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VALIDATION OF MIL-F-9490D - GENERAL SPECIFICATION FOR FLIGHT CONTROL SYSTEM FOR PILOTED MILITARY AIRCRAFT

VOLUME II: YF-17 LIGHTWEIGHT FIGHTER VALIDATION

NORTHROP CORPORATION, AIRCRAFT DIVISION
HAWTHORNE, CALIFORNIA 90250

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This study was conducted to validate military specification MIL-F-9490D, "Flight Control Systems-Design, Installation and Test of, Piloted Aircraft, General Specification For," dated 6 June 1975 by checking the specification requirements utilizing the experience and knowledge derived during the recent procurement of the YF-17 Lightweight Fighter.

This validation was based on existing ground test, flight test and analytical data as was available for this validation process. Each applicable paragraph → over

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was examined with regard to practicability, accuracy, and completness as a requirement for procurement, design, test and installation of flight control systems for future piloted military aircraft.

Recommendations have been made with regard to changes considered necessary to improve the practicability, accuracy, and completness of the specification and to improve or update the Users Guide.

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SUMMARY

Northrop validated MIL-F-9490D relative to the YF-17, a prototype development lightweight fighter, defined as a conventional takeoff Class IV aircraft. The YF-17 flight control system comprises manual flight control functions with their associated augmentation and was developed in the time period of 1972-1974, preceeding the release of the current revision of the specification MIL-F-9490D. Consequently, only the previous revision of the specification was considered during the design phase.

Of the total of 373 paragraphs of the specification, 250 paragraphs were validated as being applicable to the YF-17. Full compliance was ascertained in approximately 65 percent of the applicable requirements. Where partial or non-compliance was shown, it was ascribed primarily to the prototype nature of the program rather than the stringency of the requirement. Instances of outright non-compliance were few.

Most of the requirements, including those that appeared in the current revision the first time, were found to be valid and of the appropriate stringency. Where the requirements were considered needing revision, appropriate recommendations were made. As a whole, the specification is adjudged as an up-to-date and comprehensive statement of flight control system requirements which is well written for application to Class IV fighter airplanes.

PREFACE

This report was prepared by the Northrop Corporation, Aircraft Division, Hawthorne, California, for the Air Force Flight Dynamics Laboratory under USAF Contract F33615-76-C-3034, Project No. 1987. Thomas D. Lewis was the Project Engineer/Technical Monitor.

Mr. S. Dobos-Bubno of Northrop Controls Technology served as the program principal investigator and directed the YF-17 validation process. Mr. Larry B. Hartsook of Northrop Controls Technology served as the program coordinator between Northrop and Lockheed-Georgia. The authors wish to acknowledge their gratitude to Messrs. D. H. Johnson, J. D. Anderson, and R. L. McCormick of the Northrop Corporation, Aircraft Division, for their diligent contributions to the program.

The validation results are reported in three volumes as follows:

Volume I - Summary of YF-17 and C-5A Validations

Volume II - YF-17 Lightweight Fighter Validation

Volume III - C-5A Heavy Logistics Transport Validation

The contractor's report number is NOR 77-06. This report covers work from April 1976 to January 1977. It represents the views of the authors, which are not necessarily the same in all cases as the views of the Air Force. This report was submitted by the authors January 19, 1977.

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SECTION I

INTRODUCTION

This report is prepared as part of a continuous effort by the Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, Ohio, to update and improve Military Specification MIL-F-9490D, "Flight Control Systems-Design, Installation and Test of Piloted Aircraft, General Specification for". The specification contains requirements that are applied by the aircraft industry in design, development and ground and flight test demonstrations of new airplanes.

This volume presents the paragraph-by-paragraph validations of MIL-F-9490D as they pertain to the YF-17 Lightweight Fighter flight control system. The objective and results of this study are expressed by the following four goals:

1) Make recommendations as considered necessary to improve the practicability, accuracy, and completeness of the specification.

2) Determine the quantitative degree of compliance attained in the development program for each specification paragraph.

3) Make an assessment of stringency as to whether each requirement is good as is, is too lenient, or is too strict.

4) Provide text for the Users Guide where improvement or updating is required.

These results are summarized in tabular form in Section IV - Conclusions, as well as in narrative form in the detailed validations of Section III - Validation of Requirements.

Northrop's validation of MIL-F-9490D for the YF-17 was based on the recently concluded air combat fighter flight test program conducted from June through January 1975 at Edwards Air Force Base. In this comprehensive program, the two YF-17 prototype articles were tested for nearly 350 flight hours. The program included essentially all phases of fighter aircraft operations. Extensive testing was performed in such areas as basic airworthiness, stability and control, flight control development, high angle-of-attack flight, air combat maneuvers, weapons delivery, formation flying, emergency procedures, and aerial refueling.

The YF-17 is an advanced technology prototype fighter aircraft whose flight control system was designed to comply with MIL-F-9490C except for variations as allowed by the procurring activity for prototype aircraft. The YF-17 control system includes a control augmentation system (CAS) using both electronic and mechanical elements in the pitch axis, a fly-by-wire control augmentation system for aileron control, and mechanical control with electronic stability augmentation (SAS) in the yaw axis. Also, this aircraft has a mechanical rolling tail control and electronically controlled maneuvering leading-edge and trailing-edge flaps. Both digital and analog computations are utilized. The actuators are electrohydraulic and electromechanical. A detailed discussion of the YF-17 control system, including block diagrams and schematics, is presented in Section II - Airplane Description.

Complete validation of some requirements was not possible due to either severe data limitations or being beyond the scope of this program. In the latter case, experimental work and supplementary studies were suggested for the continued task to revise and update the requirements.

It is hoped that the recommendations of this study will serve as a basis for future specification revision programs, and may also serve as additional guidance for interpretation and application of this specification.

SECTION II

AIRPLANE DESCRIPTION

1. General Physical Characteristics

The YF-17 is a fighter aircraft prototype developed to demonstrate advanced technology applicable to air combat. Distinguishing features include the moderately swept wing with the large highly swept leading-edge root extension, differential area-ruling of the fuselage, underwing inlets with wing root slots for fuselage boundary-layer diversion, twin vertical tails, and twin jet engines.

The basic wing planform, combined with the leading-edge root extension, is identified as a hybrid wing. The vortex flow generated by the extension significantly increases lift, reduces buffet intensity and drag, and improves handling qualities. Leading edge and trailing edge flaps are used to vary the wing camber for maximum maneuvering performance.

The aircraft configuration is area-ruled to achieve a smooth overall area distribution. However, within the smooth overall area distribution, the area-ruling above and below the wing is apportioned to create favorable supersonic lift interference (increased lift at a given angle of attack) for minimum drag-due-to-lift with a small increase in zero-lift drag.

The horizontal tail is located below the wing to provide increasing longitudinal stability at high angles of attack approaching maximum lift, and to preclude buffet from the wing wake at high-g flight conditions. The tail is sized larger than the minimum required for stability and control in order to lower trim drag and increase supersonic sustained maneuvering performance.

The vertical tails are sized and located to provide positive directional stability beyond the maximum trimmed angles of attack across the speed range. The twin vertical tails are canted outboard for proper placement relative to the vortex flow field generated by the wing leading-edge extensions. The forward location of the verticals was selected to preclude reduction of horizontal tail effectiveness caused by interference with the canted vertical tails, provide low supersonic drag through the favorable influence on the area distribution of the aircraft, and integrate more effectively the vertical tail supporting structure and horizontal tail actuators into the fuselage design.

Location of the engine inlets under the wing minimizes flow angularity to the inlet and places the inlet in a position to take advantage of the compression effects of the wing leading-edge root extension, thus decreasing inlet flow Mach number and increasing pressure recovery at angles of attack. The key feature of airframe/inlet integration is a longitudinal slot through the wing root which allows passage of fuselage boundary-layer air through the slot and over the top of the wing. Thickening of the boundary layer is prevented and a narrow fuselage boundary-layer gutter can be used, resulting in a low-drag installation while maintaining high-quality airflow to the engine inlet.

Two General Electric YJ101 continuous-bleed, afterburning turbojet engines in the 15,000-pound-thrust class are installed in the aft fuselage.

Outstanding visibility is achieved by the canopy shape and location. The pilot has full aft vision at eye level and above.

Armament consists of one M61 20mm cannon and two wingtip-mounted AIM-9E missiles. External store pylons are located at wing stations 78 and 138 (left and right) and on the fuselage centerline.

The three-view drawing in Figure 1.1 shows the YF-17 airplane and dimension details. Basic dimensional data are given in Table 1.

2. Flight Controls

The primary flight control surfaces and the leading-edge and trailing-edge flaps are positioned by closed-loop hydraulic actuators. The secondary (CAS) actuators for the primary flight control surfaces are integrated with the respective power actuators in a single unit. The power actuators for each flap are controlled by a remotely located electromechanical servoactuator. Pilot primary controls consist of a conventional center stick and rudder pedals. The pilot's control feel forces are supplied artificially.

Pitch control is achieved through a blend of mechanical and electrical commands to an all-movable horizontal stabilizer. The mechanical pitch signals are generated through conventional cable and push-pull rods. An electronic pitch control augmentation system (CAS) with pitch rate and normal acceleration feedbacks is incorporated to shape the aircraft dynamics and manuevering forces to those desired over the flight envelope.

Roll control is by a combination of electrically controlled ailerons and mechanically controlled differential movement of the horizontal stabilizer (rolling tail). The ailerons are controlled by a direct electrical signal path from the control stick and a model-following roll rate command augmentation system. Yaw control is through a conventional cable and push-pull rod mechanization to the rudders complemented by a stability augmentation system (SAS) in which yaw rate, lateral acceleration, and roll-rate-times-angle-of-attack feedback signals are used. A roll-to-yaw control interconnect system is utilized and consists of electrical signals from the ailerons (ARI) and from the control stick (SRI) to the rudder actuators.

The leading-edge and trailing-edge flaps may be positioned in the full-up, full-down, automatic, and flight test modes. In the automatic mode, the flaps are positioned according to a scheduled relationship of angle-of-attack and Mach number. In the flight test mode, the leading-edge flap and the trailing-edge flap may be independently controlled to any intermediate position by means of two three-position switches on the instrument panel. The speed brake is positioned by means of a three-position slide switch on the pilot's throttle control lever.

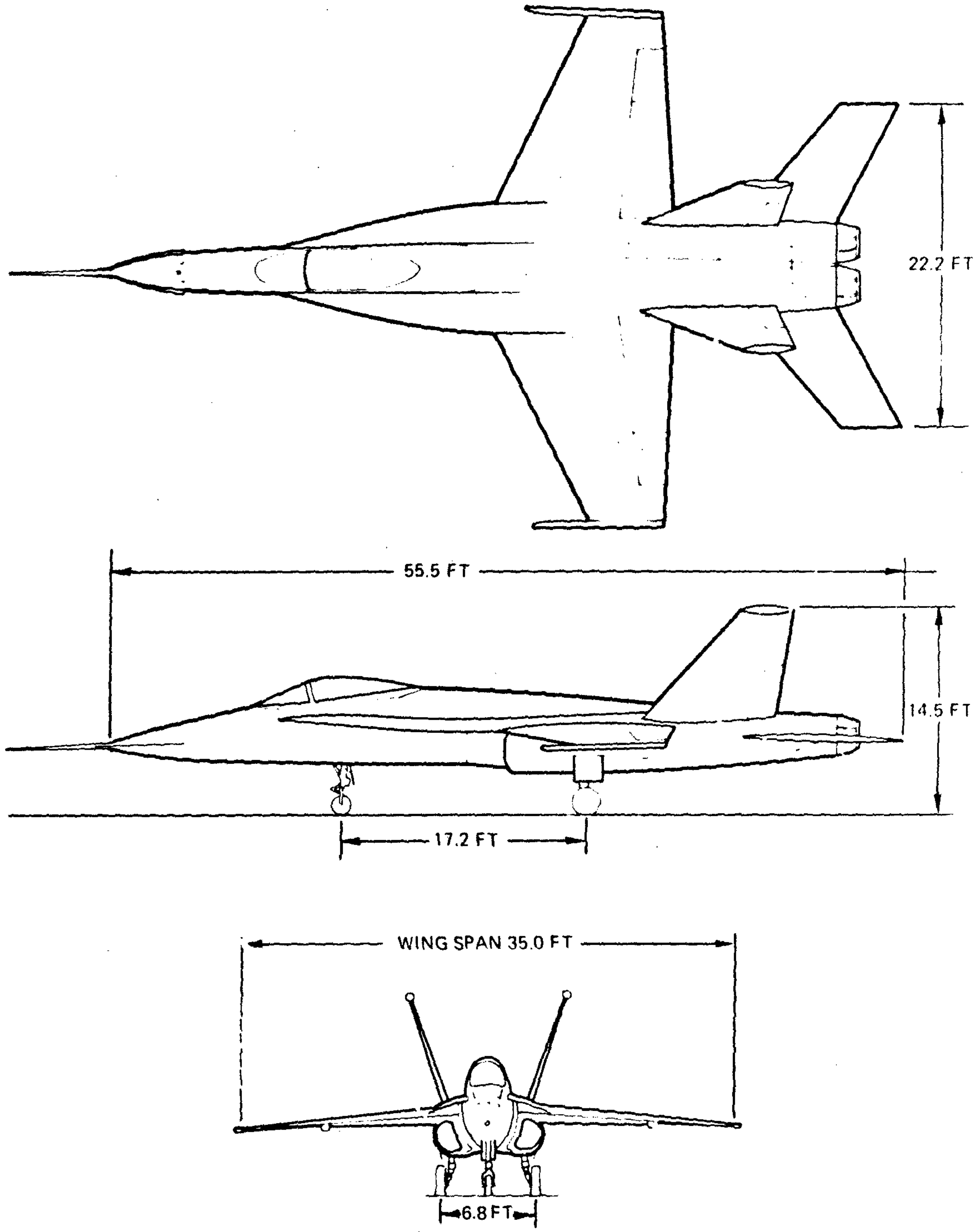

Figure 1.1 YF-17 Three-View Drawing

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TABLE 1 YF-17 BASIC DIMENSIONAL DATA

BASIC SURFACES	BASIC WING	HORIZONTAL TAIL	VERTICAL TAILS
Reference area (square feet)	350	-	--
Exposed area (square feet)(outbd of WS 53)*	229*	85	52 each
Aspect ratio (reference area)	3.5	3.0	1.2
Taper ratio (reference area)	0.35	0.6	0.4
Leading edge sweep	27°	41°	41°
25% chord sweep	20°	38°	35°
Dihedral/cant angle	-5°	-2°	20°
Span total (inches)	420	266	95
Panel span/exposed (inches)	157	96	95
Root chord at centerline (inches)	178	-	--
Chord at LE break (inches)	149	-	--
Chord at exposed root (inches)	-	80	113
Tip chord (inches)	62	48	45
MAC (inches)	129	65	84
Tail arm — Wing 0.25 chord MAC to tail 0.25 chord MAC (inches)		211	129
Airfoil Section	NACA 65A with sharp LE	NACA 65A with sharp LE	NACA 65A with sharp LE
Airfoil Thickness - at LE break (W.S. 53.2)	5%	-	-
- at exposed root	-	5.5%	5%
- at 65% span	4%	-	-
- at tip	4%	3%	3%
Airfoil Camber - at LE break	1%	0	0
- at exposed root	-	0	0
- at 65% span	1%	0	0
- at tip	1%	0	0
Incidence	0°	-	1° toe out

Leading Edge Extension	
Exposed area, LE LEX to LE wing, total (square feet)	46
Exposed span, each (inches)	32
Root chord, LE LEX to LE wing (inches)	168
Root thickness, LE LEX to TE wing	2.4%
Root incidence	4°

*Tip missiles add 44 sq ft of wetted area.

TABLE 1 YF-17 BASIC DIMENSIONAL DATA (CONTINUED)

Control Surfaces	AREA (SQ FT)	PERCENT SPAN	PERCENT CHORD	DEFLEC-TION
Leading edge flaps (total)	46	25 to 100	20	25° dn
Trailing edge flaps (total)	51	18 to 64	30	20° dn
Aileron	17	65 to 86	30	35°up25° dn
Horizontal tail	85	-	-	
Leading edge movement				
Pitch				5°up12°dn
Roll				±3.5°
Total				10°up14° dn
Rudder - each	6.3	50	20	±30°
Speed Brake (hinge at FS 574)	12.9	-	-	60°

Wetted Areas*	Square Feet
Fuselage (excluding nozzles)	750
Pitot boom	5
Canopy	40
Nozzles (cruise position)	25
Basic wing (exposed) (outboard of WS 53)	453
Aileron actuator fairing	15
Launcher rails	20
Leading edge extension (LE LEX to TE wing)	180
Horizontal tail	170
Vertical tails	208
Total	1866

Landing Gear	
Wheelbase	206 inches
Tread	82 inches
Turnover angle	61°
Tail-down angle	12°
Static ground angle	-0° 29'
Tires	
Main gear	24 x 8
Nose gear	18 x 6.5

*Tip missiles add 44 sq ft of wetted area.

The pilot can achieve intermediate positions by returning the switch to the off position. The flight control hydraulics are shown in Figure 2.1 and the electrical power distribution to the flight controls is shown in Figure 2.2. The flight control arrangement is shown in Figure 2.3. Cockpit controls and panels are shown in Figure 2.4 and the words caution panel in Figure 2.5.

Pitch Control System

The pitch control mechanical system consists of a conventional push-pull rod, bellcrank, and cable control system connected from the control stick to the control valves on tandem piston dual hydraulic system actuators, as shown in Figures 2.6 and 2.7. The control stick is fitted with a standard stick grip and a disconnect switch for the pitch CAS.

Nonlinear gearing between the pilot and the surface actuators is provided to ensure adequate handling qualities with unaugmented mechanical control. A trailing-edge flap/horizontal tail mechanical interconnect alleviates trim changes from the flap. The longitudinal gearing and stick force characteristics are shown in Figure 2.8 and 2.9.

The electronic pitch CAS provides augmentation of the mechanical control mode. Stick motion from a reference position moves the horizontal tail in accordance with the mechanical gearing curve. The CAS modifies the travel and rate of the horizontal tail to obtain desired aircraft response to pilot command over the entire flight envelope. The CAS gains are scheduled as a function of Mach number and altitude based on information from the digital air data computer (DADC). A stick position sensor provides inputs to the command model. The command signal is summed with the output of a pitch rate gyro and linear accelerometer. The summed error signal drives the limited-authority (± 3 degrees) electrohydraulic CAS actuator. The dual electromechanical CAS follow-up actuator, also driven by the error signal, performs the integration function and also extends CAS authority over +6 to -9 degrees surface travel. With landing gear down, the integration function is inhibited, and the follow-up actuator is commanded to the take off position. Block diagrams of the pitch CAS and pitch error gain function are shown in Figure 2.10 and 2.11. Schematics of the horizontal tail CAS input and follow-up input are shown in Figures 2.12 and 2.13.

Roll Control System

The roll control system utilizes ailerons and a rolling tail as shown in Figure 2.14. A conventional cable, push-pull rod, and crank mechanization transmits pilot commands to differentially operate the horizontal stabilizer surface actuators as shown in Figure 2.15. The mechanical gearing and the lateral stick force gradient are shown in Figures 2.16 and 2.17. The ailerons are operated electrically by a CAS and a direct electrical (DE) command. In the CAS, the control stick position signal is fed to an electronic model. The output of the model is compared with a roll rate gyro signal and the error (or difference) is summed with the DE signal which is directly commanded by stick displacement. This sum is used as a position command to the right and left aileron CAS actuators. The gain of the error signal is scheduled as a function of compressible dynamic pressure by the DADC. The pilot's feel forces

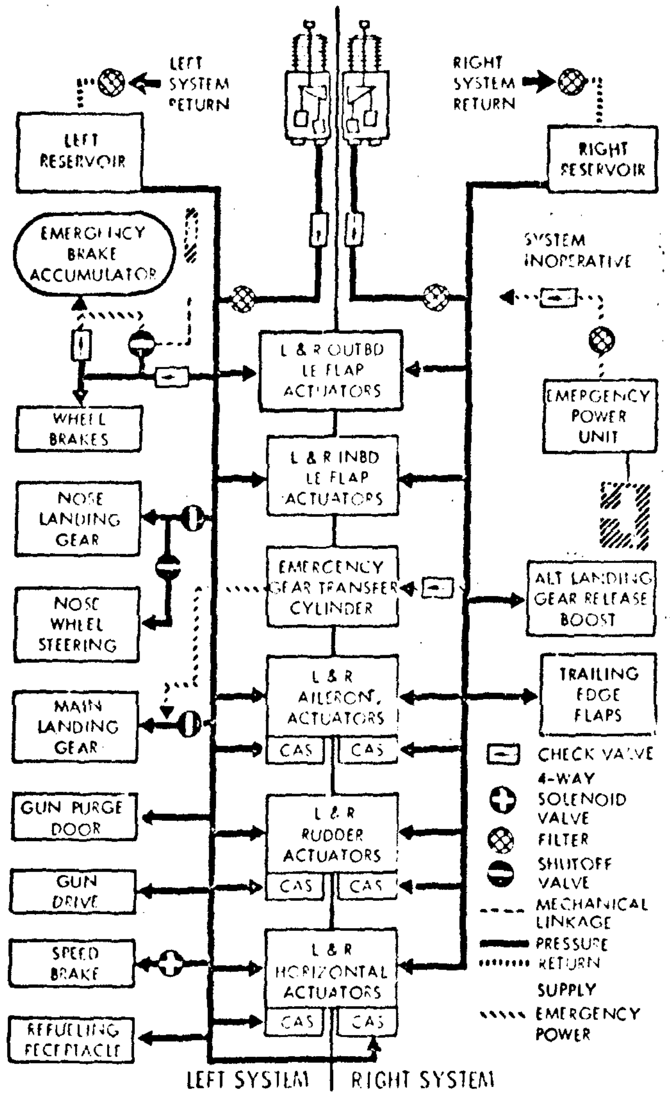

Figure 2.1 Flight Control Hydraulics System

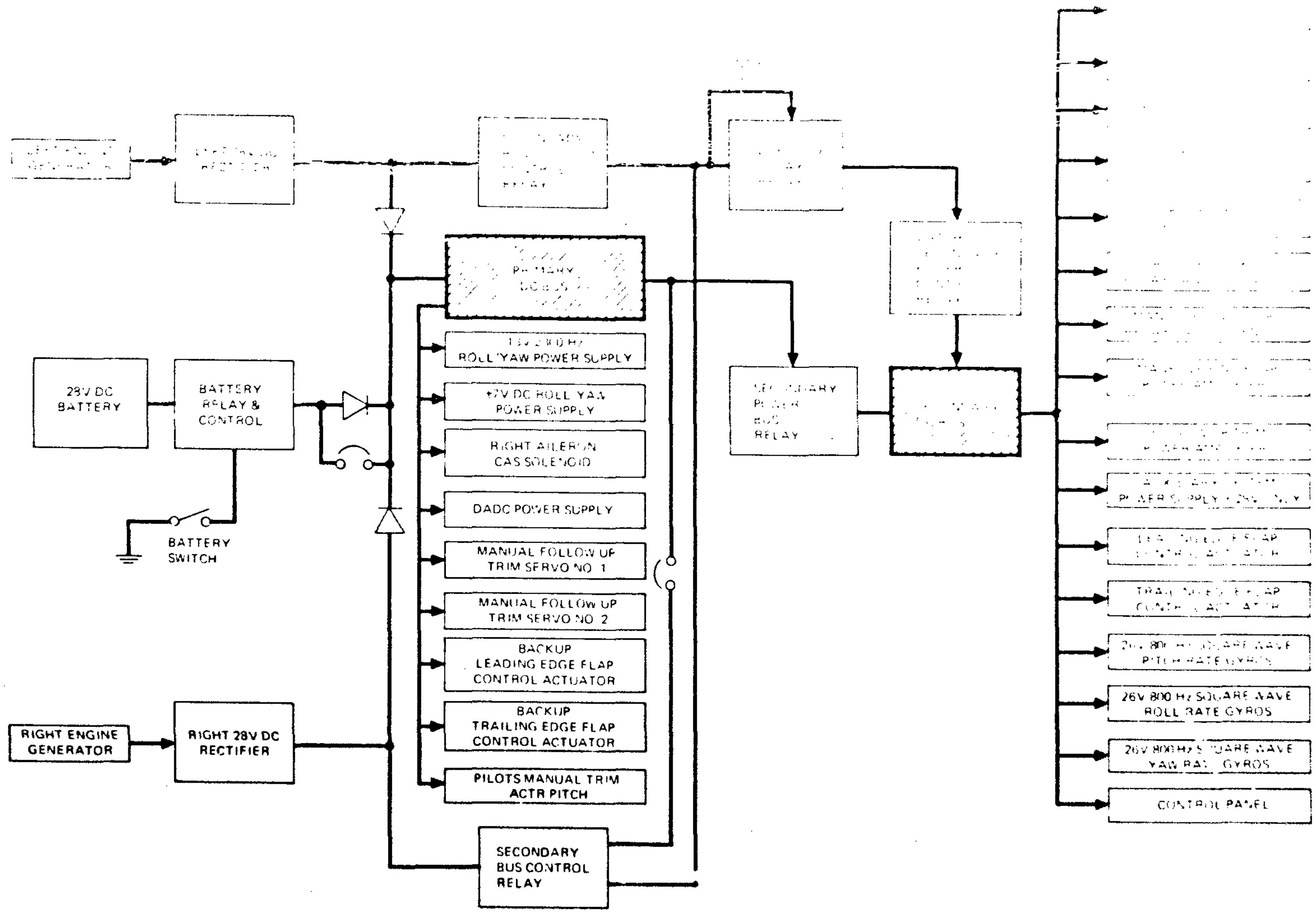

Figure 2.2 Electrical Power Distribution To Flight Control System

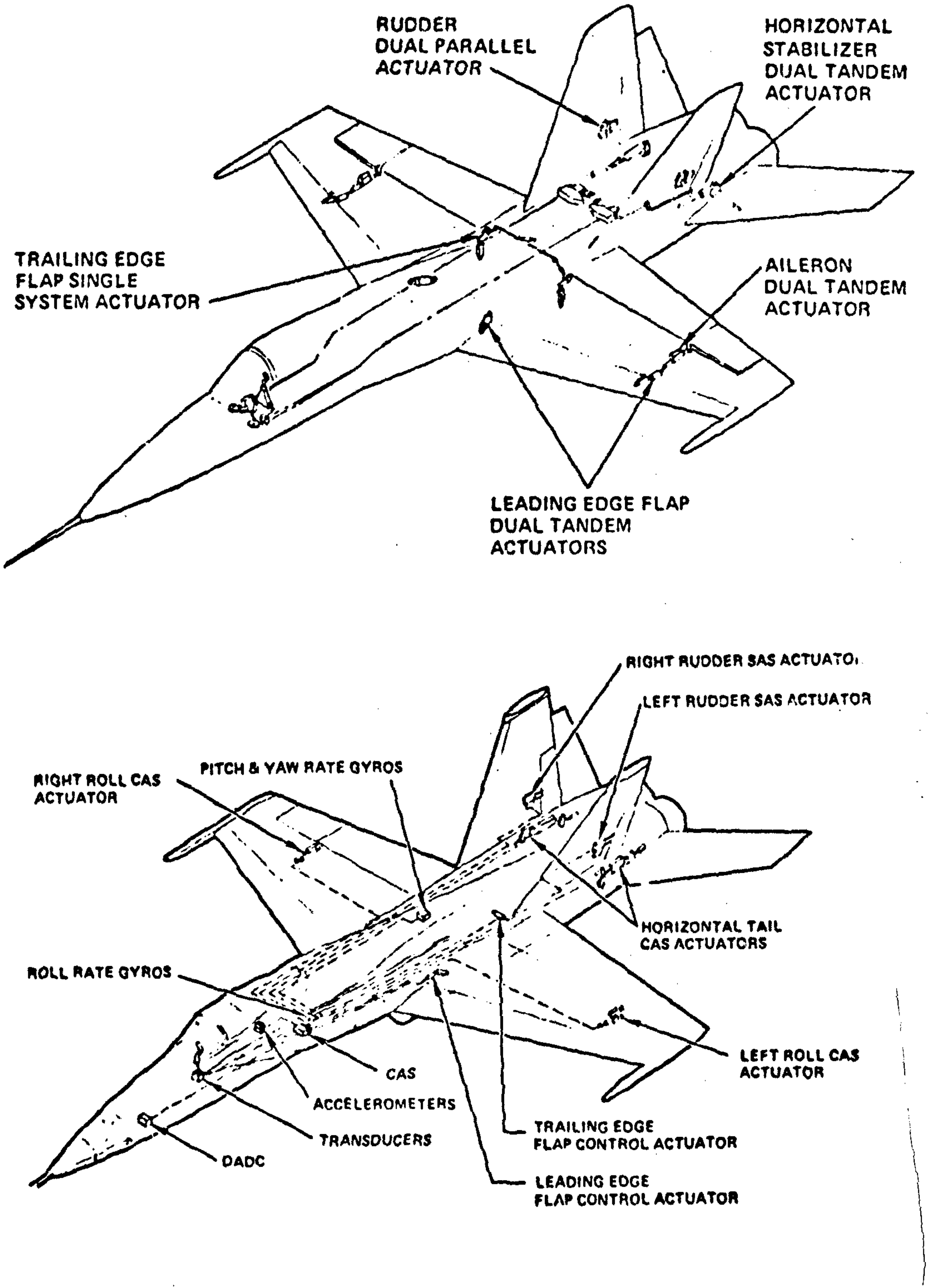

Figure 2.3 YF-17 Flight Control System Arrangement

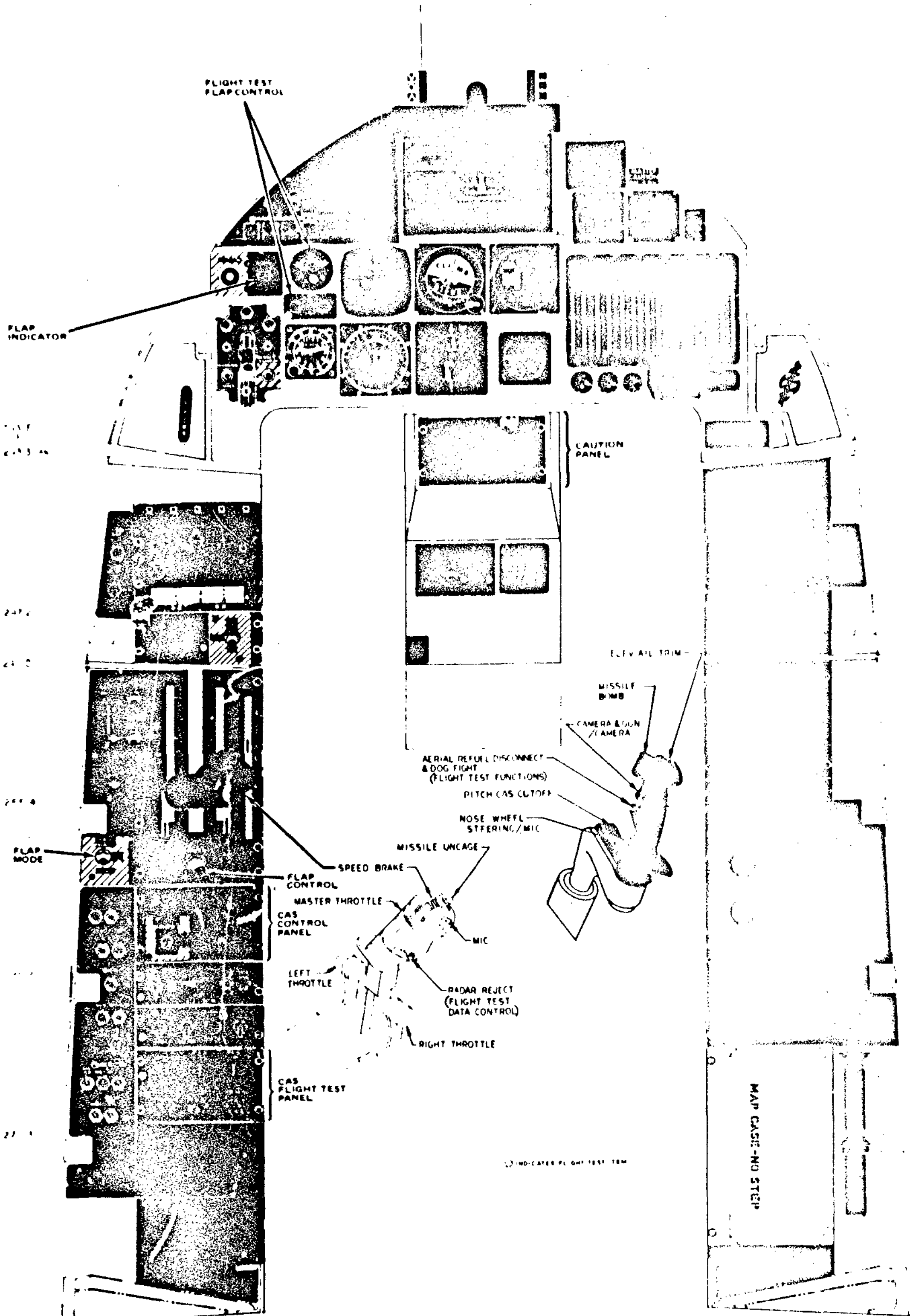

FIGURE 2.4 Cockpit Controls and Panels

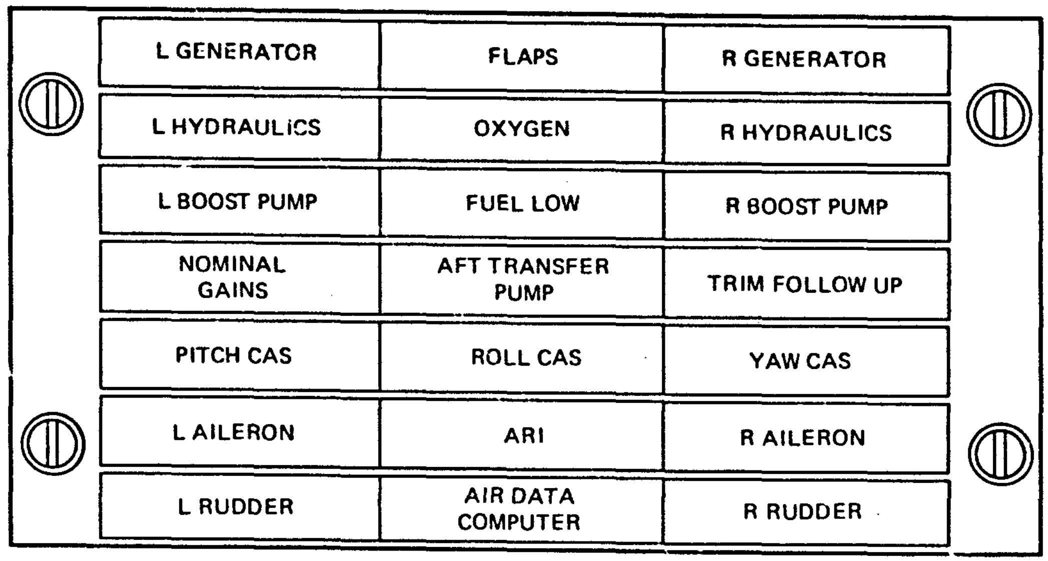

Figure 2.5 Word Caution Panel

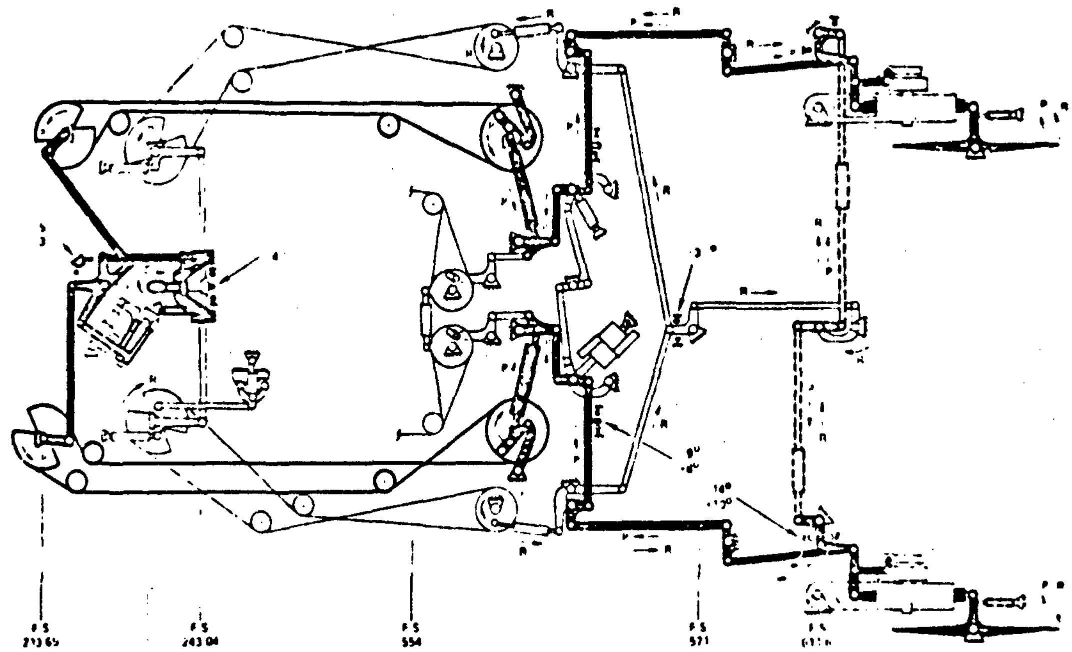

Figure 2.6 Horizontal Tail Control System - Pitch Control

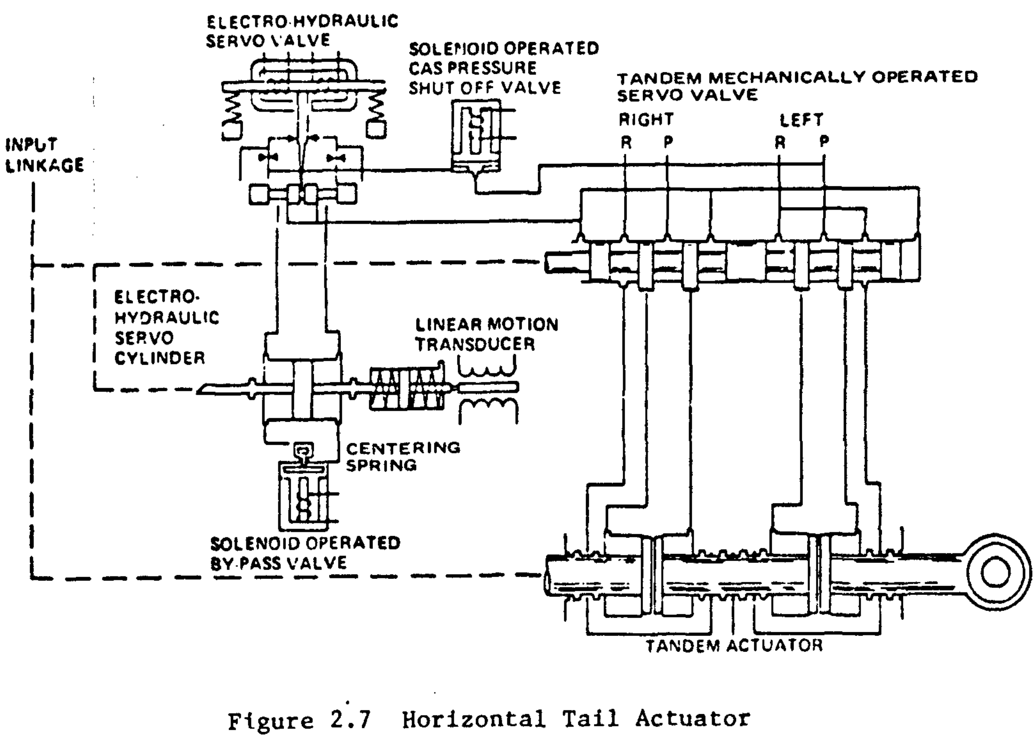

Figure 2.7 Horizontal Tail Actuator

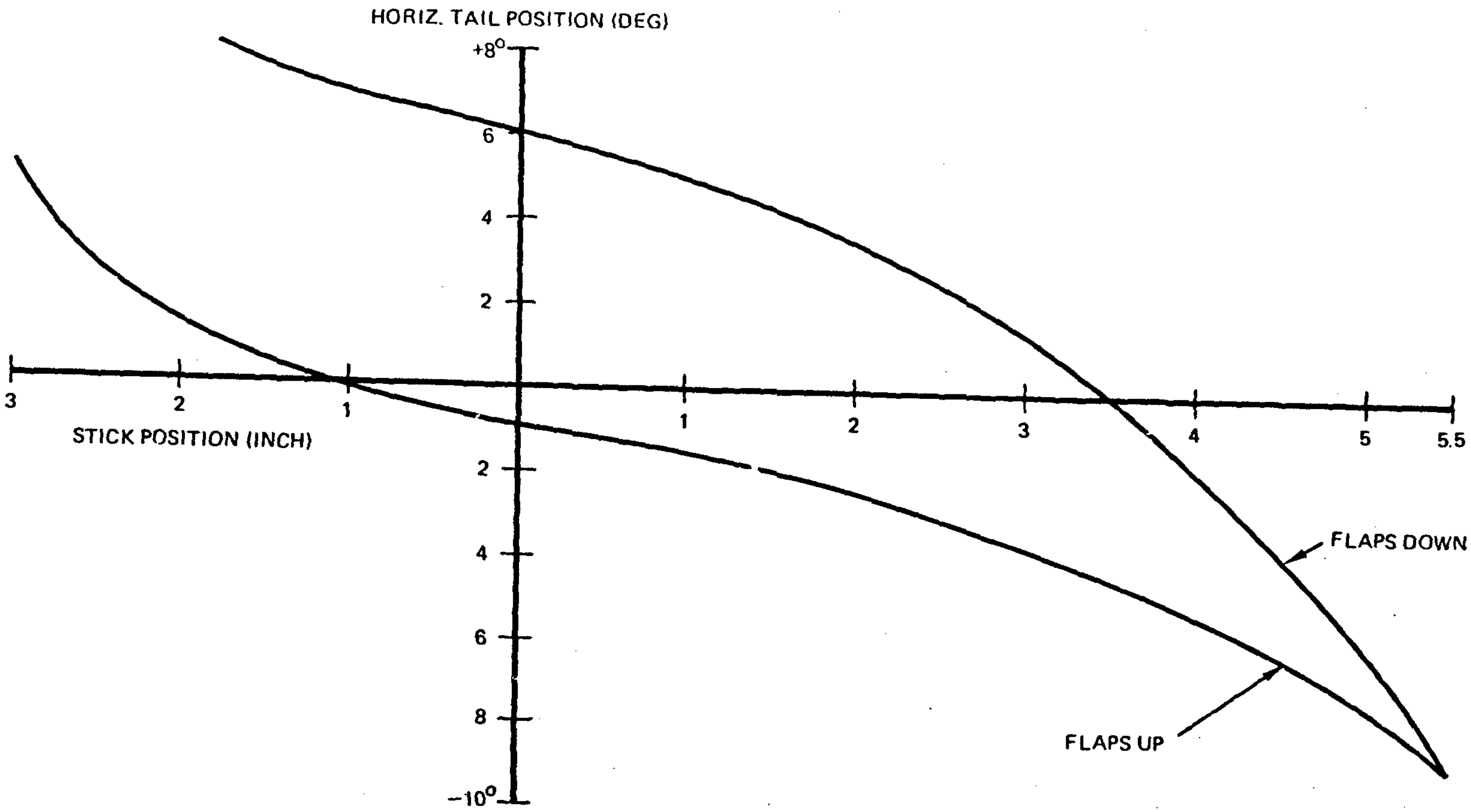

Figure 2.8 Longitudinal Control System Gearing

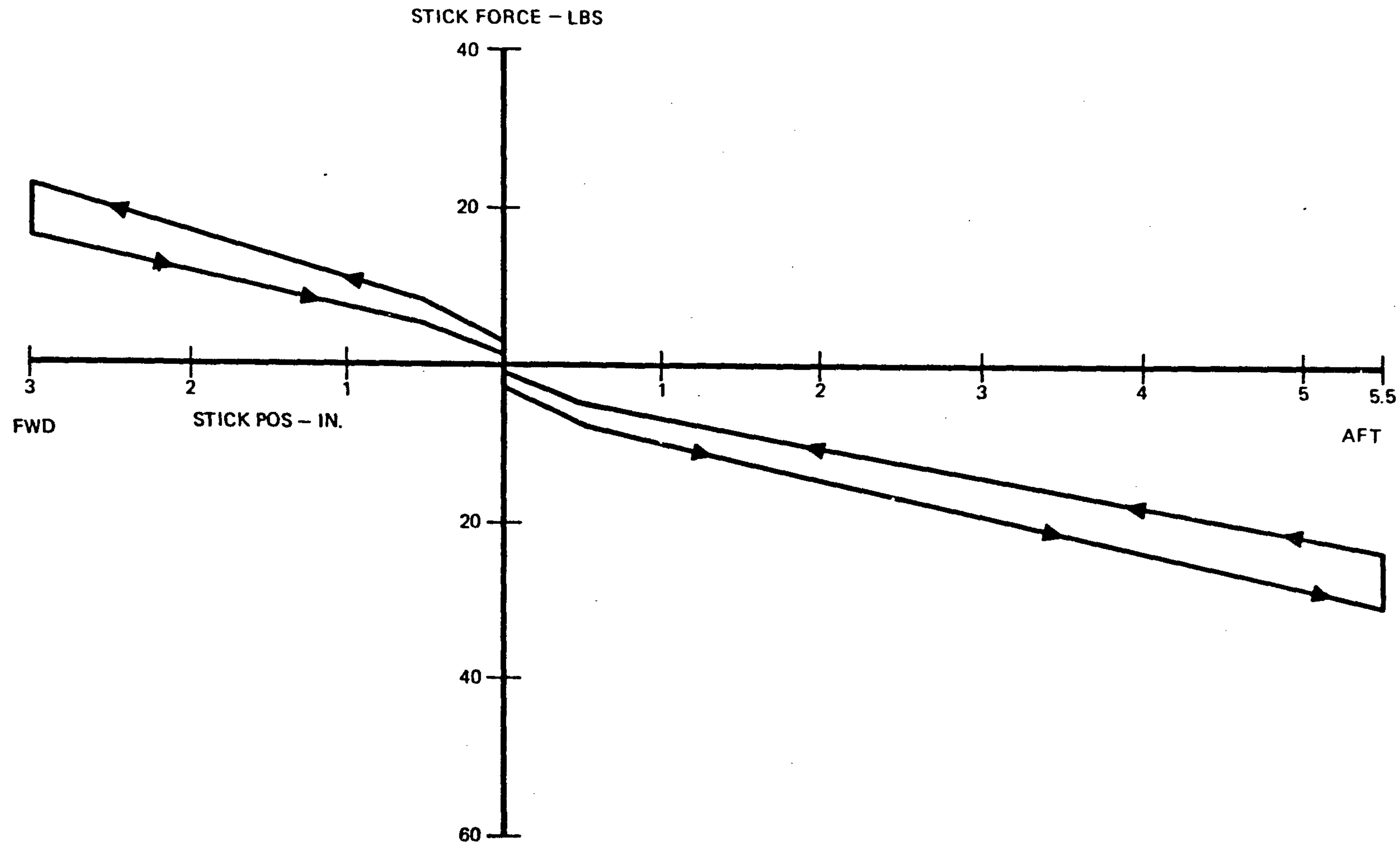

Figure 2.9 Longitudinal Stick Force Characteristics

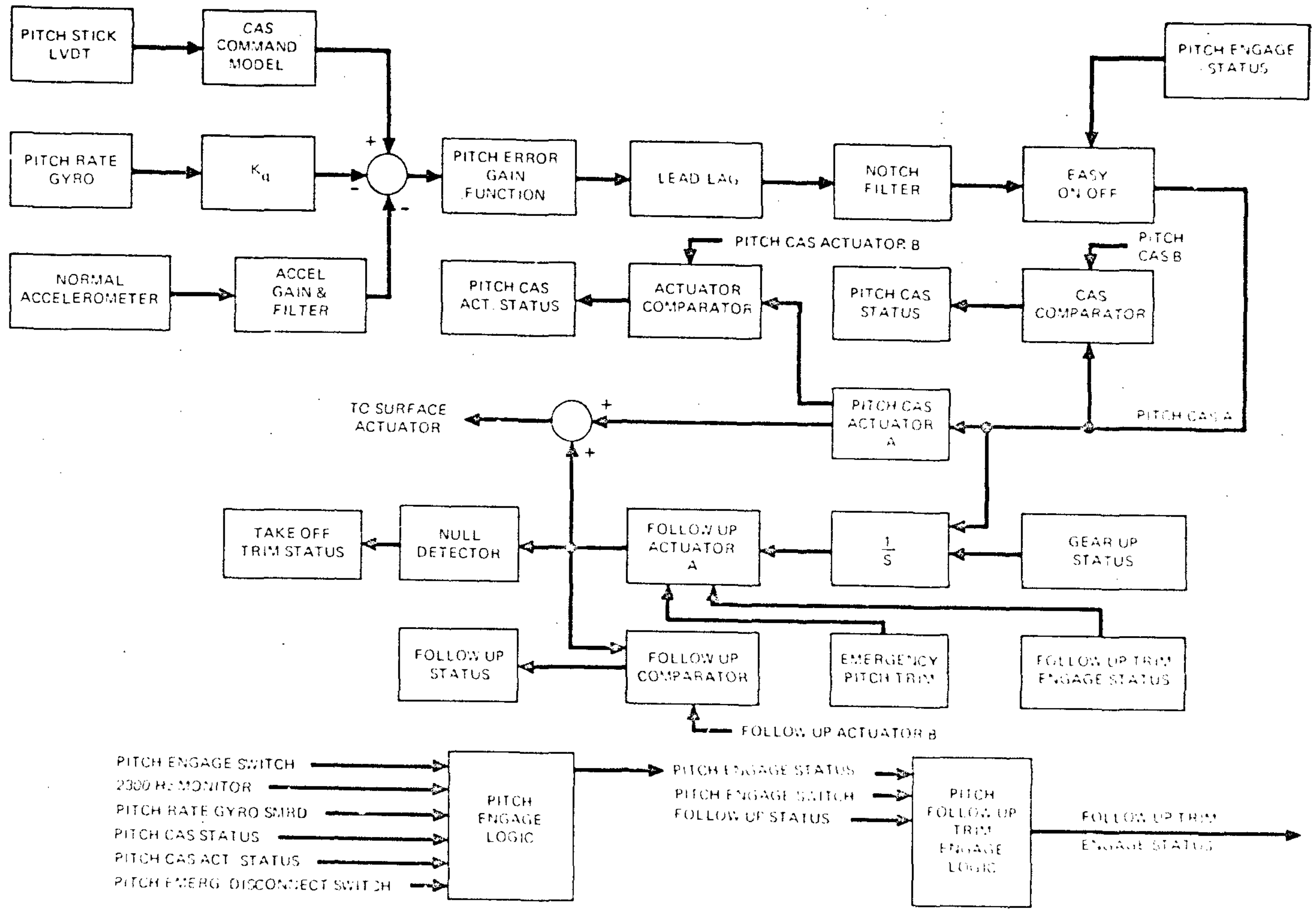

Figure 2.10 Pitch Electrical Control System (Typical for One Channel)

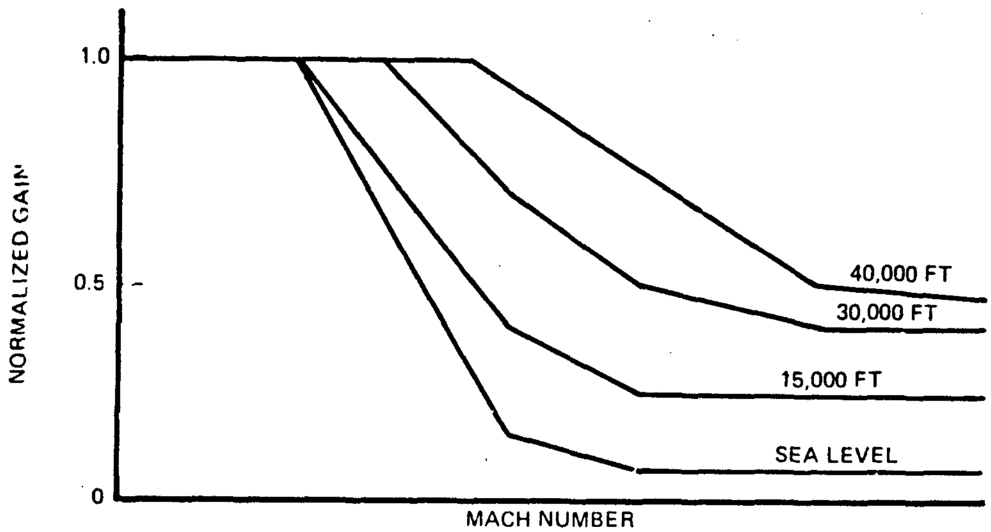

Figure 2.11 Pitch Error Gain Function

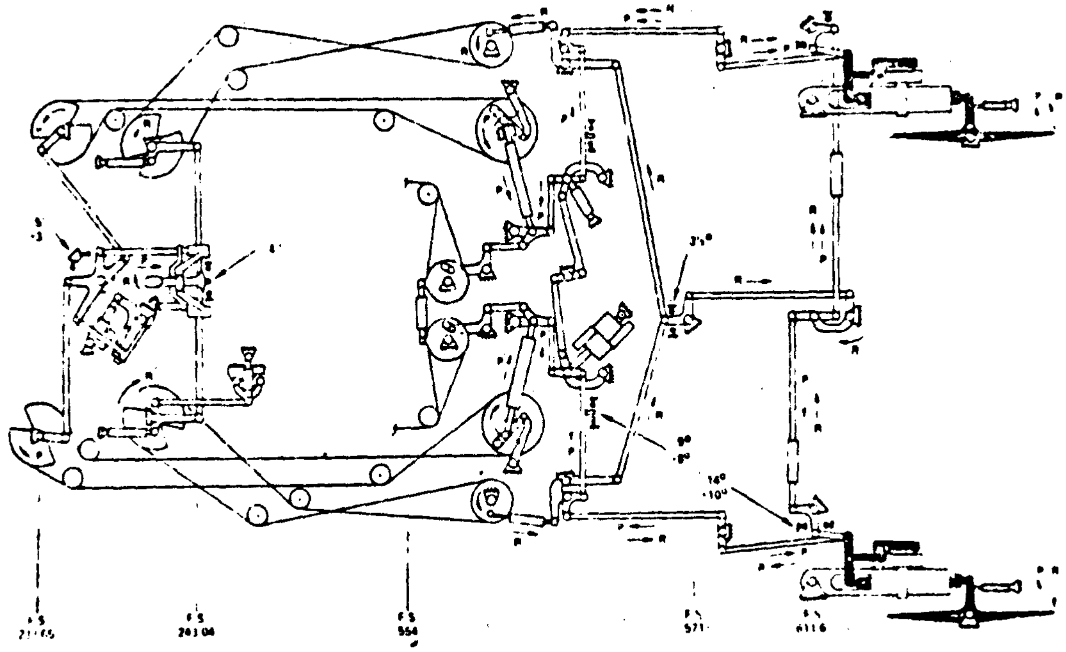

Figure 2.12 Horizontal Tail Control System - CAS Servo Input

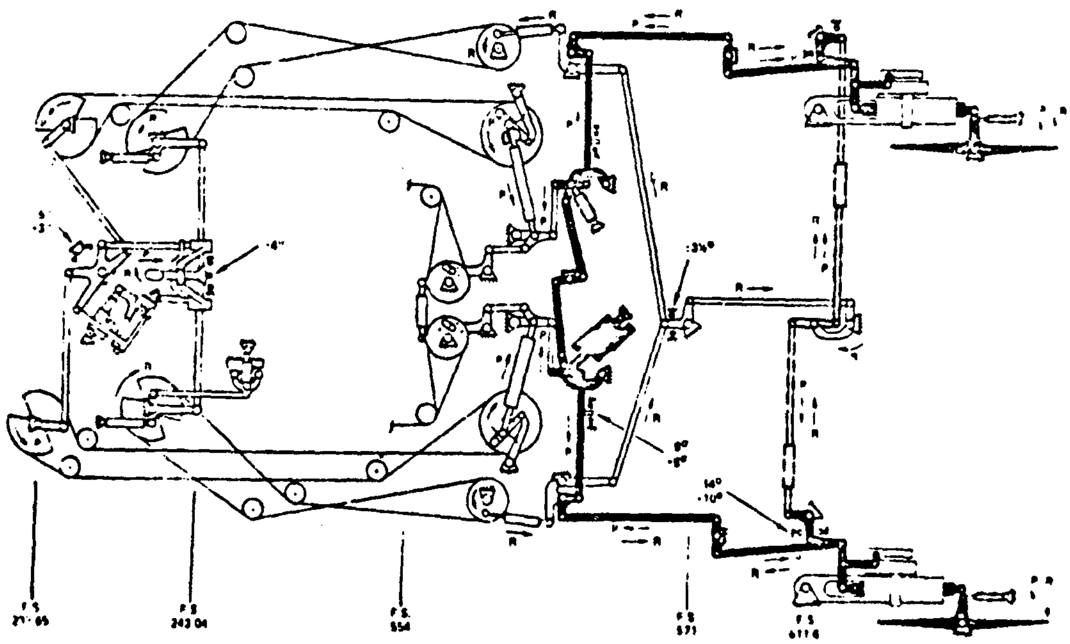

Figure 2.13 Horizontal Tail Control System - CAS Follow-up Input

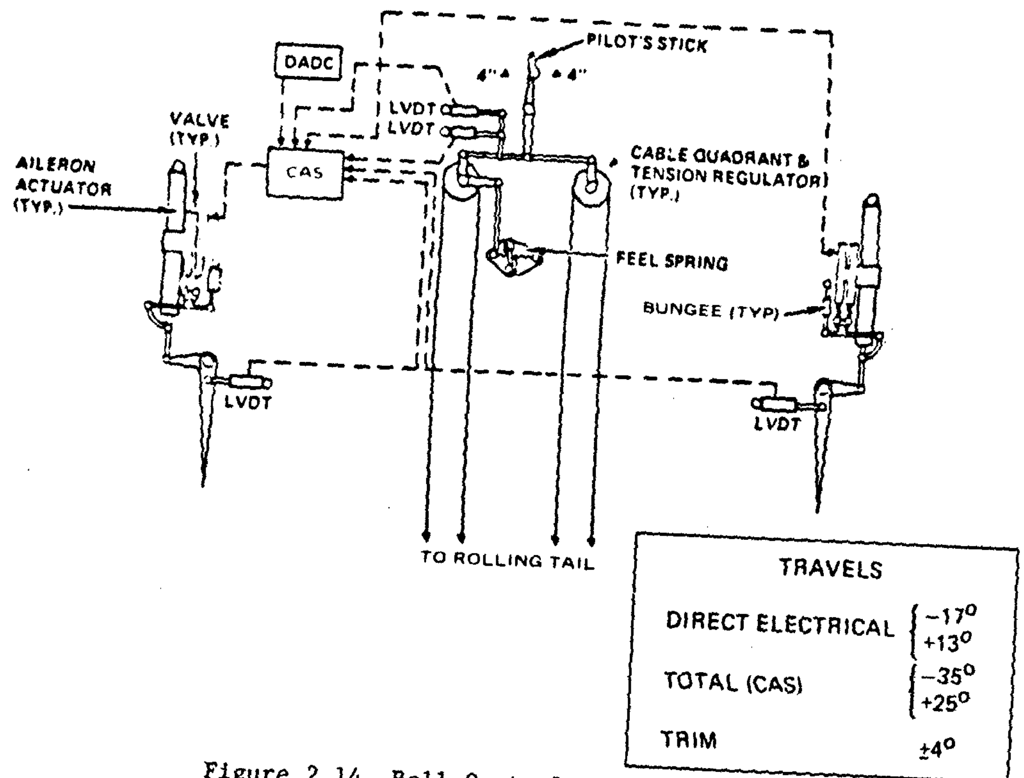

Figure 2.14 Roll Control System

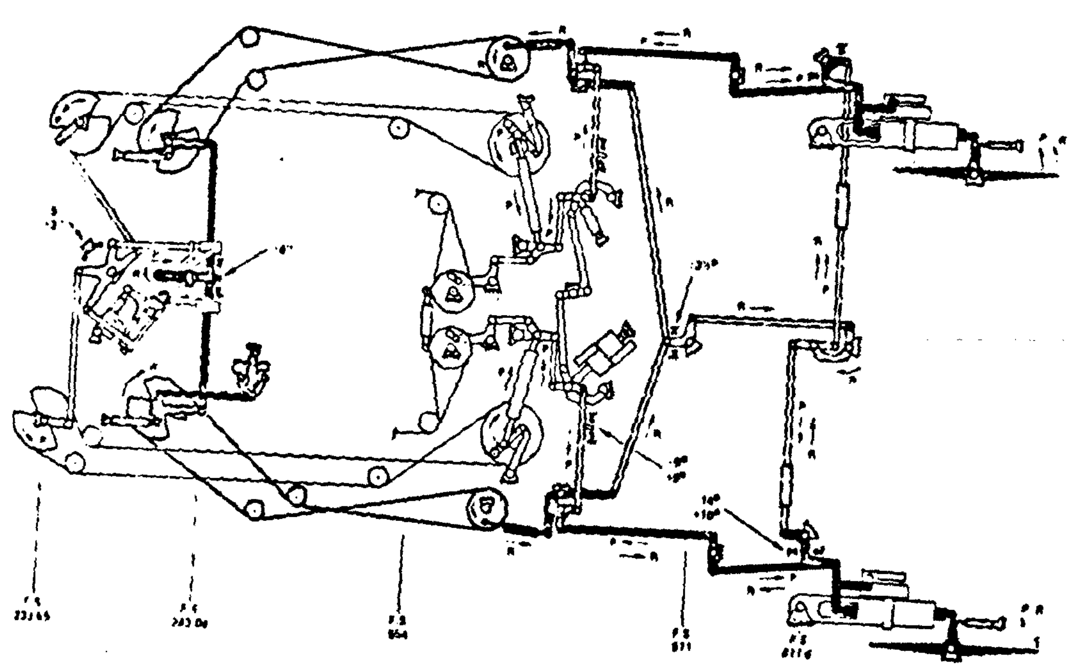

Figure 2.15 Horizontal Tail Control System - Roll Control

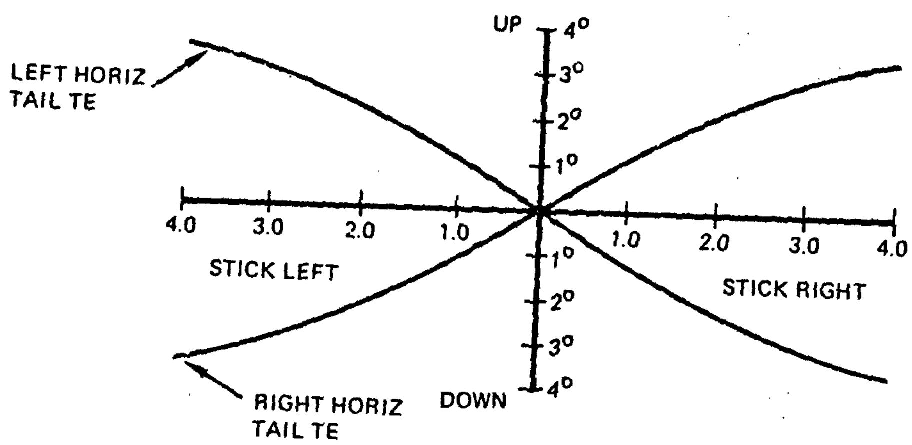

Figure 2.16 Rolling Tail Gearing

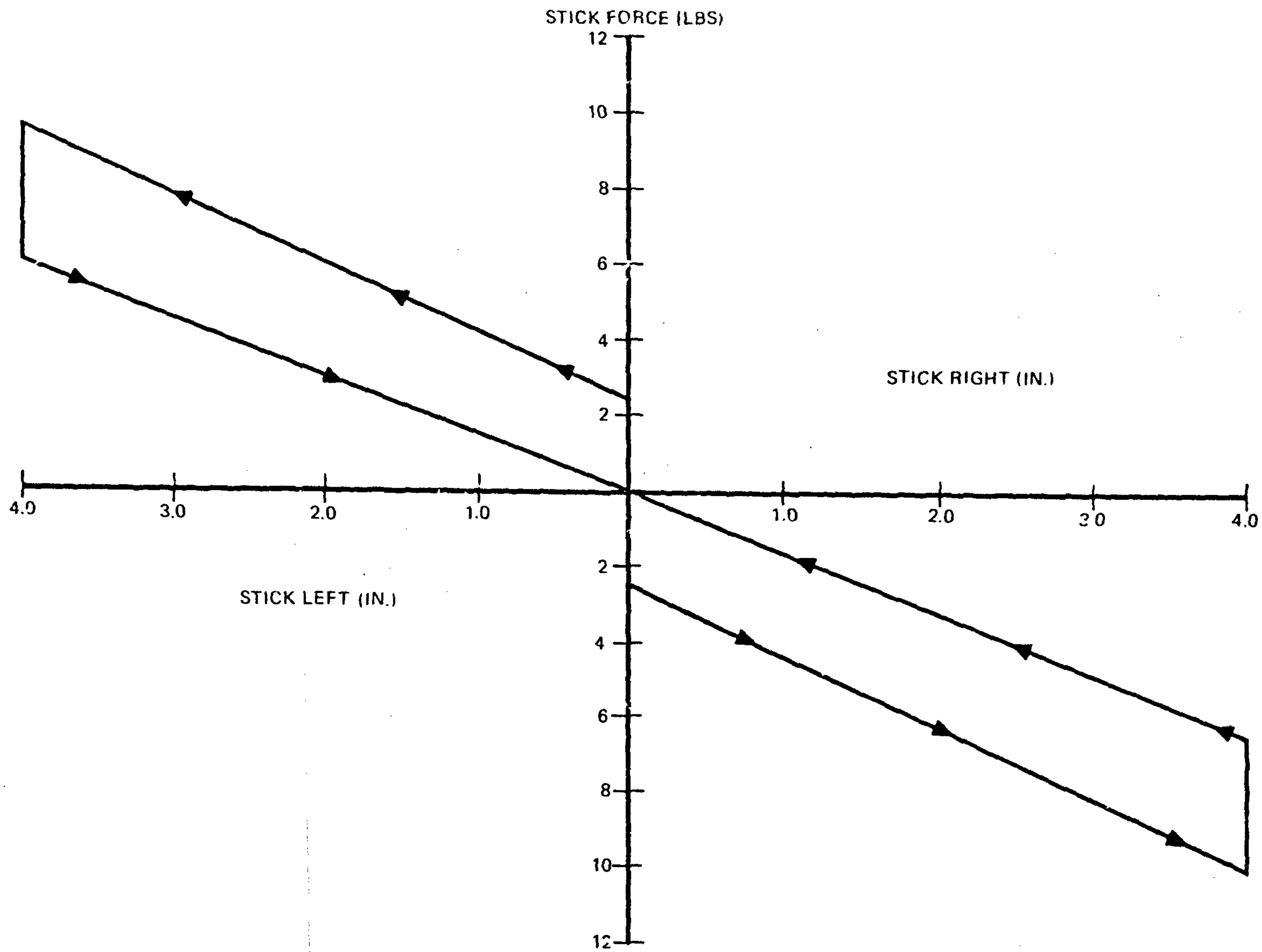

Figure 2.17 Lateral Stick Force Characteristics

are supplied by a spring. Roll trim is by means of the trim button on the control stick operating through the CAS electronics and positions both ailerons. Two dual stick position transducers are used to transmit commands to the dual CAS and the dual-dual direct electrical system. A block diagram of the roll CAS and DE command is shown in Figure 2.18. The roll error gain schedule is presented in Figure 2.19 and the roll stick shaping function in Figure 2.20.

