



AEROSPACE STANDARD

AS94900™**REV. A**Issued 2007-07
Revised 2018-08

Superseding AS94900

(R) Vehicle Management Systems - Flight Control Function, Design, Installation
and Test of Piloted Military Aircraft, General Specification For

RATIONALE

This document is revised following five years in the field, to reflect the user experience gained and to correct errors of format and content.

FOREWORD

Most of the technical concepts and approaches covered by this document represent industry "best practice." They are based on sound and proven engineering practices and have demonstrated successful production experience.

Other technical concepts and approaches require specific approval from the procuring activity before use. This requirement for approval is not intended to prohibit their use, but rather to ensure that the prime contractor has fully investigated their capability to perform reliably and to be sufficiently durable under the required conditions and that the prime contractor can present substantiating evidence for approval before the design is committed to.

The document excludes the hardware and functionality not typically considered core flight control elements in a manned aircraft, such as radio-based navigation sensors and data links. Also excluded are:

- Aerodynamic surfaces
- Engines and engine core control systems
- Rotorcraft rotors
- Fire control devices
- Crew displays
- Electronics not dedicated to flight control

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1. SCOPE

This SAE Aerospace Standard (AS) provides the general performance, design, installation, test, development, and quality assurance requirements for the flight control related functions of the Vehicle Management Systems (VMS) of military piloted aircraft. It also provides specification guidance for the flight control interfaces with other systems and subsystems of the aircraft.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS4965	Titanium Alloy, Bars, Wire, Forgings, and Rings, 6.0Al-4.0V Solution Heat Treated and Aged
AMS-A-22771	Aluminum Alloy Forgings, Heat Treated
AMS-F-7190	Forging, Steel, For Aircraft/Aerospace Equipment and Special Ordnance Applications
AIR1083	Airborne Hydraulic and Control System Survivability for Military Aircraft
ARP490	Electrohydraulic Servovalves
ARP988	Electrohydraulic Mechanical Feedback Servoactuators
ARP1281	Actuators: Aircraft Flight Controls, Power Operated, Hydraulic, General Specification For
ARP4058	Actuators: Mechanical, Geared Rotary, General Specification For
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
ARP4493	Aerospace - Direct Drive Servovalves
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP5764	Aerospace Active Inceptor Systems for Aircraft Flight and Engine Controls
ARP6001	Aerospace - Passive Side Stick Unit General Requirements for Fly by Wire Transport and Business Aircraft
AS5440	Hydraulic Systems, Military Aircraft, Design and Installation Requirements For
AS5643	IEEE-1394b: Interface Requirements for Military and Aerospace Vehicle Applications
AS6003	Time-Triggered Protocol (TTP) Communication Protocol
AS6038	Bearing, Ball, Bellcrank, Antifriction, Airframe
AS6039	Bearings, Ball, Rod End, Double Row, Self-Aligning

AS6802	Time-Triggered Ethernet
AS7949	Bearings, Ball, Airframe, Antifriction, General Standard For
AS7997	Motors, Aircraft Hydraulic, Constant Displacement, General Specification For
AS8775	Hydraulic System Components, Aircraft and Missiles, General Specification For
AS8879	Screw Threads - UNJ Profile, Inch Controlled Radius Root with Increased Minor Diameter
AS8976	Bearings, Plain, Self-Aligning, All-Metal, General Specification For
AS15002	Fitting, Lubrication, Hydraulic, Surface Check, Straight Threads, Steel, Type II
AS35411	Fittings, Lubrication
AS50881	Wiring Aerospace Vehicle
AS56761	Splicing; Cable Terminal, Process for, Aircraft
AS81820	Bearings, Plain, Self-Aligning, Self-Lubricating, Low Speed Oscillation

2.1.2 ARINC Publications

Available from ARINC, 2551 Riva Road, Annapolis, MD 21401, www.arinc.com.

ARINC 547	Airborne VHF Navigation Receiver
ARINC 579	Airborne VOR Receiver
ARINC 711-10	Airborne VOR ILS Receiver

2.1.3 ASME Publications

Available from ASME International, P.O. Box 2300, Fairfield NJ 07007-2300, Tel: 800-843-2763, infocentral@asme.org or <http://store.asme.org/>.

ASME B29.1	Chain, Roller, Power Transmission and Conveyor, Flat Link Plates, Single Pitch, Single and Multiple Strand, Connecting Links and Attachment Links
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2.1.4 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM B438/B438M	Standard Specification for Sintered Bronze Bearings (Oil-Impregnated)
ASTM B439	Standard Specification for Iron-Base Sintered Bearings (Oil-Impregnated)

2.1.5 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, or <http://www.airweb.faa.gov>.

Advisory Circular 120-28 Criteria for Approval of Category III Weather Minima for Takeoff, Landing, and Rollout

Advisory Circular 120-29 Criteria for Approving Category I and Category II Weather Minima for Approach

2.1.6 ISO Publications

Available electronically from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org or <http://webstore.ansi.org/ansidocstore/>.

ISO/IEC 12207 Standard for Information Technology - Software Life Cycle Processes.

ISO 22072 Aerospace - Electrohydrostatic actuator (EHA) - Characteristics to be defined in procurement specifications

2.1.7 NAS Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928. Tel: 703-358-1000, www.aia-aerospace.org.

NAS 516 Fitting, Lubrication - 1/8 Inch Drive. Flush Type

NASM15981 Fasteners, Externally Threaded, Self-Locking Design and Usage Limitations For

NASM24665 Pin, Cotter (Split)

NASM33540 Safety Wiring and Cotter Pinning

NASM33588 Nut, Self-Locking, Aircraft, Reliability and Maintainability Usage Requirements For

NASM33602 Bolts, Self-Retaining, Aircraft Reliability and Maintainability, Design and Usage Requirement for

2.1.8 RTCA Publications

Available from Radio Technical Commission for Aeronautics Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

DO-178 Software Considerations in Airborne Systems and Equipment Certification. Software Considerations in Airborne Systems and Equipment

DO-254 Design Assurance Guidance for Airborne Electronic Hardware

2.1.9 U.S. Government Publications

Copies of these documents are available online at <http://quicksearch.dla.mil/>.

MIL-A-8860 Airplane Strength and Rigidity, General Specification

MIL-A-8861 Airplane Strength and Rigidity, Flight Loads

MIL-A-8865 Airplane Strength and Rigidity, Miscellaneous Loads

MIL-A-8867 Airplane Strength and Rigidity, Ground Tests

MIL-A-8870 Airplane Strength and Rigidity Vibration, Flutter, and Divergence

MIL-A-87229 Auxiliary Power Systems, Airborne

MIL-C-18244 Control and Stabilization Systems: Automatic, Piloted Aircraft, General Specification

MIL-C-81774 Control Panel, Aircraft, General Requirements For

MIL-DTL-781 Terminal; Wire Rope Swaging, General Specification For

MIL-DTL-6117	Terminal, Wire Rope Assemblies, Swaged Type
MIL-DTL-6193	Joint, Universal, Plain, Light and Heavy Duty General Specification For
MIL-DTL-7034	Pulleys, Groove, Antifriction Bearing, Grease Lubricated, Aircraft, General Specification For
MIL-DTL-8878	Turnbuckles, Positive Safetying
MIL-DTL-18375	Wire Rope, Flexible, Corrosion-Resisting, Nonmagnetic, For Aircraft Control
MIL-DTL-83420	Wire Rope, Flexible, For Aircraft Control
MIL-F-83300	Flying Qualities of Piloted V/STOL Aircraft
MIL-I-8500	Interchangeability and Replacementability of Component Parts for Aerospace Vehicles
MIL-HDBK-17	Composite Materials Handbook
MIL-HDBK-454	General Guidelines for Electronic Equipment
MIL-HDBK-470	Designing and Developing Maintainable Products And Systems, Volume I and Volume II
MIL-HDBK-516	Airworthiness Certification Criteria
MIL-HDBK-781	Reliability Test Methods, Plans and Environments for Engineering Development, Qualification and Production
MIL-HDBK-838	Lubrication of Military Equipment
MIL-PRF-5503	Actuators: Aeronautical Linear Utility, Hydraulic, General Specification For
MIL-PRF-7958	Push-Pull Controls, Flexible and Rigid
MIL-S-8512	Support Equipment, Aeronautical, Special, General Specification for the Design of
MIL-STD-130	Identification Marking of US Military Property
MIL-STD-202	Test Method Standard, Electronic and Electrical Component Parts
MIL-STD-203	Aircrew Station Controls and Displays: Location, Arrangement, and Actuation for Fixed Wing Aircraft
MIL-STD-411	Department of Defense Design Criteria Standard: Aircrew Station Alerting Systems
MIL-STD-461	Electromagnetic Interference Characteristics Requirements for the Control of Subsystems and Equipment
MIL-STD-464	Electromagnetic Environmental Effects Requirements for Systems
MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-882	Standard Practice for System Safety
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-STD-1530	Aircraft Structural Integrity Program, Airplane Requirements
MIL-STD-1553	Digital Time Division Command/Response Multiplex Data Bus

MIL-STD-1773 Fiber Optics Mechanization of an Aircraft Internal Time Division Command/Response Multiplex Data Bus

MIL-STD-1797 Flying Qualities of Piloted Aircraft

MIL-STD-7080 Selection and Installation of Aircraft Electric Equipment

MS33736 Turnbuckle Assemblies, Clip Locking of

2.1.9.1 Military Guide Specifications

Available from ASC/ENSI, Building 560, 2530 Loop Rd West, Wright-Patterson AFB OH 45433-7101, Tel: 937-255-6296.

JSSG-2006 Aircraft Structures

2.1.9.2 Rotorcraft Design Standards

Available from U.S. Army Aeroflightdynamics Directorate (AFDD) Mail Stop 243-11 Moffet Field, CA 94035.

