



AEROSPACE INFORMATION REPORT

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Superseding AIR4094

(R) Aircraft Flight Control Systems Descriptions

RATIONALE

AIR4094 has been updated to Revision A for the following reasons:

- (a) To expand the scope by adding fixed wing commercial aircraft flight control systems and adding both military and commercial rotary wing and tilt rotor vehicle flight control systems.
- (b) Update information on military aircraft flight control systems that were in the original document.
- (c) Add Foreword and Applicable Documents sections.

FOREWORD

This report is written to familiarize the reader with the various hydraulic, electromechanical, and other systems used for flight controls on fixed wing, rotary wing and tilt rotor aircraft. Its purpose is to educate the reader on these different flight control systems by providing detailed information on each. The end goal is that this information will broaden the individual reader's understanding of existing flight control systems and that this knowledge will be used to better develop future flight control systems.

The information used herein is taken from available sources including vendor information, technical papers, repair manuals, and public domains from the web. There is a varying degree of information made available by industry sources for their individual flight control systems and components. Although attempts were made to be as inclusive and consistent as possible, some flight control systems and subsystems described herein contain more detail than others.

While some flight control systems in this report are described in significant detail, the information contained herein should not be used as a technical reference. See 2.2 for a list of sources used.

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1. SCOPE

This SAE Aerospace Information Report (AIR) supplies information on the flight control systems incorporated on various current and historic fixed wing, rotary wing, and tilt rotor aircraft. A brief description of the aircraft is followed by a description of the flight control system, some specific components, drawings of the internal arrangement, block diagrams, and schematics. System operation redundancy management is also presented.

1.1 Purpose

The purpose of this document is to provide system description information on various aircraft flight control systems.

2. APPLICABLE DOCUMENTS

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

2.1 SAE Publications

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

AIR4253 Description of Actuation Systems for Aircraft with Fly-By-Wire Flight Control Systems

AS5440 Hydraulic Systems, Military Aircraft, Design and Installation, Requirements For

2.2 Other References

Some of the data in this information report has been collected from material presented at previous SAE A-6 meetings, or other technical conferences. If more detailed information is desired, contact with the author(s) or company of the following references is recommended. However, it is reasonable to expect, and appreciate, that certain proprietary rights may be exercised with respect to certain data and/or information.

- AH-1 & UH-1 Helicopter Hydraulic System Upgrade, R. Olson and M. Williams, May 2001, Bell Helicopter
- AH-64A Flight Controls, M. E. Little, Sept. 2003
- V-22 Flight Control System, B.L. McManus, Boeing Vertol Company, April 1985
- BA-609, C. Fenny, May 2004, Bell Helicopter
- EH101 Servoactuators, E. Artoni, MICROTECNICA - Divisione Magnaghi Brugherio, Aug. 2003
- H1 Upgrade Hydraulic System, May 2008, Bell Helicopter
- Key Aspects and Attributes of the RAH-66 Comanche Flight Control System, B. Boczar, D.W. Borgstrom, and P. T. Everett, Nov. 2004, The Boeing Company
- Rotary Wing Flight Control Actuator Characteristics, Parker Hannifin Corporation, Feb. 2004
- S-92 Fly-by-Wire Advanced Flight Control System, B. Boczar and B. J. Hull, April 2007, Sikorsky Aircraft Corporation and BAE Systems Platform Solutions
- F-105 Flight Control Manual, Republic Aviation, Air Power Museum, Farmingdale, NY. Illustrations by AArena Consulting Inc. 2014

Unofficial information on other Military and Commercial Aircraft Fixed and Rotary Wing Flight Control Systems can be found at Wikipedia, The Free Encyclopedia, <http://en.wikipedia.org/wiki/Aircraft>, and www.smartcockpit.com.

2.3 U.S. Government Publications

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

MIL-F-8785

MIL-PRF-5606

MIL-PRF-83282

MIL-PRF-87257

MIL-STD-704

3. FIXED WING MILITARY AIRCRAFT

3.1 Fighter Aircraft

3.1.1 McDonnell-Douglas F-15 Eagle

3.1.1.1 F-15A Aircraft Flight Control System

The F-15A Eagle is a high performance air-superiority fighter aircraft. The flight control system is a conventional hydromechanical configuration with an analog dual-channel high-authority Control Augmentation System (CAS). The major factor in the design of the F-15A flight control system was the requirement for the aircraft to meet or exceed Level II flying qualities (MIL-F-8785) throughout its operational envelope without the aid of electronic augmentation.