Yaw Control and Interconnect System

Rudder pedals in the cockpit connect to the two control surface actuators through conventional cables, push-pull rods, and linkage cranks, as shown in Figure 2.21. Pilot's feel forces are provided by a spring with a built-in preload. Yaw trim control is through a cockpit control knob to bias the SAS actuators. The yaw stability augmentation system consists of a yaw rate gyro signal, a lateral accelerometer signal, and a signal that is proportional to the product of angle-of-attack and a roll rate gyro signal.

The roll-to-yaw interconnect systems are electrical and consist of the ARI and SRI. The ARI and SRI consist of signals from each aileron and lateral control stick (representing rolling tail), respectively, to the rudder SAS actuators. These signals are modified by DADC functions of angle-of-attack and Mach number. Backup angle-of-attack calculation based on trailing edge flap and horizontal stabilizer position, is provided in case of a DADC failure.

A block diagram of the yaw control and interconnect system is shown in Figure 2.22 and 2.23. The yaw SAS gain functions are shown in Figures 2.24 and 2.25.

Manuevering Flap Control System

The pilot's flap control switch controls the position of both leading-edge flaps and trailing-edge flaps through the DADC. This flap control switch includes UP, DOWN, and AUTO positions. The AUTO position sets both leading-edge and trailing-edge flaps down with gear extended and positions the flaps according to a schedule relationship of angle-of-attack and Mach number with gear retracted. The flap mode switch on the left console is used to select the flap flight test mode, with independent positioning capability of leading-edge flap and trailing-edge flap by means of switches on the instrument panel. The emergency up-position of the flap mode switch may be used to command both flaps up in case of DADC or flap control power supply failure. The functional diagram of the flaps control system is shown in Figure 2.26.

The leading-edge flaps, Figure 2.27, are operated by two dual system hydraulic actuators. LH and RH hydraulic flap actuator commands are mechanically interconnected by a cable system to assure symmetrical flap positions during normal operation. An asymmetry detection system will shut down the flap drive system to prevent unsafe flight configurations if the normal asymmetry limit is exceeded.

The trailing-edge flaps are positioned by hydraulic cylinders as shown in Figure 2.28. Both cylinders are operated by one electrical actuator through a single mechanical input linkage. An asymmetry detection system will shut down the flap drive system to prevent unsafe flight configurations if the

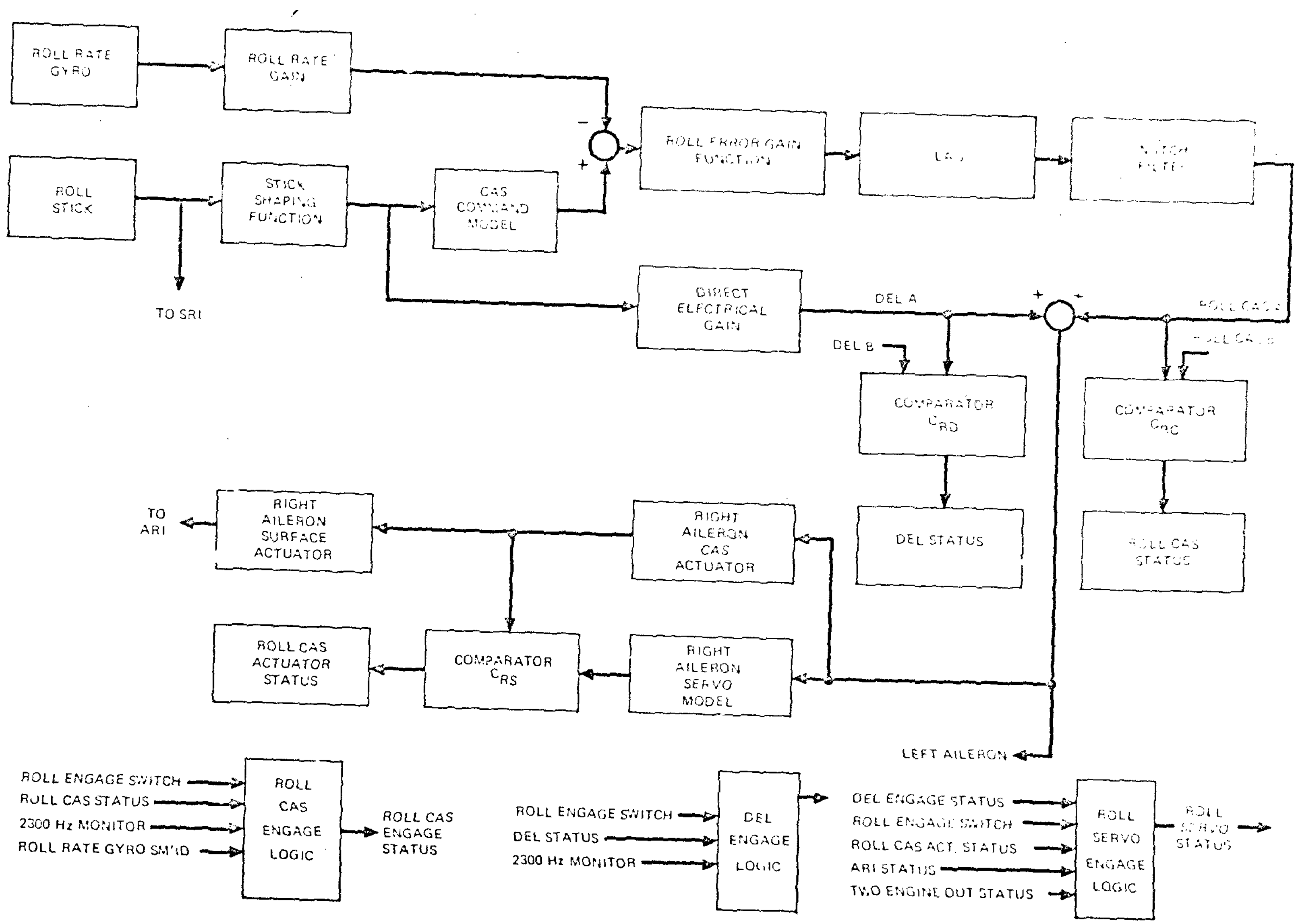

Figure 2.18 Aileron Control System (Typical for One Channel)

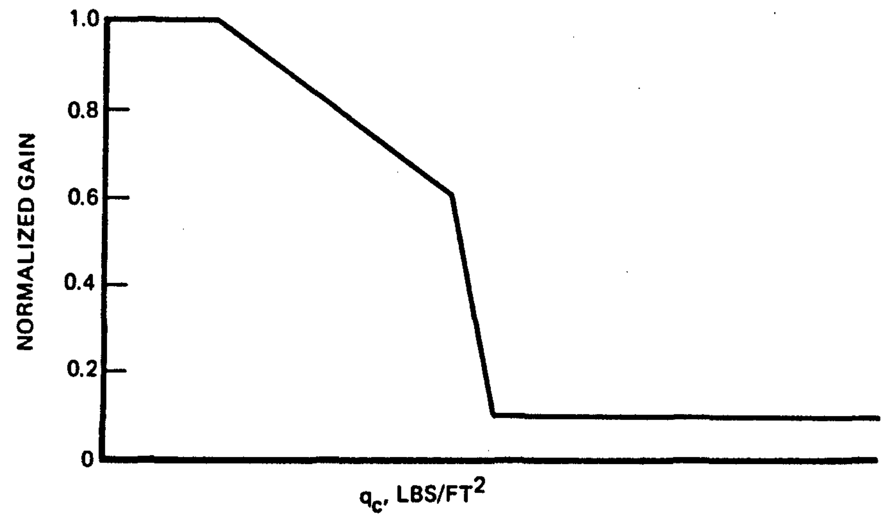

Figure 2.19 Roll Error Gain Function

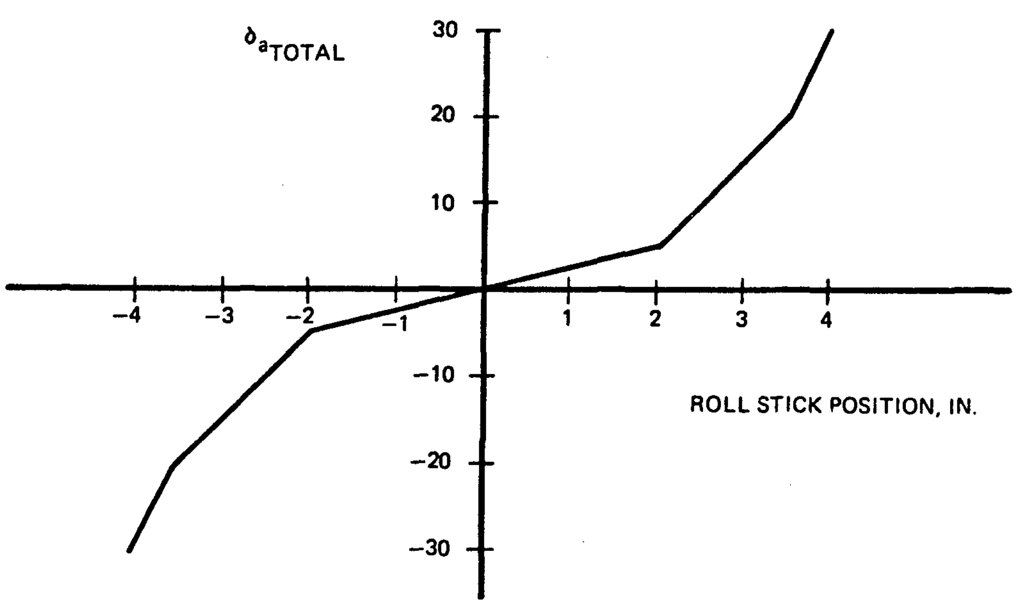

Figure 2.20 Stick Shaping Function

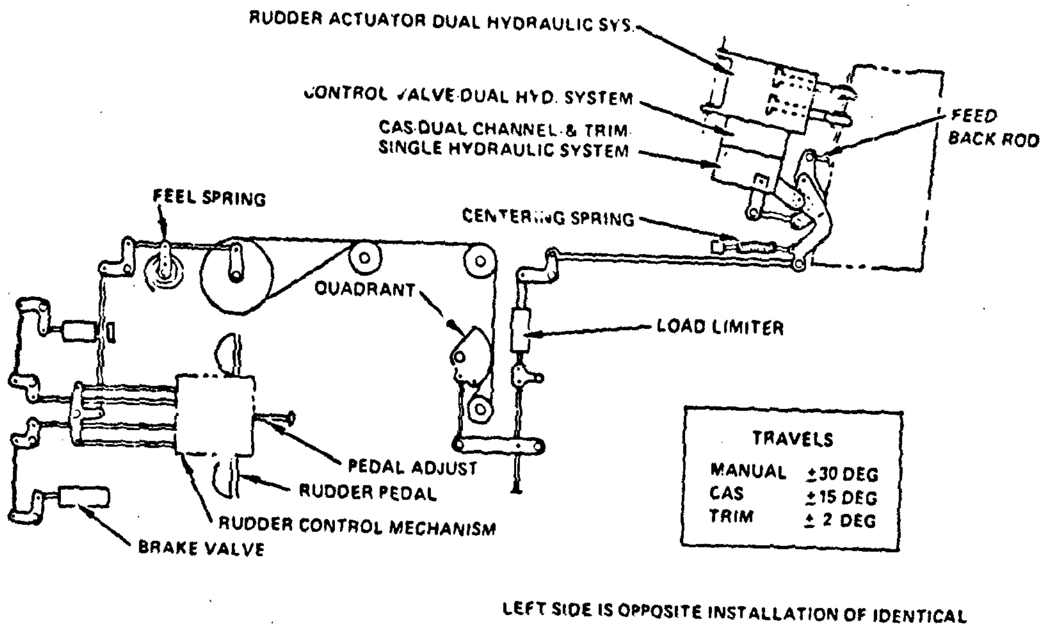

Figure 2.21 Rudder Control System

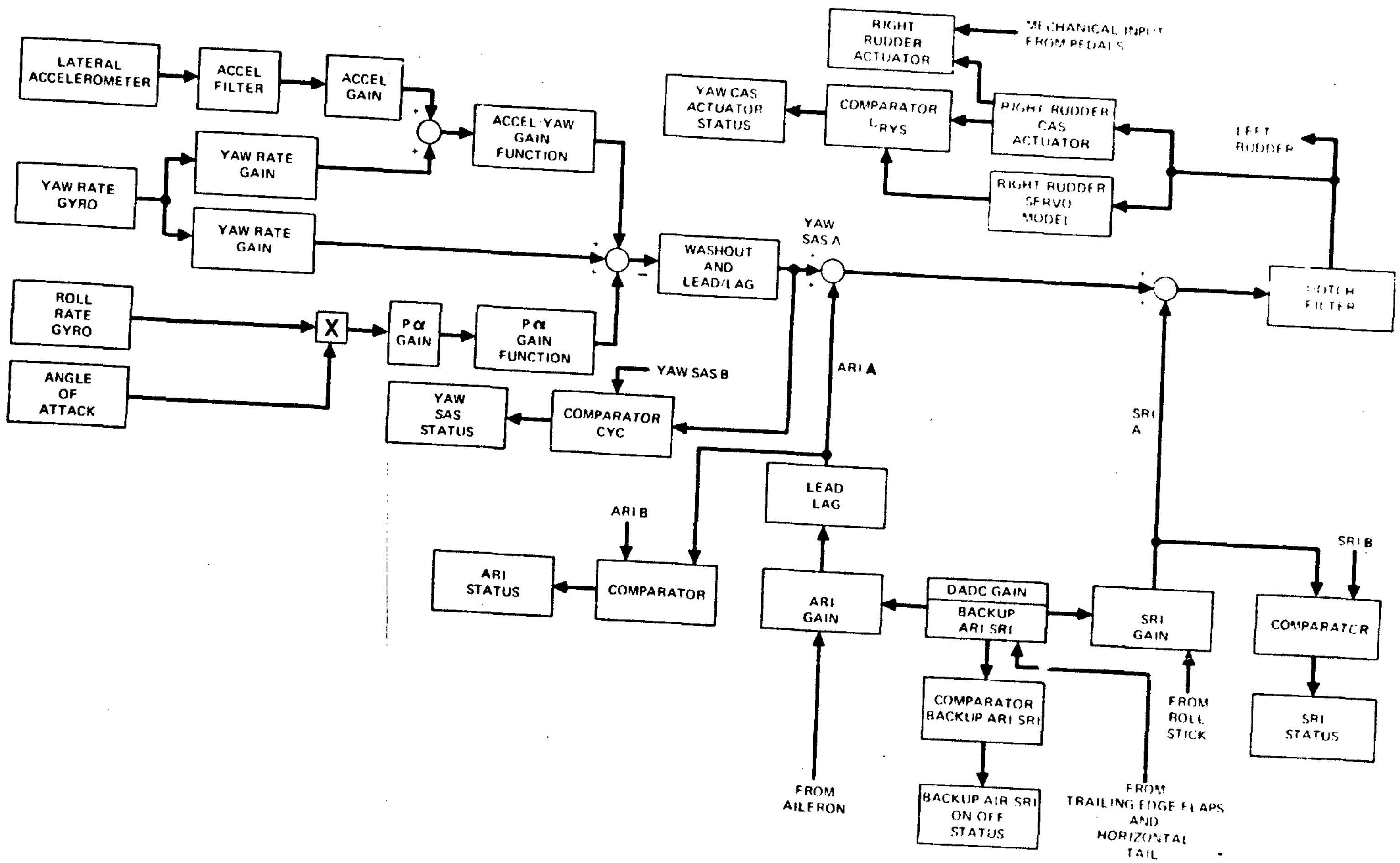

Figure 2.22 Yaw Control and Interconnect System (Typical for One Channel)

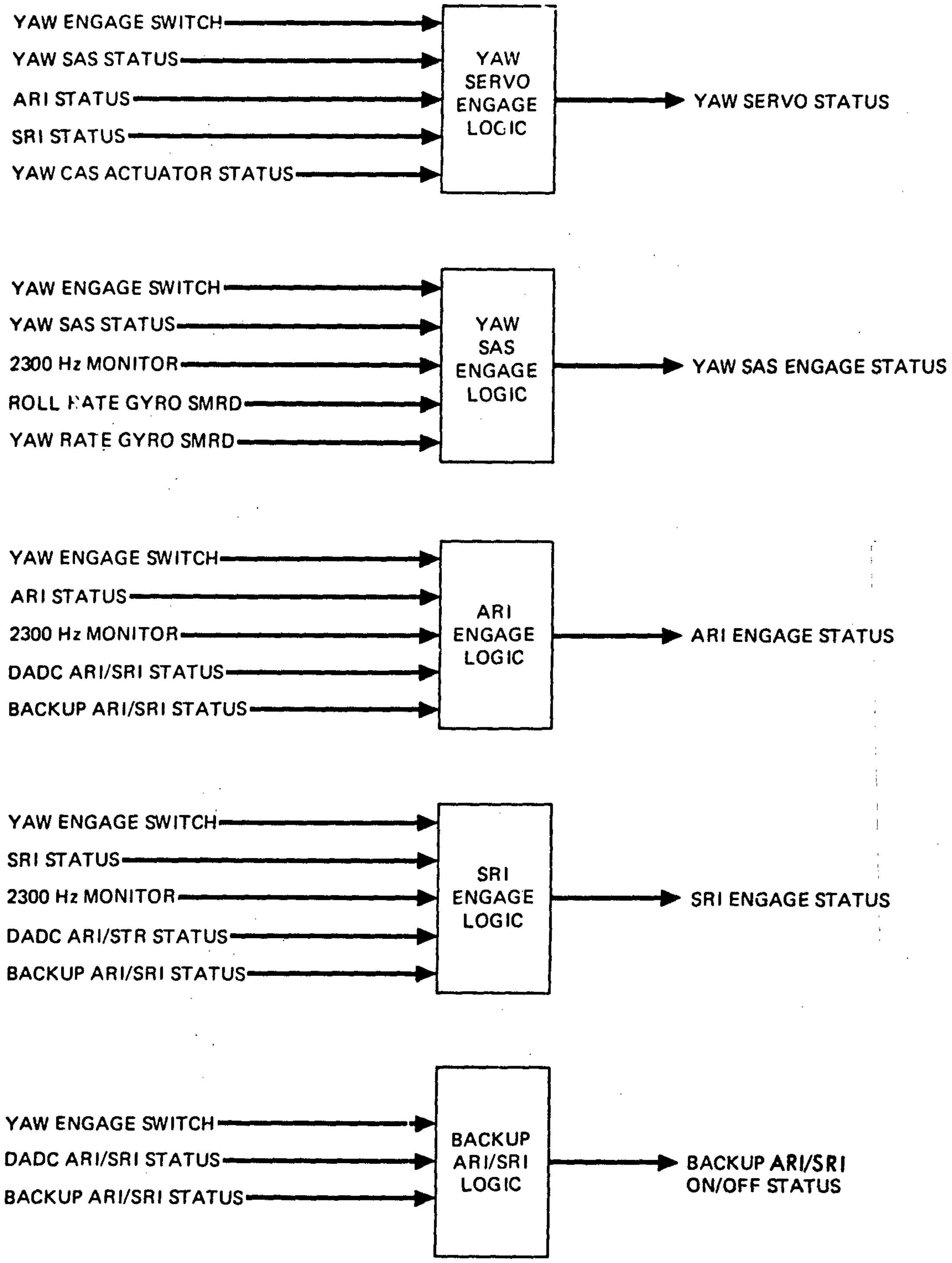

Figure 2.23 Yaw Control Logic Diagram

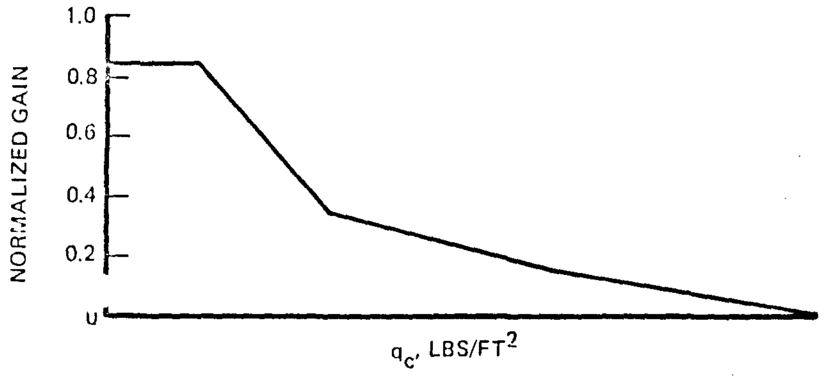

Figure 2.24 Acceleration/Yaw Rate Gain Function

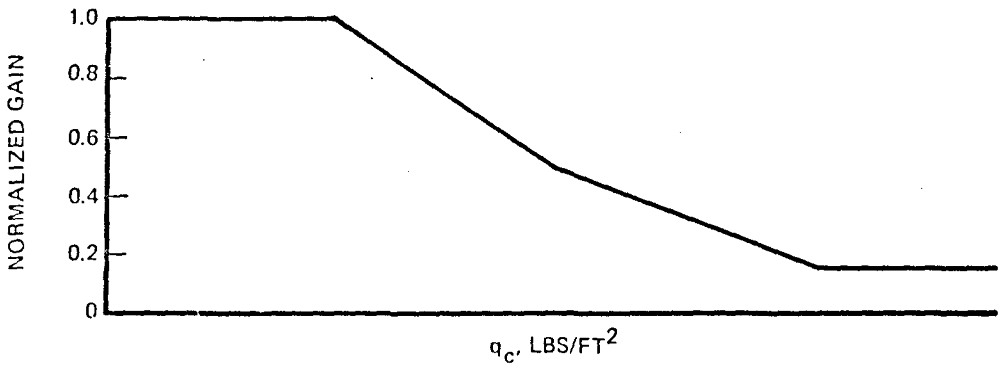

Figure 2.25 Pa Gain Function

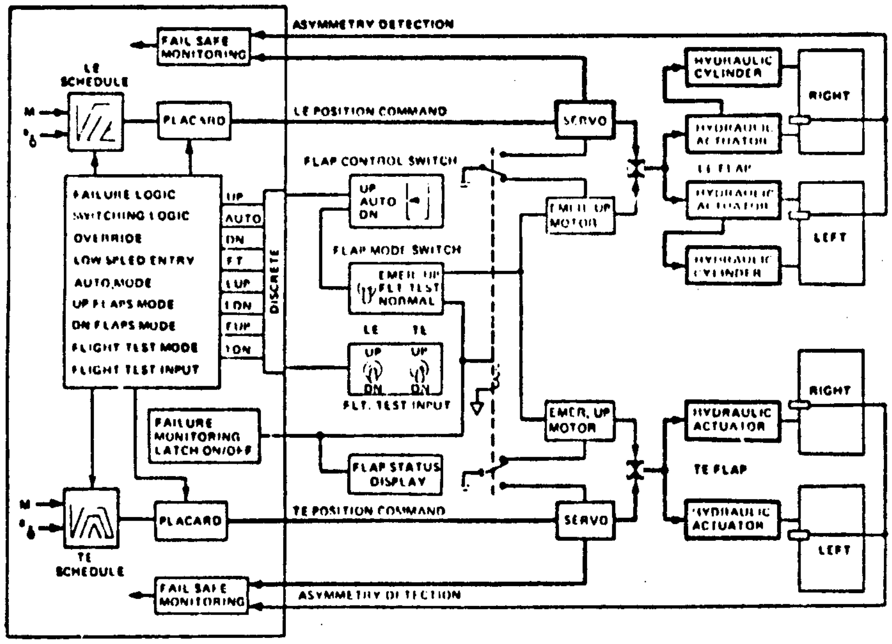

Figure 2.26 Flaps Control System

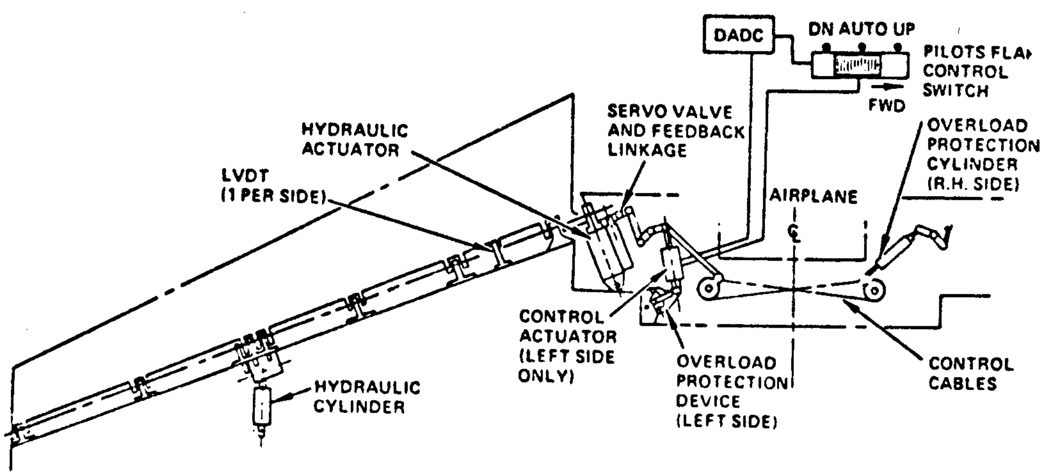

Figure 2.27 Leading-Edge Flap Control System

normal asymmetry limit is exceeded. Both cylinders are driven by the right hydraulic system. In the event of a hydraulic failure, the trailing-edge flaps will go to the faired position and become locked in that position. There is a mechanical interconnect from the trailing edge flaps to the horizontal tail to reduce longitudinal transients during operation of the flaps as shown in Figure 2.29.

Speed Brake Control System

The speed brake is power-operated by a single hydraulic cylinder which is controlled by a remote solenoid valve. A conventional speed brake control switch to control the speed brake is installed in the throttle control in the cockpit. Closed, off, and open positions of the switch permit the pilot to hold the speed brakes in any intermediate position. Figure 2.30 shows the speed brake configuration.

Throttle Control System

The thrust level of the two engines is controlled through conventional mechanical linkages and cables from the cockpit to the throttle shaft on each engine.

The pilot's cockpit control consists of a master lever and latched left and right engine control levers to allow control of both engines simultaneously with one lever. These levers provide individual engine control. The master lever may be stowed forward and individual engine control achieved with the left and right levers. The throttle control system is shown in Figure 2.31.

Inlet Ramp Bleed Control System

The inlet ramp bleed doors are located in the upper surface of the LH and RH leading edge extensions (LEX) and are positioned through the electromechanical actuators by the DADC as a function of Mach number.

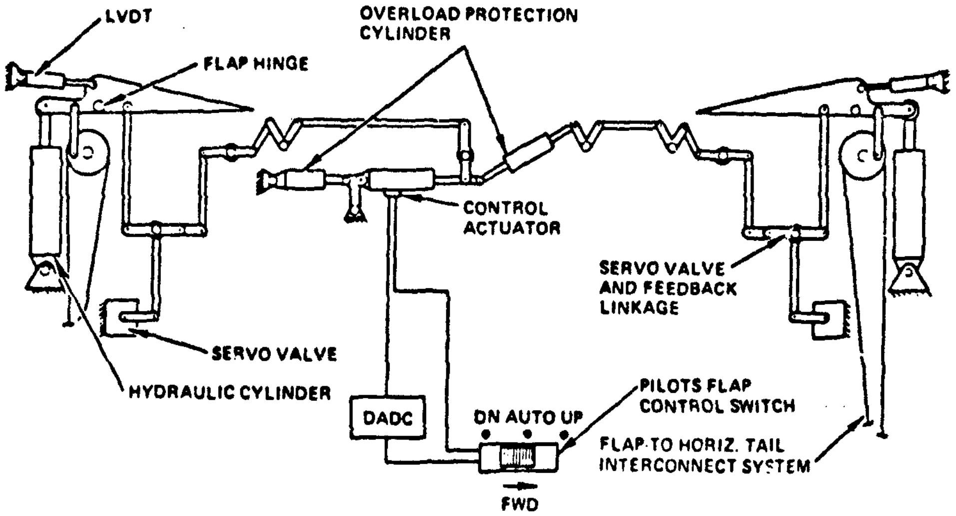

Figure 2.28 Trailing-Edge Flap Control System

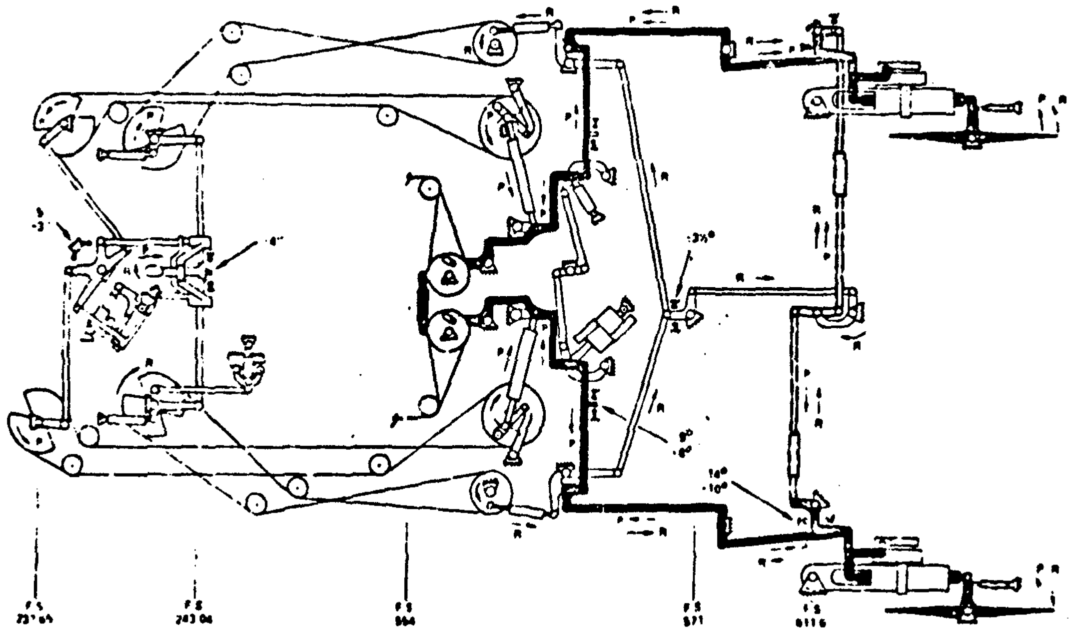

Figure 2.29 Horizontal Tail Control System - TE Flap Input

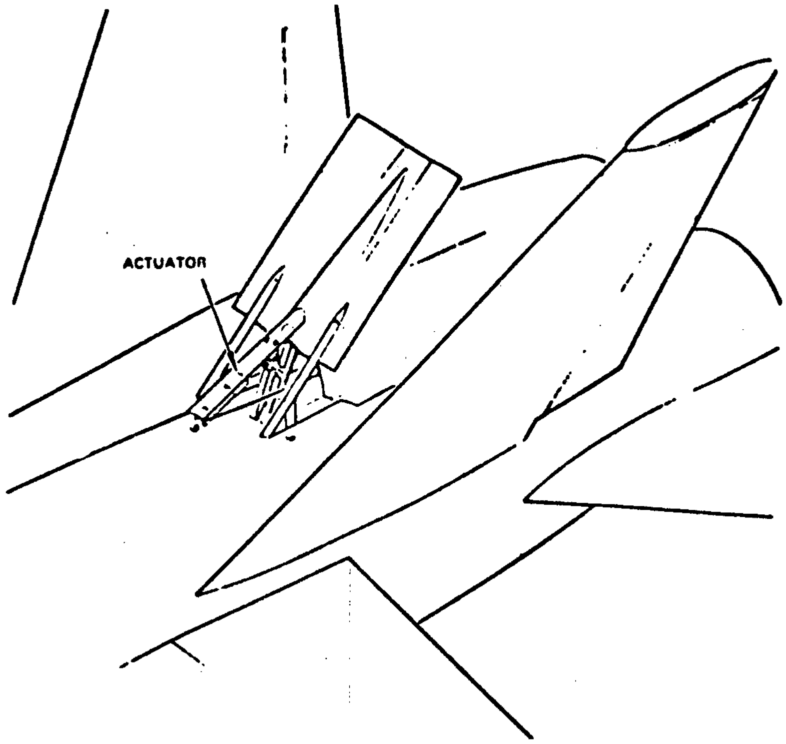

Figure 2.30 Speed Brake Control System

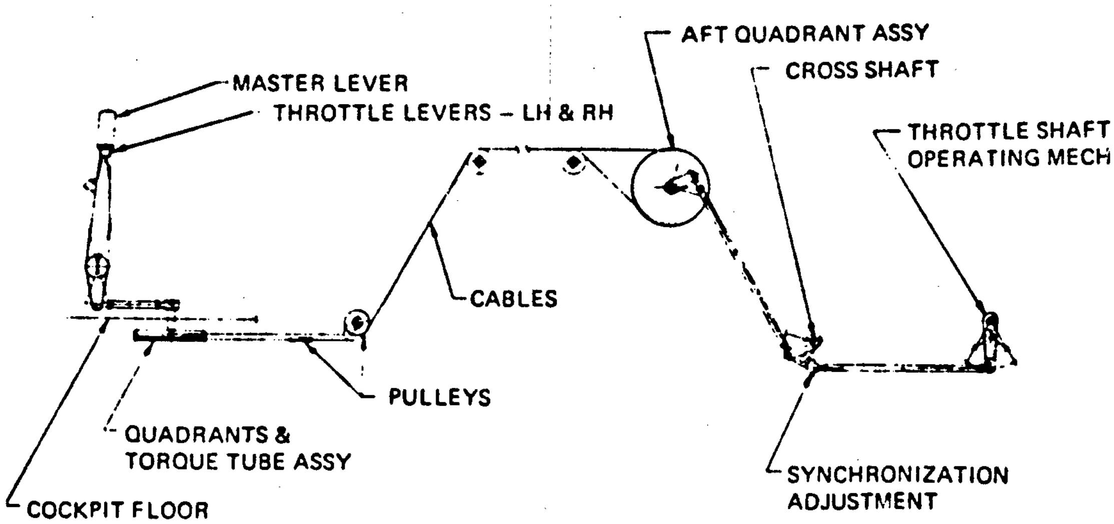

Figure 2.31 Throttle Control System

SECTION III

VALIDATION OF REQUIREMENTS

INTRODUCTION

This section presents the validation of military specification MIL-F-9490D(USAF) by checking the specification requirements utilizing the experience and knowledge derived during the recent procurement of the YF-17 Lightweight Fighter. Each specification paragraph applicable to the YF-17 is presented in sequence, either singly or in logical groups, and validated with regard to practicability, accuracy, and completness as a requirement for procurement, design, test, and installation of flight control systems for future piloted military aircraft. Specification paragraphs not applicable to the YF-17, and therefore not validated, are listed in this section in their proper numerical position together with the paragraph title and the notation NOT APPLICABLE. For ease of reference the paragraph numbers of the specification are used herein.

VALIDATION FORMAT AND METHODOLOGY

The validation format is comprised of five specific parts. A description of the possible contents of each part follows:

1. Requirement

In this part, the paragraph is written exactly as it appears in the specification.

2. Comparison

In this part, the compliance of the system, subsystem, or component with the requirement is described. Test, analytical, and descriptive data are presented where appropriate.

3. Discussion

In this part, an opinion of the requirement is given, whether or not there is compliance by the YF-17. If the system, subsystem, or component does not comply, the effect that compliance would have had is discussed. If there are valid reasons why compliance is not necessary or would be undesirable, the reasons are given. Where appropriate, an assessment is made as to whether the requirement is good, too lenient, or to strict.

The requirement is also evaluated to determine if compliance can be practically demonstrated. If not, a determination is made as to whether it can be modified to make it so. Further, the requirement is evaluated to determine if the stringency can be justified for future aircraft procurement.

If the requirement is judged valid but YF-17 data do not meet the requirement, the reasons for the discrepancy are provided. If a recommendation to change the requirement is being made, pertinent considerations to support the recommendations are given.

4. Recommendation

If a change is considered necessary to improve the practicability, accuracy, and completness of the specification, a recommendation is given. The recommendation, if any, is given in this part. If a complete rewrite of the specification paragraph is suggested, it is written in this part in specification language. If only a partial rewrite is recommended, the changes to the existing paragraph only are indicated.

5. Additional Data

If a change is considered necessary to improve or update the Users Guide, the text to be inserted into the Users Guide is given in this part.

Requirement

1. SCOPE

1.1 Scope. This specification establishes general performance, design, development and quality assurance requirements for the flight control systems of USAF manned piloted aircraft. Flight control system (FCS) include all components used to transmit flight control commands from pilot or other sources to appropriate force and moment producers. Flight control commands may result in control of aircraft flight path, attitude, airspeed, aerodynamic configuration, ride, and structural modes. Among components included are the pilot's controls, dedicated displays and logic switching, transducers, system dynamic and air data sensors, signal computation, test devices, transmission devices, actuators, and signal transmission lines dedicated to flight control. Excluded are aerodynamic surfaces, engines, helicopter rotors, fire control devices, crew displays and electronics not dedicated to flight control. The interfaces of flight control systems with related subsystems are defined.

Comparison

The YF-17 aircraft was developed to demonstrate the improvements attainable by the application of advanced technology in the general performance, aerodynamic qualities, and weapon delivery effectiveness of a fighter aircraft. To achieve this objective, wide latitude was allowed to the contractor relative to compliance with existing performance and hardware specifications. However, the specifications were used as design guides and were complied with to the extent permitted by the program objectives and the tight test development schedule. Specifically, the YF-17 flight control system design followed the guidelines of MIL-F-9490C and the applicable design hardbooks and was subjected to extensive design verification on a full scale flight controls test stand prior to first flight.

A detailed functional and hardware description of the YF-17 flight controls system is provided in Section II of this report.

Discussion

Non-dedicated crew displays have been specifically excluded from the list of flight controls components, implying that they may be designed to different, possibly less stringent requirements even if they display flight controls information. Considering the coming age of integrated displays, as well as the possibly crucial importance of flight control status information, all displays presenting flight controls status should meet, as a minimum, the requirements of this specification.

Recommendation

Revise the requirement as follows:

Change in the fourth sentence "...dedicated displays and logic switching..." to "...dedicated or multipurpose displays and logic switching..." Change in the fifth sentence "Excluded are... ...crew displays and electronics not dedicated to flight control." to "Excluded are... ...crew displays and electronics with no flight controls functions."

Additional Data

Revise the last paragraph of the Discussion to 1.1 Scope in the Users' Guide to:

"Interfaces of flight controls with other subsystems must be considered by the contractor in meeting many of the requirements of MIL-F-9490, particularly when such interfaces include integrated displays which present flight control information. Reliability and failure immunity requirements also require that failure effects in subsystems having no flight control functions be considered when such effects can impact flight controls."

Requirement

1.2 Classification

1.2.1 Flight control system (FCS) classifications

1.2.1.1 Manual flight control systems (MFCS). Manual Flight Control Systems consists of electrical, mechanical and hydraulic components which transmit pilot control commands or generate and convey commands which augment pilot control commands, and thereby accomplish flight control functions. This classification includes the longitudinal, lateral-directional, lift, drag and variable geometry control systems. In addition, their associated augmentation, performance limiting and control devices are included.

Comparison

The YF-17 contains the following systems that fall under subject classification:

a. Longitudinal Control System - Dual hydraulic conventional mechanical control system operates the all-moving horizontal stabilizer surfaces. The mechanical system is augmented by the limited authority pitch control augmentation system (CAS). The CAS utilizes pitch stick position command and pitch rate and normal acceleration dynamic feedbacks. Forward integration (automatic trim) is accomplished by a tandem, electromechanical actuator installed in series with the mechanical control system.

b. Lateral Control System - The lateral mechanical control system is summed with the longitudinal mechanical system to operate the horizontal stabilizer surfaces differentially (rolling tail). The direct electrical link (DEL) aileron control system, augmented by the roll control augmentation system, operates each aileron independently for additional roll control. The roll CAS utilizes roll stick position command and roll rate dynamic feedback.

c. Directional Control System - Dual hydraulic conventional mechanical system, augmented by the limited authority yaw stability augmentation/roll-to-yaw interconnect system, operates the twin rudder surfaces. The stability augmenter utilizes yaw rate, lateral acceleration, and roll rate times angle-of-attack dynamic feedbacks. The roll-to-yaw interconnect system positions the twin rudders proportionally to aileron and differential horizontal tail (rolling tail) deflections; the sign and constant of proportionality being determined by Mach number and angle of attack.

d. Flap Control System - The leading-edge flaps are operated by two dual hydraulic actuators per surface. The inboard actuators are controlled and synchronized by a centrally located electromechanical control actuator through a cable/linkage arrangement. The power spool of each inboard actuator also meters hydraulic flow to an outboard power cylinder, the position of which is determined by a hinge moment feedback due to aerodynamic and structural (twist) forces. The trailing-edge flaps are operated by a single hydraulic actuator per surface. The actuators are controlled by an electromechanical control actuator in an arrangement identical to that for the leading-edge flaps.

   Each electromechanical actuator is controlled by an electronic drive channel, which, in turn is controlled by the digital air data computer (DADC). The flaps can be positioned manually by selector switches or placed in the automatic modes for positioning in accordance with angle-of-attack and Mach number schedule.

   The flap control system includes a mechanical interconnect from trailing-edge flaps to the horizontal stabilizer to reduce longitudinal trim changes.

e. Speed Brake Control System - The single panel speed brake is located between the twin vertical tails and is operated by a solenoid-valve controlled single hydraulic actuator. A conventional three-position switch on the throttle provides directional and on/off control to the solenoid-valve, allowing selection of open, close, and intermediate speed brake positions.

Discussion

Subject paragraph defines MFCS components as being electrical, mechanical, and hydraulic. This is interpreted to include electromechanical and electrohydraulic combinations and analog and digital electronics as well. The list is obviously incomplete as pneumatic, and more recently, electro-optical devices have been considered in flight controls applications. To insure consistency with Paragraph 1.1 Scope, which implies that all devices dedicated to flight controls are flight control elements, the wording of this paragraph should be revised accordingly. It is not clear whether manual throttle controls are meant to be included as a flight control function or not. In the context of Paragraph 1.1 Scope, throttle controls certainly qualify as a flight control system, inasmuch as they are used to control flight path, attitude, and airspeed, particularly in the power approach/landing phase of the flight. However, the design of manual throttle controls is adequately covered by specifications and handbooks related to propulsion systems and controls (MIL-E-5007D, SD-24K, AFSC DH 2-2, etc.)

Recommendations

Revise the requirement as follows:

Change the first sentence to read,

"Manual Flight Control Systems include all components and elements which transmit . . . and thereby accomplish flight control functions.

Add to the requirement,

"Excluded are manual throttle controls consisting exclusively of mechanical elements."

Requirement

1.2.1.2 Automatic flight control systems (AFCS). Automatic Flight Control Systems consist of electrical, mechanical and hydraulic components which generate and transmit automatic control commands which provide pilot assistance through automatic or semiautomatic flight path control or which automatically control airframe response to disturbances. This classification includes automatic pilots, stick or wheel steering, autothrottles, structural mode control and similar control mechanizations.

Comparison

The YF-17 contains no systems falling under subject classification.

Discussion

Same as for Paragraph 1.2.1.1, as regards classification of component types as being electrical, mechanical, and hydraulic.

Recommendations

Revise the requirement as follows:

> "Automatic Flight Control Systems include all components and elements which generate . . ."

Requirement

1.2.2 FCS Operational State classifications

1.2.2.1 Operational State I (Normal operation). Operational State I is the normal state of flight control system performance, safety and reliability. This state satisfies MIL-F-8785 or MIL-F-83300 Level 1 flying qualities requirements within the operational flight envelope and Level 2 within the service envelope and the stated requirements outside of these envelopes.

1.2.2.2 Operational State II (Restricted operation). Opertional State II is the state of less than normal equipment operation or performance which involves degradation or failure of only a noncritical portion of the overall flight control system. A moderate increase in crew workload and degradation in mission effectiveness may result from a limited selection or normally operating FCS modes available for use; however, the intended mission may be accomplished. This state satisfies at least MIL-F-8785 or MIL-F-83300 Level 2 flying qualities requirements within the operational flight envelope and Level 3 within the service envelope.

1.2.2.3 Operational State III (minimum safe operation). Operational State III is that state of degraded flight control system performance, safety or reliability which permits safe termination of precision tracking or maneuvering tasks, and safe cruise, descent, and landing at the destination of original intent or alternate but where pilot workload is excessive or mission effectiveness is inadequate. Phases of the intended mission involving precision tracking or maneuvering cannot be completed satisfactorily. This state satisfies at least MIL-F-8785 or MIL-F-83300 Level 3 flying qualities requirements.

1.2.2.4 Operational State IV (controllable to an immediate emergency landing). Operational State IV is the state of degraded FCS operation at which continued safe flight is not possible; however, sufficient control remains to allow engine restart attempt(s), a controlled descent and immediate emergency landing.

1.2.2.5 Operational State V (controllable to an evacuable flight condition). Operational State V is the state of degraded FCS operation at which the FCS capability is limited to maneuvers required to reach a flight condition at which crew evacuation may be safely accomplished.

Comparison

No data presented; the paragraph is only qualitative in nature.

Requirement

1.2.3 FCS criticality classification

1.2.3.1 Essential. A function is essential if loss of the function results in an unsafe condition or inability to maintain FCS Operational State III.

Comparison

The following YF-17 control functions are considered essential:

Longitudinal mechanical control system.

Lateral mechanical control system (rolling tail).

Discussion

The definition for an essential function is satisfactory.

Recommendation

Retain the requirement as stated.

Requirement

1.2.3.2 Flight phase essential. A function is flight phase essential if loss of the function results in an unsafe condition or inability to maintain FCS Operational State III only during specific flight phases.

Comparison

The following YF-17 control functions have been considered flight phase essential for the reasons shown. For the purpose of this classification, a function was considered flight phase essential if a loss of the function results in a potentially unsafe condition only during specific flight phases. (See Discussion.)

a. Pitch Control Augmentation - Reduced pushover control capability if failure occurs at high angle of attack (AOA).

b. Aileron Direction Electrical Link (DEL) - Minimal roll power available at low speeds, such as high AOA and landing.

c. Directional Mechanical Control - No directional control available at high AOA and landing.

d. Roll-to-Yaw Interconnect - Causes shutdown of ailerons, hence reduced roll power.

e. Automatic Flaps - Reduced directional stability at high AOA.

f. Manual Flaps - Hot landing if flaps fail in the up position.

Discussion

The above classification of YF-17 control functions was made without regard to the likelehood of losing a particular function of the corrective measures available to the crew. For instance, an emergency trim is available to restore full pushover mechanical control capability in case of noted pitch augmentation failure. Or, no single failure can disable both ailerons or the roll-to-yaw interconnect function. In any case, by restricting the maneuvering envelop and at the expense of increased pilot workload, the YF-17 flight can be safely continued and safely terminated, but not necessarily at the destination of original intent.

The part of the definition for flight phase essential function ". . . inability to maintain FCS Operational State III only during specific flight phases." has been considered somewhat difficult to interpret and to apply. The phrase, " . . . inability to maintain FCS Operational State III" is also used in defining essential functions.

There, the loss of the function implies State IV (controllable to emergency landing) or State V (Controllable to evacuable flight condition) or, in a sense, worse than State V (that is uncontrollable). If the same interpretation is employed here, the function cannot be flight phase essential: It must be essential. It is believed that the proper interpretation for a flight phase essential function should be such that loss of the function may create an unsafe condition during specific flight phases but allows continued safe flight and safe landing if the appropriate limitations are observed.

Additionally, the term "flight phase" may be subject to individual interpretation unless specific reference is made to MIL-F-8785.

Recommendations

Revise the requirement as follows:

> "1.2.3.2 Flight phase essential. A function is flight phase essential if loss of the function results in an unsafe condition only during specific flight phases, as defined in MIL-F-8785, or requires operational restrictions to maintain Operational State III (minimum safe operation)."

Requirement

1.2.3.3 Noncritical. A function is noncritical if loss of the function does not affect flight safety or result in control capability below that required for FCS Operational State III.

Comparison

The following YF-17 control functions have been considered non-critical for the reasons stated:

a. Roll Control Augmentation - The aircraft has adequate roll damping and spiral stability. Primary function of roll CAS is to normalize roll response for tracking.

b. Yaw Control Augmentation - The aircraft has adequate Dutch roll damping and directional stability. The function of the yaw CAS is to improve ride comfort in turbulence and to optimize roll-yaw characteristics during tracking.

c. Speed Brakes - Precision speed control may be achieved without speed brakes at the expense of a slight increase in pilot workload.

Discussion

The definition for a noncritical function is satisfactory.

Recommendation

Retain the requirement as stated.

Requirement

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein. The requirements of this specification shall govern for flight control system design where conflicts exist between this specification and other reference specifications.

SPECIFICATIONS

Military

MIL-T-781	Terminal, Wire Rope, Swaging
MIL-F-3541	Fitting, Lubrication
MIL-U-3963	Universal Joint, Antifriction Bearings
MIL-B-5087	Bonding, Electrical and Lightning Protection, for Aerospace Systems
MIL-W-5088	Wiring, Aircraft, Selection and Installation of
MIL-E-5400	Electronic Equipment, Airborne, General Specification for
MIL-H-5440	Hydraulic Systems, Aircraft Types I and II, Design, Installation, and Data Requirements for
MIL-C-5503	Cylinder, Aeronautical, Hydraulic Actuating, General Requirements for
MIL-P-5518	Pneumatic Systems, Aircraft, Design, Installation, and Data Requirements for
MIL-T-5522	Test Procedure for Aircraft Hydraulic and Pneumatic Systems, General
MIL-S-5676	Splicing, Cable Terminal, Process for, Aircraft
MIL-T-5677	Thimble, Wire Cable, Aircraft
MIL-B-5687	Bearing, Sleeve, Washers, Thrust, Sintered, Metal Powder, Oil-Impregnated
MIL-C-6021	Casting, Classification and Inspection of
MIL-B-6038	Bearing, Ball, Bellcrank, Antifriction, Airframe
MIL-B-6039	Bearing, Double Row, Ball, Sealed, Rod End, Antifriction, Self-Aligning
MIL-E-6051	Electromagnetic Compatibility Requirements, Systems
MIL-T-6117	Terminal, Cable Assemblies, Swaged Type
MIL-J-6193	Joint, Universal, Plain, Light and Heavy Duty
MIL-G-6641	Gearbox, Aircraft Accessory Drive, General Specification for
MIL-P-7034	Pulley, 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-F-7190	Forging, Steel, for Aircraft and Special Ordnance Applications
MIL-D-7602	Drive, Turbine, Air, Aircraft Accessory, General Specification for
MIL-B-7949	Bearing, Ball, Airframe, Antifriction
MIL-C-7958	Control, Push-Pull, Flexible and Rigid
MIL-M-7969	Motor, AC, 400 Cycle, 115/200 Volt System, Aircraft, General Specification for
MIL-M-7997	Motor, Aircraft Hydraulic, Constant Displacement, General Specification for
MIL-I-8500	Interchangeability and Replaceability of Component Parts for Aircraft and Missiles
MIL-P-8564	Pneumatic System Components, Aeronautical, General Specifications for
MIL-M-8609	Motor, DC, 28 Volt System, Aircraft, General Specification for
MIL-S-8698	Structural Design Requirements, Helicopters
MIL-H-8775	Hydraulic System Components, Aircraft and Missiles, General Specifications for
MIL-F-8785	Flying Qualities of Piloted Airplanes
MIL-A-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-8870	Airplane Strength and Rigidity Flutter; Divergence, and Other Aeroelastic Instabilities
MIL-T-8878	Turnbuckle, Positive Safetying
MIL-S-8879	Screw Threads, Controlled Radius Root with Increased Minor Diameter; General Specification for
MIL-H-8890	Hydraulic Components, Type III, -65° to +450°F, General Specification for
MIL-H-8891	Hydraulic Systems, Manned Flight Vehicles, Type III, Design, Installation, and Data Requirements for
MIL-A-8892	Airplane Strength and Rigidity, Vibration
MIL-A-8893	Airplane Strength and Rigidity, Sonic Fatigue
MIL-B-8976	Bearing, Plain, Self-Aligning, All-Metal
MIL-S-9419	Switch, Toggle, Momentary, Four-Position On, Center Off
MIL-C-18375	Cable, Steel (Corrosion-Resisting, Nonmagnetic) Flexible, Preformed (for Aeronautical Use)
MIL-A-21180	Aluminum-Alloy Casting, High Strength
MIL-A-22771	Aluminum Alloy Forgings, Heat Treated
MIL-K-25049	Knob, Control, Equipment, Aircraft
MIL-G-25561	Grip Assembly, Controller, Aircraft, Type MC-2

MIL-V-27162	Valve, Servocontrol, Electrohydraulic, General Specification for
MIL-C-27500	Cable, Electrical, Shielded and Unshielded, Aircraft and Missile
MIL-E-38453	Environmental Control, Environmental Protection, and Engine Bleed Air Systems, Aircraft, and Aircraft Launched Missiles, General Specification for
MIL-M-38510	Microcircuit, General Specification for
MIL-B-81820	Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed
MIL-F-83142	Forging, Titanium Alloys, for Aircraft and Aerospace Applications
MIL-F-83300	Flying Qualities of Piloted V/STOL Aircraft
MIL-W-83420	Wire Rope, Flexible, for Aircraft Control
MIL-A-83444	Airplane Damage Tolerance Requirements

STANDARDS

Military

MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-143	Standards and Specifications, Order of Precedence for the Selection of
MIL-STD-250	Aircrew Station Controls and Displays for Rotary Wing Aircraft
MIL-STD-421	Chain Roller; Power Transmission and Conveyor, Flat Link Plates, Single Pitch, Single and Multiple Strand, Connective Links and Attachment Links
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Interference Characteristics Requirements for Equipment
MIL-STD-480	Configuration Control - Engineering Changes, Deviations and Waivers
MIL-STD-704	Electric Power, Aircraft, Characteristics and Utilization of
MIL-STD-810	Environmental Test Methods
MIL-STD-838	Lubrication of Military Equipment
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-STD-1530	Aircraft Structural Integrity Program, Airplane Requirements
MIL-STD-1553	Aircraft Internal Time Division Multiplex Data Bus
MS15002	Fittings, Lubrication (Hydraulic) Surface Check, Straight Threads, Steel, Type II

MS15981	Fasteners, Externally Threaded, Self-Locking, Design and Usage Limitations for
MS24665	Pin, Cotter
MS33540	Safety Wiring and Cotter Pinning, General Practices for
MS33572	Instrument, Pilot, Flight, Basic, Standard Agreement for Helicopters
MS33588	Nuts, Self-Locking, Aircraft Design and Usage Limitations of
MS33602	Bolt, Self Retaining, Aircraft Reliability and Maintainability Design and Usage, Requirements for
MS33736	Turnbuckle Assemblies, Clip Locking of

PUBLICATIONS

Military Handbooks

MIL-HDBK-5	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-HDBK-17	Plastics for Flight Vehicles

Air Force Systems Command Design Handbooks

AFSC DH 1-2	General Design Factors
AFSC DH 1-4	Electromagnetic Compatibility
AFSC DH 1-5	Environmental Engineering
AFSC DH 1-6	System Safety
AFSC DH 2-1	Airframe
AFSC DH 2-2	Crew Stations and Passenger Accommodations

(Copies of specifications, standards, drawings, publications and handbooks required by suppliers 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 this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

National Aircraft Standard

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

(Copies of National Aircraft Standards may be obtained from the Aircraft Industries Association of America, Inc., Shoreham Building, Washington, D.C.)

SAE Aerospace Recommended Practices

ARP 988	Electrohydraulic Mechanical Feedback Servoactuators
ARP 1281	Servoactuators: Aircraft Flight Controls, Power Operated, Hydraulic, General Specification for

(Application for copies should be addressed to the American Society of Automotive Engineers, Two Pennsylvania Plaza, New York, New York 10001.)

ICAO Practices

ICAO Annex 10	International Civil Aviation Organization Publication - Aeronautical Telecommunications Vol. II, Communication Procedures, International Standards, Recommended Practices and Procedures for Air Navigation Services

FAA Advisory Circular

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

Technical Reports

AFFDL-TR-74-116	Background Information and User Guide for MIL-F-9490D

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

Comparison

The design of the YF-17 flight control system and its elements followed the design guidelines provided by the AFSC handbooks and complied with major system specifications and standards to the extent considered essential to prove safety of flight and to assure the required flight controls performance within the operational envelope of the aircraft. In addition, the procurement detail specifications for newly developed items involved the salient specifications and standards applicable to that type of hardware. For example, electronic assemblies have been designed and tested to MIL-E-5400, MIL-STD-454, and MIL-STD-461/462.

The specifications, standards, and other applicable documents used in the design and test of the YF-17 flight controls, as well as the extent of compliance with these documents, is discussed under the individual paragraph validations in this volume.

Discussion

The applicable document section provides a comprehensive list of documents that must be considered in the design, development, and test of flight control systems. *The first statement of 2.1 and 2.2, "...form a part of this specification to the extent specified herein...",* is endorsed on the basis that it facilitates the interpretation of the requirement and also allows an assessment of compliance. In contrast, many other specifications contain the amnibus statement "...if a specification is referenced without indicating any specific paragraphs as being applicable, then the specification is applicable in its entirety..." making both the proper interpretation of the requirement and the assessment of compliance more difficult.

Recommendation

Retain the requirement as stated.

Requirement

3. REQUIREMENTS

3.1 System requirements. The FCS shall comply with the following requirements.

3.1.1 MFCS Performance requirements. The MFCS shall comply with applicable general flying quality requirements of MIL-F-8785 or MIL-F-83300 and the special performance requirements of the procurement detail specification.

Comparison

The technological latitude allowed and encouraged in the design and development of the prototype air combat fighters precluded strict adherence by the YF-17 to the requirements of MIL-F-8785B (ASG) and such adherence was not required. However, as an established guide to piloted aircraft flying qualifies, this specification was generally complied with. MIL-F-83300 is not applicable to the YF-17.

While a complete paragraph-by-paragraph comparison of the YF-17 with the requirement of MIL-F-8785B is beyond the scope of this report, examples of the analyses performed to verify flying qualities are shown in Figures 1 (3.1.1), 2 (3.1.1), and 3 (3.1.1).

Discussion

As a supplement to the criteria of MIL-F-8785B, longitudinal handling quality criteria has been determined for the YF-17 in terms of a pitch rate to stick force ratio frequency response envelope. The importance of phase angle and the interrelationship of maneuvering forces with the normalized dynamics are defined by these criteria. The transition of pitch rate emphasis to normal load factor has been determined to occur at a velocity of 800 feet per second. Pilot induced oscillations have been defined by the normal load factor to stick force gain margin values.

Desired lateral-directional criteria have also been defined for the YF-17 in four basic characteristics: roll time constant, Dutch roll dynamics, yaw due to roll level, and control system sensitivity.

The above types of criteria have been applied to the YF-17 as an adjunct to MIL-F-9490B. However, specific recommendations for changes in the requirements of Para. 3.1.1 are not being suggested as a general requirement.

The stringency of this requirement depends on the stringency of MIL-F-8785 as amended or revised, and on the procurement detail specification. Hence, the requirement as stated is satisfactory. Compliance can be demonstrated by ground tests, flight tests, and analysis.

Recommendation

Retain the requirement as stated.

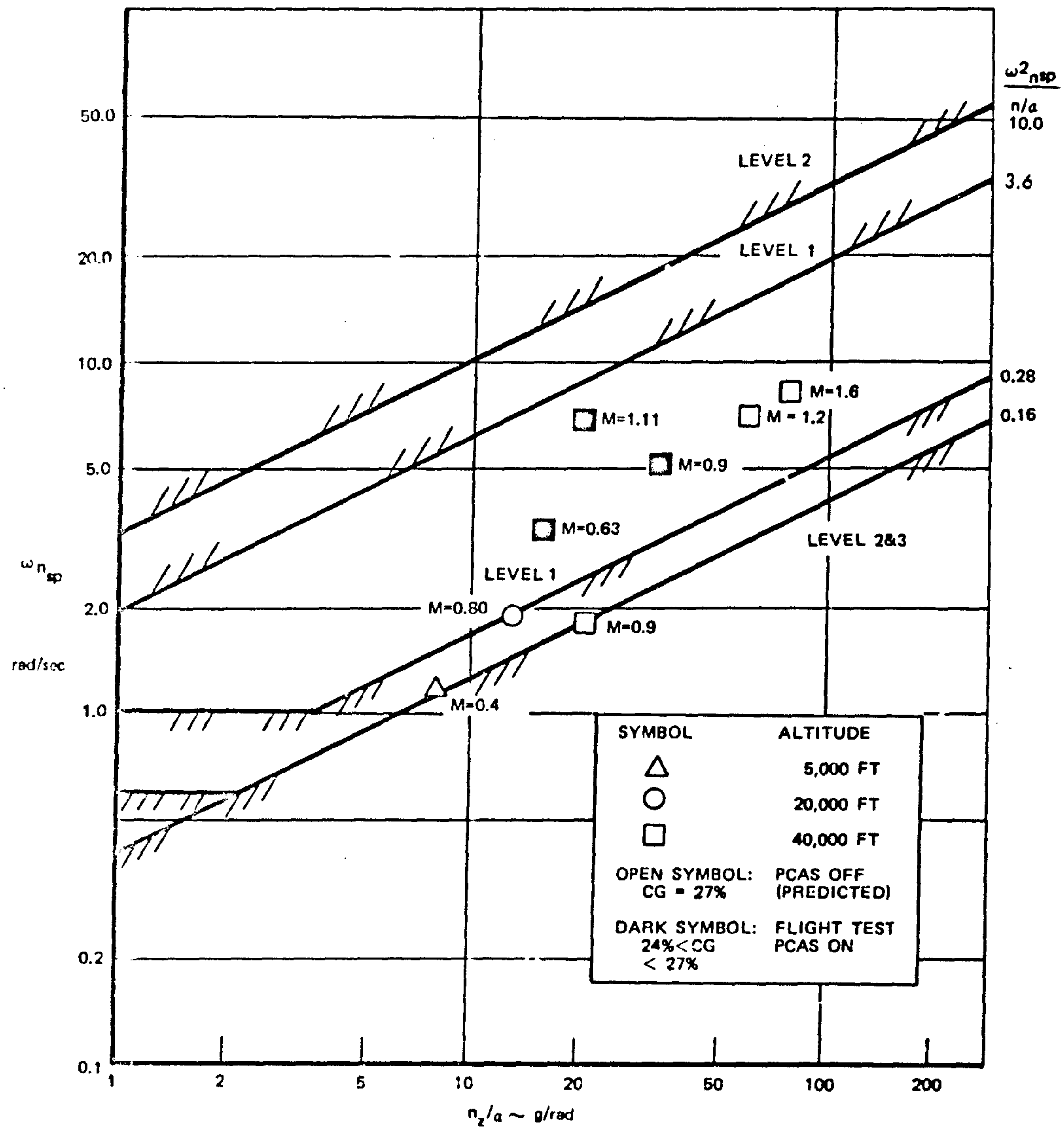

Figure 1(3.1.1) Longitudinal Short Period Dynamics (Category A)

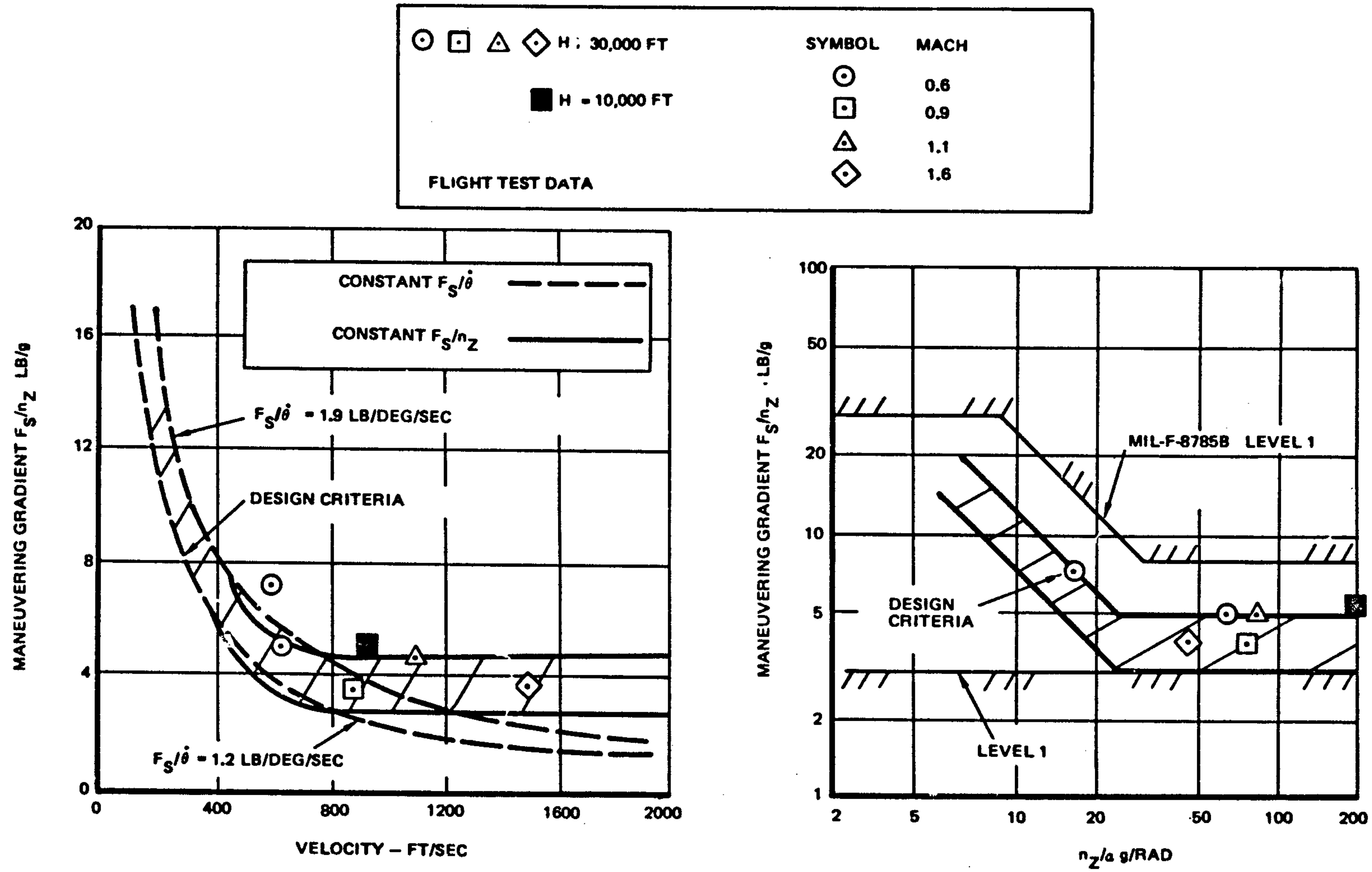

Figure 2(3.1.1) Average Maneuvering Force Gradients

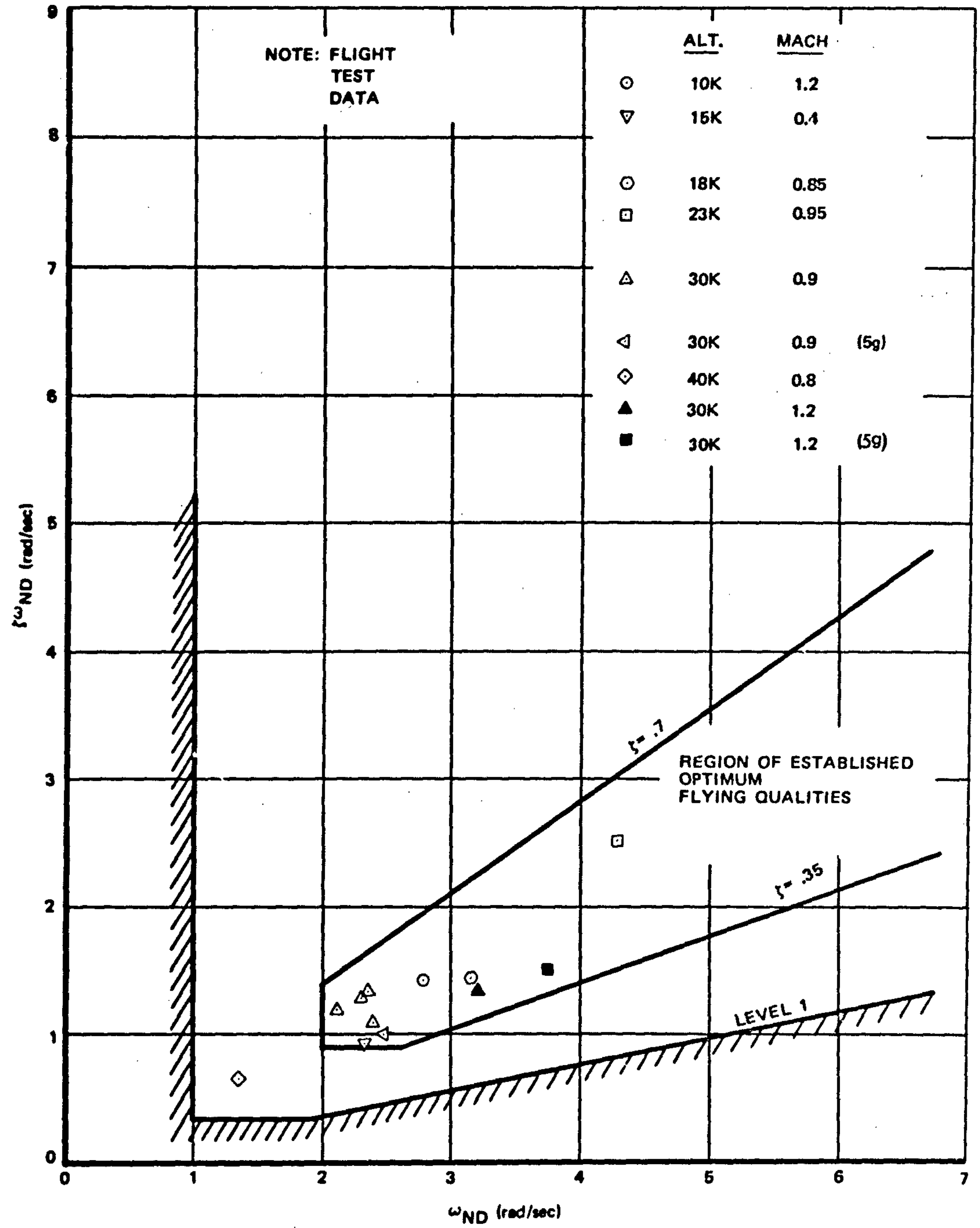

Figure 3(3.1.1) YF-17 Dutch Roll Dynamics

Requirement

3.1.2 AFCS Performance requirements.

Not applicable.