ADS-33E-PRF Aeronautical Design Standard Performance Specification Handling Qualities Requirements for Military Rotorcraft

2.1.9.3 Carrier Based Aircraft Requirements

Available from Naval Air Warfare Center Aircraft Division, Ship Suitability, Building 2649, 21950 Nickles Road, Patuxent River, MD 20670.

AR-40A Automatic Carrier Landing System Airborne Subsystems, General Requirements for

2.1.9.4 Air Force System Command (AFSC) Design Handbooks and Notes

AFSC Design Handbook DH 1-2, General Design Factors

AFSC Design Handbook DH 1-4, Electromagnetic Compatibility

AFSC Design Handbook DH 1-6, System Safety

AFCS Design Handbook DH 2-1, Flight Control System Reliability and Maintainability Investigations

AFCS Design Note DN-3B1, Mechanical Flight Controls

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP94910 Aerospace - Vehicle Management Systems - Flight Control Design, Installation and Test of, Military Unmanned Aircraft, Specification Guide For

2.3 Definitions

Refer to ARP4386 for general system terms that are used in this Aerospace Standard.

VEHICLE MANAGEMENT SYSTEMS (VMS): Vehicle Management Systems include all components used to transmit flight control commands from the pilot or other sources to produce the deflections of the aircraft effectors needed to apply the appropriate forces and moments to the aircraft.

NOTE: Flight control commands normally result in control of aircraft altitude, airspeed, flight path, attitude, aerodynamic or geometric configuration, ride quality, and structural modes.

CLASSIFICATION OF AIRCRAFT: The classification of an aircraft type is as listed in Table 1.

Table 1 - Aircraft classes

Aircraft Class	Type
I	Small, light aircraft such as: • Light utility • Primary trainer • Light observation
II	Medium weight, low-to-medium maneuverability aircrafts such as: • Heavy utility/search and rescue • Light or medium transport/cargo/tanker • Early warning/electronic countermeasures/airborne command and control, or communication relay • Anti-submarine • Assault transport • Reconnaissance • Tactical bomber • Heavy attack • Trainer for Class II
III	Large, heavy, low-to-medium maneuverability aircraft such as: • Heavy transport/cargo/tanker • Heavy bomber • Patrol/anti-submarine/early warning/electronic countermeasures/airborne command and control, or communication relay • Trainer for Class III
IV	High-maneuverability aircraft such as: • Fighter/interceptor • Attack • Tactical reconnaissance • Observation • Trainer for Class IV

FLIGHT PHASE CATEGORIES: The flight phase of an aircraft is as categorized as detailed in Table 2.

Table 2 - Flight phase categories

Category	Flight Phase
A	Those non-terminal flight phases that require rapid maneuvering, precision tracking, or precise flight-path control.
B	Those non-terminal flight phases that are normally accomplished using gradual maneuvers and without precise tracking, although accurate flight-path control may be required.
C	Terminal flight phases that are normally accomplished using gradual maneuvers and usually require accurate flight-path control.

LEVELS OF PILOT'S FLYING QUALITIES: The levels of pilot's flying qualities are as detailed in Table 3.

Table 3 - Levels of pilot's flying qualities

Level	Pilot's Flying Qualities
1	Flying qualities clearly adequate for the mission flight phase.
2	Flying qualities adequate to accomplish the mission flight phase, but some increase in pilot workload or degradation in mission effectiveness, or both, exists.
3	Flying qualities such that the aircraft can be controlled safely, but pilot workload is excessive, or mission effectiveness is inadequate, or both. NOTE: Category A flight phases can be terminated safely, and Category B and C flight phases can be completed.

FLIGHT ENVELOPES: The flight envelopes are as detailed in Table 4.

Table 4 - Flight envelope definitions

Flight Envelope Title	Flight Envelope Definition
Operational Flight Envelopes	These are the boundaries in terms of speed, altitude, and normal acceleration within which the aircraft shall be capable of operating in order to accomplish the required missions.
Service Flight Envelopes	These are the combinations of speed, altitude, and normal acceleration derived from aircraft limits, as distinguished from the mission requirements. NOTE: For each applicable flight phase and Aircraft Normal State, the boundaries of the Service Flight Envelopes can be coincident with or lie outside the corresponding Operational Flight Envelopes, but in no case shall they fall inside those Operational Boundaries.
Permissible Flight Envelope	These encompass all regions in which operation of the aircraft is both allowed and possible. NOTES: 1. These envelopes define boundaries in terms of speed, altitude, and normal acceleration. 2. From all points in the permissible flight envelope, it shall be possible to return to the service flight envelope without exceptional control system capability or exceptional pilot effort (strength or skill)

NOTE: See A.2.1 in Appendix A defining flight envelope nomenclature within aircraft flying quality engineering standards.

FLIGHT CONTROL FUNCTIONS: The flight control functions provide the means for aircraft control and maneuvering and may employ means for stability augmentation, load limiting and structural mode control, and for pilot relief and workload reduction through automatic controls.

NOTES:

1. Flight control may employ, singly or in combination, mechanical, electrical or optical transmission of commands from the pilot or other sources to the actuators that drive effectors that produce force or moments.
2. The actuation power source may be hydraulic, electric, or pneumatic.
3. While the detail hardware, firmware and software design requirements for these different configurations differ widely, the performance requirements for all configurations will be defined in terms of:
 - The Class of Aircraft
 - The Flight Phase
 - The Flying Qualities
 - The Flight Envelopes
 - Each Operational State

PRIMARY FLIGHT CONTROL FUNCTIONS: Primary flight control functions provide direct control of aircraft maneuvering by the pilot through the cockpit primary control inceptors.

NOTES:

1. This function includes stability augmentation provided through closed loop feedback of aircraft states as well as command of aircraft response necessary to meet task-oriented flying qualities requirements.
2. Primary flight control may include provisions for load limiting or structural mode control.
3. Single or multi-axes thrust vectoring for maneuver or trim control may be included in this classification.
4. Continuous primary flight control is essential to aircraft flight safety and acceptable flying qualities.
5. Basic primary flight control achieves longitudinal, lateral, and directional control by moving elevators, ailerons, spoilers, rudders, and propulsion/reaction control devices with a sidestick, control stick, or control column and wheel, and pedals.

SECONDARY FLIGHT CONTROL FUNCTIONS: Secondary flight control functions provide control of aerodynamic or propulsive configuration changes as necessary for particular flight phases such as takeoff or landing.

NOTES:

1. Control of flaps, slats, trimmable horizontal stabilizer, speedbrakes or airbrakes, wing sweep, spoilers, ground-steering, braking and propulsion-reversing devices may be included.
2. Secondary flight control is essential to satisfactory performance and may be required for flight safety.

AUTOPILOT FLIGHT CONTROL FUNCTIONS: The autopilot flight control functions provide aircrew relief and workload reduction through automatic or semiautomatic flight path control.

NOTES:

1. These functions may be integrated into the VMS or implemented by wrapping control functions around the VMS primary flight control functions.
2. They may employ control stick steering which allows pilot inputs to update reference state values.
3. This classification includes automatic pilots, stick or wheel steering, auto throttles, and similar control mechanizations.
4. Some autopilot modes may require accompanying changes to the VMS augmentation functions.

VMS OPERATIONAL STATE CLASSIFICATIONS: The VMS Operational State Classifications are as listed in Table 5.

Table 5 - VMS operational state classifications

Operational State	VMS Performance, Safety and Reliability Criteria
Operational State I (Normal Operation)	This is the normal state of VMS performance, safety and reliability. NOTE: This state satisfies Level 1 flying qualities requirements within the Operational Flight Envelope, Level 2 within the Service Flight Envelope, and the stated requirements outside of these envelopes.
Operational State II (Restricted Operation)	This is the state of less than normal equipment operation or performance, which involves degradation, or failure of only a non-critical portion of the overall VMS. NOTES: 1. A moderate increase in crew workload and degradation in mission effectiveness may result from a limited selection of normally operating VMS modes available for use; however, the intended mission may be accomplished including aerial refueling and landing at the destination of original intent. 2. This state satisfies at least Level 2 flying qualities requirements within the Operational Flight Envelope and Level 3 within the Service Flight Envelope.
Operational State III (Minimum Safe Operation)	This is the state of degraded VMS performance, safety or reliability which permits safe termination of precision tracking or maneuvering tasks, and safe cruise, descent, and landing at the destination of original intent or alternate but where pilot workload is excessive, or mission effectiveness is inadequate. NOTES: 1. Phases of the intended mission involving precision tracking or maneuvering cannot be completed satisfactorily. 2. This state satisfies at least Level 3 flying qualities requirements.
Operational State IV (Controllable to an Immediate Emergency Landing)	This is the state of degraded VMS operation at which continued safe flight is not possible; however, sufficient control remains to allow engine restart attempt(s), a controlled descent and immediate emergency landing.
Operational State V (Controllable to an Evacuable Flight Condition)	This is the state of degraded VMS operation at which the VMS capability is limited to maneuvers required to reach a flight condition at which crew evacuation may be safely accomplished.

VMS CRITICALITY CLASSIFICATIONS: The VMS Criticality Classifications are as listed in Table 6.

Table 6 - VMS criticality classifications

VMS Function Type	Associated Function
Essential VMS Function	A function is Essential if loss of the function results in an unsafe condition or inability to maintain VMS Operational State III.
Flight Phase Essential VMS Function	A function is flight phase essential if loss of the function results in an unsafe condition or inability to maintain VMS Operational State III only during specific flight phases.
Noncritical VMS Function	A function is noncritical if loss of the function does not affect flight safety or result in control capability below that required for VMS Operational State III.

STRUCTURAL CLASSIFICATIONS: The Structural Classifications are as listed in Table 7.

