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

VOLUME I: SUMMARY OF YF-17 AND C-5A VALIDATIONS

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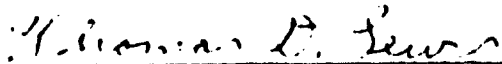
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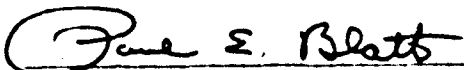
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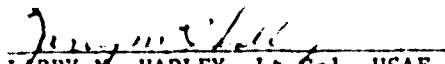


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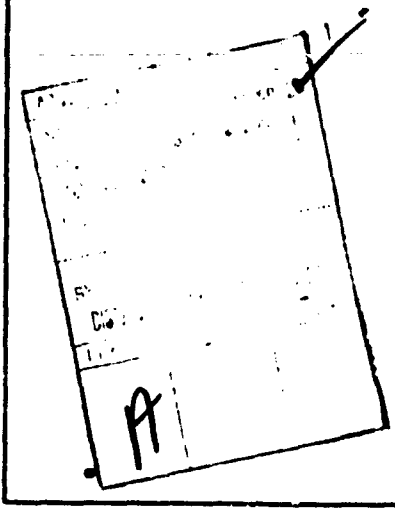
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was examined with regard to practicability, accuracy, and completeness as a requirement for procurement, design, test and installation of flight control systems for future piloted military aircraft.

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



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SUMMARY

This study was conducted to validate the new MIL-F-9490D, "Flight Control Systems - Design, Installation and Test of, Piloted Aircraft, General Specification for," dated 6 June 1975, with regard to practicability, accuracy, and completeness as a specification for procurement, design, test, and installation of flight control systems for future piloted military aircraft. This was accomplished by the Northrop Corporation with Lockheed-Georgia as an associate by checking the specification requirements utilizing the experience and knowledge derived during the recent procurements of two high performance aircraft flight control systems: the YF-17 Lightweight Fighter (Northrop) and the C-5A Heavy Logistics Transport (Lockheed).

The validation was based on existing ground test, flight test, and analytical data as was available for this validation process. Each applicable paragraph was examined and recommendations made where considered necessary to improve the practicability, accuracy, and completeness of the specification and to improve or update the Users' Guide. In addition, some recommendations are made for experimental and analytical investigations beyond the scope of this study which will provide data for further validations and updating of the requirements. Section IV of this Volume lists paragraphs of the specification where recommendations have been made.

Northrop validated a total of 250 specification requirements based specifically on its design and test experience with the two YF-17 prototype lightweight fighter aircraft. The scope of the specification including the control system classifications and criticality classifications appears suitable for Class IV airplanes. Some difficulty was encountered in the definition of Operational State IV. The distinction between this state and Operational State V becomes unclear for Class IV airplanes for all engines out operation. The inclusion of built-in-test equipment requirements in the System Requirements section and electrical signal computations requirements in the Subsystem Requirements is particularly important for current and future control systems that rely heavily on complicated electrical computation to provide good flying qualities over very extensive flight envelopes.

Lockheed validated a total of 330 specification requirements primarily by comparison with the C-5A. A few requirements were compared with the C-141A or C-130 aircraft with an eye toward future transport aircraft similarly sized and powered. It was concluded that application of this new set of requirements to the C-5A would have had little impact on its development. The classifications definitions and criticality evaluations of FCS were particularly difficult to validate primarily because of the FCS definitions provided and the lack of a workable definition of flight control function in the document. Lockheed offered recommendations for redefinition of FCS Classifications, adding two classifications, and for defining FCS function in an effort to resolve these difficulties.

It was concluded that, although it can be improved, this new definition of overall FCS requirements contained in MIL-F-9490D represents a timely and thorough statement of control system requirements and a worthwhile advancement for future procurements.

PREFACE

This report was prepared jointly by the Northrop Corporation Aircraft Division - Hawthorne, California, and the Lockheed-Georgia Company - Marietta, Georgia, for the Air Force Flight Dynamics Laboratory under USAF Contract F33615-76-C-3034, Project No. 1987. Northrop Corporation was the prime AFFDL contractor with Lockheed-Georgia performing as a subcontractor to the Northrop Corporation. 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. Ralph J. Hylton of Lockheed-Georgia Stability and Flight Controls Department served as the Lockheed principal investigator and directed the C-5A validation process. Mr. Larry B. Hartsock of Northrop Controls Technology served as the program coordinator between Northrop and Lockheed-Georgia. The authors wish to acknowledge their gratitude to the following personnel for their diligent contributions to the program: Messrs. D.H. Johnson, J.D. Anderson, and R.L. McCormick of the Northrop Aircraft Division and Messrs. William E. Jordan, Charles W. Kettering, John M. McCarty and Harold A. Valery of the Lockheed-Georgia Company.

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-9490, "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 a summary of the level of compliance achieved and the most significant conclusions and recommendations resulting from the validations performed for the new MIL-F-9490D by two distinct and unassociated classes of specification users, namely, the Northrop Aircraft Division using the prototype YF-17 Lightweight Fighter, and the Lockheed-Georgia Company using the C-5A Heavy Logistics Transport. The YF-17 is an advanced technology prototype fighter aircraft whose flight control system was designed to comply with MIL-F-9490C except for deviations as allowed by the procuring activity for prototype aircraft. The C-5A is an operational long-range, all-weather, high-altitude, high-subsonic heavy logistics transport. Its flight control system was designed to meet the system requirements, set forth in CP40002-6B, Performance/Design and Product Confirmation Requirements for C-5A Air Vehicle, Flight Control Subsystem, which were necessary to accomplish the missions defined for the C-5A. The basis for this specification was MIL-F-9490C and would be equivalent to the controls specification required by MIL-F-9490D, Paragraph 4.4.2. The impact the new Military Specification MIL-F-9490D would have on each of these aircraft were they designed to it was determined by a paragraph-by-paragraph evaluation of the specification requirements, presented in Volumes II and III of this report, based on existing ground test, flight test, and analytical data. In some instances complete validation was not possible due to either severe data limitations, especially for the prototype aircraft where there is limited use and operational experience, 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.

No attempt has been made to reconcile any differences in specification recommendations between the YF-17 and C-5A validations. This is beyond the scope and intent of this study. This summary volume is intended to provide an integrated introduction to and a summary of significant results of the two validation efforts which were intentionally kept technically distinct. For detailed validations, the reader is referred to Volume II for the YF-17 and Volume III for the C-5A validations. 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

VALIDATION OBJECTIVES

A three year program to completely revise Military Specification MIL-F-9490C (USAF), "Flight Control System Design Installation and Test of, Piloted Aircraft, General Specification for," dated 13 March 1964, to reflect the present and projected state-of-the-art of flight control system technology was recently completed by AFFDL. The new specification, MIL-F-9490D, dated 6 June 1975, reflects the present and projected state-of-the-art of flight control system technology and is intended for use as a specification for procurement design, test and installation of a flight control system for future military aircraft.

The overall objective of this program was to validate the new MIL-F-9490D with regard to practicability, accuracy, and completeness as a specification for procurement, design, test and installation of a flight control system for future piloted military aircraft. This was accomplished by evaluating each paragraph of the specification applicable to the YF-17 Lightweight Fighter and the C-5A Heavy Logistics Transport flight control systems with respect to these characteristics. It should be noted here that in satisfying this objective, it was difficult to strictly adhere to the criteria of practicability, accuracy, and completeness as the specification yardstick. Other considerations were sometimes included such as, can compliance be demonstrated or can the requirement be modified to be demonstratable. Occasionally definition of terms in the specification would lead to ambiguities or unworkable interpretations which resulted in recommendations for clarification.

This overall validation objective contains four principal components which constitute the specific program objectives addressed by the validation process. These are:

- 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.

The recommendations made in 1. above were one of four types, namely, to retain the requirement as stated, revise the requirement as noted, clarify the requirement as noted, or to delete the requirement. In some instances, a deficiency of the requirement could be detected with respect to its impact on future system technology but insufficient data existed to make a precise recommendation. Here the objective was, where possible, to suggest experimental and/or analytical studies to provide data for future validations.

SECTION III

AIRCRAFT AND FLIGHT CONTROLS CHARACTERIZATION

1. YF-17 Lightweight Fighter

The YF-17 is a high performance Class IV prototype fighter aircraft developed to demonstrate advanced technology applicable to air combat. The basic aerodynamic configuration has been designed for high lift, low drag and buffet, and handling qualities satisfying the intent of MIL-F-8785B. New technology in maneuver enhancement and high-angle-of-attack flight has thus been incorporated in the YF-17. The low horizontal tail location provides longitudinal stability at high angles of attack and the twin, canted vertical tails provide positive directional stability throughout the flight envelope. Leading-edge and trailing-edge flaps vary the wing camber for maximum maneuvering performance. A reclined pilot's seat provides an increase in pilot tolerance to high-g flight. A three-view drawing of the YF-17 is given in Figure 1.

Two General Electric YJ101 continuous-bleed, after-burning turbojet engines are installed in the aft fuselage. Location of the engine inlets under the wing, integrated with a longitudinal slot through the wing roots, results in a low-drag installation while maintaining high-quality airflow to the engine inlet. Dual hydraulic systems insure control availability in the event of a hydraulic system failure or engine failure.

New structures technology is incorporated through the use of composite materials in numerous airframe applications.

A control augmentation system (CAS) is the primary mode of flight control in the YF-17 in a dual channel, fail-safe configuration. Computational requirements are satisfied by an analog control augmentation computer and a digital air data computer (DADC), each utilizing state-of-the-art computer packaging. These computers provide gain scheduling and failure detection in the three primary axes. Self test is incorporated by a built-in-test sequence that tests all elements of the control augmentation system automatically. Block diagrams of the longitudinal, lateral, and directional control axes are shown in Figures 2, 3, and 4.

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 servo-actuator. Pilot primary controls consist of a conventional center stick and rudder pedals. The pilot's control feel forces are supplied artificially. The arrangement of the flight control system is shown in Figure 5.