3.1.2.1 Attitude hold (pitch and roll).

Not applicable.

3.1.2.2 Heading hold.

Not applicable.

3.1.2.3 Heading select.

Not applicable.

3.1.2.4 Lateral acceleration and sideslip limits.

Not applicable.

3.1.2.4.1 Coordination in steady banked turns.

Not applicable.

3.1.2.4.2 Lateral acceleration limits, rolling.

Not applicable.

3.1.2.4.3 Coordination in straight and level flight.

Not applicable.

3.1.2.5 Altitude hold.

Not applicable.

3.1.2.6 Mach hold.

Not applicable.

3.1.2.7 Airspeed hold.

Not applicable.

3.1.2.8 Automatic navigation.

Not applicable.

3.1.2.8.1 VOR/TACAN.

Not applicable.

3.1.2.8.1.1 VOR capture and tracking.

Not applicable.

3.1.2.8.1.2 TACAN capture and tracking.

Not applicable.

3.1.2.8.1.3 Overstation.

Not applicable.

3.1.2.9 Automatic instrument low approach system.

Not applicable.

3.1.2.9.1 Localizer mode.

Not applicable.

3.1.2.9.2 Glide slope mode.

Not applicable.

3.1.2.9.3 Go-around mode.

Not applicable.

3.1.2.9.3.1 Pitch AFCS go-around.

Not applicable.

3.1.2.9.3.2 Lateral-heading AFCS go-around performance standards.

Not applicable.

3.1.2.9.3.3 Minimum go-around altitude.

Not applicable.

3.1.2.10 All weather landing system.

Not applicable.

3.1.2.10.1 All weather landing performance standards - variations or aircraft and airborne equipment configurations.

Not applicable.

3.1.2.10.2 Performance standards - ground based equipment variations.

Not applicable.

3.1.2.11 Flight load fatigue alleviation.

Not applicable.

3.1.2.12 Ride smoothing.

Not applicable.

3.1.2.12.1 Ride discomfort index.

Not applicable.

3.1.2.13 Active flutter suppression.

Not applicable.

3.1.2.14 Gust and maneuver load alleviation.

Not applicable.

3.1.2.15 Automatic terrain following.

Not applicable.

3.1.2.16 Control stick (or wheel) steering.

Not applicable.

Requirement

3.1.3 General FCS design. Flight control systems shall be as simple, direct, and foolproof as possible, consistent with overall system requirements.

Comparison

The YF-17 is a prototype development aircraft, incorporating new concepts in control laws and performance enhancement. Consistent with the objectives of the program, the control systems have been configured to provide a large degree of flexibility to enhance the development process and to accommodate flight test requirements. Obviously, flexibility is obtained at the expense of simplicity, and flight test suitability often results in a system that is less direct and foolproof than would be possible in a production design. However, considering the overall requirements for the YF-17, the flight control system meets the intent of this paragraph.

Examples of flight test features incorporated in the YF-17 FCS are as follows:

Flight test gain panel - Provides capability to preset control augmentation gains on the ground and for pilot selection of three gain levels in flight.

Flap flight test controls - Provides capability to position leading- and trailing- edge flaps independently from one another throughout their deflection range.

Flap override controls - Provides capability to override automatic flap operation at the pilot's discretion.

Discussion

The requirement is valid in that it represents the fundamental philosophy of good design. To assure adherence to these design goals proper consideration must be given to all operational and maintenance aspects during the development phase. Human factors evaluation, in conjunction with cockpit and installation mockups, may be effectively used toward this end. However, a true measure of compliance cannot be established until the aircraft has accumulated sufficient service experience.

Recommendation

Retain the requirement as stated.

Requirement

3.1.3.1 Redundancy. The contractor shall determine the redundancy approaches and levels required to satisfy the requirements of this specification.

Comparison

The redundancy aspects of the YF-17 flight control systems provide a control system that degrades gradually or fails to neutral, or can be neutralized by pilot action after a failure for the flight phase essential and noncritical functions, and does not generate unmanageable transients upon failure. The dual redundancy of the essential functions (pitch-roll mechanical controls) satisfies the reliability and safety requirements for fighter aircraft.

The YF-17 can be safely flown and landed with only the pitch-roll mechanical control system (symmetrical and differential control of the horizontal tail surfaces) operational, the rudders in the neutral position, and one engine shut down. The horizontal tail control system, shown in Figure 1 (3.1.3.1), features separate dual cable runs for pitch and roll control between the cockpit and the two mixer mechanisms located in the aft fuselage, a pushrod control path from the mixer mechanism to each actuator, and pushrod safety interconnects between the two actuators. The rudder control system, shown in Figure 2 (3.1.3.1), utilizes a single cable system, splitting into two pushrod control paths for the twin rudders, and an individual centering spring for each actuator. Horizontal tail and rudder surfaces actuators are dual hydraulic.

The Pitch CAS, shown in Figures 3 (3.1.3.1) and 4 (3.1.3.1), consists of two identical channels, which by virtue of cross-channel voting and monitoring provide fail-safe capability. When the Pitch CAS is turned off, the limited authority electro-hydraulic CAS actuator returns to center and the tandem electromechanical follow-up actuator (integrator) maintains its last position. Should disengagement occur with the follow-up actuator far away from its neutral position, the actuator may be repositioned by the use of an emergency trim switch in the cockpit.

The Roll CAS and the Yaw CAS each consist of dual computational channels to provide fail-safe capability. The voted output of the dual roll channel and the dual yaw channel are split into two dual channels for independent control of the ailerons and the twin rudders, respectively. Actuation drive sero loops are simplex; fail-safe capability is achieved by comparison of the actuator response against a performance model.

The Roll Direct Electrical function (DEL) consists of dual computational channel per aileron to capitalize on aerodynamic redundancy provided by the separate aileron surfaces. Each dual channel is summed with the Roll CAS and the voted output fed to the actuation drive servo loop and the performance model for the particular aileron actuator. The roll axis is shown in Figure 5 (3.1.3.1).

The Roll-to-Yaw interconnect, which provides signals proportional to aileron and rolling tail deflections to the rudders, consists of dual computational channels for each aileron and quadruplex (dual-dual) computational channels for the rolling tail. (Note: as rolling tail deflections are proportional to lateral stick deflections, the rolling tail-to-rudder interconnect uses the same two dual command and sensors at the stick as the aileron direction electrical link (DEL). The interconnect computational channels are summed with the Yaw CAS and the voted output split into two dual channels for independent actuation of the left and the right rudder. The actuation drive servo loops are simplex; fail-safe capability is achieved by comparison of the actuator response against a performance model. The yaw axis is shown in Figure 6 (3.1.3.1).

The Roll-to-Yaw interconnect relies on air data (Mach number and angle-of-attack) for proper performance. In case of air data failure, backup computation based on horizontal tail and trailing-edge flap position is provided.

The flaps are controlled by a simplex digital computer through analog actuation drive electronics. Fail-safe capability is achieved by comparing actuator response to a digital performance model and by monitoring left and right surface positions for symmetry. In case of an electrical failure, the flaps maintain last position until commanded up by an emergency up switch in the cockpit. The leading-edge flap surface actuators are dual hydraulic. The trailing-edge flap actuation is single hydraulic; in case of hydraulic power loss, the surfaces move to the up position under the influence of aerodynamic loads and become locked in the up position by a mechanical lock integral to the actuator. The flap control system is shown in Figure 7(3.1.3.1).

<u>Discussion</u>

The requirement is endorsed on the basis that it allows the latitude necessary to develop a cost effective flight controls system.

<u>Recommendation</u>

Retain the requirement as stated.

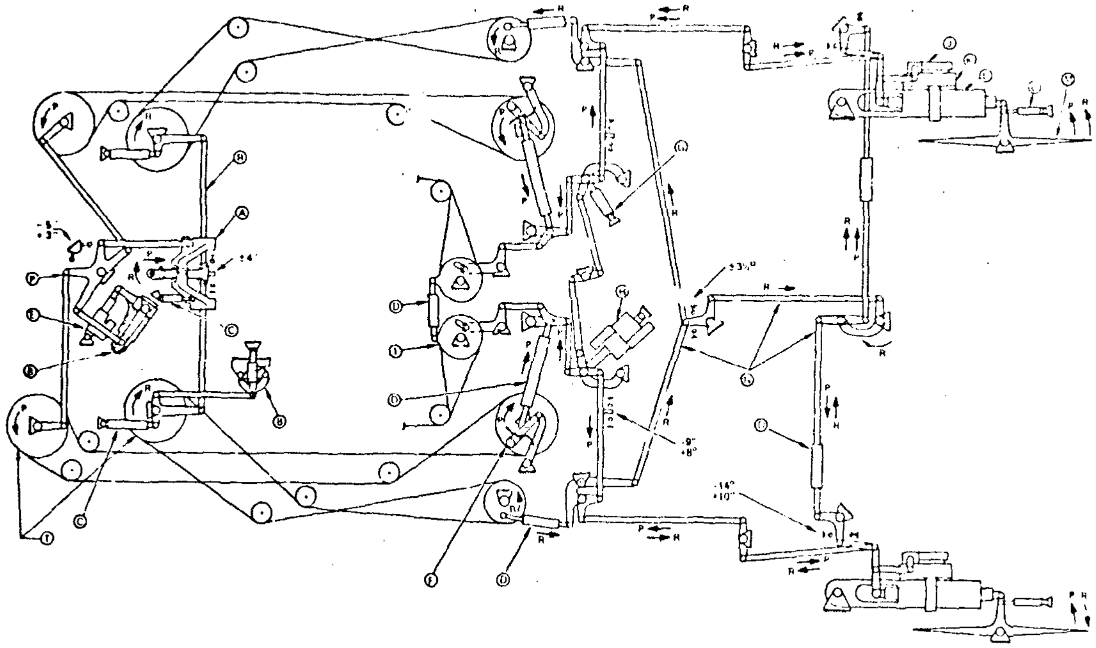

Figure 1(3.1.3.1) Horizontal Tail Control System - Pitch and Roll Control

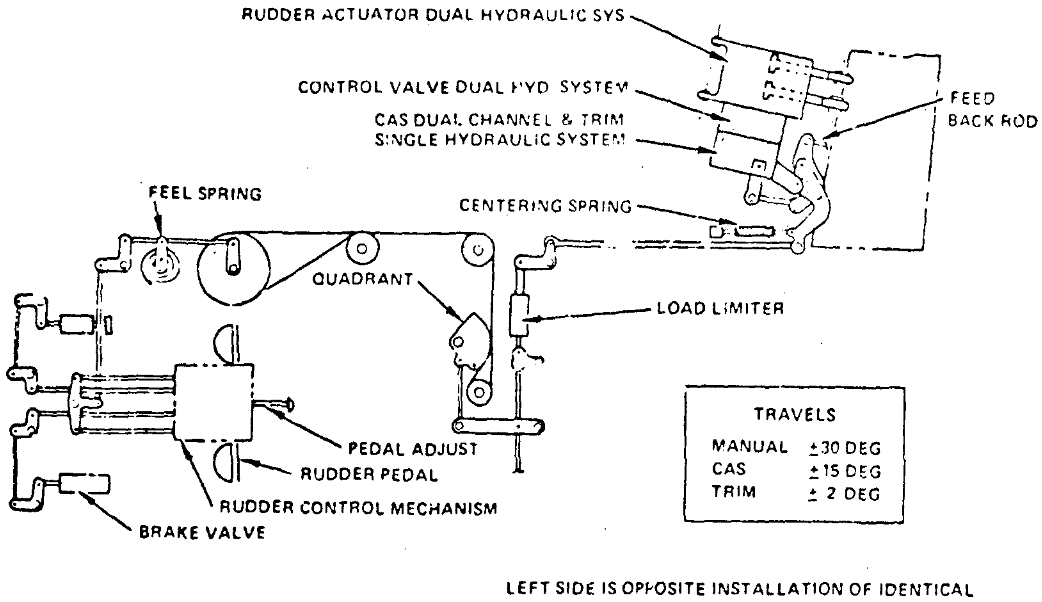

Figure 2(3.1.3.1) Rudder Control System

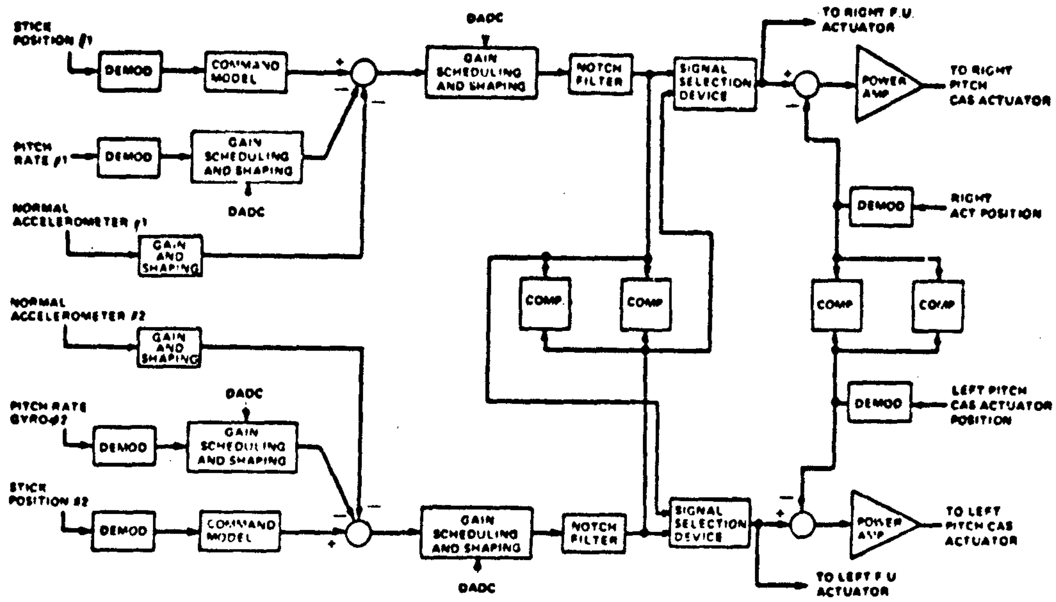

Figure 3(3.1.3.1) Dual Channel Pitch CAS

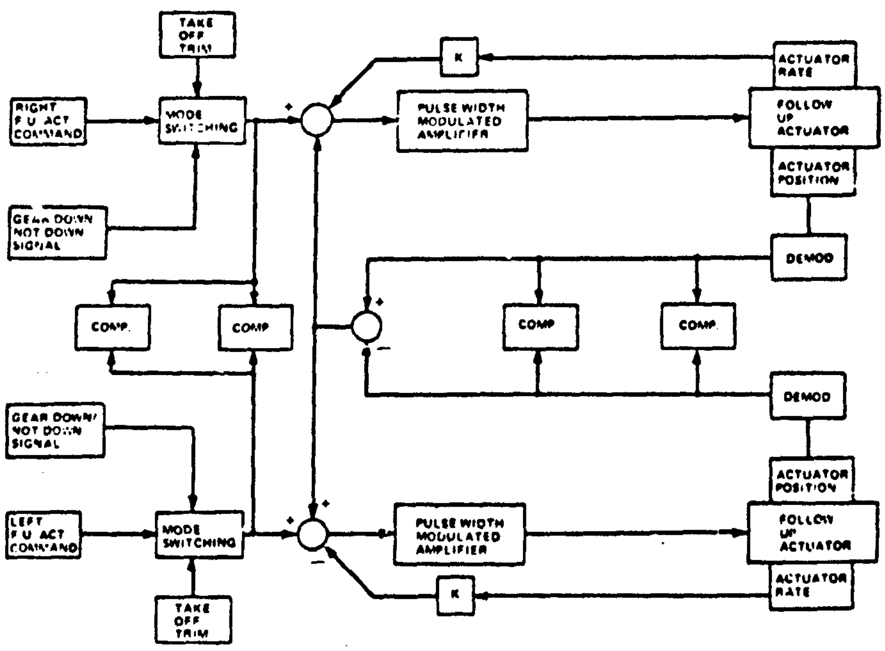

Figure 4(3.1.3.1) Dual Channel Follow-up Actuator

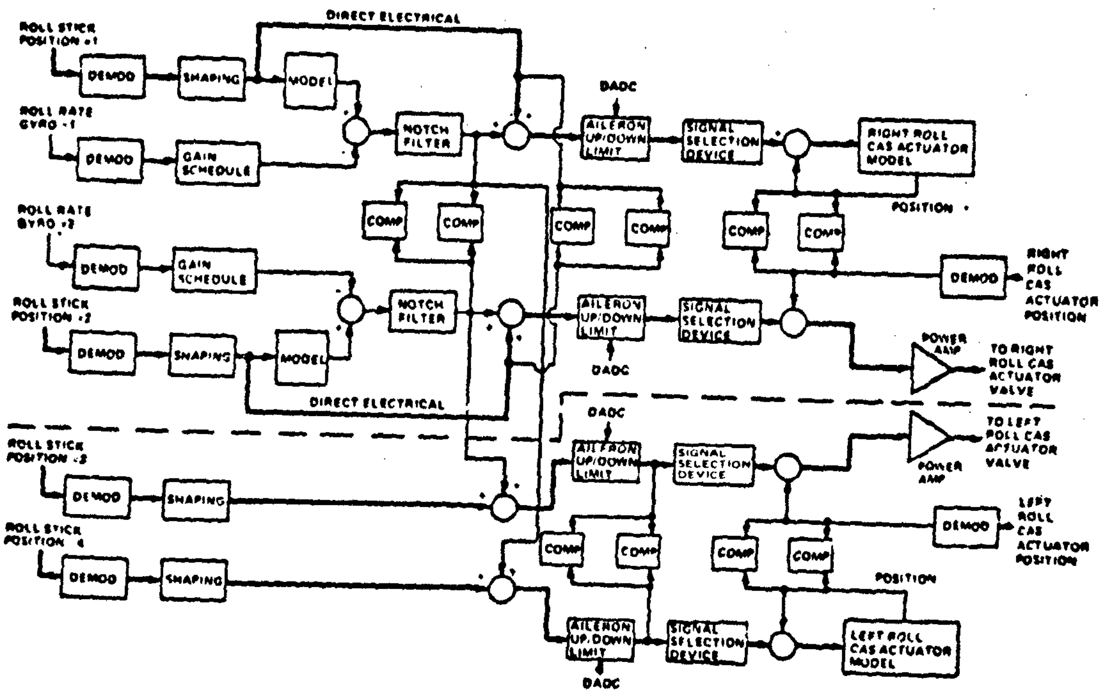

Figure 5(3.1.3.1) Dual Channel Roll Axis

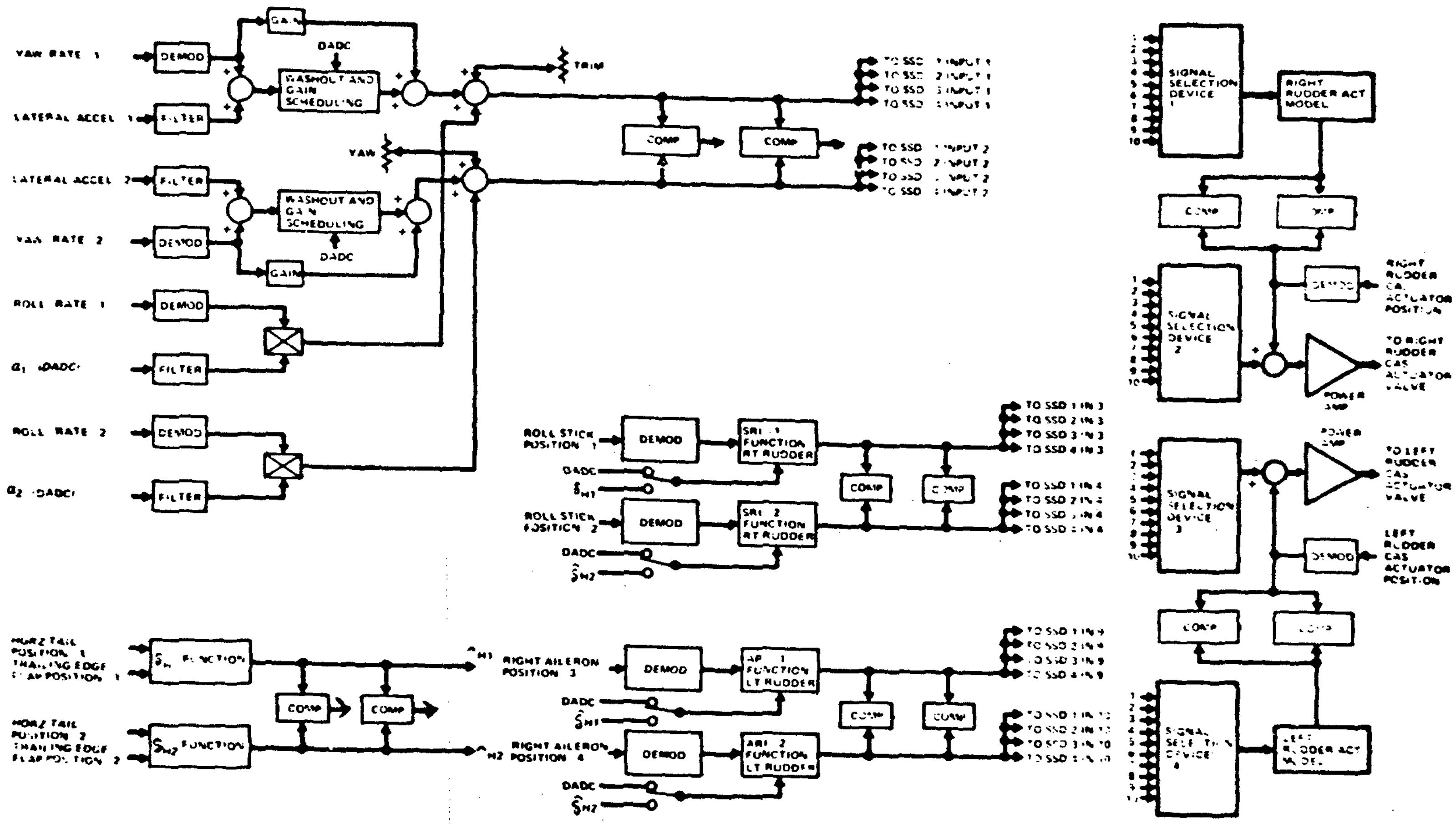

Figure 6(3.1.3.1) Dual Channel YAW, ARI, and SRI

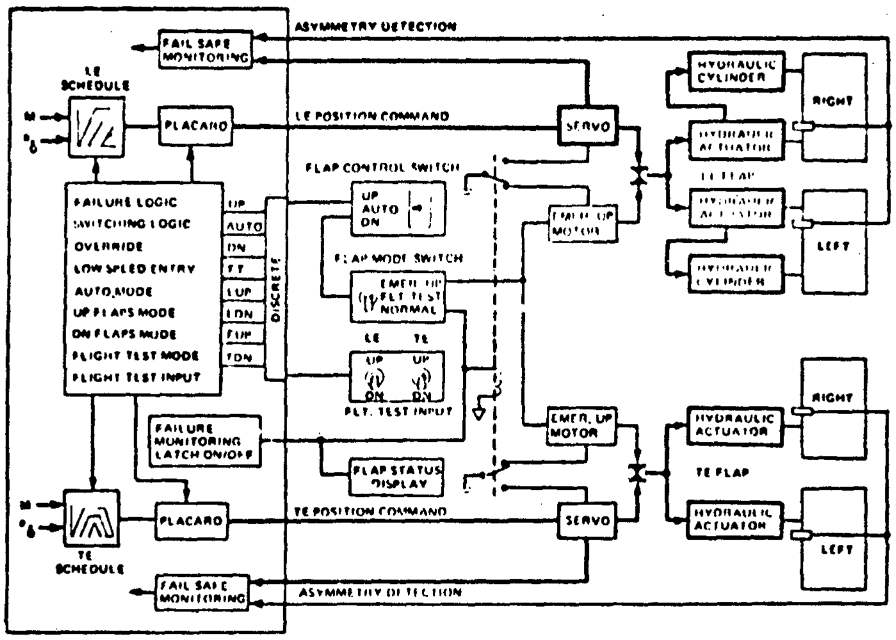

Figure 7(3.1.3.1) Flaps Control System

Requirement

3.1.3.2 Failure immunity and safety. Within the permissible flight envelope, no single failure or failure combination, which is not extremely remote, in the FCS or related subsystems shall result in any of the following effects before a pilot or safety device can be expected to take effective corrective action. For this specification, extremely remote is defined as numerically equal to the maximum aircraft loss rate due to relevant FCS material failures specified in 3.1.7.

a. Flutter, divergence, or other aeroelastic instabilities within the permissible flight envelope of the aircraft, or a structural damping coefficient for any critical flutter mode below the fail-safe stability limit of MIL-A-8870.

b. Uncontrollable motions of the aircraft or maneuvers which exceed limit airframe loads.

c. Inability to safely land the aircraft.

d. Any asymmetric, unsynchronized, unusual operation or lack of operation of flight controls that result in worse than FCS Operational State III.

e. Exceedance of the permissible flight envelope or inability to return to the service flight envelope.

Comparison

The critical failure effects quoted in subject paragraphs have been considered and the YF-17 FCS has been designed to afford the maximum practical protection from such failure situations.

The design features to achieve a high level of immunity from the quoted failure effects are as follows:

a. All actuators for control surfaces with a potential for flutter are dual hydraulic.

b. Dual voters and dual cross-channel comparators preclude propagation of any failure in the electrical FCS functions that may lead to uncontrollable motions or to maneuvers in excess of limit loads.

c. Emergency trim and override functions are provided to neutralize the effect of any failure that may impair safe landing capability.

d. The flaps are synchronized by virtue of a control cable crosstie between the servovalves of the LH and RH actuators.

Synchronous operation of the horizontal stabilizers, both for symmetrical and differential deflections, is assured by identical control paths to the LH and RH actuators. A pushrod safety interconnect between the mechanical input points of the LH and RH actuators maintains synchronism of the surfaces in case of an open in either control path.

e. Total control authority is established so as to prevent potential exceedance of the permissible flight envelope.

Discussion

The inherent characteristics of the YF-17 aircraft together with the design features of its FCS assures compliance with the intent of subject paragraph. No reliance is placed on automated functions except in preventing failure propagation and assuring fail-safe operation. On other aircraft, however, automated functions such as structural mode control (active flutter suppression) or angle-of-attack or side-slip limiting may play an essential role even in the operational flight envelope. Outright compliance with the numerical requirement "extremely remote" of subject paragraph would dictate very high redundancy levels for such functions. If, however, flight envelope/maneuver restriction may be employed after specified failures, the system configuration will not be driven to increasingly higher complexity levels.

A case in point is a redundant electrical function that tolerates one failure without degradation and meets the requirements for mission reliability. However, a subsequent failure, which is not extremely remote, occurring in certain portions of the flight envelope can result in the effects noted in the requirement. Once such failure has occurred, a timely corrective action by the pilot or safety device may not be possible. In the case of redundant electrical functions, including air data information, the special significance of the "failure preceding the last failure" must be recognized by allowing flight envelope restriction as a preventive measure.

The requirement is valid, and compliance can be demonstrated by analysis and simulation.

Recommendation

Revise the requirement as follows:

Add to the requirement,

> "Restriction of the flight envelope may be considered as a corrective action if a subsequent failure occurring outside of the restricted envelope could result in a condition worse than FCS Operational State III."

Requirement

3.1.3.2.1 Automatic terrain following failure immunity.

Not applicable.

Requirement

3.1.3.3 System operation and interface. Wherever a noncritical control or any other aircraft subsystem is interfaced with essential or flight phase essential flight control channels, separation and isolation shall be provided to make the probability of propagated or common mode failures extremely remote.

Comparison

On the YF-17, the following interface relationships exist between noncritical and essential or flight-phase essential functions:

Pitch CAS (noncritical) and longitudinal mechanical control (essential): Failures of the Pitch CAS cannot impair the integrity of the mechanical control system.

Roll CAS (noncritical) and Aileron Direct Electrical Link (flight phase essential): Failures of the Roll CAS cause shutoff of the CAS function only. Likelihood of failure propagation is minimized through the use of dual failure monitoring and shutoff logic in an OR logic arrangement. The Roll CAS and the right aileron DEL are on the same electric power supply, and it is conceivable that a power supply failure may occur as a result of a defect in the Roll CAS-associated circuitry. However, the left aileron DEL is on a different power supply, and thus the left aileron DEL would remain operational.

Yaw SAS (noncritical) and Roll-to-Yaw interconnect (flight phase essential): Prevention of failure propagation and power supply management are similar to that described for Roll CAS and Aileron DEL.

Discussion

The requirement is valid and adequately covers the interface relationship between noncritical and essential or flight phase essential functions. However, the same requirement should also apply to interface relationships between flight control channels of equal or similar criticality. A case in point is the YF-17 pitch-roll mechanical system controlling symmetrical and differential motions of the horizontal tail, thus providing two essential control functions. By employing redundant control paths, safety interconnects, and bungees, the design minimizes the probability of common mode failures.

Compliance with the requirement can be demonstrated through a failure mode and effects analysis.

Recommendation

Revise the requirement as follows:

> "Wherever a noncritical control or any other aircraft subsystem is interfaced with essential or flight phase essential flight control channels, or an essential or flight phase essential control function is interfaced with another essential or flight phase essential control function, separation and isolation . . ."

Requirement

3.1.3.3.1 Warmup. After power is applied to the FCS, the warmup time required to meet this specification shall not be more than 90 seconds for MIL-F-8785 Class IV aircraft and not more than 3 minutes for other types of aircraft.

Comparison

The YF-17 is defined as a MIL-F-8785 Class IV aircraft. Maximum allowable warmup times for YF-17 flight controls components throughout their operating environment range have been specified as follows:

Component	Warmup time
Accelerometer	30 sec
Rate gyro	90 sec
Digital air data computer	15 sec
Flight controls computer	30 sec

Component qualification testing under extremes of temperature and excitation has verified that the requirements for warmup have been met. The complete FCS has not been tested under extreme climatic conditions.

Discussion

The warmup requirement is interpreted as the maximum time allowed for the FCS to be fully operational, not including the test time (such as BIT) required to verify operational readiness, which would be in addition.

In this context, the requirement of subject paragraph is reasonable and valid for components used in Manual Flight Control Systems. One possible exception must be made relative to dynamic characteristics of the actuators under extreme low temperature soak conditions:

> If system readiness is contingent on proper tracking between the actuator and its performance model, the 90 sec requirement at low temperature extremes may be difficult to meet.

Compliance with warmup requirements can be practically demonstrated.

Recommendation

Revise the requirements as follows:

Add to the requirement,

> "FCS performance at adverse environmental extremes shall be in accordance with 3.1.9.1."

Requirement

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

Comparison

Flight phase essential and noncritical electrical controls on the YF-17 consist of the pitch CAS, Aileron DEL, roll CAS, yaw SAS, roll-to-yaw interconnect and automatic flaps. Positive inflight disengagement of all of these controls can be made under all load conditions. This is accomplished by three engage/disengage lever-lock switches and two flap switches. The pitch switch controls engagement of the pitch CAS including the follow-up trim system. The yaw switch controls the engagement of the yaw SAS and roll-to-yaw interconnect system. The roll switch controls engagement of the roll CAS and aileron DEL. The aileron electrical controls require successful engagement of the interconnect system, hence the yaw switch must be moved to the engage position before the roll switch. Conversely, disengagement of yaw will result in disengagement of roll but roll disengagement will not affect yaw. A quick disconnect of the pitch electrical controls is also provided by a stick-mounted device which the pilot can operate by striking with his hand. See comparison under Paragraph 3.1.3.3.3 for a description of the flap switches.

If the pitch CAS is disengaged under steady-state conditions, no out of trim condition will exist because of the action of the follow-up trim actuator. If disengagement is under maneuvering conditions, some out of trim will exist because the follow-up trim system is relatively slow (1 deg/sec). However, the pitch CAS is a low authority system (± 3 deg) and the follow-up actuator will freeze at disengagement and hence the pilot can easily control the out of trim condition. The follow-up actuator may be repositioned by the use of an emergency trim switch in the cockpit. Disengagement of the ailerons or the yaw SAS results in a slight out of trim condition because of the difficulty in making the required adjustments so that the surfaces are faired both CAS/SAS on and CAS/SAS off. This results in a nonfaired condition with CAS/SAS off of about 2° of aileron and 1° of rudder. In the event of a failure or nuisance disconnect of one aileron, trimming can be accomplished through the other aileron. Because aileron trim is a part of the roll CAS, disengagement causes loss of aileron trim. In this case, the pilot must provide trim manually by means of the rolling tail. A similar situation exists in the rudder system in that trimming capability is lost if the yaw SAS is disengaged, and any existing mistrim must be corrected by mechanical control from the rudder pedals. The flaps are not normally "disengaged," strictly speaking. However, the Emergency Up mode is always available because it takes precedence over all other flap modes and employs a dedicated motor in the electromechanical flap control actuator. In summary, no out of trim conditions exist at disengagement that cannot be easily controlled by the pilot.

The pilot is informed of automatic disengagement by lights on the annunciator panel.

The engagement of the pitch, roll, and yaw electrical controls requires a signal from the appropriate cockpit engage/disengage switch. These signals are used in latching circuits which maintain the engagement. Any failures in these signals would result in disengagement due to the loss of a component of the latching circuit. Hence, a failure in this circuitry would not prevent automatic or manual disengagement.

The YF-17 complies with the requirements of this paragraph if a strict interpretation is not applied to the flaps.

Discussion

An out of trim condition that is "easily" controlled by the pilot is subject to some difference of opinion and may require piloted failure effects simulation to demonstrate compliance. However, the intent of the requirement is clear.

Manual disengagement capability for certain flight phase essential MFCS electrical controls, such as an angle-of-attack limiter, may not be desirable as it may result in safety hazards in case of crew inaction or error. This may outweigh the desirability for disengagement capability.

Recommendation

Revise the requirement as follows:

> "Means for positive inflight disengagement under all load conditions of flight phase essential and noncritical electrical control functions shall be provided which are compatible with the requirements of 3.1.9.6. No out of trim . . ."

Requirement

3.1.3.3.3 Mode compatibility. Mode compatibility 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 probable.

b. Prevent the engagement of incompatible modes that could create an immediate undesirable situation or hazard.

c. Disconnect appropriate previously engaged modes upon selection of higher priority modes.

d. Provide arming of the appropriate modes while certain modes are engaged.

e. Provide for the engagement of a more basic FCS mode in the event of a failure of a higher priority mode.

Comparison

On the YF-17, correct mode selection is assured by relative simplicity of its FCS and the straightforward identification of the FCS mode. The control augmentation system is engaged/disengaged by three toggle switches, identified as Pitch, Roll, Yaw. Engagement of the Roll CAS (which includes the aileron direct electrical link) is interlocked with prior engagement of the Yaw to prevent the undesirable - albeit not hazardous - situation of aileron operation without functional roll-to-yaw interconnect. The three flap modes - Normal, Flight Test, Emergency Up - are selected by a three-position switch. In the Normal mode, flap control is transferred to a console-mounted switch with positions UP, AUTO, DOWN. In the Flight Test mode, flap control is only through the two instrument panel-mounted flight test flap switches. The Emergency Up mode disables all flap controls and positions both flaps up.

For flight test purposes, the YF-17 includes provisions to set the flaps in any position through the use of the Flight Test mode. This can result in flap-position angle-of-attack combinations that might not be desirable in an operational aircraft as contrasted to a flight test aircraft. However, considering the flight test nature of the aircraft, the YF-17 complies with this requirement.

Discussion

The requirements of subject paragraph are clearly worded and reasonable and compliance can be demonstrated.

Recommendation

Retain the requirement as stated.

Requirement

3.1.3.3.4 Failure transients. Aircraft motions following sudden flight control system or component failure shall be such that dangerous conditions can be avoided by pilot corrective action. Time delays between the failure and initiation of pilot corrective action shall be established by MIL-F-8785. Transients due to failures resulting in FCS Operational States I or II within a redundant FCS shall not exceed ± 0.5g incremental normal or lateral acceleration at the center-of-gravity or $\pm$ 10 deg/sec roll rate. Transients due to failures within the FCS resulting in FCS Operational State III shall not exceed 75 percent of limit load factor or 1.5 g's from the initial value, whichever is less, at the most severe flight condition.

Comparison

Considerable latitude relative to specification compliance was allowed in the design of the YF-17, consistent with the overall objectives of the program. The YF-17 criteria for failure transients emphasizes flight safety and structural limits in the MIL-F-8785B Level 3 sense, notwithstanding the level of flying qualities after the failure. The failure transient requirements are:

a. Normal acceleration increment less than 3.0g.

b. Sideslip within structural limits. Limit βq (the product of sideslip angle in degrees and dynamic pressure in pounds per square feet) is 3,500 below Mach 1.2, increasing linearly to 5,000 at Mach 2.0.

c. Roll rate consistent with flight safety.

These YF-17 requirements apply to worst case failures in the electrical flight control system at the most severe flight conditions, regardless of the probability of occurrence. Extensive failure mode and effects evaluation on the Northrop Large Amplitude Simulator was used both to verify numerical compliance with the established criteria and to confirm that dangerous conditions can be avoided by pilot action.

The YF-17 is in partial compliance with the requirement.

Discussion

This requirement is similar to that of MIL-F-8785B, paragraph 3.5.5.1 Failure Transients, as shown on the next page.

On one hand, the MIL-F-9490D quantitative requirements are more lenient for failures that do not affect or result in only slightly degraded flying qualities. This is endorsed on the basis that it allows more latitude in developing cost effective flight controls concepts, particularly for fighter aircraft with characteristically very high surface effectiveness in portions of the flight envelope. Very high failure transient requirements may mandate higher redundancy levels and more complex actuation designs than would be required by functional considerations.

MIL-F-9490D Operational State	Envelope	MIL-F-8785B Level of Flying Quantities
I ±0.5g incremental normal or lateral acceleration at c.g. or ±10 °/sec roll rate	Operational Flight	1. ±0.05g normal or lateral acceleration at pilot's station and ±1 °/sec in roll
	Service	2. ±0.5g at pilot's station, ±5 °/sec roll, and the lesser of ±5 ° sideslip or the structural limits
II Same as above	Operational Flight	
	Service	3. No dangerous attitude or structural limit is reached, and no dangerous alteration of the flight path results from which recovery is impossible.
III 75% of limit load factor or 1.5g's from initial value, whichever is less		

On the other hand, the MIL-F-9490D requirement places a 1.5g's transient limit on failures resulting in Operational State III which partly coincides with the Level 3 flying qualities region. This limit is considered too stringent for fighter aircraft.

Compliance with the quantitative aspects of the requirement can be demonstrated by analysis. Demonstration of compliance with the subjective aspect of the requriement requires piloted simulation.

Recommendations

Revise the requirement as follows:

Revise the last sentence to read,

> "Transients due to failures within the FCS resulting in Operational State III shall not induce dangerous alteration of attitude or flight path at the most severe flight condition and in no case shall exceed 75 percent of limit load factor."

Requirement

3.1.3.4 System arrangement. Systems shall be arranged as required to satisfy the reliability, invulnerability, failure immunity and other general requirements of this specification.

Comparison

Redundancy and system separation, as well as location of the major elements, are the primary methods used on the YF-17 for achieving compliance with these requirements. Dual mechanical control paths, redundant electronics and sensors combine to provide a control system of high reliability and low vulnerability consistent with design requirements for simplicity and minimum weight and cost.

Discussion

The requirement for system arrangement is a general quality that would appropriately be included in paragraph 3.1.3 as a general requirement that applies to FCS design. However, no need is seen to actually combine the paragraphs. Compliance with the requirement cannot be demonstrated by test, but only by a combination of analysis and subjective assessment based on past experience.

Recommendation

Retain the requirement as stated.

Requirement

3.1.3.5 Trim controls. Each of the principal control axes shall have trim controls. Wherever worse than Operational State III would result from a power-operated trim control failure that is not extremely remote, the pilot shall be given override capability for the failed control. For series trim control, no worse than Operational State III shall result from a trim control becoming inoperative in any position, except for extremely remote failures. Engagement of the AFCS shall automatically initiate any needed pitch trim. Aircraft subject to short alerts shall have the capability incorporated to return all trim to the takeoff position automatically. Any automatically controlled trim shall incorporate positive means to avoid potentially hazardous adverse trim near stall. In multicrew aircraft with electrical trim systems, interlocks in the circuitry shall prevent simultaneous commands by two aircrew members from causing any operation in opposing directions at the same time.

Comparison

The YF-17 is provided with trim controls in all three principal axes.

In pitch, parallel trim is used to relieve pilot forces during takeoff/landing and sustained high-g maneuvering. Nominal trim rate is 0.55 inch/sec. at the stick reference point. Design trim range was 5 inches of stick displacement as shown on Figure No. 1 (3.1.3.5). Due to changes during the flight test program in force gradient and stick-to-surface gearing, the trim range eventually became about 7.5 inches as shown in Figure No. 2 (3.1.3.5). Figures No. 3 (3.1.3.5) and 4 (3.1.3.5) show the related stick force gradients. With these force levels and the relatively slow trim rate, a runaway trim condition can be neutralized by gradual application of reasonable pilot forces, maintaining at least Operational State III under the most adverse conditions, including pitch CAS off. With Pitch CAS on (normal mode of operation), the force required to correct an inoperative or runaway parallel trim condition is either zero or minimal.

The Pitch CAS incorporates an electromechanical series trim actuator to enforce the integral control law (automatic trim) under gear up conditions. The actuator is tandem, each half having 3 deg. tail up and 1.5 deg. tail down authority. Maximum rate of the actuator is 1 deg/sec. In-flight comparative monitoring of the actuator prevents a runaway condition. Should actuation failure occur at either extreme position of the actuator, sufficient control authority is available to recover the aircraft from any attitude. In addition, an emergency override is provided to reposition the actuator and thus to restore full mechanical control capability. Both the override function for the series trim actuator and the parallel trim actuator derive the required electrical power from the essential D.C. bus.

In roll, series trim with ± 4.0 deg. authority (± 8 deg total aileron) is provided through the aileron CAS actuator. Trim is controlled with the conventional stick mounted trim knob, which, in turn, activates a digital integrator in the flight controls computer. Trim rate is 0.4 deg/sec in terms of total (differential) aileron deflection. Due to the low lateral force gradient, pilot force required to correct for inoperative roll trim is negligible.

In yaw, series trim with ± 2.0 deg. authority is provided through the rudder CAS actuators. Trim is proportional to rotational displacement of the trim knob located on the CAS control panel in the left console.

Although the short alert requirement was not imposed on the YF-17, capability is provided to establish take off trim with ease, albeit not fully automatically. The Pitch CAS series trim actuator is automatically positioned in the take off configuration with gear down and Pitch CAS engaged. The digital roll trim is initialized to zero position anytime power is applied to the roll channel of the flight controls computer. Depressing the take off trim push button on the CAS control panel commands the pitch parallel trim actuator to the take off position; a momentary green light on the push button signifies the proper take off position of both the parallel trim actuator and the Pitch CAS series actuator. The yaw trim knob must be manually set to the zero position for take off.

The YF-17 complies with the requirement relative to trim capability and failure effects. It does not meet the automatic take off trim requirement applicable to aircraft subject to short alert.

Discussion

The requirement is clear and reasonable, and compliance with it can be easily demonstrated. Should the short alert requirement been applied to YF-17, the capability to automatically set the take off trim position could have been easily incorporated. However, providing this capability precludes the use of proportional, knob controlled yaw trim which requires manual centering for take off and increases complexity (such as tie-in to stores management) for aircraft requiring longitudinal trim setting in accordance with cg location.

Recommendation

Revise the requirement as follows:

Change the portion related to short alerts to read,

> "Aircraft subject to short alerts and requiring a single trim setting for all takeoff conditions shall have the capability incorporated to return all trim to the take off position automatically or upon pilot actuation of a single control"

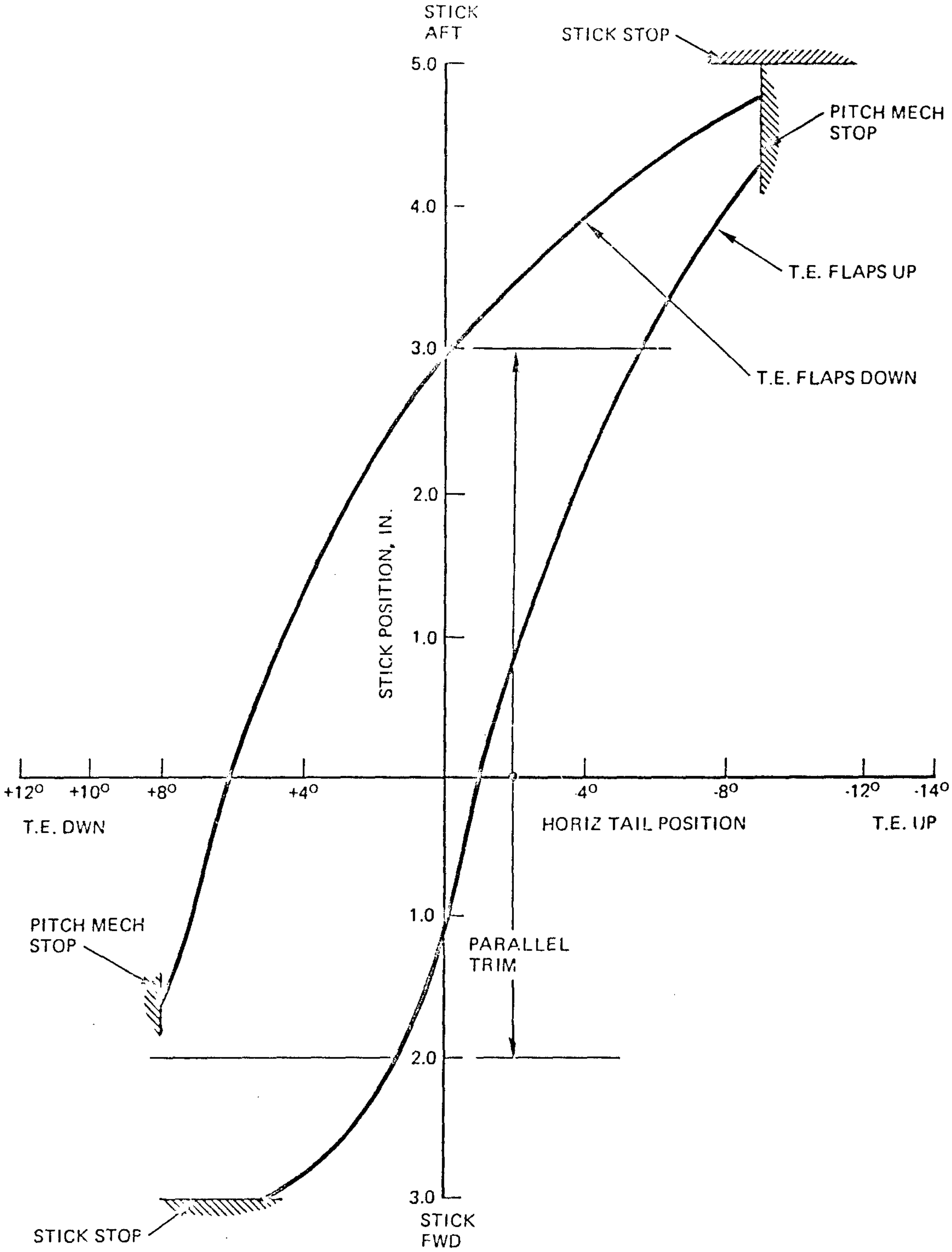

Figure 1 (3.1.3.5). Pitch Stick Position Vs. Horizontal Tail Position.

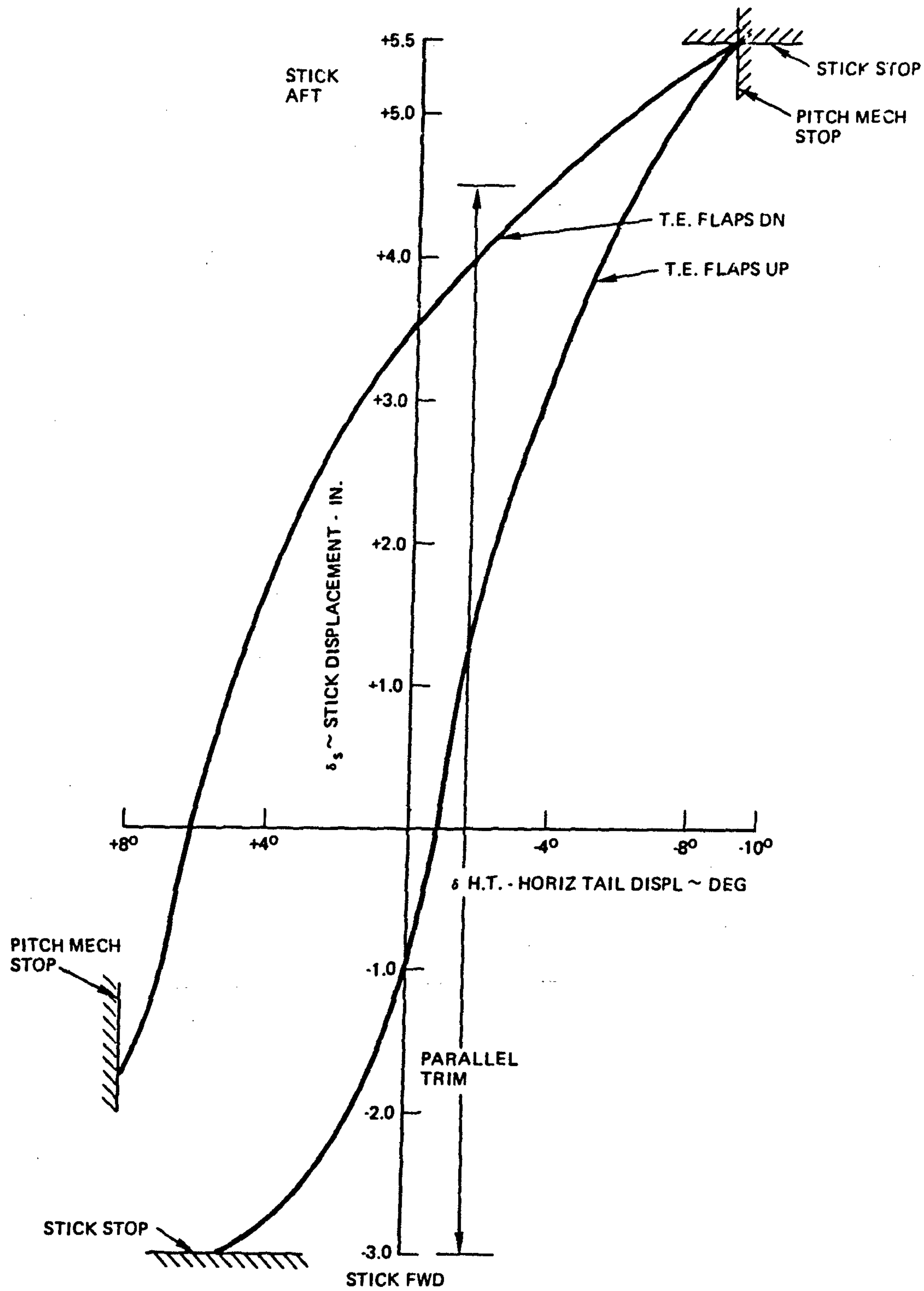

Figure 2 (3.1.3.5). Longitudinal System Gearing (MOD I).

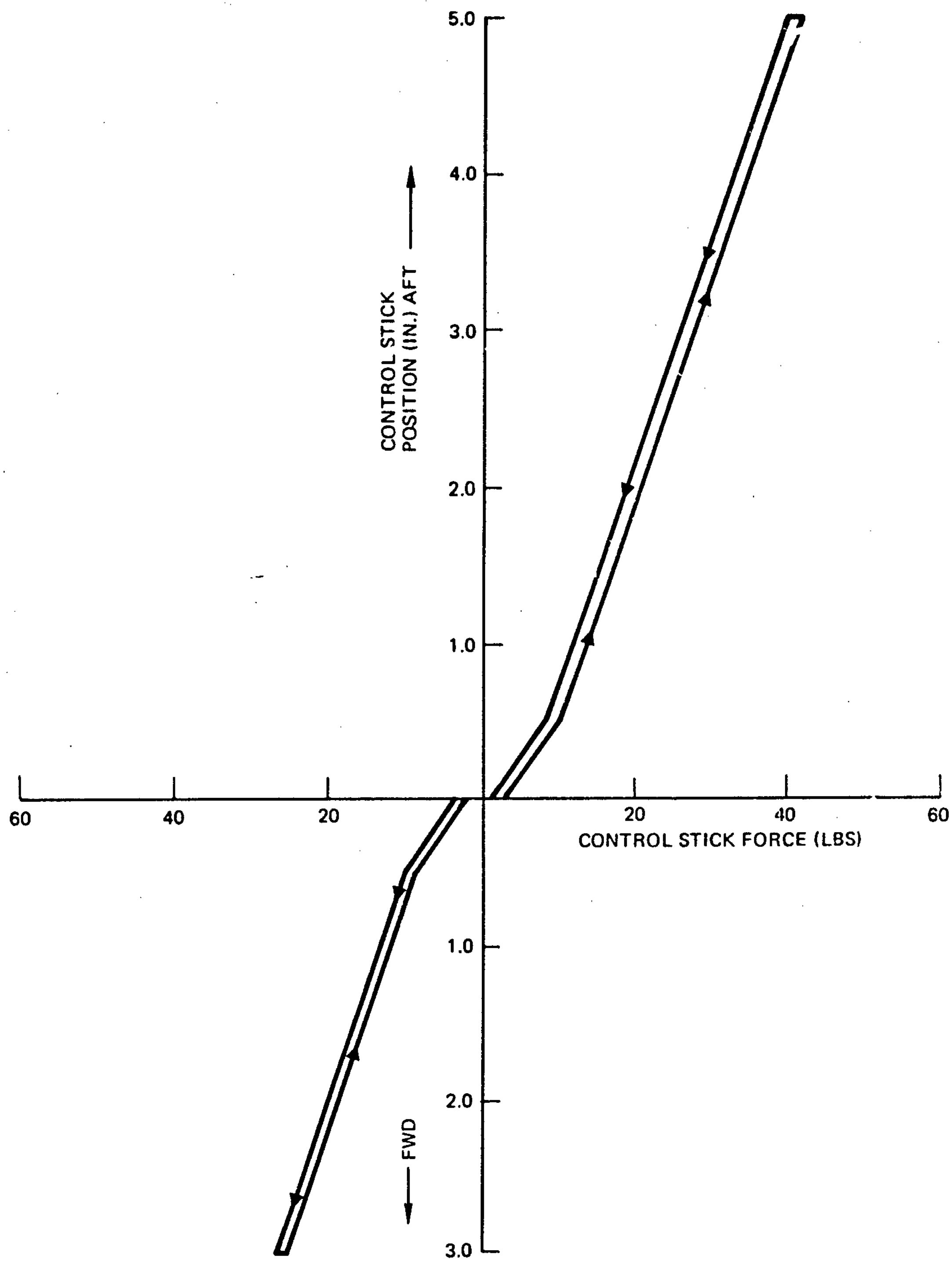

Figure 3 (3.1.3.5). Pitch Stick position Vs. Stick Force.

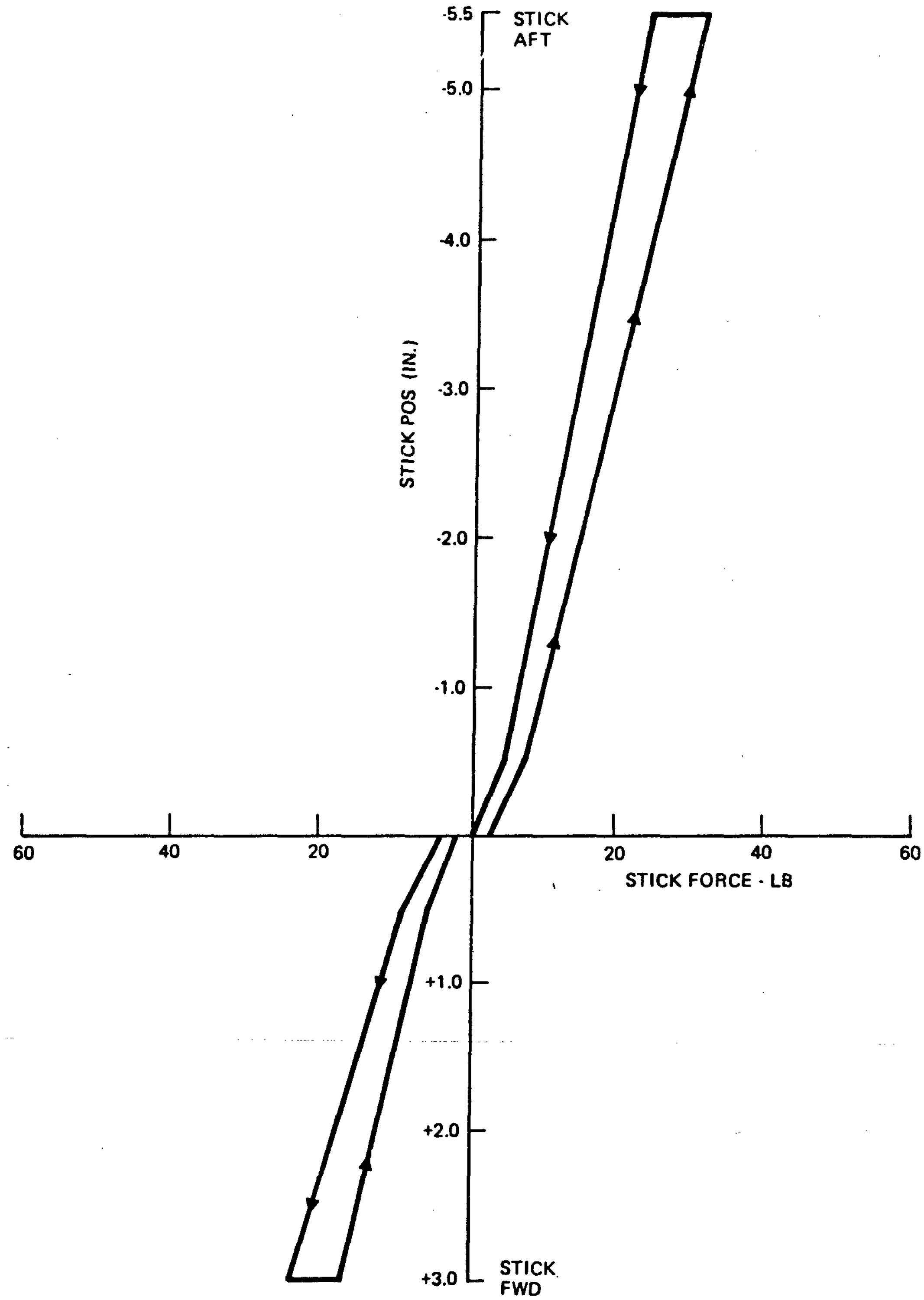

Figure 4 (3.1.3.5). Pitch Stick Force Characteristics (MOD I).

Requirement

3.1.3.6 Stability. For FCS using feedback systems, the stability as specified in 3.1.3.6.1 shall be provided. Alternatively, when approved by the procuring activity, the stability defined by the contractor through the sensitivity analyses of 3.1.3.6.2 shall be provided. Where analysis is used to demonstrate compliance with these stability requirements, the effects of major system nonlinearities shall be included.

Comparison

The compliance of the YF-17 with this paragraph and the two subparagraphs is presented in the individual validations of 3.1.3.6.1 and 3.1.3.6.2.

Discussion

The interpretation of this paragraph is that 3.1.3.6.1 defines a requirement to establish stability margins by testing and 3.1.3.6.2 to establish stability margins by analytical sensitivity analysis. Under this interpretation the gain and phase margins for aerodynamically closed loops would have to be confirmed by flight testing under 3.1.3.6.1. Normally, before this is done, analysis such as defined by 3.1.3.6.2 would be performed. However, the intent of the requirement is satisfied without mandating that both 3.1.3.6.1 and 3.1.3.6.2 be performed.

Recommendation

Retain the requirement as stated.

Requirement

3.1.3.6.1 Stability margins. Required gain and phase margins about nominal are specified in Table III for all aerodynamically closed loop FCS. With these gain or phase variations included, no oscillatory instabilities shall exist with amplitudes greater than those allowed for residual oscillations in 3.1.3.8, and any nonoscillatory divergence of the aircraft shall remain within the applicable limits of MIL-F-8785 or MIL-F-83300. AFCS loops shall be stable with these gain or phase variations included for any amplitudes greater than those allowed for residual osciliations in 3.1.3.8. In multiple loop systems, variations shall be made with all gain and phase values in the feedback patns 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. For both aerodynamic and nonaerodynamic closed loops, at least 6 db gain margin shall exist at zero airspeed. At the end of system wear tests, at least 4.5 db gain margin shall exist for all loops at zero airspeed. The margins specified by Table III 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.

(Table III presented on the following page)

TABLE III

GAIN AND PHASE MARGIN REQUIREMENTS (DB, DEGREES)

Mode Frequency Hz \ Airspeed	Below V_{oMIN}	V_{oMIN} To V_{oMAX}	At Limit Airspeed (V_L)	At 1.15 V_L
$f_M < 0.06$	GM = 6 DB (No Phase Requirement Below V_{oMIN})	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_{oMIN} = Minimum Operational Airspeed (MIL-F-8785).

V_{oMAX} = 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/FCS 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 (FCS engaged).

Nominal Phase and Gain = The contractor's best estimate or measurement of FCS and aircraft phase and gain characteristics available at the time of requirement verification.

Comparison

In general the YF-17 complied with gain margin requirements. Target gain margins of ± 6 db in all modes were demonstrated both by analysis and test as discussed under Comparison for paragraph 4.3.3, Aircraft ground tests. No attempt was made to verify phase margins by test.

Discussion

In the absence of well defined test procedures, the phase and gain margins requirements quoted in the requirement are somewhat arbitrary. Despite the fact that adequate gain margins had been demonstrated in ground test of the YF-17, unstable interaction between control system and airframe dynamics was subsequently encountered in flight requiring modified structural filters (see para. 4.3.3). If the ground tests are to provide any real assurance of stability in flight, test procedures should account for all pertinent unsteady aerodynamic and structural dynamic influences. It should also be noted that if overly simplistic analogs of airframe dynamics (such as those of NASA TN-D-6867) are used in ground tests, no assurance of in-flight stability of CAS-coupled elastic modes is derived, however substantial the demonstrated gain and phase margins might be.

In reference 1, the use of approximate aeroelastic airframe transfer functions to simulate the effects of inertial, elastic and unsteady aerodynamic forces, is suggested. The transfer functions are synthesized by means of complex curve fitting of discrete frequency response data; they are sufficiently simple in form to permit real-time simulation of the airframe dynamics on an analog or digital computer. This reference shows that marginal damping levels encountered in flight in a CAS-coupled structural mode on the YF-17 could be reproduced analytically, using synthesized airframe transfer functions, in conjunction with mathematical models of the control system. At the present time, additional work is required to demonstrate that comparable results can be achieved with a real-time simulation, in conjunction with actual flight control hardware, either on the test stand or in the aircraft.

However, the requirement is valid and, until more comprehensive analytical and test techniques are developed, it should be retained as stated.

Recommendation

Retain the requirement as stated.

Additional Data

Add to the Discussion following paragraph 3.1.3.6.2 Sensitivity Analysis in the Users' Guide:

> "If overly simplistic analogs of airframe dynamics are used in ground tests, no assurance will be obtained of the in-flight stability of control system coupled elastic modes. Approximate airframe transfer functions that simulated the effects of inertial, elastic, and unsteady aerodynamic forces were derived for the YF-17. These transfer functions were synthesized by means of complex curve fitting of discrete frequency response data and were sufficiently simple to permit real-time simulation of the airframe dynamics on an analog or digital computer. The method and results are more fully described by Arthurs, T.D., et al., in a paper presented at The 17th AIAA SDM Conference, Philadelphia, May 1976, "Aero-elastic Airframe Transfer Function Synthesis."

Requirement

3.1.3.6.2 Sensitivity analysis. Tolerances on feedback gain and phase shall be established at the system level based on the anticipated range of gain and phase errors which will exist between nominal test values or predictions and in-service operation due to such factors as poorly defined nonlinear and higher order dynamics, anticipated manufacturing tolerances, aging, wear, maintenance and noncritical material failures. Gain and phase margins shall be defined, based on these tolerances, which will assure satisfactory operation in fleet usage. These gain and phase tolerances shall be established based on variations in system characteristics either anticipated or allowed by component or subsystem specification. The contractor shall establish, with the approval of the procuring agency, the range of variation to be considered based on a selected probability of exceedance for each type of variation. The contractor shall select the exceedance probability based on the criticality of the flight control function being provided. The stability requirements established through this sensitivity analysis shall not be less than 50 percent of the magnitude and phase requirements of 3.1.3.6.1.

