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FLIGHT CONTROL SYSTEM CRITERIA FOR ADVANCED AIRCRAFT FOR INCORPORATION INTO AN UPDATED MILITARY SPECIFICATION

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THE FIRST PHASE OF A MULTI-PHASE STUDY FOR THE DEVELOPMENT OF CRITERIA FOR ADVANCED FLIGHT CONTROL SYSTEMS WAS COMPLETED.

THE STUDY CONSISTED OF REVIEW OF EXISTING SPECIFICATIONS AND LITERATURE AND THE ESTABLISHMENT OF A BASELINE CRITERIA DOCUMENT. THE BASELINE CRITERIA DOCUMENT INCLUDES REQUIREMENTS EXTRACTED FROM CURRENT MILITARY SPECIFICATIONS, ADDITIONAL REQUIREMENTS FOR ADVANCED AIRCRAFT, AND ALSO AREAS IN WHICH FURTHER STUDY IS REQUIRED.

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FOREWORD

This report documents the results of a study to develop criteria for advanced FCS, specifically for DFBW systems. The study was performed by the Grumman Aerospace Corporation in Bethpage, New York 11714, for the Naval Air Development Center in Warminster, Pa. 18974, under contract N62269-79-C-0430. Program direction was administered by Mr. Charles Abrams, Technical Manager of Navy Digital Flight Control Development at the Naval Air Development Center, and Mr. Donald Gertz, Group Head, Navigation Guidance and Control Equipment at Grumman. Technical support was provided by Mr. Walter Kaniuka of the Naval Air Development Center and Mr. Kurt Grobert of the Grumman Aerospace Corporation.

SECTION 1

INTRODUCTION

Recent advances in aircraft flight control technology have caused related military specifications to become outdated. With the advent of DFBW systems, electronics, sensors, and actuators have become essential to flight safety. Supporting systems such as electrical power generation and distribution have also become flight critical items. In addition the requirements for new design techniques related to the FCS, software, modes of operation, and the "illities" are inadequate and require further definition.

The current military specifications related to flight control systems are:

- MIL-C-18244A, Control and Stabilization: Automatic Piloted Aircraft; dated 16 March 1955
- MIL-F-18372, Flight Control Systems: Design Installation and Test of, Aircraft; dated 31 March, 1955
- MIL-C-23866A, Approach Power Control Set AN/ASN-54; dated 4 February 1965
- MIL-F-9490D, Flight Control System Design, Installation and Test of Piloted; dated 6 June 1975.

The following document although not formally employed, was also reviewed: MIL-F-0000B, Flight Control Systems - Design, Installation and Test of Pilot Aircraft; dated 6 October 1972.

These specifications basically apply to mechanical FCS with Automatic Flight Control System (AFCS) augmentation and reflect the state-of-the-art of the 1950's.

The DFBW system criteria study was initiated to examine the obsolescence problem by surveying existing requirements, outlining requirements which require further study and definition, and finally establishing a baseline criteria which can be expanded in subsequent program phases into detailed requirements.

SECTION 2

SUMMARY

The first phase of a Digital Fly-By-Wire (DFBW) criteria study has been completed under Contract N62269-79-C-043. This study was necessitated by recent advances in Flight Control System (FCS) technology that have made present military FCS specifications outdated. Specifications such as MIL-C-18244A and MIL-F-18372 date back to 1955; and although revisions/replacements have been contemplated, they have not been accomplished. With present day advances in digital computer technology, DFBW systems offering advanced control modes have become practical. Although DFBW is also applicable to VSTOL aircraft, this study addresses only those areas common to both conventional and vertical takeoff aircraft.

As the first step in the study, existing FCS specifications were examined in detail to determine current criteria for conventional FCS and the applicability of these criteria to a modern DFBW system. These specifications include: the standard Navy specifications for FCS, MIL-C-18244A, and MIL-F-18372; MIL-C-23866A for the AN/ASN-34 Approach Power Control Set; a proposed replacement for MIL-F-18372 which was prepared in 1972 and was identified as MIL-F-0000B; and an Air Force FCS specification MIL-F-9490D. Detailed paragraph-by-paragraph reviews of MIL-C-18244A, MIL-F-18372, and MIL-F-0000B were completed and are included in the appendices of this report. For each paragraph, specific comments and recommendations concerning applicability to a DFBW system are made. A matrix of criteria from these specifications was then compiled for use in preparing criteria for a DFBW system.

Present military specifications generally are limited to conventional mechanical and/or hydraulically operated primary/secondary FCS with electrical Stability Augmentation Systems (SAS) and simple pilot-relief autopilot modes. Although the electrical portion of these systems is usually not flight critical, flight safety is directly dependent upon the electrical design in DFBW systems.

The second step of the study was to identify criteria for which new requirements and capabilities are needed. This was accomplished by a review of the technical papers presented at the July 1978 Flight Control Systems Criteria Symposium (Ref. 1) and other available papers describing FCS in modern high-performance aircraft. Based on these reviews, several new items such as redundancy, survivability, input/out, EMI/

lighting protection, advanced control modes, digital computer characteristics, software, and other associated functions were identified. A detailed description is contained in the discussion section.

Several courses of action were considered in arriving at a baseline criteria for a DFBW system. Among these was combining MIL-C-18244A, MIL-F-18372, and MIL-C-23866A into a single document. Also considered was the feasibility of using MIL-F-9490 as a baseline document. Both of these approaches were considered inadequate since these specifications primarily address conventional FCS. Therefore, it was decided to generate a new baseline criteria document by integrating the matrix of criteria derived from the military specifications with the criteria derived from the review of technical papers. This was the third step of the present study and a preliminary baseline document is included in the appendices. This baseline document has not been finalized since criteria must be developed for several critical issues.

As a fourth part of the present study, recommendations were prepared for additional study phases leading to the generation of a final criteria document for a DFBW and a User's Guide. Among the tasks proposed were formulation of criteria for additional requirements identified in the present study, definition of unique VSTOL critical issues, generation and validation of an interim criteria document and a User's Guide, coordination of an industry review, and preparation of final criteria document and User's Guide.

SECTION 3

DISCUSSION

This section of the report is intended to review the effort expended in formulating the initial criteria for future DFBW systems. In Subsection 3.1 a methodology approved by the Navy Technical Monitor is described. Subsection 3.2 contains a summary of the criteria survey; whereas the detailed specific comments can be found in the appendices. In addition to the related military specifications, these documents included a recent symposium on FCS criteria sponsored by the Navy, Ref. 1, and recent literature related to the early development of FBW systems.

In performing the survey, it became apparent that additional requirements had to be established which more clearly set criteria for a DFBW system. This was due to the emphasis of existing criteria on the more conventional FCS. Subsection 3.3 points out the need for further study in these areas. Subsection 3.4 contains two documents which are basic building blocks for the development of a new all-inclusive DFBW specification. One of these is the matrix of criteria which relate the requirements of present specifications to each other paragraph by paragraph. This in a sense is the working document from which updated criteria can be developed. The second document is the outline of a baseline criteria document. This can be thought of as the framework upon which to build the new criteria. Within the scope of this contract, a preliminary version of this baseline document was generated and is contained in the appendices.

3.1 STUDY APPROACH

From the standpoint of a prime contractor for military aircraft, technological advances of the last five years make it possible to develop a DFBW aircraft with all of its incumbent potential advantages of weight reduction, improved survivability, high maneuverability, and reduced cost. The flight safety aspects of a DFBW system distinguish it from other mission related avionics in the sense that it must be operative throught all phases of flight.

Despite its revolutionary implications FBW has a readily traceable history of evolution. Early aircraft used manual control exclusively; when the pilot could no longer move the control surfaces, a hydraulic boost was added. The next major improvement was to fully powered controls; the mechanical linkage moves only the valves on the hydraulic actuators. In this design, the pilot is no longer mechanically connected directly to the control surface and must rely entirely on hydraulic power. In this case, he has to be artificially provided with stick "feel" through such devices as springs, viscous dampers, bellows, and bob weights, which generate the desired stick forces and handling qualities. All modern, high-performance aircraft have fully powered control systems.

From power augmentation the next step was the employment of a SAS, where feedbacks of aircraft motion are used to damp out unwanted motions or oscillations of the aircraft. A SAS is commonly used in all modern aircraft to provide better flying qualities.

The next advance was the employment of a Command Augmentation System (CAS), which combines the damping function with an electrical feed-forward control signal, allowing the use of higher feedback gain. CAS is being used successfully in several modern military fighters.

The traditional mechanical FCS has grown in complexity to meet the increased requirements. From the simple manual control of earlier systems, the FCS evolved into complex nonlinear linkages, mixing assemblies, power actuation devices, and active artificial feel systems containing hundreds of different parts and interconnections. For these systems, the designer's task is further complicated by the contradictory requirements for low weight and high reliability. The logical progression would be to replace this mechanical FCS with a FBW system.

The Navy recognized that the documents which govern the design and development of modern FCS are inadequate and, via a long term plan, proceeded to embark on this initial study to develop an adequate controlling document, primarily one that recognizes the state-of-the-art advances in technology as applied to a future FCS.

The specific methodology utilized for this study was iterative in nature and consisted of two major tasks:

- Literature Survey
- Criteria Formulation.

The literature survey consisted of reviewing existing military FCS specifications, both Navy and AF documents, the proceedings of the Flight Control Systems Criteria Symposium (Ref. 1), and other pertinent documents related to advanced FCS. As an aid to the formulation of new criteria, a matrix, of applicable requirements from the existing military specifications was generated (Subsection 3.4.1).

The second task, the criteria formulation, was based on the literature survey. A preliminary version of the criteria formulation consisting of an outline of the proposed requirements was generated (Subsection 3.4.2). Detailed requirements available from the existing literature, where applicable, were rewritten and inserted into the appropriate sections of the outline to form the Baseline Criteria Document. Other requirements which need further study and definition have been included in the document.

From the work performed during this study, recommendations were formulated to provide a potential path for accomplishing the end objective. The phases associated with this plan are elaborated in Section 4. It should be noted that the scheduling of these phases is not shown since it depends to a large extent on the available funds.

3.2 SURVEY AND APPLICABILITY OF EXISTING CRITERIA

The governing documents for conventional flight control systems were reviewed to determine the applicability/deficiencies of these specifications with respect to DFBW systems. A summary of these deficiences is contained in the following paragraphs with a complete specification review for MIL-C-18244, MIL-F-18372, and MIL-F-0000B contained in Appendices A, B, and C respectively.

In addition, Subsections 3.2.2 and 3.2.3 contain summaries of pertinent discussions from the Flight Control Symposium (Ref. 1) and a critique of other applicable documents reviewed during the course of this study.

3.2.1 Military Specifications

The following are general comments relative to the existing military specifications as related to DFBW systems.

- Present specifications (i.e., MIL-F-18372, MIL-C-18244A, and MIL-C-23866A) are written to define the requirements on a subsystem level
- Manual and AFCS modes are inseparable in future FCS
- Present specifications do not account for the use of modern control techniques, such as DFBW, multiplexing, fluidic control, fiber optics, distributed sensors, and microprocessors

- Redundancy requirements are not governed by reliability, fault tolerance, and survivability considerations in present specifications
- Present specifications are not sufficiently broad to cover FCS for several types of aircraft
- Present specifications do not account for the continued growth and expansion of technology including new concepts in control, hardware modularity, software language, etc.
- Requirements for prime and back-up systems do not evolve from reliability, survivability and/or fault tolerance requirements in present specifications.

Some of the major interfaces not adequately controlled in present specifications are:

- Displays and Controls:
  - Display of FCS condition in terms of performance and failure status needs to be expanded
  - Cockpit controls are not adequately defined
- Propulsion:

  Certain flight modes in the low speed regime require automatic thrust control. Auto throttles have also been considered for automatic cruise modes. When addressing direct flight path control, the problem becomes complex and multivariable in control function, which present specifications do not adequately address. Other modes of concern are thrust vectoring on any of the three axes
- Power Systems:

  Power Systems (hydraulic, electrical, and pneumatic) reliability form an important part of the overall FCS requirements. Present specifications do not adequately address interface control in this area. Consideration should be given to reliability/redundancy and degraded mode performance consistent with overall system design

- Other Avionics:

  Flight control functions rely on inputs from other avionic equipment. Guidance modes, authority limits, and gain changes, for example, require interface control. In present specifications interface definition is incomplete and should be expanded.

The following subsections contain some specific comments for each of the current specifications in terms of their limitations to define future FCS requirements. A detailed set of comments for the navy military specifications are contained in Appendices A through D.

3.2.1.1 MIL-F-18372 Flight Control Systems: Design, Installation, and Test of Aircraft, Generation Specification for

- The definitions of Para 1.2.1 relating to classification of control systems do not include complete FBW systems, fluidic controls, direct electrical linkage systems as well as primary and back-up systems using propulsive and reaction controls

- Paragraph 3.1.2.3 and amplifying paragraphs reflecting the requirement of completely isolated and independent hydraulic systems do not address the recent advances and benefits of shared power systems and hydraulic switching valve technology. The use of these techniques, because of performance benefits (primarily weight and survivability) are now well within the state of the art (i.e., F-15 and the Space Shuttle)

- The prohibition of flexible push-pull type controls in primary and secondary axes are stated in Para 3.1.1.18.4 and do not acknowledge successful use of ball bearing type flexible cables in F-15 and contemporary aircraft

- Paragraph 3.1.1.16 concerning fastenings, does not reflect the multiplicity of fastener designs now available to the flight control designer. A complete treatment of fail safe design philosophy and positive locking self-retaining bolts should be included

- Pilot control arrangement and geometry, as outlined in Para 5 of Subsection 3.2.1.2, does not reflect various hand-controller devices of both isometric and displacement design types.

In addition, the critical technology areas such as rotary mechanical actuators, no backs, clutches, load limiting devices, flutter and buzz damper installation, etc. should be included in the combined specification.

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

- The categories of operation (Para 3.1.1) do not adequately cover primary control modes and advanced control techniques, particularly for marginally stable vehicles
- Redundancy requirements inherent in FBW design concepts are inadequately defined (Para 3.1.1.1.2)
- Component selection (Para 3.1.1.2) is too restrictive to satisfy state-of-the-art technology.

Advanced FCS for modern aircraft demand more realistic maintenance procedures and assured performance under aircraft environmental conditions. Two examples include:

- The stipulated replacement time for any AFCS component of not more than 1/2 person hours is generally unrealistic (Para 3.2.1)
- Radio Interface Test requirements specified in Para 4.3.5.3 are inadequate to assure proper operation of DFBW systems, particularly for lightning protection.

This specification includes several design, data, and test requirements which could result in high cost impact. Examples are:

- Data requirements specified in Para 3.5 could be reduced significantly with minimum impact on the quality of the product
- By increasing the scope of the ground simulation testing (Para 4.2.1), flight test (Para 4.6) may be substantially reduced
- Flight verification of stability margins (Para 3.1.1.6.1) should be limited to those parameters that are found to be marginal during ground simulations.

Attention should focus on electrical power generation systems, emergency power systems, battery installations, electrical cable routing, and electrical component mounting with considerable detail given to shielding, bonding, isolation of redundant circuits and connector environment, and lightning strike protection.

3.2.1.3 MIL-C-23866A Control Set, Approach Power AN/ASN-54

This specification covers the design and performance requirements of a specific Approach Power Control Set (APC). It has been the general intent of this specification to produce an auto throttle system which will hold angle-of-attack (AOA) constant throughout all commanded maneuvers and gust disturbances, except for small momentary changes. It is also the intent of this specification to produce an overall system design which will enable the pilot to maneuver the airplane as required to maintain the proper flight path during final approach. Present low speed auto throttles provide good speed trim and stability; however, their design features are such that the airplane response to flight path angle is very sluggish if small changes in AOA are to be maintained. This causes the pilot to overcontrol to obtain a more rapid flight path change, producing large AOA changes, with the final result being a constant pumping of the stick all through the final approach. This stick pumping is unavoidable since the flight path changes recognized are transient changes which exist only for small durations.

The fact that past designs have not developed into good overall direct flight path control systems that comply with the general intent of that military specification leads one to conclude that the performance requirements as written are not adequate. Also, since flight path control involves the longitudinal control system, it seems proper to incorporate the contents of this specification within a specification structured for overall FCS design and to specify in that document requirements for a direct flight path control mode.

3.2.1.4 MIL-F-9490D (USAF) Flight Control Systems: Design, Installation, and Test of Piloted Aircraft, General Specification for

This Air Force Specification is the most recent (1975) of the military specifications relating to the FCS. In addition, there are several affiliated documents (Ref. 2-4).

A User's Guide is an excellent companion to any military specification and should be a part of any new FCS specification package. References 3 and 4 act as a review and critique of MIL-F-9490 and give two other points of view on the same requirement.

Paragraph 1.2 of MIL-F-9490 divides the FCS classification into two categories, Manual Flight Control System (MFCS) and AFCS. The User's Guide gives the justification of why the change from the classical, Primary, Secondary, and Automatic to Manual and Automatic. To reduce the number of problems related to secondary FCS, the differentiation between primary/secondary FCS requirements was dropped and combined into a single MFCS. The reason for doing away with secondary FCS as a classification is questionable. Traditionally, flaps, slats, speed brakes, etc., have been classified as secondary FCS. Reference 4 agrees with the deletion but recommends four classifications, Manual, Aerodynamic Enhancement, Automatic, and Limited. The Limited Classification has some value to DFBW.

The specification is deficient with respect to DFBW primary controls, reliability, survivability, digital computer control, built-in-test (BIT), electrical power, and EMI/lightning protection.

3.2.1.5 MIL-F-0000B Flight Control Systems: Design, Installation, and Test of Piloted Aircraft, General Specification for

The definition of a Type IV system, which is a "Control-by-Wire Flight Control System" is defined in Para 1.2.1 and specifies some general requirements in Para 3.1.1.4.

This specification has a unique approach to secondary FCS and states, "No system shall be so categorized (as a secondary FCS) until analysis demonstrates that lack of performance or malfunction will not effect safety of flight." In other words, a flap system that is safety of flight is considered part of the primary FCS and one that is not part of the secondary FCS. It should state that any FCS category (including Automatic) that is safety of flight should meet the more rigorous requirements of the primary FCS.

In general, this specification is deficient in the same manner as Ref. 6. There is a lack of detail with respect to:

- Redundancy
- EMI/Lightning
- Survivability
- Advanced Control Modes
- Digital Computer Characteristics
- System Test/Validation
- Maintainability
- Sensor Systems.

3.2.2 Flight Control System Criteria Symposium (Ref. 1)

At the symposium in July 1978 four different panel groups discussed the following subjects pertaining to a new FCS specification to replace MIL-C-18244A:

(1) Control System Design

(2) Digital Hardware

(3) Digital Software

(3) Performance Requirements.

Detailed comments are included in Appendix V. The following are some highlights from their discussion.

3.2.2.1 Control System Design

- The specification requirements should include the desired mission performance, not how to go about getting it. It should specify the velocity vector in space, not the aircraft roll rate.
- The probability of mission success and the probability of loss of control should be specified, but not the degree of fail-operability
- The magnitude of allowable transients should be related to the mission being flown as well as the type of aircraft involved. Allowable transients for a fighter are different than for a transport. There's also a difference between a transient during the landing phase where it could be catastrophic versus one at high altitude
- The present classification of primary and secondary to manual and automatic for DFBW should be changed
- The degree of criticality of the control mode should be specified. For example, failure of a mode that limits angle of attack is more critical than Altitude Hold
- Definition of a back-up system which could be mechanical, fluidic, or electrical shall specify that it is only used in an emergency situation
- BIT are those tests performed on the ground as opposed to airborne automatic tests. The airborne tests should be called "In-Flight Integrity Management" (IFIM)

- It is suggested that the term "electrical" instead of "fly-by-wire" be utilized because direct electrical link is associated with FBW. Fluidic and light transmission FCS should have a different classification
- In the automatic classification the following division is suggested: first, pilot relief; second, active controls relating to the structure; third, safety monitors; and fourth, automatic navigation with automatic carrier landings
- In defining interface requirements, the details of those interfaces vary greatly with the aircraft involved. Writing a general specification that does anything more than list areas of concern should not be done. Details of interfaces should be left to the detail specification
- The term multimode flight control means that the modes are automatically selected for mission segments and are optimized for those segments. There should be some indication to the pilot as to which mode is engaged
- The specification shouldn't inhibit the design procedures. If a design meets the safety, reliability, and performance requirements, then it should be allowed
- The automatic carrier landing and the Approach Power Compensation (APC) should be integrated into the same design.

3.2.2.2 Digital Hardware

- Definitions are needed for the terms "abort" and "loss of control." An abort is mission dependent and implies degraded handling qualities
- The Quality Assurance portion of the specification should specify how the abort rate or catastrophic failure rate is complied with: Is this accomplished analytically or by some laboratory testing? The reliability for the abort rates and catastrophic failure rates are the responsibility of the user to define and should be in the specification
- Allocating the MTBF for individual black boxes is the responsibility of the contractor. Implementing this allocation is the responsibility of the vendor
- Single point failures should be specified as having a very low probability of occurrence

- Specifications should not imply or require a back-up flight control. The contractor should decide whether or not back-up flight control is required rather than be specified in the DFBW system

- Navy's philosophy on peculiar ground support equipment or Automatic Test Equipment (ATE) for maintainability has changed. Their present thinking is, where necessary, peculiar ground support equipment or additional test equipment should not be eliminated by the specification. Anything that can be done to eliminate false removals at the aircraft level should be encouraged

- The subject of finding intermittent failures during post flight checks with non-volatile memory, that store comparator trips was discussed. Whether this or a mechanical flag on the WRA is utilized is a function of the individual design. However, a post flight identification of intermittent faults is a must

- Spare memory and speed should be specified in the specification

- Standardization of software and digital hardware will be required in the future

- Digital problems such as transport delays or digital noise should <u>not</u> be addressed in this type of specification

- Fly-by-wire with digital electronics should not be the only concern. The majority of problems are not with the electronics portion of the control system, but with the actuation systems, the hydraulic system and the interface with other systems. The design and development costs of these systems are far greater than the electronics

- Electrical actuation is not likely in the near future. Integrated actuators and power-by-wire is more promising.

3.2.2.3 Digital Software

- As a general specification it shouldn't address coding but it should be oriented towards documentation, general guidelines, and functional requirements

- It is a difficult task to define the relationship between software specifications and the verification process. What is the extent of the verification process:

- Generic software failures related to the multiplicity of potential computing paths within the software were discussed
- The distinction between flight critical and mission effective software was discussed. More stringent requirements for the software that is required for flight critical functions is desirable
- The question arose as to whether the Navy is going to be reponsible for maintaining the flight control software. If it is, there should be different requirements on documentation and controls
- It was agreed that utilization of higher order language (HOL) reduces the maintainability tasks, but requires further studies to evaluate all the tradeoffs.

3.2.2.4 Performance Requirements

- APC should be integrated into the FCS
- The FCS specification should identify the interactions with displays, structural loads, and flutter disciplines
- Although the control laws are mission task dependent they should not confuse the pilot from mission phase to mission phase and from task to task
- The specification should define the levels of reliability and maintainability in terms of mission task degradation, and the redundancy management problem should be left to the designer
- The medium of FCS implementation, that is, whether it's mechanical, electrical, fluidic, optical, or any combination thereof, should be left to the designer. And he should have the latitude to choose all hardware from the sensor to the effector within the constraints of the specification or the "ilities"
- The FCS specification needs a User's Guide which should include different design approaches.

3.2.3 Other Applicable Documents

This section summarizes six recent papers (Ref. 10 through 15) related to digital flight controls from the many that were reviewed.

3.2.3.1 "Design and Development of the Digital Flight Control System (DFCS) for the F-18" (Ref. 10)

- The F-18 is a high performance fighter aircraft that uses a control-by-wire (CBW) control system. Primary control uses redundant digital processors to compute surface position
- A direct electric link (DEL) is a backup mode which provides no augmentation and is used after multiple failures
- The stabilizer uses a mechanical backup system to provide pitch and roll control in the event of three or four processor or power supply failures
- Early design decision involved determining basic control concept, the level of redundancy, redundancy management, and degraded mode of operation
- Level 1 handling qualities are achieved following one electronic failure, and at least Level 3 qualities are achieved following a similar electronic failure. For <u>any</u> failure condition that might occur, Level 3 handling qualities are achieved
- In-line monitoring which could reduce the level of redundancy required from a quadruplex to a triplex was not developed and therefore a quad system was used
- In-service failure rates of sensors such as rate gyros and accelerometers dictated an unaugmented backup mode termed DEL
- Until in-service experience with carrier based FBW control is acquired, a mechanical backup mode is required to provide get home capability because of electromagnetic interference and corrosion
- Notch filters are required to attenuate undesirable motions which are sensed by sensors due to aeroelastic bending modes
- Flap position limits are scheduled as a function of dynamic pressure and Mach. Ailerons droop to match flaps
- At high AOA the leading edge flaps are extended to increase lateral-directional stability. For digital processor failures there is an analog backup mode for leading and trailing edge flaps
- Pitch axis Command Augmentation Systems (CAS) uses pitch rate and normal acceleration blended with longitudinal stick and with gain scheduled by air data

- Roll axis CAS uses lateral stick with roll rate with air data scheduled gain
- Forward loop integrator maintains trim without the need for the pilot trimming
- Aileron and differential tail surface authority is reduced as a function of increasing AOA to combat adverse sideslip
- Yaw axis CAS uses yaw rate and lateral acceleration and is gain scheduled as a function of AOA and limited as a function of dynamic pressure. Stick-to-rudder interconnect (SRI) is used during rolling maneuver and is gain scheduled as a function of AOA
- In the power approach flight configuration, sideslip rate is also blended with the other parameters of Yaw CAS
- Rudder Toe-in is programmed as a function of AOA to modify the aerodynamic pitching moment to reduce liftoff speed, improve bolter, and augment the longitudinal static stability
- The control law development for the F-18 FCS used a 10 db gain margin and at least 45° phase margin as a design goal
- Modifications to the early control laws resulted in increasing the pitch rate feedback gain and replacing the low-pass filter with a lag-lead filter. This increased the bandwidth and quickened the pitch response. This helped to improve the tracking capability provided to the pilot
- Three test facilities were used for software verification and interface testing
  - A software development facility consisting of the flight control computers interfacing with a flight simulator, mission simulator, and a Head-Up Display
  - An avionic laboratory containing the hardware on a test bench
  - An iron bird facility with simulation of the air-frame for closed loop operation
- Flight tests indicated the roll axis was too sensitive and hardware changes were called for. The design changes were first tested on the flight simulator and then incorporated into flight hardware.

3.2.3.2 "Impact of CCV Requirements on FCS Design" (Ref. 11)

- Controlled Configured Vehicles (CCV) require FBW FCS because of unstable longitudinal control. A three channel FBW was chosen as optimum

- Multimode control laws including direct lift, side force control, fuselage pointing, and maneuver load control are suitable to digital computers
- Fixed gain for backup using rate gyros and accelerometers provide Level 3 flying qualities
- Mission requirements dictate variable gain scheduling as a function of air data or calculations using some form of self-adaptive approach
- DFBW employed because of extensive signal processing and flexibility required by multimode control laws
- Gain scheduling technique was chosen over self-adaptive methods because of available digital air data. Air data are required for mission success
- For flight safety no more than 3.5 failures/million hrs. For mission success no more than 350 failures/million hrs
- Each command channel must have an independent hydraulic source
- Key cost parameter is life-cycle cost∿ complixity rating. Assumption was that the more complex configurations require more maintenance actions, need greater spares, and/or is more difficult to troubleshoot
- Dual-fail operational capability required for the FBW electronics, including secondary actuators
- Hydraulic system requires third source
- Electric power is DC and requires third source plus a battery
- Auxiliary sources are required for redundancy
- A self-test coverage of 95% states that one in 20 failures go undetected
- Self-test, in-line monitoring and BIT are all required
- Digital computers can delay issuance of faulty commands, thereby allowing up to 200 msec to isolate failure (otherwise it requires 50 msec)
- Self test of sensors requires sensing elements and monitoring networks to evaluate performance. This requires additional hardware adding complexity and expense. Coverage is only 74% for rate gyros and 97% for accelerometers. Therefore, self test for rate gyros is questionable
- Output of Linear Variable Differential Transformer is the difference of two coils. The sum of the voltages may be used as a self-test signal because it

is a constant and can be monitored continuously. By spring loading even mechanical failures can be detected achieving 100% coverage

- Selected configuration has 6 skewed rate gyros and triplicate accelerometers, transducers, computers, and secondary actuators with on-line monitors
- Duplex actuators for mission critical controls.

3.2.3.3 "Air Data System Redundancy Required for F-16 FBW Flight Controls" (Ref. 12)

- The F-16 utilizes a CCV concept of longitudinal relaxed static stability to realize increased performance benefits. A quadruple-redundant FBW is used to achieve dual fail performance capability
- The air data system is commensurate with the reliability of the FCS
- MIL-STD-1553 modified MUX-bus interfaces with Head-Up display, FCS, and inertial navigation systems
- Secondary FCS provides high-lift, aerodynamic braking, etc.
- Flight controls, horizontal stabilizers, flaperons, and rudder. Leading edge flaps as a function of Mach and AOA
- Pilot inputs are thru displacement-type, force-sensing control stick and rudder pedals commands which are quadruple
- Quad redundant rate gyros and accelerometers are utilized
- The integrated servo actuators have dual hydraulic supplies
- Redundancy management involves signal selection, failure detection, failure isolation, and recovery from system faults. Basic concept is an extension of the F-111 design
- The quad data is separated into a triple channel of on-line data and a single channel in standby. Prior to a failure, the mid value of the triple channel is utilized for system computations. After the first failure, the stand by channel replaces the failed signal within the triple channel
- After a second failure, the signal nearest zero is selected
- Line replaceable units include the Air Data Computer, Normal/Lateral Accelerometer Assembly, etc.

- The Air Data Computer is a central processor special purpose, fixed memory (2592 16-bit word) computer
- Continuous failure monitoring is designed into the central processor and is performed every iteration cycle
- Two types of BIT, continuous performance monitoring and ground initiated BIT, are contained in the system.

3.2.3.4 "F-18 Flight Control Fault Tolerant Design" (Ref. 13)

- The F-18 FCS is quad redundant in electronics driving five surface actuators which are themselves quad
- The primary mode of the FCS is full authority DFBW
- The FCS computers transmit information to the mission computer for display to the pilot
- Back-up control is provided with analog Direct Electrical Linkage (DEL) for ailerons and rudders. A mechanical linkage is provided for stabilizer back-up. Reversion to the back-up modes is automatic
- The electronics consist of two Flight Control Computers with two channels per Weapon Replaceable Assembly (WRA)
- The rate sensors are located in two WRA's consisting of two channels per WRA
- The computers have two voting nodes, one for sensor selection in the software and a current sum vote at the actuators
- Cross channel data between processors is by serial data buses
- There are identically stored programs in each channel
- The computation iteration rates in the computers are 160, 80, 40, 20, and 10/sec
- Data management structure is designed to minimize transport delays
- One channel in each computer interfaces with the 1553 multiplex data bus. The bus is dual and the Mission Computer is the bus controller
- The multiplex bus carries data for outer loop control and for BIT initiation; and transmits sensor data, flight test data and BIT results
- The surface command is converted to an analog signal by a 12-BIT digital to analog converter

- With BIT, if a failure is detected, the failure is isolated to the WRA and this information is transmitted to the Mission Computer
- A signal selector is placed in a signal path to reduce system failure transients to a level that is safe for flight
- A signal balancing scheme typical of analog system mechanizations is used to reduce transient levels for first and second failures. Another method is used to limit third failure transients which takes into consideration the magnitude of the difference and departure rate of the two remaining signals
- The Electro Hydraulic Valve (EHV) is the only other voting node in the signal path. Each EHV has four coils driven from the four channels and therefore hydraulic flow is the sum of the 4 coil currents. If one coil current goes hardover the high gain of the electrical feedbacks from the remaining good channels will limit the actuator output
- A quad servo actuator has 4 EHV's and two hydraulic systems. Each LVDT is excited from the appropriate channel and excited by 8 VRMS at 1800 Hz. Each channel is offset from 1800 Hz to eliminate beat frequency coupling. The stabilizer and flaps are quad
- The aileron and rudder actuators are designed for a dual redundant electrical interface. The actuators have one hydraulic system. It is fail-operational with respect to electrical failures. Channels 1 and 4 drive the left aileron and rudder actuators with channels 2 and 3 driving the right aileron and rudder
- An important design consideration in a DFBW system is power turn on and reset performance. It must account for bus switching and shutdown
- Non-volatile memory (NVM) is designed into each computer to insure that the system will recover from a power interruption with the same failure status as existed before. The failure information for a given channel is stored in that channel's NVM
- Input power for the Flight Control Computers (FCC) is +28 VDC. If voltage drops below 16 VDC the power supply will switch to the battery input line for 7 sec
- Reset logic is designed into the F-18 allowing only the resetting of the last similar failure detected

- Control law computations are performed at multiple rates. Pilot stick force command inputs are computed at 80 iterations per second, command augmentation requirements at 40, mode logic at 20 and 10, etc.
- The synchronization of the control computation at the major frame (100μsec) is implemented as a software algorithm within the executive block of computations
- Processor monitoring is accomplished through a combination of hardware and software monitors including watchdog monitor, parity monitor, scratchpad read/write test, etc.
- During flight testing the only backup mode that was automatically engaged was the fixed gain CAS model. This occurs with loss of AOA or air data signals. This was due to mistracking of left and right probes. The failure threshold levels for these sensors is not a digital problem.

3.2.3.5 "Software Development and Procurent Procedures for Future DFCS-Equipped Aircraft" (Ref. 14)

- HOL should be used in place of assembly language and provides:
  - Reduced coding and debugging costs
  - Improved reliability, documentation, and portability
  - Ease of program modification
- HOL requires more memory locations and computation time
- Verification is defined as the iterative process of determining whether the product of selected steps of the computer program development process fulfills the requirements levied by the previous step. Stated in simpler terms, verification is the determination that the software performs it's intended function
- Software does not wear out and should not experience a mean time between failures
- Software should be written under the discipline which reduces the probability of error
- Computer program life cycle consists of the following:

- Analysis
- Design
- Code and Debug
- Integration and Test
- Installation and Test
- Operation and Support

- A common problem in DFCS software development is that of computer memory being nearly or fully utilized early in the aircraft program development.
- A 20% memory reserve at the time of program delivery is a good design practice
- DFCS software has a "real-time" requirement with limited time and memory available
- Limited but well tested software maintenance is required
- Extensive Built-In-Test is required
- Software documentation consists of the following:
  - Specifications
  - Manuals
  - Progress reports
  - Analysis reports
  - Test data
  - Flight data
- Computer programs without documentation are useless
- The government should have unlimited rights to obtain, reproduce, and use in any fashion (including release to other contractors) all data produced and delivered
- A DFCS operational program will have reduced maintenance requirements
- Referencing entire Government Standards can often result in conflicts between two or more Government Standards. Therefore, only appropriate sections and not entire Government Standards should be referenced.

3.2.3.6 "Digital Fly-By-Wire Flight Control Validation Experience" (Ref. 15)

- Basic function of the flight control equipment is to augment or provide aircraft stability for controlling the path of the aircraft and reducing structural loads
- With advances in technology and confidence in flight control equipment the basic design of the aircraft are configured with active controls. These vehicles are called control configured vehicles (CCV). One active control function is this class is longitudinal stability, called relaxed static stability (RSS)
- Other modes of the flight control equipment are maneuver load control (MLC), gust load alleviation (GLA), elastic mode control and flutter suppression
- Automatic flight path control or "outer loop" functions such as Heading and Altitude Hold are not necessarily safety of flight modes
- Task is to generate criteria for new critical issues such as quality assurance, verification, validation and reliability
- Design Validation is the analysis to determine if the design meets the requirements. It will consist of:
  - Reliability analysis
  - Sneak path analysis
- Developmental tests are devised by the contractor with buyer approval and shall consist of the following:
  - Component or laboratory testing of system's components to assure that the equipment meets all operational and environmental requirements
  - Software verification
  - Design Evaluation

$$\text{Subsystem Test} \begin{cases} \text{Breadboard} \\ \text{Iron Bird} \\ \text{Flight} \end{cases}$$

$$\text{Integrated System Tests} \begin{cases} \text{Breadboard} \\ \text{Iron Bird} \\ \text{Flight} \end{cases}$$

- During the integrated testing, combining software and hardware, transient power and simulated failures should be performed. These tests should build to a total integrated system test with all elements of the system in an aircraft simulator or in the aircraft itself

- Integrated system tests can be performed in an iron bird and should include:
  - Failure modes and effects
  - Reliability
  - EMI
- It is not possible to run all possible tests on all possible facilities. A reasonable test matrix is the answer with most realistic results and without unnecessary repetition
- A decommissioned F-8 aircraft formed the backbone of the iron bird. It was the key element in the system verification, validation and flight qualification. The iron bird was more like an airplane than a simulator
- The software should not contain complex instructions which will make program verification and debugging complex and costly. It may cost some penalty in core requirements, but will save in the long run
- The software verification should cover:
  - Control laws
  - Executive
  - Computer I/O
  - Computer redundancy management
  - Sensor redundancy management
  - In-flight self test
  - Preflight tests
- Characteristics of advanced flight control systems are:
  - Increased level of reliability required
  - Increased system complexity
  - Increased use of software programs
- The F-8 group did not know of any method for demonstrating the absence of potential common-mode failures or generic design faults to their low level of probability

- Every possible fault that can be imagined should be induced during system tests. In order to effectively induce faults the system must be designed from the beginning to allow fault introduction
- System should be stressed to the maximum. The philosophy of testing should not be to show that the system works, but to try to make it fail
- To find the software errors in a large computer program through all possible paths would require an inordinate length of time. Exhaustive testing becomes impossible. It would take 7 years to test the Titan missile and still it would not be proven full of errors. The program testing can be used to show the presence of bugs, but never to show their absence. It is impossible to prove that it is error free
- The designer must produce a system design which is elegant because of its simplicity not because of its complexity.

3.3 ADDITIONAL REQUIREMENTS OF DFBW SYSTEMS

During the survey of existing criteria to determine the applicability to the next generation of DFBW systems, it became apparent that several new requirements must be addressed and that several existing requirements need be considered in a new light. These requirements have emerged or changed complexion primarily because of the elimination of the mechanical FCS, advances in control technology, improvements in the state-of-the-art of control system hardware and the need to provide a cost-effective system which meets the requirements of future Naval aircraft.

This section is intended to enumerate some of the more significant requirements and point out the reasons for this importance. Considerations which are to be addressed during a subsequent phase of this effort will be discussed relative to each requirement.

3.3.1 Redundancy to Meet High Reliability

It is evident that redundancy along with its associated redundancy management has taken on a much more significant role with the advent of DFBW systems. The reliability of state-of-the-art sensors, computers, and actuators, being what they are, demand that a multiplicity of hardware be used. Since this system is critical to the aircraft flight safety, the redundancy management must be foolproof. That is to say that the recognition of a failure and the isolation of that portion of the system must be accomplished with a high degree of confidence. False alarms and missed alarms should be minimized by the Redundancy Data Management System (RDMS). With the advent of high speed, solid state airborne digital computers, the effectiveness of the RDMS can be substantially improved.

The actual level of redundancy of each portion of the system is a function of the flight criticality, the inherent reliability and the self-testability of the hardware. For example, the rate output from a set of gyros may be flight critical in the pitch axis, but not in yaw which may lead to a requirement greater redundancy in the pitch axis than in the yaw axis. This requirement may be satisfied in several ways: namely, using additional rate, sensors, data from dissimilar hardware, or analytic redundancy techniques.

Redundancy levels must be examined throughout the aircraft related systems. It is obvious that the redundancy of the electric and hydraulic power systems must be considered relative to their impact on flight safety.

3.3.2 Survivability

Survivability to small arms fire has created a design objective for conventional flight control systems for many years. However, with DFBW systems coming into prominence, a different interpretation has been given to this requirement. It is more realistic to define a fail-operational requirement with electronic systems. Dispersion of equipment is certainly more realizable with electronic boxes than with a mechanical system, although it is known that aircraft are flying today with dual mechanical systems. Dispersion for the purpose of accomplishing a more survivable aircraft impacts many subsystems as well as electrical and hydraulic lines runs. It should be recognized, however, that certain equipment do not lend themselves to dispersion and armour plate may be required to protect that portion of the system. An example of this are the FBW actuators which must be redundant for each critical flight control surface. The survivability requirement which may lead to a highly dispersed set of hardware may have an adverse affect on maintainability. This will have to be considered along with the impact on the Environmental Control System (ECS) as well as the hydraulic and electric power sources.

3.3.3 Input/Output

The type of Input/Output and associated data transmission utilized is clearly related to the accuracy and rate at which the data is required. It is also a strong function of whether the design approach includes cross strapping or in-line channel redundancy or some combination. High accuracy and cross strapping favors digital transmission whereas channel redundancy and high rate favors analog transmission. Optical data transmission satisfies high bandwidth and EMI protection. If two way digital transmission is utilized then consideration must be given to the military standard 1553B type of system. Other bus structures are to be considered that utilize one-way digital transmission. The I/O and transmission scheme must be redundant within itself to meet the survivability/reliability requirement.

3.3.4 Sensor System

The sensor system for a generic DFBW system is composed on inertial, air data, and command and feedback transducers. Because these devices are part of a flight critical system failure tolerance is extremely important. Due to the survivability requirement, the sensors may be dispersed which in the case of inertial and air data transducers requires normalization of the data so that the failure detection scheme can be effective. Consideration will be given to skewed inertial sensors to minimize the number of sensors. A common set of sensors will be examined for sensing angular rate, linear accelerations, and aircraft attitude and heading. Since the sensors must individually be characterized, the subject of where this takes place should be addressed in future studies.

The type of command/feedback transducer will be examined as to their built-in failure detection capability. To preclude any single point failures redundant electric power will be included in future specification criteria.

3.3.5 EMI/Lightning Protection

Special consideration must be given to EMI/Lightning Protection due to the susceptibility of electronic systems to this type of disturbance. It is well known that electronic systems have ceased to function in lightning storms. For an aircraft with a DFBW system this could be disastrous. Techniques for protection against this environment will have to be greatly enhanced. This is particularly true with respect to composite aircraft which do not provide a metal shield for penetrating lightning. EMI is particularly disturbing to a digital computer which can, if not properly protected, have its memory altered. Approaches to protecting this equipment from EMI will be considered to assure safe operation of the DFBW system.

3.3.6 Advanced Control Modes

A considerable amount of work has recently been devoted to the development of advanced control modes to either improve the aircraft performance or extend its useful life. These control modes will be considered for inclusion into new FCS criteria. Direct flight path, direct lift and direct side force control are just a few techniques which could prove very useful in meeting mission requirements and improve landing characteristics. Relieving repeated stresses at the wing root may be accomplished using a Maneuver Load Alleviation (MLA) control mode. This type of control system has been demonstrated to extend the aircraft's predicted life. Redundancy in this case may be unnecessary as long as a self test scheme can be implemented with a high degree of confidence.

Reversion modes may not be considered advanced but they are critical to flight safety and represent a significant change in philosophy. Heretofore, an SAS was either deemed good or turned off. With a DFBW system several reversion modes may be included in the program depending on the failure mode. Basically these reversion modes, which may be anything from digital to analog to fluidic, provide a means of "graceful" degradation from the primary full-up sophisticated digital mode.

3.3.7 Digital Computer Characteristics

The basic intelligence of a DFBW system is contained within the redundant digital computer complex. This portion of the system not only contains the control laws which convert pilot commands and feedbacks to surface commands but also contains the RDMS. The RDMS is required to identify a failed component and isolate the failure so that it does not contaminate the signal flow to the next function. For example, all computers are required to act on identical sensor data. The commands from the redundant computers should then be bit-by-bit identical if the computers are all "healthy". In-line BIT and comparison monitoring are techniques to be examined for inclusion into a new FCS criteria document. End-to-end tests through to actuator position can be utilized as a reasonableness test each iteration.

In order to perform the above functions along with other related functions (e.g., air data) the computer must have the required speed and memory. General requirements for the computer complex will include such items as synchronization, architecture, modularization, and standardization. Specific requirements will be established relative to the use of standard hardware (e.g., AYK-14) and software (e.g., MIL-STD-1679). The use of HOL will be examined for applicability to this system.

3.3.8 Actuators

It is well recognized that FBW actuators must be full authority and redundant to meet performance and reliability requirements. Although most actuators in use today are uniquely designed for a specific application, much work has been in progress to develop generic types of FBW actuators (e.g., electrohydraulic, all electric, force position summed). It is recognized, that some designs incorporate inherent voting schemes within the basic actuator, whereas other designs can be better managed by the computer system. The redundancy of the actuator may depend upon the use of redundant surfaces or upon the criticality of the control function. The performance may be measured in terms of frequency response, load, and transient capability. Consideration in the guideline specification will be given to such items as basic design type, voting schemes, and performance parameters.

3.3.9 System Test and Validation

During this early phase of the study it has become very apparent that the success or failure of the DFBW system is dependent upon the thoroughness of the system test and validation effort. Although the validation techniques using analysis, simulation, and laboratory integration have been used in the past, it is clear that these techniques must be much more thoroughly pursued in the development phase of a DFBW system. The basic reason for this concern is the flight safety aspect of the design and the multi-path nature of the digital system with respect to control functions and redundancy management. It is obvious that the embedded software which controls the system operation is much more difficult to validate and control than the analog counterpart.

The portion of the new specification which will govern the test and validation practices to be used will initially address the requirements for performing such tasks. Consideration will be given to test witnessing, instrumentation test conditions, and tolerances. In addition guidelines will be stipulated to perform analysis tasks to provide evidence that the system meets such requirements as reliability, survivability, failure mode and effects, and EMI/lightning. Special consideration will be given to software verification since this represents an advance in the State-of-the-Art in test practices. Consideration will be given to verification techniques being developed in conjunction with HOL.

Criteria will be established for the full gamut of laboratory and aircraft tests to verify system performance with and without failures. Qualification and Acceptance type testing will also be defined to assure reliability goals. Finally, the documentation requirements will be defined for several of the major test and validation techniques to be used.

3.3.10 Operational Status

In view of the redundant nature of the DFBW system, special emphasis must be placed on defining operational status prior to each flight, that is to say that the system reliability is predicated upon the entire redundant complex system being operational. This can only be determined if each and every redundant path is checked. This may require the insertion of certain failures to verify multiple paths. This entire subject can be classified as "Self-Testability" of the system, which is vital to the success of a redundant system. For example if a quad redundant system is designed to be DUAL FAIL OP, the system should be checked with all combination and types of failures. The criteria for new DFBW systems will address these considerations.

3.3.11 Maintainability

Maintainability addresses the ability to fault isolate and repair the system. A necessary requirement is that BIT isolate to a WRA with a system as complex as a redundant DFBW system. The WRA may be at a module level or at a box level depending on the design approach. The trend is to isolate the failure to a functional module which can be replaced at the "O" level and minimizing repair at the "I" level. In fact in view of the flight safety aspect of the design and the lack of sufficiently trained Navy personnel, consideration is being given to have the equipment manufacturer provide a warranty for equipment failures. This is a basic change in the Navy procurement policy which could lead to substantial savings in life cycle cost since there would be a maximum incentive for manufacturers to provide highly reliable equipment.

3.4 FORMULATION OF CRITERIA FOR DFBW

3.4.1 Military Flight Control System Cross References

Table 1 contains a matrix of existing specification paragraphs categorized by requirements.

3.4.2 Baseline Criteria for Digital Fly-By-Wire Systems

Table 2 contains the preliminary baseline outline for the revised flight control criteria requirements.

TABLE 1 MATRIX OF CRITERIA FROM CURRENT SPECIFICATIONS (SHEET 1 OF 2)

		MIL-F-9490		MIL-C-18244A		MIL-F-18372		MIL-F-0000B	
1.0	SCOPE								
1.	Scope	1.1	Scope	1.1	Scope	1.1	Scope	1.1	Scope
1.2	Classification	1.2.2	Operational States					1.2.4	FSC Categories
3.1	System Requirements	3.1.3	General FSC Design	3.1	System Design Requirements	3.1	System Requirements	3.1	System Requirements
3.1.1	Design	3.1.3.1	Redundancy	3.1.1.2.1	System Design	3.1.1.1.2	Acceleration Effect	3.1.1.16	Interface Considerations
		3.1.3.3	Sys. Operation & Interface	3.1.1.2.2(b)	Additional Design Require.	3.1.6.1	Accessibility	3.1.1.5.2.1	Performance Requirement
		3.1.3.3.1	Warmup	3.1.1.3.1	Conditions for Engagement			3.1.1.16	Interface
		3.1.3.3.2	Disengagement	3.1.1.3.2	Warmup				
		3.1.3.3.3	Mode Compatibility	3.1.1.3.3	Synchronization				
		3.1.3.3.4	Failure Transients	3.1.1.3.4	Disengagement (in part)				
		3.1.3.6	Stability	3.1.1.3.8	Automatic Trim (in part)				
		3.1.3.6.1	Stability Margins	3.1.1.3.11	Interlocks (in part)				
		3.1.3.7	Opertaion in Turbulence	3.1.1.3.12	Structural Protection (in part)				
		3.1.3.7.1	Random Turbulence	3.1.1.3.13	Protection Against Prohibited Man				
		3.1.3.8	Residual Oscillation	3.1.1.3.14	Preflight Check (in part)				
		3.1.3.9	System Test & Monitoring Prov.	3.1.1.4.1	Reference Voltage (rewrite)				
		3.1.3.9.1	Built-in-Test Equipment	3.1.1.4.2	Command Signal Limiting				
		3.1.3.9.1.1	Preflight BIT	3.1.1.4.3	Switching Modes				
		3.1.3.9.1.2	Maintenance BIT	3.1.1.4.4	Noise Compatibility (rewrite)				
		3.1.3.9.2	Inflight Monitoring	3.1.1.4.5	Data Link (rewrite)				
		3.1.5.2.3	Engage-Disengage Transients	3.2.8.2	Calibration Adjustment				
		3.1.5.3	AFCS Emergency Provisions	3.1.1.6.1	Stability Margins				
				3.1.1.6.2	Internal Noise				
				3.1.1.5.2.1.3	Residual Oscillations				
				3.1.1.3.14	Preflight Check				
3.1.2	Performance	3.1.2	AFCS Performance	3.1.1.1	Categories of Operation	3.2.3	Control Surface Locks	3.1.1.8	Control Sensitivity
		3.1.3.2.1	Auto Terrain Following Failure	3.1.1.1.1	Augmentation	3.2.4.1	High Lift Controls	3.1.1.13	Computer Checkout
		3.1.3.7	Operation in Turbulence	3.1.1.1.2	Pilot Assist	3.2.4.2	Speed Brake Controls	3.1.1.14	Control Config. Vehicles
		3.1.5.2.1	Tie-In With External Guidance	3.1.1.1.3	Guidance			3.1.2.1	High Lift System
				3.1.1.4	General Tie-In Requirements			3.1.2.1.1	Synchronization
				3.1.1.4.2	Command Signal Limiting			3.1.2.1.2	Emergency Operation
				3.1.1.4.3	Switching			3.1.2.2	Speed Brakes
				3.1.1.4.4	Noise Compatibility			3.1.2.3	Direct Lift Control
				3.1.1.4.5	Data Link				
				3.1.1.5	Performance Requirements				
				3.1.1.5.1	Augmentation				
				3.1.1.5.2	Pilot Assist Functions				
				3.1.1.5.3	Auto. Guidance Functions				
3.1.3	Reliability								
3.1.4	Survivability	3.1.9	Invulnerability						
3.1.5	Invulnerability							3.1.1.15	Invulnerability
3.1.6	Maintainability	3.1.10	Maintenance Provisions	3.2.2	Maintenance Providions			3.2.8	Assessibility
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		3.1.10.2	Fault Isolation	3.3.1.7	Modules				
		3.1.10.3	Accessibility						
		3.1.10.4	Personnel Safety						

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SECTION 4

RECOMMENDATIONS FOR FUTURE STUDY

As a result of the Phase I study, a Baseline Criteria Document has been generated which contains requirements extracted from current military specifications and also identifies areas in which further study is required to formulate the associated requirements criteria. As a logical extension to the existing study, it is recommended these additional requirements be addressed during a subsequent study phase. Further, it is also recommended that continuing phases of flight control criteria studies be conducted to establish a finalized criteria document and a "User's Guide".