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

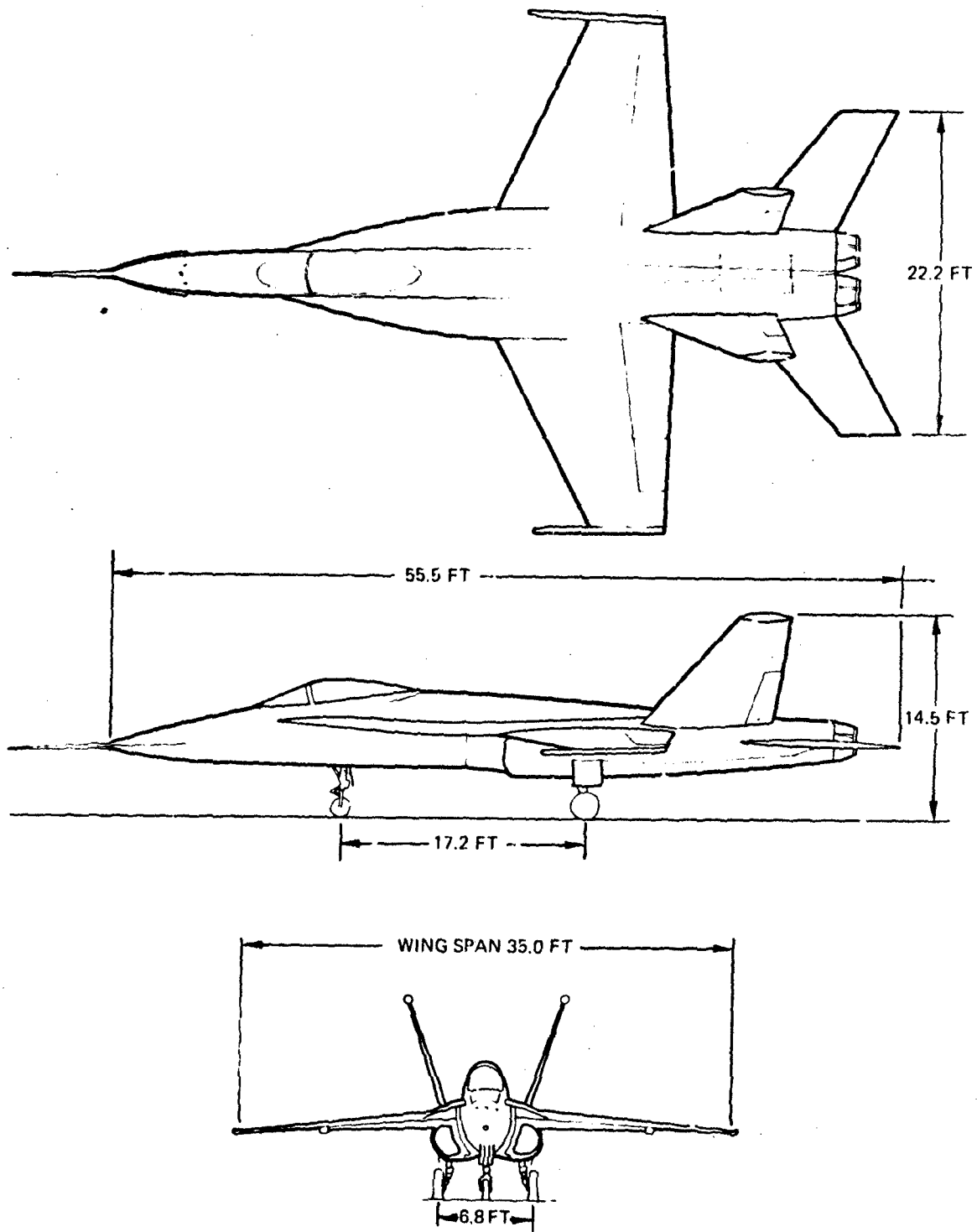


Figure 1. YF-17 Three-View Drawing

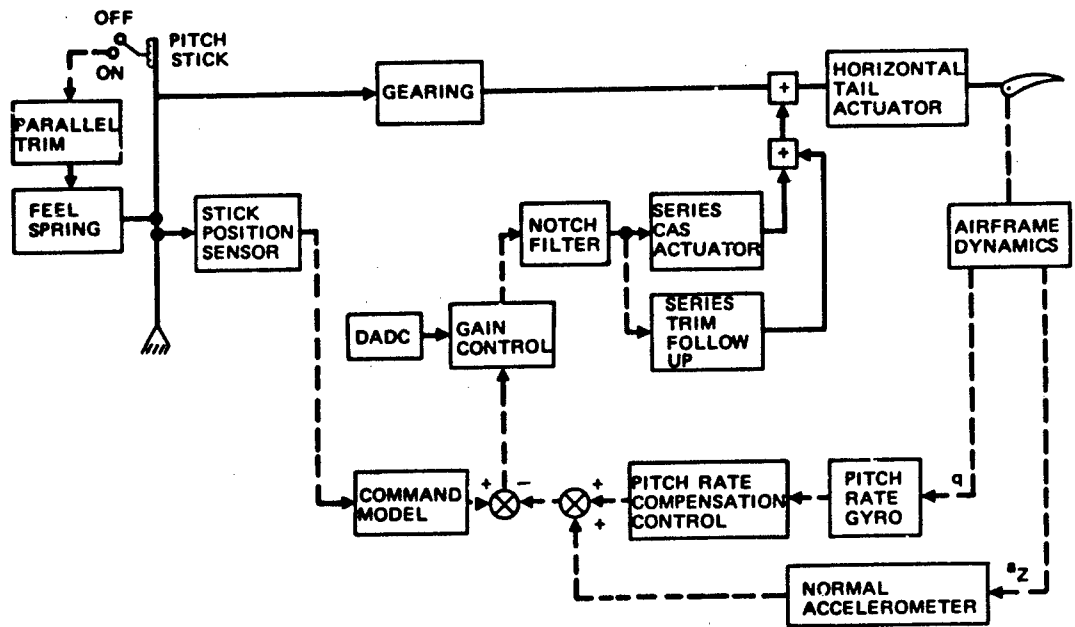


Figure 2. YF-17 Longitudinal Control System

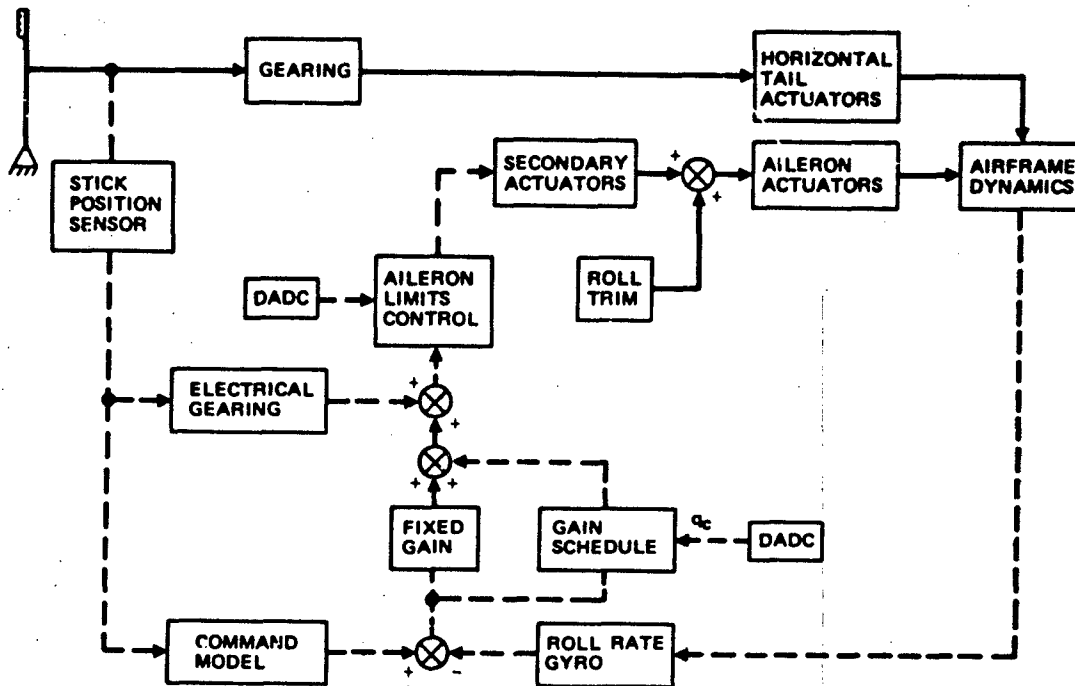


Figure 3. YF-17 Lateral Control System

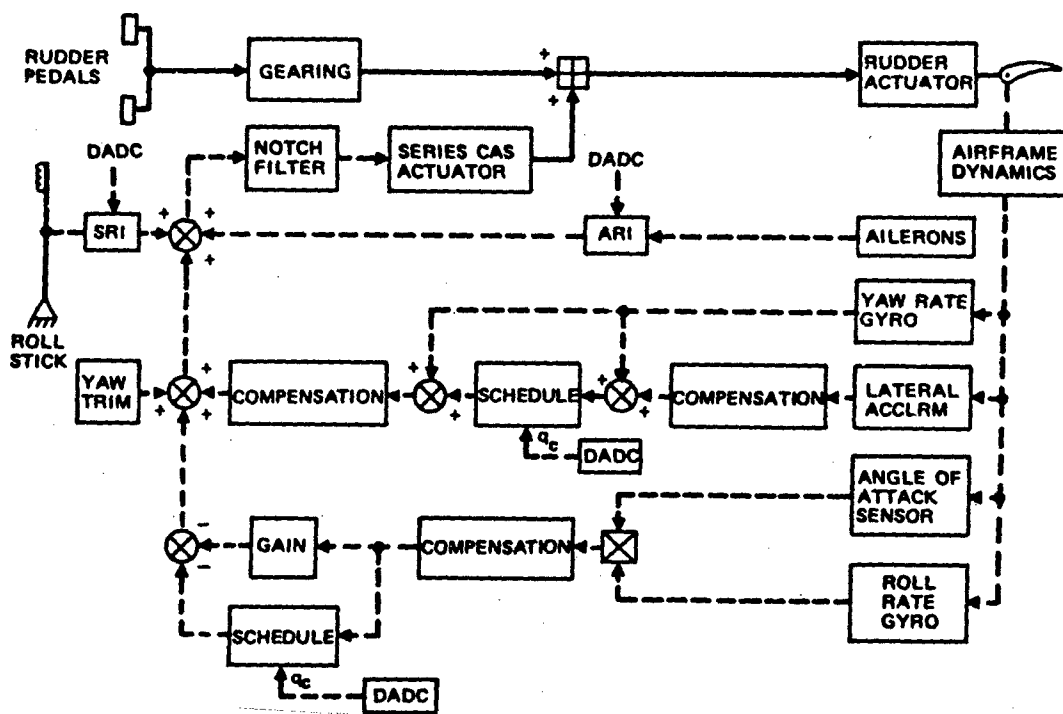


Figure 4. YF-17 Directional Control System

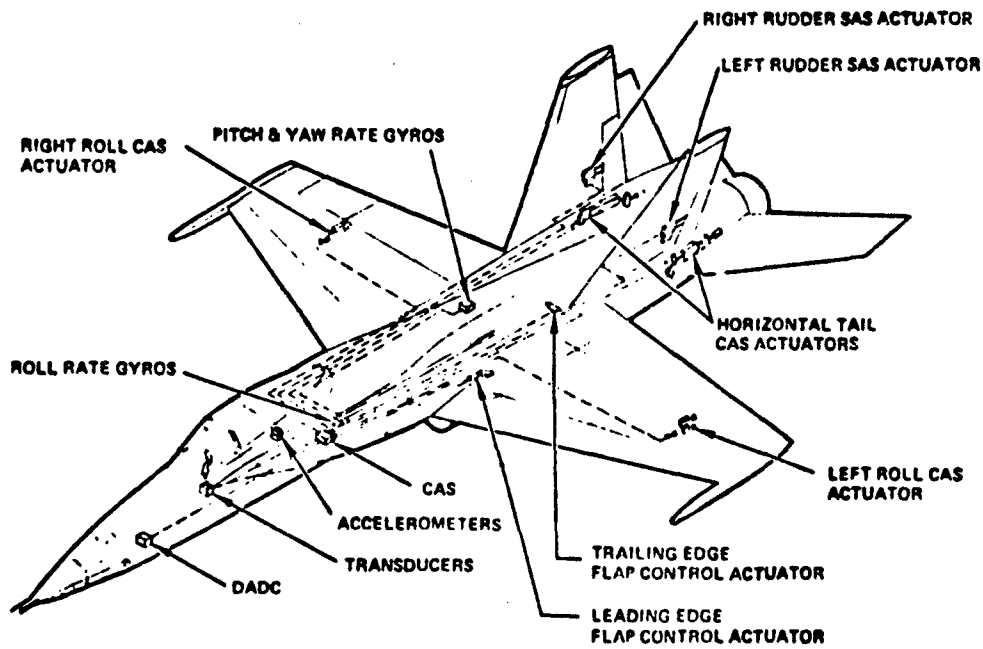
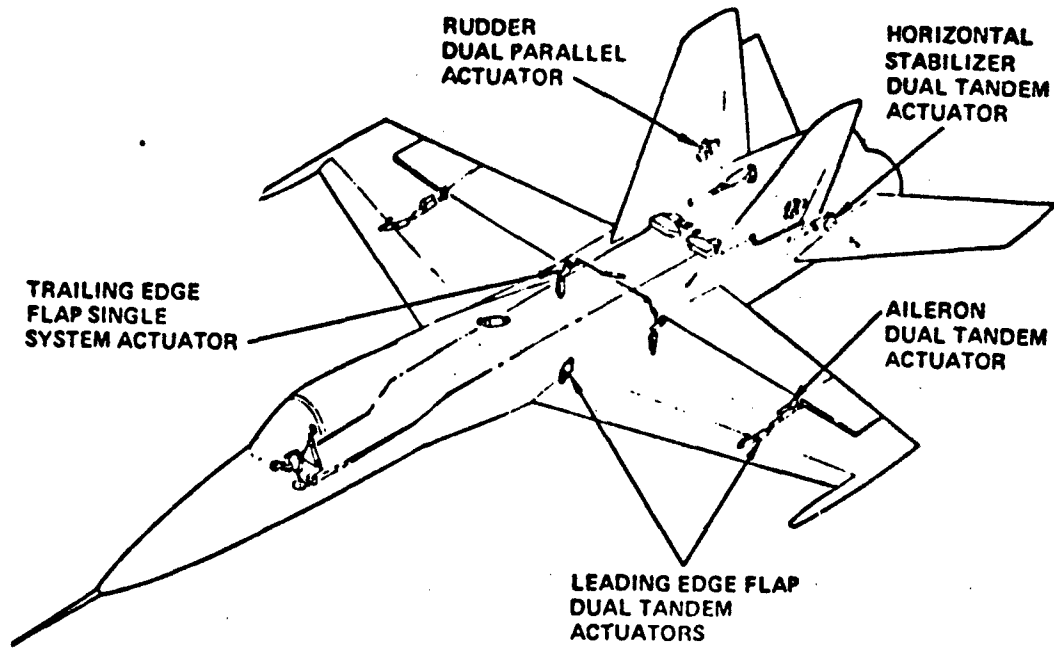


Figure 5. YF-17 Flight Control System Arrangement

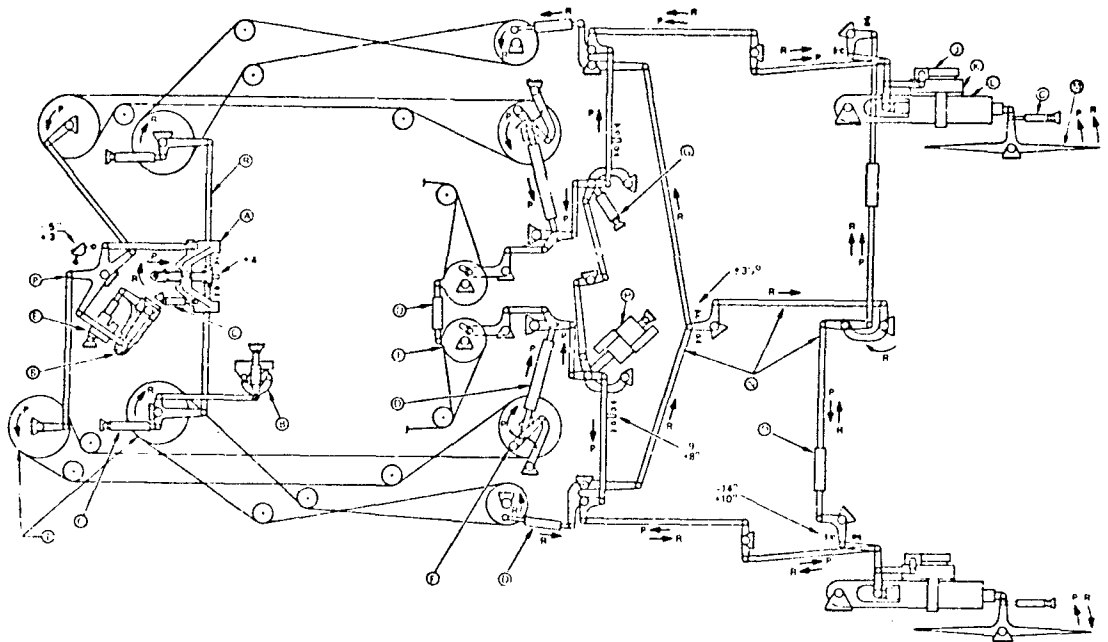


Figure 6. YF-17 Horizontal Tail Control System - Pitch & Roll Control

in the pitch CAS, pitch control can be maintained by the mechanical system alone.

Roll control is implemented by a combination of electrically controlled ailerons and mechanically controlled differential motion of the horizontal stabilator (rolling tail). A schematic of the horizontal stabilator/rolling tail mechanical system is shown in Figure 6. These two means for producing rolling moment thus provide aerodynamic redundancy in roll control. The ailerons are controlled by a direct electrical signal path from the control stick and a model-following roll-rate-command augmentation system. The fail-safe logic in the aileron system is such that a failure will only shut off the failed aileron system, allowing the other aileron to remain operational.

Yaw control is through a conventional cable and push-pull rod mechanization to the rudders complemented by a stability augmentation system in which yaw rate, lateral acceleration, and roll-rate-times-angle-of-attack feedback signals are used. A roll-to-yaw interconnect system is utilized and consists of electrical signals from the ailerons and from the control stick to the rudder actuators. The interconnect system is independently fail-safe per side and incorporates a backup system in the event of loss of the angle-of-attack signal.

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 flaps position schedules, mode selection, and failure logic are provided by digital computation and control.

In summary, the YF-17 is normally flown by a control augmentation system but can also be safely flown by a conventional mechanical system in all three axes. Dual engines and dual hydraulics provide additional safety and reliability.

2. C-5A Heavy Logistics Transport

The C-5A is a Class III (heavy logistic transport) airplane as classified in paragraph 1.3 of MIL-F-8785B. It is a long range, all weather, high altitude, high subsonic, swept wing T-tailed airplane with relatively short field performance capability. The C-5A is powered by four General Electric TF-39 turbofan engines equipped with thrust reversers.

The aircraft gross weight ranges from 319,809 lbs. empty to 769,000 lbs. maximum design gross and can carry up to 265,000 lbs. payload of a wide variety such as heavy wheeled combat support equipment and personnel. The C-5A basic configuration and dimensions are shown in the three-view drawing of Figure 7.

C-5A flight controls systems consist of manual controls, aerodynamic enhancement controls, automatic controls and limiting controls. These systems are powered from four independent hydraulic systems and four electrical

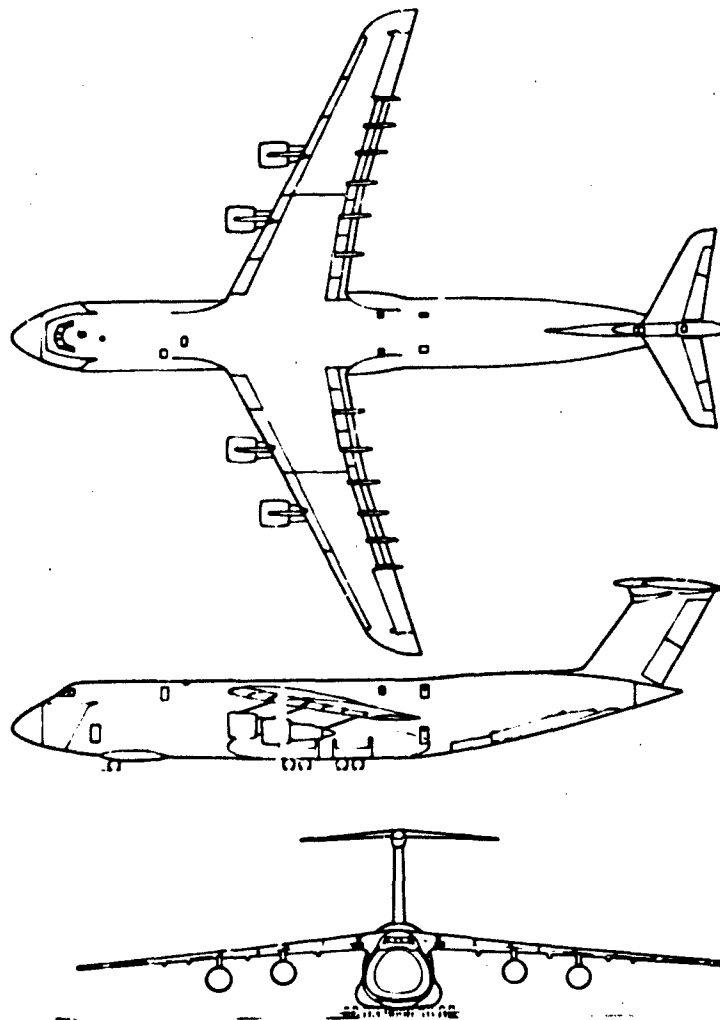


Figure 7. C-5A Three-View Drawing

systems providing either ac or dc power. The hydraulic power distribution is shown in Figure 8. The electrical power distribution is shown in Figure 9.