Table 7 - Structural classifications

Fracture Part	Structural characteristics
Fracture Critical Part	A primary structural component that is predominantly designed and limited by fatigue crack initiation and crack growth requirements rather than static requirements, the single failure of which could lead to the loss of the aircraft or aircrew. NOTE: These parts generally call for special fracture toughness controls, quality control procedures, Non-Destructive Testing (NDT) practices, analytic requirements, and inspection criteria.
Fracture Critical Traceable (FCT) Part	A single load path part, the single failure of which would cause the immediate loss of the aircraft or aircrew. NOTE: In addition to the requirements for a Fracture Critical part, an FCT part requires serialization and traceability from starting stock to tail number or major subassembly number and reverse.

AIRCRAFT DETAIL SPECIFICATION: The procuring activity detailed specification for the aircraft.

PROBABILITY OF LOSS OF AIRCRAFT (PLOA): The probability of all single and combinational failures in all elements of the aircraft that would cause inability to achieve safe flight termination.

LOSS OF CONTROL: A failure effect, the result of a single failure or a combination of failures, which would prevent continued safe flight and also prevent safe flight termination and landing, though it may allow safe crew evacuation.

PROBABILITY OF LOSS OF CONTROL (PLOC): The probability of all those single and combined failures that would cause loss of control, that is, the inability to achieve safe flight termination.

VMS PLOC: The allocated probability of the sum of all those VMS failure conditions, for all the elements defined in 3.1.1.2, that would cause loss of control.

VMS CRITICAL FAILURE: A failure which causes loss of VMS function and thereby contributes to the VMS PLOC.

RELIABILITY: The conditional probability that the system or component operates correctly throughout a specified time interval.

COVERAGE: The probability that, when a fault has occurred in a redundant FBW VMS, the fault is correctly detected and isolated to the correct channel signal path and the VMS reconfigured.

POWER ON SELF-TEST (POST): Built-In-Test (BIT) automatically conducted at application of power to a VMC component.

PERIODIC BIT (PBIT) or CONTINUOUS BIT (CBIT): Employed for real-time monitoring.

MAINTENANCE BIT (MBIT): Operator/maintainer initiated, often interactive BIT.

INITIATED BIT (IBIT): Initiated for pre-flight check out.

SHALL: Denotes requirements that are required be met wherever the criterion for conformance with the specific recommendation requires that there be no deviation."

SHOULD: Denotes requirements that are desired to be met wherever noncompliance with the specific recommendation is permissible."

WILL: Descriptions of typical actions to be performed by the procuring activity, or the prime contractor, in the future.

MAY: Description of the possible or allowable, for example, recommended courses of action or VMS characteristics.

OR: Recommendations which may be followed by satisfying any one of a set of listed options.

AND: Recommendations which can only be met if all a set of listed options are satisfied. If they are required to all be satisfied at the same time the word “simultaneously” is added.

N/A: Used for data or recommendations that are not applicable.

NA: Used for data or recommendations that are not available.

2.4 Symbols and Abbreviations

2.4.1 Symbols

c.g.	Center of Gravity
Cmo, Cm α , Cn β	Aircraft Stability Derivatives
Di	Ride Discomfort Index
ϕ_c/Y_e	Ratio Bank Command to Lateral Error
f _M	Mode Frequency
h/hc	Ratio of Altitude to Altitude Command
Hc/Ze	Ratio Altitude Command to Altitude Error
Q _{S(VMS)}	VMS Quantitative Flight Safety, Loss of Control Rate, due to VMS Failures (per flight hour)
V _{oMAX}	Maximum Operational Airspeed
V _{oMIN}	Minimum Operational Airspeed

2.4.2 Abbreviations

ACLS	Automatic Carrier Landing System
A/D	Analog-to-Digital
AFSC	Air Force System Command (Handbooks)
AGL	Above Ground Level
ALS	Automatic Landing System
ANSI	American National Science Institute
AOA	Angle of Attack
APCS	Approach Power Compensator System
ARINC	Aeronautical Radio Inc.
ARP	Aerospace Recommended Practice
BIT	Built-In-Test
CBIT	Continuous Built-In-Test

CPCI	Computer Program Configuration Item
D/d	Ratio of the Diameter (D) around the object which the sling/wire is bent divided by of overall diameter (d) of the sling being/wire used
DDV	Direct Drive Valves
DLC	Direct Lift Control
DME	Distance Measurement Equipment
DSP	Digital Signal Processor
EHA	Electrohydrostatic Actuators
EHSV	Electrohydraulic Servovalves
EMA	Electromechanical Actuators
EMI	Electromagnetic Interferences
EMP	Electromagnetic Pulse
ESS	Environmental Stress Screening
FBW	Fly-By-Wire
FCT	Fracture Critical Traceable
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FTA	Fault Tree Analysis
GM	Gain Margin
H-DOT	Vertical Rate
HSTA	Horizontal Stabilizer Trim Actuators
HUD	Heads-Up-Display
IAP	Integrated Actuation Package
IBIT	Initiated Built-in Test
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
ILS	Instrument Landing System
INS	Inertial Navigation System
JSSG	Joint Service Specification Guide
KCAS	Knots Calibrated Airspeed

LRU	Line Replaceable Unit
LVDT	Linear Variable Differential Transformer
MBIT	Maintenance Built-In-Test
MSL	Mean Sea Level
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
N/A	Not Applicable
NA	Not Available
NDT	Non-Destructive Testing
NSN	National Stock Number
OFP	Operational Flight Program
PBIT	Periodic Built-In-Test
PBW	Power-By-Wire
PDE	Power Drive Electronics
PIO	Pilot Induced Oscillation
PLOC	Probability of Loss of Control
PM	Phase Margin
POST	Power-On Self-Test
PROM	Programmable Read-Only Memory
RBD	Reliability Block Diagram
RTCA	Radio Technical Commission for Aeronautics
RVDT	Rotary Variable Differential Transformer
SAP	Safety Assessment Plan
SDP	Software Development Plan
SOF	Safety-Of-Flight
SRA	Shop Replaceable Assembly
STOL	Short Take-Off and Landing
TACAN	Tactical Air Navigation
TTE	Time-Triggered Ethernet
TTP	Time-Triggered Protocol

VG	Turbulence Penetration Airspeed
VHF	Very High Frequency
VL	Maximum Limit Speed
VMC	Vehicle Management Computer
VMS	Vehicle Management System
VOR	VHF Omni-directional Range
V/STOL	Vertical/Short Takeoff and Landing
WOW	Weight-On-Wheels
WRA	Weapon Replaceable Assembly
ZOC	Zone Of Confusion

3. REQUIREMENTS

3.1 General System Requirements

The VMS shall comply with the requirements contained in this standard such that the aircraft missions described by the procuring activity can be performed satisfactorily. The VMS shall meet all the environmental requirements of the Aircraft Detail Specification and of this standard.

3.2 Classifications, Flight Categories, and Envelopes Requirements

3.2.1 Classification of Aircraft

The procuring activity will assign an aircraft to one of these classes and the requirements for that Class shall apply. When no Class is specified, the requirements shall apply to all Classes. When operational missions dictate, the procuring activity may require an aircraft of one Class to meet selected requirements for aircraft of another Class.

3.2.2 Flight Phase Categories

When no flight phase is stated in a requirement, that requirement shall apply to categories A, B, and C

3.2.3 Safety and Operability Considerations

3.2.3.1 Flight Safety Assessment

The assessment of the quantitative flight safety of a VMS shall include calculation of the PLOC and also a calculation of the probability and assessment of the hazard of each failure condition caused by single or combined failures across the Operational Flight Envelope.

The prime contractor shall develop a Consequence of Failure Assessment Plan for approval by the procuring activity to address the failure immunity requirements outlined in 3.2.3.2 and 3.2.3.3. The Fault Tree Analysis (FTA), Failure Modes and Effects Analysis (FMEA) and Hazard Analysis methods in ARP4761 shall be used as a guide. A Reliability Block Diagram (RBD) representation of the end-to-end flight critical VMS functionality and redundancy shall be developed and provided to support the PLOC analysis.

The quantitative flight safety assessment of the VMS shall include all flight critical functions, components and subsystems. These shall include items such as: power electronic modules, mechanical controls, VMS electronic set, air data and aircraft motion sensors, cockpit controls, hydraulically or electrically powered control effectors, trim or cockpit control feel actuators, hydraulic system components, electrical power system components, including constant speed drives for generators and hydraulic system pump drive gear boxes. All moment producers integrally controlled by the engine control system, and the engine itself shall not be included. For a STOL or V/STOL aircraft the approach to be adopted for all the functions controlled by the engine control system shall be agreed between the procuring activity and the prime contractor.

A representative mission to which this requirement applies, including mission duration, is as defined by the procuring activity and described in more detail by the prime contractor, to allow the component failure rate calculations. The prime contractor, subject to approval of the procuring activity, shall define whether the FTAs and RBDs will be developed for 1 hour of flight or be developed for the duration of one flight and the end result divided by the flight length in hours. If the planned usage of the aircraft provides, after a failure, for a time to return to base which is significantly shorter than the mission time, the maximum-return-to-base time shall be specified by the procuring activity.

3.2.3.2 Quantitative Flight Safety

The VMS PLOC shall not exceed the value specified by the procuring activity or, if not otherwise specified, a value numerically equal to the maximum acceptable aircraft Loss of Control rate due to relevant VMS failures ($Q_{S(VMS)}$) specified in Table 8.

The VMS PLOC requirement shall include consideration of the mission time and the time to return to base after a failure before normalizing requirements on a per-hour basis.

Table 8 - VMS quantitative flight safety requirements

Aircraft Description	Aircraft Class	Maximum Aircraft Loss of Control Rate, From VMS Failures Per Flight Hour, after accounting for mission length, $Q_{S(VMS)}$
Small, light, medium weight Low to high maneuverability	I, II IV	1.0×10^{-6}
Large, heavy weight Low to medium maneuverability	III	1.0×10^{-8}
Rotary wing	N/A	1.0×10^{-7}

3.2.3.2.1 Effects of Imperfect Fault Detection

PLOC calculations for VMS with multiple redundant channels, typically quadruplex, triplex or dual, shall account for imperfect fault detection and redundancy management (i.e., imperfect “coverage”).