The recommended follow-on programs are depicted in Figure 1. During Phase II, the additional requirements should be formulated and combined with the Phase I results to form an Interim Criteria Document.

It is also recommended that two major tasks be accomplished during Phase III. The first task is a validation of the interim criteria. This will be accomplished by validating the criteria with data available from existing aircraft which contain FBW systems. These include the F-16, F-18A, NASA F-8C and Navy/Air Force AFTI-16/ DFCS. As a companion document to the flight control criteria, it is recommended that a baseline User's Guide for the flight control criteria be formulated as the second major task during Phase III.

During Phase IV, it is recommended that the criteria document be reviewed by government and industry representatives. In a parallel effort the User's Guide should be updated to reflect the criteria validation effort performed during the previous phase.

The last phase should incorporate the comments from the government/industry survey into the Criteria Document and the User's Guide resulting with finalized criteria document and finalized User's Guide.

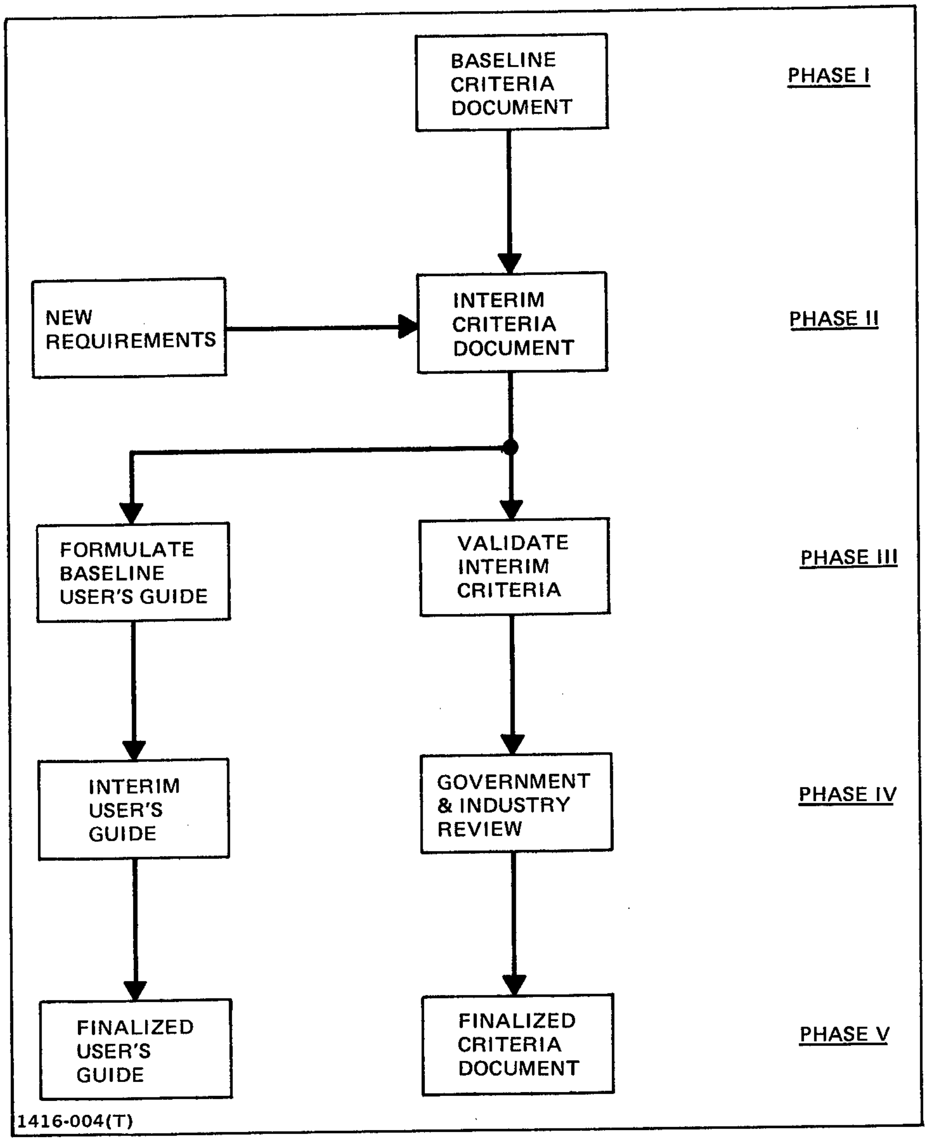

Figure 1 Recommended DFBW System Criteria Development Phases

SECTION 5

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APPENDIX A

APPLICABILITY OF MIL-C-18244A

TO DFBW SYSTEMS

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MILITARY SPECIFICATION

CONTROL AND STABILIZATION SYSTEMS: AUTOMATIC, PILOTED AIRCRAFT, GENERAL SPECIFICATION FOR

This specification has been approved by the Bureau of Naval Weapons, Department of the Navy.

1. SCOPE

1.1 Scope - This specification covers design, test and performance requirements for either GFE or CFE automatic control and stabilization systems for all U. S. Navy piloted aircraft. In the event of conflict between this specification and other referenced documents the requirements of this specification shall govern. The detail requirements for a particular system shall be as specified in the detailed specification, contract or purchase order for that system. (See 6.2)

Comments - The reference to GFE and CFE is unnecessary, because the specification will apply to all Navy piloted aircraft.

Recommendation - Delete the GFE and CFE reference and the paragraph is applicable.

2. APPLICABLE DOCUMENTS

2.1 General - The following documents, of the issue in effect on the date of invitation for bids, shall be used wherever applicable in the design, installation and operation of the automatic control and stabilization system.

SPECIFICATIONS

Military

JAN-I-225	Interference Measurements, Radio, Methods of, 150 Kilocycles to 20 Megacycles (For Components and Complete Assemblies)
JAN-T-781	Terminal; Cable, Steel (For Swaging)
MIL-F-3541	Fittings, Lubrication
MIL-S-3950	Switches, Toggle
MIL-E-4682	Electron Tubes and Transistors, Choice and Application of
MIL-W-5088	Wiring, Aircraft, Installation of
MIL-E-5272	Environmental Testing, Aeronautical and Associated Equipment, General Specification for
MIL-E-5400	Electronic Equipment, Aircraft, General Specification for
MIL-H-5440	Hydraulic System; Aircraft Type I and II, Installation and Data Requirements for

MIL-I-6115	Instrument Systems, Pitot Tube and Flush Static Port Operated, Installation of
MIL-I-6181	Interference Control Requirements, Aircraft Equipment
MIL-L-6880	Lubrication of Aircraft, General Specification for
MIL-E-7080	Electrical Equipment, Piloted Aircraft Installation and Selection of, General Specification for
MIL-M-7969	Motors, Alternating Current, 400-Cycle, 115/200 Volt System, Aircraft, General Specification for
MIL-A-8064	Actuators and Actuating Systems, Aircraft, Class A and B, Electro-Mechanical, General Requirements for
MIL-M-7793	Meter, Time Totalizing
MIL-H-8501	Helicopter Flying Qualities, Requirements for
MIL-S-8512	Support Equipment Aeronautical, Special, General Specification for Design of
MIL-M-8609	Motors, Direct Current, 28-Volt System, Aircraft, General Specification for Class A and B
MIL-D-8706	Data, Design; Contract Requirement for Aircraft
MIL-F-8785	Flying Qualities of Piloted Airplanes
MIL-D-18300	Design Data Requirements for Contracts Covering Airborne Electronic Equipment
MIL-N-18307	Nomenclature and Nameplates for Aeronautical Electronic and Associated Equipment
MIL-E-19600	Electronic Modules, General Aircraft Requirements for
MIL-R-22256	Reliability Requirements for Design of Electronic Equipment or Systems
MIL-R-23094	Reliability Assurance for Production Acceptance of Avionic Equipment, General Specification for

STANDARDS

<u>Military</u>

MIL-STD-203	Cockpit Controls; Location and Actuation of For Fixed Wing Aircraft
MIL-STD-704	Electric Power, Aircraft, Characteristics and Utilization of
MS15001	Fittings. Lubrication (Hydraulic) Surface Check, 1/4 - 28 Taper Threads, Steel, Type 1
MS15002	Fittings, Lubrication (Hydraulic) Surface Check, Straight Threads, Steel, Type II

<u>Comments</u> - Some of these specs and standards are obsolete and not applicable.

<u>Recommendation</u> - Review and update the list.

3. REQUIREMENTS

3.1 System Design Requirements - Automatic Flight Control Systems (AFCS) shall be as simple, direct and foolproof as possible with respect to design, operation and maintenance.

Comments - The expression ".....shall be simple, direct and foolproof as possible with respect to ....." is a general statement found in several MIL specs.

3.1.1 Automatic Flight Control Systems (AFCS)

3.1.1.1 Categories of Operation - The control function or functions to be performed by automatic flight control systems or components shall be determined from the military characteristics or the requirements of the aircraft or class of aircraft in which the equipment shall be used. By definition, the automatic control functions shall fall within the following categories:

3.1.1.1.1 Augmentation - The augmentation category shall include those control functions which are required to improve the stability and handling characteristics of the vehicle. The damping of the longitudinal or direction-lateral oscillatory mode shall be governed by the requirements specified in Specification MIL-F-8785.

3.1.1.1.2 Pilot Assist or Pilot Relief - The pilot assist or pilot relief category shall include those automatic control functions which simplify or ease the control of the flight path of the aircraft. These functions include but shall not necessarily be limited to the following:

(a) Attitude Hold (Pitch and Roll)

(b) Heading Hold

(c) Heading Select

(d) Automatic Turn Coordination

(e) Side Slip Limiting

(f) Altitude Hold

(g) Mach Hold

(h) Return to Level

(i) Control Stick Maneuvering

3.1.1.1.3 Guidance - The guidance category shall include those control functions which provide automatic flight path control in accordance with steering signals generated by guidance and control systems external to the flight control system. The category shall include the following types of control functions:

(a) Enroute navigation

(b) Rendevous and station keeping

(c) Terminal guidance for bomb delivery

(d) Search and tracking for fire control

(e) Automatic takeoff, approach and landing

(f) Inertial Flight Path Control

(g) Automatic Terrain Avoidance

Comments - It divides the AFCS into three categories:

- Augmentation
- Pilot relief
- Guidance

The above paragraphs, although applicable to DFBW, must also include new control modes plus reflect normal operation via computer control.

Recommendation - Revise the paragraphs to include the advanced flight control modes and operation.

3.1.1.2 Choice of Components - Systems, subsystems and components shall be selected from the following categories in the order listed, consistent with the applicable requirements and specifications:

(a) In operational use, or under procurement for operational use, by the same service.

(b) In operational use, or under procurement for operational use, by other branches of the service.

(c) Modification of category a.

(d) Modification of category b.

(e) Certified by a competent government agency for commercial aircraft use.

(f) Developed under contract to the services and approved in principle.

(g) Under development on concurrent programs having more stringent requirements or scheduled for earlier completion.

(h) Designed and developed specifically for the requirements on hand.

Compliance with the above listed order of categories shall be a major criterion in the selection of an automatic flight control system subcontractor. The proposed use of systems, subsystems and components from a category lower than category b shall be justified and any changes made during the development phase which necessitate the use of systems, subsystems or components in a lower category must be ~~approved by the~~ procuring activity. Requests for approval supported by studies showing the necessity for the use of the system, subsystem or component shall be submitted prior to the appropriate design review, at which time the procuring activity shall decide upon approval or disapproval.

Comments - The concept has merit because of the savings in hardware development and support equipment. But because all aircraft have different designs, all will have different control laws, modes, and gains and it is unlikely one can substitute a whole system into a new aircraft design. It also assumes that existing hardware has no design flaws. A DFBW system may someday evolve that will be so exceptional in design, reliability, and cost that no improvements are needed, but none has yet been built. A more logical approach would be to review the requirements and determine which components of proven design could be used.

Recommendations - Keep the paragraph but soften the requirement to exclude the provision that the major criteria in the selection of a subcontractor is existing hardware. Set the requirement as a design goal and not a mandatory requirement.

3.1.1.2.1 System Design - The AFCS shall be designed for minimum weight and volume consistent with the design of the aircraft for which it is intended.

Comments - A good general practice requirement.

Recommendation - Applicable.

3.1.1.2.1.1 Avoidance of Duplication - Automatic flight control systems, subsystems and components shall be so designed that a maximum of integration is accomplished, consistent with system reliability, operation and safety between:

(a) Those components providing the automatic control function and components or parts comprising or providing any other function of a weapon system, and

(b) The components providing the different functions of the automatic flight control system itself.

Detailed requirements of each integration situation shall be as specified in the procurement document or in the system or component specification.

Comments - The paragraph is not clear as to what the requirement is.

Recommendation - Delete.

3.1.1.2.2 Additional Design Requirements - The AFCS shall be designed to meet the following requirements:

(a) The electronic control amplifier shall consist of separate assemblies for each major channel.

Comments - The question is what is an "electronic control amplifier?" It is referred to as a flight control computer? Without a definition of terms, the requirement is meaningless.

Recommendation - Delete. Provide a definition of terms.

(b) Channels having higher reliability requirements than other channels shall be electrically isolated and have their own power supply, circuit breakers, etc.

Comments - The intent is good, but wouldn't it be inherent in the design of a high reliability channel?

Recommendation - Delete.

(c) A control panel switch shall be provided so that the AFCS can be isolated before ground power is applied or removed.

Comments - A nice design feature for a single channel AFCS, but a difficult one to implement for a multi-channel system, because it presents a single point failure.

Recommendation - Delete.

3.1.1.2.3 Interchangeability - All assemblies having the same manufacturer's part number shall be directly and completely interchangeable with respect to installation and performance without adjustment.

Comments - Stated simply, interchangeable parts require no adjustment when installed in a vehicle.

Recommendation - Applicable.

3.1.1.2.3.1 Reordered Equipment or Second Source Procurement - Where models or drawings of components of systems are furnished by the procuring activity on a contract to facilitate interchangeable construction, or where procurement is for equipment to provide interchangeable use with equipment previously procured, and the requirements for interchangeability contradict the current requirements of one or more MIL specifications, the contract requirements for interchangeability shall govern without additional approval by the procuring activity.

Comments - A special situation that tries to reinforce the interchangeability requirement.

Recommendation - Delete.

3.1.1.2.4 Repairability - No assembly or subassembly shall be encapsulated or permanently sealed without written approval of the procuring activity. This requirement is established to insure access whenever necessary to repairable parts in components and/or assemblies.

Comments - A good design practice.

Recommendation - Keep the requirement, but delete the phrase, "without written approval of the procuring activity." Any requirement can be waived with a deviation request. It is not necessary to repeat this statement in every paragraph in the specification.

3.1.1.3 Functional Design Requirements

3.1.1.3.1 Conditions for Engagement - Unless the automatic flight control system and integrated portions of other systems are properly energized and synchronized, it shall not be possible to engage the system or to switch from one functional category or mode of operation to another. It shall be possible to engage the augmentation mode independently of any other function or mode of the automatic flight control system. No control transients, which exceed the limits of 3.1.1.4.3, shall occur when switching from one functional mode of operation to another or when disengaging the system. Unless otherwise specified in the system specification, all control axes shall be engaged and disengaged simultaneously. Means shall be provided so that the pilot can visually determine the operation status of the system.

Comments - The first sentence is a general statement about synchronization which is still applicable. The second sentence calls for the engagement of augmentation before any higher modes, which also still applies. The third sentence requires transients to be less than 0.05 g's in normal acceleration and ± 1° in roll attitude, which is adequate for engage transients, but too severe for disengagement transients. It would be a satisfactory requirement when disengaging in normal straight and level flight, but for a failure situation when the aircraft is maneuvering the 0.05 g's is an unreasonable requirement. Safety should be the prime consideration.

The fourth sentence calls for the simultaneous engagement or disengagement of all control axes, unless otherwise specified, a meaningless requirement. The last sentence is still a valid requirement.

Recommendation - Rewrite.

3.1.1.3.2 Warm-Up - After the application of power, the warm-up time required shall be not more than 90 seconds for fighter or attack type aircraft and not more than 3 minutes for other types of aircraft.

Comments - In today's FCS, the device requiring the longest warm-up or run-up time is the motor-driven rate gyros. It takes about 10-20 seconds to come up to synchronous speed. Why it should take longer for other type of aircraft besides a fighter is not clear.

Recommendation - Keep the requirement, and standardize the warm up time consistent with state-of-the-art FCS systems.

3.1.1.3.3 Synchronization - The system design shall be such that, upon engagement, the aircraft's attitude or other control mode will be maintained, or the aircraft will be displaced at a predetermined rate to a predetermined attitude as defined in the system specification covering the particular automatic flight control system. Synchronization indication, if required, shall be as specified in the system specification. The synchronization rate shall be such that no transients exceeding the limits of 3.1.1.4.3 shall occur due to system engagement or mode switching after the completion of any maneuver up to the maneuver limits of the aircraft.

Comments - The first sentence is a description of an Attitude Hold mode and doesn't belong in this paragraph. The second sentence calls for a synch indicator if required. Sometimes with synch networks, an indicator is needed to display to the pilot the status of the system. It will not apply to DFBW systems. The third sentence limits the synch rates to 0.05 g's a_n and 1° in roll for system engagement or mode switching.

Recommendation - Rewrite the requirement.

3.1.1.3.4 Disengagement - Provisions shall be made for inflight disengagement and reengagement of the automatic flight control system. Disengagement shall be positive under any and all load conditions. Disengagement switches shall be normally closed and shall be located in accordance with the requirements of MIL-STD-203. A disengagement not initiated by the pilot shall be indicated by means which shall be approved by the procuring activity. In the event that servo disengagement should result from action of the structural protective means, the circuitry shall provide for immediate re-engagement at the pilot's discretion.

Comments - For DFBW systems, the first three sentences applies to higher automatic modes. One shouldn't be able to disengage the primary modes of a DFBW system. The fourth sentence is a good design practice for any FCS. The last sentence is confusing in its meaning.

Recommendation - Rewrite the requirement.

3.1.1.3.5 Series Actuators - The series actuators shall, after deactivating, be positively centered and capable of transmitting full control system load without creep. The rate of centering shall be such that no undesirable transients will be introduced. Unless a dual cross monitoring system, including dual separate actuators with a common output is used, series actuators having more than 40 percent primary control authority shall not be used.

Comments - Doesn't apply to DFBW systems.

Recommendation - Delete.

3.1.1.3.6 Overpower - With the automatic flight control system engaged and operating, it shall be possible to manually overpower or countermand the control action of the system on all axes. For fixed-wing aircraft the maximum steady forces required to maneuver the aircraft within its design limits about all axes, subsequent to overpowering or countermanding control system action shall not exceed the values specified in Sections 3.3 and 3.4 of Specification MIL-F-8585; in addition the maximum instantaneous forces shall not exceed 120 percent of the maximum steady force.

Comments - Does not apply to DFBW systems. A side issue is that this requirement addresses a particular paragraph of MIL-F-8785 (8585 is a typing error) and does not list the revision making the requirement difficult to define. It is good practice to extract the information from another spec instead of calling out a paragraph.

Recommendation - Delete.

3.1.1.3.7 Cockpit Control Motion - The control surface motion required to accomplish augmentation functions shall not be reflected at the aircraft's cockpit control. In addition there shall be no random spurious stick motion associated with any automatic flight control mode.

Comments - A good design practice for conventional FCS which does not apply to DFBW systems unless a special effort is made to bring control surface motion to the cockpit controls.

Recommendation - Delete.

3.1.1.3.8 Automatic Trim - Means shall be provided to automatically reduce the control system trim error to essentially zero. Such a means shall operate at a rate which does not significantly affect the transient performance of the automatic flight control system. Automatic trim shall be operational during the guidance and pilot assist modes only.

Comments - Automatic trim will be supplied with a DFBW system, but not as described above.

Recommendation - Rewrite the requirement.

3.1.1.3.9 Manual Trim - Powered manual trim shall be made inoperative when the automatic flight control system is engaged. The circuitry shall be arranged so as to minimize the effect of a failure in the automatic flight control system on the manual trim operation after the automatic flight control system is disengaged.

Comments - Manual Trim may be provided in a DFBW system if for no other reason than to provide for conventional pilot techniques. The implementation would be different from the above description.

Recommendation - Rewrite the requirement for a DFBW system specification.

3.1.1.3.10 Control Stick (or Wheel) Maneuvering - Where control stick maneuvering is a system requirement, provisions shall be made so that the pilot shall have full capability to maneuver the aircraft within control forces and maneuver limits specified in Specification MIL-F-8785 or the applicable system specification. This maneuvering capability shall be possible at any time when the automatic flight control system is engaged by using the normal aircraft controls. Unless otherwise specified in the applicable system specification, design shall be such as to allow the pilot to superimpose his control stick maneuvering commands over those of external guidance system signals. Cross control between the pitch and roll force sensors shall not exceed one percent of the applied forces.

3.1.1.3.10.1 Vernier Control - When control stick steering is a requirement, means shall be provided to apply vernier attitude control, unless changes commensurate with the minimum maneuver requirements can be added by control stick steering commands.

3.1.1.3.10.2 Control Stick Maneuvering Modes - Control stick steering modes shall operate as follows:

(a) Control Augmentation Mode - This mode shall provide those features as required by 3.1.1.1.1. The pilot's force on the stick or wheel shall superimpose the commanded maneuver signal onto the augmentation signal.

(b) Pilot Relief Mode - This mode shall provide the augmentation features of part (a) above and in addition those outlined by 3.1.1.1.2, parts (a) and (b).

Comments - Not applicable to DFBW systems.

Recommendation - Delete.

3.1.1.3.11 Interlocks - Interlocks to prevent engagement of the automatic flight control system in the absence of proper hydraulic pressure, electrical power of the proper voltage, proper gyro rotor speed, adequate warm-up, and normal overall operation shall be provided as part of the automatic flight control system. It shall not be possible to engage incompatible functions. Interlocks shall also be provided to prevent power from being applied to the system if lack of power to the servo units prevents synchronization. In the event of failure of any one of the hydraulic or electrical power sources, the automatic flight control system shall become disengaged within 0.5 second.

Comments - The above requirement does not apply to a multiple channel DFBW system. Although there should be interlocks to prevent engagement of the automatic modes, there is a difference in philosophy in the design of a conventional versus a DFBW system. In a conventional FCS, the safest situation after a failure is to return to the primary or manual FCS by turning the AFCS off. In a DFBW system, the intention is again to return to the primary if, one started from an automatic mode, but once in the primary mode the aim is to keep the system on. The criteria for rejecting a channel will be lack of response to a command, not improper hydraulic pressure, low voltage, improper gyro rotor speed, etc. These discretes would be valuable information for BIT. Therefore, this paragraph is not applicable to DFBW systems. Only the second sentence is worth keeping.

Recommendation - Delete except for second sentence.

3.1.1.3.12 Structural Protection - Means shall be provided to prevent automatic flight control system malfunctions from producing airplane loads in excess of the airplane limit load factor. Due to consideration shall be given to the fact that during rapid roll maneuvers the load factor of one of the wings is higher than that determined by the center of gravity acceleration. Unless proven unnecessary, the protective device for high roll performance aircraft shall respond to an appropriate combination of lift, roll velocity, and roll acceleration.

Comments - The concept is still valid in that the FCS should provide structural protection so as not to exceed the aircraft limit load factors. The requirement should be expanded to include inputs from either FCS malfunctions or from pilot's inadvertently overstressing the aircraft.

Recommendation - Rewrite the requirement.

3.1.1.3.12.1 Ground Check - **The structural protective means shall be such that it can be conveniently ground-checked by the pilot.**

3.1.1.3.12.2 Reliability - The structural protective means shall be designed for maximum reliability and shall be self-monitoring. Electrical power applied within the limits shown in 3.2.7 shall not cause the structural protective means to become inoperative.

Comments - The above two requirements should not be listed under structural protection. Structural protection is not any more important than other modes.

Recommendation - Delete.

3.1.1.3.13 Protection Against Prohibited Maneuvers - Devices which protect against prohibited maneuvers, whether initiated by the pilot or by the automatic flight control system (i.e. command signal limiting as a function of velocity - normal load limits, pitch-up inhibitors, etc.) shall be provided as specified in the applicable system specification. The design of the protective devices shall be similar to 3.1.1.3.12.

Comments - It should be included under 3.1.1.3.12 which is really structural protection.

Recommendation- Not a separate requirement; combine with structural protection.

3.1.1.3.14 Pre-Flight Check - **Means shall be incorporated into the design of the AFCS to enable the pilot to determine the operational ability of the AFCS while the airplane is on the ground prior to take-off. Additional equipment needed to meet such pilot pre-flight check requirements shall be kept to a minimum, shall be integrated into the AFCS, and shall not require use of ground test equipment. The pilot shall be enabled to initiate the pre-flight tests and to observe the results from the airplane cockpit. A means of activation to be mounted in the cockpit of the airplane, shall be provided for use in initiation of the pre-flight test. Other than the means of activation, the pre-flight test shall not require the installation of additional controls in the cockpit area. It shall be possible to perform all pre-flight tests by manipulation by the pilot of the following equipment.**

(a) The AFCS pre-flight test means of activation.

(b) The airplane control stick.

(c) The airplane control pedals.

(d) The controls on the AFCS control console.

(e) The AFCS emergency disengage switch on the stick grip.

The results of the pre-flight tests shall indicate to the pilot the proper functioning of all electronic and electrical equipment of the AFCS which perform flight control functions to the extent that no unsafe condition shall occur upon engagement of the AFCS. Specifically, the tests shall indicate to the pilot that inputs to the rudder, elevator and aileron channels of the AFCS shall result in corresponding displacements of the rudder, elevator and aileron control power mechanisms. Tests shall indicate whether or not any malfunctions exist in the structural protection system. Indication of functioning of gyro sensors, flight data unit, or signal sources external to the AFCS is not required, except: indicating of proper functioning of control stick force sensor and force switches is required. The AFCS pre-flight tests subsystem shall enable the pilot to complete all pre-flight tests in a time not to exceed 2 minutes after elapse of warm-up period specified herein or after satisfaction of AFCS interlocks from equipment not supplied by the vendor whichever occurs later. The pre-flight tests are not required to indicate the operating condition of any equipment beyond whether or not the equipment is in a functionable or non-functionable condition.

Comments - Requirement has to be rewritten to update it and remove the exclusion of testing gyro sensors.

It should also include the provision to run a ground BIT with hydraulics either on or off. This allows the ground crew the capability to troubleshooting the electronics without the need of using an external hydraulic ground cart. Most of the time in short supply on a carrier. Another helpful requirement would be the capability to operate the FCS electronics without an external cooling cart which is another cumbersome cart that gets in the way aboard a carrier.

Recommendation - Rewrite to update.

3.1.1.4 General Tie-in Requirements - Provisions shall be made for the acceptance of external guidance signals from various computers generating the necessary commands in attitude, speed, altitude, flight path rate, acceleration, etc., to control the aircraft's flight path.

Comments - A general requirement.

Recommendation - Applicable.

3.1.1.4.1 Reference Voltage - Unless otherwise specified in applicable specifications, the input signal to the automatic flight control system shall be based on the same voltage source as the corresponding feedback signal of the automatic flight control system. This shall prevent the voltage variations from changing the correlation between the commanded and actual value.

Comments - Applicable.

Recommendation - Incorporate into DFBW system spec.

3.1.1.4.2 Command Signal Limiting - Means shall be provided to limit the command signals from external guidance systems, so that the automatic flight control system will not cause the aircraft to exceed maneuver limits that are inconsistent with the external guidance function and flight conditions. Such means shall be located immediately prior to the input to the amplifier.

Comments - It is still a good design practice.

Recommendation - Keep the requirement, but rewrite paragraph to reflect DFBW systems design.

3.1.1.4.3 Switching - Switching with zero command signal input from external guidance systems shall not cause transients greater than ±0.05 g normal acceleration at the center of gravity in pitch or ±1 degree in the roll attitude.

Comments - It is still applicable.

Recommendation - Keep the requirement.

3.1.1.4.4 Noise Compatibility - The automatic flight control system shall be so designed that the noise content in the external guidance signal, as specified in the applicable system specification, shall not saturate any component of the automatic flight control system, shall not impair the response of the aircraft to the proper guidance signals, and shall not cause objectionable control surface motion or attitude variation. If the specified noise content is too great to achieve this goal, additional noise filtering shall be employed. Since additional noise filters impair the guidance performance, an optimum compromise between performance and noise filtering shall be determined by the procuring activity, the automatic flight control system contractor and the contractor responsible for the guidance computer and the overall guidance performance.

Comments - Requirement is applicable.

Recommendation - Rewrite requirement to reflect DFBW system design.

3.1.1.4.5 Data Link - If the steering information is transmitted to the automatic flight control system via a digital data link, the sampling frequency and number of bits per signal shall be compatible with the accuracy and dynamic performance requirements of the guidance loop, and the noise resulting from the sampling and digitalizing process shall not cause a total noise which will be incompatible with 3.1.1.4.4. If the steering information is transmitted to the automatic flight control system via an analog data link, the gain variation and the zero shift of the data link shall be compatible with the performance and accuracy requirements of the guidance loop and the data link noise shall not cause a total noise which will be incompatible with 3.1.1.4.4.

Comments - Another general requirement that calls for a steering mode of operation if a data link interface is present. For a DFBW system, data link interfaces will be commonplace.

Recommendation - Rewrite the requirement reflecting operation of DFBW system with a data bus interface.

3.1.1.5 Performance Requirements - The aerodynamic and flight configurations, external stores configuration, and aircraft performance range through which the automatic flight control system shall be required to provide the specified performance shall be as defined in the applicable specification. The performance requirements specified herein shall apply to all fixed-wing aircraft, helicopters, and VTOL aircraft during forward flight at a speed greater than 30 knots. Deviations from the performance requirements specified herein shall be allowed only as necessary, and shall be subject to the approval of the procuring activity.

Comments - The first sentence is applicable. The DFBW system will be turned on for the entire flight, but the automatic modes will be specified and limited by flight conditions and aircraft configurations and should be addressed in the detail design specification. The second two sentences are not applicable.

Recommendation - Rewrite the paragraph reflecting DFBW system design.

3.1.1.5.1 Augmentation - **The augmentation system shall provide handling characteristics which will satisfy, as a minimum, the requirements of Specification MIL-F-8785 for all fixed-wing aircraft and VTOL aircraft in the cruise configuration and Specification MIL-H-8501 for helicopters and VTOL in the hover and transition configurations. During turn maneuvers, the augmentation system shall provide turn coordination as specified in 3.1.1.5.2.4. The control authority of the augmentation system shall be limited as far as possible to insure that a "hard-over" signal will not cause the aircraft to exceed its limit load factor. If this is not possible because of the demands of the augmentation system, additional requirements shall be specified in the applicable system specification to insure the safety of the weapons system operation.**

Comments - Combine with first sentence of paragraph 3.1.1.3.3 to describe Control Stick Steering.

Recommendation - Rewrite and requirement is still valid.

3.1.1.5.2 Pilot Assist Function -

3.1.1.5.2.1 Attitude Hold (Pitch and Roll) - **The selected pitch and roll attitudes shall be maintained within a static accuracy of ± 0.5 degree with respect to the gyro reference. Upon completion of a pilot controlled maneuver, the airplane attitude maintained by the automatic flight control system shall be the airplane attitude at the time the commanded forces were removed, if this attitude is within the limits of the attitude hold mode. When using a flight controller, the airplane shall return to a wings level attitude when the turn control is placed in the detent position.**

Comments - Requirement is still valid.

Recommendation - Rewrite and combine with first sentence of paragraph 3.1.1.3.3 to describe Control Stick Steering.

3.1.1.5.2.1.1 Pitch Transient Response - **The short period pitch response shall be smooth and rapid. After the automatic flight control system has been manually overpowered to change the pitch attitude by at least ± 5 degrees, the aircraft shall return to the reference attitude within one overshoot which shall not exceed 20 percent of the initial deviation. The period of overpowering shall be short enough to hold the airspeed change to within 5 percent of the trim airspeed.**

3.1.1.5.2.1.2 Roll Transient Response - The short period roll response shall be smooth and rapid. After the automatic flight control system has been manually overpowered, and the overpowered controls released upon reaching a bank angle of approximately 20 degrees, the aircraft shall return to the initial roll attitude within one overshoot which shall not exceed 20 percent of the initial deviation.

Comments - These two paragraphs are an outdated method to measure overshoot by using an overpower flight maneuver. The intent is good, but it may not be possible to do an overpower in a DFBW system without redesigning the cockpit control system.

Also, even with a conventional FCS, it was never possible to get repeatable data by allowing the pilot to do an overpower. The magnitude and time of the pilot's overpower inputs was a judgement thing. A more scientific approach would be to give the requirement in terms of damping ζ and ω_n or response time.

This would set the requirements and the test to verify the response to an electrical step input not to a pilot's overpower. This input from a separate signal source is an easy task with a commonplace piece of laboratory test equipment in which the magnitude can be set exactly and is repeatable. For the flight test program, an external stimuli controlled by the pilot could be devised to put an electrical input into the computer(s) and, therefore, into the FCS. Another method would be to have a special program in the software than can put stimuli into the FCS from a keyboard.

Recommendation - Rewrite the requirement.

3.1.1.5.2.1.3 Residual Oscillations During Steady State Flight - Residual oscillations as measured in the cockpit during steady flight shall not produce normal accelerations, a_n, lateral accelerations, a_y, attitude amplitudes, θ (pitch), ψ (yaw) and ϕ (roll) greater than the following:

$$a_n \leq 0.05\ g$$

$$a_y \leq 0.02\ g$$

$$\theta \leq \pm 0.25\ g$$

$$\phi \leq \pm 0.50\ g$$

$$\psi \leq \pm 0.25\ g$$

Comments - Obviously the pitch, roll, and yaw attitudes are measured in degrees not in accelerations.

The residual oscillations specified doesn't apply to failure states or to flight control modes requiring precision control of attitudes such as precision tracking. The criteria for determining this requirement is:

(a) Level of perception to the flight crew

(b) Equipment wear considerations.

As such, these criteria are reasonable except the amplitudes of the roll and yaw attitudes should be similar. This requirement should also be compatible with MIL-F-8785 which requires a maximum of ± 3 mils of pitch attitude which is ± 0.17°.

Recommendation - Rewrite the requirement.

3.1.1.5.2.2 Heading Hold - When the heading hold is engaged, the automatic flight control system shall maintain the aircraft at its existing heading within a static accuracy of ±0.5 degree with respect to the gyro accuracy.

3.1.1.5.2.2.1 Transient Response - The short period heading response shall be smooth and rapid. After overpowering the rudder and generating a sideslip angle corresponding to approximately 0.15 g lateral acceleration, the aircraft shall return to the reference heading within one overshoot which shall not exceed 20 percent of the initial deviation.

Comments - The accuracy requirement is still valid, but again the transient response is defined by an overpower. Also because no time frame is mentioned, the response can be overly sluggish and still comply to the spec.

Heading Hold mode can be integrated with pitch and roll attitude hold to increase its effectiveness. In the combined mode, when the pilot selects a bank angle of less than 5°, the aircraft will assume that heading at the release of the control stick. When the pilot assumes a bank angle greater than 5°, roll attitude hold will prevail.

Recommendation - Rewrite the requirement.

3.1.1.5.2.3 Heading Select - Where heading select is a system requirement, the automatic flight control system shall automatically turn the aircraft through the smallest angle (left or right) to a heading either selected or preselected by the pilot and maintain that heading as in the heading hold mode. The heading selector shall have 360 degrees control. The bank angle while turning to the selected heading shall be limited to a bank angle designated by the procuring activity. The pilot shall be able to select any other bank angle by exerting the required force on the stick to command the new bank angle, then releasing the force. The aircraft shall not roll in a direction other than the direction required for the aircraft to assume its proper bank angle. In addition, the roll in and roll out shall be accomplished smoothly with no noticeable variation in roll rate.

3.1.1.5.2.3.1 Transient Response - Entry into and termination of the turn shall be smooth and rapid. The aircraft shall not overshoot the selected headings by more than 1.5 degrees.

Comments - The requirement is still valid, but the third sentence requires further definition. The bank angle while turning to the selected heading shall be limited to 60° for Class IV and 30° for other aircraft. The detail specification may use other values.

Recommendation - Still applicable, but rewrite the third sentence.

3.1.1.5.2.4 Automatic Turn Coordination -

3.1.1.5.2.4.1 Lateral Acceleration Limits, Steady Bank - The uncoordinated sideslip angle shall be not greater than 2 degrees and the lateral acceleration shall not exceed 0.03 g, whichever is the more stringent requirement, while at steady state bank angles up to 60 degrees. Lateral acceleration in all cases shall refer to body-axis acceleration at the center of gravity.

3.1.1.5.2.4.2 Lateral Acceleration Limits, Rolling - For aircraft having a roll velocity capability up to 60 degrees per second, the lateral acceleration, while the aircraft is in essentially constant altitude flight and rolling from 60 degrees on one side to 60 degrees on the other up to this roll velocity, shall be maintained within ±0.1 g by the automatic flight control system. For aircraft having a roll velocity capability in excess of 60 degrees per second, the lateral acceleration, while the aircraft is rolling at velocities up to its rolling velocity limit, shall be maintained within 0.2 g.

Comments - The above requirements are in conflict with MIL-F-8785.

Recommendation - Rewrite the requirement.

3.1.1.5.2.5 Sideslip Limiting - Where sideslip limiting is a system requirement, the static accuracy while the aircraft is in straight and level flight shall be maintained within a sideslip angle of 1 degree or a sideslip angle corresponding to a lateral acceleration of 0.02 g, whichever is the lower.

Comments - Applicable.

Recommendation - Incorporate into DFBW systems specification.

3.1.1.5.2.6 Altitude Hold - Engagement of the altitude hold function at rates of climb or dive less than 2000 fpm shall select the existing barometric altitude and control the aircraft to this altitude as a reference.

3.1.1.5.2.6.1 Control Accuracy - After engagement and stabilization or altitude control, a constant barometric altitude shall be maintained within ± 30 feet up to 30,000 feet. From 30,000 feet to 55,000 feet constant altitude shall be maintained within ± 0.1 percent. From 55,000 feet to 80,000 feet constant autitude shall be maintained within ± 0.1 percent at 55,000 feet varying linearity to 0.2 percent at 80,000 feet. Up to an altitude of 80,000 feet the AFCS shall hold the reference altitude to within ± 60 feet or 0.3 percent whichever is greater up to 30° bank angle and ± 90 feet or 0.4 percent whichever is greater from 30° to 60° bank angles. Within the capabilities of the aircraft, any periodic oscillation within these limits shall have a period of at least 20 seconds.

Comments - This requirement still applies.

A sentence should be added to state that the requirements for the different altitudes shall only apply to the capability of the particular aircraft.

Recommendation - Incorporate into DFBW specification.

3.1.1.5.2.7 Mach Hold - After engagement and stabilization on Mach hold, the automatic flight control system shall maintain the selected Mach number without further attention. The steady state Mach number error shall not exceed ± 0.01 steady state Mach number. Provisions shall be made for trimming over a range of at least ± 0.05 Mach. Any periodic oscillation within these limits shall have a period of at least 20 seconds.

Comments - Requirement is still valid.

Recommendation - Incorporate into DFBW specification.

3.1.1.5.2.8 Return to Level - This mode shall be operable from any flight attitude and shall return the aircraft automatically to a straight and level flight condition through the smallest angle with no overshoot. There shall be no stopping or reversal of either roll rate or pitch rate during this maneuver other than the overshoot specified in 3.1.1.5.2.1 and 3.1.1.5.2.2. When operated the return to level control shall disengage any other automatic control mode. When leveled the aircraft shall be in the attitude hold mode.

Comments - Requirement is still valid, but the contradictory requirements of "no overshoot" and the "overshoot specified in ...." should be clarified.

Recommendation - Rewrite the requirement.

3.1.1.5.2.9 Control Stick Maneuvering - The force applied at the stick grip reference point to effect disengagement of any other operational modes shall be minimized consistent with the prevention of nuisance disconnects. When the force on the stick is released the automatic flight control system shall maintain the aircraft at the attitude prevailing at the time of stick release.

Comments - Requirement is still valid.

Recommendation - Incorporate into DFBW specification.

— 3.1.1.5.2.9.1 Stick Feel - The stick forces experienced by the pilot shall not exceed ± 25 percent of the force experienced while maneuvering through the manual control system under similar aerodynamic conditions.

Comments - Not applicable to DFBW systems.

Recommendation - Delete.

— 3.1.1.5.2.10 Standard Legend and Definitions for AFCS Control Panel.

NOMENCLATURE	ABBREVIATION	DEFINITION
AUTOMATIC APPROACH AND LANDING	AUTO LAND	A control mode in which the aircraft's speed and flight path are automatically controlled for approach, flareout and landing.
ALTITUDE HOLD	ALT	Barometric altitude existing at time of engagement maintained automatically.
AUTOMATIC FLIGHT CONTROL SYSTEM	AFCS	A system which automatically controls the flight of an aircraft to a path or attitude described by reference internal or external to the aircraft.
ENGAGE	ENGAGE	A system state in which aircraft control surfaces are actuated by the automatic flight control system actuators.
GLIDE	GLIDE	Aircraft is automatically positioned to the center of the glide slope beam.
GROUND SPEED	GND SPD	Aircraft gound speed automatically controlled to a computed value.

NOMENCLATURE	ABBREVIATION	DEFINITION
HEADING SELECT	HDG SEL	A control feature permitting accurate selection or preselection of a desired heading or headings.
HEADING HOLD	HDG	Automatic control of aircraft to maintain heading existing at the instant of engagement.
INDICATED AIRSPEED	IAS	Indicated airspeed existing at time of engagement maintained automatically.
LOCALIZER	LOC	Aircraft is automatically positioned to and held at the center of the localizer beam.
AUTOMATIC LEVELING	LEVEL	A system control feature which automatically returns the aircraft to level flight attitude in roll and pitch.
MACH HOLD	MACH	Control of the aircraft to maintain the Mach number existing at the instant of engagement.
NAVIGATION	NAV	Control mode in which the aircraft heading is determined by signals from navigation equipment.
PITCH	PITCH	Pertains to control of the aircraft about its lateral axis.
RADAR ALTITUDE	RAD ALT	Control of the aircraft to an altitude determined by signals from a radar/radio altimeter.
REVOLUTIONS PER MINUTE	RPM	Automatic rotor speed control referenced to a helicopter rotor tachometer.
ROLL	ROLL	Pertains to control of the aircraft about its longitudinal axis.
STABILITY AUGMENTATION	STAB AUG	A state of system control in which an automatic device operates to augment the stability characteristics of an aircraft.
STANDBY	STBY	The period in which all elements of the AFCS are energized and the system ready for engagement of surface actuators.
TRIM FOR TAKE OFF	T O TRIM	A control feature in which the aircraft's trim systems are automatically displaced to the best take off position.

NOMENCLATURE	ABBREVIATION	DEFINITION
TRACK	TRACK	Aircraft is automatically maintained on Doppler track reference existing at time of engagement.
YAW	YAW	Pertains to control of the aircraft about its vertical axis.

Comments - Still applicable. Add other mode, including Automatic Carrier Landing (ACL).

Recommendation - Rewrite and incorporate into DFBW specification.

3.1.1.5.3 Automatic Guidance Functions - During the automatic guidance functions, the automatic flight control system - aircraft combination is an element within the overall guidance loop. The requirements which this combination has to meet depend upon the performance requirements of the guidance loop, the guidance method and the particular guidance computer. Unless specific performance data are established in the applicable system specification, the following requirements shall be met.

3.1.1.5.3.1 AN/SPN-10 Tie-in - All data stated below are for fixed-wing aircraft and shall be met by the aircraft in the landing configuration and over the range of the expected weight, center of gravity, and speed variations. The guidance control system shall be incremental pitch and bank commands with respect to the trim attitude at the moment the guidance signals are inserted.

3.1.1.5.3.1.1 Pitch Control -

(a) The damping factor ζ_θ of the short period mode of the pitch oscillation shall be

$$0.5 \leq \zeta_\theta \leq 1$$

(ζ = 1 means critical damping)

(b) The natural undamped frequency ω_θ of the short period mode of the pitch oscillation shall be

$$\omega_\theta \geq 0.75 + 3.1\,\zeta_\theta \quad \text{(radians per second)}$$

These requirements shall be met for step input commands up to ± 5 degrees from trimmed conditions at constant airspeed without changing trim and in the presence of noise as indicated in 3.1.1.5.3.2.5.

(c) The static gain K of the automatic flight control system, i.e., the ratio of elevator deflection to pitch attitude error, shall be

$$K \geq 2\left[\frac{C_{m\alpha}}{C_{m\delta}}\right]$$

where $C_{m\alpha}$ is the pitch moment coefficient of the airplane, and $C_{m\delta}$ is the control pitch moment coefficient.

3.1.1.5.3.1.2 Lateral Control -

(a) During the landing phase, the airplane shall perform lateral maneuvers by coordinated turns. The uncoordinated sideslip angle shall not exceed the limits specified in 3.1.1.5.2.4. The longitudinal axis of the airplane shall not be tied to a heading reference, in order to alleviate the effect of side gusts on lateral touchdown dispersion.

(b) The transfer function from bank command to actual bank angle, when fitted by a second order lag, shall exhibit a natural frequency ω_ϕ and damping factor, ζ_ϕ within the following limits:

$$0.6 \leq \zeta_\phi \leq 1.2$$

$$\omega_\phi \geq 0.46 + 1.46\, \zeta_\phi \quad \text{(radians per second)}$$

This requirement shall be met for step input commands up to ±10 degrees bank angle and in presence of noise as indicated in 3.1.1.5.3.2.5.

Comments - The AN/SPN-10 system is obsolete.

Recommendation - Paragraph should be revised to include requirements relative to the AR-40 and AR-40A.

3.1.1.5.3.1.3 Airspeed Control - The indicated airspeed shall automatically be maintained at the correct approach by controlling the forces acting on the aircraft in the flight path direction (thrust and/or drag force). The thrust control system shall include an auxiliary capability to quickly counteract any airspeed change which may result due to pitch maneuvers. The action of the auxiliary input may be checked by introducing an incremental pitch step command of 4 degrees up and 4 degrees down with respect to trim conditions. In quiet air the airspeed change which results from either pitch command shall not exceed 1.5% of the reference value in the transient and 1% in the steady state. The auxiliary signal shall not be limited below a value which will be necessary to prevent airspeed change when automatic waveoff commands are transmitted to the aircraft. The thrust control system shall have the capability to decrease the airspeed error caused by a step horizontal wind gust to 36.7% of the initial error within 4 seconds after initiation of the gust. A single overshoot shall be permitted during the correction, however it shall not exceed 20% of the initial error. The airspeed shall be within 1% of the reference speed at steady state. For certain aircraft manual control of airspeed shall be permitted when adequately justified by the contractor.

Comments - This is replaced with an Approach Power Compensator.

Recommendation - Delete.

3.1.1.5.3.1.4 Backlash and Deadspots - The total width of backlash or deadspot shall not exceed 0.1 degree of pitch command in the channel from pitch command input to control surface and in the channel from the pitch gyro to the control surface. For input signals larger than this specified backlash, the system performance shall be as specified in 3.1.1.5.3.2.1 and 3.1.1.5.3.2.2. Backlash and deadspot in the channel from pitch input to control surface shall be determined on the ground by varying the pitch command input up and down while the gyro signal is kept constant. Backlash and deadspot in the channel from pitch gyro to the control surface shall be determined by tilting the pitch gyro up and down while the pitch command signal is held at zero or a constant value. The backlash and deadspot requirements shall be met under a loaded condition corresponding to 2 degrees of incremental angle of attack with respect to the trimmed condition and under the unloaded neutral condition. Neutral condition is defined as zero torque requirement from the servo. These same requirements shall be met by the roll autopilot.

Comments - Backlash/Deadspots will still exist in DFBW systems, but requirement must be further studied.

Recommendation - Further study required.

3.1.1.5.3.1.5 Noise Compatibility - Noise which is superimposed on a proper input signal shall not saturate the automatic flight control system components and shall not cause objectionable motion of control stick or wheel. The performance requirements specified in 3.1.1.5.3.2.1 and 3.1.1.5.3.2.2 shall be met under presence of this noise. The noise content in the input signal to the pitch and roll system shall be represented by white Gaussian noise which has a power spectrum density ϕ and is passed through a filter with the transfer function $G(j\omega)$.

Pitch Command Input:

$\phi = 0.04$ (degrees of pitch command)^2 per radian per second; flat in the frequency range from 0 to at least 30 radians per second.

$$G(j\omega) = \frac{1 + 3j\omega}{\left(\frac{j\omega}{5}\right)^2 + \left(\frac{j\omega}{5}\right) + 1} \times \frac{1}{1 + \left(\frac{j\omega}{1.85}\right)}$$

Bank Command Input:

$\phi = 0.01$ (degree of bank command)^2 per radian per second; flat in the frequency range from 0 to at least 30 radians per second.

$$G(j\omega) = (.2)\,\frac{1 + 10j\omega}{\left(\frac{j\omega}{5}\right)^2 + \left(\frac{j\omega}{5}\right) + 1} \times \frac{1}{1 + \left(\frac{j\omega}{1.85}\right)}$$

Comments - The performance sensitivity with respect to noise requires a detailed analysis.

Recommendation - Conduct a DFBW system noise/performance study to determine the applicable noise models.

3.1.1.5.3.1.6 Command Signal Limiting - Means shall be provided to limit the pitch and band command signals immediately before feeding them to the automatic flight control system. The pitch command shall be limited to -13.5 and +6.5 degrees and the bank command shall be limited to ±30 degrees.

Comments - The requirement for a limiter is still valid.

Recommendation - Requires further study relative to DFBW to determine if the above limits are valid.

3.1.1.5.3.1.7 Data Link - The resolution of the data link shall be at least ± 0.04 degree minimum for pitch and ± 0.1 degree minimum for roll. The sampling interval in the case of a sampling data link shall be not greater than 0.1 second.

Comments - Parameters are still valid

Recommendation - Incorporate into DFBW criteria.

3.1.1.5.3.2 Tie-in With Ground Controlled Bombing (AN/MPQ-14, AN/TPQ-10) - The general tie-in requirements of 3.1.1.4 shall be applicable. Specific performance data for the automatic flight control system - aircraft combination shall be compatible with the performance requirements of the overall guidance loop and shall meet the requirements of the detail system specification.

Comments - The tie-in to a TPQ-10 is still valid.

Recommendation - Incorporate into DFBW criteria.

3.1.1.5.4 Additional Requirements for Rotary Wing Aircraft - In addition to the applicable requirements of 3.1.1, helicopter automatic flight control systems shall meet the following requirements.

Comments - Not applicable.

3.1.1.5.5 Additional Requirements for Convertiplane, VTOL Aircraft - The requirements of these special type aircraft are, in most cases, identical to the requirements for other conventional and rotary wing aircraft.

Comments - Not applicable.

3.1.1.5.6 Additional Requirements for Lighter-Than-Air Aircraft - The requirements of this paragraph are in addition to previous applicable requirements.

Comments - Not applicable.