3.1.1.2 System Description

The F-15A flight control system is a hydromechanical configuration with a high-authority control augmentation system. Aircraft primary control is provided by two ailerons, two rudders, and two stabilators. The CAS functions are provided by servos which are integral with the rudder and stabilator actuators.

3.1.1.3 F-15A Flight Control System Mechanization

Schematics of the longitudinal, lateral and directional control systems are shown in Figures 1, 2, and 3. Meeting Level II flying qualities without electronic augmentation requires a very specialized hydromechanical control system. The heart of this system is the Control Stick Boost and Pitch Compensator (CSBPC). This device contains two major assemblies known as the Pitch/Roll Channel Assembly (PRCA) and the Aileron Rudder Interconnect (ARI). In addition to pilot inputs, these assemblies use information from the pitot and static probes and normal acceleration to adjust the stick to control surface gearing ratios. In the pitch axis, it provides relatively constant stick force per g and pitch trim compensation for disturbances such as speed brake extension, transonic trim change, and flap extensions. A roll ratio changer maintains a relatively constant roll response and limits responses which could generate unacceptably high roll accelerations, roll rates, and structural loads. The ARI provides roll coordination at high angles of attack. The CAS, shown in Figure 4, works in conjunction with the hydromechanical control system through series servos in the rudder and stabilator actuators to fine-tune the handling qualities. The CAS accepts inputs from the cockpit controls and motion sensors to compute the commands to the series servos which provide the desired surface deflection and aircraft response. Although CAS does not have full authority over the surface actuators, the actuator mechanical inputs have a detent and the CAS authority is sufficient to fly and land the aircraft in the event of a mechanical failure between the stick and stabilator.