Coverage is measured as a percentage, ranging from zero to 100%, or as a coverage factor, ranging from zero to one, where 100% and 1.0, respectively, indicate perfect capability. The prime contractor shall substantiate any coverage factors claimed to be above 0.9 (90%).

The PLOC calculation for a true dual VMS (no redundant internal lanes per channel) with no independent tie-breaker source can only consider in-line fault coverage of the dual redundant elements. These dual elements shall be considered to have a net reliability equal to:

$$R_s = R^2 + 2R(1-R)c \quad (\text{Eq.1})$$

where:

R = reliability of a single element (typically $e^{-\lambda t}$, where t is the exposure time, λ is the critical failure rate in failures per flight hour, assuming an exponential distribution, where failure rate does not depend on elapsed quantity of service)

R_s = reliability of a subsystem

c = coverage factor

3.2.3.3 Failure Immunity and Safety

As part of the quantitative flight safety analysis a failure immunity and safety assessment shall be made to determine if the fault accommodation features of the system provide a safe reaction to, and recovery from, a single failure or a combination of failures. The failure immunity and safety analysis shall consider failures and failure combinations with a probability down to a level of the VMS PLOC (see 3.2.3.2) divided by 10.

Within the Permissible Flight Envelope, no single failure or failure combination, of the VMS or related subsystems, with a probability greater than or equal to the VMS PLOC (see 3.2.3.2) shall result in any of the following effects before the VMS takes effective corrective action or before the pilot can be expected to take effective corrective action:

- a. Flutter, divergence, or other aeroelastic instabilities of the aircraft, or a structural damping coefficient for any critical flutter mode below the fail-safe stability limit of MIL-A-8870.
- b. Uncontrollable motions of the aircraft or uncommanded maneuvers, which exceed airframe limit loads.
- c. Inability to land the aircraft safely or to reach a safe ejection envelope, as determined by the Class of aircraft.
- d. VMS failures leading to control surface deflections that would cause an immediate departure from controlled flight.

NOTE: During cruise flight, where there is no risk of contact with the ground and managed risk of contact with other aircraft, departures from flight path are considered to present less of a hazard.

- e. Exceedance of the Permissible Flight Envelope or inability to return to the Service Flight Envelope.
- f. VMS failures that could cause total loss of thrust.

Any lists of failure states to be excluded from or accommodated by these VMS requirements, regardless of probability, or of special failure states, again regardless of probability, that the aircraft shall accommodate or need not accommodate, shall be the subjects of detailed written agreements between the procuring activity and the prime contractor.

3.2.3.3.1 Automatic Terrain Following Failure Immunity

The terrain following system shall detect any potentially critical failure, in the command generation scheme, sensors, (including radar and radar altimeter) or terrain following functions, not shown to be less probable than the VMS PLOC (see 3.2.3.2) and provide warning to the pilot. Any failure resulting in loss of the automatic terrain following function or unsafe flying condition shall provide safe exit (automatic flyup) from the low altitude, high-speed environment. Take-over or injection of commands by the pilot while the system is operating shall permit a smooth and positive transition without adverse transients. Automatic flight control function accuracy (heading and roll attitude hold) shall be maintained to the degree specified in 3.3.4.2.

Within the Operational Flight Envelope, means shall be provided to prevent the VMS from responding to trajectory commands generated by on-board mission sensors that would result in an unsafe flight condition, departure from controlled flight, structural load exceedance or unsafe terrain clearance.

3.2.3.4 Transient Electrical Power Effects

Flight control or Vehicle Management computers, or embedded subsystem components shall tolerate electrical power source variations, within the limits specified for the applicable power system in the Aircraft Detail Specification, without suffering adverse effects which result in operation at below the specified VMS Operational State, or, if not specified, below Operational State III.

In the event of power source interruption, no adverse effects shall result which limit operation or performance of flight control computers upon resumption of normal quality power. The use of independent, uninterruptable backup power for the Vehicle Management Computer (VMC) shall be considered to prevent VMS dropout during momentary primary power interruptions. The hold-up time shall be long enough to ensure uninterrupted VMC operation through the worst case transient electrical power system drop-out.

3.2.3.5 Priority

Essential and Flight Phase Essential flight controls shall be given priority over noncritical controls and other actuated functions during simultaneous demand operation. However, no specific priority provisions, such as hydraulic priority valves, are required unless there is a likelihood of simultaneous demands which could prevent one or more Essential or Flight Phase Essential actuation systems from meeting their performance requirements.

Where provided, priority controls shall be highly resistant to deterioration, binding or failure while dormant under normal aircraft operations so that they will function as required when conditions dictate. If flight safety can be endangered by failure of such controls, ground checkout means for ready determination of their operability shall be provided and procedures specified.

3.2.4 Reliability Considerations

The VMS reliability shall be consistent with overall system requirements.

3.2.4.1 Mission Accomplishment Reliability

The probability of mission failure per flight hour, QM(VMS), due to relevant material failures in the VMS, shall be an allocation by the prime contractor from the vehicle requirement provided by the Aircraft Detail Specification. The allocation shall be supported by failure analysis from the Safety Plan (see 3.5.5.4).

NOTES:

1. Failures in hydraulic or electrical power sources and power distribution, or other subsystems that do not otherwise cause mission failure shall be considered where pertinent.
2. Each mission to which this requirement applies shall be established and defined by the contractor, subject to approval of the procuring activity.

3.2.4.2 Availability

The VMS availability requirement shall be an allocation by the prime contractor from the vehicle requirement provided by the Aircraft Detail Specification. The allocation shall be compatible with the Mean Time Between Failure (MTBF) (see 3.2.4.3) the Mean Time To Repair (MTTR) specified for the VMS and the VMS mission accomplishment reliability (see Appendix A 3.2.4.1).

3.2.4.3 MTBF

The VMS reliability, as measured by its MTBF, shall meet the requirements of the VMS detail specification and allow the vehicle to achieve the mission reliability and availability specified in Appendix A 3.2.4.1 and 3.2.4.2, respectively.

3.2.5 Redundancy Considerations

The prime contractor shall determine the redundancy approaches to be employed by the VMS and shall use the minimum levels required to satisfy the requirements of this standard.

3.2.5.1 Redundancy

In the design of a redundant VMS, the term redundancy refers to a mechanization which will retain functional integrity after failures and provide the same or similar flying qualities and performance capability. In practice, it can take the form of duplicate or alternate components, channels, or subsystems; each capable of performing the given function. The redundancy approach determined by the prime contractor shall:

- a. Allow the flight safety and mission reliability requirements of this standard to be met.
- b. Allow the use of the system test and monitoring provisions requirements of 3.4.1 and associated subparagraphs.

- c. Incorporate the fault accommodation features that are demonstrated by analysis and simulation to provide a safe reaction to, and recovery from, single failures or failure combinations with a probability greater than or equal to the VMS PLOC (see 3.2.3.2).
- d. Be addressed in the software requirements definition when applicable.

3.2.5.2 Isolation and Protection of Redundant Subsystems

Redundant subsystems shall employ isolation of the redundant elements to preclude failure of one portion of the system from affecting any other part of the system. Requirements for isolations of electrical signal channels are defined in 3.5.4, hydraulic subsystem requirements are in 3.6.4, and mechanical component requirements are defined in 3.7.2.

3.2.5.3 Redundancy Management

The VMS shall perform the redundancy management of the components and subsystems within the VMS itself and, where necessary, of those external to the VMS that are essential to its flight critical functions. Redundancy management shall provide failure detection and suppression of failure transients, efficient and effective system operation for maximum mission reliability and safety. Redundancy management should be employed at various levels within the system or channel to perform such tasks as: signal selection, fault isolation, reconfiguration, and actuator management. Redundancy management shall accomplish the following:

- a. Provide failure detection, isolation, and corrective action to meet the requirements of 3.2.3.3 and the transient limits in 3.3.1.10 within 0.15 seconds, or within the time before divergence to double amplitude, whichever is shorter.
- b. Prevent propagation of failures among aircraft control redundant elements.
- c. Prevent propagation of failures from other systems/subsystems to and from aircraft control redundant elements.
- d. Provide physical and electrical isolation between redundant elements in accordance with 3.5.4.3, 3.7.2.11, 3.7.4.2.3, and 3.7.5.2.
- e. Provide use of voting and comparison of redundant elements to the maximum extent possible while minimizing any aircraft performance degradation caused by the failure.
- f. Permit re-admittance of previously failed elements back into the voting plane only when operation within tolerance is evident.

However, the design shall consider the transient motions resulting from the reset to ensure they will fall within the failure transient requirements in 3.2.1.10 prior to allowing the reset, which may be automatic or operator/maintainer initiated, depending on the specific failure. The design shall consider limiting the reset of failures to only the most recent failure and not readmitting numerous identical failures in order to not introduce failed signals that appear to be acceptable (when compared with the other channels) but are no longer truly active signals.

- g. Provide tolerance to normal, non-failed transient behavior of signals within the system from sources such as mode transitions, sensors, hydraulics, electrical power and commands.

Appropriate smoothing and filtering shall be used to achieve this tolerance and to prevent disturbing feedback from reaching the crew.

- h. Provide for an automatic in-flight restart of the VMS, which will maintain aircraft control, in the event of an all-channel "generic software error."
- i. Provide system health status information to the crew of actions taken by the VMS to accommodate failures.

3.2.6 Maintainability Considerations

VMS design and installation shall permit normally assigned maintenance personnel to perform required maintenance safely and easily under all anticipated environmental conditions. Means shall be provided to permit the accomplishment within the allocated maintenance budget and personnel skill level of all required organizational and intermediate level maintenance functions including:

- Operational checkouts
- System malfunction detection
- Fault isolation to the LRU/WRA level, LRU/WRA removal and replacement, inspection
- Repair
- Servicing
- Testing

In addition, the design shall employ provisions to facilitate efficient overhaul and performance testing and evaluation at the depot level.