3.1.1.6 General Requirements -

3.1.1.6.1 Stability Margins - The AFCS shall be demonstrated to be stable in all modes of operation in all flight conditions as follows: All AFCS aerodynamic loops shall be flight demonstrated to be stable for at least one and one-half times the production gain. At the beginning of service life and under standard conditions as specified in Specification MIL-E-5272, all AFCS non-aerodynamic servo loops shall be demonstrated to be stable at three times the production gain. All AFCS non-aerodynamic loops shall be demonstrated to be stable at one and one-half times the production gain throughout all operating service conditions. At the end of service life and under standard conditions all non-aerodynamic loops shall be demonstrated to be stable at one and one-half times the production gain. It shall also be demonstrated that an additional lag of 45 degrees, when introduced into any loop with production gains, shall not result in instability.

Comments - The requirement for stability margins applies to any design, but the paragraph is not applicable to today's hardware. The production gains shouldn't vary between "at the start of service life" to "end of service life".

Recommendation - Rewrite the requirement for DFBW system application.

3.1.1.6.2 Internal Noise - There shall be no noticeable high frequency motion of the controls due to noise signals generated within the automatic flight control system. Control surface oscillations which are a necessary feature of certain self-adaptive automatic flight control systems shall not exceed the limits of the applicable specification.

Comments - The requirement is still valid to have no high frequency motion at the control surfaces, but the above paragraph gives the cause as internal noise within the AFCS. The requirement should state that no high frequency motion on the output of any control surface is permitted. The second sentence is not applicable.

Recommendation - Rewrite the paragraph and change the title. Delete the second sentence.

3.1.1.6.3 Parameter Ground Adjustment - Co.. ols shall be provided to facilitate ground adjustments of the automatic flight control system par. . eters. Such control provisions, however, shall be held to a minimum and shall not be readily . ccessible to flight crews, that is, they must be tamper resistant.

Comments - A DFBW FCS should not require any adjustments by the ground crew.

Recommendation - Write a new requirement in maintainability section of new spec.

3.1.1.6.4 Life - Components of automatic flight control systems shall have a guaranteed service life of at least 1000 hours in naval aircraft. The operating time shall be computed by reference to data in the log book of the aircraft in which the component is installed or to a time totalizing meter supplied with the equipment.

Comments - A service life of 1000 hr is too small a number for today's flight control hardware. For mechanical components which are subject to wear such as actuators and sensors, a more reasonable number would be 10,000 and 5,000 hr respectively, before wearing surfaces would have to be replaced. For electronic WRA's having no moving mechanical parts, it should be designed to be economically repairable for the airframe lifetime.

Recommendation - Write a new requirement consistent with DFBW system reliability requirements.

3.1.1.6.5 Shelf Life - The equipment shall be capable of immediate service use without operational conditioning or maintenance during storage periods up to 24 months.

Recommendation - Revise the requirement consistent with state of the art equipment.

3.2 Installation Design Requirements

3.2.1 Accessibility and Serviceability - The automatic flight control systems and components shall be designed for easy accessibility and servicing. Components shall be designed, installed, located, and provided with access doors so that inspection, rigging, removal, repair, and lubrication can be readily accomplished without major disassembly of the aircraft. Suitable provision for rigging pins, or the equivalent, shall be made for locating and holding each control system component at some point in its travel, such as the neutral or mid-point to facilitate correct rigging of the control system, and to permit removal of components, including the control surface, without disturbing the rigging. Any AFCS component shall be replaceable in not more than one-half man hour.

Comments - The first two sentences are still applicable. Add at the end of the third sentence, "if required," because it is not evident if rig pins will be needed for a DFBW system.

The one-half manhour requirement to replace a component requires further study.

Recommendation - Review requirement and incorporate in maintainability provisions.

3.2.2 Maintenance Provisions - Systems and components shall be designed to provide for ready accessibility and for connection of such test equipment as may be required for field maintenance. (See 6.3)

3.2.2.1 Design of equipment should include provisions for the connection of circuit, or other test facilities, by test point terminals or connections leading to selected positions in the system or components. Actual locations should be determined by the system or component design and as specified in the detailed system or component specification. Sufficient test points should be provided to facilitate location of the most probable malfunction which may be expected to be encountered in service usage.

Comments - A modern AFCS should require some test equipment. For normal field maintenance, BIT should be capable of troubleshooting for failures without the need of external test equipment. This is a chief advantage of digital computers.

Recommendation - Write a new requirement.

3.2.3 Foolproofness - All automatic flight control systems shall be designed so that incorrect assembly and reversed operation of controls is impossible.

3.2.4 Fouling Prevention - All elements of the AFCS shall be suitably guided, protected, or covered in all compartments where it is possible for them to be fouled by dropping of articles, loading of cargo, changing of engines, etc.

3.2.5 Draining - Adequate provisions shall be made to drain AFCS components subject to the accumulation of moisture or fluid leakage.

3.2.6 Hydraulic Systems - Hydraulic systems shall be in accordance with the requirements of Specification MIL-H-5440, and shall comply with the design objectives of 3.1 of this specification.

3.2.6.1 Ground Checkout - The hydraulic systems shall be designed and installed in such a manner that ground checkout of automatic control systems can be made by the use of a standard dual system hydraulic test stand without the necessity of reservicing any of the systems after completion of testing.

Comments - Still applicable requirements. MIL-H-5440 requires review relative to DFBW systems.

Recommendation - Review and update as required.

3.2.7 Electrical Power - The AFCS shall operate satisfactorily in accordance with the performance requirements specified herein when supplied power from sources conforming to the applicable requirements of MIL-STD-704. The performance and operational requirements of this and the applicable component specifications shall be met with equipment supplied by this power, which may be subject to steady state and transient variations within the specified tolerances of MIL-STD-704.

Comments - The electrical power system is a flight critical item. Long duration power transients could result in system dropouts.

Recommendation - Study and rewrite power requirements.

3.2.8 Calibration Adjustments, Controls and Knobs -

3.2.8.1 Controls and Knobs - Controls and knobs requiring manipulation in flight shall operate smoothly with negligible backlash or binding. Means shall be provided to prevent movement due to shock or vibrations encountered in service. Controls and knobs shall be readily accessible and of a size and shape for convenience and ease of operation under all service conditions. The direction of motion of the knob or control and the location within the cockpit shall be in accordance with the requirements of MIL-STD-203.

Comments - Applicable.

Recommendation - Retain requirement.

3.2.8.2 Calibration Adjustments - Calibration adjustments required for ground maintenance of the system or component shall be kept to a minimum. The system objective shall be to concentrate all required ground adjustments in one major component of the system. It is preferred that the removal of an auxiliary cover plate be necessary for access to calibration adjustment. Suitable means shall be provided to prevent a change in adjustment to occur due to shock or vibrations encountered in service. These adjustments shall be labeled, indexed, and marked in such a manner that only visual means are necessary for setting the desired adjustment.

Comments - This requirement is analogous to paragraph 3.1.1.6.3

Recommendation - Write a new requirement and incorporate into the maintainability section.

3.2.9 Dynamic and Static Pressure and Air Data Systems - Whenever AFCS components require connection to pitot tubes or static ports, the required performance shall be obtainable from pitot tube and static port installations conforming to the requirements of Specification MIL-I-6115. Compensation of static or dynamic signals, which may be required to obtain desired performance, shall be accomplished within the system or components. Whenever the automatic flight control system requires outputs from a central air data system in lieu of static and pitot measurements, the characteristics of the outputs, both static and dynamic shall be submitted to the using agency by the automatic flight control system contractor at the earliest possible date in order to insure compatibility between the AFCS and air data system.

Comments - The requirement is valid. However, additional requirements relative to redundancy (i.e. multiple air data inputs) should also be addressed.

Recommendation - Revise requirements relative to redundant air data parameters.

3.3 System Component Design Requirements -

3.3.1 Electrical and Electronic Components - All electrical equipment in the control systems shall be designed and installed in accordance with Specifications MIL-E-5400, MIL-E-7080, MIL-W-5088, MIL-A-8064, MIL-M-8609, MIL-E-4682, MIL-M-7969, and any other applicable specifications. Critical components shall have the best possible reliability to insure against loss of control of the aircraft. Specific consideration shall be directed toward achieving simplicity, producibility, and maintainability of equipment. The procedures outlined in Specification MIL-R-22256 shall be followed to insure that electronic equipment designs will have a high level of inherent reliability.

Comments - The first sentence calls for compliance with several MIL Specs:

MIL-E-5400	Electronic Equipment, Airborne, General Spec for
MIL-E-7080	Electrical Equipment, Selection and Installation of
MIL-W-5088	Wiring, Aerospace Vehicle
MIL-A-8064	Electro-Mechanical Actuators, General Requirements for
MIL-M-8609	DC Motors, 28 Volts, General Specification for
MIL-E-4682	Electron Tubes and Transistors, Choice and Application of
MIL-M-7969	Motors, AC, 400 Cycle, 115 Volts, General Specification for

The sentence ends with "and any other applicable specifications" a catch-all phrase. MIL-E-5400 calls out other MIL Specs including MIL-W-5088. Why list MIL-W-5088 separately? The specs have to be reviewed and the obsolete disregarded.

The second sentence doesn't apply to DFBW systems and the 3rd sentence is very general. MIL-R-22256 is a Reliability Requirement for Electronic Equipment Specification which is an obsolete spec that doesn't apply to DFBW systems.

Recommendation - Rewrite the requirement.

3.3.1.1 Electron Tubes - Electron tubes shall not be used.

Comments - Still applicable.

3.3.1.2 Electrical Tape - No pressure-sensitive (adhesive or friction) fabric or textile tape shall be used. Nonmoisture absorbing tape may be used for mechanical purposes, with the approval of the procuring activity.

Comments - Prohibit all electrical tape.

Recommendation - Rewrite the requirement.

3.3.1.3 Switches - Switches shall conform to the requirements of Specifications MIL-S-3950, JAN-S-63, or MIL-S-6743 as the application may require. The operating position requirements of Specification MIL-E-5400 shall normally apply.

Comments - MIL Specs must be reviewed.

Recommendation - Rewrite the requirement.

3.3.1.4 Electron Devices - Transistors and diodes shall be chosen and applied, and the complements reported, as outlined in Specification MIL-E-4682. The complement report must be submitted to the procuring activity for review and approval prior to design approval testing.

Comments - The above requirement calls for a listing of the transistors and diodes to be approved by the Navy. The hardware manufacturer must use MIL STD parts or the parts found on a QPL (Qualified Parts List). A complete list is redundant data since drawings are furnished to the government.

Recommendation - Delete.

3.3.1.5 Saturable Reactors - Saturable reactors in automatic flight control systems and components shall comply with the environmental and performance requirements specified herein and in detail system component specifications.

Comments - Obsolete hardware.

Recommendation - Delete.

3.3.1.6 Materials, Parts and Processes - In the selection of electronic materials, parts and processes, fulfillment of major design objectives shall be the prime consideration. In so doing, the following factors shall govern:

3.3.1.7 Modules - The electronic portions of the equipment shall be divided into modules conforming to Specification MIL-E-19600. At this level, modules may be repairable or nonrepairable in accordance with Specification MIL-E-5400. When possible, microelectronic processes shall be used; then these modules shall be subdivided further into nonrepairable (expendable) modules in accordance with instructions to be obtained from the procuring activity. Each nonrepairable module will be treated as a single part and nonstandard part approval must be obtained. The parts and materials used within the expendable module must be equal to or superior to that required by MIL specifications for similar items, MIL-STD items need not necessarily be used. The expendable module, as a whole, must pass electrical and environmental requirements. Drawings used for the purchase or construction of the module must be sufficiently complete to permit the construction of the module by other than the original manufacturer. All modules must be designed for long, reliable life.

Comments - MIL-E-19600 is an Electronic Module Spec. A hardware concept practiced 20 years ago and outdated by a new technology. Most hardware today have electronic components mounted on removable cards.

Recommendation - Delete reference to modules and review the requirement for non-repairable items.

3.3.1.7.1 Microelectronic Processes - The electronic portions of the equipment shall be constructed using microelectronic processes to the greatest extent possible. The processes used shall include the following with priority as shown: (See 6.3)

(a) The diffusion of various materials into a semiconducting base material.

(b) The evaporation or chemical deposition of thin films of various materials on an insulating base material.

Comments - The associated MIL SPECS should be referenced.

Recommendation - Rewrite requirement.

3.3.1.8 Standard and Nonstandard Parts and Material - Conventional parts may be used only when the performance requirements of the equipment cannot be met by using the requirements of 3.1.1.1, or when specifically authorized by the procuring activity. To the extent possible consistent with the requirements herein, materials, parts, processes and nonstandard parts approval requirements of Specification MIL-E-5400 shall be followed.

Comments - MIL-E-5400 addresses non-standard parts and the submittal thereof, the requirement is redundant.

Recommendation - Delete.

3.3.1.9 Lubrication - Where applicable, lubrication of the components and systems shall be in accordance with Specification MIL-L-6880. Lubrication fittings shall be in accordance with Specification MIL-F-3541, MS15001 and MS15002-1 and -2.

Comments - No component in a modern FCS should require any periodic lubrication. In the future, if a manufacturer has such a requirement, he should submit a deviation request and justify his design.

Recommendation - Rewrite the requirement disallowing any periodic lubrication for the life of the hardware.

3.3.1.10 Materials - The materials utilized in the components and systems shall be entirely suitable for the service and purpose intended. When Government specifications exist for the type material being used, the materials shall conform to these specifications. Nonspecification materials may be used if it is shown that they are more suitable for the purpose than specification materials.

Comments - Add a restriction on magnesium and magnesium alloys.

Recommendation - Rewrite the requirement.

3.3.1.11 Workmanship - Workmanship shall be sufficiently high grade throughout to insure proper operation and service life of the systems and components. The quality of the items being produced shall uniformly high and shall not depreciate from the quality of qualification test items.

Comments - Applicable.

Recommendation - Include in new specification.

3.3.1.12 Standardization - When possible, contractor designed equipment which has been approved for use in some models of aircraft shall also be used in later model airplanes if the installation and requirements are similar. This procedure will reduce supply problems, test and qualification expenses, and provide tried and proven equipment which should be more reliable.

Comments - The requirement is similar to paragraph 3.1.1.2 and should be updated to reflect standard designs such as the AYK-14 Computer.

Recommendation - Rewrite the requirement.

3.3.1.13 Totalizing Time Meter - Units of the equipment shall include a time totalizing meter conforming with the applicable requirements of Specification MIL-M-7793. Control boxes, mounting bases, junction boxes, small indicators and other items not susceptible to failure, due to circuitry and moving parts, shall be exempt from this requirement.

Comments - The requirement is still valid, but the second sentence has to be clarified. MIL-M-7793, a Time Totalizing Meter spec. is still valid, but the scale designation should be specified as "Hours" with the maximum readout of 9999.

Recommendation - Rewrite the paragraph.

3.4 Planning and Procedural Requirements -

3.4.1 Technical Development Plan - A technical development plan or program guide shall be established for the AFCS, and shall be submitted to the procuring activity for review and approval. This plan shall be revised and kept up to date as necessary. Revisions shall be submitted as part of the quarterly progress report to the procuring activity until it is mutually agreed that the revision usefullness has ended. The plan shall, in general, conform to the following:

Comments - The requirement for a master plan is still valid, but the contents of the plan listed in paragraph 3.4.1.1 through 3.4.1.2 have to be clarified.

Recommendation - Rewrite the requirement.

3.4.1.1 Scheduling -

3.4.1.1.1 Interrelationship Between Phases - The plan shall show the interrelationship between phases and/or items of development work to be accomplished. It shall show the logical sequence of work to be accomplished, and which items of work are to be completed before others can be initiated.

3.4.1.1.2 Bar Graph - The plan shall include a bar graph of all major items of work showing the starting and completion dates of these items of work.

3.4.1.1.3 Due Dates of Reports - The plan shall show the time for submittal of all required technical data and reports.

3.4.1.1.4 Schedule Changes - As the work outlined in the plan progresses, any changes, schedule difficulties or slippages shall be clearly shown in the quarterly revision to the plan together with the justification and request for approval for any such changes.

3.4.1.2 Contents of the Plan - The plan shall include, but not be limited to, the planned procedure to develop and provide design information on the following items:

(a) Preliminary automatic flight control system performance specification. See 3.5.1.

(b) Initial system synthesis - A study shall be performed which will lead to the synthesis of an automatic flight control system to fulfill the requirements specified in the preliminary performance specification.

(c) Initial system analysis - The automatic flight control system contractor shall:

   (1) Perform an analysis of the synthesized system using analog or digital computer methods and/or graphical methods such as Bode plots, Nyquist plots, root locus plots, etc.

   (2) Make a preliminary reliability analysis of the automatic flight control system.

   (3) Make a preliminary failure analysis of the automatic flight control system.

(d) Preliminary automatic flight control system report. See 3.5.2.

(e) Final automatic flight control system specification. See 3.5.1.

(f) Development of basic design - The contractor shall proceed with the development of preliminary designs and components of the automatic flight control system in rough form. An experimental model (or models) of the system may be developed to demonstrate the technical soundness of the basic idea without detailed attention to the eventual overall design or form factor and which may not contain parts of the final production design. Systems, subsystems, and components for AFCS shall be selected as specified in 3.1.1.2.

(g) Preparation of subsystems and component specifications. See 3.5.3.

(h) Design approval test specifications. See 3.5.4.

(i) Simulation studies using development models. See 4.2.1.

(j) Automatic flight control system simulation report. See 3.5.5.

(k) Design approval tests.

(l) Design approval test report. See 3.5.6.

(m) Fabrication of Service Test Models -

NOTE: Approval of the procuring activity shall be obtained prior to fabrication of service test models. In order to decrease procurement lead time, approval may also be requested at this time of fabrication of prototype models.

(n) Identification of equipment. See 3.5.7.

(o) Flight test procedures. See 3.5.8.

(p) Preliminary flight tests.

(q) Preliminary flight test reports. See 3.5.9.

(r) Performance flight tests.

(s) Contractor's demonstration flight tests.

(t) Performance flight test report. See 3.5.10.

(u) Fabrication of special maintenance and overhaul tools. See 3.5.11.

(v) Preparation of handbooks.

(w) Tooling for production.

(x) Fabrication of production models.

Comments - This is still a valid requirement but should be updated to be consistent with DFBW system design/performance requirements.

Recommendation - Revise requirements.

3.4.2 Design Approval - The procuring activity shall retain the right to disapprove any part of the design on the basis of nonconformance with the requirements of the contract or not being in the best interests of the government.

Comments - This requirement is still applicable.

Recommendation - Incorporate into DFBW specification.

3.5 Data Requirements - The design and test data listed herein are required. If applicable design data are available, the contractor shall, in lieu of submitting new design data, submit these available data supplemented by sufficient information to substantiate its applicability. Design data shall be prepared and submitted as required by Specification MIL-D-18300 and shall include the following:

Comments - The requirement is still valid. MILD-18300 is the Design Data for Avionic Equipment specification which is still applicable.

Recommendation - Rewrite the paragraph.

3.5.1 Automatic Flight Control System Specification - A performance specification shall be prepared by the contractor for the AFCS. The performance of the system and the various individual subsystems and components shall be specified. In addition, any special features or unusual requirements shall be indicated. This specification shall also define the environmental criteria and the testing required to show suitability for both the environment and the overall performance. Installation details, weights, sizes, structural limitations shall be included as required by the design. Preparation and format of this document shall be such that the areas of responsibility for the airframe, external guidance, primary flight control system and AFCS are clearly defined. The specification shall be prepared in accordance with the format outlined by Specification AV-5000.

3.5.2 Preliminary Automatic Flight Control System Report - Following the initial study and analysis of the proposed system, a preliminary automatic flight control system report shall be prepared and submitted to the procuring activity prior to manufacture of the prototype system. This report may be combined with a quarterly progress report as required by Specification MIL-D-18300.

(a) A discussion of the airframe and aerodynamic characteristics, and aircraft mission which were pertinent in the selection of the automatic flight control system.

(b) A discussion of any unusual or difficult design features and problems.

(c) A discussion of and justification for any contemplated deviations from the applicable specifications. Approval will be required from the procuring agency for such deviations.

(d) A discussion of the tie-in of the AFCS to the overall flight control system.

(e) A block diagram of the AFCS. This diagram shall clearly indicate the normal control paths, redundancey, manual overrides, emergency provisions, tie-in of external elements and the control surfaces to be actuated.

(f) A general description of the AFCS and a discussion of the theory of operation. The various modes of operation should be explained in detail.

(g) A discussion of the stability of the AFCS and its relation to the overall stability of the airplane. This may be in the form of Bode, Nyquist or root locus plots, etc. for small perturbations. Data shall also be presented for large amplitudes taking into account the main nonlinearities such as limits on actuator rates and position.

(h) Data should be presented in response to commands and disturbances, speed of response, overshoot, damping, accuracy, etc. These data should also take into account the main nonlinearities.

(i) A discussion of any required special functions such as Mach control, g limiting, etc.

(j) A predicted reliability of the proposed design, sources of data, and the analytical approach used in making this prediction and a discussion of the results in comparison to requirements shall be included.

(k) A preliminary failure analysis of the AFCS.

(l) A general control system layout showing surfaces to be actuated, method of actuation system duplication, approximate hinge moments, major components, emergency provisions, etc.

(m) A layout of the hydraulic systems supplying the AFCS. This layout shall show sources of hydraulic power, pressures required, peak and average flow rates, power spectrum, etc.

(n) A schematic wiring diagram of the electrical system affecting the AFCS. This diagram shall show source(s) of power, peak and average power requirements, voltage, current, etc.

(o) An AFCS control panel outline drawing showing the type switches used, nomenclature and functions available shall be submitted.

Comments - This is still a valid requirement, but it has to be updated for DFBW systems. Remove "Preliminary" from the title.

Recommendation - Rewrite the requirement.

3.5.3 Subsystem and Component Specifications - Detailed specifications for subsystems and components shall be prepared and submitted as engineering information. Specifications shall be prepared in accordance with Specification MIL-D-18300.

3.5.4 Design Approval Test Specifications - Design approval test specifications and procedures in accordance with Specification MIL-D-18300 for U. S. Navy aircraft shall be submitted for approval. Justification shall be submitted for special maintenance and overhaul tools and test equipment required for these tests.

3.5.5 Automatic Flight Control System Simulation Reports - Reports on simulator test equipment, test procedures and test results shall be submitted.

3.5.6 Design Approval and Preproduction Test Reports - A report shall be submitted as engineering information on the design approval and production tests. All test reports shall either contain or be accompanied by a copy of the applicable test specification.

3.5.7 Identification of Equipment - Assignment of AN nomenclature and approval of nameplate drawings shall be requested in accordance with Specification MIL-N-18307. AN nomenclature may not be required for the following, when approved by the procuring activity.

(a) Approved off-the-shelf equipment which bear the vendor's standard nameplate and part number.

(b) Approved equipment which when installed becomes a structural part of the aircraft (i.e. junction boxes, console mounts).

3.5.8 Flight Test Procedures - Flight test procedures for the AFCS shall be submitted for the approval of the procuring activity.

3.5.9 Preliminary Flight Test Reports - A report shall be prepared and submitted as engineering information on the preliminary flight tests. This report shall discuss any differences noted between the predicted and actual flight performance.

3.5.10 Performance Flight Test Report - A report shall be prepared and submitted for approval on the performance flight testing. This report shall indicate compliance with the performance specification.

3.5.11 Special Maintenance and Overhaul Tools - Prior to fabrication of special maintenance and overhaul tools, the contractor shall submit a report to the procuring agency for approval. These items shall be in accordance with Specification MIL-D-8512.

3.5.12 ECP and Deviation Data - When ECP's, requests for deviations, or other similar requests are submitted for evaluation, they shall contain sufficient drawings, test reports, and justification to permit a logical sound, engineering evaluation without the necessity for requesting or hunting additional data. The problem should be well defined and a description given of the other approaches to a solution which were attempted and the reason for their rejection.

3.5.13 Nonstandard Parts Data - These data shall be submitted as required by 3.3.1.8.

Comments - The above requirements (Para 3.5.3-3.5.13) are valid, but should be expanded to cover digital hardware/software and associated quality assurance requirements.

Recommendation - Update and expand to include all pertinent documentation.

4. QUALITY ASSURANCE PROVISIONS

4.1 Test Requirements - Appropriate testing, as outlined herein, shall be conducted throughout the development and production of flight control systems in order to insure proper design and performance and also continuing quality throughout production. The specific tests required shall be specified in the detailed specifications for the components and systems. If the tests required by the detailed specifications are inadequate to prove that the flight control system and flight control system installation incorporate the specified requirements, the contractor shall propose amendments to the contract to include tests which will provide adequate proof. If applicable tests are available, the contractor shall, in lieu of repeating tests, propose amendments to the contract to require the submittal of these data, supplemented by sufficient information to substantiate their applicability.

Comments - Requirement is applicable but must reflect DFBW systems Design/Test Requirements.

Recommendation - Rewrite the paragraph.

4.1.1 Test Witnesses - Before conducting a required test, an authorized procurement activity representative shall be notified so that he or his representative, may witness the test and certify results and observations contained in the test reports. When the procuring activity representative is notified, he shall be informed if the test is such that interpretation of the behavior of the test article is likely to require engineering knowledge and experience, in which case he will provide a qualified engineer who will witness the test and certify the results and observations during the test.

Comments - The requirement is still applicable, but it should state a time to be notified so many days in advance. In the last sentence, delete any reference to "certify the results", because the witness shall not have to approve or disapprove any tests he witnesses. He will be an observer and not a monitor or inspector.

Recommendation - Rewrite the paragraph.

4.2 Design Approval Tests - Design approval tests are accomplished on a sample or samples to determine compliance with the requirements of an investigation, study, research, development contract or purchase order, experimental and developmental specifications, exhibits or other requirements applicable thereto. A breadboard model, experimental model or developmental model shall be constructed and appropriate tests shall be conducted to insure that the operational and dynamic characteristics of the systems and components meet the requirements which have been established and are reliable in their performance characteristics.

Comments - Design approval tests is not a term in use in the industry today. Developmental tests is more appropriate.

Recommendation - Rewrite the requirement.

4.2.1 Simulator Testing - Tests shall be made with equipment mounted on a simulator and with gains adjusted as recommended by the manufacturer. The simulator shall include all relevant control rigging, hinge moments, artifical feel devices, and tilt tables, if required. In addition, it shall include a computer to simulate aircraft response, selectable for all conditions of flight.

Comments - Expand the paragraph to include more specifics in a vital test area for DFBW systems.

Recommendations - Rewrite.

4.3 Preproduction Tests - Preproduction tests are those tests accomplished on a sample or samples, representative of an article or system to be procured or delivered on a production contract or purchase order, to determine that the article meets specification requirements. These tests shall be conducted by the procuring activity or contractor at the location or locations as specified in the contract, purchase order or detailed specification. A test report in accordance with 3.5.6 shall be submitted to the procuring activity for approval.

4.3.1 Sampling - Usually, three systems or components shall be made available to accomplish the preproduction tests. Allocation of, and additional or different quantities required shall be as specified in the contract or purchase order.

4.3.2 Scope of Tests - Preproduction tests shall consist of at least the following series of accelerated tests to determine reliability and performance under the various conditions which may be encountered in service usage. The preproduction tests may be allocated among the three test systems or components. A suggested order of tests is as follows:

System or Component	System or Component	System or Component
(a) Individual tests	(a) Individual tests	(a) Individual tests
(b) Power supply variation	(b) High temperature	(b) Acceleration
(c) Dielectric strength	(c) Low temperature	(c) Vibration
(d) Radio interference	(d) Altitude	(d) Shock
(e) Sand and dust	(e) Composite rain-ice	(e) Humidity
(f) Miscellaneous	(f) Salt spray	
(g) Fungus resistance		

Breakdown of tests where additional or a different quantity of systems or components is allocated for preproduction test shall be as specified in the contract or detailed specification.

4.3.3 Contractor Testing - With the consent or request of the contractor and at the discretion of the procuring activity, any service condition tests conducted by the contractor and witnessed by an authorized procurement activity representative prior to submission for preproduction approval may be acceptable as preproduction tests.

4.3.4 Test Tolerances - In conducting service condition tests, performance tolerances shall be as specified in the system or component specification.

4.3.5 Test Procedures - Appropriate environmental tests shall be conducted on all components which are subject to deterioration or malfunction due to any environmental condition. Environmental testing shall be conducted on system components in accordance with Specification MIL-T-5422 or Specification MIL-E-5272 as required by the equipment detail specification. Modifications of test procedures shall be submitted for review and approval by the procuring activity prior to actual usage.

4.3.5.1 Power Supply Variation - Each component shall be tested individually or assembled, or both, into a system in a manner as specified in the component or system specification. Rated electrical, hydraulic and other required power sources, shall be applied and all calibration setting placed at maximum rated positions. After completion of the warm-up period, the power sources shall be varied and modulated, throughout their specified limits. The performance of the components shall be observed in the manner defined in the component or system specification. No steady state nor transient modulation changes in the power source, within permissible limits, shall cause a variation or modulation in the systems performance which may result in undesirable or unsatisfactory operation. With rated power applied, the systems switches, controls and components shall be operated as in actual service. Observation of the rated power source shall note no variation nor modulation of the power source beyond permissible operational limits when the system is operated against load conditions varying from no load to full load conditions.

4.3.5.2 Dielectric Strength - Each circuit of electrical and electronic components shall be subjected to a test equivalent to the application of a root mean square test voltage of three times the maximum (but not less than 500 v) surge d.c. or maximum surge peak a.c. voltage to which the circuit will be subjected under service conditions. The test voltage shall be of commercial frequency and shall be applied between ungrounded terminals and ground, and between terminals insulated from each other, for a period of 1 minute. Test shall be accomplished at normal ground barometric pressure. No breakdown of insulation or air gap shall occur. Circuits containing capacitors or other similar electronic parts which may be subject to damage by application of above voltages shall be subjected to twice the surge peak (but no less than 100 v) operating voltage for the specified period. If the maximum peak operating voltage is greater than 700 v, the rms value of the test voltage shall be 1050 v greater than 1.5 times the maximum peak operating voltage. Electrical and electronic components shall also be tested for resistance to air gap breakdown at the maximum altitude specified in the altitude test.

4.3.5.3 Radio Interference - The automatic flight control system and components, or both, shall be assembled and arranged in a manner as specified in the system or component specification with interconnecting cables and supporting brackets representative of an actual installation. Provisions shall also be made for inverting all components with respect to the ground plane or positioning in such a manner as to permit measurements from the bottom of all components. Measurement of radiated and conducted interference limits shall be made in accordance with Specification MIL-I-6181 with the system switches, controls and components operated as in actual service. Measured values shall not exceed the limits specified in Specification MIL-I-6181.

Comments - Preproduction or qualification testing is another vital test area that has to be reviewed and updated. Paragraphs 4.3.1 through 4.3.5.3 relate to the subject. An interesting point is that the composite rain ice test is not performed with today's hardware, but may be appropriate for the hardware environment.

Recommendation - Review and rewrite the requirement.

4.4 Acceptance Tests - Acceptance tests are all the sampling and individual tests specified herein and in the system or component specification, exhibit, or other requirements which are to be accomplished on an article or articles submitted for acceptance under contract to determine acceptability under the requirements of the procurement document. When these tests are appropriate, they will be required by the procurement document or detailed specification. Contractors' records of all inspection work and tests giving the quantitative results of tests required to determine compliance with the requirements and tests specified herein and in the system or component specifications shall be kept complete and shall be available to the procuring activity representative at all times. The record or report of inspection and tests shall be signed or approved by a responsible person specifically assigned by the contractor. Acceptance testing shall be accomplished by the contractor on articles submitted for acceptance under the contract or purchase order. Acceptance or approval of material during the course of manufacture shall in no case be construed as a guaranty of the acceptance of the finished article.

Comments - Requirement is applicable. On keeping a record of the test results for future review, the length of time should be specified.

Recommendation - Rewrite.

4.4.1 Individual Tests - Each component or system shall be examined to determine conformance to this specification and the system or component specification with respect to material, workmanship, dimensions and markings, in addition to the individual tests specified by the system or component specification in the sequence specified therein.

Comments - Delete as a separate entity and include this requirement in the paragraph on Acceptance Tests.

Recommendation - Rewrite requirement.

4.4.2 Sampling Tests - One each component or system shall be selected at random by the procuring activity representative as a representative sample from each 100 systems or components, or fraction thereof delivered on the contract or purchase order and subjected to the sampling tests. When the component or system fails to meet the specified sampling tests, acceptance of all components or systems will be withheld until the extent and cause of failure is determined. Additional components may be selected and tested if required to aid in determination of extent and cause of failure. For operational reasons, individual tests may be continued pending completion of investigation of a sampling test failure, but the final acceptance of components or systems is contingent upon the procuring activity inspector's decision regarding the overall compliance of the product with specification requirements. If investigation indicates that the defect(s) may exist in items previously accepted, full particulars concerning the defect(s) found, including recommendations for correction, shall be furnished to the procuring activity.

Comments - Does not apply to a modern FCS.

Recommendation - Delete.

4.4.3 Reliability Assurance - Equipment reliability shall be assured by testing production sample lots to specific test requirements. These tests do not replace preproduction tests, production sample tests, individual or special acceptance tests or life tests specified. Specification MIL-R-23094 shall be used as a guide in establishing requirements and procedures to assure compliance with mean-time-between-failures (MTBF) requirements for production avionics equipment. The test level, the duty cycle, the parameters to be measured, the MTBF, and the accept-reject criteria will be specified by the detail equipment specification.

Comments - One of the subjects requiring further study is how to show compliance with a 10^{-7} failure rate.

Recommendation - Requires further study.

4.5 Life Tests -

4.5.1 Component Life Testing - Components which are subject to wear, fatigue, or other deterioration due to usage, shall be life tested under realistic environmental conditions for a number of cycles representative of the desired life expectancy of the component. In most cases, life test requirements are defined in Government specifications.

4.5.2 AFCS Life Tests - One automatic flight control system or component shall normally be selected at random from those delivered on the purchase order or contract and subjected to the life test. The system shall be assembled and operated for 1,000 hours in the manner described in the system or component specification. Provisions shall be made for cyclic loading of parts or components subject to such operation and for intermittent operation of parts or components subject to such operation. Provisions shall likewise be made to subject the system or component to vibration as well as to elevate and reduce temperatures during the course of the test. At the completion of the test no deterioration of performance or of the physical condition of the equipment shall be evident beyond that permitted in the system or component specification. The following test condition schedule shall be adhered to:

Time Period	Condition
First 400 hrs.	At room ambient conditions.
Next 200 hrs.	Subject system to vibration of 0.001-inch amplitude at 10 cps. Reduce ambient temperature to -29 degrees C (20.2 degrees F).
Next 100 hrs.	Subject system to vibration of 0.005-inch amplitude at 10 cps. Increase ambient temperature to +60 degrees C (140 degrees F).
Next 200 hrs.	Subject system to vibration of 0.005-inch amplitude at 20 cps. Reduce ambient temperature to -40 degrees C (-40 degrees F). Increase altitude to 30,000 feet.
Next 100 hrs.	Subject system to vibration of 0.005-inch amplitude at 20 cps. Increase ambient temperature to +71 degrees C (159.8 degrees F).

Comments - Delete as a separate test. This test should be performed with the Reliability Assurance or Reliability Demonstration Test which has the equipment on and operating under environmental conditions.

Recommendation - Delete.

4.6 Flight Tests - The AFCS shall be flight tested in the aircraft for which it was designed. The aircraft shall be suitably instrumented so that time histories of each flight can be recorded. The following records are considered essential:

(a) Roll, pitch and yaw attitudes

(b) Roll, pitch and yaw rates

(c) Control surface position

(d) Altitude

(e) Airspeed and/or Mach number

The flight tests shall prove that the equipment will satisfactorily stabilize and/or automatically control the aircraft through its airspeed and altitude range. When the automatic flight control or stabilization system is integrated with other systems such as fire control, automatic navigation, optical controlled bombing, etc., the flight tests shall demonstrate the adequacy of the AFCS in performing its function as part of the integrated system.

Comments - Still an applicable requirement.

Recommendation - Incorporate into baseline criteria.

4.7 Failures and Retests - Component failing a service condition test shall not be resubmitted for test without furnishing complete information on the corrective action taken subsequent to the failure. This information shall be furnished to the procuring activity or in the test report, depending upon location of testing. Depending upon the nature of the failure encountered and corrective action required and at the option of the procuring activity, the rework or modifications accomplished shall also be incorporated into the other test samples. Where rework or modification may be considered as sufficient to affect performance under the other service condition tests already completed, at the option of the procuring activity, these tests shall be repeated in the specified order.

Comments - A very important requirement which should be rewritten for clarification.

Recommendation - Rewrite.

4.8 Higher Category of Service Application - Components to be used under a particular category of service application, which have previously been subjected to and accepted under the requirements of a lower, or less severe, category of service application, either as an individual component or as a component of the same or a different system shall be subjected to a rerun of those service condition tests which vary with category of service application.

4.9 Instrumentation - During the conductance of dynamic performance test, sufficient instrumentation shall be provided to record all input and output quantities fundamental to the function or basic design concept of the systems or components operation. All instrumentation used shall be accurately calibrated prior to and at the completion of all tests. In addition, ambient conditions, power supplied, voltage and frequency variations shall be noted, or recorded, as the nature of the test may warrant.

4.10 Special Test Equipment - Special test equipment used shall be accurately calibrated. Calibration data or curves shall be included in the test report or shall accompany the test equipment when submitted to the procuring activity for conductance of tests.

Comments - Para. 4.8-4.10 are still applicable requirements.

Recommendation - Incorporate into baseline criteria.

4.11 Test Technique - Dynamic performance of systems and components shall be demonstrated by using transient response or frequency response testing techniques, or both.

4.11.1 Physical Characteristics of Transients - Applied transients shall be step or ramp functions in displacement, rate of displacement, or other suitable inputs.

4.11.2 Application of Transients - Where feasible, transients shall be applied physically to inertial sensing elements by actual displacement or rotation of the unit. Electrical inputs, such as command inputs, as well as other types of inputs shall be applied in any convenient manner, such as rotation of a signal generator, switching or use of an electronic integrator.

4.11.3 Variation of Transient Amplitudes and Rates - A sufficient number of displacement transients of different amplitudes as well as rate of displacement transients of different rates shall be applied to the system or component under test to adequately define its dynamics in the region of threshold, linear operation, saturation, and velocity limit.

4.11.4 Variation of Gain - For those systems or components in which loop gains may be varied, either automatically or manually, the dynamic tests shall be accomplished over a sufficient number of gain settings to adequately define the systems or components dymanics throughout the obtainable range of gain variation.

Comments - An important requirement that requires further study.

Recommendation - Update requirement.

5. PREPARATION FOR DELIVERY

5.1 Packaging Requirements - In the event of direct purchases by or shipments to the

Government, the packaging shall be in accordance with the contract or the approved detailed specification, as applicable. Components shall be delivered complete, tested, and ready for installation. All receptacles, ports, and delicate protruding shafts or parts which may be damaged during handling shall be protected by dust-tight covers, caps, or plugs during shipping, storage, and handling.

Comments - Applicable.

Recommendation - Incorporate in baseline criteria.

6. NOTES

6.1 Intended Use - The requirements of this specification are general as applicable ... ght control systems and are based on service experience to date. Deviations to the requirements of this specification may be granted following presentation and approval of substantiating data. This specification is intended for use to incorporate by reference in the equipment detail specification or (when no specification is available) in the equipment contract or order.

Comments - Applicable.

Recommendation - Incorporate into baseline criteria.

6.2 Detail Data for Equipment Specification - Since this specification covers only the general requirements for parts, materials, processes and design, the detail specification for the equipment should specify the actual requirements for that particular equipment from the multiple choices or exceptions which are available in the following items:

(a) Type of aircraft for which AFCS equipment is to be designed and used.	
(b) Detail each integration situation requirement.	3.1.1.2.1.1
(c) Heading selection.	3.1.1.5.2.3
(d) Stick maneuvering (pitch and roll attitude).	3.1.1.5.5.3
(e) Control surface oscillations limits.	3.1.1.6.2
(f) Adequate test requirements.	Section 4
(g) Preparation for delivery.	5.1

Comments - A valid requirement.

Recommendation - Incorporate into paragraph 3.5.1 which has additional requirements for the detail equipment specification.

6.3 Additional information on "Microelectronic Modular Assemblies" and "Aircraft Electronic Equipment Maintainability" will be available upon application to the Bureau of Naval Weapons, Washington 25, D. C. Attention: Avionics Division.

Comments - A valid requirement.

Recommendation - Revise to include government agency currently responsible for microelectronics.

APPENDIX B

APPLICABILITY OF MIL-F-18372 TO DFBW SYSTEMS

1. SCOPE

1.1 Scope: This specification covers the general requirements for the design, installation, and test of flight control systems for all types of piloted aircraft contracted for by the U. S. Navy. (Power plant controls are excluded).

COMMENTS - Applicable.

RECOMMENDATION - Useable and update.

1.2 Classification: The flight control systems include:

PRIMARY FLIGHT CONTROLS - The controls for the actuation of, usually, ailerons, rudders, elevators, rotor blades on helicopters, or other control surfaces performing similar functions.

SECONDARY FLIGHT CONTROLS - The controls for the actuation of trim tabs, adjustable stabilizers, and other surfaces or devices used for trimming the airplane.

FLIGHT PATH ANGLE AND SPEED CONTROLS - The controls for the actuation of high lift-drag surfaces.

1.2.1 Primary Controls: The controls for the actuation of the primary flight control systems may be of the following types: (Any type system not in these classifications shall be discussed with the Bureau of Aeronautics during the preliminary design stages.)

Type I - Mechanical Flight Control System - A reversible control system wherein the pilot actuates the primary control surfaces of the aircraft through a set of mechanical linkages consisting of cables, pulleys, sectors and/or push-pull or torque tubes with horns, bellcranks, etc.

Type II - Power Boosted Flight Control System - A reversible control system wherein the pilot effort, which is exerted through a set of mechanical linkages, is at some point in these linkages boosted by a power source.

Type III - Power Operated Flight Control System - An irreversible control system wherein the pilot, through a set of mechanical linkages, actuates a power control servo-mechanism, which mechanism actuates the main control surfaces of the aircraft.

1.2.2 Secondary Controls - Controls for the actuation of the secondary flight control systems may be of the following types:

Type I - Mechanical Control System - An irreversible control system wherein the pilot actuates the secondary control surfaces or devices of the aircraft through a set of mechanical linkages consisting of cables, pulleys, sectors and/or push-pull or torque tubes with horns, bellcranks, etc.

Type II - Power Operated Control System - An irreversible control system wherein the pilot actuates a switch which causes a power unit (electro-mechanical actuator or hydraulic control) to move the trim surfaces or devices.

1.2.3 Flight Path Angle and Speed Controls - Controls for the actuation of the flight path angle and speed controls systems may be of the following types:

Type I - Power Operated Control - A control system wherein the pilot actuates a switch or hydraulic control valve which causes a power unit (electro-mechanical or hydraulic) to move the flight path angle or speed control devices.

Type II - Automatic - A control system wherein the control surface is automatically actuated by the aerodynamic forces.

COMMENTS - The titles, primary and secondary, are the only things of value. The meanings and the type identification will change.

RECOMMENDATION - Delete.

2. APPLICABLE DOCUMENTS

2.1 The following specifications, standards, drawings, and publications, of the issue in effect on the date of invitation for bids, forms a part of this specification.

SPECIFICATIONS:

Military

MIL-B-7949	Bearing; Ball, Anti-Friction, Airframe
MIL-B-6038	Bearing; Ball, Bellcrank, Anti-Friction, Airframe
MIL-B-6039	Bearings; Ball, Rod End, Anti-Friction, Airframe
MIL-B-5628	Bearings; Plain, Airframe
MIL-B-5629	Bearings; Rod End, Plain, Airframe
MIL-C-1511	Cable; Steel (Carbon), Flexible, Preformed
MIL-C-5424	Cable; Steel (Corrosion Resistant), Flexible-Preformed (For Aeronautical Use)
MIL-C-5688	Cable; Assemblies; Aircraft, Proof Testing and Prestretching of
MIL-C-5638	Casing; Control Cable Flexible, Aircraft
MIL-F-8785(ASG)	Flying Qualities of Piloted Airplanes
MIL-A-8629(Aer)	Airplane Strength and Rigidity
MIL-H-8501	Helicopter Flying Qualities, Requirements for
MIL-S-8698(ASG)	Structural Design Requirements, Helicopters
MIL-T-8679	Test Requirements-Ground, Helicopters
MIL-H-5440	Hydraulic Systems; Design, Installation and Tests of Aircraft (General Specification For)
MIL-J-6193	Joints; Universal, Plain, Light and Heavy Duty, Aircraft
MIL-L-6880	Lubrication of Aircraft, General Specification For
MIL-P-7034	Pulleys, Control, Anti-Friction Bearing, Grease-Lubricated Aircraft
JAN-T-781	Terminal; Cable; Steel (For Swaging)
MIL-T-6117	Terminal - Cable Assemblies; Swaged Type
MIL-T-5685	Turnbuckles; Aircraft
MIL-T-5522	Test Procedure For Aircraft Hydraulic Systems
MIL-W-5013	Wheel and Brake Assemblies; Aircraft
MIL-P-5518	Pneumatic Systems; Design, Installation and Tests in Aircraft

Bureau of Aeronautics

SD-24	General Specification for the Design and Construction of Airplanes for the United States Navy
SR-6	Contract Design Data Requirements for Aircraft
SR-38	Demonstration of Piloted Airplanes
SR-159	Stability and Control Calculations
SR-189	Aerodynamic, Structural, and Power Plant Requirements for Helicopters

STANDARDS:

MIL-STD-203 Cockpit Controls; Location and Actuation Of, For Aircraft

PUBLICATIONS:

Air Force-Navy Aeronautical Bulletins

ANA-275 Guide for Lubrication of Aircraft

(When requesting specifications, standards, drawings, and publications refer to both title and number. Copies of this specification and applicable specifications may be obtained upon application to the Commanding Officer, U. S. Naval Air Station, Johnsville, Pennsylvania, Attention Technical Records Division)

3. REQUIREMENTS

3.1 Design and Installation Requirements for All Aircraft Types

3.1.1 Requirements That Apply to All Classes of Flight Controls

3.1.1.1 General - Flight control systems shall be as simple, direct and foolproof as possible with respect to design, operation, inspection and maintenance. Early and careful consideration shall be given the new designs to the arrangement of cables and other connecting elements that extend from the cockpit to the control surfaces so as to effect the most direct and simple routing possible. The number of bends or changes in direction shall be held to a minimum. All practicable compromises in the installation of equipment shall be made to favor the most direct control system possible. Workmanship shall be of sufficiently high grade throughout to insure proper operation and adequate service life. The strength of the flight control system shall be in accordance with Specification MIL-A-8629(Aer).

COMMENTS - Applicable in part.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.1.1.1.1 Power Operated Systems - Failure of any or all the engines in flight shall not result in the pilot being unable to operate those powered services which are essential to the making of a safe descent from altitude and an emergency landing.

COMMENTS - Applicable.

RECOMMENDATION - Utilize for DFBW systems.

3.1.1.1.2 Reserve Power for Emergency Use - An independent source of power shall be provided to operate these powered services vital to the safe descent and landing of the airplane, which would otherwise be put out of action by failure of any or all of the engines of the aircraft.

COMMENTS - Applicable.

RECOMMENDATION - Utilize for DFBW systems.

3.1.1.2 Pilot's Controls -

3.1.1.2.1 Location and Actuation - The location and actuation of the pilot's controls shall be in accordance with MIL-STD-203.

3.1.1.2.2 Stops - Stops shall be provided to limit the controls in the cockpit to the desired motion ranges. The stops shall be located as near the control in the cockpit as possible. (See paragraph 3.1.1.21 for requirements regarding surface stops).

3.1.1.2.3 Removable Controls - Components provided with a disconnect feature for removal shall be so designed as to prevent incorrect installation.

COMMENTS - Applicable.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.1.1.3 Structural Deflection - Deflection of the aircraft structure in flight shall not result in excessive loss of cable rigging tension or in a change in position of any aerodynamic surface unless such change is determined to be necessary and/or desirable for the purpose of improving the stability and control characteristics of the aircraft.

COMMENTS - Loss of cable rigging tension doesn't apply to DFBW systems.

RECOMMENDATION - Delete.

3.1.1.4 Rigidity - The rigidity of the flight control systems shall be sufficient to provide satisfactory operation and to enable the aircraft to meet its stability, control and flutter requirements. Individual components shall be sufficiently rigid to withstand normal handling and servicing and shall not become adversely deformed under operating loads or airframe structural deflections.

COMMENTS - General requirement for strength & rigidity is valid.

3.1.1.5 Acceleration Effect - Acceleration forces acting upon the control system's components shall not result in forces at the pilot's control unless such forces are determined to be necessary and/or desirable for the purpose of improving the handling qualities of the aircraft.

3.1.1.5.1 Effect of Acceleration on Type II and Type III Systems - Acceleration forces acting upon hydraulic, pneumatic or electro-mechanical system components shall not affect the functioning of the normal or emergency systems. Consideration shall be given to the fluid column used in hydraulic systems.

COMMENTS - DFBW systems will contain mechanical flight control components and, therefore, the requirement that acceleration forces not be detrimental to its operation is still valid.

RECOMMENDATION - Incorporate into DFBW specification.

3.1.1.6 Vulnerability - Consideration shall be given to the spacing and arrangement of the flight control systems to reduce the vulnerability of the systems to the minimum value practicable. Also, advantage shall be taken, wherever possible, of the shielding afforded by heavy structural members or existing armor plate installation for the protection of the control systems, particularly in places such as points of cable convergence, horns, bellcranks, main sheaves and walking beams.

COMMENTS - Applicable in part. Delete the references about horns, bellcranks, etc.

RECOMMENDATION- Update and incorporate into DFBW specification.

3.1.1.7 Fouling Prevention - All elements of the control system, subject to fouling by loose gear, shall be suitably protected or covered. Consideration shall be given to the protection of control elements subject to fouling due to ice formation.

3.1.1.8 Clearances - All moving parts of a control system shall have sufficient clearance with each other and with other parts of the aircraft to prevent fouling under all operating conditions. Consideration shall be given to the effect of tolerances in manufacture, assembly, installation, rigging, normal wear and normal deflection.

COMMENTS - Not Applicable.

RECOMMENDATION - Delete.

3.1.1.9 Temperature - Flight control systems shall be designed for operation at temperatures between 160°F (+71°C) and -65°F (-54°C). However, if it is anticipated that these temperature limits will be exceeded, components for the control system shall be selected or designed to operate at the anticipated temperature.

3.1.1.10 Accessibility - All parts of the flight control systems shall be readily accessible for inspection, repair, adjustment of linkages and components, and for lubrication. Inspection doors shall be provided at pulleys, quadrants, connections and components, not otherwise readily accessible. It shall be possible to inspect the entire length of cables and push-pull rods for corrosion and signs of wear periodically without disconnecting the systems.

3.1.1.11 Drainage - Adequate provisions shall be made to drain control system components subject to accumulation of moisture.

COMMENTS - Applicable.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.1.1.12 Bearings

3.1.1.12.1 Anti-Friction - Approved type, AN airframe, ball bearings shall be used throughout the flight control system, except as indicated below. In the event design limitations do not permit the use of ball bearings, prelubricated shielded roller or needle bearings may be used. Where roller or needle bearings are used, consideration shall be given relubrication provisions. The inner race of the bearing shall be clamped to prevent rotation of the inner race with respect to the pivot bolt. Bearing installations shall be arranged in such a manner that failure of the rollers or balls will not result in a complete separation of the control. Direct axial application of control forces to a bearing shall be avoided if possible. In the event such an arrangement is necessary, a fail safe feature shall be provided.