The manual flight controls provide for pilot control of C-5A airspeed, altitude, heading, attitude and flight path. Ailerons, spoilers, elevators and rudders are controlled by fully powered hydraulic servos capable of accepting mechanical and, in some cases, electrical commands. Figures 10, 11, and 12 depict the pitch, roll and yaw axis controls respectively. The C-5A rudder controls include the rudder input travel limiter to limit the rudder travel during high speed flight. Pilot feel forces are provided artificially in pitch, roll and yaw MFCS.

Trim controls for the lateral and directional axes are commanded manually through electrical switches and are operated by electro-mechanical actuators with their conditions being indicated to the pilot. Longitudinal trim is commanded by the pilots by operation of electrical switches or trim control levers. Trim position is indicated to the pilots. Trim control and indications are shown in Figure 13.

The C-5A employs trailing edge flaps and leading edge slats for lift increases necessary for short field performance. These are retracted for high speed flight. Figure 14 shows the flap/slat mechanization and arrangements. Either pilot can deploy the flaps/slats.

A ground spoiler system is provided to spoil wing lift and increase drag to reduce stopping distance during landing or RTO. The ground spoiler system is controlled by either pilot. Figure 15 shows the ground spoiler system.

The C-5A automatic control subsystems were designated as the stall-limiter, go-around attitude system (GAAS), and automatic flight control system (AFCS) shown in Figure 16. These subsystems provide warning of an impending stall, augment stability, enhance manual control feel, control the flight of the aircraft and provide active load alleviation. The pilot is retained, in the automatic control loops, as the major system manager. At any time during any mode of operation, the pilot can take command and manually control the aircraft to complete his mission. The capabilities of the automatic controls are:

- 1) Automatic stall-warning
- 2) Automatic throttle functions
- 3) Automatic pilot basic functions
- 4) Automatic pitch trim control
- 5) Automatic enroute navigation (VOR, TACAN, and inertial)
- 6) Automatic terrain following (vertical flight path control)
- 7) Automatic terminal navigation (ILS approach, radar approach, and air drop)
- 8) Automatic landing (flare, throttle retard, and rollout)

- 9) Automatic go-around (vertical flight path control)
- 10) Pitch augmentation
- 11) Yaw augmentation
- 12) Lateral augmentation
- 13) Active lift distribution control

Operation of all automatic control systems is controlled from the flight station. Various control and test panels are located on the center console, throttle, quadrant, pilot's and copilot's side consoles, pilot's overhead panel and navigator's panel.