3.2.6.1 Operational Checkout Provisions

The VMS shall be designed with provisions for operation on the ground, without operating the main engines, to verify system operation and freedom from failure, including verifying system redundancy and the absence of dormant system failures that would not normally be detected without intrusive operation of the system, to the maximum extent possible. Electric and electronic components shall be designed to operate with the electric power generators supplied by standard ground carts. Hydraulic components shall be designed to operate with the standard hydraulic ground carts.

3.2.6.2 Malfunction Detection and Fault Isolation Provisions

The VMS shall have means for providing a high probability of detecting failures and monitoring critical performance conditions as required to isolate faults to the LRU/WRA level. These means may include cockpit instrumentation and built-in-test functions.

3.2.6.2.1 Use of Cockpit Instrumentation

Where acceptable procedures are provided, cockpit instrumentation may be used for malfunction detection and fault isolation where it provides a readily understandable condition indication either alone or in coordination with built-in test equipment.

3.2.6.3 Accessibility and Serviceability

The VMS components shall be designed, located, and provided with easy access so that inspection, rigging, removal, repair, and replacement can be readily accomplished. Suitable provisions for rigging pins, or the equivalent, shall be made to facilitate correct rigging of the VMS. In addition, all VMS components shall be designed so their removal and replacement can be accomplished without disturbing the rigging insofar as practical.

Special tools required for installation and rigging shall be avoided to the maximum extent possible. If rig or other system setup information is stored in non-volatile memory within a LRU/WRA, provisions shall be made for electronic transfer of this data from redundant LRU/WRAs into a LRU/WRA which has been installed to replace one removed for maintenance.

3.2.6.4 Maintenance Personnel and Safety Provisions

Systems and components shall be designed to preclude injury of personnel during the course of all maintenance operations including testing. All devices which contain any type of stored energy (such as mechanical, electrical, hydraulic, or pneumatic), or which can produce energy capable of causing injury to maintenance personnel, shall be provided with a positive means of disconnecting the energy source, allowing controlled release of the energy, or preventing its inadvertent release. Where positive protection cannot be provided, precautionary warnings or information shall be affixed in the aircraft and to the equipment to indicate the hazard; and appropriate warnings shall be included in the application maintenance instructions.

Safety pins, jacks, locks, or other devices intended to prevent actuation shall be readily accessible and shall be highly visible from the ground or include highly visible streamers. All such streamers shall be of a type which cannot be blown out of sight such as up into a cavity in the aircraft. Streamers shall be in accordance with MIL-S-8512.

3.2.7 Survivability Requirements

The VMS shall withstand and operate in unnatural, induced, hostile environments. The VMS shall provide at least Operational State III performance in all situations where damage sustained by the airframe and other systems would not cause loss of control.

3.2.7.1 All-Engines-Out Control

Engine generated power is required for normal VMS operation. Loss of such power may lead to a change in VMS Operational State and/or VMS functional capability.

Supplementary means or power source shall be provided as necessary to supplement the control power available from the engine(s) where engines are unproven, airframe aerodynamics not established in flight, airframe/inlet flow field interactions not adequately verified in flight, or wind milling power is insufficient to maintain Operational State IV control capability anywhere in the aircraft Permissible Flight Envelope. Such supplementary means shall provide control power for a period of time in accordance with the Aircraft Detail Specification.

The VMS design (including power sources) shall be such that unintentional loss of any or all engine thrust shall not result in less than VMS Operational State IV including any necessary transition to emergency source(s) of power for this specified period of time. Provision shall be made for in-flight return to normal power wherein the transition shall not result in a worse VMS Operational State.

3.2.7.2 Power Capacity

Sufficient electrical, hydraulic, and pneumatic power capacity shall be provided in all flight phases and with all corresponding engine speed settings such that the probability of losing the capability to maintain at least VMS Operational State III aircraft performance shall be equal to or less than the VMS PLOC (see 3.2.3.2), when considering the combined probability of system and component failure and the cumulative exceedance probability of turbulence.

The analysis and integration studies of ground and in-flight VMS power requirements shall be performed to ensure that the power demands can be met with appropriate margin and, if multiple power systems are used, are appropriately balanced between those systems.

3.2.7.3 Invulnerability Considerations for VMS Design

Degradation in the VMS operation due to variations in natural environments, adverse events of nature, induced environments, onboard failure of other systems, maintenance error, flight crew error or enemy actions shall be within the limits specified in the following subparagraphs.

3.2.7.3.1 Invulnerability to Natural Environments

The VMS shall be designed to withstand the full range of natural environmental extremes established for the particular aircraft or system without permanent degradation of performance below VMS Operational State I, or temporary degradation below VMS Operational State II.

A reduction below State I shall be experienced only at adverse environmental extremes not normally encountered and shall be transient in nature only; and, the function shall be recovered as soon as the aircraft has passed through the adverse environment.

System components and clearances with structures and other components shall be adequate to preclude binding or jamming, instability, or out-of-specification operation of any portion of the system due to possible combinations of temperature effects, ice formations, loads, deflections, including structural deflections, and buildup of manufacturing tolerances. Specific environmental conditions are defined in 4.5.2.1.

3.2.7.3.2 Invulnerability to Lightning Strike and Static Atmospheric Electricity

The VMS shall maintain Operational State II capability or better when subjected to electric field and lightning discharge except that a temporary, recoverable, more extensive loss of performance to State III is allowable in the event of a direct lightning strike to the aircraft. Structural and VMS bonding shall meet the requirements of MIL-STD-464 and follow the guidance of its referenced documents.

3.2.7.3.3 Invulnerability to Induced Environments

The VMS shall withstand the full range of worst-case induced temperatures and temperature shock, acceleration, vibration, noise, and shock, induced pressures, explosive and corrosive atmospheres, Electromagnetic Interferences (EMI) and nuclear environment projected in missions for the particular aircraft without permanent degradation or loss of capability to maintain VMS Operational State II capability.

Specific induced environmental conditions shall be in accordance with the Aircraft Detail Specification. These induced environments, within structural and crew survival limits, shall not result in temporary degradation below VMS Operational State IV capability during the exposure to the environment. Requirements for directed energy and high-power microwave weapons and nuclear radiation including Electromagnetic Pulse (EMP) shall be defined by the procuring activity. The VMS shall meet the applicable requirements of MIL-STD-464 and MIL-STD-461.

3.2.7.3.4 Invulnerability to Enemy Action

The specific enemy threats and operational capability after encountering the threats shall be defined by the procuring activity. If the threats are not defined, the Essential and Flight Phase Essential VMS for combat aircraft, including associated structure and power supplies shall withstand at least one direct encounter from the implied threat inherent to the mission defined in the Aircraft Detail Specification without degradation below Operational State III. The prime contractor shall identify the vulnerable areas (see MIL-HDBK-336) associated with the implied threat. MIL-HDBK-2069 and AIR1083 are recommended reference documents for Aircraft Survivability design.

3.2.7.3.5 System Operation and Interface

Whenever a non-critical control or other aircraft system is interfaced with Essential or Flight Phase Essential flight control channels, separation and isolation shall be provided to make the probability of propagated or common mode failures to be less than or equal to the VMS PLOC (see 3.2.3.2). The warm-up and cold weather warm-up requirements of 3.3.1.1 shall be met.

3.2.7.3.6 Signal Path Protection

Where redundant computing paths are provided they shall be isolated or separated to meet the invulnerability requirements of 3.2.7.3. Design options and techniques to enhance the survivability of redundant systems are provided in AIR1083.

3.2.7.3.7 Invulnerability to Onboard Failures of Other Systems and Equipment

The VMS shall meet its failure state/reliability budget, as allocated within the weapon system, for self-generated failure (within the VMS) and for those VMS failures induced by failures of other interfacing systems within the weapons systems (Appendix 3.1.2.1, 3.2.3). In addition, the VMS design shall comply with the following:

- a. Essential and Flight Phase Essential VMS shall retain VMS capability at Operational State III (minimum safe) or better after sustaining the following failures:
 1. Failure of the critical engine in a two-engine aircraft.
 2. Failure of the two most critical engines in aircraft having three or more propulsive engines.
 3. Failure of any single equipment item or structural member which, in itself, does not cause degradation below State III. This includes any plausible single failure of any onboard electrical or electronic equipment in any subsystem of the aircraft.
- b. The VMS for Class III aircraft, including the associated structure and power supplies, shall be designed so that the probability of failing to maintain VMS Operational State IV, as a result of an engine or other rotor burst, shall be less than or equal to the VMS PLOC (see 3.2.3.2).
- c. The VMS for Class I, II and IV aircraft, including the associated structure and power supplies, shall be designed so that the probability of failing to maintain VMS Operational State V as a result of an engine or other rotor burst shall be less than or equal to the VMS PLOC (see 3.2.3.2).
- d. In the event of a failure that has no immediate effect, such as loss of required cooling for electrical signal computation, or a series of such failures not shown to be less probable than the VMS PLOC (see 3.2.3.2), but which will unavoidably lead to degraded VMS operation, undegraded operation shall be provided for a period of time determined by the prime contractor and approved by the procuring activity.