Comparison

Sensitivity analyses were performed on the YF-17 primarily by analog computer simulations. These simulations consisted of three-degree-of-freedom longitudinal and lateral-directional simulations. The aerodynamic representation was by linear small-perturbation equations of motion. Actuator dynamics were conservatively represented as first or second order systems.

In the longitudinal simulation, nonlinearities considered included rate and position limiting of the actuators, and the threshold in the electromechanical follow-up actuator. Additional conservatism was included by simulating a range of aircraft c.g. positions beyond that expected in flight. Tolerances on feedback gain and phase were conservatively estimated and a series of computer runs were made using gains and time constants in various combinations to cover the tolerance ranges.

The lateral-directional analog computer simulation likewise included actuator rate and position limiting. The gains and time constants varied and included those in all feedback paths as well as those in the roll-to-yaw crossfeed paths.

In addition to the above analog computer simulations, digital simulations were also performed using a large scale digital computer. These programs provided check cases for the analog computer mechanizations as well as additional analyses in which the capability of a digital computer could be utilized.

In the course of control system optimization using a piloted flight simulator, sensitivity data also were obtained. This simulation included a highly nonlinear six-degree-of-freedom aerodynamic representation and nonlinear elements such as gearing curves, thresholds, and deadbands.

Verification of the major trends shown by the sensitivity analyses was made on the YF-17 flight control test stand using actual control system hardware. This was possible because of the range of adjustment of the gains and time constants built into the CAS electronics through the flight control test panel.

The above analyses did not include mode frequencies greater than the first aeroelastic mode but otherwise stability was not less than 50 percent of the magnitude and phase requirements of paragraph 3.1.3.6.1.

The YF-17 is partially in compliance with this requirement.

Discussion

The requirement is considered to be suitable for present and future military procurement.

Recommendation

Retain the requirement as stated.

Requirement

3.1.3.7 Operation in turbulence. In Operational State I, while flying in the following applicable random and discrete turbulence environment, the FCS shall provide a safe level of operation and maintain mission-accomplishment capability. For essential and flight phase essential controls, at least Operational State III shall be provided in the specified flight-safety turbulence levels. Noncritical controls shall provide at least Operational State II in turbulence up to the intensities specified in 3.1.3.7.1. Noncritical controls operating in turbulence at intensities above the specified turbulence level, shall not degrade flight safety or mission effectiveness below the level that would exist with the control inactive. Either manual or automatic means to inactivate the control for flight in heavy turbulence may be used, when required. The dynamic analysis or other means used to satisfy this requirement shall include the effects of rigid body motion, significant flexible degrees of freedom and the flight control system. Significant nonlinear effects shall be represented by conservative nonlinear or equivalent linear representations.

3.1.3.7.1 Random turbulence. The RMS turbulence intensity to be used for normal flight and for terrain following shall have a cumulative probability of exceedance as specified in Table IV.

TABLE IV

TURBULENCE INTENSITY EXCEEDANCE PROBABILITY

FCS Function Criticality \ Aircraft Class	MIL-F-8785 Class III	MIL-F-8785 Class I, II & IV
Essential	10^{-6}	10^{-5}
Flight Phase Essential	$\frac{1}{T}10^{-6}$	$\frac{1}{T}10^{-5}$
Noncritical	10^{-2}	10^{-2}

where:

T = the longest time spent in essential flight phase segment in any mission/total flight time per mission.

Table V specifies RMS vertical gust amplitude versus altitude for selected exceedance probabilities. The relationship among vertical, lateral and longitudinal RMS intensities and scales as specified in MIL-F-8785 shall be used to establish intensities for lateral and longitudinal gusts. The listed turbulence intensity levels apply at the turbulence penetration airspeed V_G. At the maximum level flight airspeed, V_H these intensity levels are reduced to 38 percent of the specified levels. The mathematical forms of continuous random turbulence to be used in conjunction with the specified intensity levels are as specified in MIL-F-8785 and the airspeeds cited are as specified in MIL-A-8860.

TABLE V

RMS GUST INTENSITIES FOR SELECTED CUMULATIVE EXCEEDANCE PROBABILITIES, FT/SEC TAS

FLIGHT SEGMENT	ALTITUDE (FT - AGL)	PROBABILITY OF EXCEEDANCE						
		2×10^{-1}	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}
Terrain Following	Up to 1000 (Lateral)	4.0	5.1	8.0	10.2	12.1	14.0	23.1
	Up to 1000 (Vertical)	3.5	4.4	7.0	8.9	10.5	12.1	17.5
Normal Flight Climb Cruise and Descent	500	3.2	4.2	6.6	8.6	11.8	15.6	18.7
	1,750	2.2	3.6	6.9	9.6	13.0	17.6	21.5
	3,750	1.5	3.3	7.4	10.6	16.0	23.0	28.4
	7,500	0	1.6	6.7	10.1	15.1	23.6	30.2
	15,000	0	0	4.6	8.0	11.6	22.1	30.7
	25,000	0	0	2.7	6.6	9.7	20.0	31.0
	35,000	0	0	0.4	5.0	8.1	16.0	25.2
	45,000	0	0	0	4.2	8.2	15.1	23.1
	55,000	0	0	0	2.7	7.9	12.1	17.5
	65,000	0	0	0	0	4.9	7.9	10.7
	75,000	0	0	0	0	3.2	6.2	8.4
	OVER 80,000	0	0	0	0	2.1	5.1	7.2

3.1.3.7.2 Discrete gusts. Discrete gust amplitudes to be used shall be established using the relationship between random and discrete gust amplitudes in accordance with MIL-F-8785, and the RMS amplitudes specified in 3.1.3.7.1. The 1-cosine discrete gusts in accordance with MIL-F-8785 shall be applied with wavelengths tuned to provide maximum excitation.

Comparison

Although there was no specific requirement to evaluate YF-17 aircraft response to atmospheric turbulence, a limited study of the YF-17 flying qualities in turbulence was performed. This effort consisted of two parts, a flight simulation using the Northrop Large Amplitude/Wide Angle Visual System (LAS/WAVS) facility, and an analytical investigation using digital pilot models in conjunction with the aircraft/control system model programmed on the simulator computers.

The piloted tasks were to hold zero roll angle and to hold trim pitch angle using the external wide angle visual earth-sky display. These tasks were performed separately by disturbing the YF-17 model by lateral turbulence, then by longitudinal gusts. The turbulence models followed the spectra presented in MIL-F-8785B, and moderate to severe rms intensities were employed. Two-axis attitude stabilization of roll and pitch angle was also simulated. Simulation flights were limited to 30 seconds to eliminate fatigue effects, and six flight conditions were examined as shown in Figure 1 (3.1.3.7).

In order to preserve the nonlinear complexity of the YF-17 description in the analytical study, the digital pilot models were programmed into the YF-17 aircraft/control system representation on the LAS/WAVS computer. The pilot models for the single-axis attitude hold tasks consisted of gain, lead, delay compensation and were adjusted for optimum performance subject to the constraints of .3 sec time delay and maximum lead of .5 sec. A full account of this model is found in the report AFFDL-TR-71-162, "Prediction and Evaluation of Flying Qualities in Turbulence," Feb. 1972, by E.D. Onstott, E.P. Salmon, and R.L. McCormick. The combined digital pilot/aircraft model/control system was then exercised to obtain the attitude hold performance statistics.

Agreement between the flight simulation and pilot model generated data is given in Figure 2 (3.1.3.7) and 3 (3.1.3.7). Each data point represents a given flight condition, and is the average of the rms tracking errors normalized to a standard of 10 ft/sec turbulence intensity.

Although piloted performance characteristics in turbulence were not evaluated extensively, the YF-17 was judged to be in compliance with subject requirements on the basis of the following three items: 1) the normalized tracking errors were substantially lower than those determined as acceptable for the A-7 and F-5 aircraft during the contract reported in AFFDL-TR-71-162; 2) no unusual sensitivities to pilot model gain or lead were uncovered during the analysis; and 3) no unfavorable pilot comments were obtained during the flight simulation.

MACH	ALTITUDE 5K	10K	30K	40K	60K
0.4	X		X		
0.8	X			X	
0.9					X
1.1		X			

Figure 1(3.1.3.7) Flight Conditions Surveyed

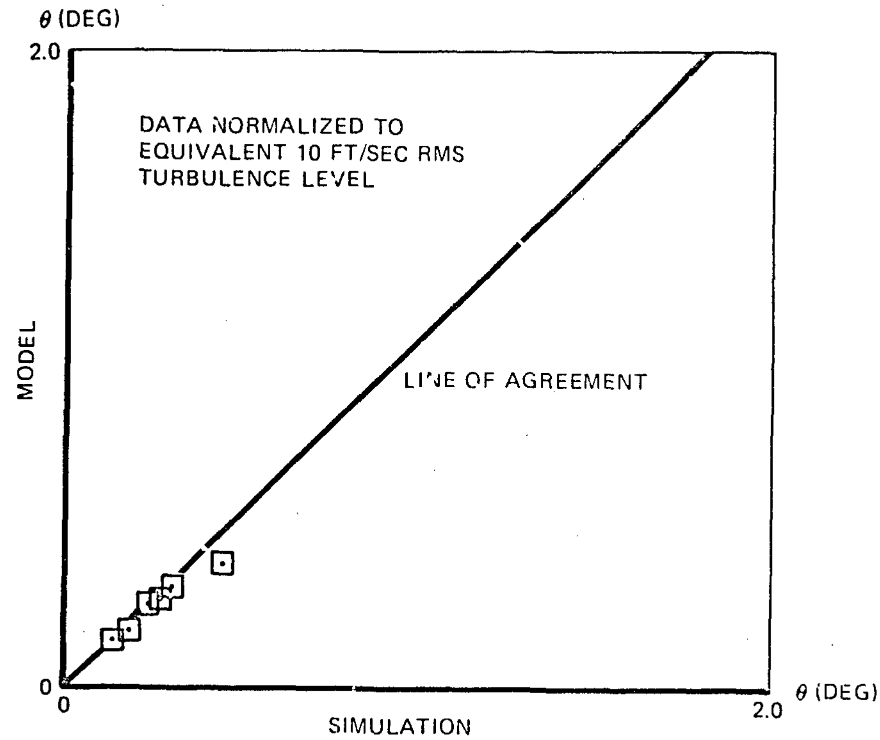

Figure 2(3.1.3.7) Longitudinal Turbulence
Tracking of The YF-17 Single-Axis (rms)

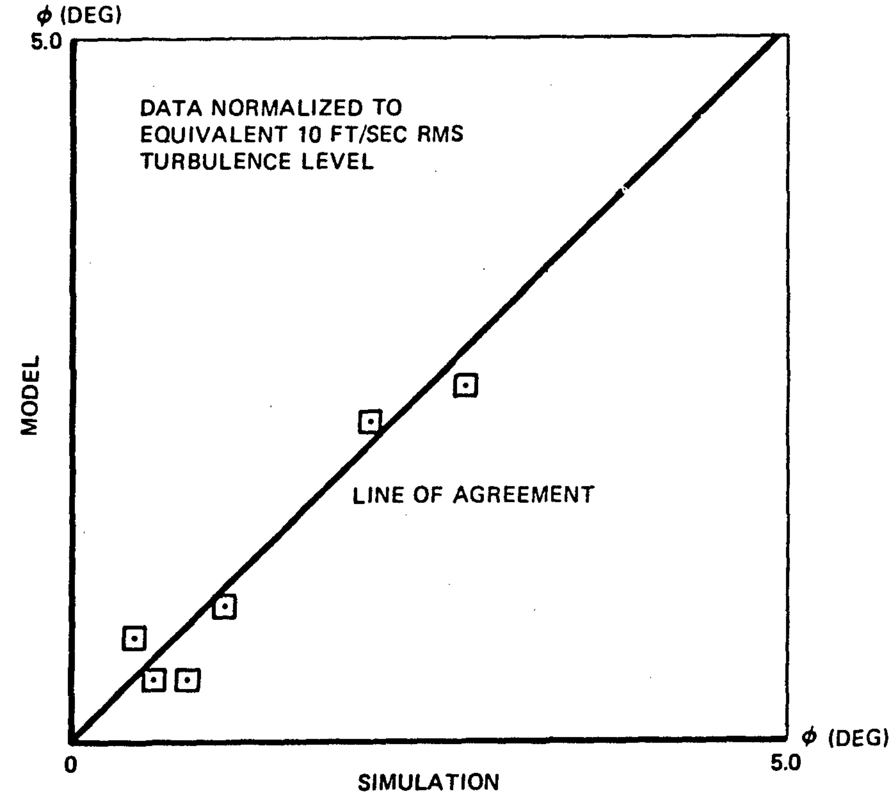

Figure 3(3.1.3.7) Lateral Turbulence Tracking
of The YF-17 Single-Axis (rms)

Discussion

The RMS gust intensities specified in MIL-F-9490D are generally higher than those specified in MIL-F-8785B, Paragraph 3.7. Typical comparisons are shown in Figure 4 (3.1.3.7) for normal flight climb, cruise, and descent for the vertical gust amplitude in ft/sec.

The stringency of the requirement is rather high compared to MIL-F-8785B but is considered to be justified for future aircraft procurement.

Although the YF-17 turbulence study described above was not performed specifically to show compliance with any military specification, the results indicate at least partial compliance with this requirement which is considered to be valid.

Altitude	FCS Function Criticality	MIL-F-9490D	MIL-F-8785B
1750	Essential	17.6	6.2
	Flight Phase Essential	2 2 → 17.6	
	Noncritical	6.9	
7500	Essential	23.6	5.3
	Flight Phase Essential	0 → 23.6	
	Noncritical	6.7	
45000	Essential	15.1	4.5
	Flight Phase Essential	0 → 15.1	
	Noncritical	0	

Figure 4(3.1.3.7) Gust Intensities Comparison

Flying qualities in turbulence cannot easily be flight tested. Compliance, supported by flight test data, must be demonstrated by means of either flight simulation or by analytical means. Specifications of acceptable levels of attitude disturbance must be established through available and new flgith simulation, combined with analysis such as that contained in AFFDL-TR-71-162.

Recommendation

Retain the requirement as stated.

Additional Data

To the seventh paragraph of the Discussion that follows 3.1.3.7.2 Discrete gusts in the Users' Guide, add a reference to Onstott, E.D., et al., "Prediction and Evaluation of Flying Qualities in Turbulence," AFFDL-TR-71-162, February 1972. The research reported therein is an extension and further evaluation of the flying qualities in turbulence analysis methods reported in AFFDL-TR-70-143 (Users' Guide Reference 54).

Requirement

3.1.3.7.3 Wind model for landing and takeoff.

Not applicable.

3.1.3.7.3.1 Mean wind.

Not applicable.

3.1.3.7.3.2 Wind shear.

Not applicable.

3.1.3.7.3.3 Wind model turbulence.

Not applicable.

Requirement

3.1.3.8 Residual oscillations. For normal operation and during steady flight, FCS induced aircraft residual oscillations at all crew and passenger stations shall not exceed 0.04g's vertical or 0.02g's lateral peak to peak acceleration. Residual oscillations in pitch attitude angle shall satisfy the longitudinal maneuvering characteristic requirements of MIL-F-8785. Residual oscillations in roll and yaw attitude at the pilot's station shall not exceed 0.6 degree peak to peak for flight phases requiring precision control of attitude.

Comparison

The YF-17 criteria for residual oscillations are based on the requirements of MIL-F-8785B, paragraph 3.2.2.1.3. A comparison of these requirements with those of MIL-F-9490D, paragraph 3.1.3.8 is given below.

	MIL-F-9490D	MIL-F-8785B
Vertical Acceleration	0.04g's p-p at all crew and passenger stations for normal operation and during steady flight	±0.05g's at the pilots station for Levels 1 and 2, but shall not interfere with pilot's performance
Lateral Acceleration	0.02g's p-p as above	Shall not interfere with pilot's performance of required tasks
Pitch Attitude	Requirements of MIL-F-8785B	±3 mils for Category A Flight Phases
Roll and Yaw Attitude	0.6° p-p at the pilot's station	Shall not interfere with pilot's performance of required tasks.

A study has been conducted to determine if residual oscillations of the YF-17 could exceed 0.1 g peak-to-peak in normal or lateral acceleration. In this study, tests have been conducted on the Northrop full-scale controls test stand using flightworthy hardware in simulated closed-loop conditions. Rate gyros have been installed on a Cargo three-axis flight table driven by analog computers programmed with longitudinal and lateral airframe dynamics. Control augmentation system gains were increased, in turn, until instability, or unacceptable residual oscillations, appeared. A 100% gain margin has been established with residual oscillations of less than 0.1g peak-to-peak in normal and lateral acceleration.

The flight test instrumentation on the YF-17 had sufficient resolution to detect 0.1g peak-to-peak accelerations. The flight test data has shown that no residual oscillations of 0.1 peak-to-peak accelerations, or greater, exist. Furthermore, absence of pilot comments indicate that any residual oscillations remain below the level of perception. However, due to instrumentation limitations, compliance with the residual oscillation requirements of MIL-F-9490D has not been established.

Discussion

The requirement is valid as it relates to weapon delivery effectiveness and crew comfort. Compliance can be demonstrated by analysis that includes system nonlinearities or by simulation using actual hardware.

From a quantitative point of view, the requirement is too stringent unless reasonable deviations can be entertained. For high performance aircraft it undoubtedly would increase the cost of the actuators or could push actuator design beyond the state of the art. Future aircraft that would especially suffer would be control configured vehicles, those with high control system gains, and aircraft with extensive operational flight envelopes. In view of these considerations, the MIL-F-8785 requirements which emphasize that "residual oscillations shall not interfere with pilot's performance of required tasks" appear more reasonable for future combat aircraft. Additional research is needed in this area; therefore, no recommendation is made at this time.

Recommendation

Retain the requirement as stated.

Requirement

3.1.3.9 System test and monitoring provisions. Test and monitoring means shall be incorporated into the essential and flight phase essential FCS as required to meet the following requirements of this specification:

Mission Reliability	3.1.6
Flight Safety	3.1.7 to 3.1.7.1
Fault Isolation	3.1.10.2 to 3.1.10.2.2
Failure Immunity and Safety	3.1.3.2 to 3.1.3.2.1
Survivability	3.1.8 to 3.1.8.1
Invulnerability	3.1.9 to 3.1.9.7

The effect of detected and undetected FCS failures taken with the probability of occurrence of such failures shall comply with the system reliability and safety requirements. This requirement shall include all failures, both active and latent, and failures in all components of the system, including mechanical, electrical and hydraulic components.

Comparison

The YF-17 complies with the requirement to the following extent:

a. All pilot operated normal and emergency trim functions and mechanical controls to the horizontal tail and the rudder may be visually verified during preflight test upon actuation of the appropriate controls.

b. Proper takeoff trim position is indicated by light for pitch trim and by the position of the trim knob for yaw trim.

c. The electrical control paths to the flaps, ailerons, and horizontal tail are continually monitored and also may be visually verified during preflight test.

d. The MFCS electrical controls, including dynamic feedback sensors, are extensively checked by preflight BIT and continually monitored in flight, as discussed in the validations for the subsequent paragraphs.

The flight test instrumentation on the two YF-17 aircraft provided additional and quite extensive monitoring of the FCS and related subsystems. However, this extensive capability would not be available on a production fighter type aircraft.

Discussion

Noncritical FCS functions also contribute to the Mission Reliability; consequently, their exclusion from the requirement does not seem warranted.

Demonstration of compliance requires a very extensive failures modes and effects analysis due to the all-encompassing nature of the requirement.

<u>Recommendation</u>

Revise the requirement as follows:

Change the first sentence to read,

> "The FCS shall incorporate test and monitoring means as required to meet the following requirements of this specification:"

Requirement

3.1.3.9.1 Built-In-Test equipment (BIT). The total maintenance aid testing, including BIT, and inflight monitoring where used, shall provide an integrated means of fault isolation to the LRU level with a confidence factor of 90 percent or greater. BIT functions shall have multiple provisions to ensure they cannot be engaged in flight. The test equipment shall not have the capability of imposing signals which exceed operating limits on any part of the system or which reduces its endurance capability or fatigue life. Ground test signals shall not be of sufficient magnitude to drive actuators into hard-stop limits.

Comparison

The YF-17 is equipped with a BIT system for preflight testing and limited maintenance testing. The BIT system does not meet the LRU failure isolation confidence factor of 90 percent. However, it is excellent for verifying control system flight readiness and for identifying general problem areas.

In order to run BIT, the aircraft must be on the ground as there are several safety interlocks that require the gear to be down and weight on wheels before BIT power can be applied through the BIT switch, as shown in Figure 1 (3.1.3.9.1). Hence, the BIT functions cannot be engaged in flight. The signals imposed do not exceed operating limits on any part of the system, reduce endurance or fatigue life, or are of sufficient magnitude to drive actuators into the hard-stop limits.

The YF-17 is in partial compliance with this requirement.

Discussion

BIT is excellent to verify readiness of the flight control system computational tasks, inflight monitor systems operation, mode switching and failure disconnect systems operation, and to identify circuits which are not operating properly. BIT systems are less effective in identifying individual LRU's which have failed. For example, should there be a short to ground in a valve drive circuit, it is very difficult for a BIT to determine if that short is in the flight control computer, the ship's wiring, or the actuator. To determine the location of such a failure using BIT would require current sensing at the actuator and in the ship's wiring near the computer. Even then, isolation of the failure to the ship's wiring or LRU with the required confidence factor is not guaranteed.

A possible approach to solving the maintenance BIT problem is to have the preflight BIT identify failed LRUs, if possible, or identify the interface circuit to the questionable LRUs if the failure is such that it cannot be positively isolated to the LRU. For each of the interfaces, a simple procedure can then be specified to isolate the failure to the LRU.

An item not covered in the requirement is the time allowable for the different types of BIT.

The requirement is generally good but is considered to be too strict for present and future military aircraft. For the YF-17 BIT system to have complied with the provision for fault isolation to the LRU level would have added considerable complexity to the system. Even then, it is questionable that the required 90 percent confidence level could have been achieved.

A system designed to this requirement could be practically demonstrated.

Recommendation

Revise the requirement as follows:

Change the first sentence to read,

> "... to the LRU level with the highest practical confidence factor."

Add to the requirement,

> "BIT running time durations shall not exceed 90 seconds for preflight BIT, and 5 minutes for maintenance BIT."

Additional Data

Add as Discussion following the statement of the requirement 3.1.3.9.1 Built-In-Test equipment (BIT) in the Users' Guide:

> "Bit is excellent to verify readiness of the flight control system computational tasks, inflight monitor systems operation, mode switching and failure disconnect systems operation, and to identify circuits which are not operating properly. BIT systems are less effective in identifying individual LRUs' which have failed. For example, should there be a short to ground in a valve drive circuit, it is very difficult for a BIT to determine if that short is in the flight control computer, the ship's wiring, or the actuator. To determine the location of such a failure using BIT would require current sensing at the actuator and in the ship's wiring near the computer. Even then, isolation of the failure to the ship's wiring or LRU with the required confidence factor is not guaranteed.
>
> A possible approach to solving the maintenance BIT problem is to have the preflight BIT identify failed LRUs', if possible, or identify the interface circuit to the questionable LRUs if the failure is such that it cannot be positively isolated to the LRU. For each of the interfaces, a simple procedure can then be specified to isolate the failure to the LRU.

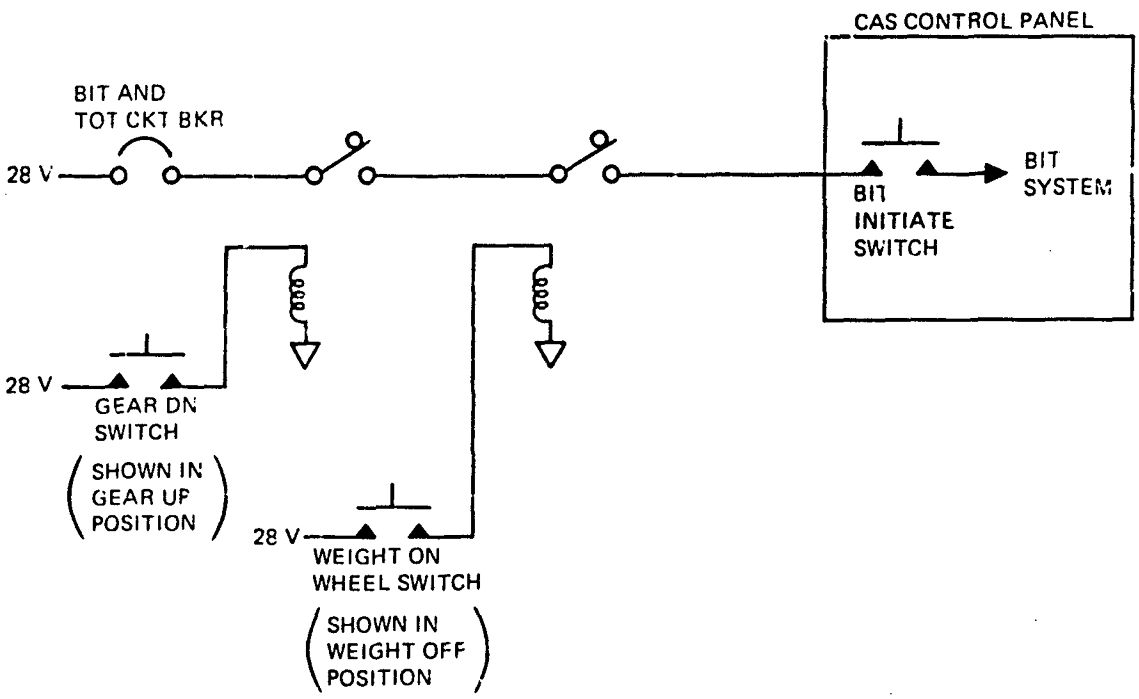

Figure 1(3.1.3.9.1) BIT Safety Interlocks

Requirement

3.1.3.9.1.1 Preflight or pre-engage BIT. Preflight or pre-engage BIT may be automatic or pilot initiated, and includes any test sequence normally conducted prior to takeoff or prior to engagement of a control to provide assurance of subsequent system safety and operability. It should be demonstrated that redundant MFCS electronic channels are operating normally without any safety-critical latent failures prior to takeoff. This includes all backup or normally disengaged channels, and fault monitoring and failure isolation elements. The preflight tests shall not rely on special ground test equipment for their successful completion. Any test sequence which could disturb the normal activity of the aircraft in a given mode shall be inhibited when that mode is engaged.

Comparison

The Built-In-Test (BIT), in the YF-17 flight control computer is designed to provide high confidence pre-flight detection and fault isolation of failures in the CAS and CAS related equipment. This testing encompasses the analog computation and digital logic circuitry of the computer plus the following interface components: the secondary hydraulic actuators, the pitch series follow-up trim electro-mechanical actuator, the maneuvering flaps electro-mechanical actuators, the rate gyros, the accelerometers, the pilot's engage switches, the flaps console switch, control system related LVDT's, and the interfaces with the DADC.

The testing of the digital logic circuitry is accomplished by forcing the logic into all possible states and verifying the proper output in each logic state. Two basic techniques are used to detect failures in the analog circuitry. These techniques are:

a. One technique employs the comparators which are used in the normal in-flight monitoring of the system. The BIT system first verifies that these comparators and their associated logic circuitry are working properly and then, via preselected voltage inputs into the analog circuitry, uses these comparators to verify analog circuitry.

b. The second technique employes special voltage comparators, window circuits, to check for specified voltages at certain points in the circuitry. This approach is employed for portions of the analog circuitry for which the comparators cannot conveniently be used to detect failures, i.e., either where a comparator does not exist or where the circuit time constant is much shorter than the comparator time delay.

The DADC is also used to detect failures in the Maneuvering Flaps portion of the system. In checking the maneuvering flaps circuitry and actuators, BIT uses the models and failure detection system of the DADC. This is accomplished by running the flaps up and down and interrogating the DADC flaps failure discrete.

Fault isolation to certain equipment external to flight control computer is provided by first verifying the computer circuitry and then applying special inputs into the individual sensors. For accelerometers, BIT uses a current source to excite their coils and then employs window circuit tests to verify a specific voltage output within the flight control computer. The rate gyros are verified by applying a selected voltage level to both A and B channel rate gyro torquing coils and verifying that the CAS comparators do not trip. To isolate the position modeled actuators, BIT first verifies the model electronics and then by inserting identical oscillating position commands into the model and servo channels, fault isolates the actuator failure. The servo comparators will trip if the two positions mistrack. For the case of the dual pitch actuators, identical commands are inserted into A and B channels and the servo comparators verify that the positions track.

The BIT computer is a special purpose digital computer which controls the sequencing and timing of events, the insertion of stimuli, and the reading and evaluating of test results. Physically, BIT consists of the control computer, the BIT display, and 27 remote elements (one on each card) which contain a serial receiver, stimulus inserters, and output multiplexers.

The central computer contains the clocks and control circuitry necessary to sequence events in accordance with the program information contained in the ROM's. It also transmits all stimulus and multiplexer control information to the remote registers and evaluates the analog and digital information received from those registers. For its man/machine interfaces the BIT computer controls the lighting of its status lights on the pilots control assembly and provides the information to control the BIT display on the front of the flight control computer.

The three cockpit CAS engage switches must be in the disengaged positions in order to initiate BIT. No special ground test equipment is required. The YF-17 complies with this requirement.

Discussion

The requirement is considered to be good and to be applicable to present and future military aircraft. It can be practically demonstrated.

Recommendation

Retain the requirement as stated.

Requirement

3.1.3.9.1.2 Maintenance BIT. Where required, BIT shall also be provided as a postflight maintenance aid for the FCS. BIT shall be designed to avoid duplicating test features included as part of the preflight test or monitoring functions.

Comparison

The YF-17 does not incorporate a separate maintenance aid (BIT) that is accomplished during a postflight inspection; however, the YF-17 preflight BIT can be useful for limited maintenance testing. This requires that a door on the left side of the aircraft be opened in order that a window on the CAS computer box be observed.

The test procedure starts by pressing the BIT 1 button on the pilot's control panel. This action causes the BIT 1 button and the window on the flight control computer to be illuminated. A digital display then appears in the window and begins changing rapidly, indicating the code numbers of the tests being performed. This continues until a code number appears indicating the completion of BIT Operation, Part 1, or until the code number of a failed test appears. In the latter case, the BIT 1 button is illuminated with a red NG. The failed test can be identified by reference to a BIT manual. In the event of a failure, the BIT procedure may be continued by pressing the cockpit BIT 2 button. The red NG is not extinguished. A second failure will be indicated by the digital display stopping at another test number. This procedure is continued until the number indicating the end of BIT Operation, Part 1, is displayed and the cockpit BIT 2 button is illuminated. At this time BIT Operation, Part II, is performed. The flap selector is placed in the emergency up position. The cockpit CAS engage switches are placed in the engage positions in pitch-yaw-roll sequence. The BIT 2 button is then pushed. All the control surfaces will cycle. The entire test then ends when the final test number appears in the window.

The YF-17 is in partial compliance with this requirement in that the maintenance capability of the YF-17 BIT is derived from features of the preflight BIT.

Discussion

The requirement does not make provision of a maintenance BIT mandatory and this is considered to be good. In the YF-17 a separate maintenance BIT would not have been justifiable as the preflight BIT is quite comprehensive. The stringency of this requirement appear to be satisfactory for present and future military aircraft, with one possible exception: The maintenance BIT may use tighter test tolerances for the purpose of detecting latent failures than either the preflight BIT or in-flight monitoring functions are using. The requirement can be practically demonstrated.

Recommendation

Clarify the requirement as follows:

Change the second sentence to read,

> "The Maintenance BIT shall make maximum use of test features already included as part of the preflight test or monitoring functions."

Requirement

3.1.3.9.2 Inflight monitoring. Continuous monitoring of equipment performance and critical flight conditions shall be active, as a minimum, during essential or flight phase essential modes of operation. False monitoring warnings, including the automatic or normal pilot response thereto, shall not constitute a specific hazard in excess of the system reliability requirements.

Comparison

The monitoring concept in the YF-17 control system is basically dual cross-channel comparison. Each computation function summing into the servo portion of an axis is monitored and switched separately. Voters are used at these summing points to prevent any failure transients in these computation functions from propagating to the control surface. Also, the voters prevent these failures from cascading tripouts into the servo channel without fulfilling the proper logic requirements. The monitoring of the servo loops is accomplished in two different manners.

1. The pitch axis has dual servos which are position compared.

2. The roll and yaw servo loops use a real servo and a position model of that loop. Again, position comparison is employed.

In all CAS actuator loops the position feedback LVDT's are offset to insure that any failure in the loops will be detected immediately.

All of the failure detection logic is dual. In the cases where the analog signals into the voters are switched, the A and B logic outputs are connected together by AND-gates to control those switches. The Built-In-Test checks for all possible latent failures in this logic. The servo logic is again dual, and each logic output controls one of the two relays connected on series for the control of current to the hydraulic bypass solenoid.

Monitoring is continuous and is active during all modes of operation.

In the pitch control system dual comparators monitor the shaped pitch CAS signals, follow-up trim actuator position LVDT signals, and the pitch CAS actuators. These comparators will detect failures associated with the control stick LVDTs, normal accelerometers, pitch rate gyros, follow-up trim actuators, pitch CAS actuators, and the internal electronics. Proper channel tracking, as well as valid status of the pitch rate gyro SMRD, DC power supply, and 2300 Hz AC power supply, are required to maintain the system engaged. Failures detected by the pitch CAS signal comparators, by the pitch CAS actuator comparators, or by the power supply and SMRD monitors will result in the pitch CAS actuators disengaging and centering. Failures detected by the follow-up comparators will result in the signals to the follow-up trim motors being switched out and the trim actuator brakes applied. The rest of the system remains operational. Failures in the monitoring system itself will have these same results and hence do not constitute specific hazards.

In the aileron control system dual comparators monitor the roll CAS signals, direct electrical signals, and aileron CAS actuator/actuator-model signals. These comparators and the power supply and SMRD monitors will detect failures in the aileron system similar to those listed above for the pitch system. Failures detected by the roll CAS comparators will result in the switching out of roll CAS signals to both ailerons. Failures detected by the direct electrical comparators or roll CAS actuator comparators will result in the right or left CAS actuator disengaging and centering. Failures in the monitoring system itself will have these same results and hence do not constitute specific hazards.

In the rudder control system dual comparators monitor the yaw SAS signals, ARI signals, SRI signals, rudder CAS actuator/actuator-model signals, and backup ARI/SRI signals. These comparators and the power supply and SMRD monitors will detect failures in the rudder system similar to those listed above for the pitch system plus angle of attack signals, aileron LVDT signals, the DADC ARI/SRI logic signal, and (in the backup ARI/SRI system) trailing-edge flap and horizontal tail LVDT signals. Failures detected by the yaw SAS comparators will result in the switching out of yaw SAS signals to both rudders. Failures detected by the ARI comparators will cause the ARI signal to be switched out to the right or left rudder and also will cause the corresponding aileron CAS actuator to disengage and center. Failures detected by the SRI comparators will cause the right or left SRI signal to be switched out to both rudder CAS actuators. If the backup ARI/SRI system is not active, failures detected by the backup ARI/SRI comparators will have no effect on the control system. If the backup system is active, such failures will cause all ARI and SRI signals to both rudders to be switched out and both aileron CAS actuators to disengage and center. Failures detected by the rudder CAS actuator comparators will result in the right or left CAS actuator disengaging and centering. Failures in the monitoring system itself will have these same results and hence do not constitute specific hazards.

The DADC provides CAS gain calculations, maneuvering flap control and normal/backup ARI/SRI logic. In flight, the DADC continuously monitors its functions to detect and isolate failures. Failure monitoring covers the entire DADC and includes end-to-end functional tests; sample problem solution as part of the computation cycle; memory, power supply, central processor, A/D and D/A converter, and parity checks; and monitoring of inputs, pressure transducers, and the digital, analog, and discrete outputs. The DADC also monitors critical flight conditions as part of the maneuvering flap control and will transfer operation of the flaps to automatic mode from one of the other flap modes as a function of angle of attack, Mach number, or dynamic pressure. (See paragraph 3.2.4.3.2 Digital Computation)

The YF-17 complies with this requirement.

Discussion

The requirement does not seem to be clear as to the inflight monitoring required for non-critical functions. The requirement could be interpreted to mean that no inflight monitoring of such functions is required at all, or that it is not required when a non-critical function is not engaged. The discussion in "Background Information and User Guide for MIL-F-9490D" does not seem to help clarify this point. Based on YF-17 experience, it is felt that inflight monitoring should be available for non-critical functions in order to provide failure detection and safe disengagement as well as to provide warning to the pilot that such functions have failed.

The requirement as it stands appears to be too lenient for present and future military aircraft. A change is considered necessary to improve the specification completeness.

Practical demonstration could be accomplished on a ground test stand and by inflight data recording.

Recommendation

Revise the requirement as follows:

Change the first sentence of the requirement to read,

> "Continuous monitoring of critical flight conditions and equipment performance for all flight control functions for which failure detection is provided shall be active inflight."

Additional Data

Add the following after the second paragraph of the Discussion to paragraph 3.1.3.9.2 Inflight monitoring in the Users' Guide:

> "Inflight monitoring should also be available for noncritical functions in order to provide detection and safe disengagement as well as to provide warning to the pilot that such functions have failed."

Requirement

3.1.4 MFCS design. The following general requirements apply. References to mechanical or electrical MFCS apply only when the mechanization is used:

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

b. Ratio changing mechanisms. Where ratio changing mechanisms are used, monitors and emergency positioning means shall be provided if improper positioning can result in a safety of flight hazard.

c. Control centering, breakout forces and freeplay. The corresponding design requirements of MIL-F-8785 or MIL-F-83300 shall be met. Selected sensitivity and breakout forces shall not lead to overcontrol tendencies.

d. Reversion. If a backup mode is provided for a flight control system, at least FCS Operational State III shall be provided following reversion. While disengaged, interaction of backup mode provisions with the normal mode shall not degrade operation below State I. If a single FCS power system is used in an essential or flight phase essential fully powered system, emergency mechanical reversion or an emergency power source shall be provided. On single-engine aircraft, the emergency power source shall be independent of engine operation. It shall be possible to re-engage the normal power source in flight following operation with manual reversion controls or emergency power. Manual or automatic changeover to or from emergency provisions shall not result in capability worse than FCS Operational State III.

e. Controller kinematics. Kinematics shall preclude hazardous unintentional inputs (crosstalk) into one or more axes with normal control motions within the limits of ultimate structural load factor, design maneuver, and turbulence induced accelerations experienced at the crew station.

f. Feedback to crew station controls. The control device motion and force required to accomplish stability and control augmentation shall not be evident at the crew station controls. Vibratory forces or motion acting upon elements downstream of the controller shall not be evident at the crew station controls. Force and motion feedback to crew station controls shall be considered as not evident if the force magnitude is less than half the lowest breakout force of the applicable control.

Comparison

a. Augmentation. The YF-17 uses control augmentation in the pitch and roll axes and stability augmentation in the yaw axis. Gain scheduling assures compatibility with airframe dynamic characteristics. In case of gain scheduling failure (air data computer or electrical wiring), the system reverts to a safe, minimum gain condition which assures at least Operational State II performance. Pilot operated gain changing device is not required for emergency backup; however, a gain changing device is used for system optimization and flight test evaluation only.

b. Ratio changing mechanisms. The only mechanical ratio changing mechanism used on the YF-17 is in the pitch control system. The mechanism varies the horizontal tail surface position with trailing edge flap motion to decrease the airplane pitching moment. This also revises the stick-to-horizontal-tail surface relationship in the pitch control system.

A dual cable system, one from each flap, is used to control the ratio changing mechanism. This precludes the need for installing an emergency backup system. In the event of a failure, the system will function normally with slight asymmetric horizontal tail motion. Such a failure can be easily detected by the maintenance crew.

c. Control centering, breakout forces and free play. At the beginning of the flight test program the stick centering and breakout forces were within the requirement. The control stick centered within 0.06 inch in both the pitch and roll directions. The stick breakout forces in the pitch system measured between 2.2 and 2.8 lbs. The stick breakout forces in the roll system measured between 1.5 and 2.0 lbs. The requirement specified in MIL-F-8785B is 3 lbs. for pitch and 2 lbs. for roll.

As the flight test program progressed, the stick forces were reduced approximately 30 percent in both the pitch and roll control systems. Also the authority of the stick over the surface was increased approximately 50 percent in the roll mode. The result was an increase in breakout force in the stick roll direction to slightly over 2 lbs. The centering capability decreased to where the stick would center within 0.10 inch in the pitch direction and 0.20 inch in the roll direction. Although the stick centering characteristics in the roll mode did not appear to be very positive when being checked out on the ground, the pilot's comments were all on the favorable side.

The free play in the pitch and roll control system was preloaded out by utilizing a dual control path up to the connection at the power actuators.

d. Reversion. There is no reversion system on the YF-17. The mechanical system is augmented by the electrical flight control system and remains fully active all the time. When the electrical flight control system is engaged or disengaged there is no change to the mechanical system.

e. Controller Kinematics. The YF-17 control stick is conventionally pivoted in pitch and centrol pivoted in roll. These kinematics did not introduce any unintentional crosstalk.

f. Feedback to crew station controls. The horizontal tail on the YF-17 is controlled by pitch and roll inputs from the control stick, trim inputs from the trailing edge flaps, low rate series trim from the CAS follow-up actuator, high rate series CAS input from a servo actuator in each power actuator, and a parallel trim actuator.

Although diligent consideration was given to these multiple inputs during the initial design phase, one condition producing feedback was revealed on the test stand prior to the flight test program. The combined travel due to the mechanical input from the stick in the pitch mode and the follow-up actuator exceeds the available system travel. Therefore, during extended duration of "g" maneuvers, the system would become saturated and the follow-up actuator would move the stick toward the neutral position. A switch was installed in the pitch system to deactivate the follow-up actuator circuit when the travel was saturated, thus preventing the follow-up actuator from back driving the stick.

Discussion

The requirements are valid and reasonable and compliance can be demonstrated. It is noted that under "e", undesirable inputs should also be included as they can have considerable effect on handling qualities.

Recommendation

Revise the requirement as follows:

Change subparagraph e. of the requirement to read,

"Kinematics shall preclude hazardous or undesirable inputs (crosstalk). . ."

Requirement

3.1.4.1 Mechanical MFCS design. In the design of mechanical components, the reliability, strength and simplicity of the system shall be paramount considerations. The signal transmission between the pilot's controls and the control surfaces shall be redundant to the extent required to meet reliability, failure immunity, invulnerability and other requirements of this specification.

Comparison

The design objectives for the YF-17 were consistent with full compliance to these requirements as applicable to a fighter aircraft. Dual mechanical controls are employed to provide a pitch/roll control system that meets the reliability and failure immunity requirements of this design specification, with paramount consideration given to maintaining simplicity. Redundant signal path separation is exemplified by cables routed on opposite sides of the fuselage. Safety interconnects in close proximity of the stabilizer actuators are employed to assure unimpaired mechanical control for pitch and roll in case of an open failure in either of the dual control paths.

The system is protected against a single-point jam condition to the greatest practical extent as described in the Comparison under paragraph 3.2.3.1.3 Fouling Prevention. If a jam occurs downstream of the pitch cable system, cable flexibility allows pitch stick displacement with force characteristics as shown in Figure 1 (3.1.4.1). This allows the pitch stick position sensor to command limited symmetrical horizontal tail motion through the pitch CAS, with roll command capability remaining unimpaired. In case of a jam downstream of the roll cable system, pitch control is not affected and the fly-by-wire ailerons remain operable with stick force characteristics similar to those shown in Figure 1 (3.1.4.1). Although not substantiated by simulation, this degraded capability is considered adequate to retain flight path controls and to accomplish an emergency landing.

Discussion

With the displacement type stick sensors used on the YF-17, the electrical CAS control paths cannot provide pitch or roll control capability if the jam occurs in the cockpit area, immobilizing the control stick. The capability to maintain safe control under this or any other single point jam condition may be achieved by utilizing force feel type command sensors for the cockpit controls. On the other hand, force sensors fail to provide an output in case of an open failure between the cockpit control and its force feel reaction point. The decision as to the type of sensor to use should consider both the control law requirements and the possible benefits attainable in the area of failure immunity. In any case, control augmentation can be effectively used to increase flight controls tolerance to a single point jam condition by providing limited backup control capability.

The requirement for simplicity is usually in conflict with requirements for failure immunity and invulnerability. As the requirements are specified qualitatively, value judgements are often required from the procuring agency during the development phase to establish a basis of compliance. However, the requirements provide valid design guides and objectives and therefore should be retained.

Recommendation

Retain the requirement as stated.

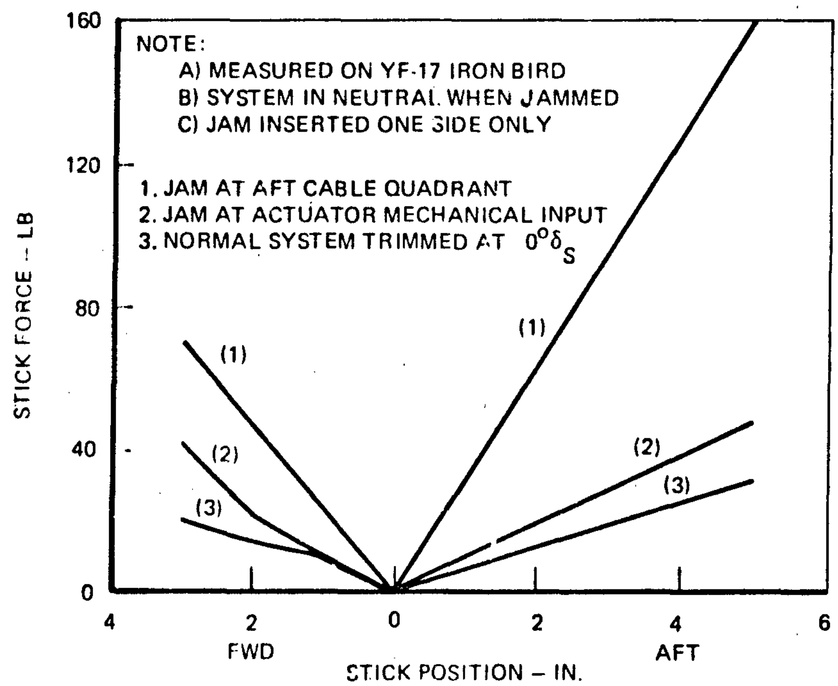

Figure 1 (3.1.4.1) YF-17 Stick Force Characteristics With Jammed Cable System

Requirement

3.1.4.1.1 Reversion - boosted systems.

Not applicable.

Requirement

3.1.4.2 Electrical MFCS design. Electrical flight control systems (6.6) shall be designed with special consideration to invulnerability to lightning strikes and to the thermal, EMI and other induced environments of 3.1.9.3.

Comparison

The YF-17 Manual flight control system (MFCS) is by definition (6.6) an electrical flight control system (EFCS) with electrical control augmentation in pitch and roll channels, stability augmentation in yaw, and direct electrical control of ailerons and maneuvering flaps. However, non-electrical backup provisions exist such that none of the electrical channels is essential per 1.2.3.1.

The YF-17 electrical flight control system was designed with special consideration to invulnerability to the induced environments of 3.1.9.3, but no provisions for invulnerability to lightning strikes were included. The YF-17 is partly compliant with this requirement.

Discussion

As reported in the validation write-up for paragraph 3.1.9.2, no lightning protection system was implemented in the YF-17 because this was considered beyond the scope of a prototype development program.

Paragraph 3.1.4.2 contains no new or unique requirements, it only references general requirements contained in paragraph 3.1.9. This paragraph serves the purpose of emphasizing the importance of invulnerability in electrical MFCS design. This emphasis is properly placed and is valid for future aircraft procurement.

Compliance with the requirements can be demonstrated by subjecting the entire aircraft to the applicable environments.

Recommendation

Retain the requirement as stated.

Requirement

3.1.4.2.1 Use of mechanical linkages. If a separate artificial feel system is used, or if mechanical linkages are used to connect a signal conversion mechanism with the control surface actuators, friction and freeplay shall not result in FCS operation below State I. Longitudinal and directional controls shall be mass balanced in the fore and aft direction and lateral controls shall be provided inboard to outboard balance, consistent with structural mode and longitudinal force requirements. Any residual vertical imbalance shall be consistent with feel requirements.

Comparison

Dual linear variable differential transducers (LVDT's) are employed on the YF-17 in the control augmentation system (CAS) as stick position sensors. These sensors are connected mechanically to the control stick for command signals to the pitch and roll axes. Each sensor is connected as close to the control stick as practical to reduce to a minimum the number of mechanical joints required. The pitch control sensor is connected directly to the control stick.

All electro-hydraulic CAS (secondary) actuators are integrated with their respective power stage minimizing the use of mechanical linkages.

The artificial feel control system is integrated with the mechanical control system and is located in close proximity of the pilot control. The mass distribution of the control stick in the fore and aft and vertical directions is the only significant source of unbalance in the control system. The control stick is counterbalanced with a separate bob weight. See Figure 1 (3.1.4.2.1).

The stick is not balanced laterally. There were no adverse effects experienced in flight test.

Friction and freeplay limits in the control systems are closely controlled by requirements for control centering, breakout forces, and control stick freeplay as specified in Paragraph 3.1.4.c. The requirements specified for centering, breakout forces, feel characteristics and freeplay were achieved. These characteristics were in turn verified to be compatible with stability and control characteristics requirements.

The YF-17 complies with the requirements.

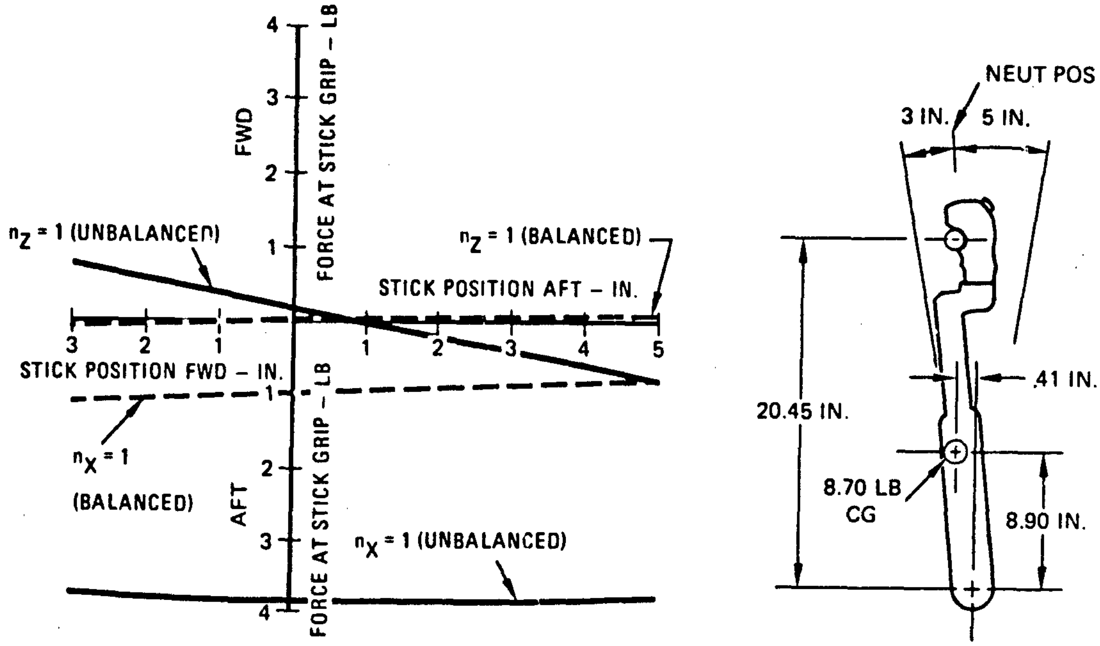

Figure 1(3.1.4.2.1) Stick Control Forces from Control Stick Bob Weight Effects

Discussion

The requirements for mass balance of the controls in the three axes are defined in a practical manner. Compliance with requirements for mass balance can be demonstrated analytically; however, piloted simulation or flight test is required to verify compatibility with stability and feel requirements.

Recommendation

Retain the requirement as stated.

Requirement

3.1.5 AFCS design.

Not applicable.

3.1.5.1 System requirements.

Not applicable.

3.1.5.1.1 Control stick (or wheel) steering.

Not applicable.

3.1.5.1.2 Flight director subsystem.

Not applicable.

3.1.5.2 AFCS Interface.

Not applicable.

3.1.5.2.1 Tie-In with external guidance.

Not applicable.

3.1.5.2.2 Servo engage interlocks.

Not applicable.

3.1.5.2.3 Engage - Disengage transients.

Not applicable.

3.1.5.3 AFCS emergency provisions.

Not applicable.

3.1.5.3.1 Manual override capability.

Not applicable.

3.1.5.3.2 Emergency disengagement.

Not applicable.

Requirement

3.1.6 Mission accomplishment reliability. The probability of mission failure per flight due to relevant material failures in the flight control system shall not exceed the applicable limit specified below. Failures in power supplies or other subsystems that do not otherwise cause mission failure shall be considered where pertinent. Each mission to which this requirement applies shall be established and defined by the contractor, subject to approval of the procuring activity.

a. Where overall aircraft mission accomplishment reliability is specified by the procurement activity, $Q_M(fcs) \leq (1 - R_M)\ A_M(fcs)$

b. Where overall aircraft mission accomplishment reliability is not specified, $Q_M(fcs) \leq 1 \times 10^{-3}$

where: $Q_M(fcs)$ = Maximum acceptable mission unreliability due to relevant FCS material failures.

R_M = Specified overall aircraft mission accomplishment reliability.

$A_M(fcs)$ = Mission accomplishment allocation factor for flight control (chosen by the contractor).

Comparison

The YF-17 aircraft does not comply with the requirements of paragraph 3.1.6b in that there were recorded approximately 30 mission failures per 1,000 flights, whereas the subject specification limits the number of such failures to one mission failure per 1,000 flights. However, the majority of YF-17 FCS failures causing a mission failure was not due to relevant material failures but rather to immature hardware and conditions peculiar to prototype development. For instance, the seizure of a gyro wheel in the pitch rate gyro which is a mature design with demonstrated high reliability would be considered a random, hence relevant failure. On the other hand, intermittent electrical connection due to wire breakage incurred during extensive modification activity on other systems in the same area would not be considered a relevant failure.

Discussion

The YF-17 being a development aircraft, it is understandable that the probability of failure per flight would be greater than that of a mature production aircraft. With this in mind, recent F-5E field experience data has been utilized to examine the relationship to the mission failure rate permitted by this specification. Reduction of this data revealed a reported failure rate of 3.44 per 1,000 flight hours based on a period of two years (1974 and 1975) with over 10,000 flight hours. This failure rate is based on failures reported as aborts plus aircrew discovered (no aborts). Postulated on the basis that only a portion of aircrew discovered failures could result in mission failures, a more realistic approach would be to assume that 10 percent of such failures will result in mission loss due to degraded capability. This would result in 0.68 failures (mission losses) per 1,000 flight hours.

Using the T-38A aircraft, with over 400,000 flight hours, the number of failures per 1,000 flight hours is 0.76 due to aborts and 3.18 for aircrew discovered failures. Mission loss per 1,000 flight hours for the T-38A is then 1.08 as compared to 0.68 for the F-5E.

Failure rates per flight hour for F-5E and T-38 aircraft are tabulated below for comparative purposes.

	Failures/FLT Hr	
	(Aborts Only)	(Aircrew Disc.)
F-5E (66-1 DATA)	.00038	.00306
T-38A (66-1 DATA)	.00076	.00318

Although the F-5E or T-38A aircraft are not truly representative from the standpoint of complexity, it is reasonable to assume that one mission failure per 1,000 flight hours is a realizable goal for mature Class IV aircraft.

In the case of Class IV aircraft, flight hours can be approximately equated with number of missions. However, wide variations exist in mission flight time between fighters, bombers, and transport aircraft and therefore, the requirement based on the number of missions places far more stringency on aircraft with long mission times. Flight hours would be more equitable than number of flight as the basis of a specification for all types of aircraft and an appropriate revision of the requirement should be considered.

Recommendation

Retain the requirement as stated.

Requirement

3.1.7 Quantitative flight safety. The probability of aircraft loss per flight, defined as extremely remote, due to relevant material failures in the flight control system shall not exceed:

$$Q_S(fcs) \leq (1-R_S)\ A_S(fcs)$$

where:

$Q_S(fcs)$ = Maximum acceptable aircraft loss rate due to relevant FCS material failures.

$A_S(fcs)$ = Flight safety allocation factor for flight control (chosen by the contractor).

R_S = Overall Aircraft Flight Safety Requirements as specified by the procuring activity.

Failures in power supplies or other subsystems that do not otherwise cause aircraft loss shall be considered where pertinent. A representative mission to which this requirement applies shall be established and defined in the FCS specification (4.4.2). If overall aircraft flight safety in terms of R_S is not specified by the procuring activity, the numerical requirements of table VII apply.

TABLE VII

FCS QUANTITATIVE FLIGHT SAFETY REQUIREMENTS

		Maximum Aircraft Loss Rate from FCS Failures
Overall A/C Flight Safety Requirement Not Specified By Procuring Activity	MIL-F-8785 Class III Aircraft	$Q_{S(fcs)} \leq 5 \times 10^{-7}$
	All Rotary Wing Aircraft	$Q_{S(fcs)} \leq 25 \times 10^{-7}$
	MIL-F-8785 Class I, II & IV Aircraft	$Q_{S(fcs)} \leq 100 \times 10^{-7}$

Comparison

YF-17 compliance with the requirements of this paragraph cannot be assessed as experience with the aircraft is limited to a few hundred flight hours. Also, due to the prototype nature of the program, no numerical predictions were made.

The aircraft can be safely flown and landed with mechanical controls only operational, requiring only hydraulic power. Failures in the electrical subsystems or augmentation systems do not impair this capability.

The YF-17 mechanical controls beam similarity to T-38/F-5 mechanical controls in the redundancy of control paths and hydraulic sources. Consequentiy, T-38/F-5 field experience could be applied to predict, at least approximately, the expected probability of YF-17 aircraft losses due to relevant material failures in the flight control system.

T38/F-5 Cumulative flight hours thru Sept'76 = 7,380,000 hours

Average mission length = 1 hour

Total losses due to relevant FCS failure = 1

MIL-D-9490D $QS_{(fcs)} \leq 5 \times 10^{-7}$ loss rate per mission

T38/F-5 Actual = $\frac{\text{FCS losses}}{\text{Flight hours (mission)}} = \frac{1}{7{,}380{,}000} = 1.355 \times 10^{-7}$ mission rate.

The conclusion based on the comparison to T38/F-5 experience is that the $QS_{(fcs)}$ value is acceptable for a fighter type aircraft assuming a mission length of not more than 3.7 hours and the utilization of loss due to relevant failures as currently defined.

Discussion

A quantitative safety requirement is applicable to fighter type aircraft and can be demonstrated through the number of aircraft lost due to FCS failures throughout the operational life of the aircraft. However, the numerical assessment of the aircraft lost due to a relevant material failure of the FCS would be difficult to determine as well as argumentative since all causes of an accident are listed without differentiating as to which was the basic cause factor. If the FCS was involved in the loss of an aircraft, a judgement would have to be made on whether the failure was relevant and to how it contributed to the accident to permit evaluation as to the extent of compliance with the quantitative requirement.

Depending on the type of aircraft involved, there may be a wide variation in the number of hours involved in any one flight. Flight hours is a more realistic basis on which to assess a hazard involving failures of the FCS since the exposure to the hazard is more a function of time than the number of flights. The accident data from the Armed Services Safety Centers from which the flight safety requirements are derived, and subsequently allocated to the FCS, are also based on flight hours as are Flight Safety Requirements specified by procuring activities.

Recommendation

Revise the requirement as follows:

Change the first sentence to read,

"The probability.....per flight hour, ...:"

Revise Table VII to reflect maximum aircraft loss rate in terms of flight hours.

Delete the sentence,

"A representative mission to which this requirement applies shall be established and defined in the FCS specification (4.4.2)."

Requirement

3.1.7.1 Quantitative flight safety - all weather landing system (AWLS).

Not applicable.

3.1.7.1.1 Assessment of average risk of a hazard.

Not applicable.

3.1.7.1.2 Assessment of specific risk.

Not applicable.

Requirement

3.1.8 Survivability. FCS Operational State IV or State V shall be provided as required by the procuring activity.

Comparison

The YF-17, similarly to other current vintage Class IV aircraft, was not designed to provide emergency landing capability with all engines out. Even though engines are out, landing of the YF-17 is theoretically possible (see Comparison under 3.1.8.1), it would be considered only under the most favorable set of circumstances, such as having the dry lakes in the Edwards Flight Test Center area for a landing field. However, the YF-17 does provide backup hydraulic and electrical power to allow engine restart attempts or to assure safe ejection.

The YF-17 complies with the requirement as applicable to Class IV aircraft.

Discussion

The requirement appears to address events other than just loss of engines but fails to be specific in this regard. Furthermore, invoking FCS operational State IV is ambiguous as this state includes the FCS capability to allow engine restart attempts and to perform an emergency landing. For Class IV aircraft, engines out landing is usually not recommended even if power for flight controls is available either from windmilling or other backup source.

The requirement needs clarification.

Recommendation

Revise the requirement as follows:

"FCS capability to allow engine restart attempts or to perform an emergency landing or to assure safe abandonment of the aircraft shall be provided as required by the procuring activity in case of the following events:

a) Loss of all engines

b) Loss of control power (hydraulic or electric)

c) Direct encounter from enemy threat defined by the procuring activity."

d) Exposure to worst case induced environments within crew and structural survival limits that result in inability to maintain Operational State III.

Requirement

3.1.8.1 All engines out control. For those aircraft which are dependent upon engine generation of flight control system power, supplementary means or power source shall be provided as necessary to supplement the control power available from the engine(s) where engines are unproven, airframe aerodynamics not established in flight, or windmilling power is insufficient to maintain operational State IV control capability anywhere in the aircraft operational envelope. Flight control system design (including power sources) shall be such that unintentional loss of any or all engine thrust shall not result in less than FCS Operational State IV including any necessary transition to emergency source(s) of power. Provision shall be made for inflight reversion to normal power wherein the transmission shall not result in a worse FCS operational state.

Comparison

The YF-17 has a hydrazine turbine-power hydraulic pump to provide hydraulic emergency power to the right hydraulic system. Hydrazine fuel is available for 10 minutes of turbine operation.

Electrical emergency power is available from a battery which is capable of supplying the minimum (dual engine out) electrical equipment for 15 minutes.

Flight control system functions available with dual engine out include the mechanically controlled horizontal tail system for pitch and roll control, the mechanically controlled rudder system, and the electrically controlled right aileron. The right aileron is desirable for more positive spin recovery. However, only the mechanically controlled horizontal tail is required for pitch and roll control during landing.

The YF-17 complies with the requirement.

Discussion

The requirement is valid and applies to current and future aircraft.

Recommendation

Retain the requirement as stated.

Requirement

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

3.1.9.1 Invulnerability to natural environments. Flight control systems shall be designed to withstand the full range of natural environmental extremes established for the particular vehicle or system without permanent degradation of performance below FCS Operational State I, or temporary degradation below FCS Operational State II. Reductions below State I shall be experienced only at adverse environmental extremes not normally encountered and shall be transient in nature only; and, the function shall be recovered as soon as the aircraft has passed through the adverse environment. System components and clearances with structure and other components shall be adequate to preclude binding or jamming, instability, or out of specification operation of any portion of the system due to possible combinations or temperature effects, ice formations, loads, deflections, including structural deflections, and buildup of manufacturing tolerances.

Comparison

The YF-17 flight control system was designed to formally documented environmental requirements which reflect the YF-17 operational envelope and the expected environmental extremes encountered by a military aircraft. System components, such as electronic assemblies and actuators, have been qualification tested to these requirements. The cable systems incorporate tension regulators to compensate for temperature variations and adequate clearances are provided between control system elements and adjacent structure. Due to the prototype nature of the program, the aircraft as a whole has not been subjected to environmental testing and full compliance with the requirement of paragraph 3.1.9.1 has not beeh established.

Discussion

The requirement is valid and applicable to all military aircraft. Demonstration of compliance requires component and system testing, as well as subjecting the entire aircraft to the expected environmental extremes.

Recommendation

Retain the requirement as stated.

Requirement

3.1.9.2 Invulnerability to lightning strikes and static atmospheric electricity. Flight Control system shall maintain State II capability or better when subjected to electric field and lightning discharges as specified in MIL-B-5087 and in AFSC Design Handbook DH 1-5, except that a temporary, recoverable, more extensive loss of performance to State III is allowable in the event of a direct lightning strike.

Comparison

The YF-17 does not comply with this requirement; development of a comprehensive lightning protection system for the aircraft and for the electrical flight control functions was considered beyond the scope of a prototype development effort. However, the mechanical system, which is considered relatively invulnerable to lightning strikes, does maintain State III capability.

Discussion

Although no lightning protection system was implemented in the YF-17, extensive studies were undertaken to formulate an effective lightning protection scheme in anticipation of the F-17 ACF development program. These studies resulted in designs for a lightning protection system which would provide the F-17 with a high probability or surviving lightning strikes with voltages, currents and waveforms as defined by MIL-B-5087B.

The fundamental elements of this lightning protection system design consisted of electrically bonding the aircraft per MIL-B-5087B, keeping the primary stroke currents on the exterior of the aircraft, minimizing the apertures in the skin through which electromagnetic fields can enter the interior, designing the fuel system and vents for immunity to lightning strikes, adding lightning diverters to the radome/antenna pods/canopy, shielding the internal wiring that is essential to flight with thin-wall aluminum conduits, designing circuits to be immune to voltage transients, and adding transient suppression circuits where necessary.

One of the most effective defenses against the internal electromagnetic fields generated by the primary stroke currents on the exterior of the aircraft is an overall wiring harness shield. Thin-walled aluminum conduit is considered one of the best shields and was recommended to protect the longer flight critical/safety wiring runs in the aircraft interior such as the pitch CAS system.

Northrop's evaluation of the proposed design for F-17 ACF lightning protection system, including aluminum conduit shielding, transient protection and full compliance with the bonding, grounding, lightning protection, and precipitation static control requirements of MIL-B-5087B, concluded that this design would comply with requirements of Paragraph 3.1.9.2. The requirements of this paragraph are adequately defined in terms of expected system performance under the adverse conditions specified and should pose no problems to the future procurement of flight control systems with designed invulnerability to these conditions.

No full-scale lightning strike tests were planned for the baseline protection system as a complete entity in a completed aircraft. Full-scale lightning strike tests were to be run on the radome, canopy, and antenna pods by Northrop. However, it had been anticipated that should nondestructive tests on a complete aircraft be undertaken by an agency with the test capability, such as ASD, compliance could have been practically demonstrated.

Recommendation

Retain the requirement as stated.

Requirement

3.1.9.3 Invulnerability to induced environments. Flight control systems shall withstand the full range of worst case induced temperatures and temperature shock, acceleration, vibration, noise and shock, induced pressures, explosive and corrosive atmospheres, electromagnetic interference (EMI), and nuclear radiation, including electromagmetic pulse, projected in missions for the particular aircraft, without permanent degradation or loss of capability to maintain FCS Operational State II capability. These induced environments within structural and crew survival limits shall not result in temporary degradation during the exposure to the environment below FCS Operational State IV capability. The FCS shall meet the requirements of MIL-A-8892, MIL-A-8893, and the applicable requirements of MIL-E-6051 and MIL-STD-461.