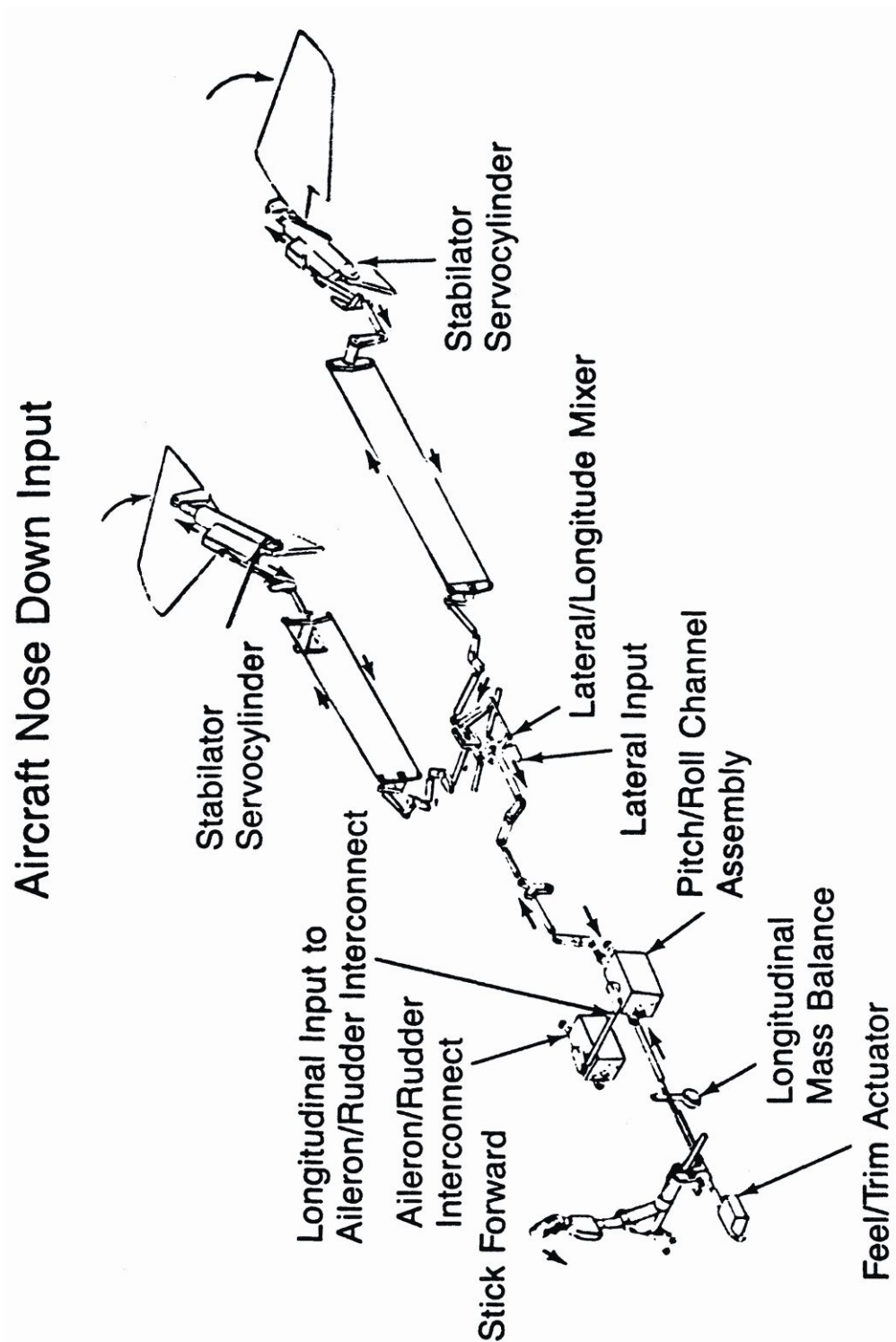


Figure 1 - McDonnell-Douglas F-15A Eagle, flight control system – longitudinal controls