3.2.7.3.8 Invulnerability to Pilot and Flight Crew Inaction and Error

The VMS shall be designed to minimize the possibility of any flight crew member controlling or adjusting system equipment to a condition state which could degrade VMS operation. For example:

- a. Protection against improper position and sequencing of controls. Wherever practicable, cockpit controls, other than stick or wheel and rudder pedals, shall be equipped with positive action gates to prevent inadvertent positioning which can compromise safe operation of the aircraft. Positive interlocks to prevent hazardous operation or sequencing of switches shall be provided.
- b. Redundant interlocks shall be used to prevent inadvertent actuation of control systems that would produce structural damage, if actuated.
- c. Pilot reaction to failure - The VMS shall be designed so that the normal pilot reaction to cues provided by probable failure conditions is instinctively correct.
- d. Crew Alerting Requirements (see 3.6.9.3)
 1. A warning signal is a visual signal which indicates the existence of a hazardous condition requiring immediate crew action to prevent loss of life, equipment damage, or abortion of mission (definition per reference MIL-STD-411). Warning signals shall be provided to the aircrew for any conditions arising within the VMS that require immediate crew action to maintain safety of flight.
 2. A caution signal is a visual signal which indicates the existence of a condition requiring immediate attention but not immediate action (definition per reference MIL-STD-411). A distinguishable caution signal shall be provided to the aircrew under all expected flight conditions for any condition within the VMS that could result in an unsafe condition if the pilot were not aware of the condition.

3. An advisory signal is a visual signal which indicates a safe or normal configuration, condition of performance or operation of essential equipment, or attracts attention and imparts information for routine action purposes (definition per reference MIL-STD-411). Advisory signals shall be provided to the aircrew for conditions within the VMS that warrant aircrew awareness, but do not require immediate awareness.

Systems, controls, procedures, and associated monitoring and crew alerting means shall be designed to preclude crew errors that create additional hazards.

3.2.7.3.9 Invulnerability to Maintenance Error

The VMS shall be designed so that it is physically impossible to install or connect any component item improperly without one or more overt modifications of the equipment or the aircraft. Provisions for adjusting the VMS on the aircraft, except during initial buildup, major overhaul, software modification, or rigging during major maintenance activities, shall be minimized. LRU/WRAs shall be designed to permit making internal adjustments only on the bench. The system shall require only a minimum of re-rigging following replacement of LRU/WRAs. In addition, all control linkages and other flight control mechanisms shall be designed to minimize the probability of jamming from inadvertent entry of maintenance tools or other material.

3.2.7.3.10 Invulnerability to Software Maintenance Error

The following provisions shall be implemented to prevent propagation of software errors from any source:

- a. Means for identification of the operational flight program (OFP) shall be provided and means/procedures shall be established to preclude the operation of the aircraft with unintended or uncontrolled VMS software.
- b. For systems designed for on-aircraft software loading, the system shall have provisions to prevent loading the same version of software already in the VMC and associated VMS processors to discourage software reload claimed as a legitimate maintenance action for intermittent hardware failures that cannot be duplicated after flight.
- c. Software configuration control and OFP installation requirements shall be documented in the Software Development Plan, 4.6.1 (h).
- d. Safety requirements shall include the establishment of safety design processes to design safety into the subsystem, as defined in 3.5.5.1.
- e. For VMS having redundant channels or software functions distributed over multiple LRUs/WRAs, provisions shall be provided so that the system automatically detects any software version incompatibilities and alerts the flight crew at power-up.

3.2.8 Electromagnetic Interference (EMI) Limits

The VMS shall operate safely within the EMI environment and shall meet the requirements of this standard and any additional requirements dictated by the Aircraft Detail Specification.

Special consideration shall be given to protecting the electronic subsystems of the VMS from lightning effects. The VMS shall operate within the limits of MIL-STD-464 and MIL-STD-461 environments, including both the VMS susceptibility to, and generation of, electromagnetic interference. Electromagnetic Interference created by the systems and components during normal operation shall be within the limits of MIL-STD-464 and MIL-STD-461, respectively.

Failure modes of all onboard systems and equipment, including flight controls, where these limits may be exceeded shall be identified in addition to sources of conducted EMI that may be detrimental to VMS operation. Additionally, the estimated magnitude of EMI created by these failure modes shall be provided for the assessment of the safety of the VMS.

3.3 System Performance Requirements

3.3.1 General VMS Performance Requirements

Unless otherwise specified by the procuring activity the VMS shall comply with the applicable general flying qualities requirements of MIL-STD-1797 for fixed wing aircraft, ADS-33E-PRF for rotorcraft, and MIL-F-83300 for V/STOL aircraft as applicable, and the special performance requirements of the Aircraft Detail Specification. The selected autopilot functions shall provide the performance capabilities specified herein and in the Aircraft Detail Specification.

3.3.1.1 Warm-Up

The cold weather warm-up time is defined as that time elapsed between the application of power and the availability of VMS full take off performance. The procuring activity shall specify the maximum warm-up time required to meet the system concept of operations. The VMS shall provide a positive indication when this warm-up time is complete. This is in addition to the normal air vehicle initialization time. Operational performance shall be met by the VMS not more than 90 seconds after power is applied during initial startup on the ground, except for cold weather startup.

The temperature and allowable startup time for this condition shall be defined in the Aircraft Detail Specification. If the VMS controls fluid powered actuation, such as hydraulic flight control surface actuators, the procuring activity shall define a cold weather start up temperature, time or both. A cold weather hydraulic warm-up mode may be provided to meet this requirement.

3.3.1.2 Disengagement

Provisions shall be made for positive in-flight disengagement of flight phase essential and noncritical controls under all load conditions. No out of trim condition shall exist at disengagement which cannot be easily controlled by the pilot. The pilot shall be informed of automatic disengagement. Disengagement circuitry shall be designed such that a failure of the circuitry itself does not prevent automatic or manual disengagement.

3.3.1.3 Status of Modes

A means shall be provided so that the flight crew can visually determine the operational status and mode of the VMS.

3.3.1.3.1 Mode Compatibility

Mode compatibility logic shall provide flexibility of VMS operation and ease of mode selection. The mode selection logic shall include the following additional requirements:

- a. Make correct mode selection by the crew highly probable.
- b. Prevent the engagement of incompatible modes.
- c. Disconnect, as appropriate, previously engaged modes upon selection of higher priority modes.
- d. Provide arming of appropriate modes while certain modes are engaged.
- e. Provide for the emergency disengagement of a higher priority mode, in the event of its failure, and reversion to a more basic VMS mode to ensure continuation in at least operational state III.
- f. Provide for mode engagement after mode engagement criteria have been met and provide positive notification of mode engagement.
- g. Provide appropriate pilot notification of modes as selections and de-selections are made. Mode status, warnings, cautions, and advisories shall be clear, concise and not ambiguous.
- h. Minimize engage and disengage transients, whether the transfer is pilot-selected or an automatic response to a failure and provide adequate time for pilot response.
- i. Alert the pilot when a mode is engaged that is incompatible with a precision manual control task such as landing.

3.3.1.4 Stability

All modes of the VMS shall be able to rapidly decrease any transient oscillation. Changes in parameters within the 3-sigma tolerance limits for all the VMS components shall not result in instability.

3.3.1.4.1 Aerodynamic-Closed Loop

An aerodynamic loop is one that relies on the deflection of an aerodynamic control surface, or a thrust vectoring means, to control the aircraft and to augment its stability or control response and hence, through aerodynamics, to close loops around the aircraft response.

The procuring activity shall define the gain and phase margins for all aerodynamically closed loops to meet the operational requirements. In the absence of this definition, the margins specified by Table 9 apply for Operational States I and II. These margins apply to all configurations, with and without external stores, with the most adverse center-of-gravity and mass distribution, throughout the Operational and Service Flight Envelopes, and during ground operations. Automatic flight control modes shall be stable with these gain or phase variations included for any amplitudes greater than those allowed for residual oscillations in 3.3.1.7.

Table 9 - Gain and phase margin requirements

Mode Frequency (Hz)	Below V_{OMIN}	Flight Envelopes		
		Within the Operational Envelope	At the bounds of the Service Envelope	At 1.15 VL
$f_M < 0.06$	GM = 6 dB (No PM requirement below V_{OMIN})	GM = ± 4.5 dB PM = ± 30 degrees	GM = ± 3.0 dB PM = ± 20 degrees	GM = 0 dB PM = 0 degrees (Stable at Nominal Phase and Gain)
$0.06 \leq f_M \leq$ First Aeroelastic Mode		GM = ± 6.0 dB PM = ± 45 degrees	GM = ± 4.5 dB PM = ± 30 degrees	GM = 0 dB PM = 0 degrees (Stable at Nominal Phase and Gain)
$f_M >$ First Aeroelastic Mode		GM = ± 8.0 dB PM = ± 60 degrees	GM = ± 6.0 dB PM = ± 45 degrees	GM = 0 dB PM = 0 degrees (Stable at Nominal Phase and Gain)

where:

VL = Limit Airspeed (MIL-A-8860)

Aeroelastic Mode = A characteristic aeroelastic response of the aircraft, as described by an aeroelastic characteristic root of the coupled aircraft/VMS dynamic equation of motion

GM = Gain Margin = The change in loop gain required to reach unity loop gain (0 dB), at the frequency where open loop phase is at 180 degrees

PM = Phase Margin = The change in open loop phase required to reach -180 degrees phase in open loop at the frequency where the open loop gain crosses unity

f_M = The lowest Frequency in Hz where the loop gain crosses 0 dB (phase margin crossover) or open loop phase crosses -180 degrees (gain margin crossover)

If the control laws or associated gains change significantly due to these factors the stability analysis shall be made at several representative values to include the most critical case. In particular, if control law gains are scheduled based on rapidly changing parameters such as angle-of-attack, the stability analysis shall include points at representative values of such gain scheduling parameters and not just 1 g steady-state flight conditions.

For those cases where the bounds of the Operational Envelope are coincident with the Service Envelope, the gain and phase margins for the Service Envelope apply. Though no gain or phase margin requirements are presented for Operational States III and IV sufficient gain and phase margins shall exist such that Operational States III and IV can be accomplished. The probability of loss of gain margin or phase margin which results in Operational State V shall be comparable with the required probability for loss of the aircraft due to VMS failure, as defined in 3.2.3.2.

“Phase stabilization” shall not be used for achieving the specified stability margins.