Comparison

The flight controls systems were designed to meet the environmental test guidelines for the YF-17 prototype aircraft as established by Reference 4. Testing of system and functional components was limited to demonstration of compliance with safety of flight requirements only.

Special tests and instrumentation were employed to ensure adequate temperature control of flight control power supply units and the air data computer.

Tests were conducted on the airframe for vibration and electromagnetic interference to ensure airframe/system compatibility.

Mechanical and environmental hazards were evaluated by analysis of system detail, assembly, and installation drawings, system schematics, and system functional analyses.

A qualification status report was compiled for functional components of the FCS. Existing test data on the same or similar units was evaluated for use as proof of compliance with minimum environmental and performance requirements specified for safety of flight.

Demonstration of compliance with requirements can be accomplished as a practical matter by analysis and component testing consistent with standard methods.

Discussion

The requirements, as specified, define critical criteria without the burden of detail. The list of possible failure modes due to induced environments should be relegated to design handbooks.

Recommendation

Retain the requirement as stated.

Requirement

3.1.9.4 Invulnerability to onboard failures of other systems and equipment. The FCS shall meet its failure state/reliability budget, as allocated within the weapon system, for self-generated failure (within the FCS) and for those FCS failures induced by failures of other interfacing systems within the weapons systems (3.1.6, 3.1.7). In addition, the FCS design shall comply with the following:

a. Essential and flight phase essential flight control systems shall retain FCS capability at Operational State III (minimum safe) or better after sustaining the following failures:

1. Failure of the critical engine in a two-engine aircraft.

2. Failure of the two most critical engines in aircraft having three or more propulsive engines.

3. Failure of any single equipment item or structural member which, in itself, does not cause degradation below State III. This includes any plausible single failure of any onboard electrical or electronic equipment in any subsystem of the aircraft.

b. Flight control systems, including the associated structure and power supplies on MIL-F-8785 Class III aircraft, shall be designed so that the probability of losing the capability of maintaining FCS operation to no less than State IV as a result of an engine or other rotor burst is extremely remote (6.6).

c. Flight control systems, including the associated structure and power supplies on MIL-F-8785 Class I, II, and IV aircraft, shall be designed so that the probability of degrading FCS operation below State V as a result of an engine or other rotor burst is extremely remote (6.6).

Comparison

Quantitative analyses were not required for the YF-17 reliability requirements thus proof of compliance with these requirements is not available. Qualitative evaluations were documented in the failure modes and effects analysis. Compliance with the specific FCS reliability are as follows:

1. Single Engine Failure

FCS capability at operational State III or better will be retained with the most critical engine failed and inoperative. The power for dual-separate electrical and hydraulic systems for the FCS is divided between the engines to ensure that either engine alone will provide the minimum safe requirements for all flight conditions.

2. Two Engine Failure - Not applicable.

3. A Single Failure in the FCS or any Subsystem of the Aircraft

A detailed study documented in the failure modes and effects analysis shows the YF-17 to be compliant with this requirement except for failures resulting in a jam condition in the mechanical system for pitch control. Failure modes resulting in a jam condition were deemed acceptably remote for prototype flight safety and permitted the use of a simplified control system for prototype flight test.

4. Failures due to Rotor Burst

The YF-17 FCS is deemed compliant with this requirements. The control actuators for the horizontal tail are mounted on opposite sides of the fuselage. The adjacent engine serves as armor plate protection against rotor burst on the engine of the opposite side. Additionally, each actuator is of a dual tandem configuration to permit independent operation with a single hydraulic system. Special attention was given to physical separation of the hydraulic systems to make a double failure extremely remote.

Discussion

These requirements are endorsed as items that should be given specific treatment to identify critical failure modes and protective measures incorporated for safety.

Recommendation

Retain the requirement as stated.

Requirement

3.1.9.5 Invulnerability to maintenance error. Flight control systems shall be designed so that it is physically impossible to install or connect any component item improperly without one or more overt modifications of the equipment or the aircraft. Provisions for adjusting the flight control system on the aircraft, except during initial buildup, major overhaul, or rigging during major maintenance activities, shall be minimized. All line replaceable units (LRU's) shall be designed to permit making internal adjustments only on the bench. The system shall require only a minimum or rerigging following replacement of LRU's. In addition, all control linkages and other flight control mechanisms shall be designed to resist jamming from inadvertent entry of maintenance tools or other material.

Comparison

General design criteria employed on the YF-17 for ensuring against maintenance error include the following:

a. Cranks, links and brackets and cables are designed to ensure proper installation.

b. Adjacent electrical and hydraulic connections are physically different to make it impossible to make the wrong connection.

c. Functionally different rate gyro and accelerometer packages have different mounting patterns.

d. Exposed cables in the equipment bays of the airplane are shrouded to protect against damage during routine maintenance activity.

The control linkage that mounts on the horizontal tail control actuators employs lock bolts for fasteners to preclude mal-adjustment in the field.

The horizontal tail mixer linkage is designed to be bench tested and installed as a unit. Production design would employ lock bolts for joint fasteners to ensure against mal-adjustment in the field and also to ensure against loss of fasteners.

The YF-17 complies with the requirement.

Discussion

The requirement is valid. Invulnerability to maintenance error is a very important consideration that must be addressed during the detail design phase.

Recommendation

Retain the requirement as stated.

Requirement

3.1.9.6 Invulnerability to pilot and flight crew inaction and error. Flight control systems shall be designed to minimize the possibility of any flight crew member controlling or adjusting system equipment to a condition state which could degrade FCS operation.

a. Protection against improper position and sequencing of controls - Wherever practical, cockpit controls, other than stick or wheel and rudder pedals, shall be equipped with positive action gates to prevent inadvertent positioning which can compromise safe operation of the aircraft. Positive interlocks to prevent hazardous operation or sequencing of switches shall be provided.

b. Protection against inflight engagement of control surface locks.

c. Pilot reaction to failure - Flight control systems shall be designed so that the normal pilot reaction to cues provided by probable failure conditions is instinctively correct.

d. Warning requirements:

(1) Warning information shall be provided to alert the crew to unsafe system operating conditions. Systems, controls and associated monitoring and warning means shall be designed to preclude crew errors that create additional hazards.

(2) A clearly distinguishable warning shall be provided to the pilot under all expected flight conditions for any failure in a redundant or monitored flight control system which could result in an unsafe condition if the pilot were not aware of the failure.

Comparison

The YF-17 is in compliance with these requirements. The control augmentation engage/disengage switches are lever-lock type, preventing inadvertent positioning. The direction of actuation for speedbrake and flap controls is conventional, assuring instinctively correct selections. Any failure in the electrical flight controls or associated subsystem is displayed on the annunciator panel.

Discussion

The requirement is valid and applicable to all military aircraft. Demonstration of compliance requires human factors evaluation, including extensive use of a cockpit mockup.

Recommendation

Retain the requirement as stated.

Requirement

3.1.9.7 Invulnerability to enemy action. Essential and flight phase essential flight control systems, including associated structure and power supplies, on all aircraft designed for combat operations shall withstand at least one direct encounter from the threat defined by the procuring activity without degredation below Operational State III.

Comparison

Vulnerability data for the YF-17 is not available. While special armor plate is not incorporated for protection in combat, extensive effort has been made to separate redundant systems and to utilize structure for protection of critical elements. The engines serve to protect the horizontal tail actuators and to further preclude damage to both actuators from one direct encounter. The protection afforded by wing spars and structure is utilized in addition to separation for protection of dual hydraulic systems by routing one system outboard on the aft spar and the other system outboard on the front spar. The nose wheel also serves to protect the cockpit and critical controls and functions as a shield between dual systems to limit damage to one side only.

Discussion

Requiring essential and flight phase essential control systems to withstand a given threat without degradation below Operational State III is a valid requirement. It provides for minimum safe operation following the defined enemy action. However, a more severe threat may exist, the encounter with which makes Operational State III maintenance impractical. Maintaining Operational State IV may be a worthwhile goal in this case. Further, even to be able to maintain Operational State V may be a valid goal for certain threats. The requirement should allow for these considerations by providing that both the threat and the resulting operational state be specified by the procuring agency.

Specifying "one direct encounter" does not seem to add anything to the specification. If the threat is to be defined, the flexibility should exist to define the manner in which the threat is imposed.

Recommendation

Revise the requirement as follows:

> "Essential and flight phase essential control systems, including associated structure and power supplies, on all aircraft designed for combat operations shall withstand the threats defined by the procuring activity without degradation below correspondingly specified operational states."

Requirement

3.1.10 Maintenance provisions. FCS design and installation shall permit noramlly available maintenance personnel to safely and easily perform required maintenance under all anticipated environmental conditions. Means shall be provided to facilitate the accomplishment of all required maintenance functions including: operational checkouts, system malfunction detection, fault isolation to the LRU (line replaceable unit) level, LRU removal and replacement, inspection, overhaul, servicing, and testing.

3.1.10.1 Operational checkout provisions. Flight control systems 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 practical. They shall be designed to operate with the power generation subsystems supplied by standard Air Force ground carts, as specified by the procuring activity or by self-contained power supplies.

3.1.10.2 Malfunction detection and fault isolation provisions. Means providing a high probability for detecting failures and monitoring critical performance conditions as required to isolate faults to the LRU level shall be incorporated in all flight control electrical and electronic systems required to perform essential and flight phase essential functions. These means may include cockpit instrumentation and bulit-in test equipment. For the mechanical and fluid power portions of the flight control system, provisions for the use of portable test equipment may also be incorporated as required to meet the maintenance support and operational concept of the particular weapon system.

3.1.10.2.1 Use of cockpit instrumentation. Where acceptable procedures result or are provided, cockpit instrumentation may be used for malfunction detection and fault isolation where it provides readily understandable condition indication either alone or in coordination with built-in test equipment, or with protable test equipment (for nonelectrical and nonelectronic components).

3.1.10.2.2 Provisions for checkout with 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.

3.1.10.3 Accessibility and serviceability. Components shall be designed, installed, located, and provided with access so that inspection, rigging, removal, repair, replacement, and lubrication can be readily accomplished. Suitable provisiions for rigging pins, or the equivalent, shall be made to facilitate correct rigging of the control system.

Comparison

Special design efforts were directed toward maintenance provisions to simplify and expedite maintenance operations.

a. Operational Checkout Provisions

Provisions are made for the use of a standard ground power unit with the capability of providing full hydraulic and electric power as required to perform a functional checkout of the FCS and all other related systems without operation of the engines.

b. Malfunction Detection and Fault Isolation Provisions.

An FCS warning and status annunciation panel is located on the center pedestal in front of the control stick to provide the pilot and maintenance personnel a visual indication of failure conditions in accordance with requirements of paragraph 3.2.1.4.2. A built-in test (BIT) system is incorporated for preflight testing of the electrical FCS in accordance with paragraph 3.2.1.4.2.1. Special provisions are incorporated in the BIT system (BIT counter display on the CAS computer) to assist maintenance personnel to isolate faults to the LRU level.

c. Provisions for the Checkout with Portable Test Equipment

1. Special provisions are provided to permit attachment of a standard pressure test unit to the air data computer to perform a check of the flap control pressure-altitude performance characteristics.

2. The CAS computer is equipped with special electrical test connector for ground testing with a simple junction box and commonly used portable test equipment (voltmeter, oscilloscope, etc.).

3. Procedures are established for the use of standard test equipment for bench tests of components and rigging aids for the FCS.

d. Accessibility and Serviceability

A strong emphasis has been given to design features to facilitate serviceability. Special items are noted as follows:

1. Each control surface actuator is designed as a module to be bench tested and adjusted without provisions or need for field adjustment.

2. Large access doors are provided on each side of the fuselage and for each control actuator to facilitate easy access for inspection, installation, and removal.

3. The pitch-roll control linkage assembly (signal shaping and summing linkage) is of a modular design packaged as a functional unit and mounted with 3 mounting bolts. The linkage is dual with a similar assembly on both L.H. and R.H. side. A bench check and rigging procedure is established to minimize adjustments required on each of the dual assemblies after installation.

Discussion

The requirements for maintenance provisions are necessarily defined in qualitative terms that are subject to a kaleidoscope of value judgements and technical factors which make demonstration of compliance an impractical exercise. Maintenance provision like safety provisions, must be relegated to periodic review by representative interests of the contractor and procuring agency during design development and documented by analysis. This procedure is consistent with current practice.

The titles and sub-titles under paragraphs 3.1.10 adequately identify the scope of the requirements and define the design objectives.

Recommendation

Retain the requirements as stated.

Requirement

3.1.10.4 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.

Comparison

The YF-17 aircraft is compliant with these requirements. The following items exemplify steps taken for safety of maintenance personnel.

a. All specifications for functional checks instruct caution to ensure that people and structures are clear of control surfaces prior to connecting power to the aircraft.

b. Pins with streamers are employed to lock landing gears down for functional tests of systems on the ground.

c. Special locks are employed on the ground to protect maintenance personnel against accidental seat ejection when occupied in the cockpit with maintenance activity.

Discussion

The definitions of requirements for safety provisions are as clearly defined as should be expected for this specification. It is expected that satisfactory compliance with requirements established by a safety review board would constitute demonstration of compliance in the future as in the past. This procedure is properly established by the procurement contract and need not be defined in this specification.

Recommendation

Retain the requirement as stated.

Requirement

3.1.11 Structural integrity

3.1.11.1 Strength. The overall flight control system shall be designed to meet the applicable load, strength, and deformation requirements of MIL-A-8860, MIL-A-8861, MIL-A-8865, MIL-S-8698, and MIL-STD-1530. The components of the systems shall be designed in accordance with the strength requirements of MIL-A-8860, MIL-C-6021, MIL-F-7190, MIL-A-21180, MIL-A-22771, MIL-F-83142, MIL-HDBK-5, and MIL-HDBK-17.

3.1.11.1.1 Damage Tolerance. Those structural elements of the flight control system that are essential to safety to flight (to control essential and flight phase essential functions) shall meet the damage tolerance requirements of MIL-A-83444.

3.1.11.1.2 Load capability of dual-load path elements. The load path remaining after a single failure in dual-load-path elements shall meet the following requirements:

a. Where the failure is not evident by visual inspection or by obvious changes in control characteristics, the remaining path shall be capable of sustaining a fatigue spectrum loading based on one overhaul period. The time interval corresponding to an overhaul period shall be established by the contractor. The remaining path shall also withstand, as ultimate load, loading equal to 1.5 times the limit loads specified in MIL-A-8865, or 1.5 times the load from an alternate source, such as a powered actuation system or loads resulting from aerodynamic or other forces, if such load is greater.

b. Where the single failure is obvious, the remaining load path shall be capable of withstanding, as ultimate load, loading equal to 1.15 times limit loads specified in MIL-A-8865, or 1.15 times the load from an alternate source, such as a powered actuation system or loads resulting from aerodynamic or other forces, if such a load is greater.

Comparison

The strength of all control elements are designed in accordance with the specified requirements. The pitch and roll controls for the horizontal tail are dualized to provide a multiple load path. Each control path is designed for ultimate load (1.5 x limit load) requirement. The rudder control is a single path control with the normal rudder control forces divided at the output end for separate but synchronous control of the two rudders. The control elements to each rudder normally carry half of the control input but each is designed to carry the full load for a jam condition.

Discussion

The strength requirements are consistent with standard design practice and are deemed satisfactory. Compliance with the requirements may be demonstrated and documented by analysis. Access required for routine in-service inspection should be subject to evaluation as part of procuring agency/contractor safety review during systems design and development.

Recommendation

Retain the requirement as stated.

Requirement

3.1.11.2 Stiffness. The stiffness of flight control systems shall be sufficient to provide satisfactory operation and to enable the aircraft to meet the stability, control, and flutter requirements as defined in the applicable portions of MIL-F-8785, MIL-A-8870, MIL-F-83300 and MIL-A-8865. Normal structural deflections shall not cause undesirable control system inputs or outputs.

Comparison

All individual YF-17 flight control actuators exceed specified design stiffness requirements. Resonant response tests were conducted on flutter-sensitive surface actuators to verify that the dynamic stiffness at predicted flutter frequencies was adequate. Nevertheless, in two instances the net torsional restraint was found to be marginal on two surfaces because flexible elements in the actuator back-up structural load path had been overlooked. Neither of these potential problems was detected until ground vibration tests of the complete aircraft were conducted. Fortunately, adequate flutter and static aeroelastic margins existed on both surfaces and no hardware changes were required before flight tests. However, predicted flutter margins on the horizontal stabilizer in the critical transonic region were reduced to the 15% minimum requirement, necessitating a more cautious approach to flight flutter testing than originally planned. This experience indicates that structural analyses tend to be more strength-conscious than stiffness-conscious and demonstrates a need for greater emphasis on careful analysis to ensure that stiffness requirements on the total actuator back-up structural load path are met.

Discussion

The requirement is valid. Demonstration of compliance requires analysis and complete aircraft ground vibration testing.

Recommendation

Retain the requirement as stated.

Requirement

3.1.11.3 Durability. Flight control systems shall be designed to meet the durability requirements of MIL-A-8866 and equal to that of the airframe primary structure considering the total number of ground and flight load cycles expected during the specified design service life and design usage of the aircraft from all commands: e.g., from the MFCS, AFCS, servo feedback and from load inputs. The requirements of MIL-A-8892 regarding vibrations and MIL-A-8893 regarding sonic fatigue also apply to the FCS.

Comparison

The flight control systems for the YF-17 are designed to requirements consistent with a specified 4000 hour service life and design usage. Demonstration of compliance with durability requirements has not been accomplished. Tests conducted were limited to flight justification types. Investigations were conducted to measure frequency response characteristics of control elements such as push-pull rods to ensure against resonant conditions in flight.

Discussion

Demonstration of compliance with durability requirements in a production aircraft would be accomplished analytically for approximately 90 percent of the structural control elements affected because of the characteristic low stress levels in a system designed for stiffness. Some small incremental increase in weight in the flight control system should be expected in the design of the remaining 10 percent, including pulley brackets and mounting structure, to achieve low stress levels consistent with analytic requirements. Other elements such as control rods, bolted brackets, and mechanism support assemblies would be subject to vibration testing and life cycle testing as required.

Recommendation

Retain the requirement as stated.

Requirement

3.1.12 Wear life. Mechanical elements of the FCS shall be designed to have wear life equal to the wear life specified for the overall aircraft. Parts subject to wear, such as hydraulic seals, bearings, control cables, sensors and hydraulic actuator barrels, may be replaced on their wearing surfaces renewed after they exceed their useful life. However, all replacements shall be within the FCS wear out-replacement budget established for the overall weapon system. Electronic and other nonmechanical LRU's shall remain economically repairable and shall meet reliability requirements throughout the specified airframe lifetime.

Comparison

The flight control system for the YF-17 was designed for 4000 hours service life, well in excess of the actual service utilization anticipated for the two prototype aircraft. This represented a prudent approach as the nature of the program did not allow extensive verification testing. Test and analysis have been conducted only to the extent required to meet flight justification requirements. FCS wear-out budget was not established for the YF-17 and, therefore, the service life requirements of replacable elements was not defined. All electronic and non-mechanical LRU's used on the YF-17 are considered economically repairable. The YF-17 complies with the intent of this requirement.

Discussion

The wear life requirements are specified in acceptable terms and are deemed to be complete and valid. Wear life, defined in terms of life cycles and related conditions, must be especially defined for each condition subject to judgement, analysis, and test.

Recommendation

Retain the requirement as stated.

Requirement

3.2 Subsystem and component design requirements

3.2.1 Pilot controls and displays. Wherever a FCS control, display or annunciator is interfaced with redundant flight control channels, mechanical and electrical separation and isolation shall be provided to make the probability of common mode failures at least extremely remote. FCS controls and displays shall be designed in accordance with MIL-STD-1472.

Comparison

The YF-17 FCS controls and displays have been designed through extensive cockpit mockup and human factors evaluation effort, using MIL-STD-1472 as a guide. Although the electrical flight controls perform only non-critical and, in a few instances, flight phase essential functions, the interface design emphasized fail safety and immunity to propagated failures. All computer generated status discretes are buffered before being transmitted to the annunciator panel. The engage switches for the roll and the yaw axes, which are dual-dual or fail-safe per side, feature electrical separation of engage/disengage logic signals. However, the probability of common mode failures has not been assessed.

The YF-17 is in partial compliance with the requirement.

Discussion

The requirement is too stringent. First, it sets a numerical value "extremely remote" on the probability for common mode failures without considering the criticality of the affected FCS function. Second, it imposes MIL-STD-1472 as a firm requirement and thereby impedes the effort of cockpit design teams in coming up with the best solution for a given problem.

Recommendation

Revise the requirement as follows:

In the first sentence, replace ". . . to make the probability of common mode failures at least extremely remote." with " . . . to achieve immunity against common mode failures consistent with the requirements of 3.1.6 (Mission Reliability) and 3.1.7 (Quantitative Flight Safety)."

In the second sentence, replace ". . . in accordance with MIL-STD-1472." with ". . . in accordance with mission requirements using MIL-STD-1472 as a guide and shall be subject to the approval of the procuring agency."

Requirement

3.2.1.1 Pilot controls for CTOL aircraft. Pilot's cockpit controls for conventional takeoff and landing (CTOL) aircraft shall be designed and located in accordance with AFSC Design Handbook DH 2-2, DN 2A1, Aircrew Controls; DN 2A5, Flight Controls; and the following subparagraphs. Strict adherence to the prescribed location and maximum range of motion of these controls is required.

Comparison

The cockpit arrangement of the flight controls in the YF-17 is arranged for compatibility with the pilot's seat being reclined 18°, in lieu of the 13° specified in AFSC DH 2-2, DN 2A1, SN 1(1). The increased reclining angle of the pilot's seat increases pilot's tolerance to high maneuvering load factors. Figure 1 (3.2.1.1) illustrates the arrangement for the YF-17 and the dimensions applicable to the pitch, roll, yaw and throttle controls. Of special note is the increased elevation of rudder pedals above the floor and shortened distance of throttle control from the neutral seat reference point.

Discussion

The reclining angle of the pilot's seat impacts on the validity of dimensions specified in DH 2-2, SN 1(1) and makes comparisons more academic than practical. The application of new concepts of control such as force-feel, side arm, primary hand controllers, dual controls, etc., will make it additionally difficult to formalize cockpit arrangement dimensions.

Dimensions applicable to cockpit arrangement of controls should be included in the design specification as exemplary of recommended values to serve as a guide. Locating dimensions and range of travel of flight controls would be established by mockup and a basic dimension control drawing subject to approval by the procuring agency.

Recommentation

Delete the last sentence of the requirement.

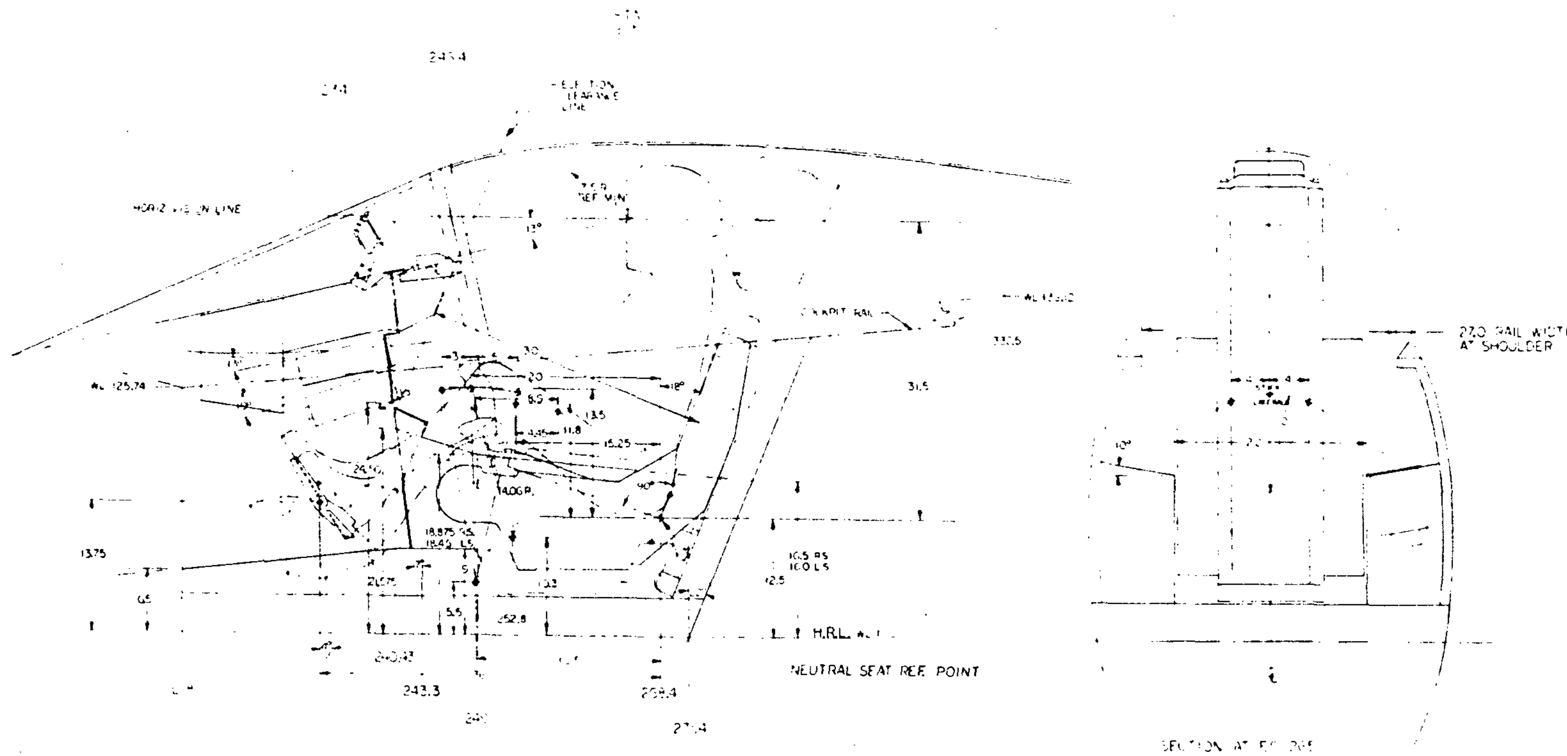

Figure 1(3.2.1.1) YF-17 Cockpit Arrangement of The Flight Controls

Requirement

3.2.1.1.1 Additional requirements for control sticks.

Not applicable.

Requirement

3.2.1.1.2 Additional requirement for rudder pedals. Rudder pedals shall be interconnected to insure positive movement of each pedal in both directions.

Comparison

The YF-17 utilizes a conventional arrangement for ruader control with pedals interconnected and thus complies with this requirement. A force-feel type of control with a travel range of 1.0 inches away from neutral was proposed for production but the interconnect feature was retained.

Discussion

This requirements is considered to be valid for present and future military aircraft and consistent with the standard mode of rudder control employed in CTOL aircraft; it can be practically demonstrated. Until sufficient experience has been accumulated to establish requirements for a fixed pedal with forcesensing control signals, the interconnected pedals should remain as a basic specification requirement.

Recommendation

Retain the requirement as stated.

Requirement

3.2.1.1.3 Alternate or unconventional controls. If pilot's controls other than conventional center located sticks, W-type wheels, rudder pedals, trim controls, and indicators, wing incidence control, wing sweep control, landing flaps control and indcator, speedbrake control, and automatic flight control panels specified in AFSC Design Handbook DH 2-2, DN 2A5, are utilized, demonstration of their adequacy and suitability is required prior to installation in an aircraft.

Comparison

All flight controls are conventional on the YF-17 with minor innovations not identified as unconventional.

Discussion

This requirement is endorsed as reasonable and practical for present and future military aircraft.

Recommendation

Retain the requirement as stated.

Requirement

3.2.1.1.4 Variable geometry cockpit controls.

Not applicable.

Requirement

3.2.1.1.5 Trim switches. Electrical trim system switches of the five-position, center-off, toggle type shall be in accordance with MIL-S-9419. Control stick grips in accordance with MIL-G-25561 shall already have the trim switches, conforming to MIL-S-9419, installed. Three-position trim switches shall be approved switches similar or equivalent to the MIL-S-9419 switches.

Comparison

The YF-17 uses standard control stick grip with a five-position "coolie hat" type trim switch in accordance with MIL-S-9419. For parallel pitch trim, the switch operates an electromechanical actuator installed in the feel mechanism. For series roll trim, the switch applies constant voltage to an electronic integrator in the flight controls computer, which in turn controls aileron trim through the roll CAS. Proportional yaw trim is controlled with a knob located on the CAS control panel.

Emergency trim to reposition the pitch CAS follow-up actuator in case of a CAS failure is controlled by a three-position toggle switch in accordance with MIL-S-2950.

The YF-17 complies with the requirement.

Discussion

The requirement is valid, and compliance with it can be demonstrated by inspection. However, the requirement is considered incomplete as it fails to include knob type controls used on many aircraft for proportional trim.

Recommendation

Revise the requirement as follows:

Change the title of the requirement to "Trim Controls."

Add to the requirement,

> "Knob type trim controls may be used for proportional trim subject to approval by the procuring agency."

Requirement

3.2.1.1.6 Two-Speed trim actuator.

Not applicable.

Requirement

3.2.1.1.7 FCS control panel. The FCS control panel shall provide the pilots with the integrated means to select the MFCS and AFCS functions.

Comparison

The YF-17 does not have AFCS functions.

Selectable MFCS functions include the pitch, yaw, and roll areas of the Control Augmentation System (CAS) and the automatic (maneuvering), manual (UP/DOWN), and flight test modes for the flaps. In addition, CAS gains may be varied in flight for flight test evaluation.

CAS related controls are located on two separate panels in the left console as shown in Figure 1 (3.2.1.1.7). The CAS control panel includes the CAS engage switches, rudder trim knob, pitch emergency trim switch, take-off trim control/indicator, and BIT control/indicator. The CAS flight test panel includes control knobs to vary system gains and switches to apply calibrated control inputs.

The essential flap controls include the flap mode switch and the flap selector switch which are located in a cluster on the left console as shown in Figure 1 (3.2.1.1.7). The flap mode switch either enables the flap selector switch or transfers control to the flight test switches located on the instrument panel or commands the flaps up in case of a failure. The flap selector switch allows manual selection of UP/DOWN flaps or, in the AUTO position, transfers flap control to the digital air data computer. The flight test flap switches with the adjacent dial indicator, as shown in Figure 2 (3.2.1.1.7), allow independent manual positioning of the leading-edge and trailing-edge flaps for flight test purposes.

The YF-17 is not in compliance with the requirement primarily due to the flight test provisions incorporated in the aircraft.

Discussion

The intent of the requirement is clearly to promote uniform and orderly cockpit design through a "master panel" concept. However, it is in conflict with the space restraints usually encountered in fighter aircraft and, in certain instances, with mission requirements. For instance, heads-up selection capability may be desirable for certain MFCS and AFCS modes, requiring locating the related controls on the instrument panel.

The requirement is too stringent for fighter aircraft.

Recommendation

Revise the requirement as follows:

> "The controls for selectable MFCS and AFCS functions and adjustable FCS parameters shall be located consistent with efficient cockpit design and mission considerations. Locating these controls on a single integrated panel or in a cluster of panels shall be considered."

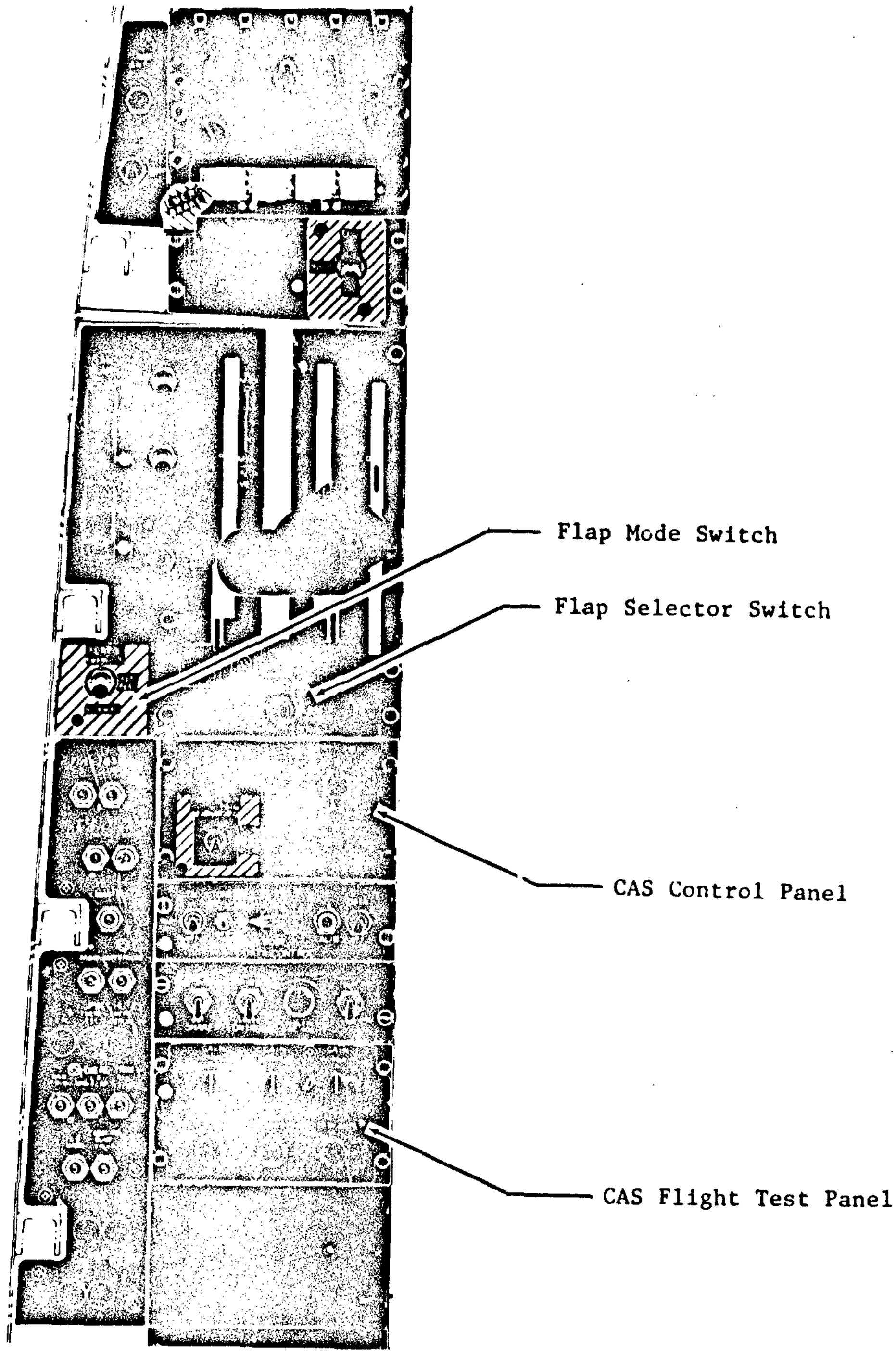

Figure 1 (3.2.1.1.7) Cockpit Left Console

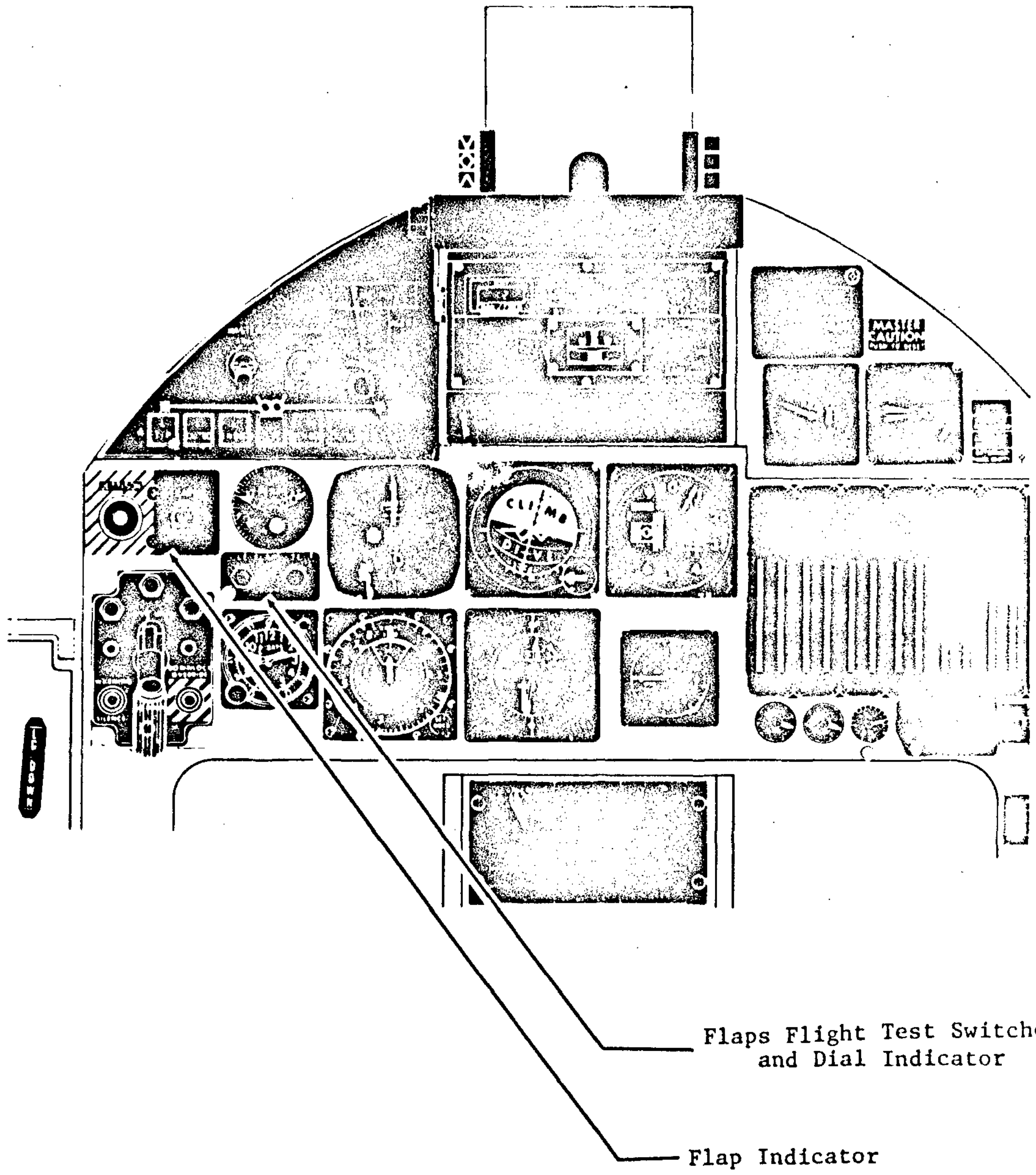

Figure 2 (3.2.1.1.7) Cockpit Instrument Panel

Requirement

3.2.1.1.8 Normal disengagement means. Means for disengagement of all modes of the AFCS shall be provided which are compatible with the requirements of 3.1.9.6.

Comparison

The YF-17 does not have AFCS functions. Normal disengagement means are provided for all three axes of the control augmentation system as discussed under Comparison for paragraph 3.1.3.3.2 Disengagement. This disengagement capability is compatibility with the requirements of paragraph 3.1.9.6.

The YF-17 complies with the intent of the requirement.

Discussion

To assure consistency with the requirements of paragraph 3.1.3.3.2, the requirement of paragraph 3.2.1.1.8 should not be limited to AFCS modes, but apply to all non-critical and flight phase essential FCS modes. However, the reference made to compatibility with the requirements of 3.1.9.6 does not provide adequate safeguards relative to disengagement capability for flight phase essential modes.

Compliance with the requirements can be practically demonstrated.

Recommendations

Revise the requirement as follows:

> "Means for disengagement of all non-critical AFCS and MFCS modes shall be provided which are compatible with the requirements of 3.1.9.6. Disengagement capability for flight phase essential FCS modes shall require approval by the procuring agency."

Requirement

3.2.1.1.9 Preflight test controls. Additional controls shall be provided in the cockpit for initiating and controlling the progress of preflight tests, where necessary.

Comparison

The YF-17 preflight BIT controls, two lighted pushbutton switches, labeled BIT 1 and BIT 2, are located on the CAS control panel in the left console as shown in Figure 1 (3.2.1.1.7). Their operation is described in detail under Comparison for paragraph 3.1.3.9.1.2 Maintenance BIT.

The YF-17 complies with the requirement.

Discussion

The requirement is valid and allows sufficient latitude in developing the preflight test concept.

Recommendation

Retain the requirement as stated.

Requirement

3.2.1.2 Pilot controls for rotary-wing aircraft.

Not applicable.

3.2.1.2.1 Interconnection of collective pitch control and throttle(s) for helicopters powered by reciprocating engine(s).

Not applicable.

3.2.1.2.2 Interconnection of collective pitch control and engine power controls for helicopter powered by turbine engine(s).

Not applicable.

3.2.1.2.3 Alternate or unconventional controls.

Not applicable.

3.2.1.3 Pilot controls for STOL aircraft.

Not applicable.

Requirement

3.2.1.4 Pilot displays

3.2.1.4.1 FCS annunciation. The FCS control panel or associated panels shall provide means to display:

a. AFCS engaged.

b. Mode engaged.

c. That automatic mode switching has occurred - if required.

d. Preselected values for selectable mode parameters.

Comparison

FCS annunciation in the context of the requirement, is provided through various means on the YF-17. Engagement of the CAS axes and related functions (pitch followup trim, roll-to-yaw interconnect, direct electrical ailerons) is indicated by the absence of the associated caution lights on the annunciator panel. Automatic mode switching occurs only with the flaps: with the flaps selected DOWN or FLIGHT TEST, the flaps revert to DADC control whenever the flap placard speed (dynamic pressure or mach number) is reached; with the flaps selected UP, DADC control is initiated upon reaching a particular angle of attack. In either case, the mode transfer is indicated by the flap indicator switching to the AUTO position.

CAS gains can be varied in flight by three-position knobs, with positions indicated as ALT1, NORMAL, ALT2, located on the CAS flight test panel. The gain values are preadjusted on the ground, and the physical position of the knobs is the only indication to the pilot.

The YF-17 is in compliance with the intent of the requirement.

Discussion

The requirement is valid and allows sufficient latitude in implementation.

Recommendation

Retain the requirement as stated.

Requirement

3.2.1.4.2 FCS warning and status annunciation. FCS warning and status annunciation shall be provided in the cockpit. Annunciation shall be designed to clearly indicate the associated degree of urgency.

a. First degree - Immediate action required (warning may be audible).

b. Second degree - Caution, action may be required.

c. Third degree - Informational, no immediate action required.

A panel comprising means for displaying first degree annunciations shall be located within the normal eye scan range of the comm[illegible]d pilot. A first degree warning or status indication, which applies [illegible] to a particular mode or phase of flight, shall be inhibited or des[illegible] [illegible]learly indicate a lesser degree of urgency for all other m[illegible] [illegible]s of flight.

Comparison

The YF-17 annunciator panel is interlinked with the master caution panel and displays twelve CAS failure conditions as discussed und[illegible] paragraph 3.2.1.4.2.2. All CAS failures automatically trigger the master caution light. The YF-17 CAS has no first degree, only second degree of u[illegible]ency. The panel is located on the center pedestal and, in addition to CAS fa[illegible]res, also displays failures of the hydraulic systems and the electrical [illegible]er generating system.

The YF-17 complies with the requirement.

Discussion

One aspect of the requirement, 'to clearly indicate the associate degree of urgency', may be difficult to meet on current vintage or less sophisticated future aircraft. Cockpit space is always at a premium, and human factors considerations may favor a simple annunciation scheme over an expansive one. However, the requirement can be easily satisfied with smart (CRT type) displays.

Recommendation

Revise the requirement as follows:

Change the second sentence to read,

"Annunciation shall indicate the associated degree of urgency, consistent with overall cockpit design objectives and human factors considerations."

Requirement

3.2.1.4.2.1 Preflight test (BIT) status annunciation. If BIT is used, this display shall:

a. Indicate the progress of the preflight test.

b. Instruct the crew to provide required manual inputs

c. Indicate lack of system readiness when failure conditions are detected.

Comparison

The preflight test (BIT) display in the YF-17 cockpit consists of two illuminated buttons on the CAS pilot control assembly (left console). The BIT sequence is as follows:

1. BIT is initiated by depressing BIT 1 switch. This will cause the yellow BIT-in-progress light on the BIT 1 switch to come on.

2. After about 90 seconds, the BIT 2 light will come on. At this time, the operator must perform the following functions:

   a) Select flaps emergency up mode.

   b) Engage yaw, roll, and pitch CAS by engaging the three lever lock switches on the CAS pilot control assembly.

   c) Depress the BIT 2 switch.

3. Depressing the BIT 2 switch will restart the BIT test sequence. The BIT 2 light will go out, the annunciator lights associated with CAS will be extinguished, and each control surface will complete two full cycles.

4. At the conclusion of a successful BIT, the green "GO" light on the BIT 1 switch will come on.

5. The BIT test is completed by depressing the BIT 1 switch again. This will deactiviate BIT and extinguish all BIT lights.

6. The pilot's attention is not required for BIT except for the operations performed in Step 2.

7. Should the BIT detect a failure, the red "NO GO" light on the BIT 1 switch will come on. This signifies that the control system is not ready to fly and maintenance should be consulted.

The YF-17 complies with this requirement.

Discussion

The requirement is good and can be practically demonstrated. It is considered suitable for future military aircraft.

Recommendation

Retain the requirement as stated.

Requirement

3.2.1.4.2.2 Failure status. Failure warnings shall be displayed to allow the crew to assess the operable status of redundant or monitored flight control systems. Automatic disengagement of an AFCS mode shall be indicated by an appropriate warning display. Manual disengagement by the crew shall not result in warning annunciation.

Comparison

Twelve annunciator panel lights are used to indicate the status of the YF-17 flight control system. Figure 1 (3.2.1.4.2.2) lists control subsystem and component failures, and the corresponding annunciator panel lights that light up to indicate these failures.

The YF-17 has no AFCS modes, hence the last two sentences of the requirement are not applicable to the YF-17.

Discussion

The requirement is valid, and compliance can be practically demonstrated.

The last sentence of the requirement is interpreted to apply to AFCS disengagement only, as warning annunciation in case of manual disengagement of a flight phase essential MFCS mode is considered desirable.

Recommendation

Clarify the requirement as follows:

Change the last sentence to read,

"Manual disengagement of an AFCS mode by the crew..."

Subsystem or Component Failure	Annunciator Panel Lights											
	Pitch CAS	Trim Follow-up	Roll CAS	L Aileron	R Aileron	Yaw CAS	L Rudder	R Rudder	Nominal Gains	ARI	Flaps	Air Data Computer
Pitch CAS	X	X										
Follow-up Actuator		X										
L. Pitch CAS Actuator	X	X										
R. Pitch CAS Actuator	X	X										
Roll CAS			X									
Left DEL				X								
Right DEL					X							
L. Aileron CAS Actuator				X								
R. Aileron CAS Actuator					X							
Yaw SAS						X						
Left ARI				X						X		
Right ARI					X					X		
Left SRI										X		
Right SRI										X		
Backup ARI SRI										X		
L. Rudder SAS Actuator							X					
R. Rudder SAS Actuator								X				
Pitch Rate Gyro	X	X										
Normal Accelerometer	X	X										
Roll Stick Left LVDT			X	X						X		
Roll Stick Right LVDT			X		X					X		
Roll Rate Gyro			X			X						
Yaw Rate Gyro						X						
Lateral Accelerometer						X						
DADC CAS Logic									X			
DADC Flaps Logic											X	
DADC ARI SRI Logic										X		
Sensors						X			X	X		X
Pressure Transducers												
Flap Controls											X	
Pitch CAS Power Supply	X	X										
Maneuvering Power Supply				X			X			X	X	
Roll/Yaw Power Supply			X		X	X		X		X		
DADC Power Supply									X		X	X

Figure 1(3.2.1.4.2.2) Failure Status

Requirement

3.2.1.4.2.3 Control authority annunciation. If available manual control authority can be reduced below the level required for maneuver control by a function such as automatic trim or stability augmentation, pilot displays shall be provided to indicate available control authority for essential and flight phase essential FCS. Warning shall be provided if remaining manual control becomes critical.

Comparison

The high performance pitch CAS (secondary) actuator on the YF-17 has very limited authority (± 3 deg) and fails to neutral; consequently, it has no effect on available manual control authority. The electromechanical CAS followup (series trim) actuator has -6 deg (trailing edge up) and +3 deg (training edge down) authority and retains its last position in case of a failure. If the pitch CAS or the follow up actuator fails under sustained high positive load factor maneuvering conditions, the available manual control authority in the nose down direction is severely reduced as shown in Figures 1 (3.2.1.4.2.3) and 2 (3.2.1.4.2.3). The remaining nose down authority is adequate to recover from the maneuver, and the pitch emergency trim on the CAS control panel may be employed to restore full manual control authority. The pilot is warned of the failure occurrence by the annunciator panel and becomes fully aware of the impaired control authority by the unusual stick force and stick position required to resume trimmed flight.

The YF-17 is in partial compliance with the requirement.

Discussion

The requirement is valid, and compliance with it can be practically demonstrated. The requirement should also include manual series trim, as a failure of such trim function can also reduce available control authority.

Recommendation

Revise the requirement as follows:

> "... such as automatic trim or stability augmentation or manual series trim, pilot displays ..."

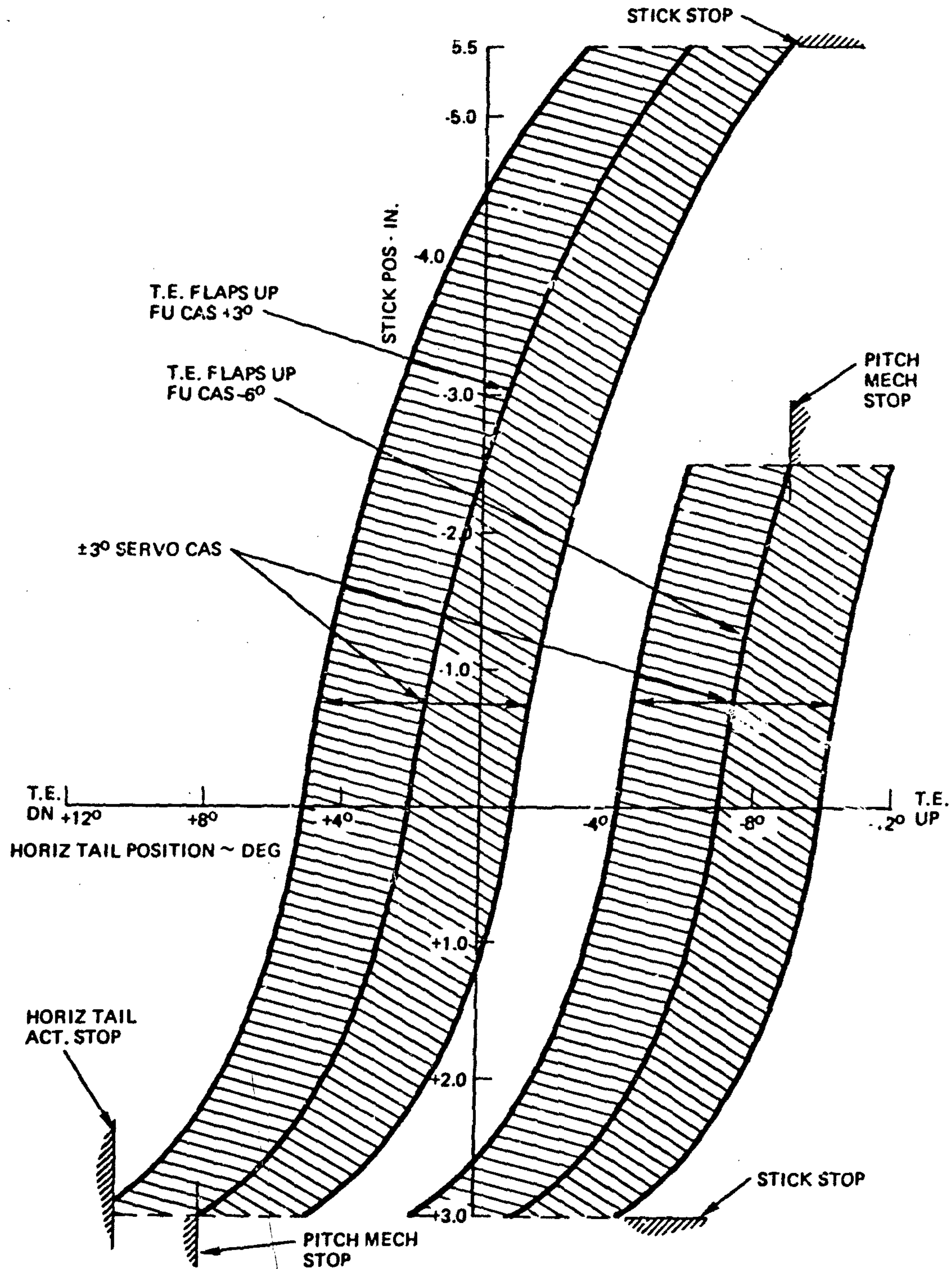

Figure 1 (3.2.1.4.2.3). Pitch Stick Position Vs. Horizontal Tail Position With Servo CAS Authority (T.E. Flaps Up).

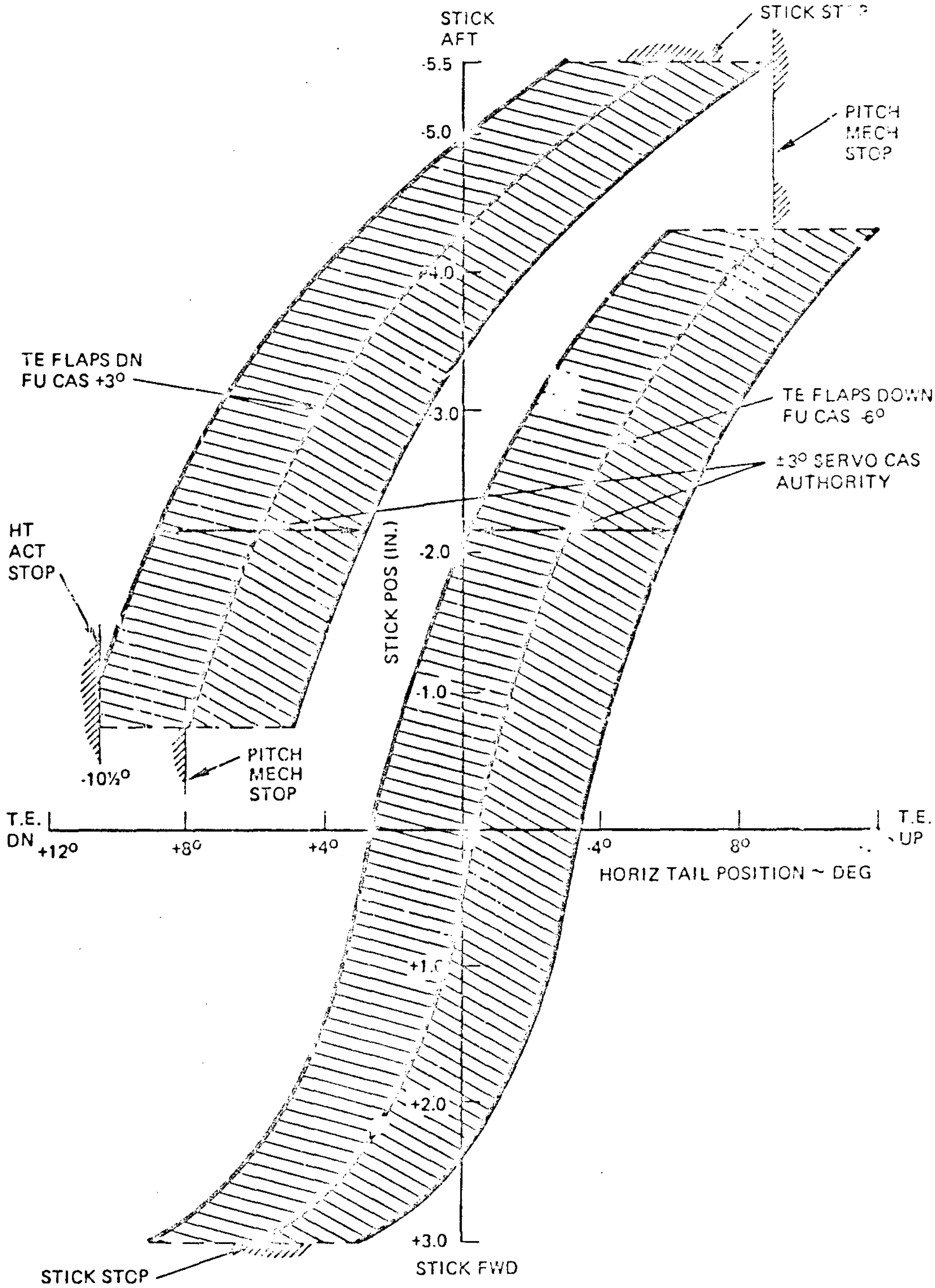

Figure 2 (3.2.1.4.2.3. Pitch Stick Position Vs. Horizontal Tail Position With Servo CAS Authority (T.E. Flaps Down).

Requirement

3.2.1.4.7 Lift and drag device position indicators. Indicators shall be provided in the cockpit to indicate to the pilot(s) the position of each lift or drag device having a separate control. They shall also indicate the correct takeoff, enroute, approach, and landing positions; and, if any extension of the lift and drag devices beyond the landing position is possible, the indicators shall be marked to identify the range of extension. In addition, an indication of unsymmetrical operation or other malfunction in the lift or drag device systems shall be provided whenever necessary to enable the pilot(s) to prevent or counteract an unsafe flight or ground condition.

Comparison

Two flap position indicators, both located on the instrument panel as shown in Figure 2 (3.2.1.1.7), are provided on the YF-17. The standard window-type flap indicator provides UP, DOWN, and AUTO indication; the last indication signifies that the flaps are under the control of the digital air data computer. This flap indicator shows a barber pole if the flaps are in the intermediate position whenever manually selected UP or DOWN or through the flight test switches or have failed. The flight test dial indicator shows the actual position in degrees for both the leading-edge and the trailing-edge flaps, as in this mode the flaps can be controlled independently from one another.

No indicator is provided for speedbrake as its position can be visually verified.

The YF-17 is in partial compliance with the requirement.

Discussion

The requirement is valid relative to lift device (flaps) position and failure indication. It is considered too stringent relative to drag device (speedbrake) position indication. Speedbrake indication usually is not provided as its aerodynamic effect can easily be identified by the pilot. It should not be required unless improper positioning or an unsymmetrical condition cannot be visually ascertained and can result in a potentially unsafe condition, such as open speedbrake during takeoff. Allowing more latitude in this regard is desirable.

Recommendations

Revise the requirement as follows:

Remove "or drag" from the first two sentences.

Insert the following sentence after the second sentence,

"Position indicators for drag devices shall be provided when required to prevent an unsafe condition due to improper positioning."

Retain the last sentence as stated.

Requirement

3.2.1.4.4 Trim indicators. Suitable indicators shall be provided to:

a. Indicate the position and the range of travel of each trim device.

b. Indicate the direction of the control movement relative to the airplane motion.

c. Indicate the position of the trim device with respect to the range of adjustment. (Trim devices such as the magnetic brake used in helicopters to instantaneously relieve pilot's control forces by changing the feel force reference to zero at the control position held by the pilot at the time the trim switch is activated shall not require separate trim indicator.)

d. Provide pilot warning of trim failures which could result in exceeding the State III requirements of 3.1.3.3.4.

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. In aircraft requiring quick takeoff capability or certain single pilot aircraft, which use a single trim setting for all takeoff conditions, a trim for takeoff light shall be provided.

Comparison

The YF-17 does not have indicators to show the position and the range of travel of the trim devices, except that the rudder trim knob on the CAS control panel provides information on the position of the rudder trim device with respect to the range of adjustment. Detailed description of the YF-17 trim functions and controls is given under Comparison for paragraph 3.1.3.5, Trim controls. As indicated in the description, all trim devices have either slow rate or a limited range, and no trim failure would result in exceeding the state III requirements of 3.1.3.3.4, Failure Transients. Takeoff trim light indication is provided for the pitch trim functions.

The YF-17 is in partial compliance with the requirement.

Discussion

The requirement is too stringent in that it mandates trim indicators for all trim functions, whether each such indicator does or does not provide useful information to the pilot. The need for an indicator should be based on this criterion, and the requirement should be revised to allow such latitude.

The remainder of the requirement relative to trim failures (item (d)) and takeoff trim considerations is reasonable.

Recommendation

Revise the requirement as follows:

"Suitable trim indicators shall be provided for all trim functions where such indication is necessary to assist the pilot in the effective and safe utilization of the aircraft. These indicators shall:

a. Indicate the position and the range . . ."

Requirement

3.2.1.4.5 Control surface position indication. Indicators shall be provided in the cockpit for all control surfaces whose positions are indicative of potential flying qualities below Level 3, when the cockpit controls do not provide a positive indication of long term or steady state control surface position, or where the effect of control surface positioning is not readily detectable by other means.

Comparison

Flight test flap position dial indicator is provided on the YF-17 to allow pilot monitoring of selected flap positions and thus to avoid undesirable combinations of flap positions and maneuvers, even though no degradation of flying qualities below Level 3 could occur.

In case of failure of the pitch CAS series trim (followup) actuator, caution light indication is provided and, if the failure occurs during maneuvering when the actuator can be well away from its neutral, stick position for trimmed flight provides the pilot with a positive cue. The pitch emergency trim function allows manual repositioning of the failed actuator.

The YF-17 is in compliance with the requirement.

Discussion

The requirement is valid and allows a desirable latitude in implementation. Compliance can be demonstrated by failure effects analysis.

Recommendation

Retain the requirement as stated.

Requirement

3.2.2 Sensors. Sensors shall be installed in locations which allow adequate sensing of the desired aircraft and flight control system parameters, and which minimize exposure to conditions which could produce failures or undesired output signals.

Comparison

Sensors used in the YF-17 flight control system provide input and feedback signals to the control system, provide signals for gain changing functions, and provide signals that are used for failure detection.

The first group of sensors includes dual pitch rate gyros, dual roll rate gyros, dual yaw rate gyros, dual normal accelerometers, and dual lateral accelerometers. The gyros are located approximately at an antinode of the first fuselage bending mode of their respective axes; the accelerometers approximately at the bending mode node and forward of the airplane c.g. Figures 1 (3.2.2) and 2 (3.2.2) show the YF-17 bending mode shapes with the locations of the accelerometers and rate gyros indicated. Also included inthe first group are a dual pitch stick position LVDT, two dual roll stick position LVDTs, and a dual LVDT on each aileron (used in the roll-to-yaw interconnect). The backup roll-to-yaw interconnect system receives signals from dual LVDTs on both the right and left trailing-edge flaps, and from dual LVDTs on both right and left horizontal tails. Angle-of-attack signals are derived from vanes located on both sides of the forward fuselage with signal processing occurring in the DADC (used in Yaw SAS and in maneuvering flaps control). Mach number data, processed by the DADC, is also used in the maneuvering flaps control system.

Gain changing signals are supplied by the DADC and include altitude, Mach number, and compressible dynamic pressure signals.

For failure detection purposes, signals are taken from right and left pitch CAS actuator LVDTs, a dual pitch follow-up actuator LVDT, right and left aileron CAS actuator LVDTs, and right and left rudder SAS actuator LVDTs.

All of the sensors installed in the YF-17 are located such as to minimize undesired output signals that might occur due to structural bending modes or structural deformation of control surfaces, and at the same time provide accessibility. The specifications for the sensors were drawn up with consideration given to performance, physical characteristics, reliability, maintainability, and environmental conditions.

The YF-17 complies with the requirement as evidenced by ground test and flight test results.

Discussion

The requirement is valid, and compliance with it is essential for proper operation of electrical flight control systems. The installation of position sensors is relatively straightforward, major considerations being rigging tolerances and accessibility for inspection and maintenance. Acceleration sensors must be installed so as to minimize pickup from all except the desired rigid body accelerations, assuming the airplane has no mode control system. The first body bending mode node is generally selected for the accelerometer location. Due to higher order mode shapes no fixed position will be completely free of unwanted signals and some compromise may be necessary. For large flexible airplanes, the problem is more severe than for relatively rigid fighter airplanes. In locating rate gyros, essentially the opposite situation exists. The desired location is a point at which rotation due to body flexibility is a minimum. This will generally be at the first body bending mode antinode. Again, the solution of the problem may involve compromises, particularly in large flexible airplanes. In fighters, the higher order modes are at relatively high frequencies and are thus less important in sensor location.

Recommendation

Revise the requirement as follows:

> "Sensors shall be installed in locations which allow adequate sensing of the desired aircraft and flight control system parameters, which minimize exposure to conditions which could produce failures or undesired output signals, and which provide for ease of maintenance and inspection."

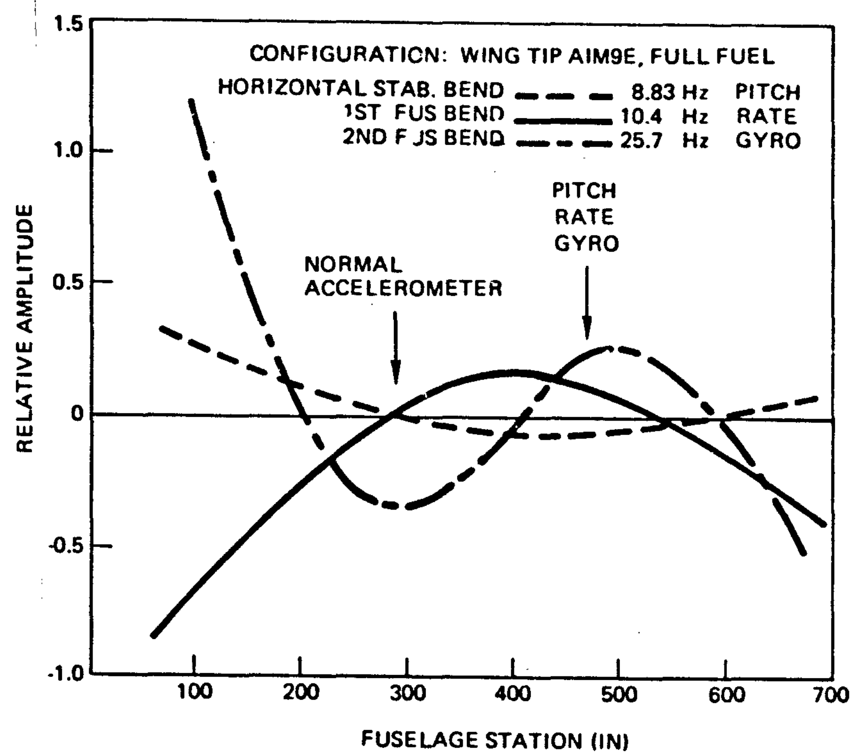

Figure 1 (3.2.2). Fuselage Vertical Bending Mode Shapes and Sensor Locations.