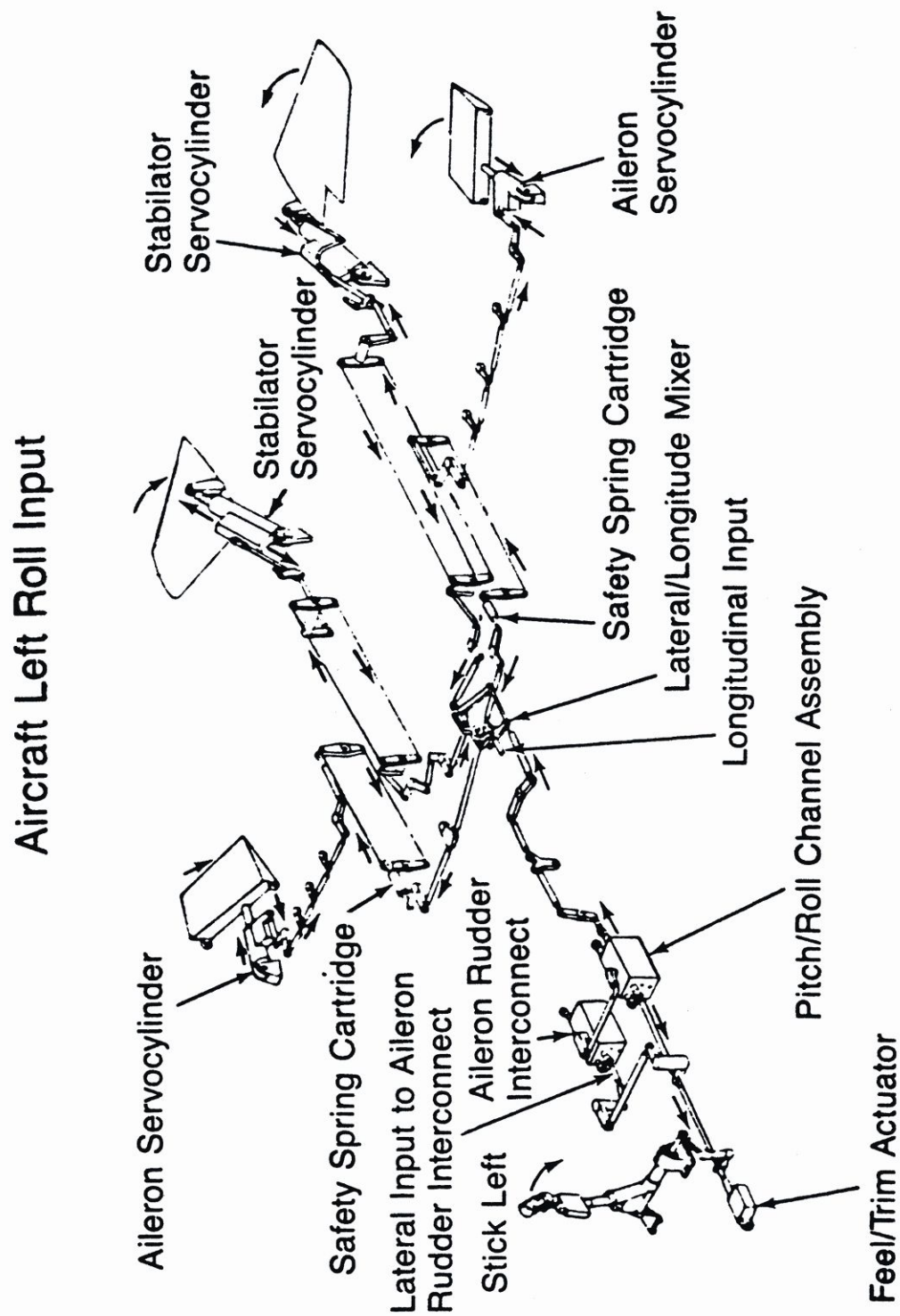


Figure 2 - McDonnell-Douglas F-15A Eagle, flight control system – lateral controls