3.1.1.12.2 Spherical Bearings - Where design limitations preclude the use of anti-friction bearings, spherical type plain bearings approved by the Bureau of Aeronautics may be used. When used, spherical type bearings shall have adequate provisions for relubrication.

3.1.1.12.3 Journal - Plain type journal bearings shall be avoided. However, where substantiated, and where play and friction are not major considerations, journal or plain bearings, with adequate and accessible provisions for lubrication, may be used.

3.1.1.12.4 Sintered - Sintered type or oil impregnated bearings shall not be used in those part of the flight control systems which have slow moving or oscillating motions. Fast moving rotating applications such as in qualified motors and actuators are considered satisfactory.

3.1.1.12.5 Self-Alignment - Self aligning bearings shall be used wherever necessary to eliminate the possibility of binding or excessive wear due to misalignment of connecting parts.

COMMENTS - General requirement for bearings still valid.

RECOMMENDATION - Incorporate into DFBW specification.

3.1.1.13 Horns and Brackets - All horns and brackets shall be designed and attached so that they can be readily replaced in service.

3.1.1.14 Shock Absorber Cords - Shock absorber cords shall not be used in flight control systems.

3.1.1.15 Chains - Chains shall not be used in flight control systems.

COMMENTS - Not applicable.

RECOMMENDATION - Delete.

3.1.1.16 Fastenings - In general, fastenings shall be in accordance with SD-24 with the following amplifications: Clevis pins shall not be used. Clevis bolts with shear castle nuts and cotter pins are considered satisfactory in shear applications. Self locking type nuts shall not be used at single attachments or where loss of the bolt would affect safety of flight. Bolts mounted upside down in single attachments shall have the head lockwired to prevent loss of bolt in the event the nut is loose. Bolts less than ¼" dia. shall not be used in any single attachment in the primary flight control systems or in any application on all flight controls or associated systems where loss of a bolt would affect the safety of the flight control systems. Provisions shall be made to prevent jamming, bending or failure of the components in the flight control systems due to possible excessive over-torque being applied to the attaching bolts and nuts. Written or printed warnings in the service handbooks, drawings, placards, etc., to prevent bolts from being over-torqued are not considered provisions to meet this requirement.

COMMENTS - Requires further study, because a DFBW system will have mechanical components which will have to be fastened.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.1.1.17 Cable Systems

3.1.1.17.1 Cables - Control cables shall conform to the applicable specifications. Carbon steel cable shall be used except where corrosion factors preclude the use of the carbon steel cable in which case, corrosion-resistant steel cable shall be used.

3.1.1.17.2 Kinematics - The kinematics of the components in the cable systems shall be such as to prevent an objectionable amount of change in cable tension throughout their flight and ground operational range.

3.1.1.17.3 Tension of Cable Systems - Wherever necessary, provisions shall be made to prevent excessive variation of cable tensions due to temperature changes. Consideration shall be given to the effect of heat from local areas such as engine nacelles, cabins, heat deicers, etc., which may cause temperature rises in an adjacent portion of a control system while the aircraft structure proper remains at the ambient air temperature.

In the interest of reducing control system friction, initial tensions should be held to the lowest practicable values that provide safe and satisfactory operation considering probable application of limit loads to the system and the effect of temperature changes.

3.1.1.17.4 Attachments - Terminals, disconnect fittings, turnbuckles, etc., shall be provided as necessary to facilitate rigging and maintenance of the control system.

3.1.1.17.5 Location of Attachments - Cable attachments shall be located in such a manner that it is impossible to cross connect cables during installation. Cable attachments shall be located in such a manner that it is impossible for them to jam or hang up on adjoining structure or other fittings.

3.1.1.17.6 Terminals - Terminals shall be of the swaged type and shall conform to the applicable specifications. Ball type swaged terminals shall not be used in primary control systems except for attaching cables to quadrants where standard fork and eye fittings are not adaptable. Ball type swaged terminals shall not be used with strap fitting as a substitute for standard fork and eye fittings. All cable assemblies fabricated with swaged terminals, shall be proof-loaded, in accordance with the applicable specification.

3.1.1.17.7 Cable Turn Radius - The ratio of sheave (pulleys, drums, sectors, etc.,) diameter to cable diameter shall not be less than the following values: (where the cable load is the maximum load expected in the cable under normal operating conditions.)

Cable Load in % of Specified Cable Breaking Strength	Sheave Ratio
1	10
10	20
20	28

Cables shall not be subjected to critical bends at the junction with cable terminals or other attaching points such as drums, horns, etc.

3.1.1.17.8 Cable Alignment - Cables shall not be misaligned with sheaves in excess of the following values: (The alignment of a cable with its pulley is defined as the angle between the center line of the cable and the plane of the pulley.)

(a) Primary flight controls - Not over 1°, except where AN219, AN220, or AN221 pulleys are used, or where side travel of the cable exists, and then not over 2°.

(b) All other controls - Not over 2°, except where AN219, AN220, or AN221 pulleys are used, or where side travel of the cable exists, and then not over 3°.

3.1.1.17.9. Turnbuckles - Turnbuckle terminals shall not have more than three (3) threads exposed at either end. All turnbuckle assemblies shall be properly safetied.

3.1.1.17.10 Take-Up Links - Vernier links shall be provided, where necessary, to facilitate proper rigging of the cable systems.

3.1.1.17.11 Pulleys and Sheaves - Pulleys shall be of adequate capacity and diameter for the size of cables and loads. Anti-friction bearing pulleys shall be used in all flight controls.

3.1.1.17.12 Drums, Sectors, and Quadrants - All cables shall be positively attached to driven or driving drums, sectors, etc. Drums, sectors, or quadrants shall have at least 10° wrap of the driving cable after the limits of its range of movement in both directions have been reached.

3.1.1.17.13 Guards - Guards shall be installed at all sheaves (pulleys, sectors, etc.,) to prevent the cable from jumping out of the groove of the sheave. Guards shall be installed at the approximate point of tangency of the cable to the sheave and where the cable wrap exceeds 90°, one or more intermediate guards shall be installed. To prevent binding of the sheave due to relative deflections in the airplane structure, all guards shall be supported by the supporting brackets of the parts which they guard. Additional guards shall be installed on sectors at the point of entry of the cable into the groove from its attachment. The design of the rubbing edges and selection of materials shall be such as to minimize cable wear and prevent jamming, even when the cable is slack.

3.1.1.17.14 Fairleads - Fairleads shall be used wherever necessary to keep cables from chafing and slapping against parts of the aircraft. Fairleads shall not cause any angular change in the cable. They shall be of non-hygroscopic, non-abrasive material. Fairleads shall be split to permit easy removal, unless the hole in the fairlead is of sufficient size to permit the cable with the swaged terminals attached to be threaded through. Where space permits the fairleads should clear the primary flight control cables by a minimum of ¼". The cables may rest against the lower edge of the hole in the fairleads on long straight runs where the cable would normally sag due to their own weight even when properly rigged.

3.1.1.17.15 Clearance - All control cables shall have a minimum of ½ inch clearance with all wiring, tubing, and removable equipment (exclusive of the basic airframe structure). Clearancesof less than ½" are permitted between the cables and the basic airframe structure provided suitable fairleads are installed.

3.1.1.18 Push-Pull Systems

3.1.1.18.1 Adjustable Terminals - Adjustable terminals shall be arranged so that there will be no possibility of a terminal becoming inadvertently detached. Adjustment shall be possible at one end only for any single tube. Where one adjustable rod end is made fixed as a means of preventing the rod from becoming detached, rivets or bolts through the threaded shank shall not be used with threaded ends less than 7/16 dia. Male shank type rod end bearings are preferred over female types.

3.1.1.18.2 Supports - All push-pull tubes shall be supported by suitable levers, bellcranks, or rollers. To prevent possible binding of the system due to misalignment or deflection, self-aligning anti-friction bearings shall be used in all terminals. Suitable precautions shall be taken to prevent jamming or undersirable wear of parts resulting from rotation of the tube about its axis.

3.1.1.18.3 Tubes - Tubes shall have a minimum wall thickness of .035 inch and shall be seamless except that steel tubes, seam-welded by the electrical resistance method, may be used. Consideration shall be given to the natural frequency of vibration of the tubes with respect to the vibrations set up in the aircraft.

3.1.1.18.4 Flexible Controls - Flexible push-pull type controls shall not be used.

3.1.1.19 Torque Systems

3.1.1.19.1 Slip Joints - All torque control systems shall incorporate splined joints or equivalent, as necessary, to prevent binding of the system due to deflections of the aircraft structure.

3.1.1.19.2 Supports - All torque tubes shall be mounted on anti-friction (preferably self-aligning) bearings.

3.1.1.19.3 Tubes - Tubes shall have a minimum wall thickness of .035 inch and shall be seamless, except that steel tubes seam-welded by the electrical resistance method, may be used. Consideration shall be given to the natural frequency of vibration of the tubes with respect to vibrations set up in the aircraft.

3.1.1.19.4 Universals - All torque tube control systems shall incorporate universals as necessary to prevent binding of the systems due to misalignment of supports or deflection of the aircraft structure.

COMMENTS - Once again, the question arises how much of a DFBW system will remain mechanical. Will the actuator connect directly to the control surface?

RECOMMENDATIONS - Requires further study to define mechanical portions of a DFBW system and associated requirements.

3.1.1.20 Differential Controls - A control system in which differential motion is obtained shall incorporate stops to prevent the cranks from reaching a locking or reversing position unless specifically required for the proper operation of the system.

3.1.1.21 Control Surface Stops - In aircraft, such as VP and VR types, employing large, heavy surfaces, stops shall be provided at each surface.

3.1.1.22 Adjustable Stops - All adjustable stops shall be positively locked or safety wired in the adjusted position. Jam nuts (plain or self locking type) are not considered adequate as locking devices for this application.

3.1.1.23 Stability Augmenting Devices - Devices installed for the purpose of augmenting stability shall be so designed that the failure of such a device will not cause discontinuity of the flight control system or any other flight hazard. The system shall be designed so that, under normal operating conditions, there is no adverse reflection on the pilot's primary controls.

3.1.1.24 Other Devices - Other devices such as spring bungees tension regulators, bob weights, dampers, etc., shall be so designed that their failure shall not cause discontinuity of the control system, or any other flight hazard. Positive locks or safety wire shall be provided at all attachments, where there is a possibility of the components in spring cartridge, dampers, etc., becoming detached as a result of inadvertent rotation of the components.

COMMENTS - Not Applicable.

RECOMMENDATION - Delete.

3.1.2 Additional Requirements For Primary Flight Controls

3.1.2.1 Type I System - In the design of flight control systems the reliability, strength, and simplicity of the system shall be of paramount consideration. Whenever push-pull tube systems are used they shall be so arranged that all the tubes are in tension for the greater load for which the system is designed. When the cable type control system is used, a single system cable may be used for lateral and directional controls. However, positive independent control of the lateral control surfaces on each side, in both directions, shall be provided to insure control in the event of failure of the controls on one side.

3.1.2.2 Type II Control Systems - The mechanical portions of the Type II control system shall meet the requirements set forth for the Type I control system. The power system for the Type II control system, if hydraulic, shall be completely independent and shall have no interconnection with any other hydraulic system, and if electrical, it shall, except for the power source, have no interconnection with any other electrical system.

3.1.2.2.1 Power System Failure - When a failure occurs in the power system of a Type II control system, regardless of the type of failure, it shall be possible to operate the flight controls directly through the mechanical system within the limitations set forth in the contract requirements. Where a mechanical advantage change device is incorporated, no hazardous lag shall exist during the change over.

3.1.2.3 Type III Control Systems - The mechanical portions of the Type III system shall meet the requirements set forth for the Type I control system. The power systems for the Type III control system, if hydraulic, shall be completely independent, and shall have no interconnection with any other hydraulic system, and if electrical, it shall, except for the power source, have no interconnection with any other electrical system. Consideration shall be given for the utilization of separate systems, that are completely independent of each other, for powering the controls about each axis, unless it can be proven that simultaneous loss of control about any two axes or all three axes is no more detrimental to the aircraft than loss of control about any one axis.

3.1.2.3.1 Single power Control System - A single power system may be employed where an emergency manual sytsem is available. When a failure occurs in a single power system it shall be possible to operate the flight controls through a direct set of mechanical linkages to obtain aircraft controllability within the limitations set forth in the contract requirements. Where a mechanical advantage change device is incorporated, no hazardous lag shall exist during the changeover. On rotary wing aircraft it is preferred that the power source be rotor driven.

3.1.2.3.2 Dual Power Control System - A dual power system shall consist of two completely independent single systems both operating simultaneously. Each system shall be an exact duplicate of the opposite system, as simple as practicable, and contain a minimum number of components. There shall be no interconnections between the two systems. When hydraulic, the power sources shall be from two (2) engine driven pumps on single engine aircraft. In multi-engine aircraft the power sources shall be from separate engines. For rotary winged aircraft, at least one power source shall be rotor driven regardless of whether the aircraft is single or multi-engined. Tandem or parallel cylinder in the same housing are conceded satisfactory for dual power control systems.

3.1.2.3.2.1. Dual System Failure - When one system of a dual system fails, the performance requirements of the aircraft, with a single system in operation, shall meet the contract requirements.

3.1.2.4 System Indicators -

3.1.2.4.1 Type II Systems - If applicable, an indicator shall be provided to warn the pilot of a power system failure, if practicable, prior to complete loss of the power boost system.

3.1.2.4.2 Type III Systems - In Type III systems an indicator shall be provided which will inform the pilot that both systems are functioning normally. In addition, the indicator shall be of such a design as to indicate to the pilot, if practicable, a failure of either or both systems prior to complete loss of the system.

COMMENTS - Not Applicable.

RECOMMENDATION - Delete.

3.1.2.5 Artificial Feel Devices - The artificial feel system shall provide a force gradient which will permit the aircraft to meet its contract requirements. Any failures in the system shall not result in control forces that are either so high or so low as to be hazardous.

COMMENTS - Applicable.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.1.2.6 Power Control Override Provisions - Provisions shall be made to permit direct pilot effort to be applied to a control valve in the event the valve becomes jammed or frozen. In other words any spring or load relieving device between the pilot and the valve, which is designed to prevent excessive loads being applied to the valve, shall become a solid link before full pilot control travel is reached.

3.1.3 Additional Requirements For Secondary Flight Controls

3.1.3.1 Manually Operated Trim Control Systems - When manually operated trim control systems are used, it shall be possible to obtain the necessary control with a minimum amount of input motion consistent with acceptable operating forces.

3.1.3.2 Power Operated Trim Control Systems - Where power units are provided for operating the trim surfaces or devices, even where more than one speed is provided, the rate, or rates, of application shall be such that preciseness of control is obtained for landing, take-off and in-flight conditions without creating a hazard.

3.1.3.2.1 Emergency Systems - Where failure of a power operated trim control system would result in marginal or undesirable control characteristics, a completely separate emergency power system, or means to override the failed power system, shall be provided.

3.1.3.3 Irreversibility - The control system for each trimming surface or device shall be irreversible, and shall maintain a given setting until changed by the pilot. It is desired that the irreversible mechanism be as near to the trim tab, or trimming device, as is practicable, preferably in the linkage which connects to the tab horn, to minimize free play at the surface and maintain rigidity in the control.

3.1.3.4 Synchronization - Where two (2) controllable trim surfaces are used on the elevators, they shall be mechanically interconnected.

COMMENTS - Not applicable to DFBW systems. Although trim will be made available it will not operate as described herein.

RECOMMENDATION - Delete.

3.1.3.5 Pilot's Controls - The location and actuation of the pilot's controls shall be in accordance with MIL-STD-203. Controls shall be clearly marked to indicate their purpose and direction of motion.

COMMENTS - Applicable.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.1.3.5.1 Position Indicator - Suitable indicators shall be provided to indicate the neutral position and the range of travel of each trim device. Where movable surfaces are used for trimming, the sensing devices for the indicator shall be operated by the surface or a mechanical link directly connected to the surface. A position sensing device is not required on the surface if the system is entirely manual, unless an electrical instrument type indicator is used. On manual type systems a mechanical type indicator on or near the cockpit control is considered satisfactory.

COMMENTS - Although a position indicator will be provided, it will not operate as described herein.

RECOMMENDATION - Delete.

3.2 Additional Design And Installation Requirements For Fixed Wing Aircraft

3.2.1 Primary Flight Controls

3.2.1.1 Friction - The requirements relative to friction in the primary flight control systems, shall be in accordance with the contract requirements.

COMMENTS - Not Applicable.

RECOMMENDATION - Delete.

3.2.1.2 Pilot's Controls

3.2.1.2.1 Longitudinal - Longitudinal controls shall be by means of a stick, or wheel. Forward movement of the stick or wheel and column shall cause the aircraft to nose down, and aft movement shall cause the aircraft to nose up. The range of movement of the longitudinal control shall be a maximum of 14". The extreme aft position shall be not more than 9" from the neutral position.

3.2.1.2.2 Lateral - The lateral control shall be by means of a stick or wheel. Movement of the stick to the right, or clock-wise rotation of the wheel, shall cause the aircraft to roll to the right; movement of the stick to the left, or counter-clockwise rotation of the wheel, shall cause the aircraft to roll to the left. The range of movement of the lateral control stick shall be a maximum of 7" to the right and 7" to the left of the neutral position. The rotation of the control wheel shall be a maximum of 110° clock-wise and 110° counter-clockwise.

3.2.1.2.3 Stick and Wheel Requirements

3.2.1.2.3.1 Control Stick - If a control stick is used, and is removable, it shall be positively latched in place when installed. It shall be possible to install the stick only in the correct manner, and suitable means shall be provided to prevent rotation of the stick.

3.2.1.2.3.2 Control Wheel - Control wheels shall be constructed of a material of adequate strength and durability, and shall be designed to have a minimum of sight interference with the instrument panel.

3.2.1.2.4 Directional Control - Directional control shall be by means of foot pedals. Pushing the right pedal shall cause the aircraft to turn to the right. Pushing the left pedal shall cause the aircraft to turn to the left. The range of movement of the foot pedals shall be a maximum of 4" forward and 4" aft of the neutral position. The foot pedals shall be interconnected to insure positive movement of each pedal in both directions.

3.2.1.2.4.1 Adjustment - The foot pedals shall be readily adjustable in flight to at least 3" forward and 3" aft of neutral, in increments not exceeding 1". Both pedals shall be adjusted simultaneously by means of a single control, and the control shall be located in accordance with MIL-STD-203.

COMMENTS - Applicable.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.2.2 Wheel Brake Controls - Right and left brakes shall be separately actuated by toe force on brake pedals on the rudder controls except for bicycle gear or quadricycle gear, where other suitable brake controls may be used subject to approval of the Bureau of Aeronautics. Pedal locations in the cockpit shall be in accordance with MIL-STD-203. The brake pedal linkages shall be so designed that a comfortable angle of approximately 90° between the pilot's foot and his lower leg is maintained throughout the full range of movement of the rudder pedals and seat. The desired shape and travel of the brake pedals are shown in Figures 1 and 2 respectively. Linkages between the brake pedals and the brake control device shall be as free as possible of lost motion or yielding of parts. Means shall be provided to positively return the brake pedals to the "off" position when toe force is removed from the pedals.

3.2.2.1 Manual Braking Systems - The pedal linkages for manual braking systems shall be such that:

a. A foot force of between 15 and 20 pounds at the tip of the pedal will be required to cause initial movement of the brake pedal.

b. A foot force of between 75 and 125 pounds at the tip of the pedal will produce the braking deceleration specified in Specification MIL-W-5013 at the normal landing gross weight.

c. The travel of the pedal for full brake application shall be as indicated in Figure 2. It shall not exceed 30° while meeting the requirements of subparagraph b above.

d. In all positions of the rudder pedal or the rudder linkage, and the seat it shall be possible for the pilot to apply sufficient static brake torque to hold the wheels locked against a coefficient of friction of 0.55 between the tires and the ground at maximum alternate weight. It shall be possible to meet this requirement with the brakes at a temperature of 21°C (70°F).

3.2.2.2 Power Braking Systems - The pedal linkages for power braking systems shall be such that:

a. A foot force of between 15 and 20 pounds at the tip of the pedal will be required to cause initial metering through the power brake valve.

b. A foot force of between 65 and 85 pounds at the tip of the pedal will produce the braking deceleration specified in Specification MIL-W-5013 at the normal landing gross weight.

c. Brake pressure sufficient to hold the wheels locked shall be available at all positions of the rudder pedal or rudder linkage and the seat assuming a coefficient of friction of 0.55 between the tires and the ground at the maximum alternate weight. It shall be possible to meet this condition with the brakes at a temperature of 21°C (70°).

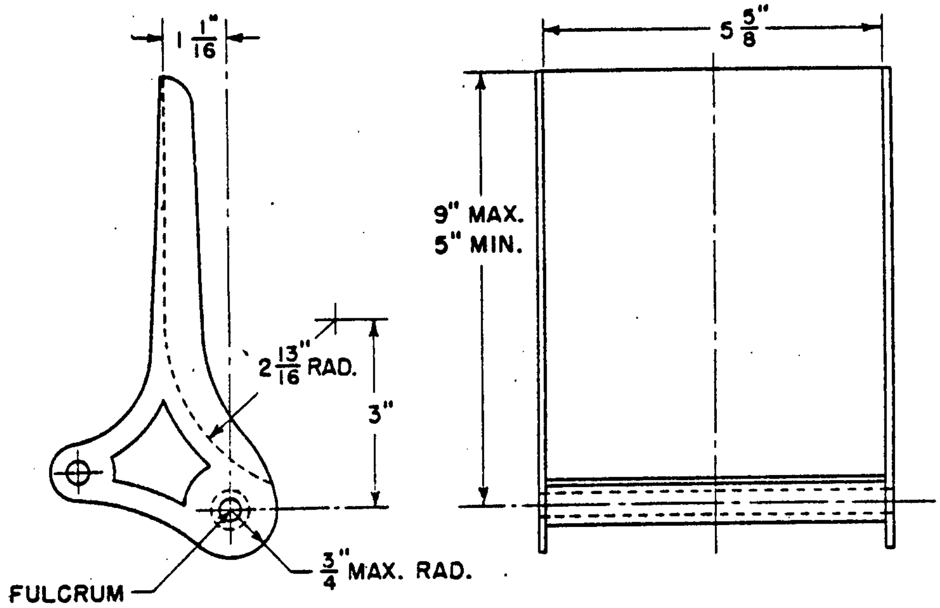
d. The travel of the pedal shall be as indicated in Figure 2. It shall be between 15 and 20° to meet the requirements of subparagraph b above.

3.2.2.3 Emergency Brake Control - The location and actuation of the emergency brake control shall be as indicated in MIL-STD-203.

3.2.2.4 Parking Brake Control - The location and actuation of the parking brake control shall be as indicated in MIL-STD-203.

COMMENTS - Manual braking systems will not be utilized.

RECOMMENDATION - Update and incorporate into DFBW specification.



NOTE:
ADEQUATE PROVISION SHALL BE MADE TO PREVENT THE PILOT'S FOOT FROM SLIPPING OFF OR THROUGH THE PEDAL.

FIGURE 1 BRAKE PEDAL SHAPE

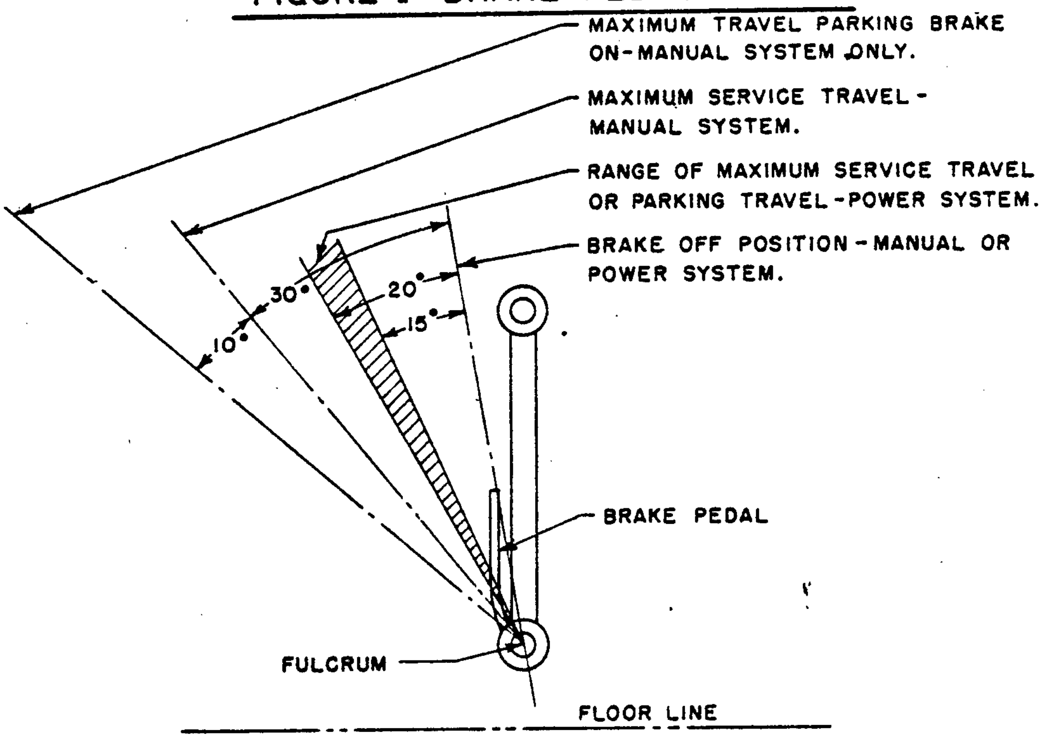


FIGURE 2 BRAKE PEDAL TRAVEL

3.2.3 Control Surface Locks - Locks shall be provided for all primary control surfaces, other than those which are actuated by irreversible control systems, to lock the surfaces in neutral, when the airplane is parked. If built-in locks are incorporated, they shall either engage the surfaces directly, or lock the controls as near to each surface as practicable. These locks shall be so arranged that they cannot be engaged during flight for any reason, such as inadvertent operation of the cockpit control lever, relative deflections between the lock control system and the aircraft, component failure, combat damage, etc.

3.2.3.1 Pilot's Control - The pilot's control for the surface locks shall be so arranged as to make it impossible for the pilot to take off with the locks engaged. Means shall also be provided to lock the pilot's control in the unlock position.

3.2.3.1.1 Locking Range - The range of movement of the pilot's control and lock control system shall be sufficient to insure complete locking or unlocking of the control surface under the most adverse conditions of structural and system deflections. In unlocking the surface locks, a maximum of 50% of the range of motion of the pilot's control shall directly and positively unlock the control surfaces. This means the first 50% of the range.

COMMENTS - Requires further study.

RECOMMENDATION - Incorporate applicable requirements into DFBW specification.

3.2.4 Flight Path Angle and Speed Controls

3.2.4.1 High Lift Controls - A suitable control system shall be provided for actuating the non-automatic high lift devices (flaps, slats, etc.)

3.2.4.1.1 Emergency Operation - 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 device. The emergency system shall be completely independent of the primary system up to, but not necessarily including, the actuator.

3.2.4.1.2 Operating Time - At the maximum limiting aircraft speed for which the device may be operated, the time of operation for power operated landing flaps shall be as follows:

TYPE OF AIRCRAFT	TIME TO COMPLETELY EXTEND	TIME TO COMPLETELY RETRACT
VP, VR, VU	Not less than three (3) seconds Not more than twelve (12) seconds	Not less than five (5) seconds Not more than twelve (12) seconds
All Others	Not less than three (3) seconds Not more than eight (8) seconds	Not less than three (3) seconds Not more than eight (8) seconds

3.2.4.1.3 Synchronization - High lift devices shall be mechanically interconnected, unless it can be demonstrated that no hazardous flight attitude will result from unsynchronized operation. In the event of a failure of the high lift control system actuators, such as a screw jack, hydraulic cylinder, etc., the high lift device shall maintain synchronization, or remain synchronized without motion.

3.2.4.1.4 Indicator - An approved type indicator shall be provided in the cockpit to indicate flap positions.

COMMENTS - Applicable. Flaps and slats will be used on a FBW aircraft and therefore, there is a need for a requirement.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.2.4.2 Speed Brake Controls - A suitable control system shall be provided for actuating the speed brakes. The speed brake control system must be capable of withstanding frequent operation at all flight speeds up to the terminal velocity of the airplane.

3.2.4.2.1 Emergency Systems - Emergency retraction is required on those speed brakes that will not automatically retract, as a result of air loads, when the control is moved to the retract position.

3.2.4.2.2 Positioning - The speed brake control system shall be of such design as to permit infinite variable positioning.

3.2.4.2.3 Operating Time - It shall be possible to completely extend the speed brakes in not less than two (2) seconds and not more than three (3) seconds. Time of operation specified shall apply at V_t at sea level and at all ambient air temperatures between -20°F (-29°C) and +120°F (+49°C). Between -20°F (-54°C) and -65°F (-54°C), and between +120°F (+49°C) and +160°F (+72°C), the time of operation shall not exceed 4½ seconds. The above values shall be met with all components of the actuating mechanism stabilized at the extreme temperature, and without assuming time for warm-up of the components.

3.2.4.2.4 Location of Control - The pilot's control for the speed brake shall be located in accordance with MIL-STD-203.

3.2.4.2.5 Actuation - The pilot's actuating mechanism shall be a three-position device with a stop position in neutral, momentary aft position to extend, and a maintained forward position for retraction.

3.2.4.2.6 Indicator - An indicator shall be provided to indicate whether speed brakes are extended.

COMMENTS - Applicable

RECOMMENDATION - Update and incorporate into DFBW specification.

3.3 Additional Design and Installation Requirements for Rotary Wing Aircraft

3.3.1 Primary Controls

3.3.1.1 Cyclic Pitch Controls - The cyclic pitch control shall be by means of a stick. Movement of the stick forward shall direct the resultant rotor thrust in the forward direction; movement of the stick aft shall direct the resultant rotor thrust in the aft direction; movement of the stick to the right shall direct the resultant rotor thrust to the right; and movement of the stick to the left shall direct the resultant rotor thrust to the left. The range of movement of the cyclic pitch control shall not be more than 14 inches in the fore and aft direction, with a maximum of 9 inches aft of the neutral position, and not more than 7 inches to the right, and 7 inches to the left, of the neutral position. If the control stick is removable it shall be positively latched in place when installed. It shall be possible to install the stick only in the correct manner, and suitable means shall be provided to prevent rotation of the stick.

3.3.1.2 Collective Pitch Control - The collective pitch control shall be by means of a lever. Movement of the lever in an upward direction shall increase the resultant rotor thrust, and movement of the lever in a downward direction shall decrease the rotor thrust.

3.3.1.2.1 Throttle Interconnection - The collective pitch control shall be interconnected with the throttle control, and synchronized to provide the proper throttle setting as collective pitch is increased or decreased. Means shall also be provided to permit throttle control independent of lever movement, by rotation of the grip on the lever.

3.3.1.2.2 Locks - An adjustable friction type lock, or equivalent, shall be provided to retain the collective pitch lever in any desired position. A lock shall also be provided to lock the collective pitch lever in the down position.

3.3.1.3 Directional Control - Directional control shall be by means of foot pedals. Pushing the right pedal shall cause the aircraft to rotate to the right. Pushing the left pedal shall cause the aircraft to rotate to the left. The range of movement of the foot pedals shall be a maximum of 4" forward and 4" aft of the neutral position. The foot pedals shall be interconnected to insure positive movement of each pedal in both directions.

3.3.1.3.1 Adjustment - The foot pedals shall be readily adjustable in flight to at least 3" forward and 3" aft of neutral, in increments not exceeding 1". Both pedals shall be adjusted simultaneously by means of a single control, and the control shall be located in accordance with MIL-STD-203. The angle of the pedals shall be adjustable on the ground only.

3.3.1.4 Blade Coning Restrainers - Suitable provisions shall be made to restrain coning of the blades when starting or stopping the rotor. It shall be possible to start or stop the rotor in wind velocities up to 60 knots, from any horizontal direction, without physical contact of the rotor blades with any part of the airframe. Means shall also be provided to prevent contact of the blades and airframe during flight maneuvers and hard landings.

3.3.1.5 Wheel Brake Controls - See paragraphs 3.2.2 through 3.2.2.4 above.

3.4 Additional Design and Installation Requirements for Lighter-Than-Air Aircraft

3.4.1 Primary Flight Controls

3.4.1.1 Longitudinal Control - Longitudinal control shall be by means of a wheel and column (yoke type). Forward movement of the wheel and column shall cause the aircraft to nose down and aft movement shall cause the aircraft to nose up. The range of movement of the longitudinal control shall be a maximum of 14". The extreme aft position shall not be more than 9" from the neutral position.

3.4.1.2 Directional Controls - Directional control shall be by means of the wheel on the column. Rotation of the wheel clockwise shall cause the airship to turn to the right and rotation of the wheel counter-clockwise shall cause the airship to turn to the left. The rotation of the wheel shall be a maximum of 110° clockwise and 110° counter-clockwise.

3.4.1.3 Control Surface Locks - See paragraphs 3.2.3 through 3.2.3.1.1 above.

COMMENTS - Although applicable to these vehicles, it is not pertinent to this study.

RECOMMENDATION - Delete.

3.5 Tests and Design Data Requirements

3.5.1 General - The contract will specify the tests and design data of this Section 3.5, that will be required; will amplify or modify the tests and design data of this Section 3.5; and may specify other tests and design data under the appropriate section of this specification. The submittal procedures for the design data shall be as indicated in Specification SR-6.

3.5.1.1 Addition of Tests and Design Data - If the tests and design data required by the contract are inadequate to prove that the flight control system and the flight control system installation incorporates the specified requirements, the contractor shall propose amendments to the contract to include tests and design data which will prove adequately that the flight control system and the flight control system installation incorporates the specified characteristics.

3.5.1.2 Deletion of Tests and Design Data - If applicable test and design data are available, the contractor shall in lieu of repeating tests and submitting design data, propose amendments to the contract to require the submittal of these data, supplemented by sufficient information to substantiate, their applicability.

3.5.1.3 Test Witnesses - Before conducting a required test the Bureau of Aeronautics Representative shall be notified in sufficient time so that he or his representative may witness the test and certify results and observations contained in the test report. When the Bureau of Aeronautics Representative is notified, he shall be informed if the test is such that interpretation of the behavior of the test article is likely to require engineering knowledge and experience, in which case he will provide a qualified engineer who will witness the test and certify the results and observations during the test.

COMMENTS - Applicable, but rewrite the test witness requirement to delete the reference that the witness shall certify the results.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.5.2 Experimental Aircraft - The following data shall be submitted:

a. Simplified Schematic arrangement of the flight control system. (See 3.5.2.1)
b. Flight control system design report. (See 3.5.2.2)
c. Flight control system failure analysis report. (See 3.5.2.3)
d. Flight control system test. (See 3.5.2.4)
e. Flight control system test reports. (See 3.5.2.5)

COMMENTS - Data requirements are applicable.

RECOMMENDATION - Perform a study to determine the total data requirements and incorporate into DFBW specification.

3.5.2.1 Schematic Arrangement - The simplified schematic drawing shall show the functions of all elements (mechanical, hydraulic, electrical, pneumatic, aerodynamic, etc.,) which constitute the flight control system of the aircraft. A description explaining the functioning of the complete system, functions of the individual elements, and other necessary explanations of the flight control system shall accompany the schematic arrangement.

3.5.2.2 Design Report - The design report shall be submitted prior to or concurrently with the drawings of paragraph 3.5.2.1 and shall contain the following information:

For Type I Control Systems - Curves or data shall be provided illustrating the following:

a. Hinge moments developed at the surface for a unit load input at the pilot's control for the full range of travel of the control.

b. Hinge moments developed at the surface for a unit load input at the pilot's control but with the system assumed to be deflected at design limit load for the full range of travel of the control. The effects of force augmenting devices such as spring bungees, centering springs, etc., shall be taken into consideration for the above data.

c. Surface position versus cockpit control position for unit load input.

d. Surface position versus cockpit control position for design limit load.

For Type II Control Systems

a. Same data as above for Type I Systems.

b. The results and a description of the methods of an analysis of the stability and performance characteristics of the installed power boost unit. The stability results shall be in the form of Nyquist, Bode, Root Locus or similar diagrams. Estimates of the effects of any significant non-linearities shall be included. The performance results shall show the maximum rate of surface travel as a function of the surface hinge moment and a graph of control surface deflection versus time under design hinge moment.

The analysis shall be conducted for "on the ground stability" and for the most critical flight condition. However, the submittal of the analysis for the former should not be held up pending the availability of the latter.

The description of the methods of analysis shall be sufficiently detailed to permit review. Derivations of equations, sources of parameter values, and sample calculations shall be included.

For Type III Control Systems - Data similar to that required under Type II Control Systems shall be submitted.

3.5.2.3 Failure Analysis Report - The failure analysis report shall include assumed failure of each critical component in the most adverse position and/or condition. In addition, the report shall consider failures of secondary flight control systems and flight path angle and drag control systems and their effect on the primary control system. For Type II and Type III systems wherein the power source is hydraulic, electric, etc., the report shall include a failure analysis of the hydraulic, electric, etc., system and components. For each assumed failure the following shall be discussed:

a. The consequences
b. The compensating provisions
c. Evaluation of the reliability of the critical component

3.5.2.4 Tests - For Type II and Type III Systems a working mock-up or simulator of the flight control system shall be constructed. Tests shall be conducted to check out the operation and stability of the system under simulated flight conditions.

3.5.2.5 System Test Reports - Prior to the conduction of the tests of 3.5.2.4, a report shall be submitted, for the approval of the Bureau of Aeronautics, outlining the test procedure. At the conclusion of the tests, a complete report of the tests shall be submitted. This report shall include a comparision of the test results with those obtained from the analysis of 3.5.2.2. Upon completion of the contractor's flight test program, a report covering the performance of the flight control system and a comparision of the flight test results with the results of the theoretical and simulated analysis shall also be submitted.

COMMENTS - Applicable, but delete reference to Type I, II and III control systems which do not apply to DFBW systems.

RECOMMENDATION - Update and incorporate into DFBW specification.

3.5.3 Production Aircraft - The following data shall be submitted:

a. Schematic arrangement of the flight control system. (See 3.5.3.1)
b. Flight control system design report. (See 3.5.3.2)
c. Plan and profile or isometric of the complete flight control system installation. (See 3.5.3.3)
d. Flight control system installation drawings. (See 3.5.3.4)
e. Flight control system component cross-section assembly drawings where necessary for clarification and for approval of individual units such as actuators, synthetic feel devices, spring cartridges, etc. (See 3.5.3.5)
f. Flight control system failure analysis report. (See 3.5.3.6)
g. Flight control system test. (See 3.5.3.7)

3.5.3.1 Schematic Arrangement - SUBMIT SAME AS 3.5.2.1 - Except bring up to date for production model airplane.

3.5.3.2 Design Report - SUBMIT SAME AS 3.5.2.2 - Except bring up to date with latest available information.

3.5.3.3 Plan and Profile or Perspective of the Complete Flight Control System - The drawing of the complete flight control system shall be a plan and profile projection or a perspective type illustration. It shall show the complete control system installation including components and mechanical arrangement and shall be on the background of the aircraft outline. Where necessary, sufficient aircraft structure shall be shown (may be in phantom) so that the relative vulnerability of the systems may be ascertained.

3.5.3.4 Installation Drawings - The installation drawings shall show the complete flight control system including mechanical, hydraulic or other power system components in addition to the motion geometry (trends) of principal linkages from the pilot's control to the operating surface. All attaching points, brackets, adjustment provisions, stops and rigging points, shall be indicated. These drawings shall be in sufficient detail to show sizes of cables, typical terminals, end fittings, levers, etc. The parts shall be labeled as to name and part number.

3.5.3.5 Component Cross-Section Assembly Drawings - Component cross-section assembly drawings shall contain sufficient information so that an evaluation of the unit can be made.

3.5.3.6 Failure Analysis Report - SUBMIT SAME AS 3.5.2.3 - Except bring up to date with latest revisions to the flight control system.

3.5.3.7 Tests - SUMBIT SAME AS 3.5.2.4 - Except bring up to date.

3.5.3.8 Test Reports - SUBMIT SAME AS 3.5.2.5 - Except bring up to date with results of latest tests.

COMMENTS - Applicable, but delete reference to production or experimental aircraft. Production aircraft is the only design the criteria shall consider.

RECOMMENDATION - Update and incorporate into the DFBW specification.

4. QUALITY ASSURANCE PROVISIONS - Not Applicable.

5. PREPARATION FOR DELIVERY - Not Applicable.

6. NOTES - Not Applicable.

PATENT NOTICE - When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

COMMENTS - Not applicable.

RECOMMENDATION - Delete.

APPENDIX C

APPLICABILITY OF MIL-F-0000B

TO DFBW SYSTEMS

MIL-F-0000B
6 Oct 1972
Superseding
MIL-F-18372(Aer)
31 Mar 1955

MILITARY SPECIFICATION
FLIGHT CONTROL SYSTEMS - DESIGN, INSTALLATION AND TEST OF, PILOTED AIRCRAFT (GENERAL SPECIFICATION FOR)

This document is a proposal for the revision of the existing U. S. Navy flight control system specification MIL-F-18372 and is not to be issued or used in the design of any flight control system prior to final approval by the Naval Air Systems Command.

1.0 SCOPE AND CLASSIFICATION

1.1 Scope - This specification covers the general requirements for the design, installation, and test of the operating mechanisms of flight control systems for all U.S. Navy piloted aircraft. The controllability requirements for piloted aircraft are specified in MIL-F-8785 and MIL-H-8501. In the event of conflict between this specification and other referenced documents, the requirements of this specification shall govern. The detailed requirements for a particular system shall be those specified in the detailed specifications, contract, or purchase order for that system.

Comments - Applicable

Recommendation - Incorporate into DFBW criteria.

1.2 Classification - The flight control systems (FCS's) shall include the following types:

1.2.1 Primary Flight Control Systems - Systems which, in conjunction with continuous pilot participation, control the flight path of the aircraft in accordance with prescribed handling and response qualities. Control forces and moments are generated as functions of pilot input as modified by feedback signals. The means of control could include aerodynamic control surfaces, helicopter rotor blades, reaction controls, and thrust orientation arrangements. The primary system shall be defined as including all components from the pilot's cockpit controls or the automatic flight control system servo to, but not including, the control surfaces or equivalent devices. The flight control systems for the actuation of the primary FCS shall be classified as follows: (Any type of system not in these classifications shall be discussed with the procuring activity, during the preliminary design stages.)

Type I -- Mechanical Flight Control System - A reversible control system where the pilot actuates the primary control surfaces of the aircraft, or equivalent devices, through a set of mechanical linkages consisting of cables, pulleys, sectors, push-pull rods, torque tubes, horns, bell cranks, etc., that provide a direct force feedback to the pilot's cockpit controls.

Type II -- Power Boosted Flight Control System - A reversible control system in which the pilot's effort, exerted through a set of mechanical linkages, is augmented by a power source that is incorporated at some point in those linkages.

Type III -- Power Operated Flight Control System - An irreversible control system where the pilot, by means of a set of mechanical linkages, actuates a power-control servomechanism that operates the main control surfaces or corresponding devices. A system of this type may have electrical pilot input modes, backed up by a standby mechanical linkage system.

Type IV -- Control-By-Wire Flight Control System - An irreversible control system where the pilot, through a set of command devices, commands control surface positions and/or specific aircraft maneuvers via electrical transmission paths exclusively. No mechanical connections exist between the command devices and the actuators that operate the control surfaces or equivalent devices, and there is no standby mechanical linkage system.

Comments - Applicable in part. Of particular interest, is the definition of a Type IV system, which is a "Control-By-Wire Flight Control System". A full up FBW system with no standby mechanical linkages.

Recommendation - Update and incorporate into DFBW criteria.

1.2.2 Secondary Flight Control Systems - These include all aerodynamic controls that are used to control the flight path of the aircraft but which are not included in the primary FCS. Systems such as flaps, dive recovery devices, speed brakes, and wing sweep may be secondary FCS's. However, no system shall be so categorized until analysis demonstrates that lack of performance or malfunction will not affect safety of flight.

Comments - The paragraph is a definition of a secondary FCS, such as flaps speed brakes and wing sweeps. The last sentence is controversial because it states, "..... no system shall be categorized until analysis demonstrates that lack of performance or malfunction will not affect safety of flight". In other words, flaps that affect safety of flight are primary FCS, but flaps that don't affect safety of flight are secondary FCS. Why change the category because of flight safety?

Recommendation - Update and incorporate in DFBW criteria.

1.2.3 Automatic Flight Control Systems (AFCS) - These systems are used to automatically augment and/or control the stability, handling characteristics, and flight path of an aircraft in conjunction with elements of the powered FCS, without the necessity for continuous pilot participation. Stability augmentation systems and any airframe response control systems that may be employed for aircraft ride smoothing, flutter suppression, and/or airframe load alleviation shall be considered as elements of the aircraft's AFCS.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW criteria.

2. APPLICABLE DOCUMENTS

2.1 General - The following documents, of the issue in effect on the date of invitation for bids, form a part of this specification to the extent specified herein.

SPECIFICATIONS:

Federal Specifications

FF-B-185	Bearings, Roller, Cylindrical; and Bearings, Roller, Self-Aligning

Military Specifications

MIL-C-172	Cases, Bases, Mounting; and Mounts, Vibration (For use with Electronic Equipment in Aircraft)
MIL-T-781	Terminal, Wire Rope Swaging
MIL-W-1511	Wire Rope, Steel (Flexible), Carbon, Preformed
MIL-F-3541	Fittings, Lubrication (Hydraulic)
MIL-S-3950	Switches, Toggle
MIL-U-3963	Universal Joint, Antifriction Bearing
MIL-B-3990	Bearing, Roller, Needle, Airframe Antifriction
MIL-W-5088	Wiring, Aircraft, Installation of
MIL-E-5272	Environmental Testing, Aeronautical and Associated Equipment, General Specification for
MIL-E-5400	Electronic Equipment, Aircraft, General Specification for
MIL-C-5424	Cable; Steel (Corrosion - Resisting), Flexible, Preformed (For Aeronautical use)

MIL-H-5440	Hydraulic Systems; Design, Installation and Tests of Aircraft (General Specification for)
MIL-C-5503	Cylinders, Aircraft, Hydraulic Actuating, General Specification for
MIL-P-5518	Pneumatic System; Design, Installation and Test in Aircraft
MIL-T-5522	Test Procedure for Aircraft Hydraulic and Pneumatic Systems, General
MIL-H-5606	Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordnance
MIL-E-5629	Bearings, Rod End, Plain, Airframe
MIL-C-5638	Casing; Control Cable, Flexible, Aircraft
MIL-S-5676	Splicing, Cable Terminal, Process for, Aircraft
MIL-T-5683	Terminals; Tie Rod, Threaded Clevis Type, Aircraft
MIL-T-5684	Tie Rods; Streamline, Round and Square Aircraft
MIL-B-5687	Bearings; Sleeve, Washers, Thrust, Sintered, Metal Powder, Oil-Impregnated
MIL-C-5688	Cable Assemblies; Aircraft, Proof-testing and Prestretching of
MIL-C-5693	Wire Strand, Steel (Corrosion Resistant) Preformed (Aircraft Applications)
MIL-B-6038	Bearing; Ball, Bellcrank, Antifriction, Airframe
MIL-B-6039	Bearings; Ball, Rod End, Antifriction, Self-Aligning
MIL-I-6115	Instrument Systems, Pitot Tube and Flush Static Port Operated, Installation of
MIL-T-6117	Terminal - Cable Assemblies; Swaged Type
MIL-I-6181	Interference, Controlled Requirements, Aircraft Equipment
MIL-J-6193	Joints; Universal, Plain, Light and Heavy Duty

MIL-C-6781	Control Panel; Aircraft Equipment, Rack or Console Mounted
MIL-P-7034	Pulleys, Groove, Antifriction - Bearing Grease - Lubricated, Aircraft
MIL-I-7064	Indicator, Position, Elevator Trim Tab
MIL-E-7080	Electric Equipment, Aircraft, Selection and Installation of
MIL-V-7915	Valves; Hydraulic, Directional Control, Slide Selector
MIL-B-7949	Bearing, Ball, Airframe, Antifriction
MIL-C-7958	Controls; Push-Pull, Flexible and Rigid
MIL-M-7969	Motors, Alternating Current, 400-cycle 115/200-Volt System, Aircraft, General Specification for
MIL-A-8064	Actuators and Actuating Systems, Aircraft, Electro-Mechanical, General Requirements for
MIL-B-8075	Brake Control Systems, Anti-Skid, Aircraft Wheels; Instructions for Preparation of Specifications for
MIL-I-8500	Interchangeability and Replaceability of Component Parts for Aircraft and Missiles
MIL-H-8501	Helicopter, Flying and Ground Handling Qualities, General Requirements for
MIL-S-8512	Support Equipment, Aeronautical, Special, General Specification for Design of
MIL-B-8584	Brake Systems, Wheel, Aircraft, Design of
MIL-M-8609	Motors, Direct Current, 28-Volt System, Aircraft, General Specifications for
MIL-T-8679	Test Requirements, Ground, Helicopter
MIL-S-8698	Structural Design Requirements, Helicopters
MIL-I-8700	Installation and Test of Electronic Equipment in Aircraft, General Specification for
MIL-D-8706	Data, Design: Contract Requirements for Aircraft
MIL-D-8708	Demonstration Requirements for Aircraft

MIL-F-8785	Flying Qualities of Piloted Airplanes
MIL-S-8805	Switches and Switch Assemblies, Sensitive and Push (Snap Action), General Specification for
MIL-F-8860	Airplane Strength and Rigidity, General Specification for
MIL-A-8861	Airplane Strength and Rigidity Flight Loads
MIL-A-8865	Airplane Strength and Rigidity Miscellaneous Loads
MIL-A-8866	Airplane Strength and Rigidity Reliability Requirements, Repeated Loads and Fatigue
MIL-A-8867	Airplane Strength and Rigidity Ground Tests
MIL-A-8868	Airplane Strength and Rigidity Data and Report
MIL-A-8870	Airplane Strength and Rigidity Flutter Divergence, and other Aeroelastic Instabilities
MIL-T-8878	Turnbuckles, Positive Safetying
MIL-B-8943	Bearings, Sleeve, Plain and Flanged, TFE Lined
MIL-B-8976	Bearings, Plain, Self-Aligning All-Metal
MIL-S-9419	Switch, Toggle, Momentary, Four-Position On, Center Off
MIL-P-10971	Pins, Spring
MIL-C-18244	Control and Stabilization Systems; Automatic, Piloted Aircraft, General Specifications for
MIL-D-18300	Design Data Requirements for Contracts Covering Airborne Electronic Equipment
MIL-N-18307	Nomenclature and Nameplates for Airborne Electronic and Associated Equipment
MIL-C-18375	Cable; Steel (Corrosion-Resisting, Non-Magnetic) Flexible, Preformed (For Aeronautical Use)
MIL-B-23964	Bolt, Self-Retaining, Positive Locking
MIL-N-25027	Nut, Selflocking, 250°F, 550°F, and 800°F
MIL-L-25142	Luminescent Material, Fluorescent

MIL-E-25499	Electrical Systems, Aircraft, Design and Installation of, General Specification for
MIL-G-25561	Grip Assembly, Controller, Aircraft Type MC-2
MIL-C-52058	Chain, Roller, Aircraft
MIL-G-81322	Grease, Aircraft, General Purpose Wide Temperature Range
MIL-B-81820	Bearings, Plain, Self-Lubricating, Self-Aligning; Low Speed
MIL-L-83176	Lubricant, Instrument Bearing, Petroleum Base
MIL-H-83282	(USAF) Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft
MIL-F-83300	Flying Qualities of Piloted V/STOL Aircraft

Naval Air Systems Command Specifications

SAR-378	Design Requirements, Design Data, and Procedure for Approval of Contractor Furnished Avionic Equipment and Subsystems Procured Under Aircraft Specifications
SD-24	General Specification in the Design and Construction of Aircraft Weapon Systems

STANDARDS

Military Standards

MIL-STD-130	Identification Marking of U. S. Military Property
MIL-STD-203	Aircrew Station Controls and Displays for Fixed Wing Aircraft
MIL-STD-250	Aircrew Station Controls and Displays for Rotary Wing Aircraft
MIL-STD-461	Electromagnetic Interference Characteristics Requirements for Equipment, Subsystem and System
MIL-STD-680	Contractor Standardization Plans and Management
MIL-STD-704	Electric Power, Aircraft, Characteristics and Utilization of
MIL-STD-838	Lubrication of Military Equipment

MIL-STD-1333	Aircrew Station Geometry for Military Aircraft
MIL-STD-1472	Human Engineering Design Criteria for Military Systems Equipment and Facilities

Military Standard Drawings

MS 15001	Fittings, Lubrication (Hydraulic) Surface Check, 1/4 - 28 Taper Threads, Steel, Type I
MS 15002	Fittings, Lubrication (Hydraulic) Surface Check, Straight Threads, Steel, Type II
MS 20219	Pulley, Groove, Secondary Control, Aircraft
MS 20220	Pulley, Groove, Flight Control, Aircraft
MS 20221	Pulley, Groove, Heavy Duty, Control, Aircraft
MS 33540	Safety Wiring, General Practices for
MS 33547	Pins - Spring, Functional Limitations of
MS 33558	Numerals and Letters, Aircraft Instrument Dial, Standard Form of
MS 33572	Instrument, Pilot, Flight, Basic Standard Arrangement for Helicopters of
MS 33574	Dimensions, Basic, Cockpit, Stick Controlled, Fixed Wing Aircraft
MS 33575	Dimensions, Basic Cockpit, Helicopter
MS 33576	Dimensions, Basic, Cockpit, Wheel Controlled, Fixed Wing Aircraft
MS 33588	Nuts and Plate Nuts, Self-Locking, Aircraft Design and Usage Limitations of
MS 33591	Turnbuckles - Lockwiring of

AIR FORCE-NAVY AERONAUTICAL BULLETINS:

ANA - 275	Guide for Lubrication of Aircraft

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

2.2 Other Publications - The following documents form a part of the specification. Unless otherwise indicated, the issue in effect on date of invitation for bids shall apply.