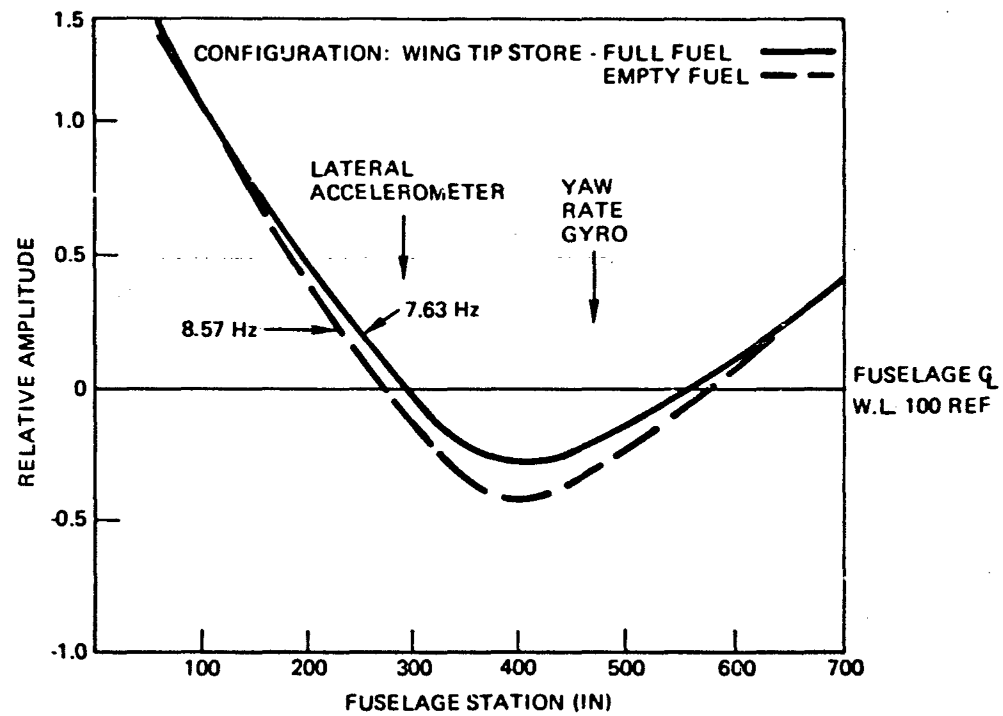

Figure 2 (3.2.2). Fuselage Lateral Bending Mode Shapes and Sensor Locations.

Requirement

3.2.3 Signal transmission

3.2.3.1 General requirements

3.2.3.1.1 Control element routing. Within the restrictions and requirements contained elsewhere in this specification, all portions of signal transmission subsystems, including cables, push-pull rods, torque tubes, and electrical wiring shall be routed through the airplane in the most direct manner over the shortest practical distances between points being connected. Protection from use as steps or handholds shall be provided.

Comparison

The flight control systems are arranged and routed in compliance with the foregoing requirements. Shrouds and flame shields around control rods in the engine bay serve also to protect against handholds. A phenolic sheet enclosure is employed around control cables in the forward equipment bay to protect cables during maintenance activity in this area.

Discussion

These requirement are in accordance with accepted design standards.

Recommendations

Retain the requirement as stated.

Requirement

3.2.3.1.2 System separation, protection and clearance. Where redundant cable, pushrod, or electrical wiring are provided, they shall be separated as required to meet the invulnerability requirements of 3.1.9. Advantage shall be taken of the shielding afforded by heavy structural members, existing armor plate, or other equipment for the protection of important components of the control systems. Clearance between flight control system components and structure or other components shall be provided as necessary to insure that no probable combination of temperature effects, air loads, structural deflections, vibrations, buildup of manufacturing tolerances, or wear, can cause binding or jamming of any portion of the control system. In locally congested areas only, the following minimum clearances may be used after all adverse effects are accounted for:

a. 1/8-inch between static elements except those within an LRU where closer clearances can be maintained or where contact cannot be detrimental.

b. 1/8-inch between elements which move in relation to each other and which are connected to or are guided by the same structural or equipment element(s) except those within an LRU where closer clearances can be maintained or where contact cannot be detrimental.

c. 1/4-inch between elements which move in relation to each other and which are connected to or are guided by different structural or equipment elements.

d. 1/2-inch between elements and aircraft structure and equipment to which the elements are not attached.

Comparison

Redundant control systems on the YF-17 for pitch and roll control are separated to provide maximum invulnerability. Advantage is taken of shielding afforded by the nose gear, fuel tanks, wing structure, and engines. The controls are routed in a symmetrica' manner on opposite sides of the fuselage.

Cables and control rods at some points do not conform with recommended clearances but are deemed acceptable for a prototype aircraft.

The YF-17 is in partial compliance with this requirement.

Discussion

Requirements for system separation are consistent with standard design objectives and are suitably defined for prototype design. Specific design requirements for production aircraft which evolve from prototype designs often conflict with other design requirements. For example, providing 1/2 inch clearance between control rods and edges of cutouts in fuselage frames may not be practical in some areas because of the size of the cutout required and the resulting structural weight penalty. However, in such cases, a deviation sould be required thus insuring that the reduced clearance is acceptable. The minimum clearances listed provide a baseline for evaluation of clearances and should be retained as recommended minimums.

The requirement is valid and, in general, the stringency can be justified for future military aircraft. In some instances it may be somewhat too stringent requiring deviations. However, it is not recommended that changes in the requirement be made. The requirement can be practically demonstrated in most parts.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.1.3 Fouling prevention. All elements of the flight control system shall be designed and suitably protected to resist jamming by foreign objects.

Comparison

The YF-17 airplane is compliant with this requirement by the standards applied to all previous and current aircraft with mechanical control systems. Insofar as a single-point jam in the pitch or rudder control could prevent mechanical control movement and additionally prevent control through the electrical control augmentation system, the system cannot be described as operable with a single-point jam condition.

Specific design actions taken for compliance with this requirement are itemized as follows:

Control Element	Design Action
Control Stick	Base of stick is completely sealed by nylon fabric boot with plastic and aluminum sheet close-out panels.
Control mechanism under cockpit floor and in nose wheel bay	Close-out cover encloses mechanism.
Control cables	Enclosed in a plastic shroud in the equipment bay, and in plastic tubes in the center fuselage.
Pitch and roll control mixer mechanism in center fuselage	Bay is completely sealed to foreign objects. Flame-choke tubes extend aft around cables and rods that exit the bay aft into the engine bay.
Control rods for pitch and roll control	Controls open to engine bay environment are made of CRES steel.
Horizontal tail actuators	Located in an isolated compartment sealed against foreign objects and fire.
Interconnect linkage between horizontal tail actuators	Enclosed by fuselage frames and fire shield to protect against fire and foreign objects.
Rudder controls in the engine bay area	Flame shields are employed at the fire wall between engines and in the interface between the engine bay and vertical stabilizer.
Overload relief springs	An overload relief spring is incorporated in the interconnect linkage between surface actuators to permit operation of one rudder with one rudder jammed.

Discussion

The requirements for fouling prevention should remain qualified with the terms "suitable" and "resist" with compliance subject to judgment and analysis. It is considered suitable for present and future military aircraft. It must be recognized that a control element without an independent backup would require more protection than the same one with independent backup. The impact on cost, weight, and maintenance must also be considered in the degree of fouling prevention features incorporated in a design.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.1.4 Rigging provisions. The number of rigging positions shall be kept to a practical minimum. They shall be readily accessible and located where space for the rigging function is available. Installed rigging pins shall be highly visible from the ground or include streamers as specified in 3.1.10.4. Control surface actuator outputs shall not be rig pinned.

Comparison

The YF-17 is not compliant with this requirement. At one location a hydraulic line prevented the use of an otherwise readily accessible rig pin. Rig pins are not applied to lock control surfaces or surface actuator outputs. The conditions do exist, however, where application of hydraulic power or removal of hydraulic power can result in damage to control linkage if rig pins are installed in the control follow-up linkage for the trailing-edge flap control system or in the T.E. flap-to-horizontal tail interconnect cable system. Installation of a spring loaded collapsible link in lieu of a solid link in each system would eliminate this hazard.

Complete compliance with this requirement would have costs not justified for a prototype flight test aircraft.

Discussion

Requirements for rigging provisions are deemed to be practical minimum requirements for present and future military aircraft. It should be clarified as a requirement that rig pins shall not be employed where application of power or removal of power will result in damage to control linkage or structure with rig pins installed.

Recommendation

Revise the requirement as follows:

Change the last sentence to read,

> "Control surfaces or control linkage shall not be rig pinned where application of power or removal of power to the control surface actuator could cause a structural failure when rig pins are installed."

Requirement

3.2.3.2 Mechanical signal transmission

3.2.3.2.1 Load capability. Elements of mechanical signal transmission systems subjected to loads generated by the pilot(s) shall be capable of withstanding the loads due to pilot's input limits specified in MIL-A-8865, Section 3.7, Flight Control System Loads, taken as limit loads, unless higher loads can be imposed such as by a powered actuation system or loads resulting from aerodynamic forces. Where higher loads are thusly imposed, they shall be met with the same margins and circumstances as specified in MIL-A-8865.

Comparison

The YF-17 complies with this requirement. Mechanical signal transmission system elements have been designed to the criteria specified in MIL-A-008865A Paragraph 3.7. The pilot-applied loads presented in Table III have been used to establish strength requirements.

Discussion

The pilot-applied loads as presented in Table III of MIL-A-008865A are considered practical for present and future military aircraft and do not present a design problem.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.2.2 Strength to clear or override jammed hydraulic valves. All mechanical elements which transmit input commands to metering valves of hydraulic servoactuators shall have strength to withstand higher loads, above those for normal valve stroking, required to clear foreign material that may occur in projected usage.

Comparison

The YF-17 is in compliance with the requirement. The input linkages on all actuators are designed to much higher loads (typically 200 pounds at the valve) that can be applied to the actuator by the interfacing control elements to clear foreign material in the main metering valve. The force transmitting capability of the mechanical elements which transmit symmetrical or differential input commands to the metering valves of the horizontal tail actuator is limited by overload springs to a minimum of 53 pounds at the valve with no overload spring deflection. As the spring is deflected, the force at the valve increases to approximately 150 pounds. In the case of the aileron actuators, which are operated entirely by secondary (CAS) actuator inputs, the overtravel bungee allows a minimum of 32 pound force application to the main metering valve. As the bungee is deflected by the CAS actuator, the force at the valve increases to approximately 38 pounds. These forces are significantly higher than the approximately 13 pounds maximum force that was required during chip shearing tests conducted by Northrop on F-5/T-38 main metering valves.

Discussion

This is a valid, necessary requirement which can be practically demonstrated. The actual force required to clear foreign material can vary according to how large a contaminant can get into a valve; so for large valves with large flow passages, higher forces can be expected. The existing general wording of the requirement covers this. The thing to be careful of is that arbitrary, high forces may be designed to which are not justified by valve size. For example, a force of 200 pounds has sometimes been considered and this, if not needed, would make actuator linkage bigger and heavier than necessary.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.2.3 Power control override provisions. Provisions shall be made to permit the pilot(s) to clear or override metering valve jams unless there is sufficient aerodynamic control power from the remaining operative surfaces to override control moments generated by the jammed surface in its most adverse position.

Comparison

The YF-17 complies with the requirement as described under comparison for 3.2.3.2.2. No other override provisions are incorporated. In the case of the aileron, which is electrically controlled, the secondary actuator provides the means to clear metering valve jams. Should the aileron valve jam fail to clear, the surface would be hardover and would have to be overriden by aerodynamic control power from the other aileron surface and differential deflection of the horizontal tail surfaces.

Discussion

Valve jams or high forces can be expected to occur in the life of an airplane and should certainly be designed for. This requirements is good and can be practically demonstrated. The part of the requirement dealing with the overriding of control moments generated by a jammed surface with aerodynamic control power cannot be practically demonstrated except by simulation.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.2.4 Control cable installations. Control cable installations shall be designed to accommodate easy servicing and rigging, and the number of adjustments required shall be kept to the practical minimum.

Comparison

The control cable installations on the YF-17 are designed with emphasis on the most direct routing with a minimum number of breakpoints and avoidance of conflict with access to other equipment. The use of one turnbuckle adjustment for each cable represents a practical minimum number of adjustments for each system.

Most turnbuckles on the YF-17 were not very easily accessible due to being located in narrow bays, but the installation is considered satisfactory for a prototype aircraft. The ease of access to turnbuckles is further compromised by the need to remove guide tubes that enclose each turnbuckle for safety. Although the safety requirement is judged to justify the compromises with maintenance access, the result is that the YF-17 only partially complies with this requirement.

Discussion

Full compliance of the YF-17 with this requirement would have required a detail design effort beyond that deemed necessary for a prototype aircraft. However, the requirement is valid, the stringency is justified for future military aircraft, and it can be practically demonstrated in a qualitative sense.

Requirements, as limited to qualitative terms represent suitable design objectives. The lack of compliance criteria is acceptable with current procurement practices where value judgments affecting compliance are programmed to be made during tests on preproduction aircraft.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.2.4.1 Control cable. Cable used for the actuation of flight controls shall be the most suitable of the following types for each application. Use of carbon steel or other type cable not listed below requires procuring activity approval.

a. Flexible nylon-coated corrosion-resisting steel wire rope in accordance with MIL-W-83420.

b. Preformed flexible corrosion-resisting steel wire rope in accordance with MIL-W-83420.

c. Preformed flexible corrosion-resisting nonmagnetic steel cable in accordance with MIL-C-18375.

Comparison

Preformed flexible corrosion-resisting steel wire rope in accordance with MIL-W-83420 has been used on the YF-17. The aircraft thus complies with this requirement.

Discussion

The nonjacketed corrosion-resisting steel wire rope cable has been used with satisfactory results. Jacketed wire rope cable would be used on production versions of the airplane for wear characteristics. Northrop does not use the type cable listed under c. (Preformed flexible corrosion-resisting nonmagnetic steel cable in accordance with MIL-C-18375.) It is questionable if there is sufficient usage of this cable in the flight control system to justify its being listed. If so the specification for the cable should be included in MIL-W-83420.

Recommendation

Revise the requirement as follows:

Delete c. Preformed flexible corrosion-resisting nonmagnetic steel cable in accordance with MIL-C-18375.

Change the description of "a" and "b" type cable to be in accordance with definition in MIL-W-83420,

a. Jacketed corrosion-resistant steel flexible wire rope in accordance with MIL-W-83420.

b. Nonjacketed corrosion resistant steel flexible wire rope in accordance with MIL-W-83420.

Requirement

3.2.3.2.4.2 Cable size. Cable shall be sized to meet the load requirements of the system with ample safety factors to compensate for wear and deterioration where pulleys, fairleads, etc., are encountered. Cable size shall also be adequate in regard to permissible cable stretch, pulley friction values, and other variables which affect system performance. Where substantial loads are carried, cables shall be sized so that limit loads do not exceed 67 percent of the rated breaking strength of the cable and do not exceed the maximum cable limit loads allowed for their pulleys.

Comparison

Dual cable controls on the YF-17 for both pitch and roll systems required special control of pulley friction valves. Corrosion resistant steel cables of 1/16 inch diameter with rig loads in pitch and roll of 27 pounds and 15 pounds respectively, provide control stick breakout forces at an acceptable low level.

Load relief bungees are installed in the pitch and roll (rolling tail) systems to protect mechanisms down stream against excessive loads due to high mechanical advantage. The bungees incidentally, then, will insure that the cable loads do not exceed 67 percent of rated braking strength. The YF-17 thus is in compliance with this requirement.

Safety factors to compensate for wear and deterioration of cables have been given low priority consideration because of the limited life requirement for the YF-17. Field experience on T-38's and a variety of other aircraft indicates that 1/16 inch diameter unjacketed cable would be unacceptable for life requirements on production airplanes because of the effects of abrasion on cables and contamination in pulley areas. The application of nylon jacketed corrosion resistant steel cables in accordance with MIL-F-83420 would provide protection against abrasion and contamination and provide the safety factors required. Compliance with life requirements would remain to be demonstrated by test.

Discussion

The requirement is considered to be valid and the stringency justified for future military aircraft. It can be practically demonstrated partly qualitatively and partly quantitatively.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.2.4.3 Cable attachments. The minimum practical number of interconnections shall be used which allow all cable segments to be connected manually. Cable disconnects shall be located and designed so that it is physically impossible to misconnect 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 or interfere with adjacent structure or equipment or on each other and will not snag on cables, wires, or tubing. Corrosion-resistant steel MS swage-type cable fittings in accordance with MIL-T-781, swaged to form cable assemblies in accordance with MIL-T-6117, shall be used wherever possible. Thimble ends in accordance with MIL-T-5677, attached to cable by splicing and wrapping in accordance with MIL-S-5676, may be used in applications where additional joints are needed to prevent bending fatigue failures. Turnbuckles used in flight control cable systems shall be in accordance with MIL-T-8878. Turnbuckle and fittings shall be designed so that they are not subject to bending forces which can cause fatigue failures. Turnbuckle terminals shall not have more than three threads exposed at either end. All turnbuckle assemblies shall be properly safetied in accordance with MS33736.

3.2.3.2.4.4 Cable routing. Control cables shall be arranged in parallel runs, and be accessible to inspection for their entire length. Cable runs located in aeroelastic structure, such as aircraft wings, shall be routed so as to minimize any induced control action, caused by structural flexure. Spacing between adjacent cables shall prevent cables, turnbuckles, and fittings from chafing during all operating conditions including vibration. Slack return cables shall not snag on each other or any other equipment or structure when the controlling cables are loaded to design limit loads at the adverse extremes of temperature, structural deflection, and other operating conditions. Cables shall not be subjected to critical bends at the junction with cable terminals or other attaching points such as on drums and sectors.

Comparison

Cable fittings and cable routing on the YF-17 are compliant with specification requirements except for the requirement for access to inspection for the entire cable length. All control cables are separately routed through a 1/2 inch diameter plastic conduit approximately 33 inches long in the center fuselage where fuel tanks and wing structure make internal access impractical. The use of nylon jacketed cable in this area would make the system compliant because inspection would not be required within the length of the conduit.

Discussion

Inclusion of reference to thimble ends seems to be inconsistent with reference to flight control systems because of rare usage. It should be deleted.

Quick disconnect fittings, such as the Mark II Model D-7 manufactured by Pacific Scientific Co., should be defined as a military standard and specified as a required type of turnbarrel to be used in those cases where cables must be disconnected to provide access to special equipment or for special maintenance.

The disconnect functions as both a turnbarrel and a quick disconnect. The cable may be quickly disconnected and reconnected without disturbance to rig load adjustments. This hardware has a long history of trouble-free usage in T-38 and F-5 series aircraft with highly favorable mention by maintenance personnel in reference to the time saved by use of this type of fitting.

Recommendation

Revise requirement 3.2.3.2.4.3 as follows:

Delete 5th sentence,

> "Thimble ends in accordance with MIL-T-5677, attached to cable by splicing and wrapping in accordance with MIL-S-6576, may be used in applications where additional joints are needed to prevent bending fatigue failures."

Add the sentence,

> "Qualified quick disconnect type fittings shall be provided on cable assemblies that must be disconnected for access to other equipment or for special maintenance."

Requirement

3.2.3.2.4.5 Cable sheaves. Cable drums, sectors, and pulleys of adequate capacity and diameter for their function and to meet aircraft life requirements shall be provided. They shall be large enough for the cable wrap angle such that the cable strands are not overstressed. The diameter and number of grooves on cable drums, and the radius and angle of control cable sectors shall be adequate for the required cable travel. Overtravel allowance shall not be less than 5 percent of full travel in either direction and at least 10 degrees. When 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. All cable grooves on drums and sectors, machined or die cast, shall have root radii properly sized for the cable size used thereon. Specific approval shall be obtained before using plain pulley in essential applications. Antifriction pulleys used in flight control systems shall be MS standards in accordance with MIL-P-7034, and the design limit load shall not exceed the allowable limit load specified for the applicable standard.

Comparison

Cable drums are not used on the YF-17. The sectors and pulleys used comply with the requirements specified.

Discussion

The requirement is good. The stringency seems justified for future military aircraft. The requirement can be practically demonstrated except for aircraft life requirements.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.2.4.6 Cable and pulley alignment. Fixed-mounted pulleys shall be aligned with their cables within 2 degrees as specified in AFSC Design Handbook DH 2-1, DN 3B1, Subnote 1.13(1), Cable Pull. Where a control cable has an angular motion with respect to the plane of the pulleys, the maximum misalignment resulting from this motion must not exceed 2 degrees, and the cable shall not contact the pulley (or quadrant) flange for the total cable travel.

Comparison

The cables are aligned within 2 degrees of the plane of the pulleys on the YF-17. Northrop uses a maximum misalignment of one degree for design thus allowing one degree for installation.

Discussion

The requirement is good, appears to be justified for future military aircraft, and can be practically demonstrated.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.2.4.7 Pulley-bracket spacers. Loose spacers between pulleys, bearings, and pulley brackets shall not be used.

Comparison

Loose spacers were used between pulleys and pulley-brackets in some places, thus the YF-17 is not in compliance with this requirement. In order to simplify the design because the YF-17 is a prototype flight test airplane, and to improve cable and pulley alignment, spacers were installed between the pulley and pulley-bracket in two different places. Replacing a pulley in the bracket would have been difficult in addition to the possibility of omitting the spacer or installing the spacer in the wrong position.

Discussion

The requirement is good. The stringency is justified for present and future military aircraft.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.2.4.8 Sheave guards. Guards shall be installed at all sheaves (pulleys, sectors, drums, etc.) as necessary 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. All guards shall be supported in a way which precludes binding of the sheave due to relative deflections in the aircraft structure. Additional guards shall be installed on sectors as necessary to ensure retention of the cable end in its attachment under slack cable conditions. 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.

Comparison

There are four sectors in the YF-17 with more than 90° cable wrap when rotated to the extreme position that do not have intermediate guards thus the YF-17 only partially complies with this requirement. There is no valid reason why additional guards were not added to the sectors with more than 90° cable wrap except for complexity of the support and because the YF-17 is a flight test airplane. There has been no adverse effects resulting from the installations. Difficulty has been experienced in controlling the space between the sheave and the guard to prevent the cable from slipping past the guard. This result is mainly due to the use of 1/16 inch diameter cable.

Discussion

The requirement is good but is somewhat too lenient for present and future military aircraft. A change is recommended for completeness.

Recommendation

Revise the requirement as follows:

Add the following between the fourth and fifth sentences,

> "Clearance between the outside diameter of the sheave and the guard shall be dimensionally controlled as required to insure that the cable cannot slip between the outside diameter of the sheave and the guard as a result of manufacturing tolerance buildup and structural deflections."

Requirement

3.2.3.2.4.9 Sheave spacing. In any given cable run, no portion of the cable shall ever pass over more than one sheave.

Comparison

The YF-17 complies with this requirement.

Discussion

The requirement is valid for present and future military aircraft.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.2.4.10 Cable tension. Cable rig loads shall insure positive cable tension in control and return legs of closed-loop cable installations under all operating conditions including airframe deflection and differential expansion and contraction between the cable and airframe structure throughout the designed operating temperature range. The cable return leg may be allowed to go slack when the control leg is loaded above the normal operating load, providing it cannot snag, when the control leg is loaded at any load up to limit load, and that there is no hazardous loss of system performance. Cable tension regulators shall be provided only if positive cable tension cannot be maintained in both legs, with reasonable rigging loads.

3.2.3.2.4.11 Cable tension regulators. When used, tension regulators shall maintain required tension at all times. Integral calibration shall be provided to show proper cable tension without the use of external tensiometers on other equipment.

Comparison

The design of the control system in the YF-17 complies with the foregoing requirements. Cable tension regulators are installed in both the pitch and roll control systems to permit reduced cable tension loads (27 pounds and 15 pounds, respectively) and to reduce cable friction forces. An indicator is incorporated in each regulator to denote proper cable tension for rigging. The regulators will maintain the rig load through a design range of ±56 inches deflection. Cable system rig loads for the rudder control and flap interconnect controls are established at modest levels and do not require tension regulators.

Discussion

It is generally good practice to include tension regulators in the systems of experimental and prototype airplanes. It is very difficult, if not impossible, to analytically determine the structural and thermal characteristics of the airplanes as they affect the control system. Due to space restrictions and equipment locations, the cables can seldom be routed on the neutral axis. Thus they are subject to a wide variety of structural loading conditions as they pass through the airplane. Heat from local areas may expose the system to numerous differing temperatures making it difficult to determine the average temperature of the system. Flight test results may be used to indicate the continued need for the regulators. If not needed, regulators are very easy to remove, whereas to add them to an existing system often requires major redesign.

Recommendation

Revise the requirement as follows:

Add the following to Paragraph 3.2.3.2.4.10,

"On experimental and prototype airplanes, cable tension regulators shall be used in flight control systems where positive cable tension cannot be assured. Flight test results shall be used to determine the continued need for the regulators."

Requirement

3.2.3.2.4.12 Fairleads and rubbing strips. Fairleads shall not cause any angular change greater than 3 degrees in the direction of the cable under all conditions including those due to structural deflections in flight. Fairleads shall be split to permit easy removal unless the size of the hole is sufficient to permit the cable with swage terminals to be threaded through.

3.2.3.2.4.13 Pressure seals. Pressure seals shall meet the compartment sealing requirements with cable installation friction requirements. They shall be designed to preclude jamming the control system.

Comparison

The YF-17 complies with the foregoing requirements.

Discussion

The requirements are good.

Recommendation

Retain the requirements as stated.

Requirement

3.2.3.2.5 Push-pull road installations. Push-pull road installation shall be designed to preclude binding or separating from the mating linkage, and shall permit servicing and rigging.

3.2.3.2.5.1 Push-pull rod assemblies. Push-pull rod assemblies shall be designed and installed such that inadvertent detachment of adjustable terminals is impossible, and such that any change in length due to loosening of the terminals cannot result in an unsafe condition. On any single rod assembly, adjustment shall be possible at one end only. The fixed end of each rod shall be attached to its mating linkage element in a manner which precludes rotation of the installed assembly. The adjustable end shall be of the clevis type or join a clevis type in such a manner that it is also prevented from rotating. When an unsymmetrical rod is used, such as one with a cutaway portion to allow for relative motion of an attached link, the rod end terminals and mating linkage elements shall positively prevent incorrect installation of the rod. Push-pull rods shall have a minimum wall thickness of 0.035 inches and shall be capable of withstanding loads of 1.5 times limit loads in both tension and compression without failure, buckling, or any other form of permanent deformation. All joints shall be made in a manner which precludes loosening and fatigue failure. All closed cavities in rod assemblies installed in unpressurized spaces shall be provided with drain holes adequate to drain ingested water unless cavities are air tight. All push-pull rod terminals shall incorporate antifriction bearings as specified in 3.2.7.2.1.1 or self-lubricating spherical bearings as specified in 3.2.7.2.1.2. All terminals pins shall be retained as specified in 3.2.8.3.2.2. Loose washers or other loose spacers shall not be used to maintain terminal spacing in the connecting linkage.

3.2.3.2.5.2 Levers and bellcranks. Applicable requirements in AFSC Design Handbook DH 1-6; System Safety, Section 3J; Flight Control Systems, Design Note 3J2; Mechanical Flight Controls; Pulleys, Brackets and Bellcranks, and Design Note 3JX; Safety Design Checklist, shall be met. Bearings shall have adequate self-aligning capability if necessary to prevent excessive deflection loads on levers and bellcranks, and, their installations shall be designed for easy replacement so that the parent part may be reused. Levers and bellcranks designed with dual load paths having the two sections positively joined by permanent fasteners, such as rivets, shall be bonded with adhesive.

3.2.3.2.5.3 Push-pull rod supports. Where long sections of push-pull rods are utilized in applications where jamming is not extremely remote, guides shall be installed at intervals to preclude fouling in the event of rod failure.

3.2.3.2.5.4 Push-pull rod clearance. Clearance between push-pull roads, and between rods and aircraft equipment and structure, shall be specified in 3.2.3.1.2 except that it shall also be sufficient to permit removal of adjacent LRU's without disconnecting the rods.

Comparison

The YF-17 is compliant with all of the foregoing requirements. Push-pull rods are all of swaged-end construction which eliminates the use of riveted end fittings. Control rods in the pitch-roll control system are installed through cut-outs in closely spaced frames. The cut-outs serve as guides to preclude fouling in the event of rod failures. All levers and bellcranks are designed for a single load path.

Discussion

Design requirements for installations, assemblies, levers and cranks, and clearances are within the range of good design practice. Requirements of paragraph 3.2.3.2.5.3 for rod supports at intervals to preclude fouling should be modified to allow for judgment as to need and suitability. A critical control path requires more protection from jamming than a redundant or non-critical control path.

Recommendation

Revise the requirement as follows:

Change 3.2.3.2.5.3 to read,

> "Where long sections of push-pull roads are utilized in applications where rod failure is not extremely remote, and where critical to safety of flight, the installation shall be designed and suitably protected to resist jamming or critical damage in the event of rod failure."

Requirement

3.2.3.2.6 Control chain.

Not applicable.

3.2.3.2.7 Push-pull flexible controls.

Not applicable.

Requirement

3.2.3.3 Electrical signal transmission. The following requirements apply to all essential and flight phase essential signal paths. Except for power sources, such systems shall be independent of failure modes associated with any other electrical system. Cross connections between redundant electrical signal paths shall be eliminated, or minimized and electrically isolated. Wire runs and components in redundant control paths shall be physically separated and electrical shielding shall be installed, as necessary, to meet failure immunity and invulnerability requirements. All interconnecting wiring shall be prefabricated, jacketed cable assemblies. The outer jackets shall be identifiable by a unique color or other means. Wiring installation shall be in accordance with MIL-W-5088.

3.2.3.3.1 Electrical flight control (EFC) interconnections. EFC (6.6) wiring in individuals channels shall be routed, isolated and protected to minimize the applicable threats to redundancy. Channel loss due to any foreseeable hazard, not extremely remote, shall be limited to a maximum of a single channel. The adequacy of the separation, isolation and protection attainable in any given location for any given hazard shall be evaluated for each aircraft design. Additional protection shall be provided for the EFC wiring where analysis shows that any single hazardous event, not extremely remote, could cause the loss of more than one EFC channel. Primary structural components shall be used to afford this protection where possible. Where it is approved by the procuring activity to route the EFC wiring through wheel wells or other areas subjected, during flight, to the slipstream or impingement of runway fluids, gravel, etc., the wiring shall be protected by enclosures and routed directly through without unnecessary termination or junctions. Where terminations or junctions to equipment in these areas are required, they shall be protected from such impingements. This shall also be done in areas where a high level of maintenance is likely to be required on other systems and equipment.

Comparison

Other than its power source, the EFC system was designed to be independent of failure modes manifesting in other electrical systems on board the aircraft. Wire runs and components in redundant YF-17 control paths are physically separated, electrically isolated, and electrical shielding is used for signal carrying conductors. No cross connections between redundant electrical signal paths are made. Some of the interconnecting wiring in the YF-17 was not prefabricated but assembled in the aircraft. No unique color or other means is used to identify EFC cables. All EFC interconnect wiring fabrication and installation was performed in accordance with the requirements of MIL-W-5088E.

EFC cabling is routed through the lower center fuselage sections, thereby avoiding wheel well and other hazardous areas where slipstream and/or extraneous matter could adversely affect wire runs. Plastic tape was wrapped about EFC cabling and in some areas near ECS bleed lines nylon convolute tubing was used to insure invulnerability to contamination and wire damage.

The YF-17 is in partial compliance with this requirement.

Discussion

Full compliance of the YF-17 with this requirement would have required detailed fabrication and installation efforts, beyond that deemed necessary or appropriate for a prototype aircraft. However, the requirement is valid, the stringency is justified for future military production aircraft. Compliance can be demonstrated by inspection.

Recommendation

Retain the requirements as stated.

Requirement

3.2.3.3.1.1 Cable assembly design and construction. The outer jacketing for EFC wiring shall not create stresses on the wire and connector terminations and shall not stress the wires in a manner which opens the connector grommet seals. During design of the cable assemblies, particular attention shall be paid to the requirements of the circuits within the cable and adequate EMI and EMP control methods, e.g., shielding, twisting, etc., shall be incorporated into the design. When shielded wires are used provisions shall be made for carrying the shields through the connectors where single point grounding is necessary. A signal return wire shall be provided for each signal level circuit in the cables. All cable assemblies shall be constructed in an area with temperature and humidity controls and positive pressure ventilation and shall be cleaned (all wire cuttings, etc., removed) and inspected after layup and prior to jacketing to assure that no potentially damaging particles have been included, particularly at the entrance to the grommet seal. All cable assemblies shall be constructed, tested and inspected by specially trained and certified personnel. Terminal boards shall not be used in EFC wiring. Splices shall be qualified, permanent-type splices.

Comparison

To avoid outer jacket stresses, the techniques and hardware specifications of MIL-W-5088E for the primary and secondary support of wires, cables and harnesses are employed on the YF-17. Care in fabrication also has contributed to the lack of wire/connector damage due to jacket stress. However, lack of strain relief hardware at some connector terminations has resulted in wire-pin breakage.

Cable assembly design considered the shielding and/or twisting of signal wires to avoid field generation, protection from high EMI field areas, and where adjacent routing could result in interaction between high and low field producing conductors (e.g., adjacent power and signal data wires).

Where single point grounding is used wire shields are carried separately through connectors. Return lines are provided for all signal carrying conductors.

Some cable assemblies were constructed on wiring jigs under environmentally controlled conditions; other interconnection wiring and some splices and connections where fuselage sections are mated were performed on the aircraft under ambient conditions. Fabrication, test inspections were performed by trained and certified personnel. Cleaning and inspection of cable assemblis was performed prior to jacketing to insure absence of extraneous materials from the finished assembly. No terminal boards are used in the EFC wirirg; only insulated permanent splices are used.

The YF-17 is in partial compliance with this requirement.

Discussion

Full compliance of the YF-17 with this requirement would have required detailed fabrication and installation effort beyond that deemed necessary or appropriate for a prototype aircraft. This paragraph adequately defines the requirements for design and construction of EFC cable assemblies. Compliance can be demonstrated by inspection.

The first sentence of paragraph 3.2.3.3.1.1 may be a bit too stringent in that outer jacketing is bound to create some stress on the wire and connector termination though far below a damage inducing threshold.

Recommendation

Revise the requirement as follows:

Change the first sentence to read,

> "The outer jacketing for EFC wiring shall not create excessive stresses on the wire and connector termination which may result in wire/pin damage or open connector grommet seals."

Requirement

3.2.3.3.1.2 Wire terminations. Crimp type wire terminations (spade, lug or connector) shall be used on all EFC cables. Soldered and potted connections shall not be used. With the terminal installed on the wire, the wire shall be visible for inspection at both ends of the crimp barrel. The length of wire visible between the insulation and barrel shall not exceed 1/16 inch.

Comparison

Crimp type wire terminations are used in the fabrication of all EFC interconnect wiring; no solder connections are used. In all cases the wire installed in the crimp barrel is visible at both ends, (generally thru an inspection hole at the wire end) and the length of visible wire between insulation and crimp barrel is less than 1/16 inch. The YF-17 is in full compliance with this requirement.

Discussion

The requirement is valid and can be readily demonstrated by inspection.

Reccmmendation

Retain the requirement as stated.

Requirement

3.2.3.3.1.3 Inspection and replacement. The EFC wiring shall be installed so that it can be inspected for damage and replaced as necessary. The installation shall provide for visual inspection in critical areas such as hazardous environment areas or areas where a high level maintenance is required on system or equipment in close proximity.

Comparison

Flight control system open wire runs and wire harnesses are routed and positioned to facilitate maintenance and inspection through equipment bay and access door entry on the YF-17. Special consideration has been given to ease of inspection and replacement in those areas where equipment proximity and hardware congestion might render maintenance difficult. Where practical, the maintenance and inspection considerations of MIL-W-5088E have been applied. The YF-17 flight control system is in compliance with requirements of Paragraph 3.2.3.3.1.3.

Discussion

This paragraph adequately defines inspection and maintenance requirements for the design and installation of EFC wiring. The requirements are valid for future aircraft procurement and compliance can be demonstrated by inspection.

Recommendation

Retain the requirement as stated.

Requirement

3.2.3.3.2 Multiplexing. Multiplexed signal transmission circuits shall be the digital time-division-multiplexing type utilzing a twisted shielded pair cable as the transmission media for the multiplex bus. The multiplex data bus line and its interface electronics, multiplex terminal unit shall meet MIL-STD-1553.

Comparison

Multiplexed signal transmission is not employed in the YF-17 EFC. However, a digital time-division-multiplexing system was proposed as the major signal communication method for the fire control avionics, and gun/stores management systems on board the F-17 ACF. The data bus, interface circuits, information flow and data formats as proposed would have met requirements of MIL-STD-1553.

Discussion

The requirement is justified for future aircraft procurement because digital time-division-multiplexing techniques are compatible with the trend toward digital mechanization of advanced flight controls and other avionic systems. The requirements of MIL-STD-1553 are well defined and are currently being applied to design of avionics on board F-16 and F-18A fighter aircraft. The use of MIL-STD-1553 for EFC will provide compatible interfaces with associated avionics subsystems. Compliance can be demonstrated by operation in a system functional mockup.

Requirements in the current MIL-STD-1553A are well defined for nonredundant multiplexed signal transmission using a single data bus; and these requirements are adaptable to multiple (redundant) bus configurations. However, operational and interface requirements for redundant multiplex bus systems are not defined in this standard.

If multiplexed signal transmission is to be employed in essential or flight phase essential EFC functions such as digital fly-by-wire controls, then additional requirements need to be developed to cover this type of application. At this time, there is insufficient data based on operational experience with multiplexed digital fly-by-wire flight controls to recommend specific additions or modifications to this specification. In order to formulate such additions or modifications a study should be initiated to investigate advanced developments in digital fly-by-wire flight control, in particular those designs employing multiplexed signal transmission. The purpose of this study would be to develop additional requirements covering the use of redundant multiplex data buses for critical flight control functions, to be included in this paragraph in a future amendment to MIL-F-9490D.

Recommendation

Revise the requirement as follows:

Add to the requirement,

> "Implementation methods for the use of redundant multiplex data buses for critical or flight phase essential flight control functions shall be subject to approval by the procuring agency."

Requirement

3.2.4 Signal computation

3.2.4.1 General requirement

3.2.4.1.1 Transient power effects. Flight control computers shall not suffer adverse effects, which result in operation below FCS Operational State I, due to power source variations within the limits specified for the applicable power system. In the event of power source interruption, no adverse effects shall result which limit operation or performance of flight control computers upon resumption of normal quality power.

Comparison

The YF-17 flight control computer, (Control Augmentation System - Electronic Component Assembly, CAS-ECA) is designed to operate from the aircraft's 28 VDC power source and to provide specified performance when supplied power within variation limits specified for that source. The 28 VDC aircraft power is designed to meet requirements of MIL-STD-704A for category B equipment.

In the event of power source interruption, the control augmentation is automatically disengaged. When normal quality power is restored, the control augmentation can be manually reengaged with no adverse effects on performance.

The YF-17 is in compliance with Requirement 3.2.4.1.1.

Discussion

This requirement properly relates performance of the flight control computers to limits specified for the applicable power source which is consistent with MIL-STD-704. In the event of power source interruption, some shut-down and initialization procedures may be required, (either manual or automatic), upon resumption of normal power but there should be no loss of performance resulting from the power interruption.

This requirement is clearly stated, is valid for future aircraft procurement and compliance can be readily demonstrated by routine laboratory and flight tests.

Recommendation

Retain the requirement as stated.

Requirement

3.2.4.1.2 Interchangeability. The requirements of 3.2.7.1.2 shall be met, and tolerances shall be such that interchange of any computer component, module, or LRU with any other part bearing the same part number shall require only minimum resetting of parameters or readjustment of other components in order to maintain overall tolerances.

Comparison

The interchangeability requirement of 3.2.7.1.2 pertaining to assemblies from different suppliers was not demonstrated in the YF-17 prototype development program. A single source supplied all flight control computers (Control Augmentation System Electronic Component Assembly, CAS-ECA) used in the prototype YF-17 program. CAS-ECA modules which are not functionally interchangeable bear different part numbers and are keyed so they cannot be physically interchanged.

The CAS-ECA modules providing command signals to aileron and rudder actuators have an inherent small offset bias which may need to be corrected when changing modules or complete CAS-ECA assemblies; depending on the magnitude of the bias difference. A minor mechanical adjustment to the associated actuator feedback linkage may be made to trim the control surface position to a zero reference. The bias error can also be corrected by the pilot's trim controls, but adjustment of the linkage provides the pilot with a full range of trim controls.

Except for demonstrating interchangeability of assemblies from different suppliers, the YF-17 flight control system is in compliance with requirements of Paragraph 3.2.4.1.2 and the referenced Paragraph 3.2.7.1.2.

Discussion

This requirement is clearly stated, is valid for future aircraft procurement and compliance can be readily demonstrated.

Recommendation

Revise the requirement as follows:

Add the following sentence,

"In addition, the allowable tolerances on the interchangeable elements shall be such that failure to readjust to overall system tolerances shall not create a hazardous condition."

Requirement

3.2.4.1.3 Computer signals

3.2.4.1.3.1 Signal transmissions. Signal transmissions between computer components and modules shall be done by using direct mechanical, hydraulic, pneumatic, or electrical connections, as required. Use of light transmission technology or other nonconeventional transmission paths requires specific approval of the procuring activity.

3.2.4.1.3.2 Signal path protection. Where redundant computing paths are provided they shall be isolated or separated when required to meet the invulnerability requirements of 3.1.9.

Comparison

Signal transmissions between computer components and modules in the YF-17 electrical flight control system computer (CAS-ECA) and between the CAS-ECA and the Digital Air Data Computer (DADC) use direct electrical connections. No unconventional transmission paths are used.

Redundant computing paths are provided in all YF-17 electrical flight control functions except for the flaps. The Control Augmentation (CAS) channels for roll, pitch and yaw are dual redundant. The Direct Electrical Control (DEL) channels for ailerons and rudders, and the aileron-to-rudder and stick-to-rudder (ARI/SRI) interconnect channels are "dual-dual". (Dual redundant channels are provided for each aileron and each rudder). Both the leading edge and the trailing edge flap controls are mechanized using a single digital command channel, a single analog actuation drive stage and a digital actuator performance model.

Isolation and separation of redundant signal paths is provided by routing redundant signals through different connectors on the CAS-ECA unit and by separating the cables routed to the right and left rudders and right and left ailerons. Additional channel isolation is provided by mounting redundant circuits on separate circuit cards in the CAS-ECA unit. A signal return wire is provided for each signal path with signal and signal return wires twisted together and shielded. These design features provide the protection needed to meet the invulnerability requirements of Paragraph 3.1.9.

The YF-17 is fully compliant with requriements of Paragraphs 3.2.4.1.3.1 and 3.2.4.1.3.2.

Discussion

The requirement for approval by the procuring activity for use of non-conventional transmission paths is clearly stated and is justified for future aircraft procurement.

Isolation or separation of redundant computing channels and signal transmission paths can provide a significant degree of invulnerability to onboard failure of other systems to induced environments, and to enemy actions. The requirement is valid for future aircraft procurement and compliance can be demonstrated in design documentation.

However, isolation of redundant computing paths will not provide invulnerability to the wide range of natural environmental conditions defined in 3.1.9 and subparagraphs. The requirement should be more specific with reference to invulnerability.

Recommendation

Revise the requirement as follows:

Revise paragraph 3.2.4.1.3.2 to read,

> "...to meet the requirements of 3.1.9 for invulnerability to onboard failures of other systems, induced environments, and enemy actions."

Requirement

3.2.4.2 Mechanical signal computation

3.2.4.2.1 Element loads. Mechanical computer signal transmission elements subjected to the pilots' input force shall be capable of withstanding the loads specified in 3.2.3.2.1.

Comparison

The mechanical signal computation for the horizontal tail control system is performed by the mechanism assembly in the top center fuselage. This package contains the linkage that shapes stick - surface control motions and includes the summing linkages for pitch-roll control and the flap-to-horizontal tail interconnect. This mechanism assembly is designed to be capable of withstanding the specified loads. The load capability of the elements in the mechanism assembly is facilitated by limiting the loads that may be transmitted. This is accomplished by bungees incorporated in series with both roll and pitch inputs to protect the mechanism from damage in the event of locked linkage, hydraulic system inoperative, or assymetric operation or controls surfacer during maintenance operations.

Discussion

This requirement is included in the scope of the coverage of paragraph 3.2.3.2.1 and paragraph 3.1.11.1 and, therefore, could be deleted.

Recommendation

Delete the requirement.

Requirement

3.2.4.2.2 Geared mechanisms.

Not applicable.

Requirement

3.2.4.2.3 Hydraulic elements. Hydraulic computing elements shall be designed in accordance with MIL-C-5503, MIL-H-8775, MIL-G-8890 or ARP 1281 as applicable. MIL-V-27162 shall be used as a general guide for the design of control valves used in hydraulic computing components.

Comparison

The specifications called out in the requirement have been adhered to in the design of YF-17 hydraulic components used for the secondary actuator of the integrated control surface actuator package elements. The YF-17 integrated packages utilize mechanical, rather than hydraulic summing of the manual and secondary (CAS) actuator inputs and contain no hydraulic performance monitoring, failure detection, or logic features. Their only function is to provide surface actuation. Therefore, strictly speaking, they should be considered hydraulic servoactuators in the sense of paragraph 3.2.6.4.1, rather than hydraulic computing elements.

Discussion

The requirement is good and insures good design practice. Demonstration can be accomplished by detail part inspection. However, the definition of what constitutes a hydraulic computing element is somewhat unclear and, to prevent misinterpretation, should be exemplified.

Recommendation

Revise the requirement follows:

> "Hydraulic computing elements, whether separate components or integrated in a hydraulic servoactuator package, shall be designed... ...components. Hydraulic computing elements include, as an example, components that perform summing, mode selection, ratio changing, performance or failure monitoring, and logic operations by hydraulic means."

Requirement

3.2.4.2.4 Pneumatic elements.

Not applicable.

Requirement

3.2.4.3 Electrical signal computation

3.2.4.3.1 Analog computation. Redundant electrical signal paths within a computer shall be isolated as required by failure immunity and invulnerability requirements specified herein. For failures which may cause a hazardous deviation in the aircraft flight path, the computer shall have provisions for rapidly disabling its command outputs or servos unless other fail-safe provisions exist.

Comparison

The YF-17 flight control computations are performed by dual analog channels for each function to ensure positive switching in case of a failure. All failure monitoring and switching logic are also dual. The YF-17 control augmentation system is designed to be fail-safe such that if either computational channel or any monitoring circuit fails, it will be shut off in a safe manner. The flight control axes are separated such that a failure in one axis will not affect another axis.

A single failure in either of the dual computational channels, or failure in a servo will cause a rapid shutoff of the hydraulic power to the servo. A return spring will center the servo actuator. In the case of the dual tandem pitch followup actuator, a failure detected in either computational channel or actuator will cause a shutoff of power to both segments of the actuator. Each actuator will freeze in its last position.

Discussion

This requirement is valid and applies to electrical flight control functions of any redundancy. Compliance can be practically demonstrated by design analysis and test.

Recommendation

Retain the requirement as stated.

Requirement

3.2.4.3.2 Digital computation. At the time of aircraft acceptance by the procuring activity, the total time used in flight control computations for worst case conditions shall not exceed 75 percent of the available computation time allocated for flight control use. Resident and bulk storage shall be sized such that at least 25 percent of each type is available for growth at the time of aircraft acceptance. Computation and sample rate shall be established at a level which ensure that the digital computation process will not introduce unacceptable phase shift, round off error, nonlinear characteristics, and frequency foldover or aliasing into the system response.

Comparison

Flight control digital computation in the YF-17 aircraft is performed in the digital air data computer (DADC). At the completion of the YF-17 flight test program, less than 2% of programmable memory was available in the DADC. The computational time for the worst case used approximately 94% of frame time. Thus the YF-17 digital computation does not meet these aspects of the requirement. The computation and sample rate are such that the digital computation process does not introduce unacceptable phase shift or other undesirable characteristics into the system response.

Discussion

It is not considered to be cost effective in all cases to make 25% of resident and bulk storage for growth and to restrict the time used in flight control computations for worst case conditions to 75% of the available time allocated for flight control use. The percentage of spare memory allocated and the required waiting time should be left to the individual aircraft specification considering the effect on aircraft performance, safety, and the expected expansion foreseen during the life of a given aircraft.

Recommendation

Revise the requirement as follows:

"At the time of aircraft acceptance by the procuring activity, the unused computation time and the unused resident and bulk storage shall be in accordance with a detail specification approved by the procuring agency. This growth capacity shall be established in consideration of the expansion foreseen during the life of a given aircraft. Computation and sample rate ..."

Requirement

3.2.4.3.2.1 Memory protection. Memory protection features shall be provided to avoid inadvertent alternation of memory contents. Memory protection shall be such that neither electrical power source transients within the limits specified nor EMI as specified in 3.2.5.4.1 shall cause loss of program memory, memory scramble, erroneous commands, or loss of ability for continued operation. The transients shall be as specified in MIL-STD-704 for Category C utilization equipment. For applications where system failures could be hazardous to safety of flight, the levels for normal, abnormal, and emergency electric system operation shall apply. For applications which are not critical to safety of flight, the levels for normal operaton shall apply. These transient requirements shall apply to cases when all or only one of the redundant power sources are operating.

Comparison

Digital memory is used in flight control computation on the YF-17 both in flight and on the ground. The DADC memory is utilized in flight as well as on the ground, while the CAS computer memory is only used for built-in test (BIT) computations on the ground. The memories of both units are read only memories (ROM) used for program storage plus about 5 percent of the total memory as random access write-read memory (RAM). Both units were designed to meet MIL-STD-704 for Category C, and both units have undergone EMI testing. There are no specific memory protection design features, except those features common to any IC Components. There have been no known memory failures in the YF-17 either in flight or on the ground.

Discussion

ROMs do not need an additional special memory protection. Existing protection of the same type used for other IC components is adequate. The reason for this is the ROM programming method. Before installation all ROMs undergo a power surge procedure in order to burn in the bit pattern required by the programming. This power is much higher than any other power that would be applied to the memory in the unit under operating conditions, and therefore normal operation cannot alter the programmed bit pattern.

RAMs and core-type memories are alterable memories for which the write cycle uses normal power for bit pattern storage. Therefore, they could be alterable during a power transient and an additional special protection would be desirable. However, this special protection is either too costly or is beyond the state of the art.

The use of RAMS for scratch pad application is acceptable provided that a self test routine is used to determine if any permanent damage has occurred. A transient power surge will not cause a flight safety problem if the software is properly designed. For example in a 10-msec frame time synchronous operation a scratch pad memory is updated 100 times per second. This means that any error caused by a power transient will be corrected. If a power surge should cause permanent damage, or lasts more than 40 msec, a monitoring system will either turn off the system fail-safe or cause a switch with negligible transient to another memory.

The application of core for program memory in a production aircraft would require special memory protection. If this is too costly or out of the state of the art then the use of ROMs would be mandatory. Use of core memory in prototype or full scale production test aircraft might be acceptable without special protection but special protective conditions would be mandatory. Such conditions would be, for example, the absence of EMI generating equipment, or the avoidance of atmospheric electrical activity.

Recommendation

Revise the requirement as follows:

Add to the requirement,

> "For read only memory (ROM) no speical memory protection is required. For read/write (R/W) memory, if used as a scratch pad (temporary storage), no special memory protection is required. A programmable R/W memory must have special protection or be used only in a test aircraft operated under protective conditions."

Requirement

3.2.4.3.2.2 Program scaling. Parameter scaling, word size, input limiting, and overflow protection shall ensure correct processing and continuous safe operation for all possible combinations of maneuvering demand and gust or other plausible disturbance within the service envelop of the system. Any condition capable of producing an overflow in an essential or flight phase essential function shall be precluded by hardware overflow detection and software or firmware that provides for data recovery and continuous safe operation following an overflow. Scaling shall provide satisfactory resolution to prevent the granularity due to digitizing processes from introducing, into the system response, unacceptable levels of nonlinear characteristics or instabilities.

Comparison

The YF-17 complies with this requirement. Computation in the DADC achieves proper scaling and at the end of the flight test program no scaling problem existed. Early in flight test program an overflow condition was found but it was immediately corrected.

Discussion

The requirement is good, although the question of what constitutes "satisfactory resolution" is left open. For example, experience with the X-14A variable stability digital flight control system showed that 10-bit resolution for A/D and D/A conversion was not adequate despite the use of a 16-bit digital processor. The YF-17 DADC with 12-bit resolution for A/D and D/A conversion is satisfactory. The term "scaling" is interpreted to include internal scaling as well as A/D and D/A conversion.

Recommendation

Retain the requirement as stated.

Requirement

3.2.4.3.2.3 Software support. For programmable computers a software support package shall be provided to aid in generation and validation of new programs. This support package shall be designed to be executable, either on the airborne computing system for which it was designed or on a large scale digital computer specified by the procuring agency. The support package shall include the necessary software and appropriate peripheral devices in accordance with the contractor data requirements list (DD 1423).

Comparison

In general, the software support for the digital air data computer in the YF-17 has been supplied by the computer vendor. The computer assembler has not been adapted to run at a Northrop facility and all assembler runs have been performed at the vendor's facility. All peripheral devices have also been located at the vendor's facility. (The only exception to this has been one two-week period when the vendor supplied a core memory and an I/O peripheral device to modify the maneuvering flaps program in the DADC at Northrop.)

Program changes to the DADC have been checked by the vendor using his acceptance test procedures and at Northrop on the flight controls test stand (iron bird) before flight in the aircraft.

The above procedure for making changes, while not ideal in all respects, has been necessitated by the prototype nature of the YF-17 and the urgency of the flight test program.

Discussion

The requirement for software support should apply to a core-type memory as well as to a ROM. Before a ROM can be validated, a core memory is required for program checkout. After the core memory program is validated, it is necessary to burn PROMs (programmable read only memory) to a specified bit pattern. Thus, peripheral equipment support is necessary to check a PROM memory in the airborne computer.

Recommendation

Revise the requirement as follows:

Change the first sentence from "For programmable computer....." to "For programmable computers with alterable memories or with ROMs...."

Requirement

3.2.5 Control power.

3.2.5.1 Power capacity. Sufficient electrical, hydraulic, and pneumatic power capacity shall be provided in all flight phases and with all corresponding engine speed settings such that the probability of losing the capability to maintain at least FCS Operational State III airplane performance shall be not greater than extremely remote when considering the combined probability of system and component failure and the cumulative exceedance probability of turbulence. Hydraulic power shall be used to actuate powered essential and flight phase essential MFCS.

Comparison

The YF-17 is in compliance with this requirement. Operational State III aircraft performance is maintained following loss of all electrical power and loss of one of the two hydraulic subsystems. Following dual engine or dual gearbox/hydraulic pump failures, which are considered extremely remote, an emergency power unit (EPU) in the right hydraulic system provides Operational State IV capability.

Discussion

The requirement is generally adequate for current aircraft and can be practically demonstrated by system functional mockup/simulator tests. However, the requirement may be too lenient for future aircraft or current aircraft with special flight controls features. Loss of power which affects the operation of the AFCS may result in loss of the aircraft in some AFCS modes such as all weather landing or automatic terrain following. Sufficient power for MFCS for FCS Operational State III can be academic in such a case.

Recommendation

Revise the requirement as follows:

Add to the requirement,

"Where operation of the AFCS is necessary for safety of flight, adequate power shall be provided by sufficient redundant means such that the probability of losing the AFCS function shall be no greater than extremely remote."

Requirement

3.2.5.2 Priority. Essential and flight phase essential flight controls shall be given priority over noncritical controls and other actuated functions during simultaneous demand operation. However, no specific priority provisions, such as hydraulic priority valves, are required unless there is a likelihood of simultaneous demands which could prevent one or more essential or flight phase essential actuation systems from meeting their performance requirements. Where provided, priority controls shall be highly resistant to deterioration, binding, or failure while dormant under normal aircraft operations so that they will function s required when conditions dictate. If flight safety can be endangered by failure of such controls, ground checkout means for ready determination of their operability shall be provided and procedures specified.

Comparison

The YF-17 is in compliance with the requirement. No priority valve is used in the YF-17 because sufficient hydraulic power is available to meet demands of utility functions and flight controls simultaneously. Had the 20 mm gun been required to fire at the high rate of 6000 shots per minute, a priority valve would have been required in the left system line to the gun.

Discussion

The requirement is necessary and valid, and can be practically demonstrated. Increased utility function demands expected in future aircraft will require that provisions be made to insure adequate power for flight controls.

Recommendation

Retain the requirement as stated.

Requirement

3.2.5.3 Hydraulic power subsystems. All hydraulic power generated and distribution systems normally used for flight control shall be designed in accordance with MIL-H-5440 and MIL-H-8891 as applicable. The FCS shall operate in accordance with this specification when supplied with such hydraulic power. Applicable requirements in AFSC Design Handbook DH 1-6, Systems Safety, Section 3F, Hydraulic Systems, shall also be met.

Comparison

The YF-17 is in partial compliance with this requirement. The right hydraulic system on the YF-17 is used for emergency gear extension by use of a transfer cylinder. Also, early in the design of the YF-17 it had been planned to use the right system hydraulic power for nose wheel steering. In the final configuration of the YF-17, nose wheel steering is on the left hydraulic system. This is due to a requirement for single engine taxi, however, rather than from dedicated system considerations. Hence, the airplane does not have a fully dedicated system for flight controls as required by MIL-H-5440. Hydraulic System distribution is shown in Figure 1 (3.2.5.3).

Full compliance with this requirement would have required an accumulator or some other power source to lower the landing gear in the event of a failure of the left hydraulic system. This would have resulted in increased weight, cost, and maintenance, and less reliability.

Discussion

The requirement is good if reasonable deviations can be entertained. With improved system redundancy, such as provided with reservoir level sensing, such deviations should be feasible, or perhaps MIL-H-5440 can be modified if better general approaches are found.

Recommendation

Retain the requirement as stated.

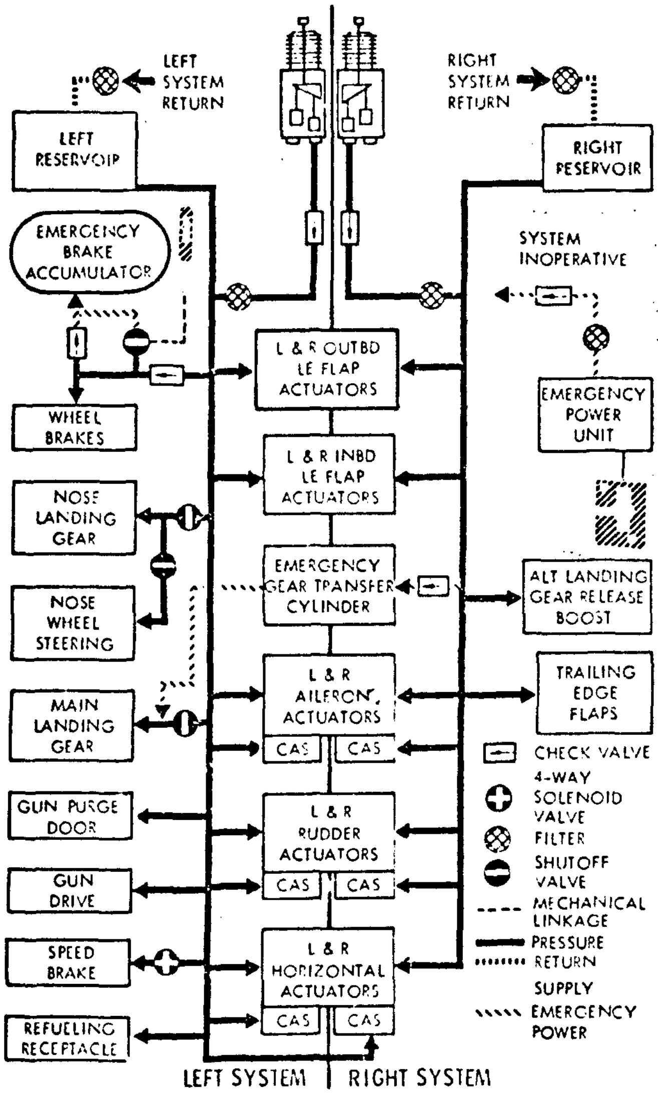

Figure 1(3.2.5.3) Flight Control Hydraulic System

Requirement

3.2.5.4 Electrical power subsystems. All electrical power generation and distribution subsystems used for flight control shall provide electrical power in accordance with MIL-STD-704. The FCS shall operate in accordance with this specification when supplied with power in accordance with MIL-STD-704. Applicable requirements in the following AFSC design handbooks shall be met:

a. DH 1-4: Electromagnetic Compatibility

b. DH 1-6: System Safety

c. DH 2-1: Airframe

d. DH 2-2: Crew Stations and Passenger Accommodations

Electrical systems which provide power to essential or flight phase essential controls, shall insure uninterruptible, isolated redundant power of adequate quality to meet FCS requirements after any malfunction not considered extremely remote. Such electrical systems shall, except for basic power source, be independent of failure modes associated with any other electrical system. Essential and flight phase essential FCS shall be automatically provided alternate sources of power where interruption could result in operation below FCS Operational State III. A protected alternate source of power shall be provided for all essential or flight phase essential control signal transmission paths sufficient to continuously maintain at least FCS Operational State III performance in the event of loss of all electrical power supplied from engine-driven generators. Control systems employing both ac and dc power inputs shall normally have interlocks incorporated to disconnect both power inputs should either type of power be lost. However, if the loss of either power source can be shown to be equivalent to loss of both or FCS Operational State III or better is maintained with either power source, interlocks are not required.

Comparison

Since this is a lengthy paragraph the YF-17 flight controls are compared to each sentence of 3.2.5.4. The YF-17 is compliant with the first and second sentences pertaining to MIL-STD-704. The third sentence is too broad in coverage and non-specific ("applicable requirements") to determine compliance. Sentences 4, 5, and 6 are not applicable to the YF-17 flight controls since electrical power is not required to maintain FCS Operational State III. Sentences 7 and 8 are not applicable because the YF-17 EFC utilizes only dc electrical power. The YF-17 is compliant with all applicable requirements of Paragraph 3.2.5.4 with possible exceptions to Sentence 3.

Discussion

The third sentence of 3.2.5.4 which specifies meeting "applicable requirements" of certain AFSC Design Handbooks is too broad in scope and non-specific. Demonstration of compliance would require interpretation of "applicable requirements" and excessive duplication of documentation. Unless there are some essential specific requirements in the referenced handbooks which are not covered elsewhere in 9490D this sentence should be deleted from Paragraph 3.2.5.4.

The remaining requirements of this paragraph are clearly stated, are valid for future aircraft procurement, and compliance can be demonstrated by analysis and testing to requirements of MIL-STD-704.

Recommendation

Revise the requirement as follows:

> Delete the third sentence of the paragraph together with the handbook references a, b, c, and d.

Requirement

3.2.5.4.1 Electromagnetic interference limits. The FCS shall operate within the limits of MIL-E-6051 and MIL-STD-461 environment. Electromagnetic interference created by the systems and components during normal operation shall be within the limits of MIL-E-6051 and MIL-STD-461, respectively. Failure modes of all onboard systems and equipment, including flight controls, wherein these limits may be exceeded shall be identified in addition to sources of conducted EMI that may be detrimental to FCS operation. Additionally, the estimated magnitude of EMI generated by these failure modes shall be provided for the assessment of the safety of the EFCS.

Comparison

The YF-17 Flight Control System (FCS) electronic equipment complies with the applicable requirements of MIL-STD-461 and MIL-E-6051 as required by MIL-F-949D. Compliance was demonstrated by laboratory test, (MIL-STD-462) aircraft ground test (MIL-E-6051) and flight tests.

Discussion

Flight Control System (FCS) electromagnetic compatibility (EMC) design and test requirement are defined in MIL-F-9490D, paragraphs 3.1.9.3, 3.2.5.4.1 and 4.3.3C.

Invulnerability to Induced Environments as defined in paragraph 3.1.9.3 states, "The FCS shall withstand the full range of worst case induced environments.", and "...shall meet the applicable requirement of MIL-STD-461 and MIL-E-6051." This wording of paragraph 3.1.9.3 implies that only the electromagnetic susceptibility requirements of MIL-STD-461 and MIL-E-6051 are applicable.

Paragraph 3.2.5.4.1, Electromagnetic Interference Limits, is placed as a subparagraph under the heading of Electrical Power Systems, paragraph 3.2.5.4, which defines detail requirements for primary power systems providing power to FCS equipment. The wording of paragraph 3.2.5.4.1 is cumbersome and although it does define specific EMC requirements for FCS equipment, its placement in the Electrical Power Systems of the specification could imply the requirements are primarily directed toward electrical power systems only.

The EMC test requirements, contained in paragraphs 4.3.3C, require testing for compliance of MIL-STD-461 and MIL-E-6051 be accomplished at the aircraft level. MIL-STD-461 is a Black-box specification and except for special conditions (Missile), is not applicable or practical for a total system.

Proper operation of FCS is vital to safe flight of the aircraft. Since loss of control due to electromagnetic incompatibility could result in loss of aircraft and endanger the pilot's life, the EMC requirements should be emphasized by placement as a primary subparagraph 3.1.3, General FCS Design.

Recommendation

Revise the requirements as follows:

a. Paragraph 3.2.5.4.1 should be deleted and new paragraphs be inserted in section 3.1.3 as `.1.3.X, titled and worded as:

3.1.3.X Electromagnetic Interference and Compatibility requirements

3.1.3.X.1 The FCS equipment shall comply with the requirements of MIL-STD-461 to the extent specified in the FCS detail specification.

3.1.3.X.2 The FCS, when integrated with the total vehicle system shall comply with the requirements of MIL-E-6051 for Category 1 equipment/subsystems.

3.1.3.X.3 The FCS shall demonstrate compliance to the 6 dB safety margin requirement of MIL-E-6051 as a minimum. For EFCS without mechanical revision mode the safety margin shall be as specified in the FCS detail specification.

b. Paragraph 4.3.2 should incorporate a new subparagraph, for EMC compliance demonstration tests, as follows:

4.3.2.X The requirements of paragraph 3.1.3.X shall be verified by test. The tests shall be in accordance with MIL-STD-462 as modified by the FCS detail specification.

c. Reference to MIL-STD-461 should be deleted from paragraph 4.3.3.(c).

Requirement

3.2.5.4.2 Overload protection. Overload protection of the primary power wiring to the system or component shall be provided by the airplane contractor. Installation requirements of the system or component specification shall specify the values of starting current versus time, surge currents if applicable, normal operating current, and recommended protective provision. Additional protection as necessary shall be provided within the system or component. Such circuit protection shall not be provided in signal circuits or other circuits where opening of the protective devices will result in unsafe motion of the aircraft.

3.2.5.4.3 Phase separation and polarity reversal protection. In systems affecting flight safety, phase reversal and polarity reversal shall be prevented as far as practical by keying, physical restraints or other positive means.

Comparison

The YF-17 is fully compliant with the requirement 3.2.5.4.2, Overload Protection. The YF-17 is not compliant with requirement 3.2.5.4.3, Phase separation and polarity reversal protection. The YF-17 EFC does not use 3 phase a.c. and the airframe ground is used as the dc return path.

Discussion

These requirements are clearly stated, are valid for future aircraft procurement, and compliance can be demonstrated by inspection. No special keying or other physical restraints are provided to prevent polarity reversal of the dc power in the YF-17 because the use of frame ground as dc return provided adequate protection. The requirement is valid since a two wire dc power distribution system could be employed.

Recommendation

Retain the requirements as stated.

Requirement

3.2.5.5 Pneumatic power subsystems.

Not applicable.

Requirement

3.2.6 Actuation

3.2.6.1 Load capability

3.2.6.1.1 Load capability of elements subjected to pilot loads. Elements of actuation systems subjected to loads generated by the pilot(s) shall be capable of withstanding the loads due to the pilot's input limits specified in MIL-A-8865, Section 3.7, Flight Control System Loads, taken as limit loads unless higher loads can be imposed such as by a powered actuation system or loads resulting from aerodynamic forces. Control signal boost actuator outputs may be load limited by spring cartridges.

3.2.6.1.2 Load capability of elements driven by power actuators. Elements subjected to loads generated by a powered actuation system, including all parts of the actuator shall be capable of withstanding the maximum output of the actuation system, including loads due to bottoming, or the maximum blowback load, as controlled by pressure relief valves or other load limiting provisions, whichever is greater, as the limit load. Ultimate load capability shall be 1.5 times limit load. In dual load path design, each path shall be capable of sustaining load as specified in 3.1.11.1.2 without failure.