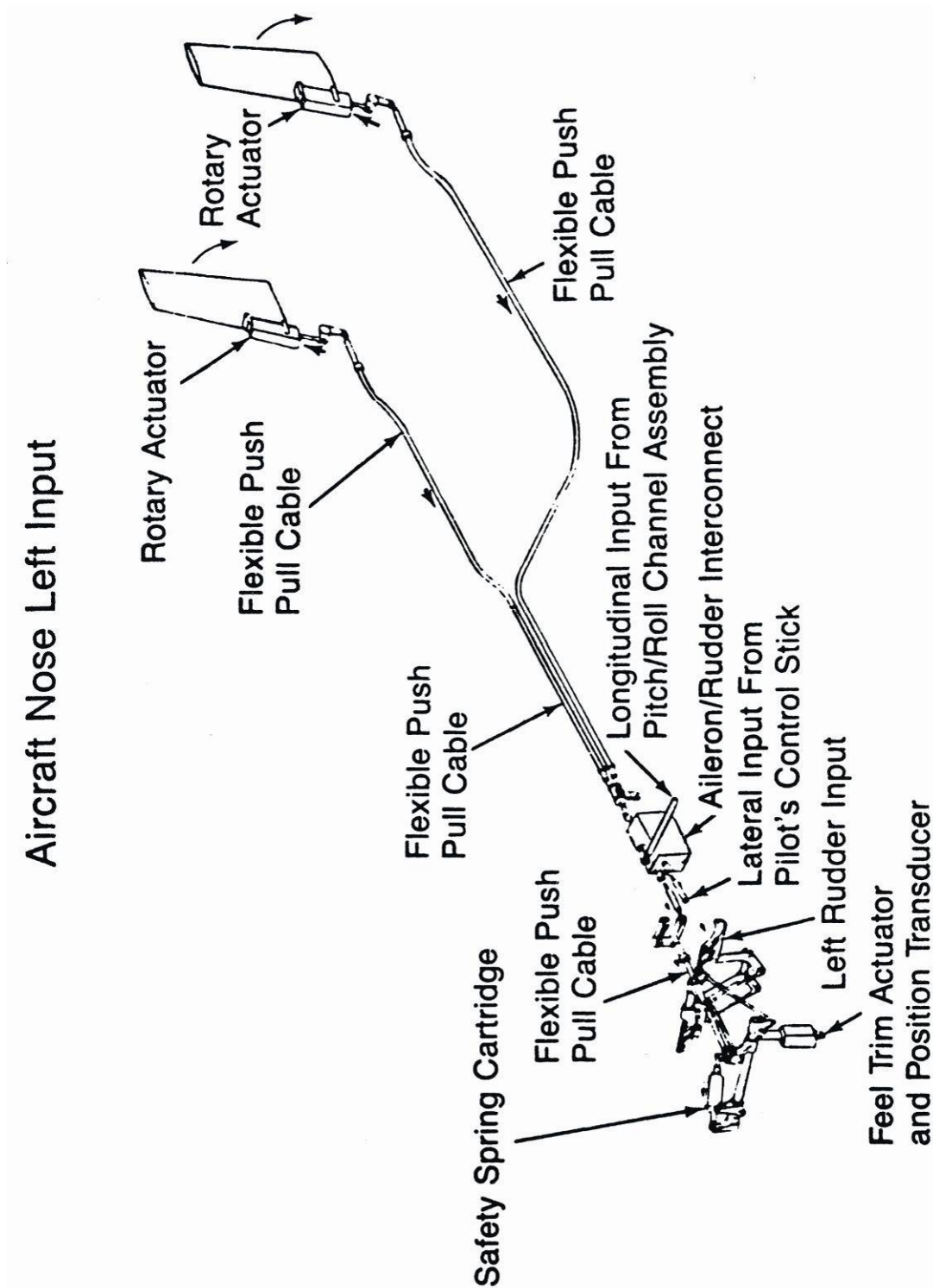


Figure 3 - McDonnell-Douglas F-15A Eagle, flight control system - directional controls