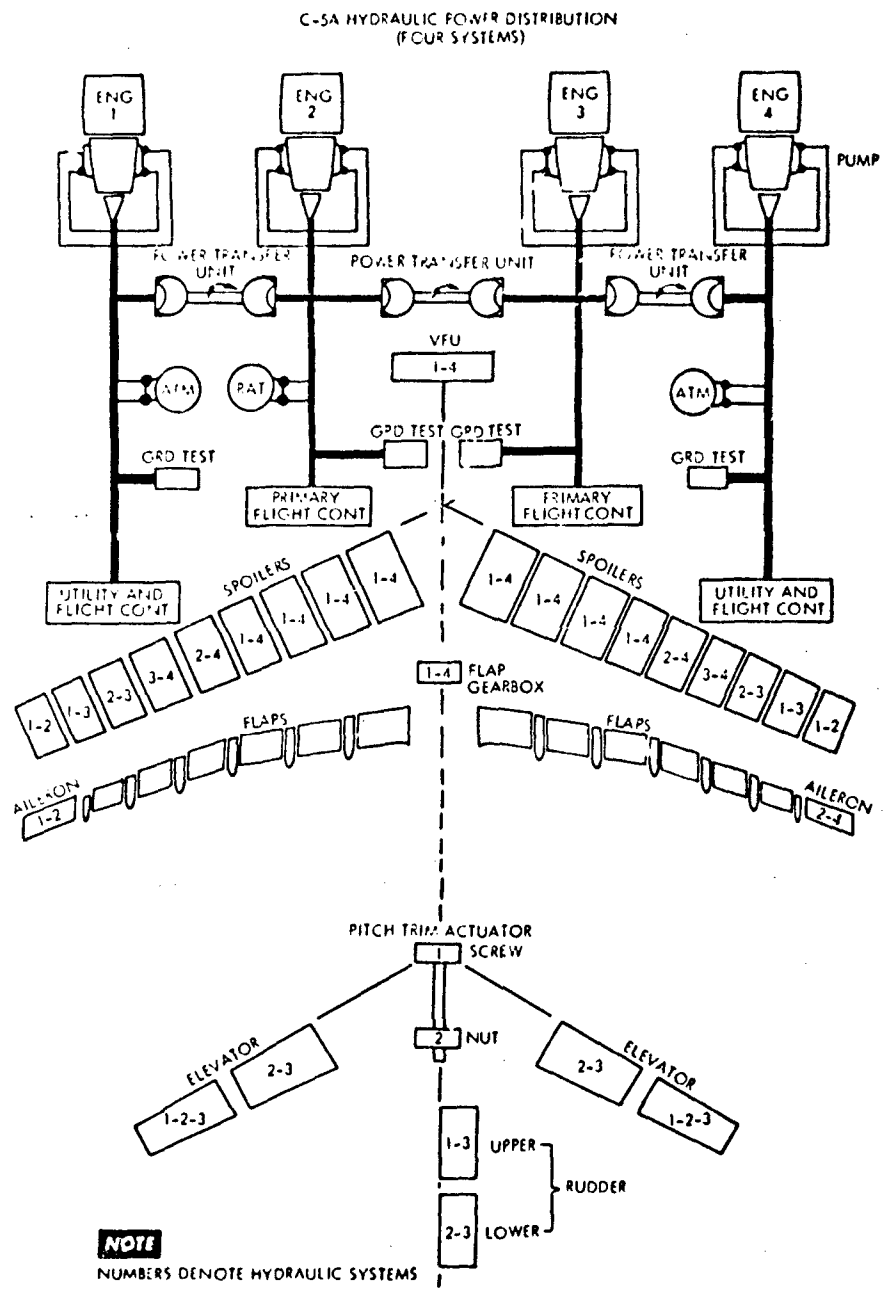


Figure 8. C-5A Flight Control Hydraulic Power Distribution

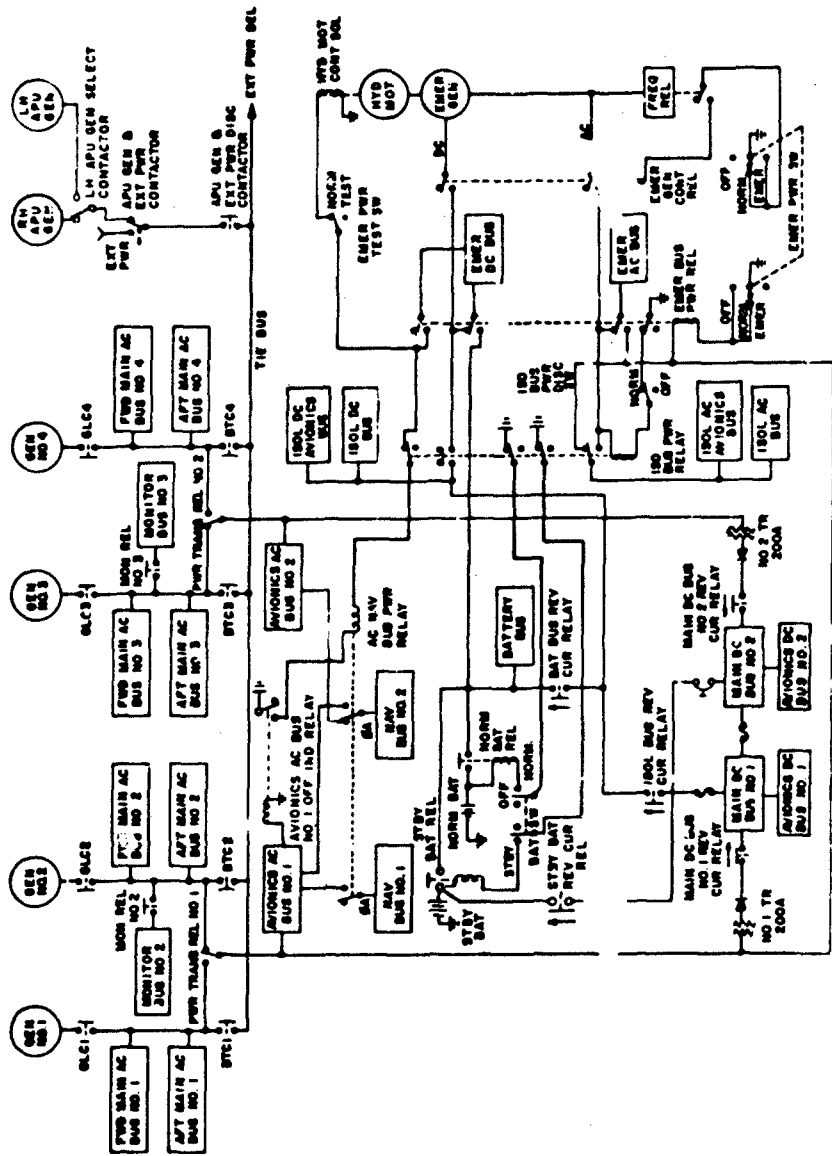


Figure 9. C-5A Electrical System

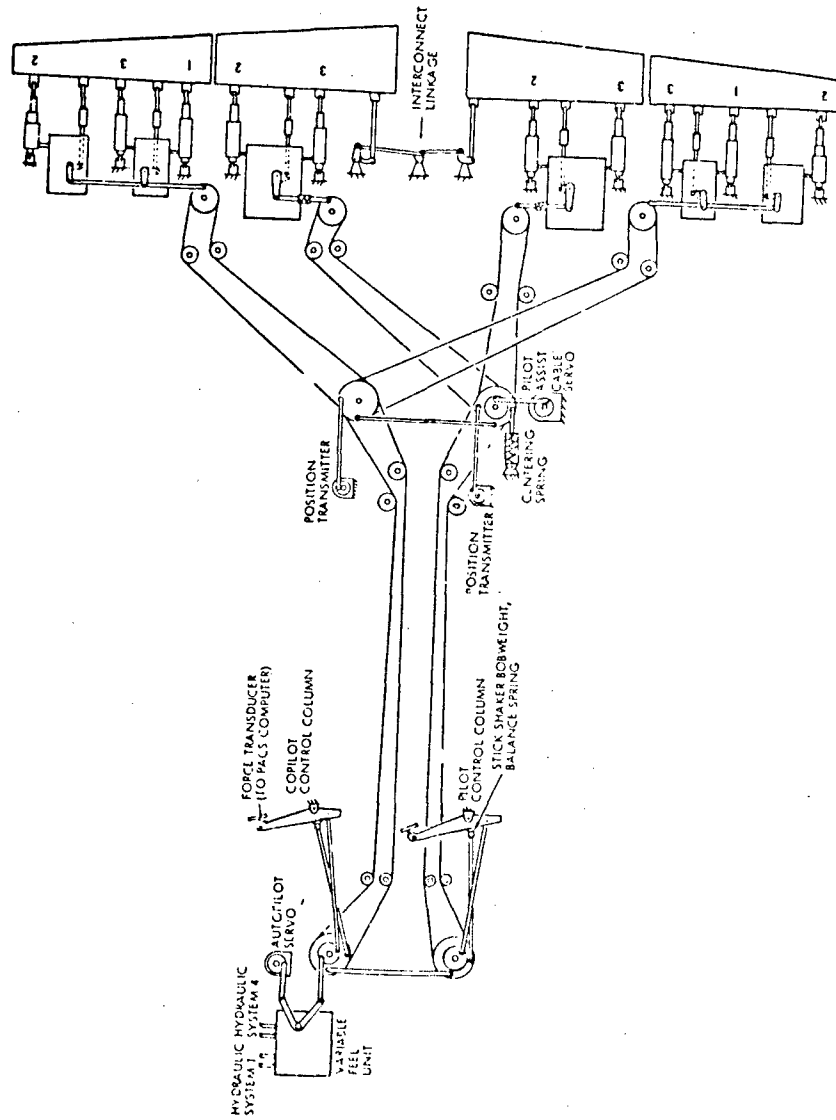


Figure 10. C-5A Elevator Control System

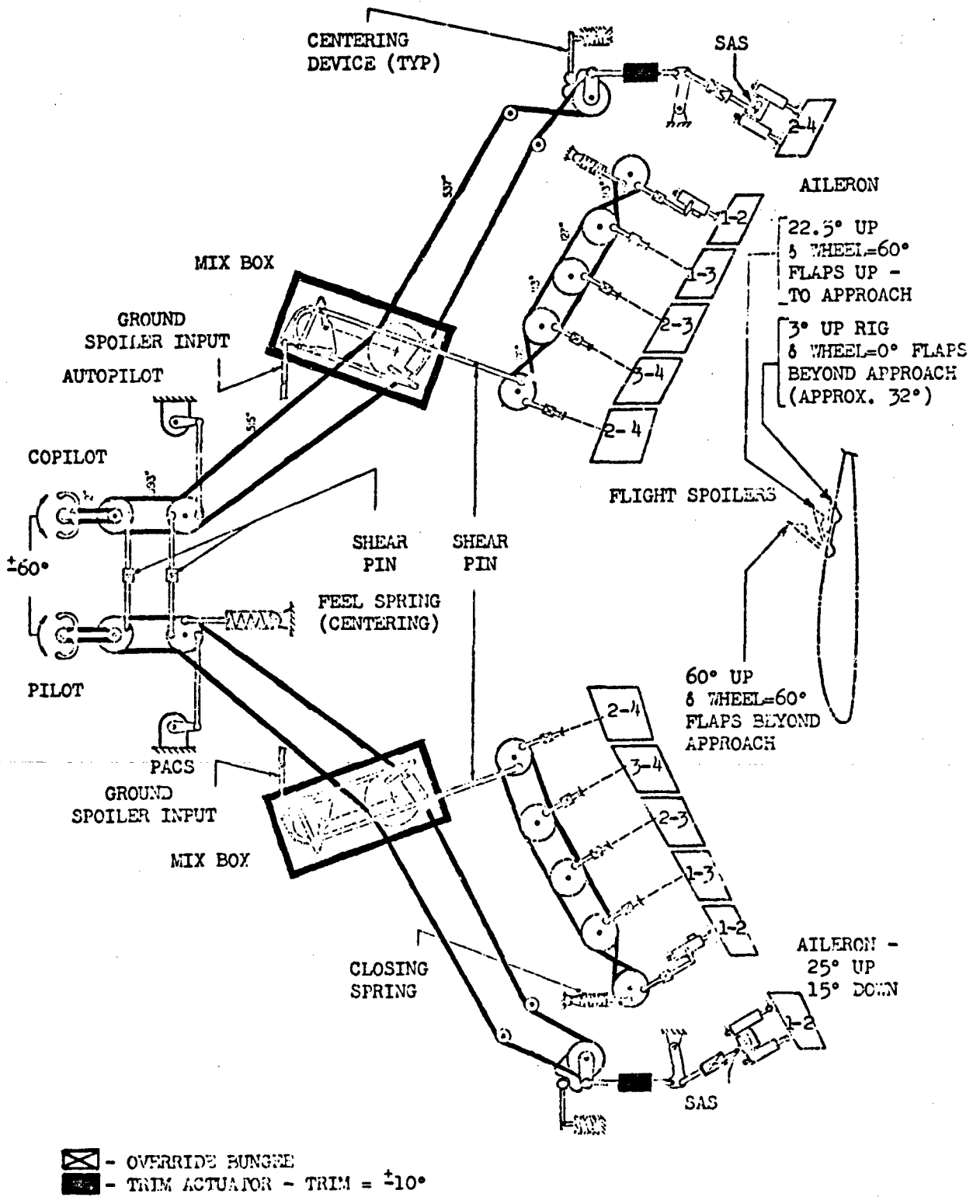


Figure 11. C-5A Roll Control System

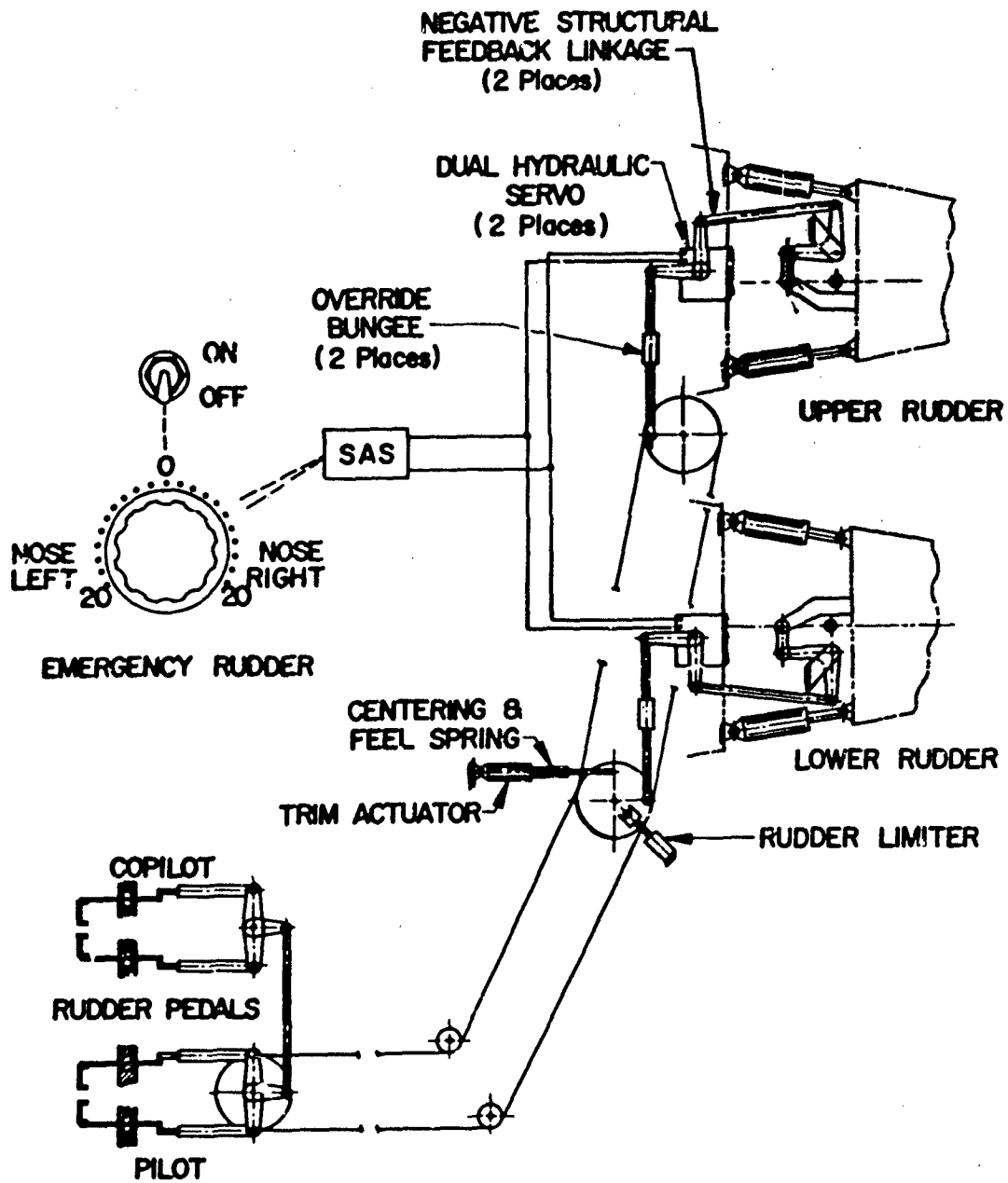
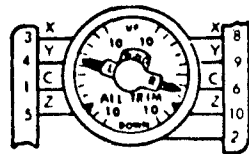
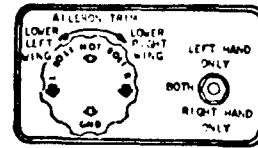


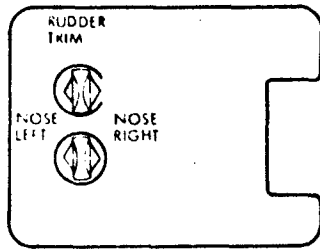
Figure 12. C-5A Rudder Control System



AILERON TRIM INDICATION



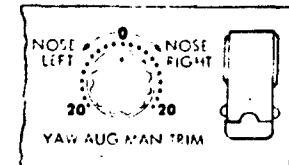
AILERON TRIM CONTROL CENTER CONSOLE



RUDDER TRIM CONTROL SWITCHES CENTER CONSOLE (COPILOT'S SIDE)



TRIM POSITION INDICATOR



EMERGENCY CONTROL SWITCHES

C-5A PITCH TRIM SYSTEM

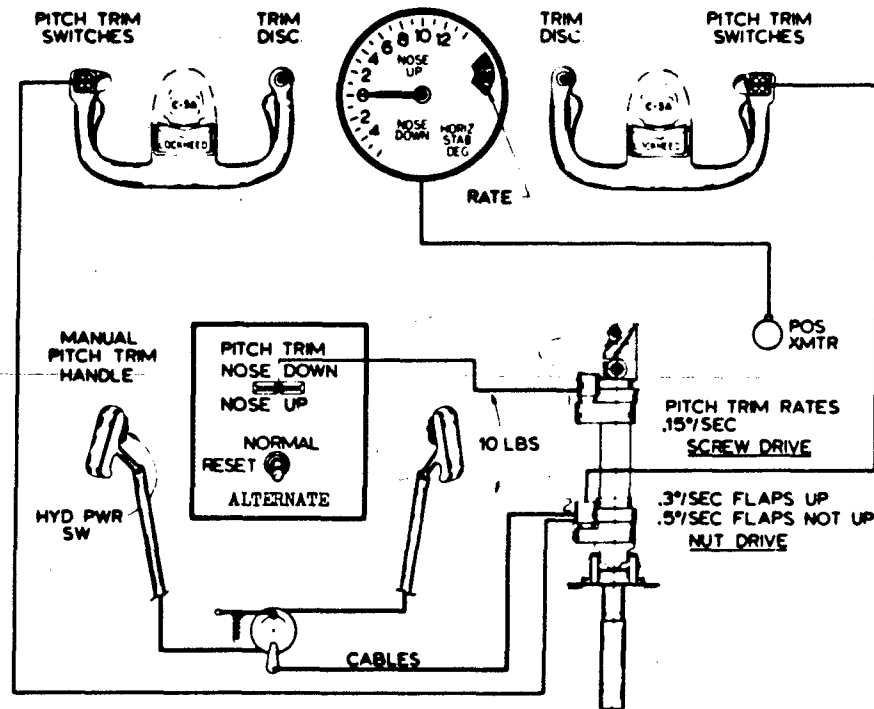


Figure 13. C-5A Trim Controls and Indication

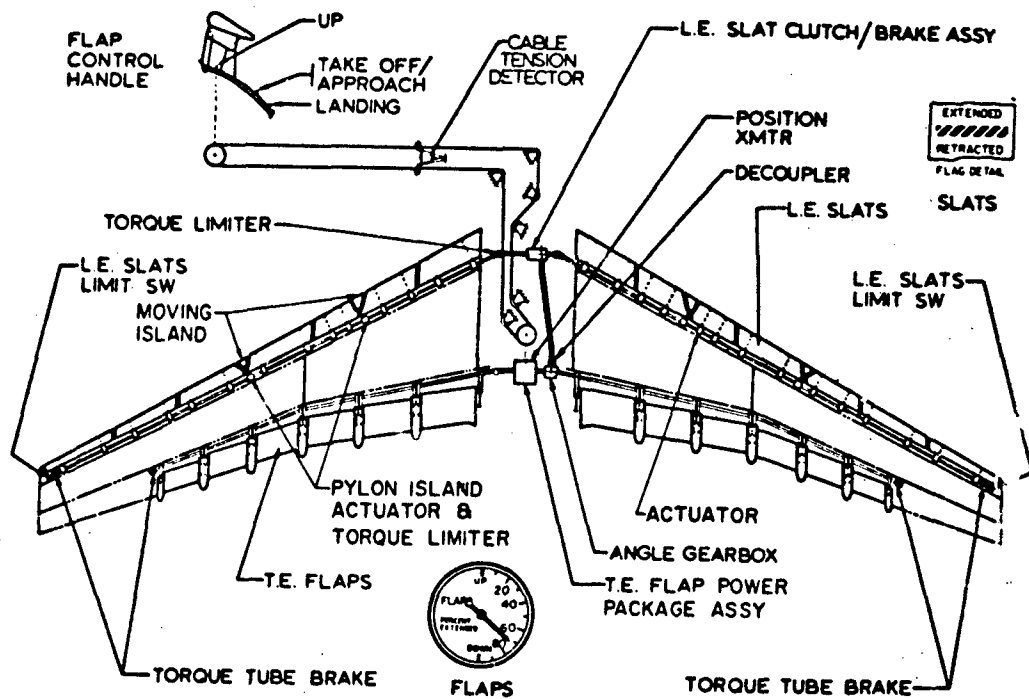


Figure 14. C-5A High Lift System

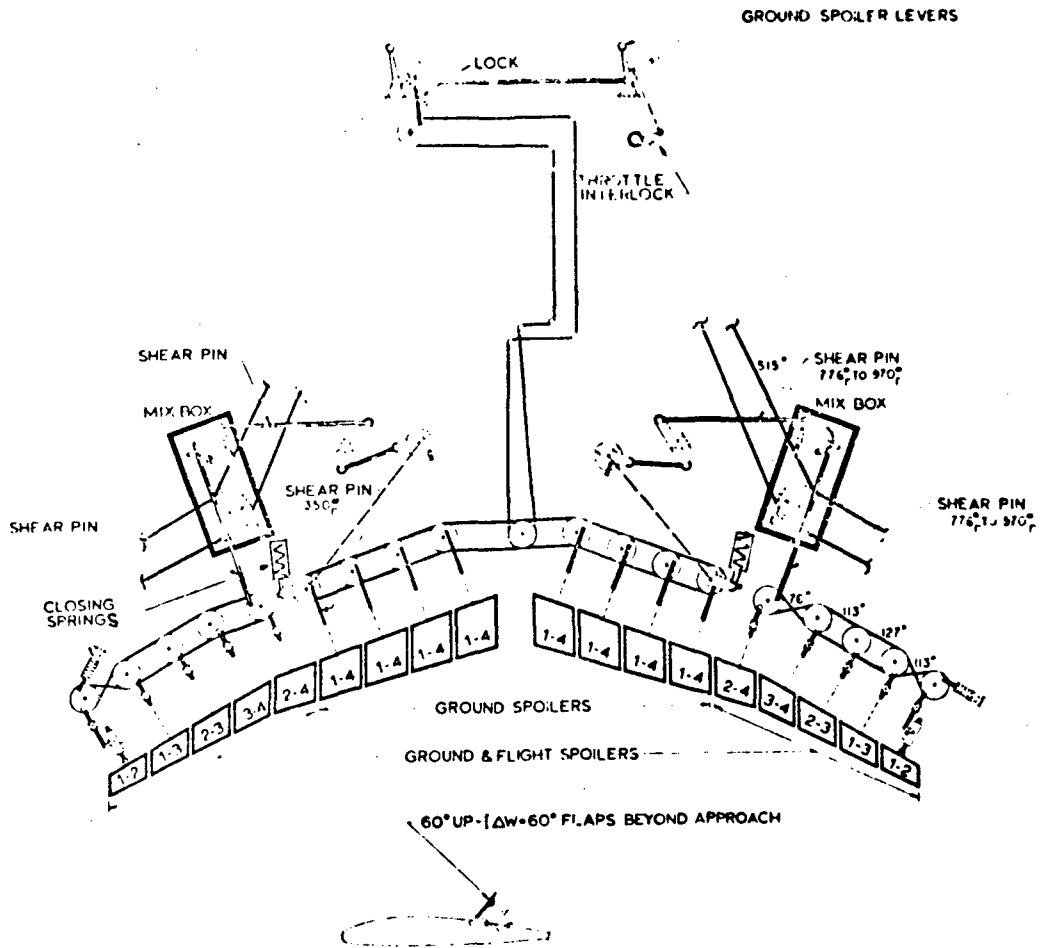


Figure 15. C-5A Ground Spoiler System (Lift Dump & Drag)