Comparison

The YF-17 Control System is in compliance with these requirements. Spring cartridge load limiters are employed to protect the pitch-roll control system but still maintain minimum load capability in compliance with the requirements of paragraph 3.2.3.2.2. The load limiters also function to protect the control system from loads resulting from asymmetric blowback or asymmetric deflection of control surfaces during ground maintenance activities.

Discussion

The actuation load requirements are specific and practical.

Recommendation

Retain the requirements as stated.

Requirement

3.2.6.2 Mechanical force transmitting actuation. For control cable actuation, the requirements specified in 3.2.3.2.4 and subparagraphs apply. For push-pull rod actuation, the requirements specified in 3.2.3.2.5 and subparagraphs apply.

3.2.6.2.1 Force transmitting powerscrews. Powerscrews with rotary input and linear output motion may be used to actuate relatively low-duty-cycle flight control surfaces, such as wing flaps and trimmable stabilizers, but specific approval from the procuring activity shall be obtained before use in high-duty-cycle applications. Nonjamming mechanical stops shall be provided at both ends of the screw to limit travel of the nut; and, they shall be designed to withstand all possible loads, including possible impact loading, without failure. Provisions shall be incorporated into the nut to minimize entry of sand, dust, and other contaminants; to retain its lubricant; and to preclude the entry or retention of water. However, positive sealing is not required if the screw is installed such that it is protected from such contamination or is inherently resistant to wear and jamming by contamination.

3.2.6.2.1.1 Threaded powerscrews. Standard thread forms only shall be used, and the thread roots shall be rounded as necessary to preclude stress cracking. Lubrication provisions shall be adequate for controlling efficiency, wear, and heating to acceptable values. Where in service lubrication is necessary, lube fittings in accordance with 3.2.7.2.5 shall be provided. If the design is dependent on inherent friction to maintain irreversibility, this characteristic must be adequate under all expected operating conditions, including the full range of loads, both steady loads and reversing or variable-magnitude loads which may be encountered due to control surface buffeting or buzz, temperatures, and environmental vibration over the full service life of the unit.

3.2.6.2.1.2 Ballscrews. An adequate number of balls and ball circuits shall be provided to keep individual ball loading within allowable nonbrinelling limits. On units used in essential and flight phase essential applications, at least two separate independent ball circuits and a secondary load path with load capability in accordance with 3.1.11.1.2 shall be incorporated.

Comparison

The YF-17 utilizes four mechanical force transmitting linear actuators, powered by electric motor, in the following flight controls' applications:

a. Pitch parallel trim

b. Pitch CAS series trim (follow-up)

c. Leading edge flap control

d. Trailing edge flap control

These actuators feature threaded powerscrews and fully comply with the requirements of paragraphs 3.2.6.2.1 and 3.2.6.2.1.1 as regards irreversibility, non-jamming mechanical stops, thread design, and sealing. They all operate relatively light loads (control functions only, not direct actuation of flight control surfaces), but are subject to high duty cycle or continuous duty operation. In so far as duty cycle is concerned, the application of these actuators, except for the pitch parallel trim actuator, is not in compliance with the requirements.

The use of these actuators on the YF-17 was approved through system design review by the procuring agency, rather than by specific approval of each separate application.

Discussion

The actuators in the noted YF-17 applications provided satisfactory performance. However, the limited experience on the YF-17 does not provide sufficient basis to endorse the use of electromechanical screw-jack actuators in a continuous duty application. On the basis of general experience, the specified requirements represent prudent design considerations, and the requirement to obtain specific approval is justified.

Recommendation

Retain the requirement as stated.

Requirement

3.2.6.3 Mechanical torque transmitting actuation.

Not applicable.

3.2.6.3.1 Torque tube systems.

Not applicable.

3.2.6.3.1.1 Torque tubes.

Not applicable.

3.2.6.3.1.2 Universal joints.

Not applicable.

3.2.6.3.1.3 Slip joints.

Not applicable.

3.2.6.3.2 Gearing.

Not applicable.

3.2.6.3.3 Flexible shafting.

Not applicable.

3.2.6.3.4 Helical splines.

Not applicable.

3.2.6.3.5 Rotary mechanical actuators.

Not applicable.

3.2.6.3.6 Torque limiters.

Not applicable.

3.2.6.3.7 No-back brakes.

Not applicable.

Requirement

3.2.6.4 Hydraulic actuation. Hydraulic actuation components shall be designed in accordance with MIL-H-8775 or MIL-H-8890, and specific component specifications as applicable. If hydraulic bypass provisions are necessary to prevent fluid lock or excessive friction load or damping, bypassing and resetting shall occur automatically when system pressure drops below or returns to the minimum acceptable value for actuation. In actuation systems designed for manual control following hydraulic failure, provisions shall be made to permit bypassing of the hydraulic systems for checkout purposes and to permit pilot training with the emergency manual system.

Comparison

Bypassing within the control cylinder is not required on any YF-17 control actuators as there is no requirement for damping or reversion to manual control power. (This feature was provided on the Northrop A-9A for manual control.)

Discussion

The requirement is good for the purpose stated and can be practically demonstrated. However, with the more sophisticated control hardware required for fly-by-wire, the feature of automatic pressure operated bypass/reset is not desirable. Shutoff and bypass need to be controlled by FCS decision. Fly-by-wire control systems have failure modes which require actuator shutoff and bypass even though pressure is available. Pressure is not the only criterion for such equipment.

Recommendation

Revise the requirement as follows:

Replace the second sentence with,

> "If hydraulic bypass provisions are necessary to prevent fluid lock or excessive friction load or damping, bypassing shall occur automatically when system pressure drops below the minimum acceptable value for actuation. Resetting shall occur when the system pressure returns to an acceptable value and/or signaled to do so by the FCS."

Requirement

3.2.6.4.1 Hydraulic servoactuators. Hydraulic servoactuators shall be designed in accordance with ARP 1281. Electrohydraulic servovalves shall be designed in accordance with MIL-V-27162. If electrical-input hydraulic servovalves having mechanical feedback of actuator position are used, the applicable requirements of ARP 988 shall be met.

Comparison

The YF-17 is in partial compliance with the requirement. ARP 1281 was not available at the time of the YF-17 actuator design. However, many of the detail requirements of ARP 1281 are standard, good design practices and have been incorporated.

MIL-V-27162 was used. No equipment is used on the YF-17 per ARP 988.

Full compliance with this requirement would have had very little effect on the YF-17 design. Some change in detail color coding of electrical wiring in the actuator packages would have been required.

Discussion

The requirement is valid, and compliance can be practically demonstrated by inspection.

Recommendation

Retain the requirement as stated.

Requirement

3.2.6.4.2 Motor-pump - servoactuator (MPS) package.

Not applicable.

Requirement

3.2.6.4.3 Actuating cylinders. Actuating cylinders without control valves and feedback provisions in the same LRU shall be designed in accordance with MIL-C-5503, except that the life cycling requirements shall be modified to reflect the specific usage. (See 3.1.12)

Comparison

The YF-17 used actuating cylinders without control valves and feedback provisions in the same LRU for actuating both leading edge and trailing edge flaps. The cylinders were designed with regard to aircraft life cycle requirements. In all cases, these were much more stringent than MIL-C-5503 requirements. Limiting requirements to just meeting MIL-C-5503 would have degraded endurance and reliability, and increased external leakage.

As an example, the YF-17 leading-edge flap actuator life cycling requirement is given below.

> Life Cycling - The actuator package shall be capable of meeting the performance requirements herein after being subjected to 1,385,000 cycles of operation as follows:

Number of Cycles	Load (lb)	Stroke (in.)
50,000	10,000	1.48
125,000	15,000	1.10
525,000	20,000	0.60 to 0.75
525,000	30,000	0.30 to 0.45
160,000	40,000	0.15

Discussion

The stroke/load endurance cycles of MIL-C-5503 are based on trail surfaces and do not reflect the load spectrums which are possible in, for example, the YF-17 leading-edge and trailing-edge flaps operating in the automatic mode. In such situations, the 2 percent stroke figure of MIL-C-5503 might possibly apply but the 2 percent load figure would not. Life cycling must be tailored to actual expected environment. The requirement should emphasize this in order to avoid a requirement that is not stringent enough for current and future aircraft.

Recommendation

Revise the requirement as follows:

> "Actuating cylinders without control valves and feedback provisions in the same LRU shall be designed in accordance with MIL-C-5503, except that life cycling requirements shall be modified to reflect the specific usage with respect to the load/stroke relationship and the expected frequency of operation. (See 3.1.12.)"

Requirement

3.2.6.4.4 Force synchronization of multiple connected hydraulic servoactuators. In essential and flight phase essential flight control actuator installations employing multiple connected servoactuators, the actuators shall be synchronized as necessary to assure specified performance and durability as specified in 3.1.11.3 in the structure between actuators without undue structural weight penalties.

Comparison

The YF-17 requires force synchronization of the leading-edge flap system in which inboard and outboard actuating cylinders are incorporated. The YF-17 complies with this requirement by the use of a "slaved" outboard cylinder, with pressure control provided by an inboard "master" valve. This insures synchronization by building synchronization into the valve eliminating the need for an aircraft adjustment with the attendant possibility of misrigging.

Discussion

The requirement is a necessary, valid requirement. Improper synchronization, or not providing for this need during design, could lead to early structural failure. However, the requirement is somewhat too lenient. Additional wording is necessary to insure that the method of synchronization, if rigging after installation is involved, is simple; that it is reliable in that it does not change with service time, flight maneuvers, or temperature; and that it can be easily inspected for proper rigging.

Recommendation

Revise the requirement as follows:

Add to the requirement,

> "Where system or component rigging is required after installation to obtain synchronization, the method shall be simple, reliable, and easily inspected. Airframe deflections and temperature changes which may affect rigging shall be considered."

Requirement

3.2.6.4.5 Hydraulic motors.

Not applicable.

Requirement

3.2.6.5 Electromechanical actuation. Electric power may be used to actuate relatively low-duty-cycle, noncritical flight control functions, such as for trim and in the AFCS, but specific approval from the procuring activity must be obtained before use in essential and flight phase essential applications. Electromechanical actuation components shall be designed in accordance with MIL-E-7080, and specific component specifications as applicable, and the following. Performance requirements shall be adequate for intended application.

Comparison

The YF-17 uses four DC powered electromechanical actuators in flight control application, as discussed under Comparison for paragraph 3.2.6.2, and two AC powered actuators for operating the engine inlet diverter doors. With the exception of the pitch parallel trim actuator, the DC actuators used for flight control functions are continuous duty, albeit lightly loaded. The two AC actuators are used in a high load, low duty cycle application that is not related to flight controls.

Discussion

Electromechanical actuators have desirable characteristics, such as retaining the last commanded position when power is lost or being operable (for a limited time) on aircraft battery, and can be effectively used to achieve certain design goals. However, their application for control functions requires a careful consideration of design and performance goals, with particular attention to duty cycle, wear, and environmental requirements. The requirement for securing specific approval from the procuring activity is endorsed. The requirement is clear and reasonable, and compliance can be easily demonstrated.

Recommendation

Retain the requirement as stated.

Requirement

3.2.6.6 Pneumatic actuation.

Not applicable.

3.2.6.6.1 High-pressure pneumatic actuation.

Not applicable.

3.2.6.6.2 Pneumatic drive turbines.

Not applicable.

Requirement

3.2.6.7 Interfaces between actuation systems, support structure, and control surfaces.

3.2.6.7.1 Control surface stops. Surface stops shall be provided each flight control surface to positively limit its range of motion. Stops shall be located so that wear, slackness, or takeup adjustments will not adversely affect the control characteristics of the airplane because of a change in the range of surface travel. Each stop shall be able to withstand any loads corresponding to the design conditions for the control system. Where power control actuators are attached directly to the control surface, stops shall be provided within the actuator. Such actuators shall not only be designed for maximum impact loads, but also for the cumulative fatigue damage due to load cycling predicted during flight and due to bottoming during ground check-out and taxiing. Where control valve command input stops are provided, the actuators shall be designed for maximum impact stop loads, and not for fatigue damage due to bottoming, except as normally encountered with the input stops and feedback provisions functioning.

3.2.6.7.1.1 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.

Comparison

Flight control surface actuators on the YF-17 are attached directly to control surfaces with stops within the actuators. The actuators comply with the foregoing requirements.

Discussion

These requirements are clear and complete. The requirements for actuator impact stop loads are necessary and practical as defined.

Recommendation

Retain the requirements as stated.

Requirement

3.2.6.7.2 Control surface ground gust protection. All flight control surfaces shall have provisions to prevent damage from ground wind loads as specified in MIL-A-8865. However, no separate provisions are required if the damping characteristics of installed flight control actuators suffice for gust protection.

Comparison

Control surface locks are not required on the YF-17. The damping characteristics of the hydraulic surface actuators provide adequate protection from ground winds.

Discussion

This requirement is endorsed as defined.

Recommendation

Retain the requirement as stated.

Requirement

3.2.6.7.2.1 Control surface locks.

Not applicable.

3.2.6.7.2.2 Protection against inflight engagement of control surface locks.

Not applicable.

Requirement

3.2.6.7.3 Control surface flutter and buzz prevention. All flight control surface actuation systems controlling surfaces which are not dynamically balanced shall be effectively irreversible or provided with sufficient damping to prevent flutter, buzz, or other relative dynamic instabilities for all operating modes and meet the requirements of MIL-A-8870. No active powered compensation technique or mechanization designed to artificially increase stiffness, damping, or natural frequency shall be used without prior approval of the procuring activity.

Comparison

The YF-17 complies with the requirements of this paragraph. A buzz prevention criterion, almost identical to that given in the User Guide, was used. Application of this criterion, in conjunction with calculated stiffness on the rudder actuator, indicated a marginal buzz situation on the rudder. As a precaution, structural provisions were made for installing a flutter damper in the fin and an off-the-shelf linear damper was procured and tested. Tests of the rudder actuator showed later that the actuator stiffness had been underestimated by approximately 50%. Subsequent wind tunnel and flight flutter tests confirmed that the rudder buzz damper was not required.

The same comments on back-up structural stiffness given in 3.1.11.2 also apply to this paragraph.

Discussion

The requirement is too broadly stated for a design requirement. An explicit numerical buzz prevention criterion should be stated. The separate airframe companies use their own variations on the criterion recommended in the User Guide. All derived from the same data base and generally do not differ by more than a few percent. In view of the general agreement, an explicit numerical criterion should be formulated, which, if met, would obviate the need for structural provisions for a buzz damper, required by MIL-A-8870A for most trailing edge control surfaces. However, until an explicit criterion is formulated, the requirement serves the purpose as a design guide and should be retained as stated.

Subjective compliance with the requirement can be demonstrated.

Recommendation

Retain the requirement as stated.

Requirement

3.2.7 Component design

3.2.7.1 Common requirement

3.2.7.1.1 Standardization. Where practical, 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. Tolerances shall be such that interchange of any LRU with any other part bearing the same part number shall not require resetting of parameters or readjustment of other components in order to maintain overall tolerances and performance.

3.2.7.1.2 Interchangeability. Like assemblies, subassemblies, and replaceable parts shall meet the requirements of MIL-I-8500 regardless of manufacturer or supplier. Items which are not functionally interchangeable shall not be physically interchangeable unless specifically approved by the procuring activity.

3.2.7.1.3 Selection of specifications and standards. Specifications and standards for necessary commodities and services not specified herein shall be selected in accordance with MIL-STD-143.

3.2.7.1.4 Identification of product. Equipment components, assemblies, and parts of flight control systems shall be identified in accordance with MIL-STD-130.

3.2.7.1.5 Inspection seals. Corrosion resistant metalic seals shall be provided at all strategic locations to indicate assembly inspection and any unauthorized disassembly.

3.2.7.1.6 Moisture pockets. All components shall avoid housing 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.

Comparison

The YF-17 is in compliance with all common requirements specified except inspection seals per paragraph 3.2.7.1.5.

Discussion

The common requirements are consistent with established standards for military hardware, except paragraph 3.2.7.1.5, and should not pose any difficulty in future aircraft. The requirement for inspection seals is common practice in quality control procedures. But the specification of corrosion resistant metalic seals is considered to be restrictive. Types of inspection seals used are commonly specified in quality control procedures.

Recommendation

Revise the requirement as follows:

Change paragraph 3.2.7.1.5, Inspection seals, as follows,

"Suitable, wear resistant inspection seals shall be provided....."

Requirement

3.2.7.2 Mechanical components. Mechanical components not covered by design requirements specified elsewhere within this specification shall be designed in accordance with applicable requirement in: Government and Industry specifications, in the order of precedence specified in MIL-STD-143; in AFSC Design Handbooks DH 2-1, DN 3B1, Mechanical Flight Controls; and DH 1-2, General Design Factors; and the following:

3.2.7.2.1 Bearings. Flight control system bearings shall be selected in accordance with AFSC Design Handbood DH 2-1, Chapter 6, Airframe Bearings, and the following.

3.2.7.2.1.1 Antifriction bearings. Approved type ball bearings in accordance with MIL-B-6038, MIL-B-6039, and MLL-B-7949 shall be used throughout the flight control system, except as indicated in the following paragraphs. Bearing installation shall be arranged in such a manner that failure of the rollers or balls will not result in a complete separation of the control. Where direct axial application of control forces to a bearing cannot be avoided, a fail-safe feature shall be provided.

3.2.7.2.1.2 Spherical bearings. Where space or other design limitations preclude the use of antifriction bearings, spherical-type, self-lubricating plain bearings in accordance with MIL-B-81820, or spherical or special-type all metal bearing in accordance with MIL-B-8976 with adequate and accessible provisions for lubrication, may be used.

3.2.7.2.1.3 Sintered bearings. Sintered type, or oil impregnated bearings shall not be used in those parts of the flight control systems which have slow moving or oscillating motions. Their use in fast moving rotating applications, such as in qualified motors and actuators, are permissible. Bearings shall conform to MIL-B-5687.

Comparison

The YF-17 is noncompliant with requirements for ball and antifriction bearings. Rod end ball bearings and selected spherical bearings are non-QPL items because of the special features required such as special shanks on rod end bearings for swaging. All bearings would qualify on the basis of similarity.

All bearings are mounted in a fork fitting or equivalent to preclude separation of the joint in the event of bearing failure for compliance with fail-safe requirements.

Discussion

The requirements for bearings define good design practice.

Recommendation

Retain the requirements as stated.

Requirement

3.2.7.2.2 Controls and knobs. Aircrew controls shall be shaped and located per the requirements of AFSC Design Handbook DH 2-2. Control knobs shall be designed and spaced per the requirements of AFSC Design Handbook DH 2-2 and MIL-K-25049.

Comparison

The YF-17 aircrew controls were designed and located using DH 2-2 as a guide. However, strict compliance was not required due to the prototype nature of the program, and cockpit design evolved through extensive cockpit mockup evaluation. The YF-17 partially complies with the requirement.

Discussion

The requirement is valid, and compliance can be practically demonstrated.

Recommendation

Retain the requirement as stated.

Requirement

3.2.7.2.3 Dampers.

Not applicable.

Requirement

3.2.7.2.4 Structural fittings. All structural fittings used in flight control systems shall comply with the design requirement specified in AFSC Design Handbook DH 1-2, Design Note DN 4B1, Design Requirements, and where applicable, the design considerations specified in Design Note DN 4B2, Forgings and Castings.

Comparison

YF-17 Flight Control System fittings do not all conform to these design requirements. Sheetmetal structures are employed in non-critical locations to meet prototype schedules and economies. Forgings and castings would normally be employed in production for these fittings and would be designed to conform to these requirements.

Discussion

The requirements are consistent with good design practice.

Recommendation

Retain the requirement as stated.

Requirement

3.2.7.2.5 Lubrication. Where applicable, lubrication fittings in accordance with MIL-F-3541, MS15002-1 and -2, or NAS 516, shall be installed to provide for lubrication in accordance with MIL-STD-838. NAS 516 fittings are restricted to nonstressed areas only.

Comparison

The YF-17 has lubrication fittings installed at all locations where lubrication is required and conforms to all applicable specifications.

Discussion

Reasonable requirement for military aircraft.

Recommendation

Retain the requirement as stated.

Requirement

3.2.7.3 Electrical and electronic components. Electrical and electronic components not covered by design requirements specified elsewhere within this specification shall be designed in accordance with MIL-E-5400, MIL-E-7080, MIL-STD-454, MIL-STD-461, MIL-W-5088, MIL-M-7969, MIL-M-8609, and the following following:

Comparison

Electrical and electronic components used in the YF-17 flight control system have been designed or procured and installed in accordance with the military standards and specifications in paragraph 3.2.7.3. Applicable military standards and specifications were included in requirements of product function specifications for the design of new components and used in the selection and installation of standard components. The YF-17 flight control system electrical and electronic components are compliant with requirements of Paragraph 3.2.7.3.

Discussion

This paragraph by invoking pertinent military specifications and standards provides satisfactory coverage in the control of part selection, control of design, development and installation of electrical and electronic flight control system components. The requirement is valid for future aircraft procurement and compliance can be demonstrated by procedures contained within the military specifications.

Recommendation

Retain the requirement as stated.

Requirement

3.2.7.3.1 Dielectric strength. Leakage current shall not exceed 10 milliamps when a dielectric stress voltage of 1,200 volts, 60 Hz, is applied for 1 minute between insulated circuits and between circuits and case; and there shall be no insulation breakdown. When 500V DC is applied between isolated circuits and the case or connector shell for a period of 10 seconds, the resistance shall be at least 50 megohms. When a component or connector has a lower design voltage limitation, the test shall be run at an appropriate lower voltage as defined by the component specification.

Comparison

Components used in the YF-17 flight control are compliant with requirements of Paragraph 3.2.7.3.1 except for solid state electronic assemblies Northrop Product Function Specifications include requirements which equal or exceed requirements of this paragraph. However, lower values for dielectric stress voltage and insulation resistance were specified for solid state electronic assemblies.

Northrop's requirement for dielectric strength specifies a test voltage of 300 volts RMS, 60 Hz, for solid state, miniature and instrument devices; all other devices are required to withstand 1500 volts RMS, 60 Hz. Dielectric strength tests were conducted in accordance with MIL-STD-202D, Method 301.

Northrop's requirement for insulation resistance references MIL-STD-202D, Method 302. Test Condition A (100 volts DC) is specified for solid state, miniature and instrument devices; all other devices are required to meet Test Condition B (500 volts DC). The insulation resistance requirement between isolated circuits and case was 100 megohms minimum for primary power circuits and 50 megohms minimum for signal and amplifier reference circuits. However the test requirement in the specification for CAS Electronic Component Assemblies was reduced to 10 megohms to accommodate the microcircuit packaging techniques used for these assemblies.

The YF-17 is in partial compliance with this requirement.

Discussion

The requirements of Paragraph 3.2.7.3.1 are valid for electrical flight control components such as cables, connectors, switches, relays and motors, but the dielectric strength and insulation resistance requirements are too stringent for the type of solid state electronics assemblies used in flight control systems currently being developed. It is anticipated that future military aircraft will employ more sophisticated and complex flight control systems and make more extensive use of solid state and microelectronic devices in digital processors and other electronic assemblies.

The 1200 volt dielectric stress test is clearly inappropriate for microelectronic assemblies, but it is not clear in the wording of Paragraph 3.2.7.3.1 whether the limitations of the third sentence apply to the first sentence of this paragraph.

The 50 megohm insulation resistance requirement is incompatible with the high density packaging techniques currently used for solid state and micro-electronic assemblies. The best methods for fabricating multilayer printed circuit boards will not provide 50 megohms isolation between circuits. Also 50 megohms resistance between circuits and case is difficult to achieve when conductive heat dissipation methods are used as recommended in Paragraph 3.2.7.3.5 of this specification.

Compliance with this requirement can be demonstrated by procedures contained in MIL-STD-202, Methods 301 and 302 if the following recommended changes are incorporated.

Recommendation

Revise the requirement as follows:

Change the third sentence to read,

> "When a component or connector has a lower design voltage limitation, both dielectric stress and insulation resistance tests shall be run at an appropriate lower voltage as defined by component specifications."

Add the following sentence at the end of this paragraph,

> "For solid state and miniature devices or assemblies the minimum insulation resistance shall be as defined by the component specification."

Requirement

3.2.7.3.2 Microelectronics. When used, microelectronic devices shall conform to the provisions of MIL-M-38510.

Comparison

Qualification to MIL-M-38510 was not a requirement for microelectronic devices used in YF-17 flight control electronics. Whenever practical microcircuits were selected from military standard parts but not necessarily qualified to MIL-M-38510. For packaging efficiency some specially designed hybrid circuits and customized standard integrated circuits are used which have not been qualified to MIL-M-38510. The YF-17 is not in compliance with the requirements of Paragraph 3.2.7.3.2.

Discussion

The use of specially designed and newly developed microelectronic devices in the YF-17 flight control electronics was necessary to achieve the minimal size, weight and power design objectives for these electronic assemblies. If the selection of devices had been limited to microcircuits qualified to MIL-M-38510, severe size, weight and power penalties would have resulted, and possibly some compromises in functional performance. The time span required to qualify a microelectronic device to MIL-M-38510 is so long and the evolution of microcircuit technology is so rapid that often by the time a particular device is qualified it is obsolete.

This requirement is too restrictive for future aircraft procurement. The cost and time delay involved in qualifying new devices would discourage the use of the kind of advanced microelectronic technology needed to build future digital fly-by-wire flight control electronics. Northrop feels that compliance with this requirement would defeat the intent of the recommendation concerning microelectronics contained in the Users Guide for MIL-F-9490D:

> "The use of microelectronic technology should be considered in the design of all systems/equipment. An objective appraisal of all factors concerning the system/equipment design should be made with the view of maximizing reliability and minimizing total cost of ownership, weight, and space within the envelope of the other performance parameters of the design."

Recommendation

Revise the requirement as follows:

> "The use of microelectronic devices shall be in accordance with the FCS specification 4.4.2. Microelectronic devices conforming to the provisions of MIL-M-38510 and available from qualified sources shall be used in preference to other similiar devices."

Requirement

3.2.7.3.3 Burn-In. All electronic LRUs shall receive a minimum of 50 hours burn-in operation and testing prior to assembly, or after assembly if such is more meaningful, prior to installation. Performance after burn-in shall be within specified tolerances.

Comparison

The YF-17 flight control electronic LRU's are in compliance with this requirement by virtue of the extended testing of the units prior to installation. A specific burn-in requirement was not included in the product function specifications for these units since this was a prototype development program and extensive evaluation testing was planned.

Discussion

Burn-in is a most critical requirement in the manufacturing and test cycle of most electronic LRU's. Burn-in permits part weakness and/or errors in fabrication to be wrung out of the end product prior to field operation, thereby insuring a lower failure rate after delivery. The procuring agency must have the final word and dictates in the specifics of the burn-in procedure. Environmental conditions of the test, test duration, pass/fail criteria, and performance requirements during and after test should be spelled out clearly in the burn-in test procedure under the guidance of the procuring activity to make the test effective.

The burn-in requirement is valid for future aircraft procurement but should be made more specific to insure effectiveness of the process.

Recommendation

Revise the requirement as follows:

> "All electronic LRU's shall receive a minimum of 50 hours burn-in operation and testing prior to assembly, or after assembly if such is more meaningful, prior to installation. Burn-in environmental conditions and pass/fail criteria shall be as specified in the individual equipment specifications subject to the approval of the procuring activity. Performance during and after burn-in shall be within the specified tolerances contained therein."

Requirement

3.2.7.3.4 Switches. The design of special electric/mechanical switches, other than toggle switches, shall be subject to the approval of the procuring activity.

Comparison

Only three special electric/mechanical switch designs, other than toggle switches, are used on the YF-17. One specially designed slide switch is mounted on the throttle control which is used for control of the speed brake. Two lighted push button switches are mounted on panels in the cockpit. One push button is used to set take off trim and the other to initiate built-in-test of the flight control system. Use of these special switches was approved by the procuring activity as parts of the complete flight control system. No separate approval was obtained for these switches since the YF-17 was not designed to this specification. The YF-17 flight control system is in compliance with the requirement of Paragraph 3.2.7.3.4.

Discussion

This paragraph provides adequate control over part selection, and control of design and development of electric/mechanical switches used in flight control systems. The requirement is not too restrictive for future aircraft procurement and compliance can be easily demonstrated.

Recommendation

Retain the requirement as stated.

Requirement

3.2.7.3.5 Thermal design of electrical and electronic equipment. 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.

Comparison

All electrical and electronic components used in YF-17 flight controls are designed for simple conductive, radiation, and free convection cooling utilizing the ambient heat sink to maintain components within permissible operating temperature limits. Some high temperature induced failures of flight control electronic components occurred during flight tests at Edwards Air Force Base. The failures occurred only during the most severe operating conditions such as high speed low altitude flight or operation on the ground without engines running (no environmental control system). Several factors contributed to this problem which was basically a failure to maintain the ambient temperature in the area where flight control electronics assemblies were located within specified limits. The problems were resolved by supplying forced cooling to a non-flight control unit located adjacent to the flight control electronics assemblies, and by restricting ground operation without either engines running or auxiliary cooling provided. With this restriction the YF-17 is in compliance with Paragraph 3.2.7.3.5.

Discussion

The requirement is valid for current and future aircraft procurement. This requirement provides a valuable guide for the design and development of flight control electrical and electronic equipment. The significance of this requirement is greatly increased when applied to critical components, those which provide essential, or flight phase essential functions. If a critical component requires forced cooling, then the means of providing that cooling becomes critical and the same requirements for redundancy and fail-operate performance will apply to the cooling system. This is a strong argument in favor of the simple conductive, radiation, and free convection cooling methods recommended in this requirement. Compliance with this requirement can be demonstrated during environmental and flight qualification testing.

Recommendation

Retain the requirement as stated.

Requirement

3.2.7.3.6 Potentiometers. Resistive variable voltage dividers shall not be used in dynamic motion applications such as sensor outputs or feedback output devices without specific approval by the procuring agency.

Comparison

No resistive variable voltage dividers are used for dynamic motion applications in the YF-17 primary flight control system. All high frequency application sensor and feedback transducers are either synchro or LVDT type devices. Only one secondary flight control subsystem utilizes a potentiometer, the engine bleed air door position sensor. This is a low duty cycle application in which the door moves to one of four discrete positions: (1) ground operation (weight or wheels), (2) flight at less than Mach 1.4, (3) flight between Mach 1.4 and 1.6, and flight above Mach 1.6. The YF-17 is compliant with the requirement of Paragraph 3.2.7.3.6.

Discussion

The intent of this paragraph to preclude the use of potentiometers in applications where the requirements for reliability and operational life exceed the demonstrated capability of available devices is valid. However, the requirement as stated is too broad in scope and too restrictive for future aircraft procurement. The specification of "dynamic motion" does not distinguish between low duty applications such as control surface position sensors. Historically the unreliability of potentiometers as dynamic motion sensors led to the use of synchro and LVDT devices. However, significant improvements have been made in potentiometer designs, and potentiometers offer advantages, such as simpler A/D conversion, compared with AC devices.

The requirement as stated in 3.2.7.3.6 would discourage the use of potentiometers in applications for which they are presently well suited, and tend to discourage the future development of potentiometers with performance equal to or better than currently used transducers.

Recommendation

Revise the requirement as follows:

> "Special precautions shall be exercised in the specification and procurement of resistive variable voltage dividers for dynamic motion applications, to insure that reliability and operational requirements are adequately specified and compliance is verified. Resistive variable voltage dividers shall not be used in high frequency dynamic motion applications (requiring more than 500,000 cycle life) without specific approval by the procuring agency."

Requirement

3.2.8 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.

3.2.8.1 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. The materials shall have no adverse effect upon the health of personnel when used for their intended purposes. This requirement shall be met for all probable failure modes and in the required environments.

3.2.8.1.1 Metals. Metals used in flight control system components shall be selected in accordance with the criteria and requirements specified in AFSC Design Handbook DH 1-2, Design Note DN 7A1, Metals.

3.2.8.1.2 Nonmetallic Materials. Nonmetallic materials, shall conform to the requirements specified in AFSC Design Handbook DH 1-2, Design Note DN 7A2, Nonmetals.

3.2.8.1.3 Electric wire and cable. Electrical wire cables containing up to seven conductors shall be constructed in accordance with MIL-C-27500. Airframe wire bundles may be constructed in accordance with contractor developed techniques provided such construction is approved by the procuring activity.

3.2.8.2 Processes

3.2.8.2.1 Construction processes. Heat treating, adhesive bondings, welding, brazing, soldering, platting, drilling, and grinding of high strength steels, materials inspection, castings, forgings, sandwich assemblies, and stress corrosion factors used in the fabrication of flight control system components shall comply with the requirements specified in AFSC Design Handbook DH 1-2, Design Note DN 7B1, Construction.

3.2.8.2.2 Corrosion protection. All flight control system component parts, except those inherently resistant to corrosion in the operational environments, shall be finished per AFSC design Handbook DH 1-2, Design Note DN7B2, Corrosion.

3.2.8.2.3 Fabrication of electrical and electronic components. The applicable requirements in AFSC Design Handbook DH 1-6, Design Note DN3H1, Electrical/Electronic Safety Design Considerations, relating to the fabrication of electrical and electronic components shall be met.

Comparison

The selection and treatment of materials, the processing, and assembly of components for the YF-17 are marginally compliant with the specification requirements. Those materials or processes not controlled by military specifications are controlled by Northrop materials and process specifications and

Northrop engineering standards. These process specifications and standards are subject to approval by the procuring agencies.

Commercial standard materials and processes were employed in some cases to facilitate schedule or avoid excessive costs. The substitute materials or processes were usable on a prototype aircraft without compromise in quality and without impact on logistics and life-cycle cost as would be the case in a production aircraft.

Discussion

The requirements specified are consistent with high quality standards required for military aircraft. The procedure of approving documented contractor techniques as specified in paragraph 3.2.8 is endorsed as the best course for maintaining quality and at the same time advancing the state of the art. Proof of compliance with requirements is not practical by the process of inspection of components but should be established by certification.

Recommendation

Retain the requirements as stated.

Requirement

3.2.8.3 Assembling

3.2.8.3.1 Mechanical joining. Individual parts may be mechanically joined with removable fasteners, or by riveted or threaded connections, or by qualified methods for permanent joining.

3.2.8.3.1.1 Joining with removable fasteners. All removable fasteners shall be selected and used in accordance with the applicable requirements specified in AFSC design Handbook DH 1-2, Design Notes 4A1, General Requirements, 4A3, Bolts, Nuts, and Washers; 4A4, Screws; 4A5, Pins; and 4A6, Other Fasteners except as follows:

a. Bolts smaller than 1/4 inch diameter shall not be used to make single-bolt connections or connections essential to proper functioning of the component.

b. Each removable bolt, screw, nut, pin, or other removable fastener, the loss of which would degrade operation below FCS Operational State III, shall incorporate two separate locking or retention devices either of which must be capable of preventing loss of the fastener by itself and retain it in its proper installation with the other locking or retention device missing, failed, or malfunctioning. Where self-retaining bolts are used, their selection and installation shall be within the limitations of MS33602, and only one type shall be used in any given system.

c. No self-locking nut may be used on any bolt subject to rotation in operation unless a nonfriction locking device is used in addition to self-locking device.

d. Lockbolts listed in AFSC Handbook DH 1-2, Design Note 4A5, Swaged-Collar-Headed Straight Pins and Collars, may be used for fastening applications not requiring removal on the aircraft.

3.2.8.3.1.2 Joining with rivets. Rivets for all riveted joints shall be selected and used in accordance with the requirements specified in AFSC Design Handbook DH 1-2, Design Note 4A2, Rivets.

3.2.8.3.1.3 Threaded joints. All threaded joints shall be provided with adequate wrenching and holding provisions for assembly and disassembly of the joint before and after service use. Internal screw threads and external rolled threads shall be in accordance with the thread form requirement of MIL-S-8879. Pipe threads shall not be used.

3.2.8.3.2 Joint retention. All adjoining parts shall be secured in a manner that will preclude loosening when subjected to internal or external loads or vibration.

3.2.8.3.2.1 Retention of threaded joints. All threaded joints which carry critical loads shall be positively locked in the assemmbled position so that load reversal at the threads is prevented. The use of jam locknuts alone is not a positive locking means unless lockwired or otherwise restrained.

3.2.8.3.2.2 Retention of removable fasteners. Unless restrained from moving by the attachment of adjoining parts, all removable fasteners shall be positively locked in place. Self-locking externally threaded fasteners shall not be used except within the limitations specified in MS15981, and self-locking nuts shall not be used except within the limitations specified in MS33588. All other types shall incorporate positive locking means or be safetied with cotter pins in accordance with MS24665, where temperature and strength permit, or be safety wired. Cotter pins and safety wiring shall be installed in accordance with MS33540.

3.2.8.3.2.3 Use of retainer rings. Retainer rings shall not be used to retain loaded parts unless the rings are positively confined by a means other than depending on internal pressure or external loads. They shall not allow freeplay which could result in structurally destructive action or fatigue failure of the retained parts or failure of gaskets or packings. Where used, retainer rings shall be commercially available types which can be installed and removed with standard tools.

Comparison

Mechanical joining and joint retention in the YF-17 are compliant with the foregoing requirements. Impedance type self-retaining bolts, MS27576, are used extensively in the horizontal tail controls for pitch and roll, rudder controls and leading edge flap controls. Conventional fasteners are specified in the trailing edge flap controls and throttle controls because of non-critical requirements. Design criteria for application of self-retaining bolts is specified in the AFSC DH 1-2, DN 4A3-1.9.1 as follows:

> A joint is defined as "critical" if it meets both of the following requirements:
>
> a. Separation could prevent pilot control of the aircraft, resulting in flying qualities less than level III as defined in MIL-F-8785.
>
> b. Requires disassembly to perform any aircraft field maintenance or to provide access for maintenance or other subsystems.

Redundant control paths in the horizontal tail controls and dual rudders make most joints non-critical for disconnection. Impedance bolts were used in these joints to increase the margin of protection against a step input or system jam that could result from a loose rod, crank, nut, or bolt.

Lockbolts are employed in the linkage joints on the horizontal tail and rudder surface actuators to provide nondisassembly joints for safety.

Discussion

Paragraph 3.2.8.3.1.1b is a restatement of requirements for self-retaining bolts as specified in AFSC DH 1-2, DN 4A3-1.9.1 and does not represent an exception as written. The criteria given in AFSC DH 1-2 provides a clear definition of those joints that are critical and should be provided with an extra margin of protection, but clarification would be useful. The use of self-retaining bolts in noncritical joints should provide an increase in flight safety to justify the higher cost, weight, and size of the self-retaining bolt.

The design requirements for joints and fasteners in flight control systems are critical and should be included in the design specification but as a practical matter are not subject to demonstration of proof of compliance by inspection, test, or analysis. These requirements may be classified as design objectives with procedures for documenting any and all deviations.

Recommendations

Revise the requirement as follows:

Change paragraph 3.2.8.3.1.1b to read,

> "Self-retaining bolts shall be used in linkage joints defined as critical in accordance with AFSC DH 1-2, DN 4A3-1.9.1. Self-retaining bolts may be used in noncritical joints where the greater cost, weight, and envelope size can be justified."

Requirement

3.2.8.3.3 Assembly of electronic components

3.2.8.3.3.1 Electrical and electronic part mounting. Electronic parts shall be mounted so that ease of producibility and maintainability is assured. Whenever feasible, parts such as resistors, capacitors, etc. shall be mounted in an even, regular, row-type arrangement. These parts shall be mounted on a base so that the leads do not cross other leads or connections. Heavy electronic parts and assemblies shall be solidly mounted so that adverse effects when subjected to vibration and shock are minimized.

Comparison

Electrical and electronic components for YF-17 flight controls were assembled in accordance with applicable requirements of MIL-STD-454B and MIL-E-5400L. The requirements for workmanship of MIL-STD-454, Requirement 9-3 are in essential agreement with the producibility and maintainability requirements of 3.2.8.3.3.1. The mounting of parts was in accordance with MIL-E-5400.

Heavy parts were securely mounted to withstand the vibration and shock environment of the YF-17 aircraft.

Electrical and electronic components used in YF-17 flight controls are in essential compliance with requirements of Paragraph 3.2.8.3.3.1.

Discussion

This paragraph provides some general guidelines for mechanical design of airborne electronic equipment which are consistent with standard practice in the industry. The requirement is valid and compliance can be demonstrated by visual inspection.

References to more detailed and informative paragraphs of MIL-E-5400 and MIL-STD-454 would provide additional valuable guide to the design and assembly of electronic components.

Recommendation

Revise the requirement as follows:

Change the first sentence to read,

> "Electronic parts shall be mounted in accordance with MIL-E-5400 and MIL-STD-454, Requirement 9, with special consideration to assure ease of producibility and maintainability."

Requirement

3.2.8.3.3.2 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 or bonding. All mating surfaces shall be clean and shall be carefully fitted, as necessary, 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.

Comparison

Electronic components for the YF-17 flight control system were fabricated and assembled in accordance with applicable requirements of MIL-B-5087B, Bonding, Electrical, (for aircraft), and MIL-STD-461A, Notice 3, Electromagnetic Interference Characteristics Requirements for Equipment. Compliance with this requirement was demonstrated by tests conducted per MIL-STD-462 and MIL-E-6051D. The YF-17 flight control system is fully compliant with this requirement.

Discussion

This requirement is in agreement with other military standards and specifications pertaining to the fabrication and assembly of electronic equipment for military aircraft and is consistent with standard practices in the industry. The requirement is valid for future aircraft procurement and compliance can be demonstrated in the performance of standard electromagnetic compatibility tests.

Recommendation

Retain the requirement as stated.

Requirement

3.2.8.3.3.3 Isolation of redundant circuits. Redundant circuits shall be isolated from each other to preclude failure of one portion of the circuit from affecting any other circuit.

Comparison

All redundant circuits used in YF-17 Flight Control Electronics are isolated to preclude failure of one circuit from affecting other circuits. This isolation is accomplished in several ways: (1) redundant signals are routed through separate connectors on electronic assemblies, (2) separate ground or signal return wires are provided for each redundant signal path, (3) redundant circuits are mounted on different circuit cards.

The YF-17 is fully compliant with the requirement.

Discussion

The requirement is simply and clearly stated and is necessary to achieve the purposes for which redundancy is employed. The requirement is valid for future aircraft procurement and compliance can be demonstrated by analysis of designs for flight control electronic assemblies. It may be noted that this requirement is essentially duplicated in Paragraphs 3.2.4.1.3.2 and 3.2.4.3.1; however, reiteration is not considered detrimental to the specification.

Recommendation

Retain the requirement as stated.

Requirement

3.2.8.3.3.4 Electrical connector installation. The number of electrical connectors shall be kept to a minimum within the required limitations for separation of redundant circuits. Connectors shall be mounted to preclude nuisance warning indications and intermittent operation when subjected to applicable temperature differentials, vibration, and shock. They shall be polarized so that it is impossible to mismate them on a particular piece of equipment.

Comparison

The design of electronic assemblies used in YF-17 flight control system minimizes the number of electrical connectors within the limits required for separation of redundant circuits. Four connectors with 131 contacts each were used for the Control Augmentation System - Electronic Component Assembly (CAS-ECA). The associated electronic assemblies, such as the dual rate gyro packages for pitch, roll, and yaw, and the dual accelerometer packages for normal and lateral acceleration, utilized a single electrical connector for each dual sensor assembly. Separation of redundant command and feedback signals were provided in the CAS-ECA connectors but redundant motion sensor signals were routed through the single connector on the sensor assemblies, consistent with the requirement for fail-safe CAS operation.

The procurement specifications for flight control electronics assemblies (including electrical connectors) imposed requirements for normal operation when exposed to the range of environmental conditions (altitude, temperature, vibration, and shock) anticipated for the YF-17 aircraft.

Unsupported cable connectors, where used, were keyed to preclude mismating. The four connectors for the CAS-ECA unit were rack mounted rather than keyed to prevent mismating.

The YF-17 is judged to be in compliance with the intent of all requirements in Paragraph 3.2.8.3.3.4.

Discussion

The requirement for mounting connectors so they will withstand applicable environmental conditions is valid but is unnecessary in this paragraph because of more stringent and specific requirements provided elsewhere in MIL-F-9490D, e.g., Paragraph 3.1.9.

Additional factors should be considered in minimizing the number of electrical connectors in a flight control system. Northrop's experience with the four 131 pin connectors used on the CAS-ECA unit is that the large number of connections created fabrication and maintenace problems. The wires were difficult to install, and the resulting cable was difficult to install in the aircraft and almost impossible to repair. A design using eight connectors with 65 pins each would have provided a more producible and maintainable system with a small penalty in size and weight. Another consideration when attempting to minimize the number of connectors is the separation of sensitive signal circuits from conductors carrying large AC or transient DC currents.

The objective of making it impossible to mismate connectors can be achieved with a rack and panel design as well as polarizing or keying the individual connectors on a piece of equipment.

Recommendation

Revise the requirement as follows:

> "The number of electrical connectors shall be kept to a minimum within required limitations for separation of redundant circuits and with due consideration given to the producibility and maintainability of the design and to isolation of sensitive signal circuits. Connectors shall be keyed, polarized, or rack mounted so that it is impossible to mismate them on a particular piece of equipment."

Requirement

3.2.8.3.3.5 Cleaning of electrical assemblies. All electrical assemblies shall be thoroughly cleaned of loose, spattered, or excess solder, metal chips, or other foreign material after assembly. Burrs, sharp edges and resin flash shall be removed.

Comparison

Electrical assemblies used in YF-17 flight controls were assembled in accordance with requirements for workmanship contained in MIL-STD-454B Requirement 9. The YF-17 is in full compliance with the requirements of Paragraph 3.2.8.3.3.5.

Discussion

This paragraph specifies only minimal requirements for cleaning of electrical assemblies and does not assure adequate quality in components for flight control systems. The requirements for workmanship specified in MIL-STD-454E, Requirement 9, Paragraph 2 and 4, 1 November 1974, would provide a more comprehensive guide to cleaning of electrical components.

Recommendation

Revise the requirement as follows:

"All electrical assemblies shall be cleaned in compliance with applicable paragraphs of MIL-STD-454, Requirement 9."

Requirement

3.2.9 Component installation

3.2.9.1 Basic requirements. Flight control system components shall be installed in compliance with the applicable requirements specified in AFSC Design Handbook DH 1-6, Section 3J, Flight Control Systems, including Design Note 3JX, Safety Design Check List, and as specified herein.

3.2.9.2 Locating components. System components shall be located to provide direct routing of the control system signal and power transmission elements (cables, rods, lines, wires, etc.) in accordance with Design Note 3J1, Routing and Separation, only to the extent that the components and transmission elements are not exposed to undue hazards.

3.2.9.3 Installations in fuel system areas. All component installations in fuel system areas shall preclude the generation of sparks both during normal operations and possible abnormal and failure conditions.

Comparison

Installation of components in the YF-12 are compliant with the safety provisions requirements. Specific components are described under systems requirements.

All controls located in areas of the fuselage that are adjacent to a fuel cell or include fuel lines are subject to explosion-proof requirements. All electrical actuators in the FCS meet explosion-proof requirements.

Discussion

Compliance with component installation requirements affecting safety, reliability and performance characteristics is not easily demonstrated by test or inspection. These requirements should be established as design objectives to be evaluated by analysis and subject to special review by the procurement agency and the contractor in accordance with current practice.

It is sometimes the case that a hazardous atmosphere may exist because of oxygen, alcohol, hydraulic fluid, or other elements other than fuel and should require explosion proof design treatment. This safety requirement should invoke consideration of these possibilities as well as for fuel.

Recommendation

Revise the requirement as follows:

Replace paragraph 3.2.9.3 in its entirety with the following,

"3.2.9.3. Installation in Hazardous Atmospheres. All component installations in areas which could possibly contain flammable fluids or vapors from any source shall not cause ignition of the flammable atmosphere when operating in such atmosphere including abnormal or

Requirement

4.2.1 Piloted simulations. Piloted simulations shall be performed during FCS development. As a minimum, the following simulations shall be accomplished:

a. Piloted simulations using computer simulation of the FCS prior to hardware availability.

b. Piloted simulations using actual FCS hardware prior to first flight.

Comparison

Piloted, or "man-in-loop," simulation played an important role in the definition and validation of the YF-17 FCS. In view of the high maneuverability of the aircraft, proper simulation of both visual cues and kinematic force effects was considered essential to the validity of the results. For this reason, practically all of the piloted simulation was motion-based. The airframe was represented by 6-DOF nonlinear equations, constantly updated as new wind tunnel test data became available or flexibility corrections were revised, to permit evaluation under all maneuvering conditions. High alpha effects, including buffet and wing rock, also were simulated. The FCS was represented by mathematical models that included all known or predicted nonlinearities, such as deadband, preload, friction, hysteresis, velocity, or displacement limits. The mathematical models were updated or refined as test data from actual hardware became available. By the use of adjustable force loading servos, the pilot was provided with representative "controls feel" characteristics.

The objective of the piloted simulation was:

a. Refinement of control laws: gains, feed-forward/feed-back blends, filter constants.

b. Refinement of pilot-FCS interface characteristics: force, displacement, cross-control harmony.

c. Evaluation of FCS hardware effects on handling qualities: ideal hardware model versus actual hardware characteristics, sensitivity to parameter variations.

d. Evaluation of failure effects: failure transient, recovery, degraded mode.

e. Pilot indoctrination.

A full-scale operational mockup, including FCS hardware, hydraulics, aerodynamic surfaces, computer tie-in capability, and basic cockpit displays, was available prior to first flight and was used extensively for open- and closed-loop systems checkout, comparisons to simulated hardware, and qualification. Test results were also used to update mathematical models and controls feel characteristics on the motionbased simulator. With these updates, the motion-based simulator was considered more representative of the actual aircraft, and the fixed-base operational mockup was not used for pilot simulation.

It is concluded that moving-base piloted simulation effort on the YF-17 satisfied the intent of the subject requirement and effectively contributed to the development of the FCS and its integration into the total aircraft system.

Discussion

Paragraph 4.2.1 appears to limit the objectives of piloted simulation to an evaluation of the effects of actual versus ideal FCS hardware characteristics, rather than considering it as a tool for both development and validation, that is, an extension of the analytical process. In any case, it fails to state specific objectives.

Fixed-base piloted simulation, as implied herein, is considered adequate only for aircraft with minimal maneuvering requirements (takeoff, cruise, landing). For highly maneuverable aircraft, in consideration of the importance of both motion and acceleration onset to the pilot, moving-base simulation is indicated. The FCS must satisfy the handling qualities requirements of MIL-F-8785B (ref. Paragraph 3.1.1.1 of MIL-F-9490D); consequently, the test program must be geared, both in scope and in techniques, to provide some assurance of meeting these requirements. As a minimum, piloted simulation should demonstrate that no severe PIO tendencies exist and that recovery from critical failures is positive and safe. Similar requirements stated in Paragraph 4.3.2.2 do not provide adequate assurance in these areas, as they do not require pilot-in-the-loop evaluation of FCS performance and FCS failure effects.

Recommendations

Revise the requirement as follows:

> "Piloted simulations shall be performed during FCS development. The objectives of the simulation shall be to (1) assess the influence of actual hardware on control characteristics from pilot "feel" and handling qualities points of view, (2) evaluate hardware failure effects, with particular emphasis on developing pilot recovery techniques, and (3) assess handling qualities with degraded FCS operation.
>
> For highly maneuverable aircraft, the importance of motion cues in evaluating certain handling characteristics and failure recovery may indicate a need for conducting a portion of the piloted simulation effort on a motion-based simulator.
>
> The scope of the piloted simulation effort, including possible requirements for motion-based simulation, shall be established prior to the test program and approved by the procuring activity."

Additional Data

Add as discussion following the statement of the requirement 4.2.1 Piloted simulation in the Users' Guide:

> "For highly maneuverable aircraft, in consideration of the importance of both motion and acceleration onset to the pilot, moving-base simulation is indicated. The FCS must satisfy the handling qualities requirements of MIL-F-8785B (ref. Paragraph 3.1.1 of MIL-F-9490D); consequently, the test program must be geared, both in scope and in techniques, to provide some assurance of meeting these requirements As a minimum, piloted simulation should also demonstrate that no severe PIO tendencies exist and that recovery from critical failures is positive and safe. Similar requirements stated in Paragraph 4.3.2.2 do not provide adequate assurance in these areas, as they do not require pilot-in-the-loop evaluation of FCS performance and FCS failure effects.

Requirement

4.3 Test requirements

4.3.1 General test requirements

4.3.1.1 Test witness. Before conducting a required test, the contractor shall notify an authorized procurement activity representative. An orientation briefing on specific test goals and procedures shall be given procuring activity observers prior to any required test sequence to be monitored by an observer.

Comparison

The procedure given by this requirement was complied with for the YF-17 and system test work orders were witnessed by USAF representatives.

Discussion

The implementation of this requirement requires considerable coordination between the contractor and the procurement activity. Although not specifically required by this paragraph, the submittal of a written test plan to the procurement activity would help in the scheduling and coordination of the tests and their observers.

Recommendation

Retain the requirement as stated.

Requirement

4.3.1.2 Acceptance tests. Appropriate FCS acceptance tests will be defined by the procurement detailed specification.

Comparison

System acceptance tests for the YF-17 flight control system were written by Northrop as inspection test work orders. These tests defined the tests to by performed on a complete system with all components installed. The acceptance test for an individual component was written by the vendor supplying that component. The acceptance test procedure was then submitted to Northrop for a revision/approval cycle.

The YF-17 is considered to be in compliance with the intent of this requirement.

Discussion

The scope and objectives of FCS acceptance tests should be defined by the procurement detailed specification. However, the actual details of the tests to be performed are generally so lengthy that they are best provided in separate documents.

The general nature of the wording of this requirement provides sufficient latitude for its implementation for present and future military aircraft.

Recommendation

Retain the requirement as stated.

Requirement

4.3.1.3 Instrumentation. Accuracy of instruments and test equipment used to control or monitor test parameters shall have been verified since its last use prior to initiation of the sequence of design verification tests. All instruments and test equipment used in conducting design verification tests shall:

a. Conform to laboratory standards whose calibration is traceable to the prime standards at the U.S. Bureau of Standards.

b. Be accurate to within one third the tolerance for the variable to be measured.

c. Be suitable for measuring the test parameter(s).

d. Be verified no less frequently than every 12 months.

Comparison

Northrop instrumentation, including that used on the YF-17, is maintained on a periodic basis no less frequently than every 12 months by a Northrop calibration laboratory. Calibration instrumentation is traceable to the standards at the U.S. Bureau of Standards. No firm instrumentation tolerances were established for the YF-17 for the variables to be measured. The required instrumentation resolution and accuracy were left to the judgment of the test engineer.

The YF-17 partially complies with this requirement.

Discussion

This paragraph provides suitable requirements for instrumentation used for measurements of FCS test parameters.

Recommendations

Retain the requirement as stated.

Requirement

4.3.1.4 Test conditions. The contractor shall establish operation test conditions which accurately represent system in-service usage throughout the applicable flight phases and flight envelopes defined in accordance with MIL-F-8785 or MIL-F-83300.

Comparison

Laboratory testing of the complete FCS was conducted at room ambient temperature and pressure, using the full scale test stand. Variations in aircraft hydraulic and electrical systems were simulated. The test parameters represented only limited portions of the flight envelope.

Test conditions for procured items, components and subassemblies, represented expected extremes of temperature, altitude, vibration, and power variations. These environmental tests were performed by the suppliers.

The flight test program was conducted at the Edwards Flight Test Center in California and was representative of in-service usage with the exception that no extreme ground temperatures, particularly low temperatures, were encountered.

The YF-17 partially complies with the requirement.

Discussion

Accurate representation of system in-service usage of the complete FCS is not pratical under laboratory conditions and is hard to achieve even under flight test conditions. However, the expected extremes of the environment encountered in service can be easily established and components can be tested to them. Mechanical subassemblies and installations (cable runs, for instance) are again difficult to test, and the expected in-service usage must be considered in the design phase.

The requirement is too stringent in requiring accurate representation of in-service usage. It is incomplete in that it fails to address the ground environmental extremes expected throughout the geographical area of development.

Recommendation

Revise the requirement as follows:

> "The contractor shall establish operational test conditions on the component and system level which adequately represent in-service usage throughout the applicable geographical area of deployment and the applicable flight phases and flight envelopes defined in accordance with MIL-F-8785 or MIL-F-83300."

Requirements

4.3.2 Laboratory tests

4.3.2.1 Component tests. All components shall be qualified to the applicable component specification by individual tests, by proof of similarity to qualified components which are qualified under conditions applicable to the specified operating conditions, by testing in system design verification tests, or suitable combinations of these methods. Component qualification requirements shall be based upon their use in the specific vehicle and its associated environment. Environmental test methods and procedures shall be selected from MIL-STD-461, or MIL-STD-810. The contractor shall generate additional methods and procedures where MIL-STD-461 or MIL-STD-810 are inadequate for the planned aircraft usage. Wear life 3.1.12 shall be demonstrated at the component level except where system wear life is more meaningful due to component interaction.

Comparison

Due to the prototype nature of the YF-17 program, extensive use of qualification on the basis of similarity was employed whenever justifiable. Components developed specifically for the YF-17 were subjected to a limited qualification program in accordance with Northrop Report NOR 72-101, Environmental Test Guidelines for the YF-17 Prototype. This report defined the applicable test methods and procedures and established the environments associated with various locations throughout the aircraft. It was also used to judge the applicability of prior qualification in establishing the rationale for qualification by similarity. Limited life/wear testing was employed for selected components, particularly actuators, as discussed in the validation for Paragraph 4.3.2.3.1. The YF-17 is in partial compliance with the requirements.

Discussion

Component test requirements are consistent with standard practice and are deemed complete and clearly defined. Compliance can be demonstrated by documentation of test requirements and test results.

Recommendation

Retain the requirement as stated.

Requirement

4.3.2.2 Functional mockup and simulator tests. Where one of the first airplanes in a new series of aircraft will not be available for extensive testing of the FCS prior to flight of that model, an operational mockup which functionally, statically, and dynamically duplicates the flight control system shall be constructed. For Essential and flight-phase essential flight controls, an accurate electrical representation shall also be provided. Production configuration components shall be used for all flight control system parts, and the hydraulic system shall be compatible with MIL-H-5440 test requirements. Primary aircraft structure need not be duplicated; however, production configuration mounting brackets shall be used and shall be attached to structure which simulates actual mounting compliance. Mechanical components of the FCS shall be duplicated dimensionally. Inertia and compliance of flight control surfaces shall be duplicated or accurately simulated. The operational mockup shall be coupled with a computer simulation of aircraft characteristics and external inputs to the flight control system. The following minimum testing shall be conducted on the operational mockup, or other appropriate test facility when approved by the procuring activity.

a. Power supply variation tests to demonstrate satisfactory operation over the range of allowable variations specified in the applicable control power specifications referenced in 3.2.5.

b. System fatigue tests (where system installation geometry or dynamic characteristics are critical to fatigue life) in accordance with MIL-A-8867 to demonstrate compliance with the requirements of 3.1.11.3. The duty cycle required shall be established by the contractor as representative of flight and ground usage.

c. Stability margin tests to verify those requirements of 3.1.3.6 which can be verified by test using an aircraft simulation or the operational mockup, but which cannot be economically or safely demonstrated in flight.

d. Tests to determine the effects of single and multiple failures on performance, safety, mission completion reliability; and the development of emergency procedures to counteract the effects of failures.

e. Miscellaneous tests to demonstrate FCS performance, and compatibility among FCS systems and with interfacing systems.

f. System wear life 3.1.12 where component wear life is interactive.

Comparison

The functional mockup was constructed to duplicate the flight control system dimensionally, statically, and dynamically. Interfacing systems such as electrical and hydraulics were duplicated to verify critical performance criteria. Flight control systems hardware was mounted on a rigid steel frame.

Production configuration mounting brackets were used where required to closely simulate structural compliance. Production configuration structure was simulated for all the flight control surfaces except for leading edge flaps.

Surface compliance and inertia was controlled for each system to duplicate actual hardware. The speed brake control and actuation system was included in the operational mockup.

Capability for simulating airloads was incorporated for each control surface. The mockup was coupled with a computer simulation of aircraft characteristics and external inputs to the flight control system.

Systems and tests conducted including safety-of-flight tests are as follows:

1. <u>Pitch Control System</u>

   A. Validate system inspection test procedure.

   B. Cross plots

      1. Stick position vs. horiz. tail position

      2. Stick force vs. horiz. tail position

   C. Static balance characteristics

   D. System friction

   E. Minimum increment of control

   F. System stability

   G. System flexibility

   H. System control hysteresis

   I. Surface rate check with simulated air loads

2. <u>Roll Control System</u>

   A. Validate system inspection test procedure

      1. Stick-to-surface backlash

      2. Horizontal tail differential deflection

      3. Aileron trim range

      4. Aileron trim rate

      5. Stick breakout forces

      6. Stick centering accuracy

   B. System friction

C. Stick forces

D. Minimum increment of control

E. System stability

F. System hysteresis

G. Impulse-input characteristics

H. Stick release characteristics

I. Frequency response characteristics

J. Malfunction tests

3. Rudder Control System

A. Validate system inspection test procedure

1. Measure pedal force vs. pedal travel

2. Measure pedal travel vs. rudder travel

B. Rudder synchronization

C. System flexibility

D. Surface rate check

E. Impulse input characteristics

F. Pedal release characteristics

G. Frequency response characteristics

H. Surface backlash

I. Malfunction tests

4. Leading-Edge Flap Control System

A. Validate system inspection test procedure

1. Actuator-to-surface backlash

2. Actuator-to-servo backlash

3. Surface travel

4. No-load surface rate

5. Control actuator control loads

B. System friction

C. Minimum incremenc of control

D. Breakout forces

E. System control hysteresis

F. System rate check without air load

G. System time contant

H. Cycle test

I. Malfunction tests

5. Trailing-Edge Flaps

A. Validate inspection test procedure

1. Backlash checks

2. Control actuator vs. surface travel

3. Control rate

4. Control breakout forces

B. System friction

C. Minimum increment of control

D. Rate check with and without simulated air loads

E. Control actuator time constant

F. Cycle test

6. Speedbrake Control System

A. Validate inspection test procedure

1. Actuator travel vs. surface travel

2. Operating rate

B. System control rate with and without simulated airloads

C. Minimum increment of control

D. System stability

7. Control Augmentation System, CAS

A. General Test Objectives

1. Align, check, and validate total CAS performance prior to first flight using production hardware and simulated airframe dynamics under open-loop and closed-loop conditions.

2. Perform preliminary design checks of CAS interface systems for design requirements using a breadboard CAS system.

3. Perform flight justification tests on flight test hardware. Check and validate design requirements. These checks and tests to apply to all failsafe systems, BIT, and total CAS. Total CAS includes DADC, CAS panel, CAS ECA, all associated sensors and actuators.

B. Detail Test Objectives

1. Check CAS engagement/disengagement transients.

2. Validate system alignment and calibration requirements for system inspection checkout tests.

3. Evaluate dynamic and nonlinear characteristics of system hardware.

4. Establish flight test procedures for total CAS.

5. Perform failure mode analysis.

6. Evaluate the effect of the mechanical control system on CAS.

8. Hydraulic System

A. Validate system inspection test procedures.

B. Establish system filling and preflight procedure.

C. Pressure impulse survey

D. Emergency power unit pump operation

E. Normal system operation at ground idle

F. Low reservoir level tests

G. Emergency wheel brakes

H. Normal wheel brakes

I. Simulation of typical mission hydraulic system usage

J. Simulation of emergency usage of emergency power unit

K. Control surface actuator characteristics

1. Horizontal tail

2. Aileron

3. Rudder

4. Speed brake

5. Leading edge flaps

6. Trailing edge flaps

L. Flight test shutoff valve

M. Air eliminator

Discussion

The specified requirements for the functional mockup and simulator tests are consistent with the program established for the YF-17. Special note is given to the inclusion of fatigue and endurance testing with minimum testing to be performed on the mockup. The conduct of fatigue and endurance tests as required to comply with safety-of-flight test requirement is a recommended practice. The merit of endurance and fatigue testing on the mockup as required for production is questioned as a practical matter because of the conflict of schedules that develop. The special conditions required for accelerated testing for fatigue life of components are more practical on some test facility other than the functional mockup in most cases. However, this option is adequately covered in the wording of the requirement.

Recommendation

Retain the requirement as stated.

Requirement

4.3.2.3 Safety-of-flight tests. Prior to first flight, sufficient testing shall be accomplished to ensure that the aircraft is safe for flight. These shall be defined in the FCS development plan and shall include, but not be limited to, the following:

4.3.2.3.1 Component safety-of-flight tests. All system components shall successfully demonstrate satisfactory performance and satisfactory operation under the environmental extremes expected in the flight test program. Certification that a component is safe for flight because of prior qualification and use on other aircraft may be allowed provided that the component design is identical to the previously qualified part in all significant respects and that its capability to operate under all conditions specified for its new application has been proven.

4.3.2.3.2 System safety-of-flight tests. The complete system shall successfully pass all of the operational mockup tests specified in 4.3.2.2 prior to first flight except that only 20 percent of the required fatigue life demonstration need by completed.

Comparison

An extensive safety-of-flight certification program was conducted for the YF-17 with tests for flight controls components and systems consistent with these requirements.

Detail design criteria for systems and components such as required to support test criteria were documented in analyses listed for Para 4.1.1.1.

Table 2 is a representative list of the components of the flight control systems and the methods used to support certification for safety-of-flight. Additionally, components were subject to inspection tests to assure proper component performance prior to installation. Qualification on the basis of similarity was employed for safety-of-flight certification whenever justifiable.

System tests for safety-of-flight on the functional mockup were performed as itemized for Para 4.3.2.2. Special tests were conducted on the flight test airplane to demonstrate interface compatibility with structure, electrical, and hydraulic systems.

Life cycle testing was conducted to meet safety-of-flight requirements. The life cycles, tabulated in Table 3, ranged from 10% to 100% as deemed required to provide a level of confidence. Variable values were selected consistent with design complexity.

The YF-17 is in partial compliance with the requirement.

Discussion

The general requirements for component and system safety-of-flight tests are consistent with standard practice and provide a satisfactory standard for safety.

It is noted that 20% of required fatigue life demonstration is specified for safety-of-flight requirement. The 10% fatigue life tests employed for the YF-17 are justified as suitable for that program because of the limited objectives and minimal design risks involved. The 20% life test requirement for flight safety is deemed suitable for a pre-production flight test program.

Recommendation

Retain the requirements as stated.

TABLE 2 COMPONENT SAFETY-OF-FLIGHT TESTS

Components	Method of Qualification		
	Tests	Similarity	Prior Qual
16-73915-1 CAS Follow-up Act.	X		
LMT-199V-20 Linear Transducer		X	
16-73017-3 Pitch Cont. Load Limiter		X	
L12-87 Linear Trim Actuator		X	
16-73045-5 Feel Spring		X	
16-73005 Mixer Mechanism	X		
16-73017-15 Roll Cont. Load Limiter	X		
A218-957568-00 Stick Grip			X
16-73017-117 Roll Cont Load Limiter		X	
OS01186 Cable Tension Regulator		X	
16-73913-1 Flap Control Actuator	X		
LMT-769T02 Linear Transducer		X	
16-73911-1 CAS/MFAS Computer	X		
16-73912-1 Pilot's Control Assy	X		
16-73913-1 Pitch Rate Gyro Assy	X		
16-73913-3 Roll Rate Gyro Assy	X		
16-73913-5 Yaw Rate Gyro Assy	X		
16-73919-1 Normal Accelerometer		X	
16-73919-3 Lateral Accelerometer		X	

TABLE 3 LIFE CYCLE TESTS FOR SAFETY OF FLIGHT

Item	Cycles
Aileron Surface Actuator	50,000
Rudder Surface Actuator	500,000
Horizontal Tail Surface Actuator	50,000
L.E. Flap Control Actuator	50,000
T.E. Flap Control Actuator	50,000
L.E. Flap Surface Actuator	1,385,000

Requirement

4.3.3 Aircraft ground tests. Prior to first flight the following minimum testing shall be performed.

a. Gain margin tests to demonstrate the zero airspeed 6 dB stability margin requirements of 3.1.3.6 for feedback systems depending on aerodynamics for loop closure and to demonstrate stability margins for nonaerodynamic loops. Primary and secondary structure shall be excited, with special attention given to areas where feedback sensors are located with loop gains increased to verify the zero airspeed requirement.

b. Functional, dynamic and static tests to demonstrate that all FCS equipment items are properly installed and that steady state responses meet FCS specification requirements. These tests shall include integrated FCS and test instrumentation as installed on the prototype airplane. Compliance with the applicable residual oscillation requirements of 3.1.3.8 shall be demonstrated.

c. Electromagnetic interference (EMI) tests to demonstrate compliance with the requirements of 3.2.5.4.1. Measurement of interference limits shall be made in accordance with MIL-STD-461 and MIL-E-6051.

d. An integrity test to insure soundness of components and connections, adequate clearances, and proper operation in accordance with MIL-A-8867.