NATIONAL AIRCRAFT STANDARDS:

NAS 509	Nut, Drilled Jam
NAS 513	Washer, Rod End Locking
NAS 559	Lock-Rod End (Key Type)
NAS 1193	Locking Device, Positive Index

(Copies of National Aircraft Standards may be obtained from the National Standards Association, Inc., 1315 Fourteenth Street, N.W., Washington 5, D. C.)

Comments - Specifications require review relative DFBW FCS.

Recommendation - Review and revise specification listing for DFBW FCS and incorporate into DFBW specification.

3. REQUIREMENTS

3.1 System Design Requirements - Flight control systems shall be as simple, direct, and foolproof as possible, consistent with overall aircraft mission requirements with respect to design, operation, inspection and maintenance. At the earliest stage in the design of the aircraft, design goal allocations shall be made for the flight control system in the areas of flight safety (failure rate), mission reliability (abort rate), and maintainability (down time per flight hour). In determining total or partial system reliability, all major failure sources must be considered, including multiple-channel failures, single point failures, latent failures in both prime and built-in-test equipment, and nuisance disengagements of redundant elements. The performance of built-in-test equipment shall reflect the test objective (e.g., flight safety, mission reliability, and maintainability) and be applicable only to that equipment which affects the objective. The influences of preflight and in-flight test qualities, test frequencies, and system life on redundant flight control reliability shall be established and satisfactorily resolved by the system design and operational concepts. Whenever possible, redundant systems shall not share a single component. The system and subsystem reliability values, associated testing, failure modes, and confidence level criteria shall be defined in the detail specification or otherwise negotaited with the procuring activity.

Comments - The first sentence is general but still applicable. The next two sentences discuss system reliability. The fourth sentence is about built-in-test objectives. The fifth about preflight and in-flight tests. The sixth about redundant systems not sharing a single failure. And the last about what should be in the detail specification. There are too many different subjects in one paragraph.

Recommendation - Update and incorporate into DFBW criteria.

3.1.1 Primary Flight Control Systems - Wherever the magnitude and linearity of hinge moments permit, and there is no requirement for irreversibility or power controls, direct mechanical controls shall be used. Otherwise, boosted or powered controls shall be used, depending upon the requirements for irreversibility. Control augmentation systems that are used to augment pilot inputs into the primary FCS in order to improve the handling qualities of an aircraft shall conform to the requirements of MIL-C-18244.

Comments - Calls for direct mechanical controls when possible, otherwise use powered controls. Not applicable to DFBW systems. The last sentence states control augmentation shall conform to MIL-C-18244.

Recommendation - Delete.

3.1.1.1 Type I Flight Control Systems - In the design of mechanical components, the reliability, strength, and simplicity of the system shall be paramount considerations. The mechanical transmission linkages between the command devices in the cockpit and the primary control surfaces, or corresponding devices, shall be duplicated, or "dualized". This requirement may be waived only upon the approval of the procuring activity. Where possible, these duplicated or dualized transmission linkages shall extend from near the command devices in the cockpit to the attachment point at the control surface or corresponding device. Whenever push-pull tube systems are used, they shall be so arranged that all tubes are in tension for the greater load for which the system is designed.

Comments - Calls for dualized mechanical controls from the command device to the surface. Not applicable to DFBW systems.

Recommendation - Delete.

3.1.1.2 Type II Flight Control System - The mechanical transmission linkages of the Type II FCS's shall meet the requirements described for the Type I FCS. The power system for the Type II FCS, if hydraulic, shall be completely independent and shall have no interconnection with any other hydraulic system. If electrical, it shall have no interconnection with any other electrical system. The basic electric power source is excepted if the power supply has the capability to automatically isolate faults and assure continuous power. When a failure occurs in the power system of a Type II FCS, it shall be possible to operate the flight controls directly through the mechanical transmission system within the limitations described in MIL-F-8785. Where a mechanical advantage change device is incorporated, no hazardous lag shall exist during the changeover. A worst case analysis shall be performed to show that the maximum lag and/or the resultant transient motions will not cause the aircraft to exceed a specified value of g's nor place the aircraft in an attitude from which it is difficult to achieve recovery. Design provision shall be made to minimize system backlash, servo friction and viscous damping effects, and to assure adequate control feel while operating in the emergency manual mode.

3.1.1.3 Type III Flight Control System - The mechanical transmission linkages of the Type III FCS shall meet the requirements defined for the Type I FCS. A power system separation is required as defined for Type II systems. A single power system may be employed where an emergency manual backup power system is available. When a failure occurs in a single power system, it shall be possible to operate the flight controls through a direct set of mechanical transmission linkages or through the backup power system to obtain aircraft controllability that will meet the emergency requirements of MIL-F-8785. An analysis shall be conducted demonstrating changeover safety, and design provisions for adequate control feel during emergency operation shall be provided as defined under Type II Systems. When one or more power supply of a multiple power system fails, the performance of the aircraft with the remaining emergency system in operation shall meet the requirements of MIL-F-8785, or as defined by the contractor and accepted by the procuring activity.

Comments - Only the second and third sentence of the first paragraph is meaningful to DFBW systems.

Recommendation - Update and incorporate into DFBW criteria.

3.1.1.4 - Type IV Flight Control System - Control-by-wire primary FCS's, which achieve specified mission completion reliability levels by the incorporation of redundant control signal channels, shall incorporate means in the aircraft to demonstrate that all redundant components are operating normally prior to takeoff. The redundant electrical signal channels shall be dispersed and protected in such a manner as to reduce vulnerability and increase survivability. Control-by-wire FCS's shall be inherently self-monitoring and shall operate at specified performance levels after sustaining specified types of failures of any electrical portions of the FCS. Vulnerability to lightning strikes and to electromagnetic impulses shall be minimal. The operational reliability of a Type IV FCS shall be demonstrated to be at least equal to that of a Type III FCS.

Comments - The paragraph describes a CBW FCS which is applicable to the criteria.

Recommendation - Update and incorporate into DFBW criteria.

3.1.1.4.1 Installation Requirements -

a. Cross connections between redundant electrical signal channels shall be minimized, and failure detection/isolation provisions shall be mechanized in such a way that no single failure can disable more than one channel. Maximum isolation shall prevent any failure in one signal channel from initiating a failure or a cascade of failures in any other signal channels.

b. Each redundant electrical signal channel shall be associated with an electrical power source that is not connected to any other signal channel. The loss of a single electrical power source shall not result in the loss of more than one signal channel in a redundant system.

c. The wiring of the redundant electrical channels for a given control axis shall be separated to the maximum extent possible. If adequate separation is not possible, physical and thermal barriers shall be provided between the channels.

d. FCS wiring shall be separated from the wiring of other systems so that a failure in other systems cannot introduce failures in the FCS.

e. Wiring shall be supported or enclosed in conduits to minimize chafing, stress, vibration, and shock.

f. Wiring shall be enclosed in conduit in areas subject to maintenance action and possible abuse by maintenance personnel. The conduits shall be able to withstand manhandling loads.

g. The number of electrical connectors shall be minimized; however, redundant systems or channels shall not share a single connector.

Comments - Applicable.

Recommendation - Incorporate into DFBW criteria.

3.1.1.4.2 Special Requirements - The following requirements shall be determined by the contractor, subject to the approval of the procuring activity:

a. Reliability level to achieve specified mission completion prediction.

b. Minimum redundancy level for the various control surfaces.

c. Minimum redundancy levels for electronic circuits and components.

d. Cooling method for electronic components.

e. Electrical power supply provisions.

f. Electrical backup power supply and limitation of backup control.

Comments - It gives a list of things the contractor shall determine, subject to approval of the procuring activity. These requirements should be applied to the detail equipment specifications.

Recommendation - Update and incorporate into DFBW criteria.

3.1.1.4.3 Provisions to Prevent Jamming of Hydraulic Power Control Valves - In a control-by-wire flight control system, jammed or sticky hydraulic control valves cannot be freed by direct pilot effort. Therefore, every precaution shall be exercised in the design of these valves, in order to make them jam-proof. Valve operating forces shall be sufficient to preclude jamming due to hydraulic contamination and/or mechanical deflections. Redundant hydraulic control valves may be employed to satisfy the above requirement.

3.1.1.4.4 Type IV Power System Failure - When one power system of a dual power system fails, the performance of the aircraft with a single power system in operation shall meet the requirements of MIL-F-8785. When two power systems fail in a multiple power control system, the airplane shall be controllable for a level of flying qualities to be defined by the contractor and approved by the procuring activity.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW criteria.

3.1.1.5 Power Supply Systems

3.1.1.5.1 Hydraulic Power Supply - Hydraulic power supply systems shall conform to MIL-H-5440, except as noted in this specification. A dualized hydraulic supply system shall consist of two separate systems, both operating simultaneously. One system shall be completely independent, while the other may be combined with the aircraft's utility system. Each system shall be as simple as possible and shall contain a minimum number of components. There shall be no interconnections between the two systems. When dual systems are used in aircraft having multiple engines, the power sources for each system shall be mounted on separate engines. For rotary-winged aircraft, at least one power system shall be rotor-driven, regardless of whether the aircraft has more than one engine. Tandem or parallel actuating cylinders in the same housing are considered to be a satisfactory design for use with dual power systems.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.1.1.5.2 Power-by-Wire Systems - A power-by-wire system transmits electrical power from a power source to the flight control surface actuators. Power shall be transmitted to each control surface actuator through a number of independent power supply systems. The redundant electrical power supply paths shall be routed to maximize the survivability of the system.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.1.1.5.2.1 Performance Requirements for Power-by-Wire Systems - The fail-safe, fail-operational, redundancy, and reliability requirements for power-by-wire systems shall be as determined by the contractor and approved by the procuring activity.

Comments - Applicable to FBW specification.

Recommendation - Incorporate into FBW specification.

3.1.1.5.3 In-Flight Damage Requirements for Type III and Type IV Systems - The hydraulic and/or electrical supply systems powering the flight control actuators shall be integrated and routed within the aircraft in a manner such that the aircraft will be controllable following in-flight damage as follows:

a. The loss of an engine pod

b. The loss of an outer wing section

c. The loss of an upper portion of the vertical fin

d. The loss of an outboard portion of the horizontal stabilizer and/or elevator

e. The ejection of power plant parts

f. Any other losses specified by the procuring activity.

Comments - Applicable to a FBW specification.

Recommendation - Incorporate in FBW specification.

3.1.1.5.4 Power Supply Checkout - The power system shall include provisions for checking emergency operations of the flight control systems during ground operation in accordance with MIL-T-5522. This requirement does not apply to single or dual power systems using reversion to manual control for emergency operation.

Comments - General requirement for ground checkout of hydraulic and electrical power supplies is valid.

Recommendation - Perform detailed review of MIL-T-5522 and other applicable specifications and incorporate into DFBW specification.

3.1.1.5.5 Power Supply Indicator System - A system shall be installed to indicate malfunctions and the status of power supply circuits.

Comments - General requirement for failure indication of hydraulic and electrical power supplies is valid.

Recommendation - Incorporate into DFBW criteria.

3.1.1.6 Trim Systems - A suitable trim system shall be provided for each of the primary control axes. The trim system shall be irreversible so that the surface loads or vibratory conditions will not alter the trim setting until it is changed by the pilot. The trim systems shall be designed to meet the performance requirements of MIL-F-8785, and also those listed in this specification. The trim requirements of the automatic flight control system (AFCS) shall comply with the requirements specified in MIL-C-18244. Electrical trim systems shall be designed with a trim range that shall not exceed the absolute minimum requirements necessary to provide trim capability over the entire flight envelope. Trim surfaces or other trim devices with authority greater than the primary control system shall not be used. The trim signal for a Type III FCS shall be applied directly to the control element of the servomechanism if considered feasible.

3.1.1.6.1 Emergency System - Where a failure of a power-operated trim control system would result in marginal or undesirable control characteristics, a completely separate emergency system, or means to override the failed power system, shall be used.

3.1.1.6.2 Trim Switches - Electrical trim system switches shall be in accordance with MIL-S-9419.

3.1.1.6.3 Trim Rate - Two-speed trim actuators should not be employed for manual trim during flight; however, a second speed may be provided for use with automatic flight control. In determining an acceptable trim rate that will meet the manual flight requirements, the following points shall be considered in addition to the requirements of MIL-F-8785:

a. The maximum average trim rate that is required to maintain stick forces near zero during the final landing approach in configuration PA (See MIL-F-8785). The trim rate that would be needed to provide flareout before landing is not pertinent, since the pilot can hold the stick against the aerodynamic force loading for the short time that is required.

b. The maximum trim rate that is required to keep stick forces near zero during maximum rate of change in airplane speed, such as in dives.

c. The maximum trim rate that is needed to maintain zero stick forces during operations that yield trim changes, such as extension of speed brakes or wing flaps, wing sweep, etc.

d. The minimum trim rate which, if it were used to control the flight control surfaces, could create a maneuver capable of generating the airframe's limit load after 2 seconds of trim operation.

Unless excessive trim sensitivity is encountered the trim rate should not be less than any of the values obtained for "a", "b", and "c", in order to permit adequate control. It should not be greater than the value of "d", thereby assuring that a runaway trim system could not create a limit load condition before the pilot could take corrective action. Note that it is not desired that the pilot should be able to trim the airplane into performing any desired maneuvers; therefore, the trim rates can and should be kept as low as possible, consistent with conditions "a", "b", and "c", above.

3.1.1.6.4 Series Trim - If series trim is used, the authority of the trim actuator should be limited, to insure that there will be adequate manual control through the pilot's control stick in the event that the trim actuator becomes inoperative in any position. Otherwise, if series trim is used with an actuator having large authority, some provision for "return to neutral" or for a suitable backup mode of operation must be included.

3.1.1.6.5 Trim Position Indicators - Indicators shall be provided as required to assist the pilot in setting aircraft configuration such as takeoff, landing, etc. Where movable surfaces are used for trimming, the sensing devices for the indicator shall be operated by the surface actuator in power-operated systems, except when surface position is a true indication of trim position in which case the sensor may be attached directly to the surface. A position sensing device is not required on the surface, or a mechanical link directly connected to the surface, if the system is entirely manual, unless an electrical instrument type indicator is used. On manual type systems a mechanical type indicator on or near the cockpit control is considered satisfactory. Aircraft which require takeoff longitudinal trim setting in accordance with cg location shall have suitably calibrated trim position indicators. Where suitable, trim indicators shall be in accordance with MIL-I-7064. For control systems where multiple trim devices (e.g., series and parallel) may be used or where the available control authority (i.e., net surface position) is not substantially indicated by the control stick or wheel position, the provision of suitable devices to indicate the available control operating range is mandatory.

3.1.1.6.6 Trim Switch Location - The location and actuation of the trim controls and indicators shall be as indicated in MIL-STD-203.

3.1.1.6.7 Trim Actuators - Electromechanical trim actuators shall be in accordance with 3.3.13. The life test shall normally include 100,000 cycles as specified in MIL-A-8064. However, in the event that an automatic flight control system injects autotrim signals into the actuator, the life cycling shall be at least 1,000,000 cycles at suitable frequency, amplitude, and load while exposed to the anticipated aircraft environmental conditions. Greater amounts of cycling shall be used if appropriate and reasonable.

3.1.1.6.8 Manually Operated Trim Control Systems - When manually operated trim control systems are used, it shall be possible to obtain the necessary control with a minimum amount of input motion consistent with acceptable operating forces.

Comments - Applicable. A very thorough discussion of trim, unfortunately most of it is not related to DFBW systems. There is even a question whether manual trim would be in a DFBW system.

Recommendation - Update and incorporate into DFBW specification.

3.1.1.7 Artificial Feel Systems - Where pilot control forces, adequate to meet the requirements of MIL-F-8785 and MIL-H-8501, are not provided by aerodynamic means, these forces must be supplied (or the aerodynamic forces augmented) by suitable artificial feel devices. The artificial feel system shall provide a force gradient which will permit the aircraft to meet its contract requirement. Any failure in the systems shall not result in control forces that are either so high or so low as to be hazardous. Artificial feel system design should provide positive control centering to the trim position without overtravel or control oscillation.

Comments - If artificial feel systems are required to meet the handling qualities and safety, the general requirement is applicable.

Recommendation - Incorporate into DFBW criteria.

3.1.1.8 Control Sensitivity - Control sensitivity and breakout forces shall be in accordance with MIL-F-8785 and MIL-H-8501. Care must be exercised in selecting values for sensitivity and breakout forces in order to prevent overcontrol tendencies at high values of "Q".

Comments - Applicable. Review the sensitivity requirements in MIL-F-8785 and MIL-H-8501.

Recommendation - Update and incorporate into DFBW specification.

3.1.1.9 Segmented Flight Control Surfaces - Segmented flight control surfaces may be used to reduce the vulnerability and increase the survivability of the primary FCS. The degradation in flight control capability and the compromise of mission completion with failures of segmented control surfaces shall be as specified or approved by the procuring activity.

Comments - Applicable to a DFBW specification.

Recommendation - Incorporate into DFBW criteria.

3.1.1.10 Reaction Control Systems - Reaction control systems which may be required to meet the controllability requirements of MIL-F-8785 and MIL-H-8501 shall be considered as an integral part of the primary FCS. The specifications applicable to primary FCS's shall apply to reaction FCS's.

3.1.1.11 Thrust Vector Control Systems - Systems which control the thrust vectors of engines in order to control aircraft flight path and attitude shall be considered a part of the primary FCS. Therefore the specifications applying to primary flight control systems shall also apply to thrust vector control systems.

The following design features of a thrust vector control system shall be as defined by the contractor and approved by the procuring activity:

a. Monitoring systems
b. Failure indication
c. Preflight checkout
d. Degree of redundancy
e. Fail-safe design philosophy

Comments - Applicable if used.

Recommendation - Incorporate into DFBW specification.

3.1.1.12 Computer Controlled Primary Flight Control Systems - A computer controlled primary FCS utilizes an electronic computer either to supervise functions of the primary flight control system or to provide closed loop control of the aircraft by the pilot by implementing a control augmentation system. Such systems may be used in conjunction with Types I, II, III, or IV flight control systems. If the electronic computers are not needed to meet the controllability requirements of MIL-F-8785, they shall be classified as part of an AFCS and shall meet the requirements specified herein for such systems. If the presence of the computers is required to meet the controllability requirements of MIL-F-8785, the computers shall be considered as an integral part of the primary FCS, and shall meet the requirements for airplane failure states that are presented in MIL-F-8785. Redundancy shall be provided, as necessary, to achieve the specified levels of flight safety and mission reliability, after considering all combinations of sensing, computing, actuation, and electrical and hydraulic failures. A computer-controlled flight control system shall be capable of monitoring system failures and shall automatically compensate for such errors. Transients due to failures shall be minimized. Appropriate information relating to the failure and its significance with respect to mission completion shall be displayed to the pilot.

Comments - Discussion whether it is classified as primary or AFCS doesn't apply to DFBW systems. Too many different requirements are in one paragraph.

Recommendation - Update and incorporate into DFBW specification.

3.1.1.13 Computerized Checkout of Primary Flight Control Systems - When computerized checkout of the primary FCS is utilized, it shall be demonstrated to the procuring activity that such a checkout will assure that all FCS components operate normally and that failures of the checkout equipment will not mask failures of the equipment being tested. Design of the checkout system shall include sufficient isolation and/or lockout provisions to prevent the introduction of extraneous signals into the primary FCS during flight. Any single malfunction of the checkout system shall not degrade more than one signal path in a redundant control-by-wire FCS.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.1.1.13.1 Design of Equipment - The computerized checkout may be an integral part of the system or a separate ground test unit. The approach to be used shall be determined by the procuring activity.

Comments - Computerized check out may be a separate ground test unit, is not appropriate for a digital computer. We would not be using the computers capability.

Recommendation - Delete.

3.1.1.14 Flight Control Systems of Control-Configured Vehicles - Aircraft designed to obtain performance benefits resulting from a CCV concept shall, as a minimum requirement, be fail-operational on the first failure and fail-safe after the second failure. Consideration shall be given to providing for manual channel selection after the second failure. When computers, associated with the primary FCS of control-configured vehicles, are necessary to meet the controllability requirements of MIL-F-8785, they are considered to be an integral part of the primary FCS.

Comments - The requirement that as a minimum a CCV shall be fail-operational on a first failure and fail safe after a second failure is acceptable for the primary mode in a DFBW system.

Recommendation - Update and incorporate into DFBW specification.

3.1.1.15 Vulnerability.

3.1.1.15.1 Vulnerability to Enemy Actions - FCS's shall be configured in a manner to reduce vulnerability and increase survivability in regard to combat damage. The number of areas where a single strike of a small projectile may cause loss of aircraft control shall be minimized to the greatest extent possible. The survivability of FCS's subject to combat damage shall be maximized by the incorporation of the following features wherever practicable:

a. Physical separation of parallel functions

b. Redundant methods of providing inputs to primary control system actuators

c. Duplication of control augmentation electrical circuits

d. An additional hydraulic input shared with other subsystems to provide backup operation of essential pitch and roll controls

e. Bellcranks, pulleys, and actuators designed and located to minimize combat damage and the design of these to employ redundant structural load paths, rip and tear stops, and nonfrangible features

f. Use of armor and thermal protection

g. No single failure in the command augmentation system's mechanical controls, hydraulic or electrical inputs shall result in an unsafe condition or loss of ability to return to base and land. (Single points such as stabilator hinges, bearings, drive horns, and actuator rod ends are outside the scope of this requirement)

h. Maximum advantage shall be taken of the shielding afforded by heavy structural members, existing armorplate, or other equipment, for the protection of important components of the control system.

i. Use of trim system to provide control inputs into the FCS in case of linkage jam or separation.

j. Employment of dissimilar methods of redundancy.

3.1.1.15.2 Vulnerability to On-Board Failures - Provision shall be made to reduce the vulnerability of the primary FCS to on-board failures such as fires, jamming by foreign objects and ice formation, failures of components of other systems which are adjacent to components of the primary FCS, and objects thrown from failed powerplant assemblies.

3.1.1.15.3 Vulnerability to In-Flight Collisions - After an in-flight collision the damage to an aircraft may be such that it will remain aerodynamically flyable. For these cases it shall be an objective to design the primary FCS to maximize the probability that the aircraft will remain controllable with undamaged portions of the FCS.

Comments - Applicable in part. Delete reference to mechanical flight controls and to in-flight collisions.

Recommendation - Update and incorporate into DFBW specification.

3.1.1.16 Interface Considerations - Interfaces between various parts of the FCS shall be designed with utmost consideration being given to safety, reliability, and maintainability, in that order. Special consideration shall be given to the interfaces to assure that failure within any portion of the integrated system does not cause failure of an otherwise functionally independent portion of the system.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.1.2 Secondary Flight Control Systems - Power for these controls shall not be derived from the primary flight control power system.

Comments - Requires further investigation.

Recommendation - Perform a power distribution study and incorporate results into DFBW specification.

3.1.2.1 High Lift Control Systems - A suitable control system shall be provided for actuating the nonautomatic high lift devices (flaps, slats, etc.)

3.1.2.1.1 Synchronization - High lift devices shall contain provisions for synchronous operation, unless it can be demonstrated that no hazardous flight attitude will result from unsynchronized operation. 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 included in the Flight Demonstration Plan, requiring procuring activity approval.

Comments - Applicable in part. The last two sentences of the second paragraph requires a flight demonstration test at a degree of asymmetry for inducing most hazardous flight attitudes. It belongs at the Flight Demonstration Plan and not here.

Recommendation - Update and incorporate into DFBW specification.

3.1.2.1.2 Emergency Operation - 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 primary system up to, but not necessarily including, the actuator.

Comments - Applicable.

Recommendation - Incorporate into DFBW specification.

3.1.2.1.3 Operating Time - The time of operation for power-operated landing flaps shall be as determined by flight tests.

Comments - "The time of operation... shall be determined by flight tests." By this time it is too late to make any changes.

Recommendation - Revise to reflect that "time of operation shall be verified" and incorporate into DFBW criteria.

3.1.2.1.4 Indicator - An approved type indicator shall be provided in the cockpit to indicate hi-lift device positions.

Comments - Applicable.

Recommendation - Incorporate into DFBW specification.

3.1.2.1.5 High Lift Systems Using Air Blowing and/or Air Suction Devices - High lift systems employing air blowing and/or air suction devices shall be designed at least to the single-failure, fail-safe criterion. The system shall be designed so that trim changes will not be hazardous to safe flight in case of a failure.

The use of insulated ducting shall be considered whenever the temperature of the air within the ducting is high enough to cause degradation to adjacent structure and components. Whenever possible the ducting shall be routed in a manner to avoid possible damaging effects of critical components.

Comments - If high lift systems are utilized, the general requirement still applies.

Recommendation - Incorporate into DFBW criteria.

3.1.2.2 Speed Brakes - The control system must be capable of withstanding frequent operation at all flight speeds up to the terminal velocity of the airplane. In some cases, blowback features may be desirable to prevent structural failure of the components.

3.1.2.2.1 Emergency Systems - Emergency retraction is required on those devices that will not automatically retract, as a result of airloads, when the control is moved to the retract position.

3.1.2.2.2 Asymmetric Operation - Where asymmetric operation of speed brakes would cause uncontrollable aerodynamic moments on the airplane, provisions shall be made to prevent this condition. Where these devices perform functions requiring asymmetric operation, provisions shall be made to prevent unintentional operation.

3.1.2.2.3 Positioning - The control system shall be of such design as to permit infinite variable positioning.

3.1.2.2.4 Actuation - The pilot's actuating mechanism shall be a three-position device with a stop position in neutral, momentary aft position to extend, and a maintained forward position for retraction.

3.1.2.2.5 Indicator - An indicator shall be provided to indicate whether speed brakes, or similar devices, are extended.

3.1.2.2.6 Operating Time - The extend and retract time shall be determined from the results of flight tests.

Comments - Applicable except determine the time to open shall be verified from flight test.

Recommendation - Update and incorporate into DFBW specification.

3.1.2.3 Direct Lift Control Systems - Direct lift control (DLC) systems shall be designed to at least the single-failure, fail-safe criterion. Means for the detection and indication of failures shall be provided. Built-in test logic shall also be provided. Interlocking logic requirements between the DLC system and any other systems or subsystems shall be as determined by the contractor and approved by the procuring activity. Whenever deflections of trailing edge flaps are used as an aid in direct lift control of the aircraft, no single failures within the DLC system shall prevent lowering of the flaps to their landing position.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.1.2.4 Maneuver Load Control Systems - Maneuver load control systems shall be designed to at least the single-failure, fail-safe criterion. Means for the detection of failures, indication of failures, and built-in test logic shall be provided. Maximum allowable flap deflections shall be limited as a function of flight condition consistent with structural considerations. The following interlocks shall be satisfied prior to engagement of the maneuver load control system:

a. Selection by pilot
b. Landing gear up
c. Proper wing sweep setting (if applicable)
d. Aircraft in flight envelope in which it is permissible to operate the maneuver load control system.

3.1.2.5 Variable Wing Sweep Control Systems - Variable wing sweep control systems shall be designed as a minimum to the single-failure, fail-safe criterion. The control system shall contain a failure detection system. The provision shall be made for an emergency back-up system to actuate the wings to the full forward position in case of failure of the main control system if such is necessary to permit a safe landing of the aircraft. The servomechanism controlling the wing sweep control system shall be stable and free of limit cycle oscillations for all flight conditions. An approved type indicator shall be installed in the cockpit to indicate wing sweep position. The additional requirements stated in SD-24 shall also apply.

3.1.2.5.1 Safety Provision - A manual locking system shall be provided for positive locking of the wing for any sweep angle during ground operation.

3.1.2.6 Stability Altering Systems - Surfaces may be used to decrease static margin, increase maneuverability, decrease trim drag, increase directional stability, etc. If these surfaces are automatically controlled then a manual override provision shall be incorporated to permit the pilot to either extend or retract the surfaces.

3.1.2.6.1 Synchronization - Stability altering surfaces shall be interconnected, unless it can be demonstrated that no hazardous flight attitude will result from unsynchronized operation.

Comments - General requirements for the above paragraphs are applicable. Specific design requirements. (e.g. para 3.1.2.5.1) should be eliminated.

Recommendation - Revise and incorporate into DFBW criteria.

3.1.3 Automatic Flight Control Systems (AFCS) - Automatic flight control systems shall be in accordance with MIL-C-18244. Automatic flight control systems, subsystems and components shall be designed so that a maximum of integration is accomplished consistent with system reliability, operation and safety.

Comments - AFCS requirements will be specified in new DFBW specification.

Recommendation - Delete.

3.1.4 Pilot's Controls - The pilot's command devices for fixed-wing aircraft shall be designed and located in accordance with MIL-STD-203, MS 33574, and MS 33576. Strict adherence to the prescribed location and maximum ranges of motion of these controls is required.

Comments - The applicable portions of this requirement should be incorporated into the DFBW criteria. However, additional requirements relative to side arm controllers and other secondary controls must be studied and incorporated.

Strict adherence to prescribed location and motion has merit for standardizing controls in the cockpit. It should not restrict or limit further designs and therefore it should be a design goal.

Recommendation - Update and incorporate into DFBW criteria.

3.1.4.1 Control Sticks - If a control stick is used, and is removable, it shall be positively latched in place when installed. It shall be possible to install the stick only in the correct manner, and suitable means shall be provided to prevent rotation of the stick. If pilot's control sticks, other than the conventional center located sticks, are utilized, demonstration of their adequacy and suitability is required prior to installation in an aircraft. An in-flight removable control stick shall be latched automatically.

3.1.4.1.1 - Systems With Two or More Control Sticks - Where two or more control sticks are used, every effort shall be made to prevent the malfunctioning of one control stick from rendering the other stick(s) inoperable. No single control stick failure, including a jam, shall render the entire flight control system inoperable.

3.1.4.2 Rudder Pedals - Rudder pedal size, shape, motion, and adjustment mechanism for fixed-wing aircraft shall conform to the requirements of MS 33574, MS 33576, MIL-B-8584, MIL-STD-1333, and MIL-STD-203. The foot pedals shall be interconnected to insure positive movement of each pedal in both directions.

Comment - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.1.4.3 Pilot's Control Forces - The control forces required at the pilot's control shall be in accordance with the requirements of MIL-F-8785. These values apply to all ambient temperatures and include all sources of control force including friction, artificial feel, bobweights, etc.

Comment - Not applicable to DFBW systems.

Recommendation - Delete.

3.1.4.4 Wheel Brake Controls - Wheel brake controls shall be in accordance with MIL-B-8584.

3.1.4.4.1 Anti-Skid Systems - Anti-skid systems shall be in accordance with MIL-B-8075.

Comment - Not applicable to DFBW criteria.

Recommendation - Delete.

3.1.4.5 Hand Controllers - The requirements for the following parameters for hand controller installations used in primary flight control systems shall be determined by the contractor and approved by the procuring activity:

a. Location
b. Breakout forces
c. Force gradients
d. Armrest requirements
e. Damping
f. Deflection

Comment - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.1.5 Control Surface Locks - All flight control surfaces shall be provided with locks or snubbers designed to prevent damage from ground wind loads as specified in MIL-A-8865. The control surfaces of any airplane which can be nosed over or up by high winds when the control surface is displaced from the neutral position shall be locked in the neutral position. The design of control valve input and feedback linkages shall be such that, with hydraulic power off, any loads caused by ground winds or control surface droop due to weight unbalance, shall not result in damage. On powered systems, if it can be shown that the actuator provides adequate damping and carries the ground wind loads without damage to any linkage, additional gust locks shall not be required.

3.1.5.1 Internal Locks - Internal locks shall either engage the surfaces directly or lock the controls as near to each surface as practicable to obtain maximum benefit.

3.1.5.2 Pilot's Lock Control - Control for the internal lock system shall be in accordance with the requirements of MIL-STD-203. Means shall be provided to lock the pilot's control in the unlock position.

3.1.5.3 Locking Range - The range of movement of the pilot's control and lock control system shall be sufficient to insure complete locking or unlocking of the control surface under the most adverse conditions of structural and system deflections. In unlocking the surface locks, a maximum of the first 50 percent of the range of motion of the pilot's control shall directly and positively unlock the control surfaces.

3.1.5.4 - In-Flight Engagement - These locks shall be so arranged that they cannot be engaged during flight for any reason, such as inadvertent operation of the cockpit control lever, relative deflections between the lock control system and the aircraft, component failure, combat damage, etc.

3.1.5.5 Control Lock Interlock - An interlock shall be provided to prevent advancing the power lever beyond the "ground idle" range unless the pilot's control lock control is in the "unlock" position.

3.1.6 Control Stops - Adjustable control stops shall be located near the cockpit controls to prevent pilot inputs in excess of that which can be tolerated by the other components in the system or which the airframe can structurally tolerate. If it is possible for maladjustment, misrigging, or other conditions to result in damage to the control surfaces, or main surfaces, due to overtravel, adjustable surface stops shall also be provided adjacent to the surface itself. In aircraft, such as VP and VR types, employing large, heavy surfaces, stops shall be provided at each surface.

3.1.6.1 Adjustable Stops - All adjustable stops shall be positively locked or safety wired in the adjusted position. Jam nuts (plain or self-locking type) are not considered adequate as locking devices for this application.

Comment - Not applicable to powered control system where the actuators can carry the ground wind loads without damage to the system.

Recommendation - Delete.

3.1.7 Additional Requirements for Rotary Wing Aircraft - These requirements are in addition to the previous specifications with the exception that the applicable flying qualities specification shall be MIL-H-8501, and the applicable structural design requirements specification shall be MIL-S-8698.

3.1.7.1 Primary Flight Controls - In general, the overall requirements for helicopter control systems are specified in MIL-H-8501 and should be adhered to, except as approved by the procuring activity.

3.1.7.1.1 Helicopter Flight Control Hydraulic Systems - In addition to previous requirements for the flight control hydraulic system, the emergency hydraulic pump, if required, shall be driven from the main rotor or gear box so that it will be operative during autorotative landings. An additional power source shall be engine driven or APU driven to facilitate ground testing without turning the rotor.

3.1.7.2 Pilot's Controls - The pilot's command devices shall be designed and located in accordance with the applicable portions of MS 33575, MS 33572 and MIL-STD-250. Strict adherence to the prescribed location and range of motions of these controls is required unless otherwise approved by the procuring activity. The range of motions shall be sufficient to meet the handling qualities requirements specified in MIL-H-8501. It shall be possible to move the control surfaces through the complete range of travel corresponding to any one aircraft axis in not more than one second when the rotor is stopped.

3.1.7.2.1 Cyclic Pitch Control Stick - If the control stick is removable it shall be positively latched in place when installed. It shall be possible to install the stick only in the correct manner, and suitable means shall be provided to prevent rotation of the stick.

3.1.7.2.2 Throttle Interconnection - The collective pitch control shall be interconnected with the throttle control, and synchronized to provide the proper throttle setting as collective pitch is increased or decreased. Means shall also be provided to permit throttle control independent of lever movement, by rotation of the grip on the lever. For turbine engine powered aircraft the collective pitch control shall be interconnected with an engine control to maintain constant rotor speed as collective pitch is increased or decreased.

Means shall be provided to individually start, stop, and control the speed of each engine, either by rotation of the collective pitch stick's grip or by independent levers located on a forward lower or overhead console.

3.1.7.2.3 Collective Pitch Lever Lock - An adjustable friction type lock or braking device shall be provided to retain the collective pitch lever in any desired position. Maximum forces required to move the lever shall be in accordance with MIL-H-8501.

3.1.7.3 Blade Coning Restrainers - Suitable provisions shall be made to restrain coning of the blades when starting or stopping the rotor. It shall be possible to start or stop the rotor in wind velocities up to 60 knots, from any horizontal direction, without physical contact of the rotor blades with any part of the airframe. Means shall also be provided to prevent contact of the blades and airframe during flight maneuvers and hard landings.

3.1.7.4 Control Surface Locks - If it is considered that damage to any of the control surfaces or control mechanisms may result from gusty air while the aircraft is parked, suitable control surface locks shall be provided in accordance with the detail requirements of 3.1.5.

3.1.7.5 Helicopter Automatic Flight Control Systems - Whenever automatic flight control features are required for helicopters they shall be in accordance with MIL-C-18244. Automatic flight control systems, subsystems and components shall be designed such that a maximum of integration is accomplished consistent with system reliability, operation and safety.

3.1.7.6 Primary Flight Path Angle Control Operating Time - The quality requirements shall be as specified in the applicable aircraft specifications.

Comments - Para 3.1.7 is unique to vertical take-off and landing vehicles and are not applicable to this study.

3.1.8 Additional Requirements for V/STOL Aircraft - The requirements of these special type aircraft are, in most cases, identical to the requirements for other conventional and rotary wing aircraft. Where two different separate sets of flight controls exist, such as in a convertiplane, it may be possible to eliminate part of the duplication in one, or both, of the systems provided that control of the system normally used for landing is maintained in the event of engine failure.

3.1.8.1 Conversion Mechanisms - Conversion mechanisms, if required, shall be powered in such a way that conversion can be accomplished at any time, regardless of any system failure.

3.1.8.2 Automatic Flight Control System, Hovering Flight - The AFCS shall control the moment generating devices (reaction controls, thrust modulation controls, etc.) and possibly thrust to provide stability augmentation, attitude hold, altitude hold, control stick steering or other modes of operation as specified in the applicable system specification.

3.1.8.3 Transition - The transition from one set of controls to another set shall be smooth and shall not cause undesirable transients.

3.1.8.4 Interface of Powerplant and Flight Control Systems - Any powerplant controls that are used for direct flight path control or to provide vehicle damping shall be considered as an integral part of the primary FCS, and shall be designed to conform to the philosophical and hardware requirements for that system.

3.1.8.5 Available Control After Loss of a Powerplant on Multi-Powerplant VSTOL Aircraft - In case of a failure or loss of a powerplant, in any part of the flight envelope, sufficient control shall be available to continue safe flight and to land the aircraft.

Comment - Paragraph 3.1.8 is unique to VSTOL aircraft and therefore not applicable to this study.

Recommendation - Delete.

3.2 Design and Installation Requirements for All Classes of Flight Control Systems -

3.2.1 Strength - The overall strength of the flight control systems shall be in accordance with the applicable portions of MIL-A-8860. The components of the systems shall be designed in accordance with the strength requirements of the military specifications pertaining to those items, such as, MIL-A-8064 for electromechanical actuating systems, MIL-C-5503 for hydraulic cylinders, etc.

3.2.2 Rigidity - The rigidity of the flight control systems shall be sufficient to provide satisfactory operation and to enable the aircraft to meet its stability, control, and flutter requirements as defined in the applicable portions of MIL-F-8785 and MIL-A-8860. Individual components shall be sufficiently rigid to withstand normal handling and servicing and shall not become adversely deformed under operating loads or airframe structural deflections.

3.2.3 Vibration - Aerodynamically, aircraft engine, and equipment generated vibrations shall not degrade system performance. Component natural frequencies of vibration shall be such that generated vibrations will not compromise fatigue life guarantees nor result in detrimental or destructive resonances.

3.2.4 Fatigue - The fatigue life of the flight control systems shall be designed in accordance with MIL-A-8866 and shall be at least equal to the fatigue life of the basic airframe structure.

3.2.5 Friction and Free Play - Friction and free play in primary control systems shall be kept to a practicable minimum. In no case shall the friction and free play values exceed those given in MIL-F-8785 and flutter-free play of MIL-A-8870.

Comment - Requires further study, because even a DFBW system will need muscle for actuation and the mechanical components. Several military specification are called out, MIL-A-8860, MIL-A-8064, MIL-C-5503, MIL-F-8785, and MIL-A-8866 which have to be reviewed to see if they apply.

Recommendation - Review referenced specifications and incorporate applicable portions into DFBW specification.

3.2.6 Control System Routing - Within the limitations and requirements contained elsewhere in this specification, all portions of the control system, including cables, push-pull rods, fluid lines, and electrical wiring shall be routed through the airplane in the most direct manner. However, in aircraft subject to combat damage all portions of the flight control system shall be routed in a manner to maximize the survivability of the flight control system.

3.2.6.1 System Separation - Where duplicate cable, push rod or fluid systems are provided, these systems shall be separated as far as possible to obtain the maximum advantage of the dual system with regard to vulnerability from gunfire, engine fires, ice formation, jamming by foreign objects, etc.

3.2.6.2 Dual Path Components - In order to increase reliability, reduce vulnerability, and increase the survivability of the flight control system, the use of the dual path design philosophy shall be considered for the following components:

a. Support brackets
b. Fasteners
c. Torque tubes
d. Arms
e. Trim actuators
f. Surface actuators
g. Hinges
h. Horns

Comment - Applicable in part. Delete portions relative to MFCS.

Recommendation - Update and incorporate into DFBW criteria.

3.2.7 Clearance - Clearance between the flight control system and other flight controls, equipment, structure, etc. shall be a minimum of 1/2 inch. At least 1 inch clearance with equipment and structure subject to high temperatures or with equipment subject to expansion due to over pressurization shall be provided. In complex mechanisms such as mixer assemblies, gear ratio changes, etc., a minimum clearance of 1/16 inch is permissible, provided the installation, rigging, normal wear, normal deflection, and temperature expansion have no effect on mechanism operation.

Comment - General requirements for clearances is required. Specific clearances should not be specified.

Recommendation - Update and incorporate into DFBW criteria.

3.2.8 Accessibility - The flight control systems and components shall be designed for easy accessibility and servicing. Components shall be designed, installed, located and provided with access doors so that inspection, rigging, removal, repair, lubrication and testing can be readily accomplished without disassembly of the aircraft. Suitable provision shall be made for locating and holding each control system component at some point in its travel, such as the neutral or mid-point to facilitate correct rigging of the control system, and to permit removal of components, including the control surface, without disturbing the rigging. The need for non-standard tools to perform maintenance shall be avoided whenever possible.

3.2.8.1 Safety - Systems and components shall be designed to provide a maximum of safety to personnel during the course of installation, maintenance, pre-flight testing, and normal usage. Adequate precautionary warnings and information shall be affixed to components when considered essential and shall be supplied with installation or maintenance instructions or special test or maintenance equipment. Similar precautionary warnings and information shall be available in the systems or components operating instructions used for pre-flight testing. Satisfactory provisions shall be made to prevent personnel from being accidentally subjected to injurious voltages or current, temperatures, or motions of component parts.

3.2.8.2 Control Surface Maintenance Lock - Means shall be provided to lock the control surface in neutral upon removal of the surface actuator for maintenance to protect the surface, controls, structure, etc. from damage due to wind gusts. The lock shall fit in place of the removed actuator to give an obvious indication of actuator removal.

Comment - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.2.9 Maintenance Provisions - Systems and components shall be designed to provide for ready accessibility and for connection of such test equipment as may be required for field maintenance.

The following requirements shall be complied with where practicable:

a. Design of the test equipment shall include provisions for connection without disassembly of flight operational connectors.

b. Systems and packages shall be designed to group and locate test points in accessible positions.

c. Test equipment shall be designed to permit fault isolation to the defective LRU with no requirement for organizational level test equipment.

Comment - Calls for test equipment for field maintenance which is not consistent with a BIT philosophy.

Recommendation - Delete.

3.2.10 Foolproofness - All control systems shall be designed so that incorrect assembly and reversed operation of controls is impossible. Connection points, test points, direction of orientation, and other essential information shall be conspicuously labled to be read from the normal position of the assembly.

Comment - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.2.11 Fouling Prevention - All elements of the flight control system shall be suitably guided, protected, or covered in all compartments where it is possible for them to be fouled by foreign objects, cargo, changing of engines, etc. There shall be no recess around a cockpit control in which foreign objects can be trapped. Consideration shall be given to the protection of control elements subject to fouling due to ice formation.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.2.12 Drainage - Adequate provisions shall be made for drainage of control system components subject to the accumulation of moisture or other liquids.

Comment - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.2.13.1 System Pressure - Systems or components operating on pressure less than the full hydraulic system pressure shall be designed to withstand and operate under the full pressure, or shall have a relief valve installed downstream and in the vicinity of the pressure reducer if the full hydraulic system pressure would be detrimental or dangerous to the low-pressure elements.

3.2.13.2 Pilot Warning - Warning of hydraulic system failure shall be provided to the pilot in the form of a red or amber warning light or in another form as specified by the procuring activity.

3.2.13.3 Filters - Filters shall be installed immediately ahead of each control valve. Filtering requirements shall be determined through testing.

During the tests the control valve shall be subject to a specified duty cycle with maximum permissible contamination level.

3.2.13.4 Ground Checkout - The hydraulic systems shall be designed and installed in such a manner that ground checkout of all systems, including automatic control system, can be made by the use of a standard dual system hydraulic test stand without the necessity of reservicing the systems after completion of testing.

3.2.13.5 Hydraulic Power Transfer Units - Hydraulic power transfer units shall be designed so that any single failure will not cause loss of both driving and driven systems. There shall be no intermixing of hydraulic fluid between the two systems. Installation of hydraulic power transfer units shall be reliable, foolproof, and safe with respect to vibration, installation, and maintenance. All connections such as pipes, hoses, electrical wires and mounting brackets shall be designed to prevent a failure in one system from causing a complete failure of the second system. No single failure in the transfer unit shall cause depletion of an hydraulic supply. Hydraulic power transfer systems shall be designed to insure that the system supplying power is protected from failures that can result in extreme heat rejection, destructive pressure oscillations, damaging overspeed, or excessive power drains.

Comment - Requires further study of MIL-H-5440 to determine compatibility to DFBW systems.

Recommendation - Update and incorporate into DFBW specification.

3.2.14 Torque Transmission Systems -

3.2.14.1 Flexible Shafting - Flexible shafting may be used in secondary flight control systems for low torque installations provided limitations of minimum bend radius, rated rotational speed, and rated torque are not exceeded and a testing program shows that extreme temperature and other operational variations and environments do not adversely affect the performance and installation.

3.2.14.2 Torque Tube System - In the design of torque tube systems. consideration shall be given to airframe deflections, differences in expansion due to temperature, impact loadings due to actuators contacting stops, etc. When torque tubes are located where maintenance or crew personnel can use them for hand holds or steps, they shall be designed for a 150-pound handling (side) load unless they are equipped with guards.

3.2.14.2.1 Supports - All torque tubes shall be mounted on anti-friction bearints spaced at close enough intervals to prevent undesirable bending or whipping of the torque tubes.

3.2.14.3 Universal Joints - Universal joints or flexible couplings shall be installed as required to prevent binding of systems due to misalignment of the supports or aircraft structural deflections. Universal joints shall not be used for angularities greater than those recommended for the specific component by the manufacturer.

3.2.14.4 Linear Expansion Joints - Splined slip joints or other suitable means shall be used to absorb linear dimensional changes due to structural deflection. Adequate engagement shall be provided.

3.2.14.5 Warning Placards - When torque tubes are located where maintenance personnel or crew members can (or "are able to") use them for hand holds or steps, placards shall be installed warning against this practice.

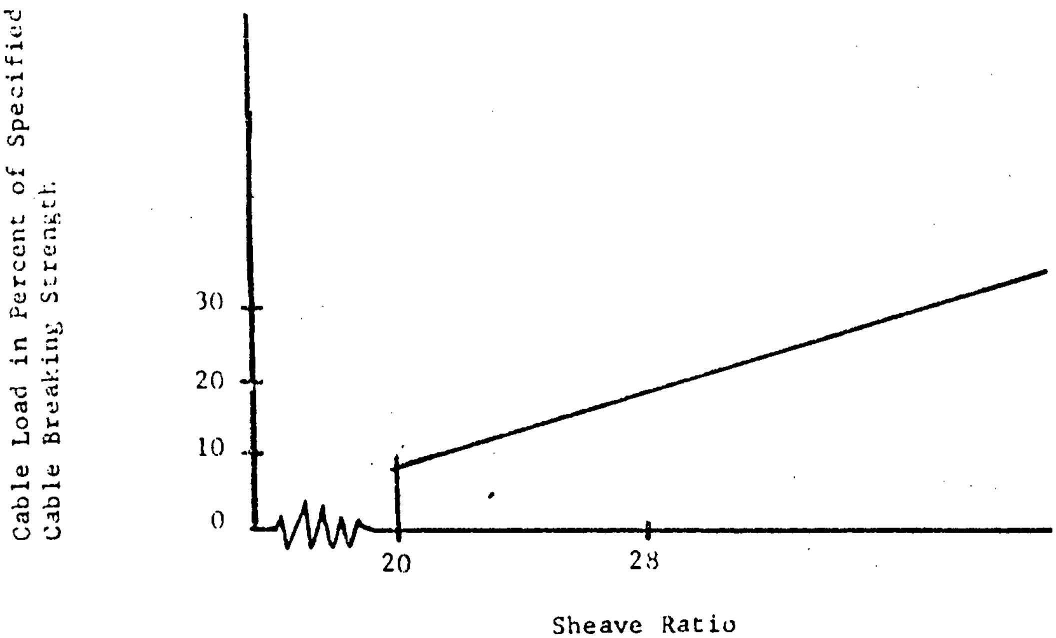
3.2.15 Cable Systems - Cable systems, in addition to meeting the other applicable requirements of this specification, shall meet the following additional requirements.