For the automatic modes, the stability requirement applies only to the airspeed, Mach, altitude, load factors and aerodynamic limits that apply to the range of operation of these modes. In multiple loop systems, variations shall be made with all feedback paths held at their nominal values except for the path under investigation. A path is defined to include those elements connecting feedback sensors to a force or moment producer. The loop breaks for analysis shall be made at the actuator commands. Where it is appropriate to do so based on symmetry, the loop break can be made at the point where the command feeds a pair of actuators (symmetric stabilator command, for example).

For multi-input, multi-output systems, alternative stability and robustness analysis and criteria, rather than classical gain and phase margins, may be considered, if providing a similar level of stability protection, and if documented and agreed upon in writing with the procuring agency.

3.3.1.4.2 Non-Aerodynamic-Closed Loop

The following requirements apply to installed servomechanisms that do not rely on aerodynamics for loop closure, such as surface servoactuators that are loaded by aerodynamics but not directly positioned by aerodynamic feedback.

3.3.1.4.2.1 Stability Margins

All non-aerodynamic-closed loops shall be stable throughout the Operational and Service Flight Envelopes, and during ground operations, and provide the following margin performance:

- a. For actuation subsystems driving an aerodynamic control surface, in the nominal gain and operating condition, the minimum stability margins for the actuation loops and the associated flexible aircraft modes shall be:

Gain margin 8.0 dB and Phase margin 60 degrees

- b. For actuation subsystems not affected by aircraft flexible modes, in the nominal gain and operating condition, the minimum stability margins shall be:

Gain margin: 6.0 dB and Phase margin: 45 degrees

- c. For all actuation subsystems, whether affected by aircraft flexible modes or not, in the worst-case operating condition, at the worst-case tolerance condition, and at the end of life, the minimum stability margins shall be:

Gain margin: 3.0 dB and Phase margin: 22.5 degrees.

3.3.1.4.3 Sensitivity Analysis

A sensitivity analysis shall be performed to show compliance in those cases where the margins in Table 9 cannot be met using a nominal model of the plant and controller and to ensure satisfactory operation in fleet usage. Tolerances on feedback gains and aerodynamic uncertainties, including control surface effectiveness, shall be established at the system level based on the anticipated range of unknowns that will exist between nominal values or predictions and in-service operation.

These plant and controller uncertainties shall be established based on variations in system characteristics either anticipated or allowed by component or subsystem specification and also such factors as poorly defined nonlinear and higher order dynamics, aerodynamic parameter uncertainty, anticipated manufacturing tolerances, aging, wear, maintenance and noncritical material failures. The prime contractor shall establish, with the approval of the procuring activity, the parameters and range of variation to be considered.

The Assessment of aerodynamic uncertainties shall be performed using variations on critical stability derivatives such as C_{m0} , $C_{m\alpha}$, $C_{n\beta}$, etc. The variations employed shall be determined by the data source and its fidelity. Variations of $\pm 20\%$ are typically used. The stability margins established through the sensitivity analysis, of variations in system characteristics, shall not be less than 50% of the gain and phase margin requirements of Table 9.

The aerodynamic hinge moments on the control effectors shall be assumed to vary by $\pm 30\%$ of the maximum predicted, for those maneuvers where the controls are deflected symmetrically, and, for differential control deflection, the hinge moments shall be assumed to differ by 15%. For asymmetric maneuvers such as rolls, a 25% difference between control surface hinge moments shall be assumed, with the upwind surface having the greater hinge moment.

For those VMS that use air data systems to support air vehicle stabilization and limiting, conservative assumptions shall be made for the linearity, gain and overall accuracy of the air data, in order to provide First Flight assurance and stabilization robustness. The variations assumed may be as large as $\pm 50\%$ of the maximum value predicted, depending on the accuracy prediction uncertainty, and shall be approved by the procuring activity.

The changes in phase and gain margin that result from these variations shall not result in an aperiodic or divergent oscillation. The values of gain and phase margin that reduce the margins of Table 9 by more than 50% shall be approved by the procuring activity.

3.3.1.5 Operation in Atmospheric Disturbances and Atmospheric Models

The VMS shall be capable of operating while flying in the following applicable random and discrete turbulence environments for all design centers of gravity, mass distributions, and external stores configurations. The dynamic analysis or other means used to satisfy these requirements shall include the effects of rigid body motion, significant flexible degrees of freedom, and the VMS. The effect of the turbulence on the pitot system and on any vanes or other sensors shall be considered.

- a. In normal operation (Operational State I) and in the turbulence environments of 3.3.1.5.1 and 3.3.1.5.2 the VMS shall provide a safe level of operation and maintain mission accomplishment capability.
- b. While operating in the turbulence levels of 3.3.1.5.1 with only the Essential and Flight Phase Essential controls engaged and active, the VMS shall provide Operational State I performance.
- c. The VMS shall provide at least Operational State III for gust intensities corresponding to exceedance probabilities specified in Table 10.
- d. Noncritical controls shall provide at least Operational State II in atmospheric disturbances at the intensities corresponding to 10^{-2} probability of exceedance.
- e. Noncritical controls operating in disturbances with gust intensities above those specified shall not degrade flight safety or mission effectiveness below the level that would exist with the control inactive. Automatic or manual means to inactivate the noncritical control for flight in heavy disturbances shall be used when required.

3.3.1.5.1 Random Turbulence

The root-mean-square turbulence intensity to be used for normal flight and for terrain following shall have a cumulative probability of exceedance as listed in Table 10. The relationship among vertical, lateral, and longitudinal root-mean-square intensities and scales shall be investigated and the results used to establish intensities for lateral and longitudinal gusts. The listed turbulence intensity levels apply at the Turbulence Penetration Airspeed, VG.

Table 10 - Turbulence intensity exceedance probability

VMS Functional Critically	Aircraft Classes	
	Class III	Class I, II, IV
Essential	10^{-6}	10^{-5}
Flight Phase Essential	$\frac{1}{T} 10^{-6}$	$\frac{1}{T} 10^{-5}$
Noncritical	10^{-2}	10^{-2}

where:

T = Longest time spent in essential flight phase segment in any mission divided by the total flight time per mission

The mathematical forms of continuous random turbulence to be used in conjunction with the specified intensity levels shall meet the applicable requirements of MIL-STD-1797, MIL-F-83300, or ADS-33E-PRF requirements. Table 11 defines root-mean-square vertical gust amplitudes versus altitude for selected exceedance probabilities.

Table 11 - Root-mean-square gust intensities for selected cumulative exceedance probabilities (feet per second true airspeed)

Flight Segment	Altitude feet-AGL (meter-AGL)	Probability of Exceedance						
		2×10^{-1}	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}
Terrain Following	Up to 1000 (304.8) Lateral	4.0	5.1	8.0	10.2	12.1	14.0	23.1
	Up to 1000 (304.8) Vertical	3.5	4.4	7.0	8.9	10.5	12.1	17.5
Normal Flight Climb Cruise and Descent	500 (152.4)	3.2	4.2	6.6	8.6	11.8	15.6	18.7
	1750 (533.4)	2.2	3.6	6.9	9.6	13.0	17.6	21.5
	3750 (1143)	1.5	3.3	7.4	10.6	16.0	23.0	28.4
	7500 (2286)	0	1.6	6.7	10.1	15.1	23.6	30.2
	15000 (4572)	0	0	4.6	8.0	11.6	22.1	30.7
	25000 (7620)	0	0	2.7	6.6	9.7	20.0	31.0
	35000 (10668)	0	0	0.4	5.0	8.1	16.0	25.2
	45000 (13716)	0	0	0	4.2	8.2	15.1	23.1
	55000 (16764)	0	0	0	2.7	7.9	12.1	17.5
	65000 (19812)	0	0	0	0	4.9	7.9	10.7
	75000 (22860)	0	0	0	0	3.2	6.2	8.4
	Over 85000 (25908)	0	0	0	0	2.1	5.1	7.2

FOOTNOTE:
1 foot = 0.3048 m

3.3.1.5.2 Discrete Gusts

Discrete gust amplitudes to be used shall be established using the relationship between random and discrete gust amplitudes in accordance with the applicable requirements of MIL-STD-1797, MIL F-83300, or ADS-33E-PRF requirements, and the root-mean-square amplitudes specified in 3.3.1.5.1. The maximum discrete gust to be used shall be defined as a single full wave of a (1-cosine) function with a peak amplitude of 66 ft/s (20.12 m/s) which may be encountered anywhere within the Operational Flight Envelope. The wavelength of the discrete gust shall be tuned to provide maximum excitation of rigid-body modes, as well as low frequency structural modes.

3.3.1.5.3 Low-Altitude Disturbance Model

The model of atmospheric disturbances specified in MIL-STF-1797 shall be used for all Category C operational analysis and simulation. The effects of wind shear, turbulence and gusts may be analyzed separately. Analysis and piloted simulation shall be required, including a complete environmental representation, demonstrating compliance with the requirements with the cumulative effects of wind shear, turbulence and gusts. A non-Gaussian turbulence representation together with a wind model may also be used to represent the intermittent nature of actual measured turbulence.

3.3.1.5.4 Carrier Landing Disturbance Model

Analysis and simulation shall be employed to determine aircraft control response and path control accuracy during carrier landing. The model of atmospheric disturbances specified by 3.3.1.5.3 shall be supplemented by the model specified for carrier landing operations in MIL-STD-1797.

3.3.1.6 Internal Noise

There shall be no noticeable high frequency motion of the control surfaces due to noise signals generated by the VMS.

3.3.1.7 Residual Oscillations

Residual oscillations shall not interfere with the pilot's performance of his required tasks. For normal operation during steady flight in calm air, the VMS induced aircraft residual oscillations at all crew and passenger stations shall not exceed 0.05 g vertical or 0.02 g lateral peak to peak acceleration.