Comparison

a. Gain margin tests.

(1) Structural resonance tests and filter development - Structural resonance tests were first run without any notch filters in the system to identify structural modes. All three control augmentation axes, as well as the roll-to-yaw crossfeed, were engaged, and all primary control surface positions were recorded. Stick and rudder pedal raps were performed to excite structural resonance while system gains were set at twice the zero airspeed or normal level. (Note: "Normal Gain" refers to the design gain level established analytically prior to flight test evaluation.) Results of this test are shown in Table 4.

The high frequency modes (49, 95, 48 Hz) were not sustained by the augmentation system due to limited actuation bandwidth and therefore, not considered a problem. To eliminate coupling with the lower frequency modes, the bandwidth of the pitch secondary actuator was reduced from 100 radians/sec to 50 radians/sec, and the first set of structural filters shown in Table 5 was added to the system.

TABLE 4 STRUCTURAL RESONANCE, NO NOTCH FILTERS

Aircraft Configuration: No fuel, wingtip missiles, deflated tires

Axis	Resonant Frequency	Remarks
Pitch	11.6 Hz	Sustained oscillations
	30.3 Hz	
Roll	19.0 Hz	
	49 Hz	Damped oscillations/not sustained by the augmentation system
	95 Hz	
Yaw	48 Hz	

TABLE 5 STRUCTURAL (NOTCH) FILTERS

Axis	Filters (Hz)			Gain Margin
	1st Set	2nd Set	3rd Set	3rd Set Filter
Pitch	11.0/11.0	9.5/9.5	9.5/9.5	9 db
Roll	20.0/20.0	20.0/20.0	7.0/8.5 + 8 Hz lag	9 db
Yaw	20.5/20.5	8.0/8.0	8.0/8.0	6 db

With the notch filters installed and the pitch secondary actuator bandwidth reduced, the structural resonance test was rerun in empty weight configuration at twice, as well as at three times, the normal gain level. (Flight tests provisions allowed pilot selection of 1.5 times the normal gain level; hence, the objective was to demonstrate a 6 db gain margin with the maximum gain available to the pilot.) No resonance (sustained oscillation) was in evidence. A lightly damped 2.5 Hz oscillation appeared in roll that was attributed to the aircraft rocking on the landing gear. In addition, a 10 Hz oscillation that damped out in approximately 2 seconds also appeared in roll after especially severe lateral stick raps.

As moderate mode frequency shifts were expected as a function of fuel loading, the structural resonance test was rerun with full fuel, indicating a 9.5 Hz resonant condition in pitch.

A root-locus analysis, modeling the pitch augmentation system and the first four fuselage bending modes, was performed for both the empty fuel and the full fuel structural configurations. This analysis indicated that the full fuel configuration can be stabilized with a 9.5 Hz notch filter which would also provide an approximately 6 db gain margin for the empty fuel case. Consequently, the pitch notch filter was changed from 11 Hz to 9.5 Hz, and, at the same time, the yaw notch filter was changed from 20.5 Hz to 8 Hz to further improve the already acceptable damping of the 8.6 Hz lateral fuselage bending mode.

To validate the second set of notch filters, the structural resonance test was rerun indicating a more than adequate gain margin in all axes. However, continuing analysis of structural dynamics/control system compatibility indicated that an interaction potential existed under certain flight conditions between the approximately 7 Hz wing bending mode and the roll augmentation system. This interaction potential was consequently verified in flight during tests conducted specifically for this purpose.

For this reason, the roll axis symmetrical 20 Hz notch filter was replaced with a staggered 7.0 Hz/8.0 Hz notch filter and a cascaded 8 Hz lag filter was added to stabilize the 19.0 Hz mode. Ground resonance test and flight test with the final set of filters were satisfactory, and the gain margins shown in Table 5 were demonstrated.

(2) Ground Limit Cycle Tests - Limit cycle tests were conducted on all three control axes (one axis at a time) in accordance with the procedure described in NASA TN D-6867. The airframe was represented with the simplified, single-degree-of-freedom equation (control power with integration, K/S) on the analog computer, and only the rate feedback loops were closed. The actual gyros were bypassed as no convenient method of torquing the gyros was readily available. The computed aircraft rate was filtered to account for gyro dynamics and then applied to the control system electronics which incorporated the first set of notch filters. Computed rate and actual surface positions were recorded. Total loop gain, the product of control power and rate feedback gain, was increased in increments until a divergent limit cycle was obtained. At each gain increment, the respective surface was pulsed to determine limit cycle amplitude and frequency.

Limit cycle amplitude and frequency were plotted as a function of total loop gain to determine the maximum allowable total loop gain satisfying the following criteria: a) A minimum of 6 db gain margin before divergence occurs and b) limit cycle amplitude remaining below the level at which objectionable residual oscillations would be expected to occur in flight.

The predicted total loop gain was obtained for a sufficient number of flight conditions to represent the entire flight envelope. It was calculated from the rate feedback gain scheduling function and the value of the control derivative for the particular flight condition. Total loop gains were established for both flexible and rigid values of the control derivatives, for both normal and pilot-selectable maximum (1.5X normal) rate feedback gains, and, in the roll axis only, for both wing tip missiles on and wing tip missiles off configurations.

A thorough review of the above data by AFFTC (Edwards AFB) and Northrop personnel led to the following conclusions and recommendations (Reference: YF-17 Structural Resonance and Limit Cycle Tests, unpublished paper by Mr. Paul Kirsten, AFFTC/DOEEP, Edwards AFB, California).

(a) Predicted total loop gains for the yaw axis assured more than adequate gain margin.

(b) An approximately 6 db gain margin existed in the pitch axis with normal rate feedback gain and flexible control derivative. With maximim pilot selectable gain (1.5X normal) and assuming that the aeroelastic correction to the rigid control derivative was not fully applicable, the gain margin was substantially less.

(c) The roll limit cycle gain margin with normal gain, missiles on, flexible control derivative was barely acceptable. It was unacceptable with higher than normal gain, or missiles off, or if the aeroelastic correction to the rigid control derivative was not fully applicable.

(d) A cautious flight test program was indicated a view of the large flexibility effect predicted for the YF-17 aileron derivative.

(e) An in-flight limit cycle margin check at 15,000 ft. altitude, during a slow acceleration from 300 KT to 450 KT, was recommended for the pitch and, particularly, the roll axis.

In view of the roll axis/structure interaction predicted from flutter analysis, the maximum roll gain flown was 90% of normal with no indication of limit cycling tendency, as described in the section on In-Flight Structural Resonance and Limit Cycle Tests. With 30% of normal gain preferred from handling qualities point of view, the in-flight check in effect demonstrated a 9 db limit cycle gain margin.

No indication of pitch axis limit cycling tendency in-flight was found at 1.5 times normal gain, demonstrating an about 6 db limit cycle gain margin with the preferred pitch gain setting of 85% of normal.

With the procedures used in structural resonance and limit cycle tests, no need was seen to use frequency response techniques beyond verifying that the control system characteristics as installed in the aircraft matched those on the full scale controls test stand.

(3) In-Flight Structural Resonance and Limit Cycle Tests - The ground structural resonance and limit cycle tests demonstrated adequate stability margins for the pitch and yaw axes. The pitch axis was stabilized with a 9.5 Hz notch filter. The yaw axis, per se, did not require any structural filter. However, an 8 Hz notch filter was incorporated to reduce coupling between the 8.6 Hz lateral fuselage bending mode and yaw rate feedback that tended to reduce damping.

In the roll axis, structural dynamics/control system compatibility checks, using flutter analysis with active controls represented, predicted a potential instability that was not apparent during ground resonance tests. Furthermore, the limit cycle gain margin was judged insufficient, particularly with wingtip missiles off, considering that the large aeroelastic correction predicted for the roll control derivative may not be fully applicable. For these reasons, an in-flight evaluation of structural resonance and limit cycle characteristics was decided upon. The initial flights were flown at 10% of normal roll gain, predicted to provide a minimum of 6 db gain margin in the worst possible case.

The flight condition considered most critical from both structural resonance and limit cycle points of view was between 0.6 and 0.95 Mach at 15,000 ft. Lateral and longitudinal stick raps were performed at every 0.05 Mach increment, while surface positions and wingtip accelerations were telemetered and monitored on the ground. At 0.8 Mach, with the 20 Hz notch filter and the roll gain set at 30% of normal (30% at zero airspeed, 25% at 0.8M, 15K due to q_c scheduling), very lightly damped wing-tip oscillations at 7 Hz occurred.

The roll notch filter was changed from 20 Hz to a staggered 7/8.5 Hz notch, and a 20 Hz lead term was removed from the feedback compensation. The latter, in effect, was equivalent to adding a 20 Hz lag filter and was intended to stabilize the 19 Hz mode. The modified filters gave fully satisfactory results. Neither structural resonance, nor roll limit cycle could be induced at 90% of normal gain. By this time, the preferred gain setting in roll was established at 30% of normal gain, hence, an absence of structural resonance or limit cycle at the 90% setting represented a 3 to 1 gain margin.

(4) Conclusions and Summary - As a result of the YF-17 structural resonance and limit cycle tests, it is concluded that:

(a) The final configuration was free of structural resonance and divergent limit cycle tendencies, with adequate gain margin demonstrated for the gains actually used by ground tests and/or in-flight checks.

(b) In-flight residual oscillations due to small amplitude limit cycle were nonexistent or remained below the level of perception.

(c) Combined utilization of analytical predictions, ground tests, and in-flight checks were required to achieve successful airframe/control system integration.

(d) Analytical results were of fundamental importance in predicting airframe/control system interaction under airloads, hence not evidenced by ground structural resonance tests. If flutter analysis with active controls is not performed, extreme caution in flight testing is indicated.

(e) Analytical techniques also were very useful in establishing sensor locations and developing effective notch filter configurations with a minimal number of iterations.

(f) The structural resonance tests confirmed analytical predictions of inertial structural modes, validated notch filter configurations relative to structural resonance tendencies on the ground, and provided a level of confidence that no inertial mode/control system interaction would occur in flight. They failed to reveal, as mentioned before, the potential of airframe/controls interaction under airloads that was predicted by analysis and substantiated in flight.

(g) The ground limit cycle tests gave a good indication of the effects of control system nonlinearities as manifested in limit cycle amplitudes/frequencies in the stable region. Performed periodically on a test aircraft, limit cycle tests could be used to detect control system wear.

(h) In applying limit cycle test and thu results to predict limit cycle divergence, to establish gain margin, the following should be considered:

If the aerodynamic control derivatives are assumed to be accurate, use of the single degree-of-freedom, simplified aerodynamic model leads to conservative results. In-flight verification of limit cycle characteristics may be used if an increase in the maximum allowable gain is desired.

Flexibility corrections applied to control derivatives may be over-optimistic. This may result in actual gain margins below those indicated by ground tests, indicating a cautious approach in flight testing. On the other hand, use of rigid rather than flexible derivatives in ground testing may impose unnecessarily severe restrictions on the maximum allowable gains.

In some instances, if overly simplistic analogs of airframe dynamics (such as those of NASA TN-D-6867) are used in ground tests, no assurance of in-flight stability is derived however substantial the demonstrated gain and phase margins might be.

(.) The YF-17 complies with the requirements of 4.3.3.a.

b. Functional, Dynamic and Static, Tests - The functional, dynamic and static tests of the integrated FCS were performed on the flight controls test stand using an analog computer to provide the aerodynamic loop closure whenever required. This verified compliance with the FCS design criteria. Applicability of the results to the actual aircraft was verified by showing equivalence in FCS operation, sensor phasing, and individual gain paths between the aircraft and the test stand through an open loop comparison. In addition, the flight control computers to be used in flight were all checked out on the test stand prior to installation in the aircraft. Compliance with the residual oscillation requirement of 3.1.3.8 was demonstrated during aircraft ground limit cycle test.

   The YF-17 complies with the requirements of 4.3.3.b.

c. EMI Tests - All YF-17 electrical and electronic assemblies were tested to reduce requirements of MIL-STD-461 with the testing done per MIL-STD-462. There were minor deviations to the specified requirements in some of the individual assemblies. The total aircraft was tested per MIL-E-6051 to assure safety of flight and safe carrying of armament only. There were no adverse EMI effects throughout the flight test programs.

   The YF-17 is in partial compliance with the requirements of 4.3.3.c.

d. Integrity Test - Integrity of the component installations and electrical connections was verified by operating the flight control system during engine run ups, slow speed and high speed test runs. Since the electrical flight control system has a continuously active monitoring system, any, even momentary, loss of connection would be detected and would result in disengagement.

   Mechanical control system and actuation installations were checked for proper operation and adequate clearances by operating each function through its full range with all inspection doors and panels open.

The YF-17 complies with the requirements of 4.3.3.d.

Discussion

a. Gain Margin - Despite the fact that adequate gain margins had been demonstrated in ground test on the YF-17, unstable interaction between control system and airframe dynamics was subsequently encountered in flight requiring modified structural filters. If the specified gain and phase margins are to provide any real assurance of stability, ground test procedures should account for all pertinent unsteady aerodynamic and structural dynamic influence. At the present time, research is needed to define adequately such ground test procedures. However, the requirement is valid and, until more definitive test techniques are developed, should be retained as stated.

b. Additional discussion on this subject matter is provided in the validation for paragraph 3.1.3.6.1, Stability Margins.

b. Functional dynamic and static, tests.

   The requirement is valid.

c. EMI Tests - The EMC test requirements require testing for compliance to MIL-STD-461 and MIL-E-6051 be accomplished at the aircraft level. MIL-STD-461 is a black-box specification and except for special conditions (missile), is not applicable or practical for a total system.

   The requirement is valid except for the reference made to MIL-STD-461.

d. Integrity Tests - The requirement is valid.

Recommendation

Revise the requirement as follows:

Delete reference to MIL-STD-461 in 4.3.3.c.

Requirement

4.3.4 Flight tests. Flight tests shall be conducted, as defined in the FCS development plan, to demonstrate compliance with requirements where compliance cannot reasonably be demonstrated by other tests or analyses. The design and test condition guidelines tabulated in MIL-F-8785 shall be considered in establishing the flight test plan. Flight test data shall be used to verify the analytical trends predicted and shall be compared to the performance and design requirements of the FCS specification. Comparable data trends shall be required for verification where analytical data is used to extend or extrapolate flight test data to show compliance. In addition, tests shall be conducted to assure that the flight control system, in all operational states, does not violate the flutter requirements of MIL-A-8870.

Comparison

During the YF-17 flight test program at Edwards AFB in 1974, 28 flights were made wholly or in part for the purpose of flight control development. Sixteen flights were conducted wholly or in part to investigate flutter. The results of flight testing of the two YF-17 prototype airplanes is summarized in Reference 6.

Discussion

The paragraph states a general requirement that flight tests be conducted to demonstrate compliance and verify analyses. It leaves the specific tests to be defined in the FCS development plan, MIL-F-8785, and MIL-A-8870. Hence, the stringency of this requirement depends in practice on these other documents and is thus applicable for future military procurement.

Compliance with MIL-A-8870 is also specifically required by Paragraphs 3.1.11.2 and 3.2.6.7.3. Its inclusion here emphasizes its importance and is appropriate to the overall inclusiveness of this paragraph.

Recommendation

Retain the requirement as stated.

Requirement

4.4 Documentation. FCS data submittal and approval requirements for each specific model aircraft shall be in accordance with contract requirements. The data shall be furnished in accordance with appropriate line items of the Contractor Data Requirements List (DD Form 1423). Typical information and data items are listed in this section.

Comparison

The YF-17 prototype development contract did not require formal data submittal. However, design and test data was maintained on file and was reviewed by procuring activity design review personnel.

The YF-17 is in compliance with the intent of the requirement.

Discussion

The requirement is reasonable as it allows a desirable latitude in data submittal requirements by relegating the specifics to each individual contract. Data preparation and submittal are expensive commodities and as such have a significant impact on aircraft development costs.

Recommendation

Retain the requirement as stated.

Requirement

4.4.1 Flight control system development plan. A flight control system development plan shall be prepared by the contractor for approval by the procuring activity. This plan shall be revised and updated at intervals as specified by the procuring activity until it is mutually agreed that no further revision is required. The plan shall include a minimum of:

a. A detailed milestone chart showing the interrelationship between phases of development work to be accomplished. Design reviews shall be identified and scheduled and an outline of the progressive design verification process to be used by the contractor shall be included. Starting and completion dates for all work items and due dates for all reports shall be identified.

b. A FCS synthesis and analysis plan describing the general approach and analytical procedures to be used. Analyses planned to generate requirement for the FCS specification shall be described.

c. A verification plan defining the means selected by the contractor for verifying that the design meets each of the requirements of the FCS specification. Verification means shall be specifically correlated with each specification requirement.

d. Flight safety, reliability, maintainability, and vulnerability analysis plans to include a description of the analytical or other means selected by the contractor for design verification in these areas.

e. A functional mockup test plan, including the test procedures to be used and a listing of requirements to be satisfied by each test.

f. A ground test plan and ground test procedures defining the ground tests and functional checks to be performed prior to first flight.

g. A flight test plan and detailed flight test procedures. Each procedure shall be correlated with one or more requirements of the FCS specification.

Comparison

The prototype development nature of the YF-17 program demanded a reduction in detail planning. A specific schedule was established which reflected the major points of design to be satisfied according to the demands of hardware procurement timing. The YF-17 prototype program allowed flexibility in design but did not sacrifice in proficiency. A specific plan was established for various phases of the design, as influenced by configuration changes and aero data availability.

The YF-17 is in partial compliance with the requirement.

Discussion

The requirements for a detailed FCS development plan are sound. However, they appear to address the hardware aspects as if they were solely influential in reaching the desired results. An additional statement should be added which reflects the design evolution of configuration changes and attendant aerodynamic changes. These items impact on the hardware aspects. Furthermore, the schedule should reflect the interrelationship to the schedule for MIL-F-8785B requirements.

Recommendation

Revise the requirement as follows:

Add the following sentence to b,

> "Pertinent wind tunnel test and flying quality analysis milestones shall be identified."

Requirement

4.4.2 Flight control system specification. he contractor shall prepare a flight control system specification incorporating:

a. Applicable general system, implementation, and test requirements of this specification.

b. Special requirements of the procurement air vehicle detail specification.

c. Special requirements determined by the contractor, as required by the general specification.

A preliminary FCS specification shall be prepared within 90 days of contract award and progressively updated, as requirements are finalized.

Comparison

A single document incorporating the specified data was not employed for the YF-17.

System requirements for each control function (longitudinal control, for instance) were delineated in a separate Design Criteria document. In addition, the detail procurement specifications for electrical flight controls and air data computer incorporated extensive interface, test, and system performance requirements to enhance overall FCS integration. System test requirements (test stand and aircraft ground tests) were defined in formal Design Test Work Orders (DTWO).

The YF-17 is in partial compliance with the requirement.

Discussion

The application of a flight control system specification presents interesting possibilities for control and documentation that have not been employed on previous contracts. The requirement is endorsed for future procurements.

Recommendation

Retain the requirement as stated.

Requirement

4.4.3 Design and test data requirements. If applicable design data are available the contractor shall, in lieu of preparing new design data, use these available data supplemented by sufficient information to substantiate their applicability.

Comparison

The YF-17 uses several subassemblies, and components that had been developed and fully qualified for another aircraft. One of these is the rudder pedal assembly. The original design and test data, along with supplementary data that verified the applicability of the existing data was used for flight justification.

Discussion

The requirement is endorsed on the basis that it eliminates duplication of effort while it provides adequate substantiating data.

Recommendation

Retain the requirement as stated.

Requirement

4.4.3.1 FCS analysis report. A report describing FCS analysis shall be prepared using an outline prepared by the contractor, subject to procuring activity approval. This report shall be initially prepared immediately following the preliminary FCS analysis and synthesis and periodically updated throughout the development period. The final update shall include as a minimum:

a. Design requirements and criteria used during the FCS analysis and synthesis.

b. Block diagrams of the FCS. These diagrams shall include transfer or describing functions and indicate normal control paths, redundancy, manual overrides, emergency provisions, location and type of sensors and control device used.

c. A general description of the FCS. The various modes of operation shall be described and the theory of operation discussed.

d. Discussions of unusual or difficult design features and problems.

e. A description of the stability and performance of the FCS and a correlation of system characteristics with the requirements of the FCS specification. Data shall be presented for both linear, small perturbation analyses and for nonlinear simulations or analyses which consider nonlinearities such as actuator rate, electronic amplifier saturation, and actuator position limits. Where analytical predictions are used to satisfy specification requirements, the assumptions, analytical approximations and the tolerances placed on these analytical predictions by the contractor shall be documented and justified.

f. Results of the FCS flight safety, reliability, maintainability and vulnerability analyses. The reliability analysis results shall include a detailed listing of possible failure modes. The approach and sources of data used shall be discussed and the results compared to and correlated with requirements of the FCS specification. Analytical methods used shall be documented and justified by the contractor.

g. A general control system layout or series of layouts showing control surfaces, actuation systems, feel systems, pilot's controls and control panel organization. Means of providing redundancy and emergency provisions shall be illustrated. Layouts shall include wiring schematics for all electrical and electronic portions or the FCS and attendant electrical, hydraulic, and pneumatic power inputs to the FCS.

h. A description of piloted simulations performed, as required by 4.2.1. Where piloted simulation data is used to verify specification requirements, the simulator and flight configurations simulated shall be described and the data compared to and correlated with the requirements of the FCS specification.

i. Mathematical models of the FCS, the unaugmented airplane and other data required to allow the procuring activity to independently simulate the FCS at any point during or following the aircraft development process. Mathematical models, block diagrams, stability and performance data and layouts shall be updated following flight tests to incorporate modifications made during testing.

Comparison

Flight Control System functional and hazard analyses were performed on the YF-17 FCS and maintained on file. This included the results of extensive failure effects and degraded mode simulation. No requirement existed to submit these analyses either separately or as part of another report. However, system design and safety features were thoroughly reviewed by the procuring agency design review team.

Failures that occurred on the YF-17 were compiled and assessed. However, a reliability analysis of detailed listing of possible failure modes was not made.

Discussion

This requirement is reasonable for military aircraft.

Recommendation

Retain the requirement as stated.

Requirement

4.4.3.2 FCS qualification and inspection report. The contractor shall document results of inspections used to demonstrate compliance with requirements of the FCS specification. Where inspection of component qualification status documentation is used to verify compliance with the FCS specification, the contractor prepared component specification shall be submitted as a part of the FCS inspection report.

Comparison

Qualification and inspection reports for the YF-17 were limited to safety of flight requirements. These reports were compiled and reviewed internally, without requirement for submittal. The documentation assembled was similar to that defined in this requirement. Consequently, the YF-17 complies with the intent of the requirement.

Discussion

Comprehensive documentation of FCS qualification and inspection results is consistent with current practice and is endorsed for future aircraft procurement. The requirement is interpreted to mean an orderly compilation and referencing of applicable documentation rather than preparation of a formal report for submittal to the procuring activity. Data preparation and submittal requirements should be in accordance with the data requirements of each individual contract.

Recommendation

Revise the requirement as follows:

Change the title to read,

"FCS qualification and inspection documentation"

Change the last sentence to read,

"Where inspection of component qualification status documentation is used to verify compliance with the FCS specification, the contractor prepared component detail specification shall be included in the FCS qualification and inspection documentation."

Requirement

4.4.3.3 FCS test report. A report describing and correlating tests performed and data generated to verify requirements of the FCS specification shall be prepared by the contractor. This report may be prepared in volumes, and shall include a minimum of:

a. A detailed description of the operational mockup including part numbers and the test conditions under which data was generated and a comparison of the FCS specification. Inclusion or exclusion of control surface aerodynamic hinge moments, simulation of aircraft structural compliance in lieu of airframe parts or use of other approximations in operational mockup construction shall be justified. All discrepancies or corrective actions arising from operational mockup testing shall be reported.

b. A description of the airplane ground tests performed and data generated and a discussion of any system adjustments or modifications required to satisfy requirements of the FCS specification.

c. A comparison of flight test data with requirements of the FCS specification and a description of the airplane configurations and flight conditions tested. Modifications to the FCS made during the flight test phase to meet FCS specification requirements shall be documented and justified.

Comparison

Test results from the YF-17 prototype program were compiled in test letters, each of which details a specific area of testing. While this documentation is not as comprehensive as that outlined in the above requirement, the format adopted provided a convenient means for expeditious dissemination of test data. Each of the test letters included a statement of the test objectives, test period dates, test results, and conclusions.

The contents of the test letters is not confined to the flight control system alone, but includes test results from the entire YF-17 test program. The FCS is included in the Systems Evaluation section of the report and is a factor in other sections such as those covering high angle-of-attack flight, handling qualities, stability and control, and aerial refueling. The section of the report on reliability and maintainability also covers the FCS.

The YF-17 test documentation partially complies with this requirement.

Discussion

This requirement adequately specifies the contents for a FCS test report for a production program. Requirements for a prototype program may be satisfied by somewhat less extensive reporting.

Recommendation

Retain the requirement as stated.

Requirement

5. PREPARATION FOR DELIVERY.

Not applicable.

5.1 Packaging requirements.

Not applicable.

6. NOTES.

Not applicable.

6.1 Intended use.

Not applicable.

6.2 Procedure for requesting deviations.

Not applicable.

6.3 Reordered equipment or second source procurement.

Not applicable.

6.4 User's guide.

Not applicable.

6.5 Abbreviations.

Not applicable.

6.6 Definitions.

Not applicable.

6.7 Use of limited coordination specifications.

Not applicable.

6.8 Identification of changes.

Not applicable.

SECTION IV

CONCLUSIONS

Northrop validated 249 specification paragraphs of MIL-F-9490D. It was found that 183 of these were acceptable as presented. Full compliance exists for approximately 65 percent and partial compliance for approximately 30 percent of these paragraphs. The YF-17 is noncompliant with about 3 percent of the applicable paragraphs and for about 2 percent of these paragraphs, compliance is undetermined. In general, the reason that some degree of noncompliance exists is related to the prototype nature of the YF-17. A production version of the airplane would have had a higher degree of compliance. However, in some instances the reason that compliance is only partial relates to some disagreement with the specification requirements as applied to Class IV airplanes. The area of YF-17 partial compliance or noncompliance are mostly in subsystem and component design requirements where full compliance would have required design, fabrication, installation details or equipment testing beyond that deemend necessary or appropriate for a prototype aircraft.

Some requirements are considered too stringent, particularly when applied to all military aircraft without distinction as to the class of aircraft. Others are considered too lenient, particularly as to related to electrical flight control functions and elements. In general, assessments of the requirements as to their stringency resulted in the conclusion that the stringency is good for approximately 71 percent of the applicable paragraphs. Of the applicable paragraphs, 12 percent are considered too stringent and 17 percent too lenient and/or unclear. Recommendations have been made whenever the revision of a requirement is considered desirable for any of these reasons or to facilitate interpretation. Table 6 of this section provides a complete paragraph-by-paragraph summary of where paragraph revisions are considered necessary together with the assessments of compliance and stringency, and an indication of where text has been supplied for the Users' Guide. The last page of the table summarizes the symbology used.

As a result of this validation, it was found that, in general, the specification is well written for application to Class IV airplanes. The specification presents the important considerations involved in flight controls design in the proper order of hierarchy, thereby not only encouraging but actually mandating a systematic approach to system synthesis. The organization of the specification encourages a systematic approach to system development by placing system considerations ahead of the subsystem and detail design requirements. Relative to content, it is quite comprehensive and provides a useful coverage of all considerations essential to flight controls design. However, a table of contents placed in the beginning of the document would greatly assist the designer to quickly identify all requirements applicable to his particular discipline and also serve as an overall design checklist.

Report Document AFFDL-TR-74-116, "Background Information and Users' Guide for MIL-F-9490D," was found to be a very valuable supportive and interpretive aid during the validation process. It is well organized and addresses to some degree most of the requirements. The Users' Guide is arranged in a good usable format although there is a broad variation in the quantity of data provided for the different requirements. However, the comprehensive collection of background and reference information contained in the volume is considered a highly valuable asset to the designer in performing his task.

Some observations resulting from an analysis of the applicability of the requirements as applied to fighter aircraft are given below as they pertain to the requirements paragraph listed.

1.2.2.4 Operational State IV (controllable to an immediate emergency landing).

Engine restart attempts are feasible in Class IV airplanes but, in general, an all engine out landing is either not possible or is not recommended due to aerodynamic considerations. In this case, FCS Operational State V is more applicable to this class of airplanes.

3.1.3.3.4 Failure transients.

The requirement dealing with failures which result in Operational State III seems to be too restrictive. Rather than specifying a maximum load factor increment (1.5 g's), structural limits along with recovery and controlability should be the major considerations. For Class IV airplanes, MIL-F-8785B is more applicable.

3.1.3.8 Residual Oscillations.

Due to the large operational envelopes in which Class IV airplanes operate, and their high control system gains and high surface effectiveness, it may be difficult to meet this requirement throughout the envelope. The prime consideration for this requirement should be mission effectiveness, consistent with pilot tolerance, as implied in MIL-F-8785B.

3.1.6 Mission accomplishment reliability.
3.1.7 Quantitative flight safety.

The differences between Class III and Class IV airplanes are recognized in para. 3.1.7. Applicability to Class IV airplanes would be improved if the requirements of both of these paragraphs were expressed in flight hours rather than missions. The numerical values in Table VII of para. 3.1.7 would have to be adjusted accordingly.

3.1.8.1 All engines out control.

For Class IV airplanes, loss of all engines generally results in Operational State V.

3.1.9.7 Invulnerability to enemy action.

Class IV airplanes usually do not have sufficient aerodynamic surface redundancy to maintain Operational State III, or even State IV, following even one direct enemy encounter. More flexibility in the requirement is considered desirable.

3.2.1.1 Pilot control for CTOL aircraft.
3.2.1.1.7 FCS control panel.

Class IV airplanes should have more design flexibility in the specification due to their missions flown, high g maneuvering, and limited cockpit space.

4.2.1 Piloted simulations.

Motion cues in piloted simulation are more important for Class IV airplanes than for Class III airplanes.

Finally, it should be noted that the specification addresses and provides much needed guidance relative to electrical flight controls which find increased applications in aircraft designs and are characterized by rapidly evolving hardware technology and capabilities.

By virtue of its comprehensive coverage of the considerations essential to flight controls development, this revision of the specification makes a significant contribution toward assuring an orderly and circumspect design process.

TABLE 6 TABULAR SUMMARY OF YF-17 VALIDATION STUDY

PARAGRAPH	TITLE	SPEC. RECOMM.	LEVEL OF COMPLIANCE	STRINGENCY	TEXT FOR USER GUIDE
* 1.0	SCOPE & CLASSIFICATIONS				
1.1	SCOPE	X	F	L	X
* 1.2	CLASSIFICATIONS				
* 1.2.1	FLIGHT CONTROL SYSTEM (FCS) CLASSIFICATIONS				
1.2.1.1	MANUAL FLIGHT CONTROL SYSTEMS (MFCS)	X	F	L	
1.2.1.2	AUTOMATIC FLIGHT CONTROL SYSTEMS (AFCS)	X	N/A	CNA	
* 1.2.2	FCS OPERATIONAL STATE CLASSIFICATIONS				
1.2.2.1	OPERATIONAL STATE I (NORMAL OPERATION)		F	G	
1.2.2.2	OPERATIONAL STATE II (RESTRICTED OPERATION)		F	G	
1.2.2.3	OPERATIONAL STATE III (MINIMUM SAFE OPERATION)		F	G	
1.2.2.4	OPERATIONAL STATE IV (CONTROLLABLE TO AN IMMEDIATE EMERGENCY LANDING)		P	S	
1.2.2.5	OPERATIONAL STATE V (CONTROLLABLE TO AN EVACUABLE FLIGHT CONDITION)		F	G	
* 1.2.3	FCS CRITICALITY CLASSIFICATIONS				
1.2.3.1	ESSENTIAL		F	G	
1.2.3.2	FLIGHT PHASE ESSENTIAL	X	F	L	
1.2.3.3	NONCRITICAL		F	G	
* 2.0	APPLICABLE DOCUMENTS				
2.1	(NO TITLE)		P	G	
2.2	OTHER PUBLICATIONS		P	G	
* 3.0	REQUIREMENTS				
3.1	SYSTEM REQUIREMENTS				
3.1.1	MFCS PERFORMANCE REQUIREMENTS		P	G	
3.1.2	AFCS PERFORMANCE REQUIREMENTS	DNV			
3.1.2.1	ATTITUDE HOLD (PITCH & ROLL)	DNV			
3.1.2.2	HEADING HOLD	DNV			
3.1.2.3	HEADING SELECT	DNV			
3.1.2.4	LATERAL ACCELERATION & SIDESLIP LIMITS	DNV			
3.1.2.4.1	COORDINATION IN STEADY BANKED TURNS	DNV			
3.1.2.4.2	LATERAL ACCELERATION LIMITS, ROLLING	DNV			
3.1.2.4.3	COORDINATION IN STRAIGHT & LEVEL FLIGHT	DNV			
3.1.2.5	ALTITUDE HOLD	DNV			
3.1.2.6	MACH HOLD	DNV			
3.1.2.7	AIRSPEED HOLD	DNV			
* 3.1.2.8	AUTOMATIC NAVIGATION	DNV			
3.1.2.8.1	VOR/TACAN	DNV			
3.1.2.8.1.1	VOR CAPTURE & TRACKING	DNV			
3.1.2.8.1.2	TACAN CAPTURE & TRACKING	DNV			
3.1.2.8.1.3	OVERSTATION	DNV			
3.1.2.9	AUTOMATIC INSTRUMENT LOW APPROACH SYSTEM	DNV			
3.1.2.9.1	LOCALIZER MODE	DNV			
3.1.2.9.2	GLIDE SLOPE MODE	DNV			
3.1.2.9.3	GO-AROUND MODE	DNV			
3.1.2.9.3.1	PITCH AFCS GO-AROUND	DNV			
3.1.2.9.3.2	LATERAL-HEADING AFCS GO AROUND PERFORMANCE STANDARDS	DNV			

* title paragraph

TABLE 6 TABULAR SUMMARY OF YF-17 VALIDATION STUDY (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.	LEVEL OF COMPLIANCE	STRINGENCY	TEXT FOR USER GUIDE
3.1.2.9.3.3	MINIMUM GO-AROUND ALTITUDE	DNV			
3.1.2.10	ALL WEATHER LANDING SYSTEM (AWLS)	DNV			
3.1.2.10.1	AWLS PERFORMANCE STANDARDS – VARIATIONS OF AIRCRAFT & AIRBORNE EQUIPMENT CONFIGURATIONS	DNV			
3.1.2.10.2	PERFORMANCE STANDARDS – GROUND BASED EQUIPMENT VARIATIONS	DNV			
3.1.2.11	FLIGHT LOAD FATIGUE ALLEVIATION	DNV			
3.1.2.12	RIDE SMOOTHING	DNV			
3.1.2.12.1	RIDE DISCOMFORT INDEX	DNV			
3.1.2.13	ACTIVE FLUTTER SUPPRESSION	DNV			
3.1.2.14	GUST & MANEUVER LOAD ALLEVIATION	DNV			
3.1.2.15	AUTOMATIC TERRAIN FOLLOWING	DNV			
3.1.2.16	CONTROL STICK (OR WHEEL) STEERING	DNV			
3.1.3	GENERAL FCS DESIGN		P	G	
3.1.3.1	REDUNDANCY		F	G	
3.1.3.2	FAILURE IMMUNITY & SAFETY	X	F	G	
3.1.3.2.1	AUTOMATIC TERRAIN FOLLOWING FAILURE IMMUNITY	DNV			
3.1.3.3	SYSTEM OPERATION & INTERFACE	X	F	L	
3.1.3.3.1	WARMUP	X	U	S	
3.1.3.3.2	DISENGAGEMENT	X	F	L	
3.1.3.3.3	MODE COMPATIBILITY		F	G	
3.1.3.3.4	FAILURE TRANSIENTS	X	P	S	
3.1.3.4	SYSTEM ARRANGEMENT		F	G	
3.1.3.5	TRIM CONTROLS	X	P	S	
3.1.3.6	STABILITY		P	G	
3.1.3.6.1	STABILITY MARGINS		P	G	X
3.1.3.6.2	SENSITIVITY ANALYSIS		P	G	
3.1.3.7	OPERATION IN TURBULENCE		P	G	X
3.1.3.7.1	RANDOM TURBULENCE		P	G	X
3.1.3.7.2	DISCRETE GUSTS		P	G	X
3.1.3.7.3	WIND MODEL FOR LANDING & TAKEOFF	DNV			
3.1.3.7.3.1	MEAN WIND	DNV			
3.1.3.7.3.2	WIND SHEAR	DNV			
3.1.3.7.3.3	WIND MODEL TURBULENCE	DNV			
3.1.3.8	RESIDUAL OSCILLATIONS		P	G	
3.1.3.9	SYSTEM TEST & MONITORING PROVISIONS	X	P	L	
3.1.3.9.1	BUILT-IN-TEST EQUIPMENT (BIT)	X	P	S	X
3.1.3.9.1.1	PREFLIGHT OR PREENGAGE BIT		F	G	
3.1.3.9.1.2	MAINTENANCE BIT	X	P	G	
3.1.3.9.2	INFLIGHT MONITORING	X	F	L	X
3.1.4	MFCS DESIGN	X	F	G	
3.1.4.1	MECHANICAL MFCS DESIGN		F	G	
3.1.4.1.1	REVERSION – BOOSTED SYSTEMS	DNV			
3.1.4.2	ELECTRICAL MFCS DESIGN		P	G	
3.1.4.2.1	USE OF MECHANICAL LINKAGES		F	G	
3.1.5	AFCS DESIGN	DNV			
3.1.5.1	SYSTEM REQUIREMENTS	DNV			
3.1.5.1.1	CONTROL STICK (OR WHEEL) STEERING	DNV			
3.1.5.1.2	FLIGHT DIRECTOR SUBSYSTEM	DNV			
* 3.1.5.2	AFCS INTERFACE	DNV			

* title paragraph

TABLE 6 TABULAR SUMMARY OF YF-17 VALIDATION STUDY (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.	LEVEL OF COMPLIANCE	STRINGENCY	TEXT FOR USER GUIDE
3.1.5.2.1	TIE-IN WITH EXTERNAL GUIDANCE	DNV			
3.1.5.2.2	SERVO ENGAGE INTERLOCKS	DNV			
3.1.5.2.3	ENGAGE-DISENGAGE TRANSIENTS	DNV			
*3.1.5.3	AFCS EMERGENCY PROVISIONS	DNV			
3.1.5.3.1	MANUAL OVERRIDE CAPABILITY	DNV			
3.1.5.3.2	EMERGENCY DISENGAGEMENT	DNV			
3.1.6	MISSION ACCOMPLISHMENT RELIABILITY		N	S	
3.1.7	QUANTITATIVE FLIGHT SAFETY	X	U	S	
3.1.7.1	QUANTITATIVE FLIGHT SAFETY – AWLS	DNV			
3.1.7.1.1	ASSESSMENT OF AVERAGE RISK OF A HAZARD	DNV			
3.1.7.1.2	ASSESSMENT OF SPECIFIC RISK	DNV			
3.1.8	SURVIVABILITY	X	F	G	
3.1.8.1	ALL ENGINES OUT CONTROL		F	G	
3.1.9	INVULNERABILITY		U	G	
3.1.9.1	INVULNERABILITY TO NATURAL ENVIRONMENTS		P	G	
3.1.9.2	INVULNERABILITY TO LIGHTNING STRIKES & STATIC ATMOSPHERE ELECTRICITY		N	G	
3.1.9.3	INVULNERABILITY TO INDUCED ENVIRONMENTS		P	G	
3.1.9.4	INVULNERABILITY TO ONBOARD FAILURES OF OTHER SYSTEMS AND/OR EQUIPMENT		P	G	
3.1.9.5	INVULNERABILITY TO MAINTENANCE ERROR		F	G	
3.1.9.6	INVULNERABILITY TO PILOT & FLIGHT CREW INACTION & ERROR		F	G	
3.1.9.7	INVULNERABILITY TO ENEMY ACTION	X	U	S	
3.1.10	MAINTENANCE PROVISIONS		P	G	
3.1.10.1	OPERATIONAL CHECKOUT PROVISIONS		F	G	
3.1.10.2	MALFUNCTION DETECTION & FAULT ISOLATION PROVISIONS		P	G	
3.1.10.2.1	USE OF COCKPIT INSTRUMENTATION		P	G	
3.1.10.2.2	PROVISIONS FOR CHECKOUT WITH PORTABLE TEST EQUIPMENT		F	G	
3.1.10.3	ACCESSIBILITY & SERVICEABILITY		F	G	
3.1.10.4	MAINTENANCE PERSONNEL SAFETY PROVISIONS		F	G	
*3.1.11	STRUCTURAL INTEGRITY				
3.1.11.1	STRENGTH		F	G	
3.1.11.1.1	DAMAGE TOLERANCE		F	G	
3.1.11.1.2	LOAD CAPABILITY OF DUAL-LOAD-PATH ELEMENTS		F	G	
3.1.11.2	STIFFNESS		F	G	
3.1.11.3	DURABILITY		U	G	
3.1.12	WEAR LIFE		F	G	
*3.2	SUBSYSTEM & COMPONENT DESIGN REQUIREMENTS				
3.2.1	PILOT CONTR[illegible] & DISPLAYS	X	P	S	
3.2.1.1	PILOT CONTROLS FOR [illegible] AIRCRAFT	X	P	S	
3.2.1.1.1	ADDITIONAL REQUIREMENTS FOR CONTROL STICKS	DNV			

* title paragraph

TABLE 6 TABULAR SUMMARY OF YF-17 VALIDATION STUDY (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.	LEVEL OF COMPLIANCE	STRINGENCY	TEXT FOR USER GUIDE
3.2.1.1.2	ADDITIONAL REQUIREMENT FOR RUDDER PEDALS		F	G	
3.2.1.1.3	ALTERNATE OR UNCONVENTIONAL CONTROLS		F	G	
3.2.1.1.4	VARIABLE GEOMETRY COCKPIT CONTROLS	DNV			
3.2.1.1.5	TRIM SWITCHES	X	F	G	
3.2.1.1.6	TWO-SPEED TRIM ACTUATOR	DNV			
3.2.1.1.7	FCS CONTROL PANEL	X	N	S	
3.2.1.1.8	NORMAL DISENGAGEMENT MEANS	X	F	L	
3.2.1.1.9	PREFLIGHT TEST CONTROLS		F	G	
3.2.1.2	PILOT CONTROLS FOR ROTARY-WING AIRCRAFT	DNV			
3.2.1.2.1	INTERCONNECTION OF COLLECTIVE PITCH CONTROL & THROTTLE(S) FOR HELICOPTERS POWERED BY RECIPROCATING ENGINE(S)	DNV			
3.2.1.2.2	INTERCONNECTION OF COLLECTIVE PITCH CONTROL & ENGINE POWER CONTROLS FOR HELICOPTERS POWERED BY TURBINE ENGINE(S)	DNV			
3.2.1.2.3	ALTERNATE OR UNCONVENTIONAL CONTROLS	DNV			
3.2.1.3	PILOT CONTROLS FOR STOL AIRCRAFT	DNV			
* 3.2.1.4	PILOT DISPLAYS				
3.2.1.4.1	FCS ANNUNCIATION		F	G	
3.2.1.4.2	FCS WARNING & STATUS ANNUNCIATION	X	F	S	
3.2.1.4.2.1	PREFLIGHT TEST (BIT) STATUS ANNUNCIATION		F	G	
3.2.1.4.2.2	FAILURE STATUS	X	F	L	
3.2.1.4.2.3	CONTROL AUTHORITY ANNUNCIATION	X	P	L	
3.2.1.4.3	LIFT & DRAG DEVICE POSITION INDICATORS	X	P	S	
3.2.1.4.4	TRIM INDICATORS	X	P	S	
3.2.1.4.5	CONTROL SURFACE POSITION INDICATION		F	G	
3.2.2	SENSORS	X	F	G	
* 3.2.3	SIGNAL TRANSMISSION				
* 3.2.3.1	GENERAL REQUIREMENTS				
3.2.3.1.1	CONTROL ELEMENT ROUTING		F	G	
3.2.3.1.2	SYSTEM SEPARATION, PROTECTION, & CLEARANCE		P	G	
3.2.3.1.3	FOULING PREVENTION		F	G	
3.2.3.1.4	RIGGING PROVISIONS	X	P	L	
* 3.2.3.2	MECHANICAL SIGNAL TRANSMISSION				
3.2.3.2.1	LOAD CAPABILITY		F	G	
3.2.3.2.2	STRENGTH TO CLEAR OR OVERRIDE JAMMED HYDRAULIC VALVES		F	G	
3.2.3.2.3	POWER CONTROL OVERRIDE PROVISIONS		F	G	
3.2.3.2.4	CONTROL CABLE INSTALLATIONS		P	G	
3.2.3.2.4.1	CONTROL CABLE	X	F	G	
3.2.3.2.4.2	CABLE SIZE		F	G	
3.2.3.2.4.3	CABLE ATTACHMENTS	X	F	L	
3.2.3.2.4.4	CABLE ROUTING		P	G	
3.2.3.2.4.5	CABLE SHEAVES		F	G	

* title paragraph

TABLE 6 TABULAR SUMMARY OF YF-17 VALIDATION STUDY (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.	LEVEL OF COMPLIANCE	STRINGENCY	TEXT FOR USER GUIDE
3.2.3.2.4.6	CABLE & PULLEY ALIGNMENT		F	G	
3.2.3.2.4.7	PULLEY-BRACKET SPACERS		N	G	
3.2.3.2.4.8	SHEAVE GUARDS	X	P	L	
3.2.3.2.4.9	SHEAVE SPACING		F	G	
3.2.3.2.4.10	CABLE TENSION	X	F	L	
3.2.3.2.4.11	CABLE TENSION REGULATORS		F	G	
3.2.3.2.4.12	FAIRLEADS & RUBBING STRIPS		F	G	
3.2.3.2.4.13	PRESSURE SEALS		F	G	
3.2.3.2.5	PUSH-PULL ROD INSTALLATIONS		F	G	
3.2.3.2.5.1	PUSH-PULL ROD ASSEMBLIES		F	G	
3.2.3.2.5.2	LEVERS & BELLCRANKS		F	G	
3.2.3.2.5.3	PUSH-PULL ROD SUPPORTS	X	F	L	
3.2.3.2.5.4	PUSH-PULL ROD CLEARANCE		F	G	
3.2.3.2.6	CONTROL CHAIN	DNV			
3.2.3.2.7	PUSH-PULL FLEXIBLE CONTROLS	DNV			
3.2.3.3	ELECTRICAL SIGNAL TRANSMISSION		P	G	
3.2.3.3.1	ELECTRICAL FLIGHT CONTROL (EFC) INTERCONNECTIONS		P	G	
3.2.3.3.1.1	CABLE ASSEMBLY DESIGN & CONSTRUCTION	X	P	S	
3.2.3.3.1.2	WIRE TERMINATIONS		F	G	
3.2.3.3.1.3	INSPECTION & REPLACEMENT		F	G	
3.2.3.3.2	MULTIPLEXING	X	N/A	CNA	
*3.2.4	SIGNAL COMPUTATION				
*3.2.4.1	GENERAL REQUIREMENTS				
3.2.4.1.1	TRANSIENT POWER EFFECTS		F	G	
3.2.4.1.2	INTERCHANGEABILITY	X	P	L	
*3.2.4.1.3	COMPUTER SIGNALS				
3.2.4.1.3.1	SIGNAL TRANSMISSIONS		F	G	
3.2.4.1.3.2	SIGNAL PATH PROTECTION	X	F	L	
*3.2.4.2	MECHANICAL SIGNAL COMPUTATION				
3.2.4.2.1	ELEMENT LOADS	X	F	G	
3.2.4.2.2	GEARED MECHANISMS	DNV			
3.2.4.2.3	HYDRAULIC ELEMENTS	X	F	L	
3.2.4.2.4	PNEUMATIC ELEMENTS	DNV			
*3.2.4.3	ELECTRICAL SIGNAL COMPUTATION				
3.2.4.3.1	ANALOG COMPUTATION		F	G	
3.2.4.3.2	DIGITAL COMPUTATION	X	P	S	
3.2.4.3.2.1	MEMORY PROTECTION	X	F	L	
3.2.4.3.2.2	PROGRAM SCALING		F	G	
3.2.4.3.2.3	SOFTWARE SUPPORT	X	P	L	
*3.2.5	CONTROL POWER				
3.2.5.1	POWER CAPACITY	X	F	L	
3.2.5.2	PRIORITY		F	G	
3.2.5.3	HYDRAULIC POWER SUBSYSTEMS		P	G	
3.2.5.4	ELECTRICAL POWER SUBSYSTEMS	X	P	L	
3.2.5.4.1	ELECTROMAGNETIC INTERFERENCE LIMITS	X	F	L	
3.2.5.4.2	OVERLOAD PROTECTION		F	G	
3.2.5.4.3	PHASE SEPARATION & POLARITY REVERSAL PROTECTION		N	G	
3.2.5.5	PNEUMATIC POWER SUBSYSTEMS	DNV			
*3.2.6	ACTUATION				
*3.2.6.1	LOAD CAPABILITY				
3.2.6.1.1	LOAD CAPABILITY OF ELEMENTS SUBJECTED TO PILOT LOADS		F	G	
3.2.6.1.2	LOAD CAPABILITY OF ELEMENTS DRIVEN BY POWER ACTUATORS		F	G	
3.2.6.2	MECHANICAL FORCE TRANSMITTING ACTUATION PROVISIONS		P	G	

* title paragraph

TABLE 6 TABULAR SUMMARY OF YF-17 VALIDATION STUDY (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.	LEVEL OF COMPLIANCE	STRINGENCY	TEXT FOR USER GUIDE
3.2.6.2.1	FORCE TRANSMITTING POWERSCREWS		P	G	
3.2.6.2.1.1	THREADED POWERSCREWS		P	G	
3.2.6.2.1.2	BALLSCREWS	DNV			
3.2.6.3	MECHANICAL TORQUE TRANSMITTING ACTUATION PROVISIONS	DNV			
3.2.6.3.1	TORQUE TUBE SYSTEMS	DNV			
3.2.6.3.1.1	TORQUE TUBES	DNV			
3.2.6.3.1.2	UNIVERSAL JOINTS	DNV			
3.2.6.3.1.3	SLIP JOINTS	DNV			
3.2.6.3.2	GEARING	DNV			
3.2.6.3.3	FLEXIBLE SHAFTING	DNV			
3.2.6.3.4	HELICAL SPLINES	DNV			
3.2.6.3.5	ROTARY MECHANICAL ACTUATORS	DNV			
3.2.6.3.6	TORQUE LIMITERS	DNV			
3.2.6.3.7	NO-BACK BRAKES	DNV			
3.2.6.4	HYDRAULIC ACTUATION PROVISIONS	X	F	S	
3.2.6.4.1	HYDRAULIC SERVOACTUATORS		P	G	
3.2.6.4.2	MOTOR-PUMP - SERVOACTUATOR (MPS) PACKAGE	DNV			
3.2.6.4.3	ACTUATING CYLINDERS	X	F	L	
3.2.6.4.4	FORCE SYNCHRONIZATION OF MULTIPLE HYDRAULIC SERVOACTUATORS	X	F	L	
3.2.6.4.5	HYDRAULIC MOTORS	DNV			
3.2.6.5	ELECTROMECHANICAL ACTUATION		P	G	
3.2.6.6	PNEUMATIC ACTUATION	DNV			
3.2.6.6.1	HIGH-PRESSURE PNEUMATIC ACTUATION	DNV			
3.2.6.6.2	PNEUMATIC DRIVE TURBINES	DNV			
*3.2.6.7	INTERFACES BETWEEN ACTUATION SYSTEMS, SUPPORT STRUCTURE, & CONTROL SURFACES				
3.2.6.7.1	CONTROL SURFACE STOPS		F	G	
3.2.6.7.1.1	ADJUSTABLE STOPS		F	G	
3.2.6.7.2	CONTROL SURFACE GROUND GUST PROTECTION		F	G	
3.2.6.7.2.1	CONTROL SURFACE LOCKS	DNV			
3.2.6.7.2.2	PROTECTION AGAINST INFLIGHT ENGAGEMENT OF CONTROL SURFACE LOCKS	DNV			
3.2.6.7.3	CONTROL SURFACE FLUTTER & BUZZ PREVENTION		F	G	
*3.2.7	COMPONENT DESIGN				
*3.2.7.1	COMMON REQUIREMENTS				
3.2.7.1.1	STANDARDIZATION		F	G	
3.2.7.1.2	INTERCHANGEABILITY		F	G	
3.2.7.1.3	SELECTION OF SPECIFICATIONS & STANDARDS		F	G	
3.2.7.1.4	IDENTIFICATION OF PRODUCT		F	G	
3.2.7.1.5	INSPECTION SEALS		N	S	
3.2.7.1.6	MOISTURE POCKETS		F	G	
3.2.7.2	MECHANICAL COMPONENTS		P	G	
3.2.7.2.1	BEARINGS		P	S	
3.2.7.2.1.1	ANTIFRICTION BEARINGS		P	G	
3.2.7.2.1.2	SPHERICAL BEARINGS		P	G	
3.2.7.2.1.3	SINTERED BEARINGS	DNV			
3.2.7.2.2	CONTROLS & KNOBS		P	G	
3.2.7.2.3	DAMPERS	DNV			
3.2.7.2.4	STRUCTURAL FITTINGS		P	G	
3.2.7.2.5	LUBRICATION		F	G	

* title paragraph

TABLE 6 TABULAR SUMMARY OF YF-17 VALIDATION STUDY (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.	LEVEL OF COMPLIANCE	STRINGENCY	TEXT FOR USER GUIDE
3.2.7.3	ELECTRICAL & ELECTRONIC COMPONENTS	X	F	G	
3.2.7.3.1	DIELECTRIC STRENGTH		P	S	
3.2.7.3.2	MICROELECTRONICS	X	N	S	
3.2.7.3.3	BURN-IN	X	F	L	
3.2.7.3.4	SWITCHES		F	G	
3.2.7.3.5	THERMAL DESIGN OF ELECTRICAL & ELECTRONIC EQUIPMENT		P	G	
3.2.7.3.6	POTENTIOMETERS	X	F	S	
3.2.8	COMPONENT FABRICATION		P	G	
3.2.8.1	MATERIALS		P	G	
3.2.8.1.1	METALS		P	G	
3.2.8.1.2	NONMETALLIC MATERIALS		P	G	
3.2.8.1.3	ELECTRIC WIRE AND CABLE		P	G	
*3.2.8.2	PROCESSES				
3.2.8.2.1	CONSTRUCTION PROCESSES		P	G	
3.2.8.2.2	CORROSION PROTECTION		P	G	
3.2.8.2.3	FABRICATION OF ELECTRICAL & ELECTRONIC COMPONENTS		P	G	
*3.2.8.3	ASSEMBLING				
3.2.8.3.1	MECHANICAL JOINING		F	G	
3.2.8.3.1.1	JOINING WITH REMOVABLE FASTENERS	X	F	S	
3.2.8.3.1.2	JOINING WITH RIVETS		F	G	
3.2.8.3.1.3	THREADED JOINTS		F	G	
3.2.8.3.2	JOINT RETENTION		F	G	
3.2.8.3.2.1	RETENTION OF THREADED JOINTS		F	G	
3.2.8.3.2.2	RETENTION OF REMOVABLE FASTENERS		F	G	
3.2.8.3.2.3	USE OF RETAINER RINGS		F	G	
*3.2.8.3.3	ASSEMBLY OF ELECTRONIC COMPONENTS				
3.2.8.3.3.1	ELECTRICAL & ELECTRONIC PART MOUNTING	X	F	L	
3.2.8.3.3.2	SHIELDING & BONDING OF FINISHED SURFACES		F	G	
3.2.8.3.3.3	ISOLATION OF REDUNDANT CIRCUITS		F	G	
3.2.8.3.3.4	ELECTRICAL CONNECTOR INSTALLATION	X	F	S	
3.2.8.3.3.5	CLEANING OF ELECTRICAL ASSEMBLIES	X	F	L	
*3.2.9	COMPONENT INSTALLATION				
3.2.9.1	BASIC REQUIREMENTS		F	G	
3.2.9.2	LOCATING COMPONENTS		F	C	
3.2.9.3	INSTALLATIONS IN FUEL SYSTEM AREAS	X	F	L	X
3.2.9.4	ELECTRICAL & ELECTRONIC COMPONENT INSTALLATIONS	X	F	S	
3.2.9.5	ELECTRICAL & ELECTRONIC EQUIPMENT COOLING	X	N/A	L	
3.3	ROTARY WING PERFORMANCE & DESIGN	DNV			
3.3.1	SPECIAL MFCS PERFORMANCE REQUIREMENTS	DNV			
3.3.2	SPECIAL AFCS PERFORMANCE REQUIREMENTS	DNV			
3.3.2.1	ATTITUDE HOLD (PITCH, ROLL, & YAW)	DNV			
3.3.2.2	HEADING HOLD & HEADING SELECT	DNV			
*3.3.2.3	ALTITUDE HOLD	DNV			
3.3.2.3.1	BAROMETRIC ALTITUDE STABILIZATION	DNV			

* title paragraph

TABLE 6 TABULAR SUMMARY OF YF-17 VALIDATION STUDY (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.	LEVEL OF COMPLIANCE	STRINGENCY	TEXT FOR USER GUIDE
3.3.2.3.2	STABILIZATION OF ALTITUDE ABOVE THE TERRAIN	DNV			
3.3.2.4	HOVER HOLD	DNV			
3.3.2.5	VERNIER CONTROL FOR HOVERING	DNV			
3.3.2.6	GROUNDSPEED HOLD	DNV			
*3.3.3	SPECIAL DESIGN REQUIREMENTS	DNV			
*3.3.3.1	MFCS DESIGN	DNV			
3.3.3.1.1	CONTROL FEEDBACK	DNV			
3.3.3.1.2	FEEL AUGMENTATION	DNV			
3.3.3.2	AFCS DESIGN	DNV			
*3.3.3.3	SWASHPLATE POWER ACTUATORS	DNV			
3.3.3.3.1	REDUNDANCY	DNV			
3.3.3.3.2	JAMMING	DNV			
3.3.3.3.3	FREQUENCY RESPONSE	DNV			
3.3.3.4	ACTUATION STIFFNESS	DNV			
3.3.3.5	FATIGUE LIFE DESIGN	DNV			
3.3.3.5.1	FAIL-SAFE	DNV			
3.3.3.5.2	DISPLAY	DNV			
3.3.3.6	BUILT-IN TEST	DNV			
*4.0	QUALITY ASSURANCE				
*4.1	GENERAL REQUIREMENTS				
4.1.1	METHODS FOR DEMONSTRATION OF COMPLIANCE		F	G	
4.1.1.1	ANALYSIS		F	G	
4.1.1.2	INSPECTION		F	G	
4.1.1.3	TEST		F	G	
4.2	ANALYSIS REQUIREMENTS		P	G	
4.2.1	PILOTED SIMULATIONS	X	F	L	X
*4.3	TEST REQUIREMENTS				
*4.3.1	GENERAL TEST REQUIREMENTS				
4.3.1.1	TEST WITNESS		F	G	
4.3.1.2	ACCEPTANCE TESTS		F	G	
4.3.1.3	INSTRUMENTATION		P	G	
4.3.1.4	TEST CONDITIONS	X	P	S&L	
*4.3.2	LABORATORY TESTS				
4.3.2.1	COMPONENT TESTS		P	G	
4.3.2.2	FUNCTIONAL MOCKUP & SIMULATOR TESTS		F	G	
4.3.2.3	SAFETY-OF-FLIGHT TESTS		P	G	
4.3.2.3.1	COMPONENT SAFETY-OF-FLIGHT TESTS		P	G	
4.3.2.3.2	SYSTEM SAFETY-OF-FLIGHT TESTS		P	G	
4.3.3	AIRCRAFT GROUND TESTS	X	P	G	
4.3.4	FLIGHT TESTS		F	G	
4.4	DOCUMENTATION		F	G	
4.4.1	FCS DEVELOPMENT PLAN	X	P	L	
4.4.2	FCS SPECIFICATION		P	G	
4.4.3	DESIGN & TEST DATA REQUIREMENTS		F	G	
4.4.3.1	FCS ANALYSIS REPORT		P	G	
4.4.3.2	FCS QUALIFICATION & INSPECTION REPORT	X	P	S	
4.4.3.3	FCS TEST REPORT		P	G	
*5.0	PREPARATION FOR DELIVERY	DNV			
5.1	PACKAGING REQUIREMENTS	DNV			
*6.0	NOTES	DNV			
6.1	INTENDED USE	DNV			
6.2	PROCEDURE FOR REQUESTING DEVIATIONS	DNV			
6.3	REORDERED EQUIPMENT OR SECOND SOURCE PROCUREMENT	DNV			

* title paragraph

TABLE 6 TABULAR SUMMARY OF YF-17 VALIDATION STUDY (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.	LEVEL OF COMPLIANCE	STRINGENCY	TEXT FOR USER GUIDE
6.4	USER'S GUIDE	DNV			
6.5	ABBREVIATIONS	DNV			
6.6	DEFINITIONS	DNV			
6.7	USE OF LIMITED COORDINATION SPECIFICATIONS	DNV			
6.8	IDENTIFICATION OF CHANGES	DNV			

* title paragraph

Table Symbols

Specification Recommendation

(blank) - retain requirement as stated
X - recommendation made
DNV - did not validate

Level of Compliance

F - full compliance
P - partial compliance
N - no compliance
U - undetermined
N/A - not applicable to YF-17

Stringency

G - good as is
S - too strict
L - too lenient
CNA - could not assess

Text for Users Guide

(blank) - no text change
X - text provided for inclusion

SECTION V

RECOMMENDATIONS

The validation process, as well as the careful study of the specification requirements and User Guide material necessitated by this effort, revealed areas where revisions or additional studies are deemed desirable to further definitize particular requirements as indicated. In these instances, specific recommendations have been made under individual paragraph validations. Highlights of these recommendations, as well as recommendations that address the specification as a whole, are presented below.

- A need for additional studies is recommended for several of the requirements. These include:

  3.1.3.6.1 Stability margins. Continuing research should be conducted on the synthesis of aeroelastic airframe tranfer functions which include unsteady aerodynamic forces.

  3.1.3.8 Residual oscillations. Additional research is needed to determine criteria which will produce satisfactory performance without imposing undue penalties on actuator design.

  3.2.1.1.2 Additional requirement for rudder pedals. Experience needed to establish requirements for a flight rudder pedal with force sensing control signals should be accumulated.

  3.2.3.3.2 Multiplexing. Studies should be initiated to investigate advanced developments in fly-by-wire flight control designs employing multiplexed signal transmission.

  4.3.3 Aircraft ground tests. The validity of the use of approximate aeroelastic airframe transfer functions to simulate the effects of inertial, elastic, and unsteady aerodynamic forces should be further demonstrated.

- Add a distinction as to the class of the aircraft to improve the applicability [illegible] of these requirements:

  3.1.3.3.4 Failure transients. Because of the extensive flight regimes in which Class IV airplanes operate, the aerodynamic effectiveness of their control surfaces (considering the airplane mass and moments of inertia) can attain very high values compared to Class III airplanes. Hence, a failure transient requirement expressed as a specific g-value imposes a considerably more severe requirement for Class IV than for Class III airplanes. The requirement should be revised so that Class IV airplanes are not penalized excessively.

  3.1.3.8 Residual oscillations. The high control effectiveness of Class IV airplanes makes this requirement much more severe for Class IV airplanes than for Class III. This requiement, in fact, appears to push actuator design beyond the state of the art for fighter aircraft.

3.1.6 Mission accomplishment reliability. As wide variations exist in mission flight times between various classes of aircraft, the requirement places far more stringency on aircraft with long mission times. The requirement expressed in flight hours relative to each class of aircraft would be more equitable.

3.1.8 Survivability. Different considerations apply to fighter and other types of aircraft.

3.1.9.7 Invulnerability to enemy action. Due to lack of aerodynamic surface redundancy, maintaining Operational State III on a fighter following a direct encounter with an enemy threat is at best problematical.

- Remove reference to Operational State IV from 3.1.8, Survivability, and replace it with a specific definition of FCS capability for particular events. The Operational State IV definition is useful to describe a degraded FCS state but in this instance allowed different interpretations depending on the aircraft type and the nature of the event resulting in the degraded state.

- Remove reference to Operational State III from 3.1.9.7, Invulnerability to enemy action, and reword the requirement to allow the tailoring of FCS capability following an encounter with an enemy threat to the type of aircraft and its mission requirements.

- Clarify the definition for Flight Phase Essential control functions, 1.2.3.2, by adding specific reference to MIL-F-8785 and rearranging of wording. As it now stands, it allows several shades of interpretation. A clear definition is important as it governs system redundancy and failure correction concepts as well as provisions for disengagement capability.

- Condense the requirements relative to system test and monitoring (BIT) or provide extensive cross referencing between related paragraphs. These requirements apply primarily to electrical MFCS and AFCS functions, are interdependent, and are usually implemented within the framework of an overall system monitoring concept. As it now stands, the requirements are splintered into several sections, none of which is complete in itself, as exemplified below:

3.1.3.9 3.1.3.9.1 3.1.3.9.1.1 3.1.3.9.2	System test and monitoring provisions

3.1.10.1 3.1.10.2 3.1.10.2.1	Operational checkout provisions
3.2.1.1.9	Preflight test controls
3.2.1.4.1 3.2.1.4.2 3.2.1.4.2.1 3.2.1.4.2.2	FCS and BIT annunciation

- Remove wording from the individual paragraphs relating to control cables and push-pull rods (subparagraphs under 3.2.3.2.4 and 3.2.3.2.5) which are repetitions of requirements contained in referenced documents. In this area, the specification is considered too detailed for a general specification.

- Modify 3.2.9.5, electrical and electronic equipment cooling, to recognize the potentially crucial importance of cooling augmentation to hardware associated with essential EFCS functions. The requirement currently mandates integration of cooling augmentation with other cooling provisions without regard to criticality.

- Insert a table of contents in the front section of the specification (as was provided in the C revision of the specification). This would assist the various disciplines to identify all requirements applicable to their particular area of endeavor with relative ease and thus improve the usability of the specification.

- Review the discussions supplied in the User Guide to separate, to the extent possible, the argument in support of the requirement from general technical background information. As User Guide discussions are often necessary to arrive at the intended interpretation of a requirement, highlighting of the supporting arguments would greatly facilitate this task. Such a review was not performed in this validation effort as not being within the scope of the validation task.

REFERENCES

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