3.2.15.1 Clearance - Clearances of less than 1/2 inch are permitted between cables and basic airframe structure provided suitable fairleads are installed. Allowance shall be made for cable vibration in long spans. A minimum of 1/2-inch clearance shall be maintained in return cables when cable systems are loaded to design limit loads.

3.2.15.2 Fairleads - Fairleads shall be used wherever necessary to keep cables from chafing and slapping against each other and adjacent parts of the aircraft. Fairleads shall not cause any angular change in the direction of the cable. Where space permits, the fairleads should clear the primary flight control cables by a minimum of 1/4 inch. The cables may rest against the lower edge of the hole in fairleads on long cable runs where the cables would normally sag due to their own weight even though properly rigged.

3.2.15.3 Guards - Guards shall be installed at all sheaves (pulleys, sectors, drums, etc.) to prevent the cable from jumping out of the groove of the sheave. Guards shall be installed at the approximate point of tangency of the cable to the sheave. Where the cable wrap exceeds 90 degrees, one or more intermediate guards shall be installed. To prevent binding of the sheave due to relative deflections in the aircraft structure, all guards shall be supported by the supporting brackets of the part which they guard. Additional guards shall be installed on sectors at the point of entry of the cable into the groove from its attachment. The design of the rubbing edges of the guard and the selection of materials shall be such as to minimize cable wear and prevent jamming even when the cable is slack. Cantilever guards shall not be used unless the supporting structure provides adequate rigidity.

3.2.15.4 Cable Turn Radius - The ratio of sheave diameter to cable diameter shall not be less than the following values: (where the cable load is the maximum load expected in the cable under normal operating conditions)



Cables shall not be subjected to critical bends at the junction with cable terminals or other attaching points such as drums, horns, etc.

3.2.15.5 Cable Alignment - Cables shall not be misaligned with sheaves in excess of the following values: (The alignment of the cable with its sheave is defined as the angle between the cable and the plane of the pulley.)

a. Primary flight controls - Not over 1 deg, except where MS 20220, or MS 20221 pulleys are used, or where side travel of the cable exists, and then not over 2 deg.

b. All other controls - Not over 2 deg, except where MS 20219, MS 20220, or MS 20221 pulleys are used, or where side travel of the cable exists, and then not over 3 deg.

3.2.15.6 Attachments - Terminals, disconnect fittings, turnbuckles, etc. shall be provided as necessary to facilitate rigging and maintenance of the cable systems.

3.2.15.7 Location of Attachments - Cable disconnect shall be located and designed so that it is physically impossible to improperly connect in any manner, either cables in the same system or the cables of different systems. Cable disconnects and turnbuckles shall be so located that they will not hang up on adjacent structure or equipment or on each other and will not snag on cables, wires, or tubing.

3.2.15.8 Turnbuckles - Turnbuckle terminals shall not have more than three (3) threads exposed at either end. All turnbuckle assemblies shall be properly safetied in accordance with MS 33591.

3.2.15.9 Cable Tension - Cable tension regulators shall be provided, as required, to insure positive cable tension under all operating conditions. In the interest of reducing control system friction, initial tensions should be held to the lowest practical values that provide safe and satisfactory operation considering probable application of limit loads to the system and the effect of temperature variations.

3.2.15.9.1 Slack Absorbers - Springs, or other devices, used to take up slack in cables shall be designed and located such that the slack portion of the cable, the spring, and the spring attachment will not bind or hang up on adjacent structure, equipment, etc. If a guide (tube, etc.) is used, the spring and the cable attachment shall not protrude from the tube at full spring deflection.

3.2.15.10 Cable Size - Cable size shall be adequate to meet the load requirements of the system with ample safety factors to compensate for wear and deterioration where pulleys, fairleads, etc., are encountered. However, cable size shall also reflect permissible cable stretch, pulley friction values, and other variables which affect system performance. Maximum cable loads shall not exceed 75 percent of design ultimate cable breaking strength. Cables of 1/16 in. diameter may be used only upon approval of the procuring activity.

3.2.15.11 Sheave Spacing - Minimum spacing and positions of sheaves shall be as justified by engineering test data.

3.2.15.12 Cable Wrap - On sheaves where cable wrap varies with cable travel, the initial wrap with the sheave in the neutral position shall be at least 115 percent of the full cable travel in either direction. If overtravel exceeds the minimum required, cable wrap shall be increased a corresponding amount.

3.2.15.13 Overtravel - Overtravel allowance shall not be less than 5 percent of full travel in either direction.

3.2.16 Push-Pull Rod Systems - Push-pull rods shall be designed to permit easy servicing and rigging, and to accommodate tension and/or compression load requirements. Where rods are used on the power side of an actuator, they shall be designed for the appropriate fatigue requirements.

3.2.16.1 Supports - All push-pull rods shall be supported by levers, bell-cranks, or roller guides to preclude rod buckling and to prevent fouling in the event of rod failure.

3.2.16.2 Flexible Push-Pull Control Systems - Flexible push-pull controls shall not be used in primary flight control systems. Approved types of flexible push-pull controls may be used elsewhere.

3.2.17 Control Chain - Each application of chains shall require approval by the procuring activity.

Comment - Para. 3.2.14-3.2.17 apply to MFCS and therefore are not applicable to this study.

Recommendation - Delete.

3.2.18 Electrical and Electronic Systems - Electrical installations as required for the electrical components of the flight control systems shall be designed and installed in accordance with the provisions of MIL-W-5088,

MIL-E-5400, MIL-E-7080, MIL-E-25499, MIL-STD-704, and all other existing specifications for systems and components. Electrical systems that are especially critical for aircraft flight control or in which safety of flight is jeopardized if malfunctions occur shall incorporate built-in limiting devices, emergency disconnects, alternate systems, and other safety measures as required to assure safe operation. Electrical systems used in primary flight control systems shall have no interconnection with any other system, except at the power source. Great care shall be exercised to prevent propagation of failures among primary flight control axis through a common or biased power source. Interconnection of power sources and protective methods shall be as defined by the contractor and approved by the procuring agency. Radio interference created by the electrical systems or components shall be within the limits indicated by MIL-E-6181. The FCS shall meet the EMI requirements of MIL-STD-461. Dual or redundant electrical and electronic systems shall have maximum separation and shall in no case feed into the same connector.

Comment - Requires a review of the reference specifications. In addition, a determination of these requirements relative to MIL-E-5400 should also be made.

Recommendation - Review referenced specifications and incorporate applicable requirements in DFBW specification.

3.2.18.1 Overload Protection - Overload protection of the primary power wiring to the system or component shall be provided to protect against an excessive surge of current. Additional protection as necessary shall be provided within the system or component. Such circuit protection shall not be provided in signal circuits where the opening of the protective device will result in the application of an unsafe control motion to the aircraft. Protection against lightning strikes shall be provided.

Comment - The first two sentences are straight forward, asking for protection against a current surge. The third sentence, "Such circuit protection shall not be provided .... where the opening of the protective device will result in ... an unsafe control motion ..." It raises the question of why the circuit design was allowed, because an open wire will result in the same condition. Therefore, it is not suitable for military aircraft.

Recommendation - Update and incorporate into DFBW specification.

3.2.18.2 Electrical Power Supply - Flight control system electrical components shall operate satisfactorily in accordance with the performance requirements specified herein when supplied from power sources conforming to the applicable requirements of MIL-STD-704.

Comment - Power requirements for DFBW requires further study.

Recommendation - Perform an in-depth study of the power requirements for a DFBW FCS and incorporate results into DFBW specification.

3.2.18.2.1 Standby Limits - Reduced operational performance is permissible under standby conditions provided safety of flight is not compromised and no damage shall result to the equipment. The equipment shall resume normal operation automatically whenever the specified demand is required.

Comment - Not applicable.

Recommendation - Delete.

3.2.19 Calibration Adjustments, Controls and Knobs -

3.2.19.1 Controls and Knobs - Controls and knobs requiring manipulation in flight shall operate smoothly with negligible backlash or binding. Means shall be provided to prevent movement due to shock or vibration encountered in service. Controls and knobs shall be readily accessible and of a size and shape for convenience and ease of operation under all service conditions. The direction of motion of the knob or control and its location within the cockpit shall be in accordance with the requirements of MIL-STD-203.

Comment - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.2.19.2 Calibration Adjustments - Calibration adjustments required shall be kept to a minimum, and at as few locations as possible. Suitable means shall be provided to insure that only intentional and normal changes in adjustment occur in service.

Comment - Calibration adjustments of a sophisticated digital DFBW system by the ground crew or flight crew is an unnecessary and an unwanted design.

Recommendation - Incorporate a requirement into the DFBW specification which does not allow calibration adjustments.

3.2.20 Dynamic and Static Pressure Systems and Air Data Systems - Whenever flight control system components require connection to pitot tubes or static ports, the required performance shall be obtainable from pitot tube and static port installations conforming to the requirements of MIL-I-6115. Compensation of static or dynamic signals, which may be required to obtain desired performance, shall be accomplished within the system or components.

Comment - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.2.21 Integrated Actuator Packages (IAP) - The fail-safe design philosophy for IAP shall be based on the type of control surface being actuated. When segmented surfaces are employed a non-redundant IAP may be satisfactory. When a one-piece slab surface is actuated, redundant power supplies and internal switching for emergency operation are required. If a non-redundant motor pump is employed in the IAP, consideration shall be given to the possibility of switching to hydraulic power from another source in the event of failure of the motor pump. Provision shall be made for failure detection and, on the ground checkout, for determining the quality of performance and isolating faults.

Comment - Applicable.

Recommendation - Incorporate into DFBW specification.

3.2.22 Auxiliary Power Supplies - Where redundant primary power sources are available, no failure of the auxiliary power supply shall degrade the performance of more than one primary power source. Auxiliary power supplies used to insure the capability of operation after a second failure shall have a power rating and a demonstrated degree of reliability equivalent to the primary system. Auxiliary power supplies used to insure fail-safe capability after a third failure shall have a demonstrated degree of reliability equivalent to the primary system, but may have a reduced power rating.

3.2.22.1 Hydraulic Power Transfer Units Integral to Auxiliary Power Supplies - Hydraulic power transfer units integral to the auxiliary power supply shall meet the requirements of paragraph 3.2.13.5.

3.2.22.2 Auxiliary Power Supplies for Emergency Use - On special approval of the procuring activity, an auxiliary power supply may be used to provide emergency power to a Type II, Type III, or Type IV FCS. In such an event, the operating characteristics of the unit must be such that control power to meet the emergency requirements of MIL-F-3785 is provided continuously without overheating of the auxiliary power supply.

3.2.22.3 Auxiliary Power Supplies for Ground Checkout - Auxiliary power supplies that are used for ground checkout shall be isolated from the control system's primary power sources, whenever the primary power sources are in use.

Comment - Applicable.

Recommendation - Incorporate into DFBW specification.

3.2.23 Stability Augmenting Devices - Devices installed for the purpose of augmenting stability shall not cause discontinuity of the primary FCS in the event of failure of such devices. The system shall be designed so that, under normal operating conditions, there is no adverse reflection of force or motion at the pilot's primary controls.

3.2.24 Other Devices - Other devices such as spring bungees, tension regulators, bobweights, dampers, etc., shall be so designed that their failure will not cause discontinuity of control. Positive locks or safety wire shall be provided at all attachments where there is a possibility that the components in the spring cartridges, dampers, etc., might become detached as a result of inadvertent rotation of the components.

3.2.25 Differential Mechanisms - A control system in which a differential motion is obtained shall incorporate stops to prevent mechanisms from reaching a locking or reversing position unless that geometry is specifically required for the proper operation of the system.

3.2.26 Modular Component Interfaces - In FCS's configured to accept modular components, the mechanical, electrical, and hydraulic connections shall be of an approved positive locking type, preferably quick disconnects. All modular systems shall be capable of independent rigging, calibration or other necessary adjustments so that the aircraft system modules may be reassembled without subsequent adjustments.

3.3 Component Design Requirements for all Classes of Flight Control Systems

3.3.1 General - The design of components shall conform to government specifications if specifications exist for that particular component. If component specifications do not exist, all pertinent general government specifications regarding materials, workmanship, processes, etc., shall be adhered to where possible. AN, NAF, NAS, and MS or previously approved components shall be used where possible and when suitable for the purpose. Components shall be designed to meet the reliability requirements of the components specifications as determined by the system reliability requirements specified in 3.1.

3.3.2 Bearings

3.3.2.1 Antifriction - Ball bearings in accordance with MIL-B-6038, MIL-B-6039, and MIL-N-7949 shall be used throughout the flight control system, except as indicated in the following paragraphs. In the event design limitations do not permit the use of ball bearings, pre-lubricated, shielded roller or needle bearings may be used in accordance with MIL-B-3990 and FF-B-185. Where needle or roller bearings are used, provisions shall be made for relubrication. The inner race of the bearing shall be clamped to prevent rotation of the inner race with respect to the pivot bolt. Bearing installation shall be such that failure of the rollers or balls will not result in a complete separation of the control. Axial application of forces to a bearing shall be avoided; however, in the event such an arrangement is necessary, a fail-safe feature shall be provided.

3.3.2.2 Spherical Bearings - Where design limitations preclude the use of antifriction bearings, spherical type, plain bearings in accordance with MIL-B-81820 or as approved by the procuring activity may be used. Spherical bearings shall have adequate provisions for lubrication. Teflon (TFE) lined bearings may be used without provision for lubrication where approved by the procuring activity.

3.3.2.3 Journal Bearings - The use of plain type journal bearings shall be limited to applications where play and friction are not major considerations. Journal or plain bearings designed in accordance with MIL-B-8976 and MIL-B-5629 may be used, provided there are adequate and accessible provisions for lubrication. TFE lined bearings conforming to MIL-B-8943 may be used without lubrication when approved by the procuring activity.

3.3.2.4 Sintered Bearings - Sintered type or oil impregnated bearings shall not be used in slow moving or oscillating application. Fast moving, rotating applications such as in qualified motors and actuators are permissible, in which case the bearings shall conform to MIL-B-5687.

3.3.3 Cable Assemblies - Cables shall be in accordance with MIL-C-5424 or MIL-C-5693. The use of corrosion-resistant cable is preferred. Nonmagnetic, corrosion-resistant cable shall conform to MIL-C-18375. Cable assemblies using swaged type terminals shall be proof load tested in accordance with MIL-C-5688. Plain carbon steel cable in accordance with MIL-W-1511 and nylon coated cables may be used upon approval of the procuring activity.

3.3.3.1 Cable Terminals - Standard cable fittings in accordance with MIL-T-6117 and MIL-S-5676 shall be used.

3.3.3.2 Cable Tension Regulators - Tension regulators shall be of a size which will insure that the cable system being regulated will remain at the proper tension at all times. Lock wire provisions for the adjusting mechanism shall be provided. The design shall be as simple as possible to accomplish the desired result and shall permit easy adjustment of the cable tension. Integral calibration shall be provided to show proper cable tension without the use of external tension meters or other equipment.

3.3.4 Turnbuckles - Turnbuckles used in flight control cable systems shall be in accordance with MIL-T-8878.

3.3.5 Pulleys - Standard pulleys in accordance with MIL-P-7034 shall be used.

3.3.6 Fairleads and Rubbing Strips - Fairleads shall be split to permit cable removal or have holes large enough to permit the cable with terminals or attached end fittings to be threaded through. Fairleads shall be made of non-abrasive, non-hygroscopic materials and the rubbing edges shall be designed to minimize cable wear and prevent cable binding. Rubbing strips shall meet the same requirements as fairleads.

3.3.7 Push-Pull Rod Assemblies - Push-pull rod assemblies shall be designed and installed such that inadvertant detachment of adjustable terminals is impossible.

Adjustment shall be possible at one end only for any single tube unless dual end adjustment is absolutely necessary; in which case each application shall require approval by the procuring activity. Where one adjustable rod end is made fixed as a means of preventing the rod from becoming detached, rivets or bolts through the threaded shank shall not be used with threaded ends less than 7/16 in. diameter. Male shank type rod end bearings are preferred over female types.

3.3.7.1 Dual End Adjustable Terminals - Where dual end adjustment is authorized, the rod shall be designed so that either terminal will bottom on the tube with tube rotation prior to the opposite end terminal becoming detached. Both terminals shall be wired with a locking device and safetied.

3.3.7.2 Rod End Locking Devices - Terminals and rod ends shall be locked by NAS 559 or NAS 1193 rod end locking devices and properly safetied. Each application of NAS 513 rod end locking device shall require specific approval of the procuring activity.

3.3.8 Tubes - Torque and push-pull tubes shall have a minimum wall thickness of 0.035 inches and shall be seamless, except that steel tubes seam-welded by the electrical resistance method may be used.

3.3.9 Universal Joints and Flexible Couplings - Universal joints and flexible couplings shall be in accordance with MIL-J-6193 and MIL-U-3963. Other flexible couplings may be used following approval of the procuring activity and determination by the contractor that they are adequate from static, dynamic, impact, and fatigue considerations.

Comment - Many paragraphs refer to MFCS.

Recommendation - Incorporate applicable portions into DFBW criteria.

3.3.10 Actuating Cylinders - Hydraulic cylinders used for actuating flight control surfaces or systems shall be designed and tested in accordance with MIL-C-5503.

3.3.10.1 Environmental Conditions - During the life cycling, the ambient temperature conditions and the hydraulic fluid shall be as expected to exist in the aircraft. In addition to the test requirements specified in MIL-C-5503, at least salt spray, and vibration tests as specified in 4.1.3.6.9 and 4.1.3.6.11, respectively, shall be accomplished.

3.3.10.2 Design Details - If bypass provisions are necessary, they shall be provided integrally in the cylinder and valve assembly. In Type III and Type IV FCS's, bypass mechanisms shall operate from the system pressure and shall be automatic in opening and closing as hydraulic pressure drops or increases. Type II FCS's may use by-pass systems that are manually actuated. Where dual cylinders are required, they may be designed as tandem cylinders, in one barrel, provided there is no interconnection between the two which will permit interflow and permit one failure to jeopardize both systems. Retaining rings shall not be used in assembling the cylinders, but rather, all end caps, etc., shall be secured by threading to the barrel or other components and be lock wired. Cylinder rod ends shall be appropriately fastened to the piston rod and suitably safetied to prevent relative rotation.

3.3.10.3 Surface Control Actuators - In the case of surface control actuators which are essential to the flight of the aircraft, the actuators shall be dualized to provide control surface operation in the event of a single hydraulic system failure. Where dual actuators are used, the control valves shall also be dualized to maintain maximum reliability. Dual tandem hydraulic actuators shall incorporate the "rip stop" design feature to prevent a rupture in one barrel from propagating to the adjacent barrel. The valve housing shall also incorporate the "rip stop" design feature. In aircraft subject to combat damage the hydraulic pressure and return port pair to one actuator section shall be as widely separated as possible from the pressure and return port pair of the other actuator section. Ports and lines shall be designed to prevent incorrect assembly and reversed operation.

3.3.11 Hydraulic Power Control Valves - Specification MIL-V-7915 shall be used as a general guide for the design and testing of the mechanical input power control valve. These valves shall be designed to give smooth operation with flow rate vs. spool displacement, in accordance with system performance requirements. Internal leakage shall be a practicable minimum, consistent with permissible operating forces, extreme temperature effects, control sensitivity, and other governing factors. The control valves shall be connected or attached to the actuating cylinders during the endurance, extreme temperatures, vibration, and salt spray tests.

3.3.12 Electro-Hydraulic Power Control Valves - Electro-hydraulic power control valves shall be designed to give hydraulic flow rates or pressures proportional to the energizing current flow. Use of a current level high enough to eliminate a second stage in the control valve shall be considered when feasible. Small orifices and magnetic fields around orifices shall be avoided, if possible, and orifices shall be protected by filters with a pore size small enough to positively prevent orifice clogging, and with sufficient surface area to provide adequate filter life. Valve design and design of the electrical circuitry to the valve should be such that current required to initiate flow in either direction shall be a small proportion of the current applied to the valve in a maneuver. With no current applied, the valve shall remain at or near neutral under all expected conditions of hydraulic pressure, temperature, vibration, shocks, and normal degradation through use. Internal hydraulic leakage rates shall be small in comparison to flow rates which the valve can generate in a maneuver situation. Hydraulic portions of the valve shall conform to MIL-H-5440 and the electrical portions with the pertinent specifications in accordance with 3.3 of this specification. Complete environmental and life testing are required for these components, including operation for a specified time, using a fluid contamination level which may be expected in a combat maintenance environment.

3.3.13 Electromechanical Actuators and Electric Motors - Electromechanical actuators and actuating systems shall be designed in accordance with MIL-A-8064. Electric motors shall be in accordance with MIL-M-8609 and MIL-M-7969.

Comments - Para 3.3.10-3.3.13 are applicable.

Recommendation - Update and incorporate into DFBW specification.

3.3.14 Flexible Controls - Approved anti-friction, flexible push-pull controls in accordance with the applicable portions of MIL-C-7958, may be used in secondary flight control systems.

3.3.14.1 Design and Installation Requirements - Efficiency, misalignment, supports, and minimum bend radius shall conform to the requirements recommended for the specific component by the manufacturer. Scheduled servicing and lubrication shall not be required. Adjustments that are critical to the operation or performance of the assembly shall incorporate means for protective locking. Flexible control assemblies shall have unlimited shelf life and shall provide immediate service without operational conditioning or maintenance. The minimum service life shall be 25,000 operating cycles.

3.3.15 Retaining Rings - Standard retaining rings may be used in locations where they are not subjected to heavy loads and where their loss would in no way compromise control of the aircraft. Each installation utilizing retaining rings must be approved by the procuring activity. Utilization of nonstandard retaining rings is subject to the approval of the procuring activity.

Comments - Paragraphs 3.3.14-3.3.15 are not applicable to DFBW.

Recommendation - Delete.

3.3.16 Electrical and Electronic Components - All electrical equipment in the control systems shall be designed and installed in accordance with MIL-E-5400, MIL-E-7080, MIL-W-5088, MIL-A-8064, MIL-M-8609, MIL-M-7969, and any other applicable specifications. Critical components shall have the best possible reliability to insure against loss of control of the aircraft. Specific consideration shall be directed toward achieving simplicity, producibility, and maintainability of equipment. Electronic parts shall be selected after establishing a reliability prediction model based on past experience for each component. This model shall include consideration of derating, temperature, voltage and current variations, place of usage (aircraft or ground based) and manufacturing quality control process.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.3.16.1 Electrical Tape - No pressure-sensitive (adhesive or friction) fabric or textile tape shall be used. Nonmoisture absorbing tape may be used for mechanical purposes, with the approval of the procuring activity.

Comments - Applicable.

Recommendation - Incorporate into DFBW specification.

3.3.16.2.1 Toggle Switches - Toggle switches shall conform to the requirements of MIL-S-3950. The operating position requirements of MIL-E-5400 shall normally apply.

3.3.16.2.2 Sensitive Switches - Sensitive switches shall comply with the requirements of MIL-S-8805.

3.3.16.2.3 Pushbutton Switches - The use of pushbutton switches will require approval of the procuring activity.

3.3.16.2.4 Special Switches - The design of manually actuated special switches shall be subject to the approval of the procuring activity. All applications of special design switches shall comply with the performance and environmental requirements of this and the detail specifications.

Comments - Applicable.

Recommendation - Review MIL-S-3950, MIL-S-8805 and MIL-E-5400 and incorporate into DFBW specification.

3.3.16.3 Semiconductors - Semiconductors selected for use in flight control systems and components shall exhibit no transient or permanent change in operational rating which may affect the performance of the system or component when the system or component is subjected to the extremes of environmental and operating conditions specified herein and in detailed system and component specifications. Such operational ratings shall be considered as those characteristics pertinent to the system or component performance.

Comments - Requirements for semiconductors are covered in other related avionic specifications.

Recommendation - Delete.

3.3.16.4 Connectors - Since connectors and receptacles represent a high percentage of electronic equipment failures, special emphasis shall be given to proper selection and application of those devices and their number should be kept to a minimum. Dual or redundant systems shall not feed into the same connector.

Comments - Applicable. The statement, "Since connectors .... represent a high percentage of ... failures ... their number should be kept to a minimum" is appropriate to DFBW systems.

Recommendation - Incorporate into DFBW specification.

3.3.17 Fastenings - In general, fasteners shall be in accordance with applicable military standards and the airplane detail specification. In applications for which no suitable standard part is available on the date of invitation for bids, commercial parts may be used provided they conform to all of the requirements of this and the detail specification. Ability to inspect installed fasteners to insure integrity and security shall be assured.

3.3.17.1 Bolt Retention - Self-locking nuts, cotter pins, safety wire, or some equivalent positive means of bolt retention, shall be used throughout the flight control systems.

3.3.17.2 Self-Locking Nuts - Self-locking nuts shall not be used for critical applications such as attachment of rod ends to bellcranks, attachment of pulleys or quadrants to brackets, and attachment of trim actuators to structure, where a single attaching bolt is used to retain the component or connect the system. Self-locking nuts shall be in accordance with MIL-N-25027 and MS 33588. Self-locking nuts shall not be used with self-retaining bolts.

3.3.17.3 Spring Pins/Roll Pins - The use of friction-retained pins without auxiliary means of retention is prohibited. Entrapment by a component qualifies as an auxiliary means of retention only when specifically approved by the procuring activity.

3.3.17.4 Bolts - Bolts smaller than 1/4 inch shall not be used to make single bolt connections, or connections which are essential to the proper functioning of the systems. They may be used in attaching brackets to airframes, etc., when several of the bolts are used in a single application.

3.3.17.4.1 Self-Retaining Bolts - Self-retaining bolts shall be used in accordance with the airplane detail specification requirements and

MIL-STD-1515 where omission of a cotter pin and/or nut would jeopardize safe flight. Any deviations must be approved by the procuring activity.

3.3.17.5 Lockwiring - All hardware and components which are not positively secured by other means, shall be secured by lockwire or cotter pins in accordance with MS 33540 and MS 33591.

Comments - Applicable.

Recommendation - Incorporate into DFBW specification.

3.3.18 Control Stick Grips - Unless otherwise specified pilots control stick grips shall be in accordance with MIL-G-25561.

Comments - Review MIL-G-25561 to see if applicable.

Recommendation - Update and incorporate into DFBW specification.

3.3.19 Control Wheels - Unless otherwise specified, control wheels shall be of the W type, 14 to 16 inches in diameter. They shall be constructed of a lightweight, nonhygroscopic, nonslippery, nonsticky black material with a low heat conductivity. The forward face of the portions gripped by the hand shall have corrugations to fit the fingers and provide a good finger-type grip surface.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.3.20 Control Surface and Control Stick Dampers - Such devices shall be completely defined by a detail specification in accordance with the requirements of each specific application. Such dampers will generally be either hydraulic or electro-mechanical and will conform to applicable specifications for these types of equipment. Dampers shall be designed so that they can be overpowered by the pilot in the event of failure or malfunction and shall have very low breakout friction and inertia forces. Hydraulic dampers shall be equipped with a visual indication of their fluid level, and provisions shall be made for refilling hydraulic dampers without removing them from the aircraft.

3.3.20.1 Additional Requirements for Control Surface Dampers - Damper endurance requirements shall be established from maximum stroke at maximum rate values. Damper damping requirements shall be defined at the anticipated flutter frequency and shall be compatible with the flutter requirements of MIL-F-8870.

Comments - Control surface damping should be incorporated in the actuation system criteria. If required, the stick dampers should be incorporated in the artificial feel system requirements.

Recommendation - Update and incorporate as required into DFBW criteria.

3.3.21 Stability Augmentation System Servo Actuators - Servo actuators for stability augmentation systems, either electro-mechanical or hydraulic, shall be designed and tested in accordance with the specifications covering that general type of equipment except that the life cycling shall be increased to at least 5 million cycles, or to a value as determined by analysis, at the anticipated frequencies, amplitudes, and loads of the actual system. Environmental conditions during life cycling shall be those expected in the aircraft installation. Servicing or minor repair of the servo will be permitted after one half of the determined number of cycles have been completed. All other mechanical components of the stability augmentation system shall be cycled together with the servo actuator, to demonstrate their integrity. Consideration shall be given to providing built-in test capability.

Comments - This requirement is not applicable to a DFBW criteria. A specific SAS actuator does not exist in a FBW system.

Recommendation - Delete.

3.3.22 Integrated Actuator Packages - Integrated actuator packages (IAP) shall be **inherently** self-monitoring and shall operate at specified performance after a specified number of failures. Provisions shall be provided in the aircraft to indicate that each IAP is operating normally prior to take-off. The redundancy of power supply paths to each IAP shall be as specified by the procuring activity. The following factors shall be considered in the design and construction of IAP's:

a. Stiffness
b. Required response rate
c. Required hinge moment capability
d. Environment
e. Required operational life
f. Specified fail-safe design philosophy
g. Specified MTBF requirements
h. Vulnerability and survivability considerations
i. Simplicity of removal and replacement
j. Heat dissipation

Comments - Applicable, but why isn't this paragraph combined with 3.2.2.1?

Recommendation - Update and incorporate into DFBW specification.

3.3.23 Lubrication - Where applicable, lubrication of the components and systems shall be in accordance with MIL-STD-838. Lubrication fittings shall be in accordance with MIL-F-3541, MS 15001, and MS 15002-1 and -2.

Comments - Not applicable to DFBW systems.

Recommendation - Requirement should be added to DFBW specification to prohibit the use of lubrication of DFBW systems.

3.3.24 Materials - The materials utilized in the components and systems shall be entirely suitable for the service and purpose intended. When Government specifications exist for the type material being used, the materials shall conform to these specifications. Nonspecification materials may be used if it is shown that they are more suitable for the purpose than specification materials.

3.3.24.1 Shielding and Bonding on Finished Surfaces - Nonconductive oxides or other nonconductive finishes shall be removed from the actual contact area of all surfaces required to act as a path for electric current and from local areas to provide continuity of electrical shielding and bonding. All mating surfaces shall be clean and shall be carefully fitted to minimize radio frequency impedance at joints, seams and mating surfaces. The resultant exposed areas, after assembly at such joints or spots, shall be kept to a minimum.

To prevent "welding" damage due to lightning strikes, provision shall be made to eliminate the possibility of inadequate natural grounding whenever using heavy anodic treatment or plastic lined oliver bearings in actuators.

Comments - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.3.25 Control Devices and Attachments - Control devices and attaching means shall be structurally designed in accordance with MIL-A-8861. The rigidity of the surfaces and attachments shall be adequate to eliminate flutter or other undesired effects. If the surfaces are not balanced to prevent flutter in the event the surface actuator becomes disconnected, extra precautions, such as dual actuating rods, shall be taken to insure that the surface will not become disconnected from the actuators. Bearings, hinges, rod ends, etc., used in attachments shall be in accordance with the requirements of 3.3.2.

Comments - Requirement is applicable.

Recommendation - Update and incorporate into DFBW criteria.

3.3.26 Pressurized or Sealed Equipment - Whenever pressurization or hermetic sealing is utilized to meet the requirements of this specification, and the design is such that the case must be opened for maintenance, the following provisions shall be met.

3.3.26.1 Case - The case shall be of a type that will permit opening and clearing for access to the equipment for repair and maintenance. The operation and performance of the equipment should be unaffected by replacement and resealing in the case. The case shall be capable of withstanding any atmospheric pressure and temperature change developed under the required external operating conditions.

3.3.26.2 Inspection - When possible and advantageous, external means shall be provided for observing performance or operationally checking the equipment without removal from the case.

3.3.26.3 Filling Medium - Whenever the filling medium is a gas, it shall be noncombustible, of at least 98 percent purity, free of dust particles, and containing not more than 0.006 mg. of water per litre. The filling medium shall be 100 percent helium or a mixture of 88 to 92 percent nitrogen with the remainder helium. Whenever practicable, 100 percent helium shall be used. The absolute pressure of the filling medium shall be between one half and one atmosphere.

3.3.26.4 Filling Tube - A filling tube of a malleable type metal shall be provided which shall be capable of being formed into a recess in the case so as to be flush with the surface.

Comments - The requirement is obsolete.

Recommendation - Rewrite the requirement for DFBW specification to prohibit pressurized or sealed equipment.

3.3.27 Control Panels - Unless otherwise defined in the detail system or component specification, engaging, transfer, selector and maneuvering switches and controls not designed for installation on the aircraft's control column nor to fulfill other special installation requirements, shall be designed to comply with the applicable requirements of MIL-C-6781.

3.3.27.1 Dial Markings - The style and proportion of numerals and letters used on dials shall conform to Standard MS 33558. Such markings shall be visible from any point within the frustrum of a cone, the side of which makes an angle of 30 degrees with the perpendicular to the dial and the small diameter of which is the dial aperture.

3.3.27.2 Fluorescent-Luminescent Material - All markings requiring fluorescent-luminescent materials shall conform to MIL-L-25142, type I or III as applicable.

Comments - Requires review of MIL-C-6781, MS 33558 and MIL-L-25142 to see if applicable.

Recommendation - Review referenced MIL-Specs and incorporate applicable requirements into DFBW specification.

3.3.28 Identification of Product - Equipment components, assemblies and parts of flight control systems shall be identified in accordance with Standard MIL-STD-130.

Comment - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.3.29 Interchangeability - Electrical, physical, functional and performance interchangeability shall exist between like assemblies, subassemblies, and replaceable parts regardless of manufacturer or supplier in accordance with MIL-I-8500. Substitution of such like assemblies, subassemblies and replaceable parts shall be readily effected without physical or electrical modifications or adjustment to any part of the system or component assemblies and without resorting to selection. Provisions shall be made for design tolerances sufficient to accommodate various sizes and characteristics of any one type of article such as tubes, resistors, valves and other components having the limiting dimensions and characteristics set forth in the specifications for the particular component involved, without departure from the specified performance.

Comment - Applicable.

Recommendation - Update and incorporate into DFBW specification.

3.3.30 Cooling - The design and location of each component shall be consistent with the maximum permissible operating temperatures expected under all conditions of service as defined by the requirements of this and other applicable specifications.

3.3.30.1 Components Located in High Ambient Temperatures - Components which, when installed in aircraft, can reasonably be expected to be subjected to high ambient temperatures during ground or flight operation of the aircraft, shall be so designed that such temperatures shall result in no damage or impairment of performance of the component. Forced cooling, air blast cooling, or other similar cooling aids shall not be considered in the design without prior approval of the procuring activity. Such approval shall be predicated upon the feasibility of a considerable size and weight reduction and assurance that adequate cooling provisions shall be provided at the anticipated aircraft installation location.

3.3.32 Standardization - Equipment approved for use in other aircraft, in which the equipment has not exhibited unacceptable performance, shall be utilized to the greatest extent possible in accordance with MIL-STD-680. Use of such equipment shall not result in unacceptable compromise of performance, reliability, availability, and system cost.

Comment - Requires review of MIL-STD-680 to determine applicability.

Recommendation - Review MIL-Spec and incorporate applicable requirements into DFBW specification.

3.3.33 Workmanship - Workmanship shall be of sufficiently high grade throughout to insure proper operation and service life of the systems and components. The quality of the items being produced shall be uniformly high and shall not depreciate from the quality of qualification test items.

Comment - Applicable.

Recommendation - Incorporate into DFBW specification.

3.3.30.2 Heat Dissipation - Components, which under operation, dissipate heat shall be operable over the temperature range encountered in service. The following design techniques shall be employed, in order of performance as listed, to maintain heat rise within operable limits:

a. Use of thermal characteristics of finishes, induced draft and ventilation by means of baffles, internal vents and louvers and packaging in heat dissipating fluids.

b. Air vents with adequate protection against climatic and environmental service conditions to all exposed parts.

c. Forced cooling, if above means are still insufficient, or if a significant reduction in overall size or weight can be realized. Fans or blowers employed shall operate from the aircraft's a.c. power supply.

d. If heat dissipation requirements are such that the use of heat exchangers, liquid, air blast or evaporative coolants must be resorted to, or must be provided in the aircraft installation, prior approval of the procuring activity shall be required. Such approval shall be predicated upon availability of required provision at the anticipated aircraft installation location.

Comment - An important requirement normally overlooked which effects maintenance and the working conditions in a hanger.

Recommendation - Update and incorporate into DFBW specification.

3.3.31 Orientation - Normal installation position or range of positions shall be as specified in the equipment specification. However, partial or complete inversion of the equipment, as encountered during flight, with the equipment either nonoperative, in standby operation, or in full operation shall result in no permanent detrimental effect on the equipment's performance.

Comment - Applicable.

Recommendation - Incorporate into DFBW specification.

4. QUALITY ASSURANCE PROVISIONS

4.1 Test Requirements - Appropriate testing, as outlined herein, shall be conducted throughout the development and production of FCS's in order to insure proper design and performance and also continuing quality throughout production. The specific tests required shall be specified in the detailed specifications for the components and systems. If the tests required by the detailed specifications are inadequate, the contractor shall propose amendements to the contract to include tests which will provide adequate proof. If applicable previous tests are available, the contractor shall, in lieu of repeating tests, propose amendments to the contract for submittal of these data, supplemented by sufficient information to substantiate their applicability. The timing and sequence of the tests shall be as defined by the contractor and approved by the procuring activity.

Comment - It is an exact duplication of paragraph 4.1 of MIL-C-18244A and the same comments applies. Only the first two sentences are meaningful.

Recommendation - Update and incorporate into DFBW specification.

4.1.1 Test Witnesses - Before conducting a required test, an authorized procurement activity representative shall be notified so that he or his representative may witness the test and certify results and observations contained in the test reports. When the procuring activity representative is notified, he shall be informed if the test is such that interpretation of the behavior of the test article is likely to require engineering knowledge and experience, in which case he will provide a qualified engineer who will witness the test and certify the results and observations during the test. An orientation briefing on specific test goals and procedures shall be given to the observer prior to the required tests.

Comment - Almost the same as MIL-C-18244 except this paragraph adds a last sentence, requiring a briefing of the tests for the observer, which is apropos. The requirement should delete any reference to "certify the results", which may imply approval of the test results. The observer is not an inspector or a monitor.

Recommendation - Update and incorporate into DFBW specification.

4.1.2 Developmental Tests - Developmental tests are those tests accomplished on a sample or samples to determine compliance with the requirements of research, development or test contract. For Types II, III, and IV flight control systems, a functional mockup or simulator shall be constructed and tests shall be conducted to insure that the operational and dynamic characteristics of the systems and components meet the requirements which have been established.

For feedback control systems, that materially affect the aircraft's response qualities or have flight safety implications, closed-loop tests shall be conducted using, to the maximum extent practicable, the actual aircraft and system components mounted in their flight configurations.

4.1.2.1 Functional Mockup and Simulator Testing - Prior to construction of a functional mockup or simulator, a report describing the proposed mockup or simulator shall be submitted to the procuring activity for approval. The functional mockup or simulator of the FCS shall be constructed using actual production components and electronic computing equipment to determine system performance. Pending availability of production components, prototype components or suitable laboratory models may be used. Prior to the conduct of tests, a report shall be submitted, for the approval of the procuring activity, outlining the test procedure. Prior to first flight, a report shall be submitted showing compliance with the approved test procedures. At the conclusion of the tests, a complete report of the tests shall be submitted. This report shall include a comparison of the test results with those obtained from a theoretical analysis of the system. Upon completion of the contractor's flight test program, a report covering the performance of the FCS and a comparison of the flight test results with the results of the theoretical and simulated analysis shall also be submitted. A sufficient quantity of such test data shall be collected to give reasonable assurance that the systems are suitable for the purpose intended. When the system is to include an AFCS, the complete physical characteristics of the primary FCS, such as, response times, inertia, damping, system stretch, rates, operating forces, etc., must be determined to permit AFCS design.

Preliminary testing of components or subassemblies may be required to assure reasonable success of the entire system design.

4.1.2.1.1 Types II, III, and IV Flight Control Systems Ground Testing - Tests shall be conducted to verify the operation and stability of the system under simulated flight and "on the ground" conditions. Where possible, these tests shall include closed-loop ground testing using the actual aircraft, with aerodynamic effects simulated by a general purpose computer. The computer will receive measured control surface positions from the aircraft andcompute the associated sensed quantities. These will be applied in lieu of the normal sensor outputs to the aircraft's flight control computer, which will complete the control loop by driving the relevant control actuators. The general purpose computer will compute the aircraft's response at various key flight conditions, so that the flight control stability and performance analysis can be verified. Compliance with residual oscillation requirements shall be demonstrated. In cases where structural flexure can appreciably affect closed-loop stability, evaluation of this property (structural flexure) shall also be accomplished - where possible, by closed-loop ground tests. All control elements in their flight configurations—sensors, computers, and actuators—with simulated loads as required to correct for the lack of surface aerodynamics,will be utilized to evaluate the effects of structural flexure. The closed-loop structural response tests will determine potential instabilities and limit angles over the pertinent frequency ranges of the bending modes.

4.1.2.1.1.1 Frequency Response Tests - Frequency response tests shall be performed, to ensure that the bandwidths of the FCS's are adequate to provide control of the aircraft in all flight regimes. The response at the control surfaces shall not lag the cockpit control inputs by more than the values specified in MIL-F-8785, at the maximum characteristic frequency in a given operating mode (short period mode or roll damping mode).

4.1.2.1.1.2 Stiffness Tests - Tests shall be performed to ensure that the actuating systems have adequate stiffness for the suppression of control surface flutter and to minimize static error under aerodynamic load.

4.1.2.1.1.3 Static Performance Tests - Tests shall be performed to ensure that the requirements for control surface resolution, accuracy, repeatability, and allowable hysteresis have been met.

4.1.2.1.2 Automatic Flight Control Systems - Simulator testing of the AFCS shall be performed in accordance with MIL-F-18244.

4.1.2.1.3 Ground Testing of Control Linkage Strength and Rigidity - Ground testing of FCS linkages shall be performed as specified in MIL-A-8867.

4.1.2.1.4 Failure Effects Analysis and Development of Emergency Procedures - The mockup of the FCS shall be used to determine the effects of single and multiple failures on performance, safety, mission completion reliability, and the devleopment of emergency procedures to counteract the effects of failures. The requirements for these studies, tests, and the reporting of results shall be determined by the contractor and approved by the procuring activity.

Comments - A good description of the required developmental and simulator tests. However, it has to be rewritten for DFBW systems to delete references to different types of control systems and the failure mode tests has to be expanded upon.

Recommendation - Update and incorporate into DFBW specification.

4.1.3 Design Approval Tests - Design approval tests are those tests accomplished on a sample or samples, representative of an article or system to be procured or delivered on a production contract or purchase order, to determine that the article meets specification requirements. These tests shall be conducted by the procuring activity or contractor at the location or locations as specified in the contract or purchase order.

4.1.3.1 Test Report - A report in accordance with 4.5.5 shall be submitted to the procuring activity for approval.

4.1.3.2 Sampling - Usually, three systems or components shall be made available to accomplish the preproduction tests. Allocation of, samples, and additional or different quantities required, shall be as specified in the contract or purchase order.

4.1.3.3 Service Condition Tests - Service condition tests shall consist of at least the following series of accelerated tests to determine reliability and performance under the various conditions which may be encountered in service usage. The service condition tests may be allocated among the three test systems or components. A suggested order of tests is as follows:

System or Component No. 1	System or Component No. 2	System or Component No. 3
a. Individual tests	a. Individual tests	a. Individual tests
b. Power supply stability	b. High temperature	b. Acceleration
c. Dielectric strength	c. Low temperature	c. Vibration
d. Radio interference	d. Altitude	d. Shock
e. Structural	e. Composite altitude-temperature	e. Explosion proof

System or Component No. 1 (Continued)	System or Component No. 2 (Continued)	System or Component No. 3 (Continued)
f. Sand and dust	f. Composite rain-ice	f. Humidity
g. Miscellaneous	g. Salt spray	
h. Fungus resistance		

4.1.3.3 Where more or less than three systems or components are allocated for preproduction tests, the breakdown of the tests shall be as specified in the contract or detailed specification.

4.1.3.4 Contractor Testing - With the consent or request of the contractor and at the discretion of the procuring activity, any service condition tests conducted by the contractor and witnessed by an authorized procurement activity representative prior to submission for preproduction approval may be acceptable as preproduction tests.

4.1.3.5 Test Tolerances - In conducting service condition tests, performance tolerances shall be as specified in the system or component specification.

4.1.3.6 Test Conditions - Appropriate environmental tests shall be conducted on all components which are subject to deterioration or malfunction due to any environmental condition. Where possible, and applicable, the environmental testing shall be in accordance with the requirements of MIL-E-5272. Modifications of the MIL-E-5272 test procedures should be submitted for approval by the procuring activity prior to actual usage.

4.1.3.6.1 Power Supply Variation - Each component shall be tested individually or assembled, or both, into a system in a manner as specified in the component or system specification. Rated electrical, hydraulics and other required power sources shall be applied and all calibration settings placed at maximum rated positions. After completion of the warm-up period, the power sources shall be varied and modulated, throughout their specified limits. The performance of the components shall be observed in the manner defined in the component or system specification. No steady state nor transient modulation changes in the power source, within permissible limits, shall cause a variation or modulation in the system's performance which may result in undesirable or unsatisfactory operation. With rated power applied, the system's switches, controls and components shall be operated as in actual service. Observation of the rated power source shall note no variation nor modulation of the power source beyond permissible operational limits when the system is operated against load conditions varying from no load to full load conditions.

4.1.3.6.2 Dielectric Strength - Each circuit of electrical and electronic components shall be subjected to a test equivalent to the application of a root mean square test voltage of three times the maximum (but not less than 500 v.) surge d.c. or maximum surge peak a.c. voltage to which the circuit will be subjected under service conditions. The test voltage shall be of commercial frequency and shall be applied between ungrounded terminals and ground, and between terminals insulated from each other, for a period of 1 minute. Test shall be accomplished at normal ground barometric pressure. No breakdown of insulation or air gap shall occur. Circuits containing capacitors or other similar electronic parts which may be subject to damage by application of above voltages shall be subjected to twice the surge peak operating voltage for the specified period. If the maximum peak operating voltage is greater than 700 v., the rms value of the test voltage shall be 1.5 times greater than the maximum peak operating voltage. Electrical and electronic components shall also be tested for resistance to air gap breakdown at the maximum altitude specified in the altitude test.

4.1.3.6.3 Radio Interference Limits - The flight control system and components, or both, shall be assembled and arranged in a manner as specified in the system or component specification,with interconnecting cables and supporting brackets representative of an actual installation. Provisions shall also be made for inverting all components with respect to the ground plane,or positioning in such a manner as to permit measurements from the bottom of all components. Measurement of radiated and conducted interference limits shall be made in accordance with MIL-I-6181 with the system switches, controls and components operated as in actual service. Measured values shall not exceed the limits specified in MIL-I-6181.

4.1.3.6.4 Electromagnetic Interference - The flight control systems and components shall be tested for susceptibility to electro-magnetic radiation from external sources in accordance with MIL-STD-461 and the detailed specification.

4.1.3.6.5 Sand and Dust - Each component, with simulated external connections attached, shall be subjected to sand and dust test in accordance with MIL-E-5272, procedure I. The component shall be subjected to individual tests before and after exposure. Any dust film or dust penetration shall not result in a deterioration of the performance of the component.

4.1.3.6.6 Structural Tests - In addition to the normal static structural tests, tests are required to insure that the requirements of 3.2.1 are met and that structural deformations of the control system do not impair the controllability of aircraft. The control system dynamic characteristics under all possible combinations of loads should be determined.

4.1.3.6.7 Fungus - Equipment which has parts of organic material, or other materials which may grow fungus, shall be subjected to a fungus resistance test, procedure I, of MIL-E-5272. The component shall be subjected to individual tests before and after exposure. Any fungus present shall not result in a deterioration of the performance or service life of the component.

4.1.3.6.8 Extreme Temperature Tests - Dynamic operation using expected high and low temperature and temperature shock shall be verified on all components subject to binding or malfunction resulting from:

a. Differential contraction of mating parts

b. Deterioration of lubricant

c. Deterioration of hydraulic fluid

d. Deterioration of any type seal device

e. Deterioration of electrical parts

f. Altered hydraulic or electrical characteristics

g. Change in performance functions

These tests shall be performed in accordance with high-temperature tests, procedure II; low-temperature tests, procedure II; and temperature shock tests, procedure I, respectively, of MIL-E-5272. Prior to low-temperature tests, a 72-hour soak at -65 degrees F. (18.3 degrees C) is always required. The high-temperature range shall be specified by the detail specification.

The component shall be subjected to individual tests before, during and after exposure. From these tests and a visual examination there shall be no evidence of damage or deterioration which will prevent the component from meeting its operational requirements.

4.1.3.6.9 Humidity and Corrosion - Components subject to failure due to corrosion, entrance of moisture, or formation of ice should be given humidity test, procedure I, and salt spray tests, in accordance with MIL-E-5272. In addition, if ice formation might be detrimental to the equipment, an icing test shall be conducted as follows:

a. Cool test items to -12 degrees C (10.4 degrees F.) or lower.

b. Reduce ambient air pressure to simulate 40,000 feet pressure altitude and maintain for at least 15 minutes.

c. Increase ambient air pressure to ground level by introducing warm moist air at a temperature of at least 49 degrees C (120 degrees F.) and a relative humidity of 95 ($\pm$5) percent. Continue circulating warm moist air until the test item temperature is at least 5 degrees C (41 degrees F.). Items a, b, and c constitute one cycle of testing. Twenty-five cycles shall be performed to determine acceptability. Following each five cycles, the test item shall be functionally checked while at a -12 degree C (-24.4 degrees F.) temperature. At the conclusion of the 25 cycles, and following the functional check, the equipment shall be examined for evidence of internal moisture, corrosion, or other defects, any of which is considered as failure to pass the test.

4.1.3.6.10 Altitude - Electrical equipment and other flight control system items which may be adversely affected by high-altitude operation shall be tested in accordance with high-altitude test, procedure II of altitude test of MIL-E-5272. A percentage of the total life test cycles, consistent with service requirements of the component, but not less than 25 percent, shall be conducted at the high-altitude condition.

4.1.3.6.11 Vibration, Shock and Acceleration - All equipment subject to failure or malfunction due to vibration, shock, or high accelerations shall be tested in accordance with vibration tests, procedure I; shock tests, procedure I; and acceleration tests, procedure I; of MIL-E-5272. Realistic shock and acceleration values shall be specified in the contractor's detailed specifications if different from those specified in MIL-E-5272.

4.1.3.6.11.1 Rigidly Mounted Components - Components designed to be rigidly mounted to the airframe including components and their individual vibration mounts and individual groups of components mounted on a single vibration mount shall be subjected to procedure I of MIL-E-5272. The component shall perform within the requirements of the detail specification before, during, and after the test.

4.1.3.6.11.2 Vibration Isolated Rack Mounted Components - Flight control system components which are to be assembled with components of other systems on a vibration isolation rack shall, as a complete assemblage, be subjected to procedure I of MIL-E-5272. In the case where the rack configuration is not known, or where the components of the other system cannot be simulated by dummy loads, the flight control system components shall be subjected to procedure III of MIL-E-5272. The components shall perform within the requirements of the detail specification before, during, and after the test.

4.1.3.6.11.3 Vibration Isolated Panel Mounted Components - Components designed for mounting on vibration isolated panels shall be subjected to procedure III of MIL-E-5272. The components shall perform within the requirements of the detail specification before, during, and after the tests.

4.1.3.6.12 Explosion Proof - Electronic or electrical components not hermetically sealed shall be subjected to MIL-E-5272, procedure I. Additional tests in accordance with MIL-E-5272, procedure II, shall be required of those components which may be installed in areas in which explosive mixtures normally occur.