Residual oscillations in pitch attitude angle shall satisfy the longitudinal maneuvering characteristic requirements of MIL-STD-1797, MIL-F-83300, or ADS-33E-PRF as applicable. Residual oscillations in roll and yaw attitude at the pilot's station shall not exceed 0.6 degree peak to peak for flight phases requiring precision control of attitude. These limits do not apply to failure states such as VMS Operational States below State I. Residual oscillation that result in measurable actuator motion or cylinder chamber pressure variation shall be considered in defining actuator service life.

3.3.1.8 Acceleration Effects

Acceleration forces acting upon the VMS components shall not cause un-commanded control inputs, cause components to malfunction or to become inoperative within the Operational Flight Envelope and during catapult launches.

3.3.1.9 Structural Protection

If required by the procuring activity and defined in the Aircraft Detail Specification, structural protection shall be provided to prevent the pilot or VMS, while within the Operational Flight Envelope, from applying commands that will cause the aircraft to exceed its limit load factor. Provisions for pilot override under emergency conditions shall be incorporated.

3.3.1.9.1 Flight Load and Fatigue Alleviation

Provisions for flight load and fatigue alleviation shall be defined in the Aircraft Detail Specification. These provisions shall be developed using best system engineering practice to determine the tradeoff with flying qualities and flight control actuator requirements.

3.3.1.9.2 Gust and Maneuver Load Alleviation

Provisions for flight maneuver load and gust alleviation shall be determined by the prime contractor and documented in the VMS Specification, 4.1.2. These provisions shall be developed using best system engineering practice to determine the tradeoff with flying qualities and flight control sensor and actuator requirements.

3.3.1.10 Failure Transients

Aircraft motions following VMS or component failures shall be such that dangerous conditions can be avoided by automatic VMS corrective action or, for less complex aircraft, by pilot corrective action. A specified value of time delay between the failure and initiation of pilot corrective action shall be incorporated when determining compliance. The value of time delay shall be determined by the prime contractor and approved by the procuring activity. This time delay includes an interval between the occurrence of the failure and the occurrence of a cue such as acceleration, rate, displacement, or sound that will definitely indicate to the pilot that a failure has occurred, plus an additional interval which represents the time required for the pilot to diagnose the situation and initiate corrective action. During operation at a trimmed flight condition the transients shall not exceed the levels defined in Table 12. A time delay of at least 2 seconds between the failure cue and initiation of pilot corrective action shall be incorporated when determining compliance. During maneuvering flight, no single failure within the VMS, of probability equal to or greater than the VMS PLOC, shall result in: intolerable flying qualities, a dangerous change in flight path, departure from controlled flight, or exceeding the aircraft structural limits.

Table 12 - Failure transients

Operational State I or II (after failure)	± 0.5 g max incremental normal acceleration or ± 0.5 g lateral acceleration at the pilot's station or ± 10 degrees/s roll rate, except that neither stall angle of attack nor structural limits shall be exceeded. For Category A flight phases vertical or lateral excursions of 5 feet (1.7 m), ± 2 degrees bank angle
Operational State II (after failure and VMS reconfiguration)	± 2.0 g max incremental normal or ± 0.5 g lateral acceleration at the pilot's station, ± 20 degrees/s roll rate, the lesser of 5 degrees sideslip and the structural limit.
Operational State III (after failure)	No dangerous attitude reached or structural limit exceeded and no dangerous alteration of the flight path from which recovery is impossible.

3.3.2 Primary Flight Control VMS Requirements

The following requirements apply. References to mechanical or electrical flight controls apply only when that mechanization is used.

3.3.2.1 Primary Flight Control Functional Modes of the VMS

The primary functional modes control the basic longitudinal, lateral, and directional axes of the aircraft through such control effectors as elevators, ailerons, rudders and canards for fixed wing aircraft and swashplates and tail rotors for rotorcraft. The Aircraft Detail Specification shall determine the applicable modes. The modes may be separated and divided by axis and selectable by the pilot or there may be one primary mode of operation, nonselectable.

3.3.2.2 Operability Following Failures

The performance and capability of any of the Primary Functional Modes after a failure or failures shall be determined by the prime contractor and documented in the VMS Specification, 4.1.2.

3.3.2.3 Augmentation

When used, augmentation shall be compatible with all control modes and airframe dynamic considerations. Single failures in a gain scheduling function, shall not degrade augmentation performance below Operational State II. Pilot-operated gain changing devices shall only be used as emergency backup equipment. Specific approval shall be obtained from the procuring activity for this feature. Positive mechanical, electrical, or software/firmware limits shall be provided in gain schedulers to preclude exceeding limiting gain values.

3.3.2.4 Ratio Changing Mechanisms

Where ratio changing mechanisms are used, monitors and emergency positioning means shall be provided if improper positioning can result in a safety of flight hazard. The requirements for rate of ratio changing shall be defined based on the requirements of MIL-STD-1797, ADS-33E-PRF, and MIL-F-83300 for transient response to configuration or control mode change.

3.3.2.5 Reversion to Emergency Backup Modes

If a mechanical backup mode is provided for a VMS, at least VMS Operational State III shall be provided following reversion to that backup mode. While the backup mode is disengaged, interaction of backup mode provisions with the normal mode shall not degrade operation below State I.

If a single VMS power system is used in an Essential or Flight Phase Essential fully powered system, emergency mechanical reversion or an emergency power source shall be provided. On single-engine aircraft, the emergency power source shall be independent of engine operation. It shall be possible to re-engage the normal power source in flight following operation with manual reversion controls or emergency power. Manual or automatic changeover to or from emergency provisions shall not result in capability worse than VMS Operation State III.

3.3.2.6 Inceptor Requirements

Inceptors shall comply with the following requirements and those of 3.7.7.1. For side stick and hand controllers, refer to ARP5764 for recommendations for active inceptors and to ARP6001 for passive inceptors.

3.3.2.6.1 Control Centering Breakout Forces and Free Play

The corresponding design requirements shall meet the applicable requirements of MIL-STD-1797, MIL-F-83300, or ADS-33E-PRF. Selected sensitivity and breakout forces shall not lead to overcontrol tendencies. The control sensor electrical deadband shall not be less than the equivalent mechanical deadband or the equivalent of the breakout forces.

3.3.2.6.2 Control Force Sensitivities

The pitch, roll, and yaw control force sensitivities shall meet the requirements of MIL-STD-1797, MIL-F-83300, or ADS-33E-PRF requirements as applicable.

3.3.2.6.3 Controller Kinematics

Kinematics shall preclude hazardous unintentional inputs (cross-coupling) into one or more axes with normal control motions within the limits of ultimate structural load factor, design maneuver, and turbulence induced accelerations experienced at the crew station. Controller damping and mass balance shall be set to minimize any aircraft-pilot coupling and/or pilot augmented oscillation tendencies.

3.3.2.7 Feedback to Crew Station Controls

The control device motion and force required to accomplish stability and control augmentation shall not be evident at the crew station controls. Vibratory forces or motion acting upon elements downstream of the controller shall not be evident at the crew station controls. Force and motion feedback to crew station controls shall be considered as not evident if the force's magnitude is less than half the lowest breakout force of the applicable control. There shall be no feedback through a mechanical backup during normal or degraded operation of the PFCS. Full freedom of operation of cockpit controls shall be possible at all times that stability augmentation is in use. Provisions shall be made in cockpit control motions so that recovery from an augmentation actuation hardover is possible under all flight conditions. The cockpit control position may shift under this condition.

3.3.2.8 Active Feel Augmentation

The pilot and copilot shall have the capability of overriding the feel system at all times. Upon failure of the active feel augmentation system, the control feel shall revert to a breakout force and a force gradient versus deflection required by MIL-F-83300, MIL-STD-1797, or ADS-33E-PRF.

3.3.2.9 Surface Rate Capability

The VMS control surface rate capability shall be adequate to satisfy the Flying Quality, Control Margin, and Pilot Induced Oscillation (PIO) requirements specified in MIL-STD-1797.

3.3.2.10 Data Latency

The VMS data latency and computational delay shall be minimized to ensure the aircraft will satisfy the Flying Quality, Control Margin, and PIO requirements specified in MIL-STD-1797 and ADS-33E-PRF.

3.3.3 Secondary Flight Controls

The Aircraft Detail Specification shall specify which modes are applicable. Typical secondary modes include but shall not be limited to the following:

- a. High Lift Control
- b. Speed Brakes
- c. Direct Lift Control
- d. Variable Wing Sweep Control
- e. Stability Altering Systems
- f. Trim (manual and automatic)
- g. Maneuver Flaps
- h. Nose Wheel Steering
- i. Wheel Brake Control Anti-Skid

Outputs from the Secondary Functional Mode controllers shall not cause objectionable aircraft response characteristics.

3.3.3.1 High Lift Control

A control system shall be provided for actuating high lift devices. Unless specified in the Aircraft Detail Specification, the prime contractor shall specify the time to operate the landing flaps.

Under normal operating conditions a typical requirement would be: not less than 3 seconds, nor more than 8 seconds, at the maximum aircraft speed for which they should be operated. For Class II and III transport aircraft typical operating times are in the range of 15 to 20 seconds.

High lift devices shall contain provisions for synchronous operation, unless it can be demonstrated that no hazardous flight attitude will result from unsynchronized operation. The demonstration may be conducted using pilot simulation provided the aerodynamic data base has been explicitly developed to include asymmetric flap forces and moments. In the event of a failure in the high lift control system, the high lift device shall maintain synchronization, or remain synchronized without motion.

The degree of asymmetry and the flight conditions for demonstration shall generally be the most critical for inducing hazardous flight attitudes. This demonstration shall be approved by the procuring activity and included in the VMS Development Plan, 4.1.1.

An emergency means for operating the high lift devices shall be provided on aircraft where safe operational landings cannot be accomplished without use of the high lift devices. The emergency system shall be completely independent of the basic high lift system up to, but not necessarily including, the actuators.