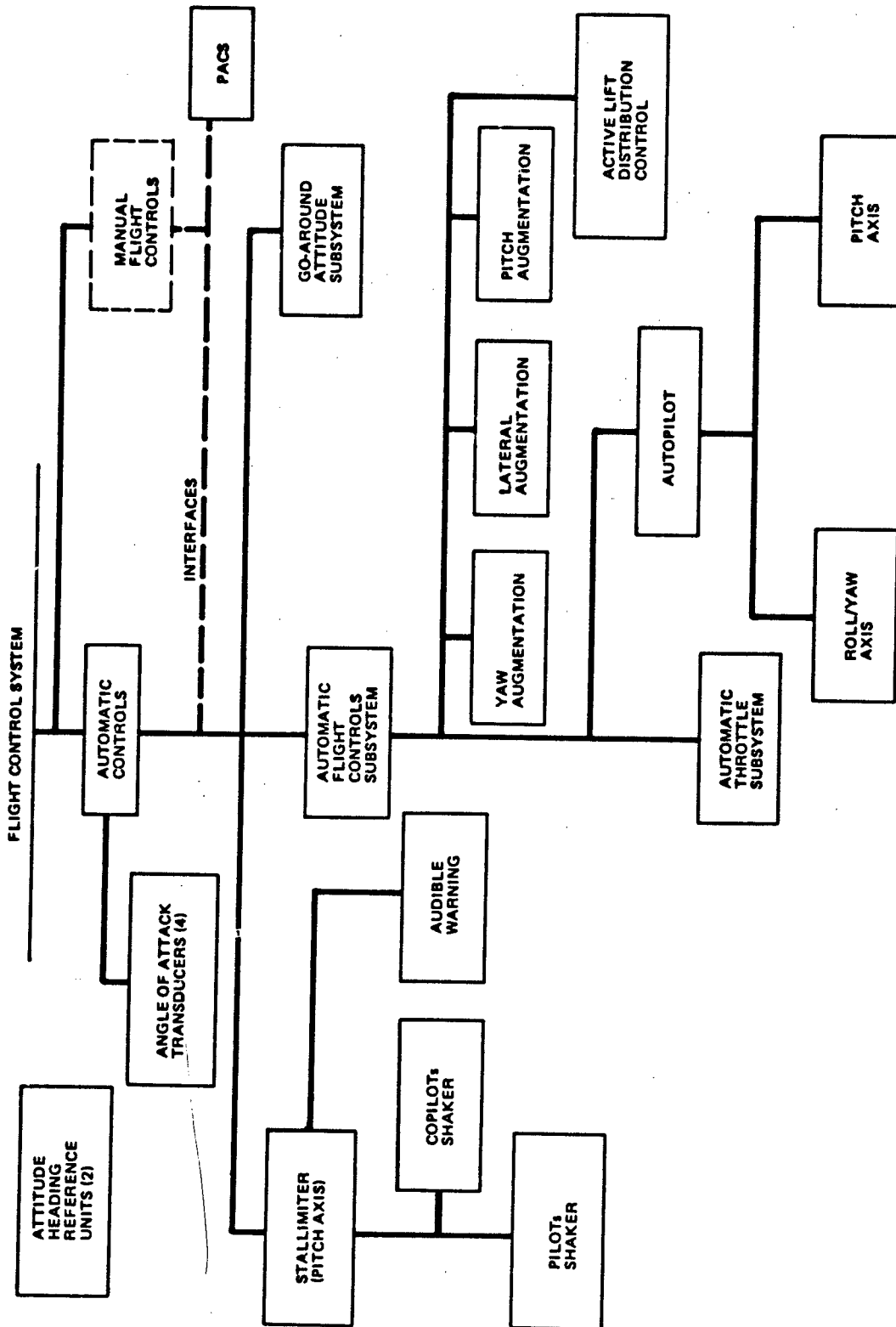


Figure 16. C-5A Automatic Controls Subsystems

SECTION IV
VALIDATION SUMMARY

1. YF-17 Validation

Each of the requirements of the specification applicable to the YF-17 was examined according to the validation process as discussed in Section II-Validation Objectives. While the validation performed was based specifically on Northrop's experience with the design and test of the two YF-17 prototype aircraft, it is felt that the results have applicability to Class IV aircraft in general.

The YF-17 complies fully or partially with most of the applicable requirements of MIL-F-9490D. 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.

In all, Northrop found 183 out of a total of 249 specification requirements (including title paragraphs) validated to be acceptable as presented. Examples of observations made and conclusions reached during this study with respect to the validation objectives are listed below. Table 1 at the end of this section presents a complete summary of the validation results.

- The areas of YF-17 partial compliance or noncompliance are mostly in subsystem and component design requirements. Full compliance would have required design, fabrication, installation details or equipment testing beyond that deemed necessary or appropriate for a prototype aircraft. Examples include:

3.2.3.1.2 System separation, protection and clearance
(Cable and control rod clearance)

3.2.3.1.4 Rigging provisions
(Rig pin accessibility)

3.2.3.2.4 Control cable installations
(Turnbuckle accessibility)

3.2.3.2.4.7 Pulley-bracket spacers
(Spacers are used)

3.2.3.3.1.1 Cable assembly design and construction
(Lack of strain relief hardware of some connector terminations)

3.2.4.3.2 Digital computation
(Computational time; storage for growth)

3.2.5.3 Hydraulic power subsystem
(Airplane does not have a fully dedicated system for flight controls)

3.2.7.2.4 Structural fittings
(Sheet metal structure used)

3.2.7.3.2 Microelectronics
(Not necessarily qualified to MIL-M-38510)

- In a few instances system requirements are not fully met. The reason for this is generally the same as above, i.e., the prototype nature of the YF-17. Examples include:

3.1.9.2 Invulnerability to lightning strikes and static atmospheric electricity
(No lightning system implemented)

3.1.9.7 Invulnerability to enemy action
(Not required in a prototype aircraft)

3.2.4.3.2 Digital computation
(Less than required reserve storage)

- In a few instances, the degree of compliance has not been established for the YF-17. Examples include:

3.1.3.8 Residual oscillations
(Insufficient resolution of flight test instrumentation)

3.1.9.1 Invulnerability to natural environments
(Complete environment testing not performed)

3.1.11.3 Durability
(Tests limited to flight justification type)

- Some of the requirements are considered to be too stringent, or unsuitable in some manner for Class IV aircraft. Examples include:

3.1.3.9.1 Built-In-Test equipment (BIT)
(Fault isolation to the LRU level with a confidence factor of 90 percent would be difficult to attain)

3.2.1.1 Pilot controls for CTOL aircraft
(Does not allow innovative cockpit configurations such as the YF-17's 18 degree reclined seat)

3.2.4.3.2.1 Memory protection
(Too stringent for ROM-type storage)

3.2.4.3.2.3 Software support
(Not specific enough)

3.2.7.3.1 Dielectric strength
(Too stringent for solid state electronic assemblies)

3.2.7.3.6 Potentiometers
(Too broad in scope and too restrictive)

- Some of the requirements are considered to be too lenient, or unsuitable in some manner for Class IV aircraft. Examples include:

3.1.3.3 System operation and interface
(Interface relationships between flight control channels of equal or similar criticality)

3.1.3.9 System test and monitoring provisions
(Noncritical FCS functions also contribute to the Mission Reliability)

3.1.3.9.2 Inflight monitoring
(Inflight monitoring for all control functions)

- Areas were identified which require further research to improve a requirement. Examples include:

3.1.3.6.1 Stability margins
(Real-time simulation of CAS-coupled structural modes)

3.1.3.8 Residual oscillations
(Effect of residual oscillations on pilot's performance)

3.2.1.1.2 Additional requirement for rudder pedals
(Forcesensing fixed rudder pedals)

3.2.3.3.2 Multiplexing
(Redundant multiplex data buses and I/O requirements for critical flight control functions)

4.3.3 Aircraft ground tests
(More comprehensive definition of ground test techniques)

The tabulated summary in Table J at the end of this section identifies the paragraphs that were validated for the YF-17. The table indicates the degree of compliance for each paragraph as full, partial, non-compliance, or not established. Included is an assessment of the stringency of each requirement as to whether it is good as is, is too strict or too lenient. The table also indicates those paragraphs for which specification revisions are recommended and where text for the User's Guide is provided.

2. C-5A Validation

Each requirement applicable to the C-5A aircraft was subjected to the validation process. Lockheed has also commented upon or validated other requirements not related to the C-5A when its background and experience could be satisfactorily applied and the requirement was believed to relate to future generations of propeller driven and jet powered transport aircraft and FCS.

In all, Lockheed found 235 out of a total of 330 specification requirements (including title paragraphs) validated to be acceptable as presented. For both the requirements accepted as presented and the requirements for which changes were recommended, a need for additional clarification in the Users' Guide was recognized in many instances. It was also recognized that, in many cases, the information in the Comparison and Discussion sections contained worthwhile information for clarifying particular requirements. In these instances, this information was provided as Additional Data.

Some problems and conclusions with respect to the validation of these requirements to the C-5A are summarized below.

- Application of this new set of requirements would probably have had only relatively minor effects on the C-5A development and final configuration because the differences in C-5A and MIL-F-9490D specifications tended to offset each other.
- Some requirements are too stringent for Class III aircraft. Examples include 3.1.2.9.1 Localizer Mode, 3.1.2.9.2 Glide slope mode, 3.1.2.12 Ride smoothing.
- Some requirements are too lenient such as 3.2.1.1.6 Two speed trim actuator.
- Lockheed was not able to apply some requirements consistently and satisfactorily even after several attempts. Problems were experienced particularly with the application of 1.2.1 FCS Classifications and 1.2.3 FCS Criticality classifications. A need for additional FCS Classifications and a redefinition of MFCS and AFCS are believed to be necessary. The validation of Section 1.2 follows and contains the recommended changes.

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 consist 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.

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 C-5A classifies the Flight Control Systems as Primary Flight Controls, Secondary Flight Controls, Automatic Flight Controls and Limiting Controls. This is a different classification than is contained in MIL-F-9490D. The C-5A classifications would not meet the new classifications, but whether the C-5A meets or does not meet this definition is not relevant.

Discussion

The attempt to do away with the old primary and secondary flight control classifications is good. However, including augmentation, performance limiting and control devices under a general classification of manual flight controls is confusing. These systems have traditionally been considered to be automatic controls and the detail design can differ considerably from the other manual controls. It is felt that these automatic controls should be contained under another classification. In addition, the classification of systems within the MFCS should be by function and/or operation.

The AFCS classification states that "semiautomatic flight path control" devices are included. The background information and "Users' Guide" for MIL-F-9490D states that "Semiautomatic control includes flight director functions when the option of automatic or semiautomatic operation is provided." It is not evident from the "Users' Guide" when the flight director is to be included as part of this specification. Requirement 1.1 (Scope) states that this specification includes dedicated displays, and Requirement 3.1.5.1.2 attempts to give some flight director system requirements. It is recommended that this specification should include the flight director system (including flight instruments) requirements. Paragraph 3.1.5.1.2 should be revised and expanded to include these system requirements.

The AFCS classification contained in MIL-F-9490D includes structural mode mechanizations. These systems should be carried under a different classification since their function is very different from autopilot and auto-throttle systems in that they have no direct effect on airspeed, altitude, heading, attitude or flight path.

Recommendation

Revise the requirement as follows:

"1.2.1 Flight Control System (FCS) Classifications. FCS are classified as to their function, the role of the pilot in the initiation of their primary control activity, the maintenance of or diversion from established flight conditions, their ability to improve ride qualities or stability, their role in reducing the magnitude of structural loads and improving structural fatigue life, and their ability to prevent surface flutter. FCS classifications are independent of the methods used for their mechanization. Flight Control systems may consist of more than one subsystem which are not classified herein. FCS have traditionally employed a combination of hardware components consisting of mechanical, hydraulic, pneumatic, electrical and electronic components suitably arranged and programmed to transmit surface commands and to provide feedback of surface and aircraft response as required. Actual hardware component selections are to be limited only by what is available and by what can be developed and shown to be suitable. FCS can be designed to be completely independent from each other or can utilize another FCS component in performing their particular function.

"1.2.1.1 Manual Flight Control Systems (MFCS). MFCS are those using pilot commands as the primary action to initiate control system activity to provide changes in control forces and moments necessary to produce changes in airspeed, altitude, heading, attitude and flight path. MFCS functions include pitch, roll, yaw, side force, lift, drag, trim and thrust.

"1.2.1.2 Aerodynamic Enhancement Flight Control Systems (AEFCS). AEFCS are those systems which improve ride qualities, improve stability of the aircraft or augment the pilot's ability to control.

"1.2.1.3 Automatic Flight Control System (AFCS). AFCS are those systems providing automatic maintenance of or diversion from established flight path condition and/or providing dedicated displays for pilot primary control of the flight path or for monitoring automatic control. AFCS provides automatic activity primarily independent of pilot commands except as required for control wheel steering or to activate, deactivate, preselect or reselect modes of operation. AFCS provide automatic control of such preselected flight conditions as airspeed, altitude, attitude and heading. AFCS may also provide automatic flight path control such as terrain following and precision course direction (auto land and auto nav). The AFCS includes autopilots, autothrottles,

flight directors (including flight instruments), and similar control subsystems.

"1.2.1.4 Limiting Flight Control Systems (LFCS). LFCS are those FCS which provide structural load alleviation or flutter suppression. These controls may act automatically to reduce the combined loads effects of maneuvering when encountering external disturbances (gusts and turbulence). Also they may provide fixed or varying degrees of aerodynamic damping necessary to assure overall flutter-free operation."

- At least one set of requirements is beyond the scope of MIL-F-9490D and that is 3.1.2.10 All weather landing system since that system includes not only aircraft equipment but ground based equipment, operations and procedures over which the contractor has no control. Lockheed recommended the replacement of this set of requirements with those appropriate for 3.1.2.10 Automatic landing system.
- As a design guide, the specification is too specific in some areas. An example is 3.2.1.1 Pilot controls for CTOL aircraft.
- Requirements for active controls need to be developed and included. An example is need for Active Lift Distribution Control Systems (ALDCS) such as the C-5A system described in Volume III of this report and discussed briefly in the validation of paragraph 3.1.2.11 Flight load fatigue alleviation.
- Some requirements need to be studied further to provide intelligent expansion of detail requirements. An example is 3.1.5.1.2 Flight director subsystems.
- There are requirements which should be different for Class III and Class IV aircraft based on differing vehicle requirements such as mission type and duration, vehicle service life and maneuvering requirements. These differing vehicle requirements affect FCS in areas such as vulnerability, survivability, servo design and performance characteristics, servo stability, and system redundancy.
- MIL-F-9490D requirements in general represent substantial improvements over other specifications with respect to some requirements definition. Examples are included under 3.1.3.8 Operation in Turbulence.

The tabulated summary Table 1 identifies the paragraphs validated using the C-5A and those requirements for which changes were recommended and for which additional data were provided for the Users' Guide. Also summarized in the table are the C-5A degrees of compliance with the validated paragraphs.

3. Tabulated Summary

Each paragraph of MIL-F-9490D, dated 6 June 1975, is listed in Table 1 by paragraph number and title. This table summarizes the results of the YF-17 and C-5A validations with respect to the four principal validation objectives discussed in Section II. The first pair of columns indicates if a recommendation for a requirement modification resulted from the validation program (indicated by an X). The next pair of columns show the quantitative degree of compliance attained in the development program (full, partial, or none). This is followed by an assessment of the requirement stringency (good, too lenient, too strict) as judged with respect to current and anticipated aircraft designs. The last two columns indicate where text has been provided, in Volumes II and/or III, for inclusion in the Users Guide to improve its usability. The symbology used in the table is summarized below and on the last page of the table. In a few instances, requirements not related to one of the aircraft were validated when there was sufficient background and experience to warrant an evaluation. In these cases the Compliance column was labeled N/A (not applicable).