4.1.3.6.13 Combined Temperature - Altitude Tests - Components and systems subject to leakage or which may experience cooling problems, should be subject to the following tests:

4.1.3.6.13.1 System Operation Test - When applicable, each system specification shall specify a composite temperature altitude test to be conducted on the system or separately on each component. The temperature-altitude-time schedule shall simulate as accurately as possible the conditions to be encountered during operations use of the weapon system. Should the exposure periods, temperature ranges and altitude ranges of the temperature-altitude-time schedule equal or exceed the requirements of either the high-temperature, low-temperature, or altitude tests, the respective individual environmental tests shall not be required.

4.1.3.6.13.2 Leakage Test - All components or subassemblies of components which are hermetically-sealed and contain a fluid other than a gas shall be subjected to a leakage test in accordance with the following procedure. With rated power applied the component shall be operated in an ambient temperature of + 175 degrees F. (79.4 degrees C) and an ambient pressure equivalent to 55,000 feet altitude. The period of exposure shall be for 2 hours or until the internal temperature of the component has stabilized, whichever is the longer time. Throughout the exposure period the component shall be observed for leakage. No leakage of the fluid shall occur during the test.

4.1.3.6.14 Life Tests -

4.1.3.6.14.1 Component Life Testing - Components which are subject to wear, fatigue, or other deterioration due to usage, shall be life tested under realistic environmental conditions for a number of cycles representative of the desired life expectancy of the component. In most cases, life test requirements are defined in Government specifications. Hydraulic components shall be tested while using hydraulic fluid at a typical fleet environment fluid cleanliness level.

4.1.3.6.14.2 System Life Testing - The mechanical portions of the complete FCS, such as pulleys, cable rods, torque tubes, control sticks or wheels, etc., should be tested as a complete system. It is considered that the best way to do this is in a complete system mockup in which loads, relative distances and locations, and other characteristics are realistic. The information required by 4.1.2 and 4.4.1.1 can thus be readily obtained and the structural testing required by 4.1.3.6.6 can also be accomplished while the life cycling is in progress. Life test parameters will be specified by the contractor and approved by the procuring activity.

4.1.3.6.15 Miscellaneous Tests - Equipment which is located so that it is subjected to rain, sunshine, and sand and dust shall be tested in accordance with sunshine tests, procedure I; rain tests, procedure I; sand and dust tests, procedure I; and immersion tests, procedure I; of MIL-E-5272. Any additional tests as deemed necessary by the contractor should be included and defined in the detail equipment specification.

Comments - Developmental tests is a more appropriate title than Design Approval Tests. Requires further study because, how much of the preproduction tests is a duplication of the requirements in MIL-E-5272. Delete references to vibration panels which are disallowed.

Recommendation - Update and incorporate into DFBW specification.

4.1.3.7 Failures and Retests - Components failing a service condition test shall not be resubmitted for test without furnishing complete information on the corrective action taken subsequent to the failure. This information shall be furnished to the procuring activity or in the test report, depending upon location of testing. Depending upon the nature of the failure encountered and corrective action required and at the option of the procuring activity, the rework or modifications accomplished shall also be incorporated into the other test samples. Where rework or modification may be considered as sufficient to affect performance under the other service condition tests already completed, at the option of the procuring activity, these tests shall be repeated in the specified order.

4.1.3.8 Higher Category of Service Application - Components to be used under a particular category of service application, which have previously been subjected to and accepted under the requirements of a lower, or less severe category application, either as an individual component or as a component of the same or a different system, shall be subjected to a rerun of those service condition tests which vary with category of service application.

4.1.3.9 Instrumentation - During the conducting of dynamic performance test, instrumentation shall be provided to record input and output quantities fundamental to the function or basic design concept of the systems' or components' operation. All instrumentation used shall be accurately calibrated prior to and at the completion of tests. In addition, ambient conditions, power supplied, voltage and frequency variation shall be noted, or recorded, as the nature of the test may warrant.

4.1.3.10 Special Test Equipment - Special test equipment used shall be accurately calibrated. Calibration data or curves shall be included in the test report or shall accompany the test equipment when submitted to the procuring activity for performance of tests.

4.1.3.11 Test Technique - Dynamic performance of systems and components shall be demonstrated by using transient response or frequency response testing techniques, or both.

4.1.3.11.1 Physical Characteristics of Transients - Applied transients shall be step or ramp functions in displacement, rate of displacement, or other suitable inputs.

4.1.3.11.2 Application of Transients - Where feasible, transients shall be applied physically to inertial sensing elements by actual displacement or rotation of the unit. Electrical inputs, such as command inputs, as well as other types of inputs shall be applied in any convenient manner, such as rotation of a signal generator, switching, or use of an electronic integrator.

4.1.3.11.3 Variation of Transient Amplitudes and Rates - A sufficient number of displacement transients of different amplitudes, as well as rate of displacement transients of different rates, shall be applied to the system or component under test to adequately define its dynamics in the region of threshold, linear operation, saturation, and velocity limit.

4.1.3.11.4 Variation of Gain - For those systems or components in which loop gains may be varied either automatically or manually, the dynamic tests shall be accomplished over a sufficient number of gain settings to adequately define the systems or components dynamics throughout the attainable range of gain variation.

Comment - The same as paragraph 4.7 in MIL-C-18244A and the same comments apply. Change service condition test to preproduction test.

Recommendation - Update and incorporate into DFBW specification.

4.2 Acceptance Tests - Acceptance tests consist of all the individual tests specified herein and of contractor defined system or component tests which are to be accomplished to determine acceptability under the requirements of the procurement document. When these tests are appropriate, they will be indicated by the procurement document or detailed specification. Contractors' records of all inspection work and tests, giving the quantitative results of tests required to determine compliance with the requirements and tests specified herein and in the system or component specifications, shall be kept complete and shall be available to the procuring activity representative at all times. The record or report of inspection and tests shall be signed or approved by a responsible person specifically assigned by the contractor. Acceptance testing shall be accomplished by the contractor on articles submitted for acceptance under the contract or purchase order. Acceptance or approval of material during the course of manufacture shall in no case be construed as a guaranty of the acceptance of the finished article.

Comment - Applicable. The length of time that tests results shall be stored should be added to the specification.

Recommendation - Update and incorporate into DFBW specification.

4.2.1 Sampling Tests - Sampling tests shall be performed in accordance with the requirements of aircraft detail specification.

4.2.2 Individual Tests - Each component or system shall be examined to determine conformance to this specification and the system or component specification with respect to material, workmanship, dimensions and markings, in addition to the individual tests specified by the system or component specification in the sequence specified therein.

Comment - Applicable.

Recommendation - Incorporate into DFBW specification.

4.3 Flight Tests - Flight testing shall consist of those tests required to demonstrate the functional reliability and consistency of operation and the accuracy of performance of the equipment-airplane combination for the condition specified. Test data shall be observed visually or by recording, as may be required to determine compliance with the requirements specified. The operation and performance observed or recorded shall be equal to or better than the minimum acceptable criterion specified in the applicable performance specification. Flight test demonstration shall be conducted in accordance with the requirements of MIL-D-8708, MIL-I-8700, and MIL-T-5522, as applicable.

4.3.1 Testing of Integrated Flight Control System, Hydraulic Systems, and Test Instrumentation Prior to First Flight - To insure that the installation of test and monitoring instrumentation system will not degrade the reliability of the flight control and hydraulic power systems, the integrated systems shall be tested as installed in the prototype aircraft prior to its first flight. The effects of vibration, structural deflections, temperature differentials, electro-magnetic radiation, and environmental effects shall be investigated.

4.3.1.1 Flight Control System Integrity Test - Prior to first flight, the flight control systems of the first flight article shall be subjected to an integrity test to insure soundness of components and connections, adequate clearances, and proper operation. The test shall consist of static and dynamic checks as follows:

a. The control surface, blade, etc. (or the input to the surface actuator servovalve) shall be held fixed to react to forces applied at the pilot input control such that limit design load is achieved throughout the control system. (Actual loads may be somewhat lower due to tolerance buildup and system deflection.) In systems where limit design load cannot be achieved due to load relieving bungees, etc., maximum operating loads shall be applied to the system. Maximum operating loads can be achieved, for example, by cycling the cockpit control to the system stop with power on, shutting off power, then cycling the control to the opposite stop against full opposite trim, etc. Performance of this static integrity test is not required if the proof load test of MIL-A-8867 and MIL-A-8868 is performed on the first flight article.

b. Each control surface shall be cycled five times throughout its range of travel with applied surface hinge moments to demonstrate operation at 50 percent of the ultimate system capability.

Comment - Does not apply to DFBW.

Recommendation - Delete.

4.4 Planning and Procedural Requirements -

4.4.1 Technical Development Plan - A technical development plan or program guide shall be established for the FCS. The plan shall, in general, conform to the plan specified in SAR-378 and shall be submitted to the procuring activity for approval. This plan shall be revised quarterly until it is mutually agreed that its usefulness has ended.

4.4.1.1 Scheduling -

4.4.1.2 Interrelationship Between Phases - The plan shall show the interrelationship between phases and/or items of development work to be accomplished. It shall show the logical sequence of work to be accomplished, and which items of work are to be completed before others can be initiated.

4.4.1.3 Bar Graph - The plan shall include a bar graph of all major items of work showing the starting and completion dates of these items of work.

4.4.1.4 Due Dates of Reports - The plan shall show the time for submittal of all required technical data and reports.

4.4.1.5 Design Reviews - The plan shall show the time for convening of design reviews.

4.4.1.6 Schedule Changes - As the work outlined in the plan progresses, any changes, schedule difficulties or slippages shall be clearly shown in the quarterly revision to the plan together with the justification and request for approval for any such changes.

4.4.2 Contents of the Plan - The plan shall include, but not be limited to, the planned procedure to develop and provide design information for the following items:

a. Preliminary FCS performance specification. See 4.5.1.1.

b. Initial system synthesis which will lead to an FCS able to fulfill the requirements specified in the preliminary performance specification.

c. Initial system analysis to determine requirements for FCS stability, reliability, vulnerability and projected failures. Stability, gain, and phase margins shall be indicated.

d. Final FCS performance specification. See 4.5.1.

e. Method for the design and development of all FCS's.

f. Determination of the components of the FCS that are to be developed by prime contractor and those to be subcontracted.

g. FCS' design report. See 4.5.2.

h. Preparation of subsystems and component specifications.

i. Design approval test specifications. See 4.5.3.

j. Simulator studies using development models. See 4.1.2.1.

k. Flight control system simulation reports. See 4.5.4.

l. Design approval tests.

m. Design approval test report. See 4.5.5.

n. Fabrication of service test models.

o. Specification for qualification tests. See 4.5.6.

p. Flight test procedures. See 4.5.7.

q. Preliminary flight tests.

r. Preliminary flight tests report. See 4.5.8.

s. Performance flight tests.

t. Contractor's demonstration flight tests.

u. Performance flight test report. See 4.5.9.

v. Fabrication of special maintenance equipment. See 4.5.10.

w. Preparation of handbooks.

x. Tooling for production.

y. Fabrication of production models.

4.4.3 Design Reviews - Design reviews will be convened at the request of either the procuring activity or contractor at times and places mutually agreed upon. These reviews should be attended by specialists in the various fields associated with the subject systems and the intended application. The purpose is to focus attention of the concerned specialists (procuring agency, weapons systems contractor, airframe contractor, AFCS contractor) on the design at each stage. Some of the items which should be considered during the design reviews are:

a. Functional compatibility of the FCS with the airframe characteristics and desired aircraft performance.

b. Reliability, vulnerability, survivability, and safety of the FCS.

c. Minimum complexity, weight, and size consistent with (a) and (b).

d. The suitability of the design from the viewpoint of cost, fabrication, and ease of maintenance.

e. Service utilization.

f. Logistic support.

g. Use of existing equipments.

A detailed agenda for the design review shall be forwarded to the procuring activity at a minimum of two weeks prior to the review date.

Comments - Add to the first sentence to specify that several design reviews shall be listed in the Tech. Develop. Plan. The design reviews are useful means to monitor the manufacturers progress.

Recommendation - Update and incorporate into DFBW specification.

4.4.4 Design Approval - The procuring activity shall retain the right to disapprove any part of the design on the basis of nonconformance with the requirements of the contract.

Comments - Applicable.

Recommendation - Incorporate into DFBW criteria.

4.5 Data Requirements - The design and test documents required shall be listed on form DD 1423 of the aircraft procurement contract. If applicable design data are available, the contractor shall, in lieu of submitting new design data, submit these available data supplemented by sufficient information to substantiate its applicability. The procedures for submittal of design data on aircraft shall be in accordance with MIL-D-8706 or as described on Form DD 1423. The contractor may, at the time of presentation, propose change to the applicable supplement to MIL-D-8706.

Comments - Review MIL-D-8706 to determine if applicable to DFBW system.

Recommendation - Incorporate applicable MIL specs into DFBW criteria.

4.5.1 Flight Control System Performance Specification - A system performance specification, referencing the various individual subsystems and components shall be prepared by the contractor. In addition, any special features or unusual requirements shall be indicated. This specification shall also define the environmental criteria and the testing required to show suitability for both the environment and the overall performance. Installation details, weights, sizes, structural limitations and airframe characteristics shall be included as required by the design. Preparation and format of this document shall be such that the areas of responsibility for the airframe, external guidance, primary FCS and AFCS are clearly defined.

Comments - Change title to "Detail Equipment Specification". Requirement is applicable.

Recommendation - Update and incorporate into DFBW specification.

4.5.1.1 Preliminary Flight Control Performance Specification - A preliminary FCS performance specification shall be prepared to provide early guidelines for the detail design. This specification shall be made final at the earliest practicable date. The technical development plan will indicate the time when the final data is required.

Comments - Change title to be consistent with Para 4.5.1.

Recommendation - Update and incorporate into DFBW criteria.

4.5.2 Flight Control System Design Report - The flight control system design report shall be a comprehensive report on the FCS. The report shall contain the following information, as a minimum:

a. A discussion of the FCS from the overall performance standpoint showing that the proposed system will meet the overall requirements of the flight control system specification.

b. Expected reliability of the system, subsystem and components showing how the reliability criteria will be met.

c. A failure effects analysis of the FCS which shall include assumed failure of each critical component in the most adverse position and/or condition. In addition, the report shall consider failures of the AFCS and its effect on the FCS. For systems where the power source is hydraulic, electrical, etc., the report shall include a failure effects analysis of the power source system and components. For each assumed failure the consequences, compensating provisions, and probable reliability of critical components shall be discussed. For a fail-operative system, second failure effects shall also be evaluated.

d. General system requirements.

e. Test requirements.

f. List of component and subsystem specifications.

g. The tie-in of the AFCS to the overall FCS.

h. A block diagram of the FCS and AFCS if applicable. The diagram shall clearly indicate the normal control paths, redundancy, manual overrides, emergency provisions, tie-in external elements and the control surfaces to be actuated.

i. Where applicable, a general description of the AFCS and a discussion of the theory of operation. The various modes of operation should be explained in detail.

j. An analysis of the stability of the FCS and its relation to the overall stability of the airplane. Data shall also be presented for large amplitudes taking into account the main nonlinearities such as limits on actuator rates and position.

k. Data should be presented showing response to commands and disturbances, speed of response, overshoot, damping, accuracy, and critical hinge moments, etc. This data should also take into account the main nonlinearities.

l. A discussion of any required special functions such as Mach control, g limiting, surface travel as a function of q, etc.

m. A reliability prediction of the proposed design, sources of data, the analytical approach used in making this prediction, and a discussion of the results in comparison to requirements shall be included.

n. A general control system layout drawing showing surfaces to be actuated, method of actuation system duplication, approximate hinge moments, major components, emergency provisions, etc.

o. A schematic diagram of the power systems supplying the flight control systems. The required power spectrum shall be indicated.

p. A schematic wiring diagram of the electrical system affecting the flight control system. This diagram shall show source(s) of power, peak and average power requirements, voltage, current, etc.

q. Internal and external wiring diagrams.

r. Schematic drawings showing the functions of all elements (mechanical, hydraulic, electrical, aerodynamic, etc.) that constitute the FCS of the aircraft. Descriptions explaining the functions of the complete system, functions of the individual elements, and other necessary explanations of the FCS shall accompany the schematic drawings.

s. Component design information.

t. Explanation of control laws employed in designing the FCS.

u. An analysis of the control surface actuation systems to demonstrate that the following basic requirements can be met in all flight regimes:

(1) Adequate stability margins to guarantee stability.

(2) Adequate frequency response (bandwidth) capability to ensure control of the aircraft.

(3) Adequate stiffness to prevent control surface flutter and sufficient static stiffness to minimize static error under aerodynamic load.

Comment - Requirement must be rewritten for DFBW systems. Delete paragraph c. which calls for the failure effects analysis to be part of the report.

Recommendation - Update and incorporate into DFBW specification.

4.5.3 Design Approval Test Specifications - Design approval test specifications and procedures in accordance with MIL-D-18300 shall be submitted for approval. Justification shall be submitted for special maintenance and overhaul tools and test equipment required for these tests.

4.5.4 Flight Control System Simulation Reports - Reports on the simulator test equipment, test procedures, and test results shall be submitted in accordance with 4.1.2.1.

4.5.5 Design Approval Test Report - A report shall be submitted summarizing for approval, engineering information obtained from the para.4.1.3 tests.

4.5.6 Specification for Qualification Tests - Specifications and procedures for qualification testing shall be submitted to the procuring activity for approval.

4.5.7 Flight Test Procedures - Flight test procedures for the flight control system shall be submitted for the approval of the procuring activity.

4.5.8 Preliminary Flight Tests Report - A report shall be prepared and submitted as engineering information on the preliminary flight tests. This report shall discuss any differences noted between the predicted and actual flight performance.

4.5.9 Performance Flight Test Report - A report shall be prepared and submitted for approval on the performance flight testing. This report shall indicate compliance with the performance specification.

4.5.10 Special Maintenance Equipment - Prior to fabrication of special maintenance and overhaul tools, the contractor shall submit a report to the procuring activity for approval. These items shall be in accordance with MIL-D-8512.

Comments - The term, Design Approval Tests, is not in use today. Developmental Tests is more appropriate.

Recommendation - Update and incorporate into DFBW criteria.

4.5.11 Drawings - Engineering drawings shall be submitted to permit detailed evaluation and engineering approval of systems and components. At least the following are required for engineering approval of the system.

4.5.11.1 Flight Control System Illustration - A plan and profile projection or a perspective type illustration of the complete FCS shall be submitted. It shall show the complete FCS installation including components and mechanical arrangement and shall be shown on the background of the aircraft outline. Where necessary, sufficient structure shall be shown (in phantom) so that relative vulnerability of the FCS may be ascertained. All armor plating and thermal protection features shall be shown.

4.5.11.2 Installation Drawings - The installation drawings shall show the complete FCS including mechanical, hydraulic, or other power system components in addition to the motion geometry (trends) of principal linkages from the pilot's control to the control surface or corresponding device. All attaching points, brackets, adjustment provisions, stops, and rigging points shall be indicated. These drawings shall include sufficient detail to show sizes of cables, typical terminals, end fittings, levers, etc. The parts shall be labeled with name and part number.

4.5.11.3 Component Cross-Section Assembly Drawings - These drawings shall contain sufficient information to evaluate the operational and assembly concept of each component.

Comments - The first sentence, "Engineering drawing shall be submitted to permit detailed evaluation and engineering approval of systems and components", is misleading. The submittal of drawings does not constitute approval or disapproval of the system. The contractural requirements are in the specifications and the purchase order, not in the drawings.

Recommendation - Rewrite the requirement and incorporate into the DFBW specification.

APPENDIX D

DIGITAL FLY-BY-WIRE DFBW SYSTEM CRITERIA

DIGITAL FLY-BY-WIRE SYSTEM CRITERIA

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DIGITAL FLY-BY-WIRE SYSTEM CRITERIA

1.0 SCOPE

1.1 SCOPE

These criteria covers the design, test, and performance requirements for digital fly-by-wire (DFBW) control systems for U.S. Navy piloted aircraft (excluding helicopters). It encompasses all components used to transmit flight control commands to appropriate force and moment producers excluding the aerodynamic surfaces and engines. For the purpose of these criteria, the DFBW system shall encompass primary and secondary flight controls, AFCS, and autopilots. In the event of conflict between these criteria and other referenced documents, these criteria shall govern. The detail requirements for a particular system shall be specified in the detailed equipment specification, aircraft detailed specification, contract, or purchase order for that system.

1.2 CLASSIFICATION

1.2.1 Classification of Airplanes

For the purpose of these criteria, aircraft shall be divided into four classes:

- Class I: Small light aircraft such as light observation
- Class II: Medium weight and low to medium maneuverability aircraft such as antisubmarine and reconnaissance
- Class III: Large, heavy, low to medium maneuverability aircraft such as heavy transport and bombers
- Class IV: High maneuverability aircraft such as fighters and attack.

1.2.2 Flight Phase Categories

For the purposes of these criteria, the aircraft's flight profile is separated into three general categories as follows:

- Category A: Those non-terminal flight phases that require rapid maneuvering, precision tracking, or precise flight path control, e.g., air-to-air combat, terrain following and close formation flying
- Category B: Those non-terminal flight phases that require gradual maneuvers without precision tracking, although accurate flight path control may be required, e.g., cruise and loiter

- Category C: Terminal flight phases that can be accomplished using gradual maneuvers and usually require accurate flight-path control, e.g., takeoff and landing.

1.2.3 Levels of Flying Qualities

For the purposes of these criteria three levels of pilot's flying qualities shall be specified. The levels are:

Level 1: Flying qualities clearly adequate for the mission flight phase

Level 2: Flying qualities adequate to accomplish the mission flight phase, but some increase in pilot workload or degradation in mission effectiveness, or both, exists

Level 3: Flying qualities such that the airplane can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both. Category A flight phases can be terminated safely, and Category B and C flight phases can be completed.

1.2.4 Flight Control System Categories

For purposes of these criteria the flight control system (FCS) shall be divided into four categories as follows:

- Primary. Primary flight control is a control system where continuous pilot inputs are needed to control the flight path of the aircraft by moving control surfaces. The basic longitudinal, lateral, and directional axes of an aircraft which move elevators, ailerons, and rudders with a control stick and pedals is an example
- Secondary. - Secondary flight controls are all aerodynamic controls that control the flight path of the aircraft which are not included in the primary category. Systems such as flaps, slats, speed brakes, and wing sweep are examples
- Automatic. The automatic flight control systems automatically transmits command to the control surfaces to control the flight path of the vehicle without the necessity of continuous pilot inputs. The autopilot is an example.
- Back-up. An independent control system that becomes activated at the pilot's discretion.

2.0 APPLICABLE DOCUMENTS

The following documents, of the issue in effect on the data of invitation for bids or request for proposal, form a part of these criteria to the extent specified herein. The requirements of these criteria shall govern for FCS design where conflicts exist between these criteria and other reference criteria.

SPECIFICATIONS

Military (TBD)

STANDARDS (TBD)

Military (TBD)

PUBLICATIONS (TBD)

3.0 REQUIREMENTS

3.1 SYSTEM REQUIREMENTS

DFBW system shall be as simple, direct and foolproof as possible with respect to design, operation and maintenance.

3.1.1 Design

The DFBW system shall be designed for minimum weight and volume consistent with the structural integrity requirements of the aircraft for which it is intended.

3.1.1.1 Redundancy - The contractor shall determine the redundancy design and the levels required to satisfy the reliability, invulnerability, and safety of the aircraft.

3.1.1.1.1 Redundant Channels - Redundant channels shall comply with the following:

a. Cross connections between redundant electrical signal channels shall be minimized, and failure detection/isolation provisions shall be mechanized in such a way that no single failure can disable more than one channel. Maximum isolation shall prevent any failure in one signal channel from initiating a failure or a cascade of failures in any other signal channels.

b. Each redundant electrical signal channel shall be associated with an electrical power source that is not connected to any other signal channel. The loss of a single electrical power source shall not result in the loss of more than one signal channel in a redundant system.

3.1.1.2 Interface - Wherever the DFBW system is interfaced with another system the circuits shall be separated and isolated to make the probability of propagated or common mode failures extremely remote. Interfaces between various parts of the DFBW system shall be designed to assure that a failure does not cause another failure of an otherwise functionally independent part of the system.

3.1.1.2.1 Synchronization - Unless the DFBW system and interfacing systems are properly energized and synchronized it shall not be possible to engage the associated mode(s).

3.1.1.2.2 Signal Limiting - Means shall be provided to limit the command signals from external guidance systems so that the autopilot will not cause the aircraft to execute undesirable maneuvers.

3.1.1.2.3 Switching - Switching to an external guidance system with a zero command signal input shall not cause a transient that is detectable to the flight crew.

Switching from one mode to another under a nonmaneuvering flight condition shall cause no objectionable transients to the flight crew.

3.1.1.2.4 Noise Compatibility (TBD)

3.1.1.3 Warmup - After the application of power, the warmup time shall not be more than 90 seconds.

3.1.1.4 Disengagement - Provisions shall be made for inflight disengagement and reengagement of any DFBW system mode, other than the primary mode. Disengagement shall be positive under any load condition. The pilot shall be informed of any automatic disengagement. Disengagement circuitry shall be designed such that a failure of the circuitry itself does not prevent automatic or manual disengagement.

3.1.1.5 Status of Modes - A means shall be provided so that the pilot can visually determine the operational status of the system.

3.1.1.5.1 Mode Compatability - Mode compatability logic shall provide flexibility of FCS operation and ease of mode selection. The mode selection logic shall:

a. Make correct mode selection by the crew highly probable.

b. Prevent the engagement of incompatible modes.

c. Disconnect appropriate previously engaged modes upon selection of higher priority modes.

d. Provide for the engagement of a more basic DFBW system mode in the event of a failure of a higher priority mode.

3.1.1.6 Failure Transients - For flight phase categories B and C, transients due to failures within the DFBW system shall not induce dangerous alterations in attitude or flight path and shall not exceed ± 0.5g incremental normal acceleration or TBD. g lateral acceleration at the center-of-gravity or ± 10°/sec roll rate. For flight phase category A, failures shall be such that a dangerous condition can be avoided by pilot corrective action. At critical flight conditions, failures shall not cause the aircraft to exceed 75% of limit load factor or 1.5g's from the initial value, whichever is less.

3.1.1.7 Calibration Adjustments - The DFBW system shall be designed so that no calibration adjustments or harmonization is required for ground maintenance of the command transducers, sensors, or computers under all service conditions for the life of the vehicle. Any electronic WRA's can be replaced with the same manufacturer's part number and no adjustment or calibration shall be required on the aircraft.

3.1.1.8 Stability - All modes of the DFBW system must be able to rapidly decrease any transient oscillation and a slight change in parameters must not result in instability.

3.1.1.8.1 Aerodynamic Closed Loop - An aerodynamic loop is one which relies on aerodynamics for loop closure such as stability augmentation. Required gain and phase margins about nominal are defined in Table I for all aerodynamically closed loops. With these gain or phase variations included, no oscillatory instabilities shall exist with amplitudes greater than those allowed for residual oscillations in 3.1.1.9, and any nonoscillatory divergence of the aircraft shall remain within the applicable limits of MIL-F-83300. Automatic modes shall be stable with these gain or phase variations included for any amplitudes greater than those allowed for residual oscillations in 3.1.1.9. For the automatic modes the stability requirements applies only to the airspeed range of operation of these modes. In multiple loop systems, variations shall be made with all gain and phase values in the feedback paths held at nominal values except for the path under investigation. A path is defined to include those elements connecting a sensor to a force or moment producer. The margins specified by Table I shall be maintained under flight conditions of most adverse center-of-gravity, mass distribution, and external store configuration throughout the operational envelope and during ground operations. Where analysis is used to demonstrate compliance with these stability requirements, the effects of major system nonlinearities shall be included.

3.1.1.8.2 Nonaerodynamic Closed Loop - A nonaerodynamic closed loop is one which doesn't rely on aerodynamics for loop closure such as a servo actuator. All nonaerodynamic closed loops shall be stable at twice their nominal gain, at nominal phase. They shall also be stable when an additional 45° of phase lag is introduced into the loop with nominal gains. If a system wear test is applicable, the loop shall still be stable when at least one and one-half times the nominal gain is applied, at nominal phase, at the completion of the wear test.

3.1.1.8.3 Internal Noise - There shall be no noticeable high frequency motion of the control surfaces due to noise signals generated by the flight control system.

3.1.1.9 Residual Oscillations - Residual oscillations shall not interfere with the pilot's performance of his required tasks. As a minimum the residual oscillations, as measured in the cockpit during steady state flight, shall not produce normal accelerations (a_n),

TABLE I

GAIN AND PHASE MARGIN REQUIREMENTS (dB, DEGREES)

Mode Frequency Hz \ Airspeed	Below $V_{o_{MIN}}$	$V_{o_{MIN}}$ To $V_{o_{MAX}}$	At Limit Airspeed (V_L)	At 1.15 V_L
$f_M < 0.06$	GM = 6 dB (No Phase Require- ment Below $V_{o_{MIN}}$)	GM = ±4.5 PM = ±30	GM = ±3.0 PM = ±20	GM = 0 PM = 0 (Stable at Nominal Phase and Gain)
$0.06 \leq f_M <$ First Aero-Elastic Mode		GM = ±6.0 PM = ±45	GM = ±4.5 PM = ±30	
$f_M >$ First Aero-Elastic Mode		GM = ±8.0 PM = ±60	GM = ±6.0 PM = ±45	

where: V_L = Limit Airspeed (MIL-A-8860).

$V_{o_{MIN}}$ = Minimum Operational Airspeed (MIL-F-8785).

$V_{o_{MAX}}$ = Maximum Operational Airspeed (MIL-F-8785).

Mode = A characteristic aeroelastic response of the aircraft as described by an aeroelastic characteristic root of the coupled aircraft and control system dynamic equation-of-motion.

GM = Gain Margin = The minimum change in loop gain, at nominal phase, which results in an instability beyond that allowed as a residual oscillation.

PM = Phase Margin = The minimum change in phase at nominal loop gain which results in an instability.

f_M = Mode Frequency in HZ (Control system engaged).

Nominal Phase and Gain = The contractor's best estimate or measurement of control system and aircraft phase and gain characteristics available at the time of requirement verification.

lateral accelerations (a_y), attitude amplitudes in pitch (Θ), roll (ϕ), and yaw (Ψ) greater than the following:

a_n	0.05 g's p-p (peak to peak)
a_y	0.02 g's p-p
Θ	0.17 degrees p-p
ϕ	0.50 degrees p-p
Ψ	0.50 degrees p-p

3.1.1.10 Operation in Turbulence (TBD)

3.1.1.11 Structural Protection - Means shall be provided to prevent the pilot from inadvertently putting in commands or the DFBW system from producing commands that would cause the airplane to exceed the limit load factor.

3.1.1.12 Acceleration Effect - Acceleration forces acting upon the flight control system's components shall not cause them to malfunction or become inoperative within the operational flight envelope.

3.1.1.13 System Test - BIT functions intended for ground checkout shall have multiple provisions to insure it cannot be engaged in flight.

3.1.1.13.1 Preflight BIT - Means shall be provided in the design to enable the pilot to determine the operational status of the DFBW system to at least TBD % probability for detecting failures, while the aircraft is on the deck prior to takeoff. This equipment shall be integrated into the hardware and software and shall not require the use of ground test equipment. The pilot shall be able to initiate these tests in conjunction with other preflight tests, be informed the tests are running and shall be provided with the results in the cockpit. Other than the means of activation, the preflight BIT shall not require the installation of additional controls in the cockpit. Part of the pilot's preflight checkout procedure will be to do control sweeps of the rudders, stabilizers, ailerons, etc., which may be done prior to or after the preflight BIT. The DFBW system preflight shall not exceed 2 minutes.

3.1.1.13.2 Maintenance BIT - Maintenance BIT shall be provided in the design to determine the operational status and shall fault isolate to the WRA level, insofar as practical. It shall be designed to make maximum use of the test features already included as part of the preflight BIT and inflight monitoring. During the BIT operation, the control surface motion shall be kept to a reasonable deflection and the servos shall be inhibited for those portions of the test where they are not specifically tested (unnecessary servo motion). Maintenance BIT shall operate in various aircraft ground configurations such as with the wings folded, swept back, etc., with hydraulic pressure on and off, with the flaps up and down, and shall give meaningful test results. It shall not stroke those actuators where the control surfaces do not have proper clearances. It shall not exceed TBD minutes.

3.1.1.13.3 Inflight Monitoring - The DFBW system shall be inherently self-monitoring. It shall provide for continuous monitoring of critical flight equipment performance for all flight control functions for which failure detection is required. False monitoring warnings, including the automatic or normal pilot response thereto, shall not constitute a hazard.

3.1.2 Performance Requirements

The DFBW system is divided into four catagories: primary, secondary, automatic and backup. The detail equipment specification shall specify which modes or categories are applicable to the aircraft in which the equipment is used.

3.1.2.1 Primary Functional Modes - The primary functional modes control the basic longitudinal, lateral and directional axis of the aircraft through such control surfaces as elevators, ailerons, rudders, etc. The detail equipment specification shall determine which of the following modes is applicable. They may be separated and divided by axis and selectable by the pilot or there may be only one primary mode of operation, nonselectable.

3.1.2.1.1. Fault Tolerances (TBD)

3.1.2.1.2 Control Sensitivity - Control sensitivity shall be in accordance with (TBD)

3.1.2.1.3 Stability Augmentation/Command Augmentation (TBD)

3.1.2.1.4 Command Augmentation - With application of force on the control stick or pedals a aircraft rate is commanded. This mode shall comply with the requirements of (TBD).

3.1.2.1.5 "G" Force Command Mode/C* & D* - With application of force, on the control sitck or pedals "G" forces will be commanded. This mode shall comply with the requirements of (TBD).

3.1.2.1.6 Control Configured Vehicle (TBD)

3.1.2.2 Secondary Functional Modes - The detail equipment specification shall specify which is applicable, but shall not be limited to the following:

- High Lift Control (flaps, slats, etc.)
- Speed Brakes
- Direct Lift Control
- Throttle Control
- Trim (manual and automatic)
- Nose Wheel Steering
- Maneuver Flaps
- Direct Sideforce Control/Lateral Translation
- Fuselage Pointing/Gun Control
- Wheel Brake Control
- Anti-skid
- Control Surface Locks
- Maneuver Load Control/Load Alleviation

3.1.2.2.1 High Lift Control - A control system shall be provided for actuating high lift devices (flaps, slats, etc.). Unless specified in the detail equipment specification, the time to operate the landing flaps shall not be less than 3 seconds, nor more than 8 seconds, at the maximum aircraft speed for which they should be operated. Suitable synchronization to prevent misalignment of the flaps shall be provided. An indicator to provide flap position shall be provided.

3.1.2.2.1.1. Emergency Operation - Where safe operational landings cannot be accomplished without the use of the high lift device an emergency means of operating the system shall be provided.

3.1.2.2.2. Speed Brakes - A control system shall be provided for actuating speed brakes which must withstand structural damage if opened at V_L. Blowback may be used to prevent structural damage. The time to extend the speed brakes over the operating range shall be specified in the detailed point design specification.

3.1.2.2.2.1 Speed Brake Control - The pilot's activation of the speed brakes shall be in accordance with MIL-STD-203. The mechanization shall be a three-position device with stop position in neutral, momentary aft position to extend, and a forward position for retraction.

3.1.2.2.3 Direct Lift Control - As a minimum the system shall be designed to be fail-safe. Means shall be provided to notify the pilot the system is on and operational. This will require some in flight monitoring. When the system is operating it shall introduce a minimum roll rate to the vehicle.

3.1.2.2.4 Control Surface Locks - Shall not be required because the control system shall be designed to withstand the ground wind loads without damage.

3.1.2.3 Automatic Functional Modes - When the following automatic functions are used, the following specified performance shall be provided. The aerodynamic and flight configurations, external stores configuration, and aircraft performance range through which the system shall be required to provide the specified performance shall be defined in the detail equipment specification.

(a) Unless otherwise specified, these requirements apply in smooth air and include sensor errors.

(b) Except where otherwise specified, a damping ratio of at least 0.3 shall be provided for nonstructural controlled mode responses.

(c) Unless otherwise specified, the pilot assist and automatic guidance modes shall be limited to 0.9 Mach.

(d) For demonstration purposes, all input disturbances shall be an order of magnitude greater than the allowable residual oscillation.

3.1.2.3.1 Automatic Categories - The automatic functions are divided into the following two major categories.

(a) Pilot Assist or Pilot Relief - The pilot assist or pilot relief category shall include those automatic control functions which simplify or ease the control of the flight path of the aircraft. These functions include, but shall not be limited to the following:

- Attitude Hold (Pitch and Roll)
- Heading Hold
- Heading Select

- Automatic Turn Coordination
- Altitude Hold
- Return to Level
- Control Stick Maneuvering
- Angle of Attack Hold
- Stall-Spin Prevention/Avoidance
- Adverse/Proverse Yaw Compensation
- Gust Load Alleviation/Ride Smoothing
- Maneuver Load Control
- Elastic Mode Control
- Flutter Suppression
- Structural Mode Control

(b) Guidance - The guidance category shall include those control functions which provide automatic flight path control in accordance with steering signals generated by guidance and control systems external to the DFBW system. The category shall include, but shall not be limited to the following:

- Enroute navigation
- Rendevous and station keeping
- Terminal guidance for bomb delivery
- Search and tracking for fire control
- Automatic approach, landing
- Inertial Flight Path Control
- Automatic Terrain Avoidance

3.1.2.3.2 Attitude Hold (Pitch and Roll) - The selected pitch and roll attitudes shall be maintained within a static accuracy of ±0.5% with respect to the attitude reference. Upon completion of a pilot controlled maneuver, the airplane attitude maintained by the AFCS shall be the airplane attitude at the time the commanded forces were removed, if this attitude is within the limits of the attitude hold mode. When using a flight controller, the airplane shall return to a wings level attitude when the turn control is placed in the detent position.

3.1.2.3.3. Heading Hold - When the heading hold is engaged, the AFCS shall maintain the aircraft at its existing heading within a static accuracy of ±0.5 degree with respect to the heading reference.

3.1.2.3.3.1 Transient Response - The short period heading response shall be smooth and rapid and shall hold the heading to within approximately 0.15g lateral acceleration.

3.1.2.3.4 Heading Select - Where heading select is a system requirement, the AFCS shall automatically turn the aircraft through the smallest angle (left or right) to a heading either selected or preselected by the pilot and maintain that heading as in the heading hold mode. The heading selector shall have 360 degrees control. The bank angle while turning to the selected heading shall be limited to a bank angle designated by the procuring activity. The pilot shall be able to select any other bank angle by exerting the required force on the stick to command the new bank angle, then releasing the force. The aircraft shall not roll in a direction other than the direction required for the aircraft to assume its proper bank angle. In addition, the roll in and roll out shall be accomplished smoothly with no noticeable variation in roll rate.

3.1.2.3.4.1 Transient Response - Entry into and termination of the turn shall be smooth and rapid. The aircraft shall not overshoot the selected headings by more than 1.5 degrees.

3.1.2.3.5 Automatic Turn Coordination - Except for flight phases using direct side force control or for a system that intentionally applies sideslip to the aircraft, the following performance shall be provided whenever any lateral-directional AFCS function is engaged. Lateral acceleration refers to apparent (measured, sensed) body axis acceleration at the aircraft center of gravity.

3.1.2.3.5.1 Lateral Acceleration Limits, Steady Bank - The incremental sideslip angle shall be not greater than 2 degrees from the trimmed value and the lateral acceleration shall not exceed 0.03 g, whichever is the more stringent requirement, while at steady state bank angles up to 60° during normal maneuvers with the AFCS engaged.

3.1.2.3.5.2 Lateral Acceleration Limits, Rolling - Body axis lateral acceleration at the cg shall not exceed ±0.5 g for the aircraft in essentially constant altitude flight while rolling smoothly from one side to the other at bank angle rates up to the maximum obtainable through the AFCS modes.

3.1.2.3.6 Sideslip Limiting - Where sideslip limiting is a system requirement, the static accuracy while the aircraft is in straight and level flight shall be maintained within a incremental sideslip angle of ±1° from the trimmed value or a sideslip angle corresponding to a lateral acceleration of ±0.02 g, whichever is the lower.

3.1.2.3.7 Altitude Hold - Engagement of the altitude hold function at rates of climb or dive up to 2000 ft per minute shall select the existing barometric altitude and control the aircraft to this altitude as a reference. For engagement at rates above 2000 feet per minute, the AFCS shall not cause any unsafe maneuvers.

3.1.2.3.7.1 Control Accuracy - After engagement of altitude hold with a perturbation of 2000 feet per minute or less the following specified accuracies shall be achieved within 30 sec. Up to 30,000 ft the AFCS shall hold the aircraft within ±30 ft of the barometric altitude. From 30,000 to 55,000 ft constant altitude shall be maintained within ±0.1%. From 55,000 to 80,000 ft constant altitude shall be maintained within ±0.1% at 55,000 ft varying linearity to ±0.2% at 80,000 ft. Up to an altitude of 80,000 ft the AFCS shall hold the reference altitude to within ±60 ft or ±0.3% whichever is greater up to 30° bank angle and ±90 ft or ±0.4% whichever is greater from 30° to 60° bank angles. Within the capabilities of the aircraft, any periodic oscillation within these limits shall have a period of at least 20 sec. These accuracies apply for airspeeds up to Mach 0.9. Above Mach 0.9, the detail specification shall specify the accuracy requirements.

3.1.2.3.8 Return to Level - This mode shall be operable from any flight attitude and shall return the aircraft automatically to a straight and level flight condition through the smallest angle with no overshoot. There shall be no stopping or reversal of either roll rate or pitch rate during this maneuver. When operated the return to level control shall disengage any other automatic control mode. When leveled, the aircraft shall be in the attitude hold mode.

3.1.2.3.9 Control Stick Maneuvering - The type of control stick maneuvering shall be specified in the detail specification. If a force disconnect control stick steering type is used, the force applied at the stick grip reference point to effect disengagement of any other operational modes shall be minimized consistent with the prevention of nuisance disconnects. When the force on the stick is released, the automatic flight control system shall maintain the aircraft at the attitude prevailing at the time of stick release.

3.1.2.3.10 Angle of Attack Hold (TBD)

3.1.2.3.11 Structural Mode Control - Limit control surface motion to within the structural load considerations of the aircraft.

3.1.2.3.12 Mach Hold (TBD)

3.1.2.3.13 Automatic Guidance Functions - During the automatic guidance functions, the AFCS - aircraft combination is an element within the overall guidance loop. The requirements which this combination has to meet depend upon the performance requirements of the guidance loop, the guidance method and the particular guidance computer. Unless specific performance data are established in the applicable system specification, the following requirements shall be met.

3.1.2.3.13.1 General Tie-In Requirements - Provisions shall be made for the acceptance of external guidance signals from various computers generating the necessary commands in attitude, speed, altitude, flight path rate, acceleration, etc., to control the aircraft's flight path.

3.1.2.3.13.2 Command Signal Limiting - Means shall be provided to limit the command signals from external guidance systems, so that the AFCS system will not cause the aircraft to exceed maneuver limits that are inconsistent with the external guidance function and flight conditions.

3.1.2.3.13.3 Switching - Switching with zero command signal input from external guidance systems shall not cause transients greater than ±0.05 g normal acceleration at the center of gravity in pitch or ±1 degree in the roll attitude.

3.1.2.3.13.4 Noise Compatibility - The AFCS shall be so designated that the noise content in the external guidance signal, as specified in the applicable system specification, shall not saturate any component of the AFCS, shall not impair the response of the aircraft to the proper guidance signals, and shall not cause objectionable control surface motion or attitude variation. If the specified noise content is too great to achieve this goal, additional noise filtering shall be employed. Since additional noise filters impair the guidance performance, an optimum compromise between performance and noise filtering shall be determined by the procuring activity, the AFCS contractor and the contractor responsible for the guidance computer and the overall performance.

3.1.2.3.13.5 Data Link - If the steering information is transmitted to the automatic flight control system via a digital data link, the sampling frequency and number of bits per signal shall be compatible with the accuracy and dynamic performance requirements of the guidance loop, and the noise resulting from the sampling and digitalizing process shall not cause a total noise which will be incompatible with (TBD). If the steering information is transmitted to the AFCS via an analog data link, the gain variation and the zero shift of the data link shall be compatible with the performance and accuracy requirements of the guidance loop and the data link noise shall not cause a total noise which will be incompatible with TBD.

3.1.2.3.14 ACLS Tie-In - All data stated below are for fixed-wing aircraft and shall be met by the aircraft in the landing configuration and over the range of the expected weight, center of gravity, and speed variations. The guidance control system shall be incremental pitch and bank commands with respect to the trim attitude at the moment the guidance signals are inserted.

3.1.2.3.14.1 Longitudinal Control -

(a) The damping factor $\varepsilon,_{\theta}$ of the short period mode of the pitch oscillation shall be $0.5 \leq \xi_{\theta} \leq 1$ ($\xi = 1$ means critical damping)

(b) The natural undamped frequency ω_{θ} of the short period mode of the pitch oscillation shall be $\omega_{\theta} \geq 0.75 + 3.1\ \xi_{\theta}$ (radians per second)

These requirements shall be met for step input commands up to ±5 degrees from trimmed conditions at constant airspeed without changing trim and in the presence of noise as indicated in 3.1.2.3.14.5.

(c) The static gain K of the automatic flight control system, i.e, the ratio of elevator deflection to pitch attitude error, shall be

$$K \geq 2 \left[\frac{C_{m\alpha}}{C_{m\delta}} \right]$$

where $C_{m\alpha}$ is the pitch moment coefficient of the airplane, and $C_{m\alpha}$ is the control pitch moment coefficient.

3.1.2.3.14.2 Lateral Control

(a) During the landing phase, the airplane shall perform lateral maneuvers by coordinated turns. The uncoordinated sideslip angle shall not exceed the limits specified in 3.1.2.3.6. The longitudinal axis of the airplane shall not be tied to a heading reference, in order to alleviate the effect of side gusts on lateral touchdown dispersion.

(b) The transfer function from bank command to actual bank angle, when fitted by a second order lag, shall exhibit a natural frequency ω_ϕ and damping factor ξ_ϕ within the following limits:

$$0.6 \leq \xi_\phi \leq 1.2$$

$$\omega_\phi \geq 0.46 + 1.46\ \xi_\phi \text{ (radians per sec)}$$

This requirement shall be met for step input commands up to ±10% bank angle and in presence of noise as indicated in 3.1.2.3.14.5.

3.1.2.3.14.3 Airspeed Control - The indicated airspeed shall automatically be maintained at the correct approach by controlling the forces acting on the aircraft in the flight path direction (thrust and/or drag force). The thrust control system shall include an auxiliary capability to quickly counteract any airspeed change which may result due to pitch maneuvers. The action of the auxiliary input may be checked by introducing an incremental pitch step command of 4 degrees up and 4 degrees down with respect to trim conditions. In quiet air the airspeed change which results from either pitch command shall not exceed 1.5% of the reference value in the transient and 1% in the steady state. The auxiliary signal shall not be limited below a value which will be necessary to prevent airspeed change when automatic waveoff commands are transmitted to the aircraft. The thrust control system shall have the capability to decrease the airspeed error caused by a step horizontal wind gust to 36.7% of the initial error within 4 seconds after initiation of the gust. A single overshoot shall be permitted during the correction, however it shall not exceed 20% of the initial error. The airspeed shall be within 1% of the reference speed at steady state. For certain aircraft manual control of airspeed shall be permitted when adequately justified by the contractor.

3.1.2.3.14.4 Backlash and Deadspots - The total width of backlash or deadspot shall not exceed 0.1 degree of pitch command in the channel from pitch command input to control surface and in the channel from the pitch gyro to the control surface. For input signals larger than this specified backlash, the system performance shall be specified in (TBD). Backlash and deadspot in the channel from pitch input to control surface shall be determined on the ground by varying the pitch command input up and down while the gyro signal is kept constant. Backlash and deadspot in the channel from pitch gyro to the control surface shall be determined by tilting the pitch gyro up and down while the pitch command signal is held at zero or a constant value. The backlash and deadspot requirements shall be met under a loaded condition corresponding to 2 degrees of incremental angle of attack with respect to the trimmed condition and under the unloaded neutral condition. Neutral condition is defined as zero torque requirement from the servo. These same requirements shall be met by the roll autopilot.

3.1.2.3.14.5 Noise Compatibility - Noise which is superimposed on a proper input signal shall not saturate the AFCS components and shall not cause objectionable motion of control stick or wheel. The performance requirements specified in (TBD) shall be met under presence of this noise. The noise content in the input signal to the pitch and roll system shall be represented by white Gaussian noise which has a power spectrum density ϕ and is passed through a filter with the transfer function G ($j\omega$).

Pitch Command Input:

ϕ = 0.04 (degrees of pitch command)^2 per radian per second; flat in the frequency range from 0 to at least 30 radians per second.

$$G(j\omega) = \frac{1 + 3\ j\omega}{\frac{j\omega}{5}^2 + \frac{j\omega}{5} + 1} \times \frac{1}{1 + \frac{j\omega}{1.85}^2}$$

Bank Command Input:

ϕ = 0.01 (degree of bank command)^2 per radian per second; flat in the frequency range from 0 to at least 30 radians per second.

$$G(j\omega) = \frac{1 + 10\ j\omega}{\frac{j\omega}{5}^2 + \frac{j\omega}{5} + 1} \times \frac{1}{1 + \frac{j\omega}{1.85}^2}$$

3.1.2.3.14.6 Command Signal Limiting - Means shall be provided to limit the pitch and bank command signals immediately before feeding them to the AFCS. The pitch command shall be limited to -13.5° and +6.5° and the bank command shall be limited to ±30°.

3.1.2.3.14.7 Data Link - The resolution of the data link shall be at least ±0.04° minimum for pitch and ±0.1° minimum for roll. The sampling interval in the case of a sampling data link shall be not greater than 0.1 sec.

3.1.2.3.15 Tie-In With Ground Controlled Bombing (AN/MPQ-14, AN/TPQ-10) - The general tie-in requirements of 3.1.1.4 shall be applicable. Specific performance data for the AFCS - aircraft combination shall be compatible with the performance requirements of the overall guidance loop and shall meet the requirements of the detail system specification.

3.1.2.3.16 VOR/TACAN Hold (TBD)

3.1.2.4 Backup Functional Modes - Every DFBW system shall be able to withstand multiple failures and still be operational. In the event of complete failure, caused by internal or external forces, the system shall have a backup functional mode activated by the pilot which will give him at least level 3 flying qualities. The backup system shall be different and isolated from the primary flight controls as far as practical.

3.1.3 Reliability (TBD)

3.1.4 Survivability (TBD)

3.1.5 Invulnerability (TBD)

3.1.6 Maintainability

The DFBW system design and installation shall permit maintenance personnel to safely and easily perform required maintenance under all anticipated service conditions. Means shall be provided to easily accomplish all the required maintenance functions including: operational checkouts, system malfunction detection, fault isolation to the WRA, WRA removal and replacement, inspection, and retest. Emphasis shall be placed on ease of maintenance and minimum dependence on ground support test equipment.

3.1.6.1 Accessibility and Serviceability - The DFBW system 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 DFBW system. In addition, all DFBW system 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 kept to a minimum.

3.1.6.2 Operational Checkout Provisions - The DFBW system shall be designed with provisions for operation on the ground, without operating the main engines, to verify system operation and freedom from failure to the maximum extent possible. Electric and electronic components shall be designed to operate with the electric power generators supplied by Navy ground carts. Hydraulic components shall be designed to operate with the standard Navy hydraulic ground carts.

3.1.6.3 Malfunction Detection and Fault Isolation Provisions - Means providing a TBD probability for detecting failures and isolating faults to the WRA level shall be incorporated in all flight control electrical and electronic systems. These means shall include built-in-test equipment. For the mechanical and hydraulic portions of the DFBW system, provisions for the use of portable test equipment may be used, but should be minimized.