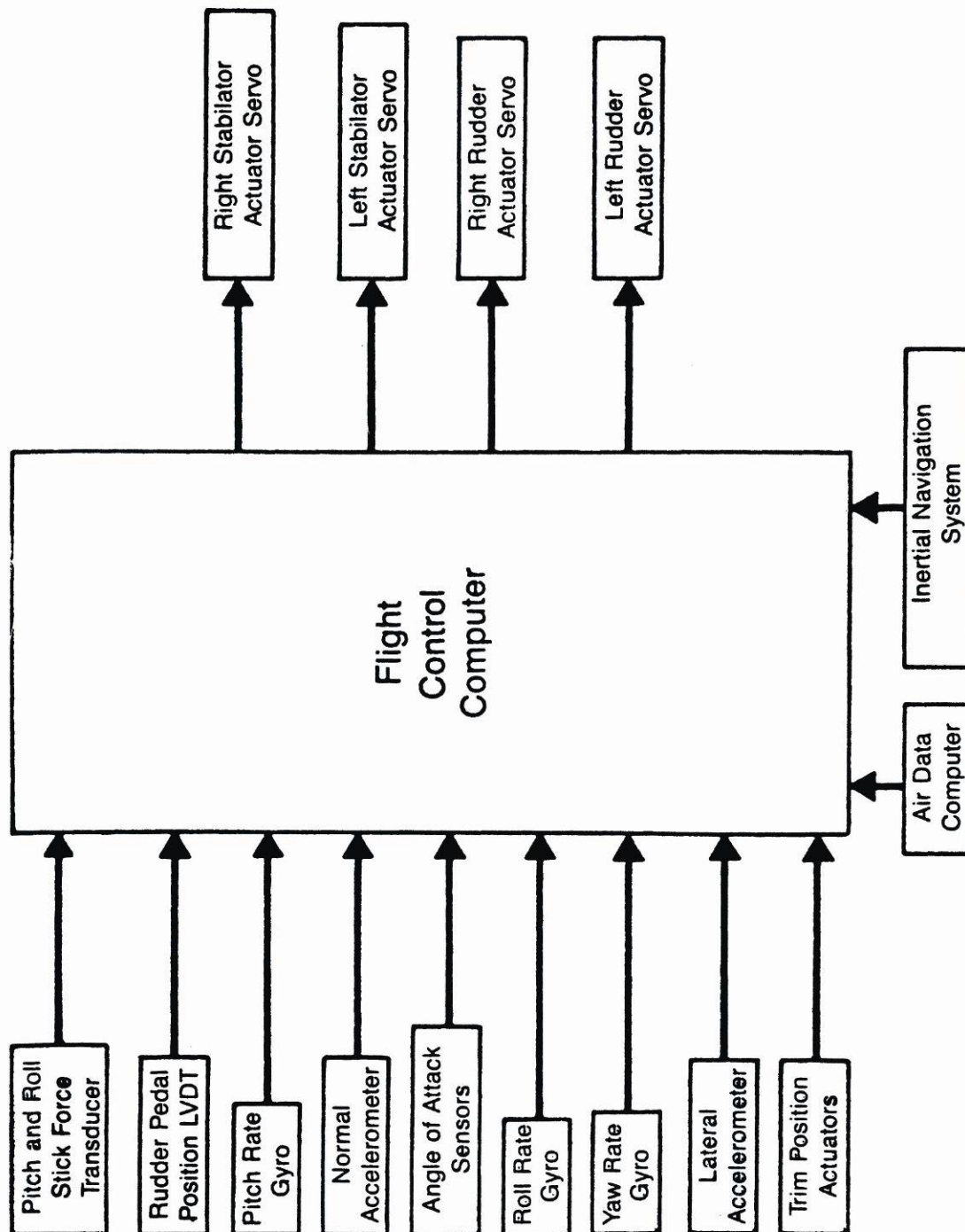


Figure 4 - McDonnell-Douglas F-15A Eagle, control augmentation system

The hydraulic systems incorporate reservoir level sensing and switching valves which result in all actuators having at least two normal sources of hydraulic pressure or a normal source backed up through a switching valve to a second source. The stabilator actuators normally use two hydraulic systems, one of which has an emergency backup. The CAS servos within the stabilator actuators are supplied by the hydraulic system having the backup supply; therefore, two hydraulic failures must occur before the CAS is lost and three failures must occur before total stabilator control is lost.

All of the electrical functions of the primary flight control system can be operated from the primary or emergency electrical busses. If the primary electrical system fails, a hydraulically driven emergency generator is switched into the system using the emergency bus. If all electrical power is lost, the aircraft can be safely flown via the mechanical control system. Electrical power interruptions less than 50 ms have no effect on CAS operation.

3.1.2 General Dynamics/Lockheed Martin F-16 Fighting Falcon

3.1.2.1 System Description

The F-16 fly-by-wire Flight Control System (FLCS) consists of many interacting components, as illustrated in Figure 5. Pilot commands to the FLCS are generated by a sidestick controller, rudder pedals, and switches in the flight control panels. The electrical commands from these cockpit components are fed to the Flight Control Computer (FLCC), which can be viewed as the “heart” of the FLCS. The FLCC also receives aircraft inertial motion inputs from pitch, roll, and yaw gyros and from normal and lateral accelerometers. Additionally, air data information is transmitted to the FLCC after measurement by total pressure, static pressure, and angle-of-attack (AOA) probes; conversion of pneumatic pressure to electrical signals by the Pneumatic Sensor Assembly (PSA); and signal conditioning by the Electronic Component Assembly (ECA). The FLCC combines these inputs through appropriate control laws to produce control-surface commands that position five primary control surfaces through Integrated Servoactuators (ISAs). Primary control surfaces are defined as two flaperons, two all-moveable horizontal tails, and a rudder. The FLCS provides information back to the pilot through various indicator, caution, and warning lights located in the cockpit.

The F-16 also incorporates several secondary control surfaces - the leading-edge flap and speed brakes. The leading-edge flap is driven by a power drive unit that is programmed by the ECA as a function of AOA, altitude, and Mach number to provide optimum wing contour during maneuvering. The two speed brakes are directly controlled by the pilot.

Protection against failure is achieved by redundancy as shown by Figure 6. Critical functions are replicated up to four times in the FLCS. In the event of consecutive component failures, the system can sense the error by comparison of redundant branches and then provide a valid output command by a selection process.

The F-16 FLCS also employs built-in self-test to protect against operation with failure. Inherent in the design of the redundancy management system is the assumption that it is working properly. One of the primary functions of built-in self-test is to check the capability of the redundancy management system to detect and correct failures.