Table Symbols

Specification Recommendation

(blank) - retain the requirement as stated
X - recommendation made (see Vol. II and/or III)
DNV - did not validate

Level of Compliance

F - full compliance
P - partial compliance
N - no compliance
U - undetermined
N/A - not applicable to aircraft validated

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 (see Vol. II and/or III)

TABLE 1 VALIDATION SUMMARY BY PARAGRAPH

PARAGRAPH	TITLE	SPEC. RECOMM.		LEVEL OF COMPLIANCE		STRINGENCY		TEXT FOR USER GUIDE	
		YF-17	C-5A	YF-17	C-5A	YF-17	C-5A	YF-17	C-5A
* 1.1	SCOPE & CLASSIFICATIONS								
1.1	SCOPE	X		F	F	L	G	X	
* 1.2	CLASSIFICATIONS								
* 1.2.1	FLIGHT CONTROL SYSTEM (FCS) CLASSIFICATIONS		X						
1.2.1.1	MANUAL FLIGHT CONTROL SYSTEMS (MFCS)	X	X	F	F	L	S		
1.2.1.2	AUTOMATIC FLIGHT CONTROL SYSTEMS (AFCS)	X	X	N/A	F	CNA	S		
* 1.2.2	FCS OPERATIONAL STATE CLASSIFICATIONS								
1.2.2.1	OPERATIONAL STATE I (NORMAL OPERATION)		X	F	F	G	G		
1.2.2.2	OPERATIONAL STATE II (RESTRICTED OPERATION)		X	F	F	G	G		
1.2.2.3	OPERATIONAL STATE III (MINIMUM SAFE OPERATION)			F	F	G	G		
1.2.2.4	OPERATIONAL STATE IV (CONTROL-LABLE TO AN IMMEDIATE EMERGENCY LANDING)			P	F	S	G		
1.2.2.5	OPERATIONAL STATE V (CONTROL-LABLE TO AN EVACUABLE FLIGHT CONDITION)			F	N/A	G	CNA		
* 1.2.3	FCS CRITICALITY CLASSIFICATIONS								
1.2.3.1	ESSENTIAL			F	F	G	G		
1.2.3.2	FLIGHT PHASE ESSENTIAL	X	X	F	F	G	G		
1.2.3.3	NONCRITICAL			F	F	G	G		
* 2.0	APPLICABLE DOCUMENTS								
2.1	(NO TITLE)		X	P	P	G	L		
2.2	OTHER PUBLICATIONS		X	P	P	G	L		
* 3.0	REQUIREMENTS								
3.1	SYSTEM REQUIREMENTS								
3.1.1	MFCS PERFORMANCE REQUIREMENTS			P	F	G	G		
3.1.2	AFCS PERFORMANCE REQUIREMENTS	DNV	X	F	F		G		
3.1.2.1	ATTITUDE HOLD (PITCH & ROLL)	DNV		F	F		G		
3.1.2.2	HEADING HOLD	DNV	X	F	F		G		X
3.1.2.3	HEADING SELECT	DNV	X	F	F		L		
3.1.2.4	LATERAL ACCELERATION & SIDESLIP LIMITS	DNV		F	F		G		
3.1.2.4.1	COORDINATION IN STEADY BANKED TURNS	DNV	X	F	F		L		
3.1.2.4.2	LATERAL ACCELERATION LIMITS, ROLLING	DNV		F	F		G		
3.1.2.4.3	COORDINATION IN STRAIGHT & LEVEL FLIGHT	DNV	X	F	F		L		
3.1.2.5	ALTITUDE HOLD	DNV		F	F		G		
3.1.2.6	MACH HOLD	DNV	X	F	F		L		
3.1.2.7	AIRSPEED HOLD	DNV	X	F	F		L		
* 3.1.2.8	AUTOMATIC NAVIGATION	DNV							
3.1.2.8.1	VOR/TAC IN	DNV		F	F		G		
3.1.2.8.1.1	VOR CAPTURE & TRACKING	DNV	X	F	F		L		
3.1.2.8.1.2	TACAN CAPTURE & TRACKING	DNV	X	F	F		L		
3.1.2.8.1.3	OVERSTATION	DNV	X	F	F		L		
3.1.2.9	AUTOMATIC INSTRUMENT LOW APPROACH SYSTEM:	DNV	X	F	F		L		
3.1.2.9.1	LOCALIZER MODE	DNV	X	P	P		S		
3.1.2.9.2	GLIDE SLOPE MODE	DNV	X	P	P		S&L		
3.1.2.9.3	GO-AROUND MODE	DNV	X	P	P		S		
3.1.2.9.3.1	PITCH AFCS GO-AROUND	DNV		P	P		S		
3.1.2.9.3.2	LATERAL-HEADING AFCS GO-AROUND PERFORMANCE STANDARDS	DNV	X	P	P		S		

* title paragraph

TABLE 1 VALIDATION SUMMARY BY PARAGRAPH (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.		LEVEL OF COMPLIANCE		STRINGENCY		TEXT FOR USER GUIDE	
		YF-17	C-5A	YF-17	C-5A	YF-17	C-5A	YF-17	C-5A
3.1.2.9.3.3	MINIMUM GO-AROUND ALTITUDE	DNV			F		G		
3.1.2.10	ALL WEATHER LANDING SYSTEM (AWLS)	DNV	X		P		S		
3.1.2.10.1	AWLS PERFORMANCE STANDARDS - VARIATIONS OF AIRCRAFT & AIRBORNE EQUIPMENT CONFIGURATIONS	DNV	X		P		G		
3.1.2.10.2	PERFORMANCE STANDARDS - GROUND BASED EQUIPMENT VARIATIONS	DNV	X		P		S&L		
3.1.2.11	FLIGHT LOAD FATIGUE ALLEVIATION	DNV			F		L		
3.1.2.12	RIDE SMOOTHING	DNV	X		F		S		
3.1.2.12.1	RIDE DISCOMFORT INDEX	DNV			F		G		
3.1.2.13	ACTIVE FLUTTER SUPPRESSION	DNV	DNV		F		G		
3.1.2.14	GUST & MANEUVER LOAD ALLEVIATION	DNV			F		G		
3.1.2.15	AUTOMATIC TERRAIN FOLLOWING	DNV			F		G		
3.1.2.16	CONTROL STICK (OR WHEEL) STEERING	DNV	X		F		S		X
3.1.3	GENERAL FCS DESIGN			P	F	G	G		
3.1.3.1	REDUNDANCY			P	F	G	G		
3.1.3.2	FAILURE IMMUNITY & SAFETY	X		P	F	G	G		
3.1.3.2.1	AUTOMATIC TERRAIN FOLLOWING FAILURE IMMUNITY	DNV			F		G		X
3.1.3.3	SYSTEM OPERATION & INTERFACE	X		F	F	L	G		
3.1.3.3.1	WAR IUP	X		U	F	S	G		
3.1.3.3.2	DISENGAGEMENT	X		F	F	L	G		X
3.1.3.3.3	MODE COMPATIBILITY	X		F	F	S	G		
3.1.3.3.4	FAILURE TRANSIENTS	X	X	F	F	S	G		
3.1.3.4	SYSTEM ARRANGEMENT	X		F	F	S	G		
3.1.3.5	TRIM CONTROLS	X	X	F	F	S	G		
3.1.3.6	STABILITY			P	F	S	G		
3.1.3.6.1	STABILITY MARGINS		X	P	F	S	G	X	
3.1.3.6.2	SENSITIVITY ANALYSIS			P	F	S	G	X	
3.1.3.7	OPERATION IN TURBULENCE			P	F	S	G	X	
3.1.3.7.1	RANDOM TURBULENCE			P	F	S	G	X	
3.1.3.7.2	DISCRETE GUSTS			P	F	S	G	X	
3.1.3.7.3	WIND MODEL FOR LANDING & TAKEOFF	DNV			F		G		
3.1.3.7.3.1	MEAN WIND	DNV			F		G		
3.1.3.7.3.2	WIND SHEAR	DNV			F		G		
3.1.3.7.3.3	WIND MODEL TURBULENCE	DNV			F		G		
3.1.3.8	RESIDUAL OSCILLATIONS		X	P	F	G	G		
3.1.3.9	SYSTEM TEST & MONITORING PROVISIONS	X		P	F	L	G		
3.1.3.9.1	BUILT-IN-TEST EQUIPMENT (BIT)	X	X	P	F	S	G	X	
3.1.3.9.1.1	PREFLIGHT OR PREENGAGE BIT			P	F	S	G		
3.1.3.9.1.2	MAINTENANCE BIT	X	X	P	F	S	G	X	
3.1.3.9.2	INFLIGHT MONITORING	X	X	P	F	S	G		
3.1.4	MFCs DESIGN	X		F	F	L	G		
3.1.4.1	MECHANICAL MFCs DESIGN			F	F	L	G		
3.1.4.1.1	REVERSION - BOOSTED SYSTEMS	DNV			F		G		
3.1.4.2	ELECTRICAL MFCs DESIGN		X	P	F	G	G		
3.1.4.2.1	USE OF MECHANICAL LINKAGES			F	F	G	G		
3.1.5	AFCS DESIGN	DNV			F		G		
3.1.5.1	SYSTEM REQUIREMENTS	DNV			F		G		
3.1.5.1.1	CONTROL STICK (OR WHEEL) STEERING	DNV	X		F		S		
3.1.5.1.2	FLIGHT DIRECTOR SUBSYSTEM	DNV			F		L		X
* 3.1.5.2	AFCS INTERFACE	DNV							

* title paragraph

TABLE 1 VALIDATION SUMMARY BY PARAGRAPH (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.		LEVEL OF COMPLIANCE		STP/NGENCY		TEXT FOR USER GUIDE	
		YF-17	C-5A	YF-17	C-5A	YF-17	C-5A	YF-17	C-5A
3.1.5.2.1	TIE-IN WITH EXTERNAL GUIDANCE	DNV			F		G		
3.1.5.2.2	SERVO ENGAGE INTERLOCKS	DNV	X		F		G		
3.1.5.2.3	ENGAGE-DISENGAGE TRANSIENTS	DNV			F		G		
*3.1.5.3	AFCS EMERGENCY PROVISIONS	DNV			F		G		
3.1.5.3.1	MANUAL OVERRIDE CAPABILITY	DNV			F		G		
3.1.5.3.2	EMERGENCY DISENGAGEMENT	DNV			F		G		
3.1.6	MISSION ACCOMPLISHMENT RELIABILITY		X	N	F	S	G	L	
3.1.7	QUANTITATIVE FLIGHT SAFETY	X	X	U	F	S	S	S	
3.1.7.1	QUANTITATIVE FLIGHT SAFETY - AWLS	DNV	X		F			L	
3.1.7.1.1	ASSESSMENT OF AVERAGE RISK OF A HAZARD	DNV	X		F			L	
3.1.7.1.2	ASSESSMENT OF SPECIFIC RISK	DNV	X		F			L	
3.1.8	SURVIVABILITY	X			F	G	G	G	
3.1.8.1	ALL ENGINES OUT CONTROL		X		F	F	G	G	
3.1.9	INVULNERABILITY				F	F	G	G	
3.1.9.1	INVULNERABILITY TO NATURAL ENVIRONMENTS				F	F	G	G	
3.1.9.2	INVULNERABILITY TO LIGHTNING STRIKES & STATIC ATMOSPHERE ELECTRICITY			N	F	G	G		
3.1.9.3	INVULNERABILITY TO INDUCED ENVIRONMENTS			P	F	G	G		
3.1.9.4	INVULNERABILITY TO ONBOARD FAILURES OF OTHER SYSTEMS AND/OR EQUIPMENT			P	F	G	G		
3.1.9.5	INVULNERABILITY TO MAINTENANCE ERROR			F	F	G	G		
3.1.9.6	INVULNERABILITY TO PILOT & FLIGHT CREW INACTION & ERROR			F	F	G	G		
3.1.9.7	INVULNERABILITY TO ENEMY ACTION	X			F	F	S	G	
3.1.10	MAINTENANCE PROVISIONS				F	F	G	G	
3.1.10.1	OPERATIONAL CHECKOUT PROVISIONS				F	F	G	G	
3.1.10.2	MALFUNCTION DETECTION & FAULT ISOLATION PROVISIONS		X		F	F	G	S	
3.1.10.2.1	USE OF COCKPIT INSTRUMENTATION		X		F	F	G	S	
3.1.10.2.2	PROVISIONS FOR CHECKOUT WITH PORTABLE TEST EQUIPMENT		X		F	F	G	S	
3.1.10.3	ACCESSIBILITY & SERVICEABILITY				F	F	G	G	
3.1.10.4	MAINTENANCE PERSONNEL SAFETY PROVISIONS				F	F	G	G	
*3.1.11	STRUCTURAL INTEGRITY				F	F	G	G	
3.1.11.1	STRENGTH				F	F	G	G	
3.1.11.1.1	DAMAGE TOLERANCE				F	F	G	G	
3.1.11.1.2	LOAD CAPABILITY OF DUAL-LOAD- PATH ELEMENTS				F	F	G	G	
3.1.11.2	STIFFNESS				F	F	G	G	
3.1.11.3	DURABILITY				F	F	G	G	
3.1.12	WEAR LIFE				F	F	G	G	X
*3.2	SUBSYSTEM & COMPONENT DESIGN REQUIREMENTS				F	F	G	G	
3.2.1	PILOT CONTROLS & DISPLAYS	X	X	P	F	S	S		
3.2.1.1	PILOT CONTROLS FOR CTOL AIRCRAFT	X	X	P	F	S	S		
3.2.1.1.1	ADDITIONAL REQUIREMENTS FOR CONTROL STICKS	DNV	DNV						

* title paragraph

TABLE 1 VALIDATION SUMMARY BY PARAGRAPH (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.		LEVEL OF COMPLIANCE		STRINGENCY		TEXT FOR USER GUIDE	
		YF-17	C-5A	YF-17	C-5A	YF-17	C-5A	YF-17	C-5A
3.2.1.1.2	ADDITIONAL REQUIREMENT FOR RUDDER PEDALS			F	F	G	G		
3.2.1.1.3	ALTERNATE OR UNCONVENTIONAL CONTROLS			F	F	G	G		
3.2.1.1.4	VARIABLE GEOMETRY COCKPIT CONTROLS	DNV	DNV						
3.2.1.1.5	TRIM SWITCHES	X	X	F	P	G	S		
3.2.1.1.6	TWO-SPEED TRIM ACTUATOR	DNV	X		P		L		
3.2.1.1.7	FCS CONTROL PANEL	X		N	F	S	L		
3.2.1.1.8	NORMAL DISENGAGEMENT MEANS	X		F	F	L	G		
3.2.1.1.9	PREFLIGHT TEST CONTROLS			F	F	G	G		
3.2.1.2	PILOT CONTROLS FOR ROTARY-WING AIRCRAFT	DNV	DNV						
3.2.1.2.1	INTERCONNECTION OF COLLECTIVE PITCH CONTROL & THROTTLE(S) FOR HELICOPTERS POWERED BY RECIPROCATING ENGINE(S)	DNV	DNV						
3.2.1.2.2	INTERCONNECTION OF COLLECTIVE PITCH CONTROL & ENGINE POWER CONTROLS FOR HELICOPTERS POWERED BY TURBINE ENGINE(S)	DNV	DNV						
3.2.1.2.3	ALTERNATE OR UNCONVENTIONAL CONTROLS	DNV	DNV						
3.2.1.3	PILOT CONTROLS FOR STOL AIRCRAFT	DNV	DNV						
* 3.2.1.4	PILOT DISPLAYS								
3.2.1.4.1	FCS ANNUNCIATION			F	F	G	G		
3.2.1.4.2	FCS WARNING & STATUS ANNUNCIATION	X		F	P	S	G		
3.2.1.4.2.1	PREFLIGHT TEST (BIT) STATUS ANNUNCIATION			F	F	G	G		
3.2.1.4.2.2	FAILURE STATUS	X	X	F	F	L	G		
3.2.1.4.2.3	CONTROL AUTHORITY ANNUNCIATION	X	X	P	P	L	S		
3.2.1.4.3	LIFT & DRAG DEVICE POSITION INDICATORS	X	X	P	P	S	G		
3.2.1.4.4	TRIM INDICATORS	X		P	F	S	G		
3.2.1.4.5	CONTROL SURFACE POSITION INDICATION			P	P	G	G		
3.2.2	SENSORS	X		F	F	G	G		
* 3.2.3	SIGNAL TRANSMISSION								
* 3.2.3.1	GENERAL REQUIREMENTS								
3.2.3.1.1	CONTROL ELEMENT ROUTING			F	F	G	G		
3.2.3.1.2	SYSTEM SEPARATION, PROTECTION, & CLEARANCE			P	F	G	G		
3.2.3.1.3	FOULING PREVENTION			F	F	G	G		
3.2.3.1.4	RIGGING PROVISIONS	X		P	F	L	G		X
* 3.2.3.2	MECHANICAL SIGNAL TRANSMISSION								
3.2.3.2.1	LOAD CAPABILITY			F	F	G	G		
3.2.3.2.2	STRENGTH TO CLEAR OR OVERRIDE JAMMED HYDRAULIC VALVES			F	F	G	G		
3.2.3.2.3	POWER CONTROL OVERRIDE PROVISIONS			F	F	G	G		
3.2.3.2.4	CONTROL CABLE INSTALLATIONS			P	F	G	G		
3.2.3.2.4.1	CONTROL CABLE	X		P	F	G	G		
3.2.3.2.4.2	CABLE SIZE			F	F	G	G		
3.2.3.2.4.3	CABLE ATTACHMENTS	X		F	F	L	G		
3.2.3.2.4.4	CABLE ROUTING			P	F	G	G		
3.2.3.2.4.5	CABLE SHEAVES			F	F	G	G		