3.1.6.3.1 Cockpit Instrumentation - Cockpit instrumentation may be used for malfunction detection and fault isolation of the mechanical and hydraulic components of the DFBW system.

3.1.6.4 Portable Test Equipment - Where the use of built-in-test equipment would cause excessive penalties and where the use of portable test equipment is compatible with the maintenance support concept, provisions shall be made to permit the use of generally available and commonly used portable test equipment. Components which require peculiar, special, or new items of test equipment shall be avoided unless dictated by aircraft design, mission requirements, or state-of-the-art improvement.

3.1.6.5 Maintenance Personnel Safety Provisions - Systems and components shall be designed to preclude injury of personnel during the course of all maintenance operations including testing. 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 streamers which are. All such streamers shall be of a type which cannot be blown out of sight such as up into a cavity in the aircraft.

3.1.7 Safety (TBD)

3.2 COMMON COMPONENT REQUIREMENTS

3.2.1 Component Design

Systems, subsystems, or components that are in operational use today shall be used in lieu of designing and developing new hardware. This existing hardware must meet the requirements of this specification and the detail equipment specification. The order of preference shall be:

a. In operational use by the Navy.

b. In operational use by another branch of service.

c. Certified by a government agency for commercial aircraft.

3.2.1.2 Moisture Pockets - All components shall avoid designs which result in pockets, wells, traps, and the like into which water, condensed moisture, or other liquids can drain or collect. If such designs are unavoidable, provisions for draining shall be incorporated.

3.2.1.3 Interchangeability - All WRA's having the same manufacturer's part number shall be directly and completely interchangeable in the aircraft without any need for adjustment. Items which are not functionally interchangeable shall not be physically interchangeable unless specifically approved by the procuring activity.

3.2.1.4 Electric and Electronic Components - Electrical and electronic components shall be designed in accordance with MIL-E-5400 and this specification. In the event of conflict between this criteria and other referenced documents, this criteria shall govern.

3.2.1.4.1 Repairability (TBD)

3.2.1.4.2 Solderless Wrap Wiring - Solderless wrap wiring, for internal wiring, shall conform to (TBD)

3.2.1.4.3 Dielectric Strength (TBD)

3.2.1.4.4 Microelectronics - Integrated circuits shall be used to the greatest extent possible. They shall conform to the requirements of (TBD)

3.2.1.4.5 Burn-In - All electronic WRA's shall receive a minimum of a TBD hours burn-in test prior to installation and after original acceptance testing. Performance after burn-in shall meet the normal acceptance test procedure.

3.2.1.4.6 Potentiometers (TBD)

3.2.1.4.7 Electrical Tape - No pressure sensitive (adhesive or friction) fabric or textile tape shall be used.

3.2.1.4.8 Switches - The design of special electric/mechanical switches, other than toggle switches, shall be subject to the approval of the procuring activity.

3.2.1.4.9 Power Supply (Internal) - The DFBW system shall operate in accordance with the performance specified herein when supplied from external power sources(s) designed to (TBD). They shall be designed with monitors for internal thermal shutdowns compatible with the systems reliability.

3.2.1.4.9.1 Overload Protection - Overload protection of the wiring carrying the input power to the system shall be provided to protect against an excessive surge of current and a short circuit. Additional protection shall be provided within the system to protect the power supply of the computer(s).

3.2.1.4.10 Elapsed Time Meter - The WRA's shall include an elapsed time meter with the scale designated in hours and the maximum readout of 99,999. Control panels and small components with a high reliability shall be exempt from the requirement.

3.2.1.4.11 Vibration Isolation Panels - To meet the vibration, shock and acceleration requirements, externally mounted vibration isolation panel(s) shall not be allowed. The WRA's shall be rigidly mounted to the airframe.

3.2.1.5 Mechanical Components - (TBD)

3.2.1.5.1 Temperature Range - Mechanical components not covered by design requirements specified elsewhere shall be designed for operation at temperatures between 160°F (+71°C) and -65°F (-54°C).

3.2.1.5.2 Strength - The DFBW system shall be designed to MIL- TBD

3.2.1.5.3 Fastenings (TBD)

3.2.1.6 Foolproofness - All components of the DFBW system shall be designed so that incorrect assembly and reversed operation is impossible. Direction of operation and other essential information shall be conspicuously labeled.

3.2.1.7 Workmanship - Workmanship of the DFBW system shall be of sufficiently high grade to insure proper operation and service life of the system and components. The quality of the items being produced shall be uniformly high and shall not depreciate from the quality of the qualification test items.

3.2.1.8 Thermal Design - Wherever feasible, components shall be designed with heat-dissipating efficiency adequate to allow simple conductive, radiation, and free convection cooling utilizing the ambient heat sink to maintain the components within their permissible operating temperature limits. Operation under specified conditions shall not result in damage or impairment of component performance.

3.2.1.8.1 Ground Operation - Components which, when operated during ground testing are expected to be subject to high temperatures and therefore shall be designed that such temperatures will not damage or impair the components. Using externally operated forced cooling or other similar cooling aids shall not be considered in the design.

3.2.1.9 Service Life - Mechanical components subject to wear shall have a guaranteed service life of at least TBD hours. Rate gyroscopes and accelerometers shall be at least TBD hours. Electric and electronic WRA's shall be designed to be economically repairable for the airframe lifetime.

3.2.1.9.1 Shelf Life (TBD)

3.2.10 Lubrication

The components of the DFBW system shall be designed for no requirement for periodic lubrication for the service life of the hardware.

3.2.2 Component Fabrication

The selection and treatment of materials processing, and assembly, may be in accordance with established contractor techniques, in lieu of the following requirements, upon approval by the procuring activity.

3.2.2.1 Materials - When Government specifications exist for the type material being used, the materials shall conform to these specifications. Nonspecification materials may be used if it is shown that they are more suitable for the purpose than specification materials. These materials shall have no adverse effect upon the health of personnel when used for their intended purpose. This requirement shall be met for all probable failure modes and in the required environments.

3.2.2.1.1 Metals - Metals used in the DFBW system components shall conform to the requirements specified in TDB.
Magnesium and magnesium alloys shall not be used.

3.2.2.1.2 Nonmetallic Materials - Nonmetallic materials used in DFBW system components shall conform to the requirements specified in TBD.

3.2.2.2 Assembly of Electronic Components - When screws are used to assemble an electronic component, the different types of screws and different sizes shall be minimized consistent with the mechanical bonding requirements.

3.2.2.3 Identification - Equipment WRA's, subassemblies, components and parts of the FCS shall be identified in accordance with MIL-STD-130.

3.2.3 Component Installation

3.2.3.1 Cockpit Controls - There shall be no recesses around cockpit flight controls in which foreign objects can be trapped. The flight controls shall be designed to ensure that the controls clear all of the following:

(a) Aircraft structure
(b) Auxiliary controls
(c) Furnishings
(d) Instruments and instrument panels
(e) Pilot's body by at least TBD inches in all positions

3.2.3.2 Component Protection - All components of the DFBW system shall be protected where it is possible for them to be abused.

3.2.3.3 Electric Installation - The DFBW system shall comply with the following requirements:

a. The redundant electrical signal paths shall be dispersed and protected in such a manner as to reduce vulnerability and increase survivability

b. The wiring of the redundant electrical channels for a given control axis shall be separated to the reasonable extent possible. If adequate separation is not possible, physical and thermal barriers shall be provided between the channels

c. Wiring shall be enclosed in conduit in areas subject to maintenance action and possible abuse by maintenance personnel. The conduits shall be able to withstand manhandling loads

d. In an electrical signal path from the source to the recipient, the number of electrical connectors shall be minimized; however, redundant systems or channels shall not share a common connector.

3.2.3.3.1 Water Intrusion - WRA's that are installed in the vehicle with connectors located on the top or on the side, shall be designed so that moisture traveling along the cables shall have no deleterious effect. Aircraft connectors pertaining to the DFBW system shall not be installed in a position to trap moisture.

3.2.3.4 Electronic Equipment Cooling - If cooling augmentation for the electronic equipment is required, the cooling provisions design shall be consistent with the DFBW system reliability, operation and safety requirements.

3.3 SPECIFIC COMPONENT REQUIREMENTS.

3.3.1 Integrated Controls and Displays

The means to command the digital computer(s) shall be by the pilot's controls, either by primary flight controls, the control panel(s), or by a keyboard control. The status of the system shall be displayed by either a dedicated flight control display or by an integrated display. The pilot's command controls shall be designed and located in accordance with MIL-STD-203, and the requirements of this document.

3.3.1.1 Primary Flight Controls - Transducers appropriately located in the controls shall provide the pilot command inputs to the DFBW system digital computers.

3.3.1.1.1 Longitudinal - Longitudinal control shall be by means of a stick, wheel, or hand controller. Forward movement of the stick, hand controller, or wheel shall cause the aircraft to nose down and aft movement shall cause the aircraft to nose up.

3.3.1.1.2 Lateral - The lateral control shall be by means of a stick, wheel, or hand controller. Movement of the stick or hand controller to the right, or clockwise rotation of the wheel, shall cause the aircraft to roll to the right; movement of the stick or hand controller to the left, or counter-clockwise rotation of the wheel, shall cause the aircraft to roll to the left.

3.3.1.1.3 Directional - Directional control shall be by means of foot pedals or a hand controller. Pushing the right pedal shall cause the aircraft to turn to the right. Pushing the left pedal shall cause the aircraft to turn to the left.

3.3.1.1.4 Control Stick - If a control stick is used, and is removable, it shall be positively latched in place when installed. It shall be possible to install the stick only in the correct manner, and suitable means shall be provided to prevent rotation of the stick.

(a) The range of movement of the longitudinal control stick shall be a maximum of TBD. The extreme aft position shall be not more than TBD from the neutral position.

(b) The range of movement of the lateral control stick shall be a maximum of 3.5" to the right and 3.5" to the left of the neutral position.

3.3.1.1.4.1 Dual Controls - Where two or more control sticks or control wheels are used, every effort shall be made to prevent the malfunctioning of one from rendering the other inoperable.

3.3.1.1.5 Control Wheel - Control wheels shall be constructed of a material of adequate strength and durability, and shall be designed to have a minimum of sight interference with the instrument panel.

(a) The range of movement of the longitudinal control wheel shall be a maximum of TBD. The extreme aft position shall be not more than TBD from the neutral position.

(b) The rotation of the control wheel shall be a maximum of TBD clockwise and TBD counter-clockwise.

3.3.1.1.6 Foot Pedals - The foot pedals shall be readily adjustable in flight to at least TBD forward and TBD aft of neutral, in increments not exceeding TBD. Both pedals shall be adjusted simultaneously by means of a single control, and the control shall be located in accordance with MIL-STD-203.

(a) The range of movement of the foot pedal shall be a maximum of TBD forward and TBD aft of the neutral position. The foot pedals shall be interconnected to insure positive movement of each pedal in both directions.

3.3.1.1.7 Hand Controllers - The requirements for the following parameters for hand controller installations used in primary flight control systems shall be determined by the contractor and approved by the procuring activity:

(a) Location

(b) Breakout forces

(c) Force gradients

(d) Armrest requirements

(e) Damping

(f) Deflection

3.3.1.2 Trim System - A suitable trim system shall be provided for each of the primary control axis. It may be automatic or manual or a combination of both. The trim system need not have the authority or rate to be able to perform all desired maneuvers. Manual trim shall maintain a given setting until changed by the pilot. It shall have a deadband in each axis to give the pilot a preciseness of control and its rate shall not be so slow as to be ineffectual or so fast as to create a hazard.

3.3.1.2.1 Trim Switches - Electrical trim switches installed for manual trim shall be in accordance with MIL-S-9419. The electrical signal on these switches shall be 28 VDC or less.

3.3.1.3 Controls and Knobs - Controls and knobs shall operate smoothly with negligible backlash or binding. Means shall be provided to prevent movement due to shock or vibrations encountered in service. Controls and knobs shall be readily accessible and those with like functions shall be similarly shaped, and those for different functions shall have clear distinguishing features. The direction of motion of the knob or control and the location within the cockpit shall be in accordance with the requirements of MIL-STD-203.

3.3.1.3.1 Control Panel - A control panel shall be provided to allow the pilots the means to control the DFBW system modes.

3.3.1.3.2 Standard Captions - The following abbreviations when applicable shall be used on the control panel.

Nomenclature	Abbreviations
Altitude Hold	ALT
Automatic Carrier Landing	ACL
Automatic Flight Control System	AFCS
Automatic Leveling	LEVEL
Autopilot	AUTOPILOT
Command Augmentation	CMD AUG
Data Link Vector	VEC
Engage	ENGAGE
Heading Select	HDG SEL
Heading Hold	HDG
Mach Hold	MACH
Navigation	NAV
Pitch	PITCH
Precision Course Direction	PCD
Radar Altitude	RAD ALT
Roll	ROLL
Stability Augmentation	STAB AUG
Standby	STBY
Yaw	YAW

3.3.1.4 Keyboards (TBD)

3.3.1.5 Displays - A cockpit display shall be provided so that the flight crew can visually determine:

(a) Operational status

(b) FCS mode status

(c) BIT status

(d) Flight information

This information may be displayed on a DFBW system display, the DFBW system control panel, or an integrated display panel(s) consistent with the system reliability, operation, and safety. An automatic mode disengagement or change in modes not initiated by the pilot shall be indicated to the pilot.

3.3.1.5.1 Control Surface Indicator(s) - Cockpit display(s) showing the position of the control surfaces shall be provided. The system shall be accurate to ± 1° or better.

3.3.1.5.1.1 Additional Surface Displays - Suitable displays shall be provided showing the position of the flaps, slats, and speed brakes.

3.3.1.5.2 Critical Display Systems - Critical display systems needed to provide the pilot with information essential to safe flight such as an asymmetric warning system or a stall warning system shall be redundant.

3.3.1.6 Artifical Feel System - An artifical feel system may be supplied if applicable to provide a force gradient to the pilot. Any failure in the system shall not result in control forces that are either so high or so low as to be hazardous.

3.3.2 Transducers and Sensors (TBD)

3.3.3 Data Transmission and I/O (TBD)

3.3.3.1 Multiplexing (TBD)

3.3.3.2 Fiber Optics (TBD)

3.3.4 Digital Computer Hardware (TBD)

3.3.5 Software (TBD)

3.3.6 Electric Power

The electric power source shall be designed consistent with the flight control system reliability, operation and safety.

3.3.6.1 Redundant Electric Power - Each redundant electrical signal channel shall be associated with an electrical power source that is not connected to any other signal channel. The loss of a single electrical power source shall not result in the loss of more than one signal channel in a redundant system.

3.3.7 Actuation (TBD)

3.3.7.1 Strength - The components shall be designed to (TBD)

3.3.7.2 Redundancy - When one system of a dual actuation system fails the aircraft shall meet Level 1 flying qualities. When two actuation system of a multiple system fails, the aircraft shall be controllable to meet Level 3 flying qualities.

3.3.7.3 Hydraulic System - The following requirements apply if applicable. (TBD)

3.3.7.3.1 Hydraulic Supply - Hydraulic supply systems shall conform to MIL-TBD except as noted in this specification. A dualized hydraulic supply system shall consist of two separate systems, both operating simultaneously. One system shall be completely independent, while the other may be combined with the aircraft's utility system. There shall be no interconnections between the two systems. When dual systems are used in aircraft having multiple engines, the sources for each system shall be mounted on separate engines. Tandem or parallel actuating cylinders in the same housing are considered to be a satisfactory design for use with dual systems.

3.3.7.3.2 Ground Checkout - The hydraulic system shall be designed so ground checkout can be made with standard hydraulic test stands without the necessity of reservicing the system after completion of testing.

3.3.7.3.3 Integrated Actuator Package (TBD)

3.3.7.3.4 Auxiliary Power Supply (TBD)

3.3.7.3.5 Hydraulic Actuators (TBD)

3.3.7.3.6 Jamproof Valves - Every effort shall be made to design the hydraulic valves to preclude jamming due to hydraulic contamination and/or mechanical deflections.

3.3.7.4 Electrical Actuators - The following requirement apply if electrical actuators are used.

3.3.7.4.1 Electrical Power - Electrical power from a power source to the flight control actuator shall be transmitted through a number of independent power supply systems. The redundant electrical paths shall be routed to maximize survivability.

4.0 QUALITY ASSURANCE - (Specific Requirements TBD)

- 4.1 Requirements
  - 4.1.1 Analysis Requirements
  - 4.1.2 Test Requirements
    - 4.1.2.1 Test Witnesses
    - 4.1.2.2 Instrumentation
    - 4.1.2.3 Test Conditions
    - 4.1.2.4 Test Tolerances
- 4.2 Analysis
  - 4.2.1 Piloted Simulations
  - 4.2.2 Reliability Analysis
  - 4.2.3 Survivability Analysis
  - 4.2.4 Failure Mode Effects Analysis
  - 4.2.5 EMI/EMP/Lightning
- 4.3 Software Verification
  - 4.3.1 Module Test
  - 4.3.2 Subprogram Test
  - 4.3.3 Program Performance Test
- 4.4 Laboratory Development Tests
  - 4.4.1 Simulator Test
    - 4.4.1.1 System Integration Tests
    - 4.4.1.2 Static Performance Tests
    - 4.4.1.3 Dynamic Performance Tests
    - 4.4.1.4 Power Supply Variation Tests
    - 4.4.1.5 System Fatigue Tests
    - 4.4.1.6 Failure Mode Testing
    - 4.4.1.7 Emergency Procedures Verification
  - 4.4.2 Safety of Flight Tests
    - 4.4.2.1 Component Tests
    - 4.4.2.2 System Tests
- 4.5 Aircraft Tests
  - 4.5.1 Ground Tests
    - 4.5.1.1 FCS Integrity Test
    - 4.5.1.2 Functional Tests
    - 4.5.1.3 Electromagnetic Interference

4.5.2 Flight Tests

4.5.2.1 Mode Verification

4.5.2.2 Performance Verification

4.5.2.3 Failure Mode Demonstration

4.6 Preproduction Tests (Qualification)

4.6.1 Acceptance Test

4.6.2 Electromagnetic Interference

4.6.3 Environmental Test

4.6.4 Reliability Demonstration

4.6.5 Maintainability Demonstration

4.6.6 Support Equipment Compatability Demonstration

4.7 Acceptance Tests

4.7.1 Examination of Product

4.7.2 Operational Tests

4.7.3 Manufacturing Run-In Test

4.7.4 Reliability Acceptance Test

4.8 Documentation

4.8.1 Technical Development Plan

4.8.2 Detail Equipment Specification

4.8.3 Software Documentation

4.8.4 Design/Analysis Reports

4.8.5 Test Reports

5.0 PREPARATION FOR DELIVERY

5.1 PACKAGING REQUIREMENTS

In the event of direct purchases by or shipments to the Government, the packaging shall be in accordance with the contract or the approved detail equipment specification, as applicable. Components shall be delivered complete, tested, and ready for installation. All receptacles, ports, and delicate protruding shafts or parts which may be damaged during handling shall be protected by dust-tight covers, caps, or plugs during shipping, storage, and handling.

6.0 NOTES

6.1 INTENDED USE

The requirements of this specification are general as applicable to flight control systems and are based on service experience to date. Deviations to the requirements of this specification may be granted following presentation and approval of substantiating data.

6.2 PROCEDURE FOR REQUESTING DEVIATIONS

The requirements of MIL-STD-480 shall be met. Substantiating data shall be in the form of a test, simulation or analytical data generated by the contractor or manufacturer.

6.3 ABBREVIATIONS

ACLS	-	Automatic Carrier Landing System
AFCS	-	Automatic Flight Control System
BIT	-	Built-in-Test
CAS	-	Command Augmentation System
CCV	-	Control Configured Vehicle
CSS	-	Control Stick Steering
C.G.	-	Center of Gravity
CPU	-	Central Processing Unit
CTOL	-	Conventional Takeoff and Landing
DFBW	-	Digital Fly By Wire
DLC	-	Direct Lift Control
EMI	-	Electromagnetic Interference
FBW	-	Fly-By-Wire
FCS	-	Flight Control System
fm	-	Frequency Mode
g	-	Gravitational Constant
G.M.	-	Gain Margin
Hz	-	Hertz
I/O	-	Input/Output
an	-	Normal Acceleration
ay	-	Lateral Acceleration
θ	-	Pitch Angle
ϕ	-	Roll Angle
Ψ	-	Yaw Angle

P.M. - Phase Margin
RSS - Relaxed Static Stability
SAS - Stability Augmentation System
TACAN - Tactical Air Navigation
TAS - True Airspeed
TBD - To be Determined
VOR - Very High Frequency Omnidirectional Range
V/STOL - Vertical/Short Takeoff and Landing
WRA - Weapon Replaceable Assembly

6.4 DEFINITIONS

Acceptance. The determination by the user (customer) that the product meets his requirements.

Active Control System. A system which actively commands the movement of control surfaces on the basis of sensor inputs to provide some function or characteristic not available in the aircraft passively.

Aerodynamic Closed Loop. Is one which relies on aerodynamics for loop closure such as stability augmentation. A nonaerodynamic closed loop does not rely on aerodynamics for loop closures. An example is a servo-actuator loop.

Assembler. A program which translates mnemonic assembly language instructions into the binary instructions used by the processor, assigns values to named addresses, and performs other functions as an aid to the programmer in writing a software program.

Assembly Language. A programming language which uses the set of processor executable instructions in mnemonic format to write the software program.

Automatic Carrier Landing System. A carrier landing system which provides automatic flight control to touchdown. The system includes all the elements of the airborne equipment and the carrier based equipment.

Automatic Flight Control System (AFCS). AFCS consist of components which generate and transmit automatic control commands which provide pilot assistance through automatic flight path control or which automatically control airframe response to disturbances. This classification includes autopilots, autothrottles, structural mode controls, etc.

Autopilot. A part of the AFCS which automatically performs functions performed by a pilot, such as maintaining attitude or heading.

Built-in-Test (BIT). Integral onboard testing devices which enable rapid isolation on the ground of a faulty Weapon Replaceable Assembly (WRA), without removing the WRA from the aircraft. Usually a warning of malfunction is given by an external device on the WRA.

Central Processing Unit (CPU). The central element of a digital computer. It generally contains an Arithmetic/Logic Unit, a number of registers, and the necessary control circuits.

Channel. The term describing a single signal or control path within a device or system that may contain many paths. A channel is an entity within itself and contains elements individual to that channel. A model may be used as a reference channel in a detection-correction system.

Command Augmentation System (CAS). An active control system that augments the pilot's control inputs with sensor inputs to provide him direct control of aircraft motion rather than control surface position.

Compiler. A program which translates a higher order language into the language of a particular computer and performs the assembler functions.

Comparison Monitor. A device which compares signals and warning outputs from two or more sources and provides its own signal to indicate that the two or more outputs are within or outside specified tolerances.

Computer. A system containing a processor, variable storage memory, program storage memory, input and output interface circuits, and support circuits including control, timing, power supply, etc. The computer can perform a large variety of functions by the sequential execution of a set of basic operations in the processor. The commands for the set of operations is called the software program and is stored in the program memory. (The hardware necessary to convert input signals to the proper digital form and also the hardware necessary to convert the output signals to the proper form is usually included within the definition of a computer.)

Control Configured Vehicle (CCV). An aircraft whose basic aerodynamic and/or structural design includes the use of an active control system.

Control Law. A set of equations which define control surface position as a function of sensed inputs.

Control Wheel (stick) Steering. An AFCS mode which permits pilot control inputs to be introduced into the system through the wheel or stick when the AFCS is engaged and controlling the airplane.

Damping Ratio. The equivalent second order viscous damping ratio. The critical damping ratio is defined as unity.

Direct Lift Control (DLC). A system that will enable the pilot to give vertical translation to the aircraft without a rotational moment.

Elastic Mode Suppression. Active control to increase the damping of lightly damped structural bending modes excited by gusts.

Fail-Operational. A system will continue to operate with no degradation in performance after a failure.

Dual Fail-Operational. A system that will continue to operate with no degration in performance with 100% probability after the first failure and operate with no degradation in performance with a 95% probability after the second failure.

Fail-Passive. A system that does not cause an unsafe condition after a failure. There is no disruption in the aircraft performance. The function just ceases to be performed.

Fail-Safe. A system that does not cause an unsafe condition after a failure. It may be completely passive or it may require immediate pilot corrective action. It does not preclude continued safe flight and a safe landing.

Fail-Soft. A system that does not cause an unsafe condition after a failure. Pilot corrective action may be required within for example 6 seconds.

Failure. A condition which can give rise to a fault, usually considered permanent.

Fault. An anomaly in the performance of a system.

Fault Tolerant. A system which is able to continue to provide critical functions after the occurrence of a fault.

Flight Control System (FCS). FCS include all components used to transmit flight control commands from the pilot or other sources to appropriate force and moment producers. Excluded are aerodynamic surfaces, engines, crew displays and electronics not dedicated to flight control.

Flight Envelope. Altitude and Mach range of aircraft.

Flutter Suppression. Active control to suppress aeroelastic flutter modes.

Fly-By-Wire (FBW). The use of electrical signals to connect the pilot's control devices with the control surfaces.

Gust-Load Alleviation (GLA). Active control to reduce loads due to gust.

Higher Order Language (HOL). A language which enables a programmer to use simple English phrases in writing a software program. It is not dependent on the particular computer and is more universal than assembly language.

Integrated Actuator Package (IAP). An actuator design wherein the driving hydraulic source is contained within the package.

Integrated Circuits. An entire functional electronic circuit, fabricated on one tiny monolithic silicon chip. It may contain anywhere from a few to thousands of transitors, resistors, diodes, capacitors, etc.

Large Scale Integration (LSI). An integrated circuit on a single small silicon chip, upon which more than 1000 digital gates have been fabricated.

Maneuver-Load Control (MLC). Active redistribution of the increased loads due to maneuvers in order to reduce structural loads.

Microelectronic. Synonymous with integrated circuits.

Microprocessor. A digital Central Processing Using (CPU) fabricated on one or more LSI chips. All contain an Arithmetic/Logic Unit, several registers, and the necessary control. When data storage, a clock, some input output interface circuits, and a power supply are added, the microprocessor becomes a microcomputer. It may mean just a CPU or an entire microcomputer.

Processor.
1. Short for microprocessor.
2. A software program which includes the compiling of a given programming language, e.g. BASIC processor, COBOL processor.

Qualification. A formal process whereby a system or aircraft is defined to be ready for flight operations.

Random Failure. Any failure whose occurrence is unpredictable in an absolute sense and which is predictable only in a probabilistic or statistical sense. Random failures are those which cannot be attributed to wearout, defective design, or abnormal stress, and can occur at any time within the equipment's useful life.

Redundancy. A design approach such that two or more independent failures, rather than a single failure, are required to produce a given undesirable condition. Redundancy may take the form:

a. Providing two or more components, subsystems, or channels, each capable of performing the given function.

b. Monitoring devices to detect failures and accomplish annunciation and automatic disconnect or automatic switching.

c. Combination of the two above features.

Redundancy Management. The process of managing redundant elements in order to identify a failure and then reconfiguring the system to remove the effects of the failed element and continue operation with unfailed elements.

Relaxed Static Stability (RSS). The use of active control to allow the static stability of the basic unaugmented airframe to be relaxed. The aircraft with the active system operating will have the normal stability margins.

Ride-Control System. Active control to improve the quality of the ride for the crew and passengers.

Software. A set of instructions intended to be stored in programmable memory of a computer for the purpose of providing step-by-step control to the processor. This includes source program instructions requiring assembly or compilation as well as binary machine language instructions.

Stability Augmentation System (SAS). An active control system which augments the natural stability of an aircraft.

Transient Fault. A temporary anomaly in the performance of a system.

Validation. The determination that a resulting product meets the objectives that led to the specification for the product. This determination usually includes operation in a real environment.

Verification. The determination that a design meets the specification. Verification is usually a part of the validation process. A simulated environment is often used.

Variable Geometry Control System. Those components and subsystems which transmit control commands from the pilot(s) and which produce forces and moments to change the aerodynamic configuration of the aircraft. Variable geometry controls include those for changing wing sweep angle and wing incidence angle, folding wing tips, deploying canard surfaces, and varying the angle of the nose of the aircraft with the body.

Weapon Replaceable Assembly. TBD

APPENDIX E

PANEL DISCUSSION SUMMARY

FLIGHT CONTROL SYSTEMS CRITERIA SYMPOSIUM

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CALIFORNIA

JULY 11-13, 1978

SUMMARY OF

PANEL DISCUSSION ON

CONTROL SYSTEM DESIGN

Panel Chairman: George Vetsch

I. Current Design Problems

You will find many of the points made here are the same as made in the Performance discussion because the same topics are bothering most of us. The principal point, which has run through several papers presented earlier in the symposium is that we should specify the desired mission segment performance, not how to go about getting it. By this, we mean that if the task is one of pointing the velocity vector, then the part of the velocity vector in space should be specified, not the rate that the aircraft rolls. We might, in fact, be obtaining the change of direction of velocity vector by flat turning or by some means other than conventional roll control. If the task is one of pointing attitudes of the aircraft, then we should have specifications relative to the pointing attitudes of the airplane, i.e., the pitch and heading attitudes. We should specify the probability of mission success and the probability of loss of control, not the degree of fail-operability. The specifications of dual fail-op without some recognition of the probabilities of these failures really makes very little sense. Some people within the group feel there should be an overall specification that no single failure should exist unless they are extremely remote. There is some difference of opinion whether even that requirement should be included.

With regard to failure transients, a number of points should be made. First, magnitude of allowable transients should be related to the category and mission segment that is being flown. There is a great deal of difference between the allowable transients for fighter and transport aircraft. There's also a large difference in a fighter between the approach-to-landing segment where a transient could cause an immediate catastrophe versus one in an air-combat situation at high altitude. Acceptable levels of G should vary greatly with the flight segment, as well as the category of the aircraft involved. One possibility is to specify the level of transient as a percent of the limit load factor of the aircraft instead of an absolute number. This would allow higher G, fighter class of aircraft to have larger transients, particularly on occurrence of the fault that fails you down to the level of just being able to fly the aircraft. It is possible that two factors may limit the load factor allowed. It may be structural and therefore a percentage of limit load or it may be a physiological constraint on the part of the pilot. Physiological constraints can vary from an increase in workload, in that some failure that causes a degradation in stability might cause a large amount of activity on the control stick, to one that causes G forces so large that they incapacitate the pilot. One of these two factors, either the structure or the pilot should constrain the size of the transient that's allowable. The ability to recover control is another factor that ought to be considered.

We should classify performance by the specific mission, not just firing and bombing as is presently in MIL-F-8785-B. Mission segments should include air-to-surface bombing and gunnery, air combat, take-off and landing and cruise. The performance should be tied to the appropriate segment of flight.

II. Definition of Control System Features

Another area that we were asked to address was the definition of control systems features. The present classification of "primary" and "secondary" losses meaning when you begin to talk about advanced fly-by-wire systems including digital systems. We should change to a manual and automatic classification, and within this classification include all parts of the flight control system. That includes sensors, electronics, actuators, et cetera, so that there's not a separate electronic Spec. The degree of criticallity of control should be included. For example, failure of an automatic mode that is designed to limit angle of attack in an air-combat situation is a serious degradation. Failure of an automatic mode designated to hold altitude is less serious.

Some of our group believe a back-up system should be defined. There's a difference of opinion in this area. A back-up system is defined as a control system that is used only in the event of failures and emergency situations. This back-up system could be mechanical, fluidic, or electrical. The difference between the back-up system and what we are calling manual and automatic flight control modes is largely that it's never flown except in an emergency situation.

An adequate pilot-vehicle interface, including both controller tactile and display effects, is essential and should be included in the specification. The relationship among flight controller characteristics, pilot displays, and controllers needs definition.

We think that we should define Built-In Tests, as being the part of the test that is done on the ground to sharply divide it from airborne automatic tests. BIT is a manually executed test and one that involves motion of the surface and torquing of the gyros, actions that would be unsafe to do in the air, but are essential to check out the redundancy management aspects of redundant systems.

Another area that should be defined is automatic tests while airborne. Terminology that has been applied to this function is "In-Flight Integrity Management". This includes the entire process wherein the control system is tested, monitored, or reconfigured, and the results of this information provided to the pilot so that he knows the status of the system.

III. Classification of Control Systems

We suggested earlier that flight control systems should be divided into manual and automatic. Manual system range from mechanical to boosted-mechanical, mechanical with stability augjentation system (meaning damping only and no pilot input transducers), mechanical plus CAS (wherein the pilot input transducers are added and we have a dual command path). We suggest the term "electrical" instead of "fly-by-wire", to allow varying degrees of what is now called fly-by-wire including direct electrical link.

The electrical flight control system would have a stability augmentation system capability where damping is added and a control augmentation system capacity where the pilot transducers provide inputs. We also think there is a need for a miscellaneous classification to cover such areas as fluidic and light transmission methods.

In automatic controls we suggest this nomenclature: First, the pilot relief functions including the autopilot type modes, attitude, attitude hold, heading, and heading select. Second, active control technology would include modes relating to the structure of the airplane, maneuver load control to change the lift distribution across the wing, gust aviation, and automatic flutter prevention to enable reduction in weight and still have an aircraft that's stable. Third would be safety monitors including Alpha Beta, and N_z limitors. The fourth class would include trajectory control features such as autonav, auto-ILS, and automatic carrier landing features.

IV. Interface Requirements

Another area we were asked to address was one of interface requirements involving the flight control system. There are four classes of interfaces involved: (1) the "intra-" system including the interfaces among the sensors, computational elements, actuators, and the pilots interface directly to the flight control system, (2) the power interface to the electrical, hydraulic and pneumatic power sources, (3) "inter-" systems involves interconnections to such systems as propulsion, fire control, navigation and pilot-vehicle interface of the airplane for coupling purposes, (4) structural interfaces with the airplane including control surfaces, structural strength, stability, and flexibility effects. All of these are general classifications of areas where interfaces are required within the flight control system and to other systems of the airplane. Details of these interfaces vary greatly with the aircraft involved. Writing a general specification that does anything more than list areas of concern that must be taken care of, probably shouldn't be done. Details of interfaces should be left to the detail spec for the airplane.

V. Multimode Systems

Another area that has been developing in recent years is multimode flight control. This term presently means manual flight control modes that are used for selected mission segments and are optimized for those mission segments. We suggest that since, in the future, automatic modes may also be optimized for mission segments, that the term should be broadened and that we ought to talk about both manual and automatic multimodes. The kinds of specifications that could be applied to those systems that include multimodes involves such things as switching among the modes, which should be smooth and transient-free, and the means of executing these switches. The means should be immediately available, particularly for transition to such modes as air combat.

Logic is needed to prevent the selection of incompatible modes. We don't want a landing multimode selected at high speed, for example. Some indication to the pilot of which mode is engaged needs to be supplied. This should be very readily evident in the displays he's looking at because the displays should be designed for these modes so that the proper information is available to the pilot for each mission segment.

The performance of the flight control system within each multimode should be natural. There should be no unnatural changes in the way the aircraft responds. It should perform as the pilot expects it to. When he's in an air-to-ground weapon delivery task, he needs smooth control of the velocity vector, when he switches to air combat, he needs much higher acceleration.

VI. Proposed System Designs

In terms of proposed system designs, the specification shouldn't inhibit use of designs that will meet requirements. If a design will meet the safety, reliability and performance requirements that are imposed, then it should be allowed. In the initial proposal, at least, the contractor should be free to propose the flight control system he believes will meet the government's needs.

VII. Integration of Propulsion Control

Another area we were asked to address was the integration of propulsion control with flight control. Of course, the dynamics of the engine and the engine controller must be included in the design of these coupled modes, particularly carrier landing. Forces and moments resulting from engine thrust, air flow effects and gyroscopic moments must be accommodated in the flight control system design. This is another way of saying that the specification for the automatic carrier landing and the APCS should be integrated from the beginning. They shouldn't be two separate designs that somehow get into the same airplane. The specification shouldn't be oriented to any one specific design as it presently is for the APCS.

SUMMARY OF

PANEL DISCUSSION ON

DIGITAL HARDWARE

Panel Chairman: James Rebel

Panel Members

Howard Belmont	Erwin Naumann
Shawn Donley	Gunar Soderlund
Wally Fields	Wally Kuhnel
Dick McCorkle	Rudy Seeman

I think, first of all, I'd better explain who we are because once I get into our comments, you're going to see a lot of repetition of what you just heard from the first two sub-committees. We're the Digital Hardware working group. There was myself as chairman, Howard Belmont, Shawn Donley, Wally Fields, Dick McCorkle, Erwin Naumann, Gunnar Soderlund, Wally Kuhnel, and Rudy Seeman.

As we perceived our task, the purpose was to address how this new specification should address hardware--digital hardware or otherwise--for all flight control systems. And as you shall see, we ranged farther afield than that. A lot of the areas have been touched on by some of the other groups. But this makes sense in a way because hardware is impacted by and impacts software, and the design requirements, and the performance requirements. It's all linked together.

One of the first things we did (it's a definite requirement) was to identify classes of control systems. There's such a wide variation that the first thing a specification ought to address is the definition of classes. For example, a Class I system: a full authority fly-by-wire, CAS system. A class II system, a Class III system, and so on all the way down to the most elementary flight control system possible.

Now taking that and trying to work with some of the more general aspects of hardware, the first thing we locked onto was reliability aspects. The specification has to deal not so much with requirements of redundancy in terms of numbers of streams of the system, or whether it should be single fail-op, or dual fail-op, or what have you; but rather dealing with mission requirements in terms of the number of flight hours between catastrophic failure or some sort of quantitative abort requirement.

One of the side topics we got on at that point was "Do we have in hand right now adequate numbers to come up with some specification requirements like that?" And I think the conclusion we reached is "Yes, the data is available but somebody must go out and get it." The last exercise in this area was the Honeywell study about seven years ago. Perhaps it's time to go back and redo that again and generate another data base for this specification based on more recent experience, both military and commerical.

Dealing with the problem of specifying abort rates, several questions came up. (Basically, what we ended up doing in a lot of cases is coming up with a shopping list of questions that have to be answered before they can be put into some sort of specification format). Some of the questions we dealt with are: The definition of an abort. What is an abort? It's obviously mission dependent, but what goes into making an abort necessarily imply degraded handling qualities? Also, a definition of loss of control. What is catastrophic loss of control? Does it mean functional loss of an axis or does it mean the airplane turns turtle on you and it's time to eject or just what is a precise definition of loss of control?

We dealt briefly with the verification impact. In other words, the section 4 portion of the Specification. How do we deal with the data we've just been talking about? How do you determine specification compliance for an abort rate or catastrophic failure rate? Do you do this analytically or is this done by some laboratory testing?

The requirements for reliability It was felt basically that the first level, that is to say the determination of these abort rates and catastrophic failure rates, are primarily the responsibility of the government or the user. Now this is what should be in the specification.

Allocations of the MTBF requirements for individual black boxes is primarily the responsibility of the prime contractor. And implementation of this allocation is probably the responsibility of the vendor or supplier of the equipment. As mentioned earlier, somewhere in the specification we have to make allowances for single point fialures. We can't outright prohibit single point failures but we ought to insure that if they exist there should be a ver low probability of their ever occurring.

We discussed the subject of back-up flight control at some length and we really didn't reach any conclusion about it other than the fact that specifications should in no way imply or require the presence, or the absence, of a back-up flight control. The mission of the airplane, the class of the flight control system, and the other operational requirements should determine on the part of the contractor whether or not back-up flight control system is required and the nature of this back-up control system, rather than be specified in a top level specification.

Also the specification should address reversion requirements. What constitutes a reversion from one level of redundancy to another and what difference is there between that and the maintenance type MTBF? In other words, any sort of arbritrary failure as opposed to catastrophic MTBF where the failure implies some sort of disastrous consequences.

The second area of hardware we dealt with was maintainability. Under this we discussed the requirement for fault isolation and detection. One item that came up was the use of peculiar ground support equipment or ATE. The Navy's philosophy has changed almost 360 degrees over the last ten years or so. Our general conclusion was that, where necessary, this peculiar ground support equipment or additional test equipment should not be eliminated by the specifications. But that anything that can be done to eliminate false removals and facilitate maintenance at the aircraft level should be encouraged by the specification. Now if this implies additional ground support equipment, then by all means use it. In the long run it's going to pay for itself.

A subject of intermittent failures came up also under maintainability. Also the requirements for some means of determining failures post flight. Determination of what these intermittents were goes a long way towards making flight control systems more effective and easier to maintain. Whether this is some sort of non-volatile memory that stores comparitor trips or whether it's some sort of mechanical flag set on the WRA, is really a function of the individual design. But some means of post flight identification of intermittent faults is an absolute must.

We finally got around to our prime purpose. That was digital hardware and the aspects of digital flight control systems. One hard conclusion we came up with was the fact that spare memory and speed are definite requirements and should be spelled out in the spec. But what those numbers are and where they should be applied in the development of the program has to be determined. In other words, a percentage of spare memory, is going to vary as a function of the maturity of the system. You obviously need more earlier in the development but what those numbers are and where they should be invoked in the system development is something that has yet to be determined.

We diverged a little bit into the software field. And we discussed the impact of higher order language and, in general, the impact of standardization in all digital areas. That is, even standardization of processors itself. I think it's fair to say standardization of software, standardization of digital hardware and a number of other areas is coming, and sooner or later some degree of standardization is going to be imposed on almost all avionics. I think we owe it to ourselves to get one step ahead of the game and find out just what impact this standardization is going to have on digital flight control systems, to determine what is going to be a beneficial impact and what is going to be a negative impact, so we can prepare to either work with or around this upcoming standardization. I think somebody mentioned that we have to determine right now whether we're going to want to kiss these people or shoot them.

Detail problems concerning digital flight control systems such as transport delays, or digital noise or any of the other current problems that have been brought up on digital flight control systems, especially their impact on flying qualities was not addressed in any detail. Nor do we feel that it really should be addressed in this type of specification. That's something of a more immediate design nature and should not even be addressed in this type of specificaiton.

These are some general comments that came up. The point was made that perhaps a lot of emphasis that has been put on, both at this symposium workshop as well as other areas, on fly-by-wire systems and digital flight control systems. The majority of the emphasis and apparently the majority of the problems would be with the electronics portion of the control system, where in fact, the actuation systems, the hydraulic system and the interface with other systems is perhaps a bigger problem. The design and development costs of these systems are far greater than any of the electronics.

Other miscellaneous subjects that were addressed include electrical actuation. It was basically felt that this was something that's not likely to be seen within the next few years and that the area of integrated actuators and Power By Wire was more promising.

The area of redundancy management is a very difficult one. Somehow we must insure that whatever scheme is arrived at must insure that the most critical failures or the most probable failures are those that are detected and isolated.

Now finally, just some general philosophy. It was felt that the purpose of this symposium, although it was oriented to a particular specification, served all the attendees regardless of their interests and perhaps it might be a good idea to conduct this sort of thing on a periodic basis, both as far as continuing the update of specifications (or future updates) as well as just an interchange of knowledge. Although administratively flight control comes under a lot of other similar get-togethers, nowhere is there any unique gathering of all the sometimes separate technologies involved in flight control systems.

SUMMARY OF

PANEL DISCUSSION ON

DIGITAL SOFTWARE

Panel Chairman: Garry Gross

As we saw the purpose of this session, there were two objectives. One was to identify areas where studies are needed to define methods of specifying software requirements specifically for flight control applications. And realizing that this is a general specification, we didn't think the specification should get into details about how the designer should be coding his problem, but should be oriented more towards requirements on documentation, general guidelines, and functional requirements.

The second purpose was to identify areas where studies are needed to define the relationship between software specifications and the verification process. How do you verify that you've met the requirements for software? That's a difficult task.

Therefore, we prepared a list of what were considered to be critical issues. The first being the proper specification of the functional requirements; not only proper, but it should be specified independent of the implementation requirements. By this I mean the pecularities of a particular machine or particular hardware scheme should not affect the definition of requirements. They should be totally independent of the machine.

The next item is the impact on safety and reliability of the environment (e.g. data) and the multiplicity of potential computing paths within the software which are part of the class of so-called "generic" software failures.

Another item is the extent and the adequacy of the verification process. How long do you verify it, and when do you know you've adequately completed the job?

An important area is the distinction between flight critical and mission-effective software. The point was brought up that maybe we want to separate those two ideas and have more rules, more stringent requirements for the software that's required for flight critical functions, such as more fault tolerance. Loss of mission-effective software may mean the pilot can't complete the mission...he'll have to return to base, but an airplane won't be lost.

The configuration management and control and the impact of end-users involvement. End-user involvement meaning "Is the Navy going to be totally responsible for maintaining the flight control software?" I don't think so, but if it is, there should be very different requirements on documentation and controls. The Navy is going to want a lot more if they have to maintain the software.

The next point is getting a lot of visibility lately, the desirability of requiring a specified higher order language. Software types are talking about the effects on maintainability of the software. Agreed, a higher order language makes maintainability a lot easier, but what about the cons? If there are any, what are they? I think this area should be investigated further.

The last two items are fairly new areas. The impact of fault tolerance techniques and the impact of error correcting and other sophisticated software transmission codes. Should these be used? When can they be used?

SUMMARY OF

PANEL DISCUSSION ON

PERFORMANCE REQUIREMENTS

Panel Chairman: Warren Clement

Our panel discussion was asked to consider as much as possible of the following scope of control system performance requirements from the symposium call for papers:

> Applications of modern control theory; snythesis of control laws; stability margins; interface with MIL-F-8785B; tracking/alignment/nulls; sensor performance; inner/outer loop frequency response criteria; time domain criteria; models for turbulence/bubble/ship motions; simulation requirements; documentation requirements; APC performance criteria.

We began with two leading questions for the purpose of stimulating and organizing the discussion. Following a restatement of each question here, we shall list recommendations in the form of a consensus of answers to each question; and, in some cases, there will be more questions rather than answers in response to the original questions.

We started off with Question A: "What is the pilot trying to do with the airplane and how should it be specified?" In formulating answers to Question A we also considered answers to consequential Question B: "What is the cost to the pilot and the cost to the aircraft subsystems in meeting the performance requirements?"

We shall list recommendations based on Question B subsequently, because we addressed primarily Question A from which ten recommendations follow.

A. Requirements on Performance Itself

1. The flight control system specifications should quantify the performance of tasks in the mission phases required by the Navy in terms of demonstrable measures. By "demonstrable" we mean something that one can reveal convincingly during the test and evaluation. For example, the performance measures should be expressed in terms of command following tasks and also in terms of disturbance regulation tasks in a variety of specified environments, including, in addition to the customary environments, the degree of vulnerability to electromagnetic interference, threat damage, loss of control, inadvertent built-in tests during flight, and any other emergencies in flight.

2. Interactions with related disciplines

    a. The flight control system specification should identify interactions with propulsion control because, from the standpoint of flight control, the propulsion system is a force effector.

The scope of propulsion control should include the APCS, which should not be separate from but, instead, should be integrated with the flight control system.

b. The flight control system specifications should identify interactions with display and pilot workload disciplines, because the flight control system specifications should address manual as well as automatically controlled tasks. There should be a recognition of the undesirability of conflicts in techniques and performance between automatically and manually controlled tasks in general and between automatically and manually controlled landing in particular.

c. The flight control system specification should identify interactions with structural loads and flutter disciplines, because the flight control system specification will ultimately have to address active control of loads.

3. The flight control system specification needs to recognize that although the control laws may be mission task-dependent, the control laws should not confuse the pilot from mission phase to mission phase and from task to task. There should be a clear understanding of how to use and to interpret the control-and-display system for each task.

4. The flight control system specification should define levels of reliability and maintainability in terms of mission task degradation, whereas the issue of redundancy management should be left to the designer.

5. Flight control specification compliance should not depend on pilots' skill or ability, because the group is making the recommendation that manual control functions should be addressed by the flight control system specifications.

6. A better cooperative and coordinated relationship should exist between the flying quality and flight control system disciplines and between the respective specifications as well, especially in regard to specifying the motions of the vehicle and the manipulator centering are cited by reference in the flight control specification, whereas the details of manipulator-force-gradients are in the flying quality specification.

7. Demonstrable performance measures for the six degrees of freedom required to perform each mission task should be put in the flying quality specification rather than in the flight control system specification. This is in order to provide the designer with the specifications on closed loop stability and dynamic characteristics of inner loop variables at the outset of the design process. The designer, however, should be allowed the freedom to respond to these requirements with the necessary controls, control authorities, and control power required to satisfy the command following

and disturbance regulation requirements set up at the outset in the flight control system specification. This is a key point of interaction and, in fact, the group is dividing the performance requiements by recommending that outer-loop requirements should be in the flight control system specifications and that inner-loop requirements should be in the flying quality specifications.

8. The flying quality specification should also address the purity of motion (or the lack of cross coupling) in each of the six degrees of freedom.

9. The medium of flight control system implementation, that is, whether it's mechanical, electrical, fluidic, optical, or any combination thereof, should be left to the designer. And he should have the latitude to choose the medium of implementation all the way from the sensor to the effector guided in part by the specification on the "ilities" and the specification on the threat environment.

10. The flight control system specification needs a "background and users' guide" which should include different design methods and the relationships among the applicable criteria for those design methods, because it is presently difficult for the designer to transform between time and frequency domain criteria, for example.

B. Requirements on the Cost of Performance

We shall list three recommendations based on Question B which addressed the issue of the cost to the pilot and to the aircraft subsystems in meeting performance requirements.

1. How can pilot workload or pilot operability be measured objectively so that you could ever demonstrate compliance with any kind of a specification on the cost of performance? Presently, only subjective evaluation is made by the pilot opinion rating of the flying qualities and by pilot judgment and acceptance of motions in performing the various mission tasks, but we need more confidence in the connections between subjective ratings and objective measures of workload or operability in order to extrapolate the small samples of results by test pilots to the ultimate field of operational experience.

2. How can the cost to the inanimate subsystems be measured objectively? Presently, only by qualification and acceptance testing under presumed stresses and presumed environments and by the prediction of the various "ilities" in advance of operational experience. Again, there's the recognition of a difference in levels of confidence between what can be done during the design phase or during qualification and acceptance testing and what may happen during the ultimate operational experience.

3. The "background and users' guides" for the flight control system and the flying quality specifications should introduce the use of

pilot models for making design trade-offs between manual and automatic operations, but it's premature to suggest the use of pilot models beyond that point in design. Much more confidence-building research is needed before we can employ pilot models for demonstrating compliance to specifications.

This concludes our summary of the results of the panel discussion on performance requirements.

APPENDIX F

ACRONYMS

FBW	FLY-BY-WIRE
DFBW	DIGITAL FLY BY WIRE
SAS	Stability Augmentation System
FCS	Flight Control System
EMI	Electro-Magnetic Interference
AFCS	Automatic Flight Control System
AOA	Angle of Attack
APC	Approach Power Compensator
MFCS	Manual Flight Control System
BIT	Built In Test
IFIM	Inflight Integrity Management
ATE	Automatic Test Equipment
HOL	Higher Order Language
CBW	Control By Wire
DEL	Direct Electrical Link
FAIL OP	Fail Operational Performance
DUAL FAIL OP	Two Fail Operational Performance
CAS	Command Augmentation System
SRI	Stick-to-Rudder Interconnect
CCV	Control Configured Vehicle
LVDT	Linear Variable Differential Transformer
LRU	Line Replaceable Unit
WRA	Weapons Replaceable Assy.
EHV	Electro-Hydraulic Valve
NVM	Non-Volatile Memory
MLC	Maneuver Load Control
GLA	Gust Load Alleviation
MLA	Maneuver Load Alleviation
RDMS	Redundancy Data Management System
VDC	VOLTS DIRECT CURRENT