Figure 7 is a schematic of the F-16 pitch axis, which shows the system redundancy levels. The pitch axis is the most critical on the F-16 because of the longitudinal static instability of the aircraft. This figure shows two of the most critical parts of the redundancy management system of the F-16 FLCS. The first is the signal “selector”. This device selects a good electronic channel even after two consecutive electronic branch failures. The evolution of the selector design was a significant part of the development of the F-16 analog fly-by-wire FLCS. The second critical part of the redundancy management system is the electrical-to-mechanical interface provided by the servoamplifier monitor system and the self-contained hydro mechanical failure detection and correction logic in the ISA.

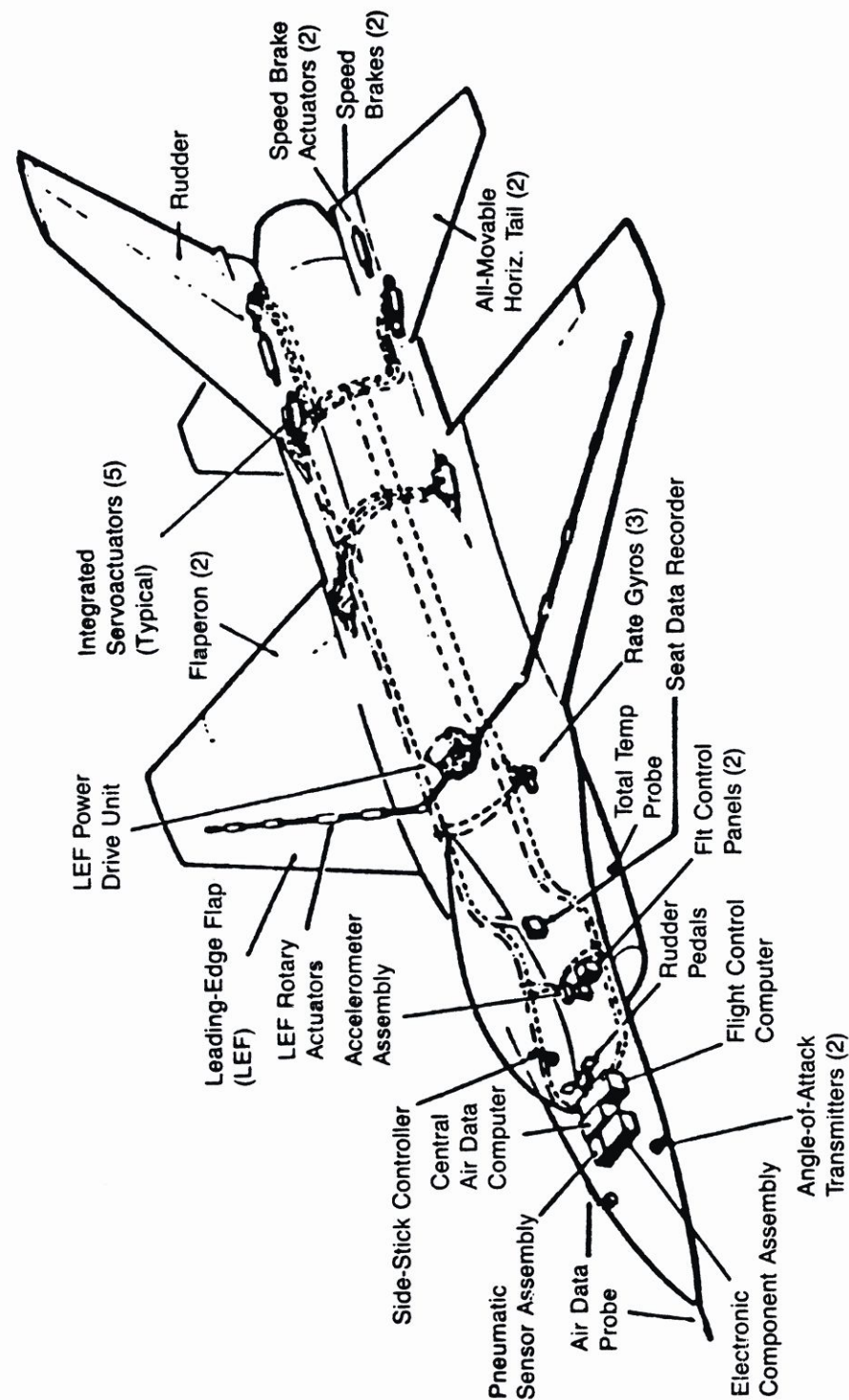


Figure 5 - General dynamics/Lockheed Martin F-16 Fighting Falcon, flight control system components