* title paragraph

TABLE 1 VALIDATION SUMMARY BY PARAGRAPH (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.		LEVEL OF COMPLIANCE		STRINGENCY		TEXT FOR USER GUIDE	
		YF-17	C-5A	YF-17	C-5A	YF-17	C-5A	YF-17	C-5A
3.2.3.2.4.6	CABLE & PULLEY ALIGNMENT		X	F	F	G	G		
3.2.3.2.4.7	PULLEY-BRACKET SPACERS			N	P	G	G		X
3.2.3.2.4.8	SHEAVE GUARDS	X		P	F	L	G		X
3.2.3.2.4.9	SHEAVE SPACING			F	F	G	G		
3.2.3.2.4.10	CABLE TENSION	X		F	F	L	G		
3.2.3.2.4.11	CABLE TENSION REGULATORS			F	F	G	G		
3.2.3.2.4.12	FAIRLEADS & RUBBING STRIPS			F	F	G	G		X
3.2.3.2.4.13	PRESSURE SEALS			F	F	G	G		X
3.2.3.2.5	PUSH-PULL ROD INSTALLATIONS			F	F	G	G		
3.2.3.2.5.1	PUSH-PULL ROD ASSEMBLIES		X	F	P	G	S		
3.2.3.2.5.2	LEVERS & BELLCRANKS			F	F	G	G		
3.2.3.2.5.3	PUSH-PULL ROD SUPPORTS	X		F	F	L	G		
3.2.3.2.5.4	PUSH-PULL ROD CLEARANCE			F	F	G	G		
3.2.3.2.6	CONTROL CHAIN	DNV		F	F	G	G		
3.2.3.2.7	PUSH-PULL FLEXIBLE CONTROLS	DNV		F	F	G	G		
3.2.3.3	ELECTRICAL SIGNAL TRANSMISSION		X	P	F	G	G		
3.2.3.3.1	ELECTRICAL FLIGHT CONTROL (EFC)			P	F	G	G		
	INTERCONNECTIONS			P	F	S	G		
3.2.3.3.1.1	CABLE ASSEMBLY DESIGN & CONSTRUCTION	X		P	F	S	G		
3.2.3.3.1.2	WIRE TERMINATIONS			F	F	G	G		
3.2.3.3.1.3	INSPECTION & REPLACEMENT			F	F	G	G		
3.2.3.3.2	MULTIPLEXING	X		N/A	N/A	CNA	G		
* 3.2.4	SIGNAL COMPUTATION								
* 3.2.4.1	GENERAL REQUIREMENTS								
3.2.4.1.1	TRANSIENT POWER EFFECTS			F	F	G	G		
3.2.4.1.2	INTERCHANGEABILITY	X	X	P	F	L	L		
* 3.2.4.1.3	COMPUTER SIGNALS								
3.2.4.1.3.1	SIGNAL TRANSMISSIONS			F	F	G	G		
3.2.4.1.3.2	SIGNAL PATH PROTECTION	X		F	F	L	G		
* 3.2.4.2	MECHANICAL SIGNAL COMPUTATION								
3.2.4.2.1	ELEMENT LOADS	X		F	F	G	G		
3.2.4.2.2	GEARED MECHANISMS	DNV		F	F	L	G		
3.2.4.2.3	HYDRAULIC ELEMENTS	X		F	F	L	G		
3.2.4.2.4	PNEUMATIC ELEMENTS	DNV		F	F	L	G		
* 3.2.4.3	ELECTRICAL SIGNAL COMPUTATION								
3.2.4.3.1	ANALOG COMPUTATION			F	F	C	G		
3.2.4.3.2	DIGITAL COMPUTATION	X	X	P	N/A	S	L		
3.2.4.3.2.1	MEMORY PROTECTION	X		F	N/A	L	G		
3.2.4.3.2.2	PROGRAM SCALING			F	N/A	L	G		
3.2.4.3.2.3	SOFTWARE SUPPORT	X	X	P	N/A	L	G		
* 3.2.5	CONTROL POWER								
3.2.5.1	POWER CAPACITY	X		F	F	L	G		
3.2.5.2	PRIORITY			F	F	L	G		
3.2.5.3	HYDRAULIC POWER SUBSYSTEMS			F	F	L	G		
3.2.5.4	ELECTRICAL POWER SUBSYSTEMS	X		P	F	L	G		
3.2.5.4.1	ELECTROMAGNETIC INTERFERENCE	X	X	P	F	L	S		
	LIMITS								
3.2.5.4.2	OVERLOAD PROTECTION			F	F	G	G		
3.2.5.4.3	PHASE SEPARATION & POLARITY REVERSAL PROTECTION		X	N	F	G	L		
3.2.5.5	PNEUMATIC POWER SUBSYSTEMS								
	ACTUATION	DNV			N/A		G		
* 3.2.6	LOAD CAPABILITY								
* 3.2.6.1	LOAD CAPABILITY OF ELEMENTS								
3.2.6.1.1	LOAD CAPABILITY OF ELEMENTS SUBJECT TO PILOT LOADS		X	F	F	G	L		X
3.2.6.1.2	LOAD CAPABILITY OF ELEMENTS DRIVEN BY POWER ACTUATORS			F	F	G	G		
3.2.6.2	MECHANICAL FORCE TRANSMITTING ACTUATION PROVISIONS		X	P	F	G	L		

* title paragraph

TABLE 1 VALIDATION SUMMARY BY PARAGRAPH (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.		LEVEL OF COMPLIANCE		STRINGENCY		TEXT FOR USER GUIDE	
		YF-17	C-5A	YF-17	C-5A	YF-17	C-5A	YF-17	C-5A
		3.2.6.2.1	FORCE TRANSMITTING POWERSCREWS		X	P	F	G	L
3.2.6.2.1.1	THREADED POWERSCREWS			P	F	G	L		
3.2.6.2.1.2	BALLSCREWS	DNV	X		F		L		
3.2.6.3	MECHANICAL TORQUE TRANSMITTING ACTUATION PROVISIONS	DNV			F		L		
3.2.6.3.1	TORQUE TUBE SYSTEMS	DNV	X		F		L		
3.2.6.3.1.1	TORQUE TUBES	DNV			F		L		
3.2.6.3.1.2	UNIVERSAL JOINTS	DNV			F		L		
3.2.6.3.1.3	SLIP JOINTS	DNV	X		F		L		
3.2.6.3.2	GEARING	DNV	X		F		L		
3.2.6.3.3	FLEXIBLE CHAFTING	DNV	DNV						
3.2.6.3.4	HELICAL SPLINES	DNV			N/A		L		
3.2.6.3.5	ROTARY MECHANICAL ACTUATORS	DNV	X		P		L		
3.2.6.3.6	TORQUE LIMITERS	DNV			F		L		
3.2.6.3.7	NO-BACK BRAKES	DNV			F		L		X
3.2.6.4	HYDRAULIC ACTUATION PROVISIONS	X	X	F	F	S	G		X
3.2.6.4.1	HYDRAULIC SERVOACTUATORS			P	F		S		X
3.2.6.4.2	MOTOR-PUMP - SERVOACTUATOR (MPS) PACKAGE	DNV	X		N/A		G		
3.2.6.4.3	ACTUATING CYLINDERS	X	X	F	F	L	L		X
3.2.6.4.4	FORCE SYNCHRONIZATION OF MULTIPLE HYDRAULIC SERVOACTUATORS	X		F	F	L	L		
3.2.6.4.5	HYDRAULIC MOTORS	DNV			F		G		
3.2.6.5	ELECTROMECHANICAL ACTUATION		X	P	F	G	L		X
3.2.6.6	PNEUMATIC ACTUATION	DNV	DNV						
3.2.6.6.1	HIGH-PRESSURE PNEUMATIC ACTUATION	DNV	DNV						
3.2.6.6.2	PNEUMATIC DRIVE TURBINES	DNV	DNV						
*3.2.6.7	INTERFACES BETWEEN ACTUATION SYSTEMS, SUPPORT STRUCTURE, & CONTROL SURFACES								
3.2.6.7.1	CONTROL SURFACE STOPS			F	F	G	G		
3.2.6.7.1.1	ADJUSTABLE STOPS			F	F	G	G		
3.2.6.7.2	CONTROL SURFACE GROUND GUST PROTECTION			F	F	G	G		
3.2.6.7.2.1	CONTROL SURFACE LOCKS	DNV	X		F		L		
3.2.6.7.2.2	PROTECTION AGAINST INFLIGHT ENGAGEMENT OF CONTROL SURFACE LOCKS	DNV	X		F		L		
3.2.6.7.3	CONTROL SURFACE FLUTTER & BUZZ PREVENTION			F	F	G	G		
*3.2.7	COMPONENT DESIGN								
*3.2.7.1	COMMON REQUIREMENTS								
3.2.7.1.1	STANDARDIZATION			F	F	G	G		
3.2.7.1.2	INTERCHANGEABILITY			F	F	G	G		
3.2.7.1.3	SELECTION OF SPECIFICATIONS & STANDARDS			F	F	G	G		
3.2.7.1.4	IDENTIFICATION OF PRODUCT			F	F	G	G		
3.2.7.1.5	INSPECTION SEALS		X	N	F	S	S		
3.2.7.1.6	MOISTURE POCKETS			F	F	G	G		
3.2.7.2	MECHANICAL COMPONENTS			P	F	G	G		
3.2.7.2.1	BEARINGS			P	F	G	G		
3.2.7.2.1.1	ANTIFRICTION BEARINGS		X	P	F	G	S		
3.2.7.2.1.2	SPHERICAL BEARINGS			P	F	G	L		
3.2.7.2.1.3	SINTERED BEARINGS	DNV			F		G		
3.2.7.2.2	CONTROLS & KNOBS	DNV		P	F	G	G		
3.2.7.2.3	DAMPERS	DNV		P	F	G	G		
3.2.7.2.4	STRUCTURAL FITTINGS			P	F	G	G		
3.2.7.2.5	LUBRICATION		X	F	F	G	S		

* title paragraph

TABLE 1 VALIDATION SUMMARY BY PARAGRAPH (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.		LEVEL OF COMPLIANCE		STRINGENCY		TEXT FOR USER GUIDE	
		YF-17	C-5A	YF-17	C-5A	YF-17	C-5A	YF-17	C-5A
		3.2.7.3	ELECTRICAL & ELECTRONIC COMPONENTS	X	X	F	P	G	S
3.2.7.3.1	DIELECTRIC STRENGTH		X	P	F	S	L		
3.2.7.3.2	MICROELECTRONICS	X	X	N	F	S	L		
3.2.7.3.3	BURN-IN	X	X	F	F	S	L		X
3.2.7.3.4	SWITCHES		X	F	F	L	L		
3.2.7.3.5	THERMAL DESIGN OF ELECTRICAL & ELECTRONIC EQUIPMENT			P	F	G	L		
3.2.7.3.6	POTENTIOMETERS	X		F	F	S	G		
3.2.8	COMPONENT FABRICATION			P	F	S	G		
3.2.8.1	MATERIALS			P	F	G	G		
3.2.8.1.1	METALS		X	P	F	G	G		
3.2.8.1.2	NONMETALLIC MATERIALS			P	F	G	L		
3.2.8.1.3	ELECTRIC WIRE AND CABLE			P	F	G	G		
*3.2.8.2	PROCESSES								
3.2.8.2.1	CONSTRUCTION PROCESSES		X	P	F	G	S		
3.2.8.2.2	CORROSION PROTECTION			P	F	G	G		
3.2.8.2.3	FABRICATION OF ELECTRICAL & ELECTRONIC COMPONENTS		X	P	F	G	G		
*3.2.8.3	ASSEMBLING								
3.2.8.3.1	MECHANICAL JOINING			F	F	G	G		
3.2.8.3.1.1	JOINING WITH REMOVABLE FASTENERS	X		F	F	S	G		
3.2.8.3.1.2	JOINING WITH RIVETS			F	F	G	G		
3.2.8.3.1.3	THREADED JOINTS			F	F	G	G		
3.2.8.3.2	JOINT RETENTION			F	F	G	G		
3.2.8.3.2.1	RETENTION OF THREADED JOINTS			F	F	G	G		
3.2.8.3.2.2	RETENTION OF REMOVABLE FASTENERS			F	F	G	G		
3.2.8.3.2.3	USE OF RETAINER RINGS			F	F	G	G		
*3.2.8.3.3	ASSEMBLY OF ELECTRONIC COMPONENTS								
3.2.8.3.3.1	ELECTRICAL & ELECTRONIC PART MOUNTING	X		F	F	L	G		
3.2.8.3.3.2	SHIELDING & BONDING OF FINISHED SURFACES			F	F	G	G		
3.2.8.3.3.3	ISOLATION OF REDUNDANT CIRCUITS			F	F	G	G		
3.2.8.3.3.4	ELECTRICAL CONNECTOR INSTALLATION	X		F	F	S	G		
3.2.8.3.3.5	CLEANING OF ELECTRICAL ASSEMBLIES	X		F	F	L	G		
*3.2.9	COMPONENT INSTALLATION								
3.2.9.1	BASIC REQUIREMENTS			F	F	G	G		
3.2.9.2	LOCATING COMPONENTS			F	F	G	G		
3.2.9.3	INSTALLATIONS IN FUEL SYSTEM AREAS	X		F	F	L	G	X	
3.2.9.4	ELECTRICAL & ELECTRONIC COMPONENT INSTALLATIONS	X		F	F	S	G		
3.2.9.5	ELECTRICAL & ELECTRONIC EQUIPMENT COOLING	X		N/A	F	L	G		
3.3	ROTARY WING PERFORMANCE & DESIGN	DNV	DNV						
3.3.1	SPECIAL MFCS PERFORMANCE REQUIREMENTS	DNV	DNV						
3.3.2	SPECIAL AFCS PERFORMANCE REQUIREMENTS	DNV	DNV						
3.3.2.1	ATTITUDE HOLD (PITCH, ROLL, & YAW)	DNV	DNV						
3.3.2.2	HEADING HOLD & HEADING SELECT	DNV	DNV						
*3.3.2.3	ALTITUDE HOLD	DNV	DNV						
3.3.2.3.1	BAROMETRIC ALTITUDE STABILIZATION	DNV	DNV						

