)

TABLE I. Example: Mission-threat analysis parameters matrix.

Mission-Threat Element	Conceptual Design	Acquisition Phase		Operational
		Preliminary Design	Point Design	
Mission Type Amphibious assault Close air support Interdiction Combat air patrol				
Flight Profile Altitude Speed Acceleration or deceleration Weapon load Radius Dash speed Wpn del speed				
Performance Maneuver Combat fuel load Time on station Climb Dive Weather Geo location				
Threat Air-to-air Missiles Rockets Guns				
Ground-to-air Missiles Rockets Guns				
Ship-to-air Missiles Rockets Guns				

TABLE II. Example: Aircraft weapon system geometric description matrix.

Aircraft Geometric Description	Conceptual Design	Acquisition Phase		Operational
		Preliminary Design	Point Design	
Methodology				
Graphic (manual)	X	X		
SHOTGEN/FASTGEN		X	X	X
MAGIC/GIFT		X	X	X
System Evaluated				
Structure	X			
Crew, etc.	X			
Component Material				
Type		X	X	X
Thickness		X	X	X
Hardness		X	X	X
Detail Level				
Subsystem	X	X		
Component		X	X	X

TABLE III. Example: Failure mode and effects analysis matrix.

Failure Mode and Effects	Conceptual Design	Acquisition Phase		Operational
		Preliminary Design	Point Design	
Definition Number System Subsystem Component				
Function System Subsystem Component				
Redundancy Level Subsystem Component				
Failure Mode Premature OPN Failure to operate Failure to cease operation Failure during OPN Operate below required level				

TABLE IV. Example: Critical functions evaluation matrix.

Critical Functions	Conceptual Design	Acquisition Phase		Operational
		Preliminary Design	Point Design	
Mission Segment Takeoff Climb Cruise Dive Combat Land Vertical Conventional				
Subsystem Crew Pilot/Copilot Flight controls Longitudinal Lateral Directional Propulsion Conventional No. engine operational Vertical No. engines No. fans etc.				

TABLE V. Vulnerability evaluation methodologies.

Phase of Design	Evaluation Methodology	Target Description	Threat Damage Mechanism	Output
Conceptual	Manual	Engineering drawings	Penetrator/blast	Av Blast contours
Conceptual	VAREA[a]	SHOTGEN	Penetrators	Av
all others	COVART	SHOTGEN	Penetrators	Av
		MAGIC	Penetrators	Av
		FASTGEN	Penetrators	Av
		GIFT	Penetrators	Av
All (less conceptual)	Laser vulnerable area code	SHOTGEN MAGIC	Flux	Av
All (less conceptual)	Point burst	SHOTGEN MAGIC	Penetrator/blast Penetrator/blast	Av Av
All	Internal blast	Manual	Blast	$P_{K/H}$
All	External blast	Manual	Blast	Blast contours

[a] JTCG/ME Report Nos. JTCG/ME-71-6-1/2

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MIL-HDBK-268(AS)

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NOTICE 1
1 December 1995

MILITARY HANDBOOK

SURVIVABILITY ENHANCEMENT, AIRCRAFT CONVENTIONAL WEAPON THREATS, DESIGN AND EVALUATION GUIDELINES

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34	1 December 1995	34	5 August 1982

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Of the two nitrogen storage and supply systems, cryogenic liquid is preferred over high pressure - a low temperature liquefied nitrogen system is considerably lighter in weight. To overcome the logistic requirements (one of a number of disadvantages of a remotely supplied liquid nitrogen system), two candidate onboard nitrogen generating systems have emerged - absorption (oxygen absorption by a molecular-sieve); diffusion (oxygen preferentially removed from the primary gas stream by a polymeric permeable membrane).

b. Suppression techniques

(1) Metal arrester (Explosafe). An explosion suppression technique consisting of multisheet bundles of 0.003 in. (0.076 mm) thickness aluminum sheets. Each sheet having several short cuts at regular intervals forms an expanded metal mesh. Limited test data indicate that the metal arrester can suppress explosion.

(2) Intumescent coatings/ablator materials. When exposed to heat, the intumescent coating expands to many times its original thickness and forms a carbonaceous porous matrix char which functions as a thermal barrier for the surface underneath. At the surface of this char, flame-quenching gaseous products are generated at block convective heating by forming an outflowing front of gas which chemically interferes with the flame. Although the ablator barrier (insulation) principle of intumescent coatings provides the greatest amount of protection for a given weight penalty against HEL radiation, toxicity of gases formed should be an important consideration when ablative materials are contemplated as a countermeasure. Consideration should also be given to integrate HEL protection with ballistic protection schemes to achieve the most effective combined protective system. Less effective protective techniques against HEL include reflection or mass ingestion. However, some combination of these techniques might be best for HEL radiation protection.

(3) Extinguishment systems. Fire or explosion extinguishment systems (MIL-E-22285) operate on the principle of detecting the initiation of a flame front (MIL-D-27729) or warning of fire (MIL-F-7872 and MIL-F-23447) by means of an IR-sensitive lead sulphide photoelectric cell, an ultraviolet (UV)-sensitive tube, or by means of a piezoelectric sensor, and using this detection to trigger the explosive or nonpressurized release of an appropriate extinguishing agent. However, in "dry bay" compartments

Supersedes page 34 of 5 August 1982.

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