* title paragraph

TABLE 1 VALIDATION SUMMARY BY PARAGRAPH (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.		LEVEL OF COMPLIANCE		STRINGENCY		TEXT FOR USER GUIDE	
		YF-17	C-5A	YF-17	C-5A	YF-17	C-5A	YF-17	C-5A
3.3.2.2	STABILIZATION OF ALTITUDE ABOVE THE TERRAIN	DNV	DNV						
3.3.2.4	HOVER HOLD	DNV	DNV						
3.3.2.5	VERNIER CONTROL FOR HOVERING	DNV	DNV						
3.3.2.6	GROUNDSPED HOLD	DNV	DNV						
*3.3.3	SPECIAL DESIGN REQUIREMENTS	DNV	DNV						
*3.3.3.1	MFCS DESIGN	DNV	DNV						
3.3.3.1.1	CONTROL FEEDBACK	DNV	DNV						
3.3.3.1.2	FEEL AUGMENTA N	DNV	DNV						
3.3.3.2	AFCS DESIGN	DNV	DNV						
*3.3.3.3	SWASHPLATE POWER ACTUATORS	DNV	DNV						
3.3.3.3.1	REDUNDANCY	DNV	DNV						
3.3.3.3.2	JAMMING	DNV	DNV						
3.3.3.3.3	FREQUENCY RESPONSE	DNV	DNV						
3.3.3.4	ACTION STIFFNESS	DNV	DNV						
3.3.3.5	FATIGUE LIFE DESIGN	DNV	DNV						
3.3.3.5.1	FAIL-SAFE	DNV	DNV						
3.3.3.5.2	DISPLAY	DNV	DNV						
3.3.3.6	BUILT-IN TEST	DNV	DNV						
*4.0	QUALITY ASSURANCE								
*4.1	GENERAL REQUIREMENTS								
4.1.1	METHODS FOR DEMONSTRATION OF COMPLIANCE			F	F	G	G		
4.1.1.1	ANALYSIS			F	F	G	G		
4.1.1.2	INSPECTION			F	F	G	G		
4.1.1.3	TEST			F	F	G	G		
4.2	ANALYSIS REQUIREMENTS			F	F	G	G		
4.2.1	PILOTED SIMULATIONS	X	X	F	F	L	L	X	
*4.3	TEST REQUIREMENTS								
*4.3.1	GENERAL TEST REQUIREMENTS								
4.3.1.1	TEST WITNESS		X	F	F	G	L		
4.3.1.2	ACCEPTANCE TESTS			F	F	G	L		
4.3.1.3	INSTRUMENTATION		X	F	F	S&L	L		
4.3.1.4	TEST CONDITIONS	X	X	F	F	S&L	L		
*4.3.2	LABORATORY TESTS								
4.3.2.1	COMPONENT TESTS			P	F	G	G		
4.3.2.2	FUNCTIONAL MOCKUP & SIMULATOR TESTS		X	P	F	G	L		X
4.3.2.3	SAFETY-OF-FLIGHT TESTS			P	F	G	G		
4.3.2.3.1	COMPONENT SAFETY-OF-FLIGHT TESTS			P	F	G	G		
4.3.2.3.2	SYSTEM SAFETY-OF-FLIGHT TESTS		X	P	F	G	S		
4.3.3	AIRCRAFT GROUND TESTS	X		P	F	G	G		X
4.3.4	FLIGHT TESTS			P	F	G	G		
4.4	DOCUMENTATION			P	F	G	G		
4.4.1	FCS DEVELOPMENT PLAN	X		P	F	L	G		
4.4.2	FCS SPECIFICATION			P	F	L	G		
4.4.3	DESIGN & TEST DATA REQUIREMENTS		X	P	F	L	G		
4.4.3.1	FCS ANALYSIS REPORT			P	F	S	L		
4.4.3.2	FCS QUALIFICATION & INSPECTION REPORT	X		P	F	S	L		
4.4.3.3	FCS TEST REPORT			P	F	G	G		
*5.0	PREPARATION FOR DELIVERY	DNV	DNV						
5.1	PACKAGING REQUIREMENTS	DNV	DNV						
*6.0	NOTES	DNV	DNV						
6.1	INTENDED USE	DNV	DNV						
6.2	PROCEDURE FOR REQUESTING DEVIATIONS	DNV	DNV						
6.3	REORDERED EQUIPMENT OR SECOND SOURCE PROCUREMENT	DNV	DNV						

* title paragraph

TABLE I VALIDATION SUMMARY BY PARAGRAPH (CONTINUED)

PARAGRAPH	TITLE	SPEC. RECOMM.		LEVEL OF COMPLIANCE		STRINGENCY		TEXT FOR USER GUIDE	
		YF-17	C-5A	YF-17	C-5A	YF-17	C-5A	YF-17	C-5A
6.4	USER'S GUIDE	DNV	DNV						
6.5	ABBREVIATIONS	DNV	DNV						
6.6	DEFINITIONS	DNV	X		P		L		
6.7	USE OF LIMITED COORDINATION SPECIFICATIONS	DNV	DNV						
6.8	IDENTIFICATION OF CHANGES	DNV	DNV						

* title paragraph

Table Symbols

Specification Recommendation

(blank) - retain requirement as stated

X - recommendation made (see Vol. II and/or III)

DNV - did not validate

Level of Compliance

F - full compliance

P - partial compliance

N - no compliance

U - undetermined

N/A - not applicable to aircraft validated

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 (see Vol. II and/or III)

SECTION V

APPLICABILITY OF REQUIREMENTS

The scope of MIL-F-9490D includes all USAF manned piloted aircraft. The applicability thus encompasses all four classes of airplanes as defined in MIL-F-8785B as well as other aircraft such as rotary wing aircraft. The study reported on here was limited to two airplanes, one a Class IV fighter and the other a Class III heavy transport/cargo airplane, hence the following discussions are limited to these two classes of airplane.

In general, the specification is well written for application to Class IV fighter airplanes. However, there are certain requirements that do not seem to be of equal applicability to both fighters and heavy transports. There are requirements which should differ considerably for fighter and transport type aircraft because of vehicle mission type and duration, vehicle design service life and vehicle design maneuvering limits and airspeed. Typical comparisons in these areas are given below.

<u>Parameter</u>	<u>Fighter</u>	<u>Transport</u>
Typical Mission Length (Hours)	1	6
Hostile Environment	Usually	Rarely
Design Service Life (Flight Hours)	4,000	30,000 - 40,000
Design Maneuver Limits (+ g's)	8-9	2.5
Speed Limits (Mach No.)	>1.0	< 1.0

Analysis of the applicability of the requirements as applied to fighter and heavy transport type aircraft in light of the above mentioned characteristics are discussed below for each type of aircraft. In some cases the same observation is made regarding the applicability of a requirement for both types of aircraft. In these cases the same comment appears both in the fighter and the transport discussions.

1. Fighter

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.

2. Heavy Transport

1.2 Classification

FCS classifications as presently defined in the specification are a confusing mixture of control functions, system types and hardware. Lockheed has recommended a further breakdown of classifications and new definitions related to control functions and the method for initiating control activity, but not related to system mechanization methods. Lockheed has defined "function" in order to satisfactorily classify control systems criticality. These clarifications are believed to be important and applicable to all classes of CTOL aircraft.

1.2.2.4 Operational State IV (controllable to an immediate emergency landing).

The survivability requirements for this class of aircraft generally require at least FCS Operational State IV following an all engine-out condition. This requirement is further enhanced by the nature of the mission requirements which may carry passengers without benefit of inflight egress provisions. For example, the C-5A has a ram air turbine RAT to provide emergency control power for the all engine-out condition.

1.2.3 FCS Criticality classification

The requirements under this paragraph which define the essential criticality of FCS functions must be clarified and generally agreed upon for uniformity of interpretation. The mechanizations to achieve various flight control functions can be vastly different for a fighter and a heavy transport aircraft due to space and available power supply redundancy.

3.1.2.11 Flight load fatigue alleviation.

This requirement for flight load fatigue alleviation has application on the heavy transport aircraft which has operational envelopes different from the other aircraft categories. The specification is currently unclear and restrictive in the reference to MIL-A-8866, which should be deleted.

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 controllability should be the major considerations. For Class III airplanes, MIL-F-8785B is more applicable.

3.1.6 Mission accomplishment reliability.

The quantitative value stated in the requirement is believed to be unrealistic and should be revised. In addition, the requirement should be expressed in terms of the mission flight hours as recommended in Lockheed's validation.

3.1.7 Quantitative flight safety.

It is recommended that the numerical values of the aircraft loss rate specified in Table VII be revised to reflect an aircraft loss rate that is a function of mission length expressed in flight hours. In addition, the semantics of Requirement 3.1.7.1 dealing with the AWLS safety should be revised and 3.1.7.1.1 Assessment of average risk of a hazard changed to 3.1.7.1.1 Hazard risk assessment for clarity as has been recommended in Lockheed's validation.

3.1.8 Survivability.

3.1.8.1 All engines out control.

Heavy transport are generally required to meet the minimum requirement of maintaining Operational State IV after the loss of all engines as discussed in comment on 1.2.2.4 Operational State IV.

3.1.9 Invulnerability.

3.1.9.7 Invulnerability to enemy action.

It is felt that the typical Class III heavy transport , such as the C-5A, would meet the specified invulnerability to enemy action requirement for sustaining one direct encounter, equivalent to that sustained by a fighter, and equivalent to a failure mode as discussed in Requirement 1.2.2 and 1.2.3.

3.2.1.1 Pilot controls for CTOL aircraft.

This specification should allow more design flexibility to be commensurate with the aircraft and mission requirements. This can be achieved, as has been recommended, by deletion of the last sentence of the requirement for "Strict adherence to the prescribed location and maximum range of motion of these controls is required."

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

1. Specification

1.1 Organization

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 first part of the specification goes beyond a mere definition of scope and listing of functions governed by the requirements: It addresses the criticality of the functions, which, once established, influences the redundancy levels as well as the general architecture of the flight control system and determines the extent of applicability of many of the detail requirements. The subsequent delineation of system requirements, particularly with regard to mission reliability, quantitative flight safety and invulnerability, provide the information necessary to firm up the system concepts relative to redundancy, reliability, physical arrangement, and interface with other systems. The requirements for maintenance provisions further encourage an integrated approach to the design process. Finally, the comprehensive detail requirements for subsystem and components provide the information necessary for a successful hardware solution for the overall system concept.

The breakdown of the requirements section into system, subsystem, and component subsections inevitably introduces repetitions of certain requirements and topics. An example of this are the requirements pertaining to system test and monitoring provisions and related controls and displays. This is not considered detrimental in itself. However, eliminating the duplication of wording by the use of cross referencing would improve readability.

1.2 Coverage

1.2.1 Scope and Classification

The scope of the specification provides a comprehensive listing of flight control functions and related elements. It specifically excludes crew displays and electronics not dedicated to flight control. This exclusion is neither warranted nor desirable, considering the coming age of multipurpose displays and integrated avionics and, with these, shared signal transmission lines. If the shared elements and transmission lines perform important flight control functions, their performance and design relative to these functions should be governed by this specification.

Manual throttle controls also satisfy the definition for a flight control function, inasmuch as they are used to control airspeed, as well as flight path and altitude, particularly during power approach. In view of their criticality to aircraft control, and the fact that they may use either mechanical or electrical signal transmission between the cockpit and the engine(s), manual throttle controls including signal transmission and interface with the fuel control valve(s) should be governed by this specification.

1.2.2 Requirements

The requirements section provides a detailed, useful coverage of all considerations essential to flight controls design. The specification philosophy is presumed to strive for flight control systems which will cost effectively meet the definitive system requirements, but still provide the contractor with the design flexibility necessary to take full advantage of advancements in FCS state-of-the-art. This is generally achieved by specifying design guidelines while leaving detail qualitative and quantitative requirements to be specified in the detail specification and subject to USAF review and approval. There are some areas in this specification where the application of the philosophy can be improved. Relative to accuracy and completeness, the coverage in the individual requirements tends to vary from subjective and general, requiring interpretation, to quantitative or very specific. For example, the coverage on mechanical systems and elements extends into detail design considerations beyond the scope of a general specification. Most of these requirements are currently covered in the design handbooks in even greater detail and compliance with them can be assured by invoking the applicable design handbook section. Trimming down the extensive coverage in the mechanical area would serve to reduce the volume and improve the readability of the specification.

The coverage relative to electrical flight control systems and elements including redundancy considerations, is rather general. This is endorsed on the basis that it allows the flexibility required to synthesize a cost effective flight control system while taking full advantage of the state-of-the-art both in functional application and in hardware.

In some instances, the wording of individual requirements allows several interpretations. The material provided in the Users Guide is often useful but not always adequate to arrive at the intended interpretation. Several recommendations have been made during the validation process to facilitate interpretation of such requirements.

1.2.3 Quality Assurance

This section provides a comprehensive treatment of development and test requirements, with the proper emphasis on the ultimate objective: Demonstration of performance and compliance with the requirements of the total complement of the flight control system.

1.3 Usability

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. In particular, it 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 unique capabilities as well as unique problems.

On the other hand, this comprehensiveness has been achieved at the expense of increased volume and to some extent, reduced readability. To facilitate the task of the user in identifying the requirements pertaining to the various disciplines and, in general, enhance the efficient utilization of the specification, the following revisions are recommended:

- 1) Provide a table of contents (as was provided in the C revision of the specification).
- 2) Remove wording from individual paragraphs which are repetitions of requirements of the document that the particular paragraph invokes.
- 3) Use more extensive cross referencing between similar requirements appearing in more than one paragraph (for instance, the requirement involved under system requirements and a similar requirement also stated under subsystem requirements).
- 4) Provide uniformity of numerical units for compatible requirements. For example, in the requirement on turbulence, the gust velocities are referred to in terms of knots and feet per second.

2. Users' Guide

2.1 Contents

Report Document AFFDL-TR-74-116, "Background Information and Users' Guide for MIL-F-9490D," was found to be a very valuable supportive and interpretative aid in the use of military specification MIL-F-9490D. Pertinent literature, data and/or arguments have been used to support most individual requirements. In addition, pertinent background literature has been referenced as regards more recent research and development programs dealing with advancements in flight control system state-of-the-art.

The report is well organized and addresses to some degree most of the requirements. Presumably the emphasis is on developing a specification of design guidelines to give the contractor maximum design flexibility to provide the most cost-effective design to meet the air vehicle requirements.

This requires that more emphasis be placed on the supportive documents such as the Users' Guide to provide interpretive guidelines as well as to present state-of-the-art industry practices.

In reviewing the "Users' Guide", particularly in the discussion of industry practices, the design practices of one aerospace company are more prevalent than others. The Users' Guide should therefore be expanded to include a broader base of industry practices and be subjected to periodic review and update to include state-of-the-art advancements. Some Users' Guide inclusions have been recommended in this validation effort. The Users' Guide may also serve as a focal point for integrating other design practice guidelines in lieu of revising the specification. These could include publications such as the Air Force Systems Command Design Handbooks, Society of Automotive Engineers Aerospace Recommended Practices, etc.

2.2 Usability

The Users' Guide is arranged in a good usable format. The discussion guidelines are generally good although there is a broad variation in the quantity of data provided for the different requirements. Some requirements need more data for better interpretation.

The discussions in some cases should differentiate moreso between interpreting the requirement and presenting the "industry practices" which may be used to satisfy that requirement.