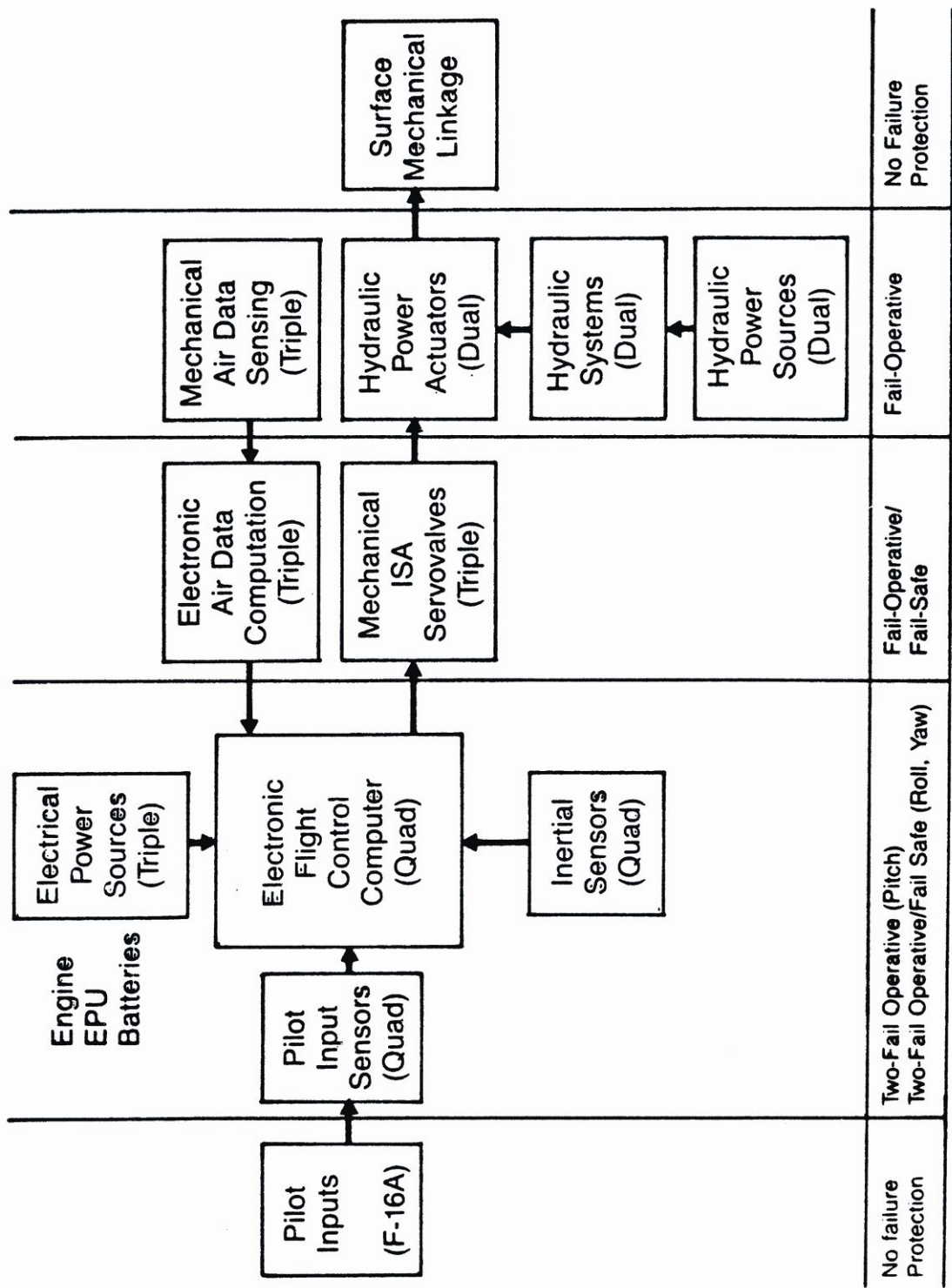


Figure 6 - General dynamics/Lockheed Martin F-16 Fighting Falcon, redundancy and failure protection levels

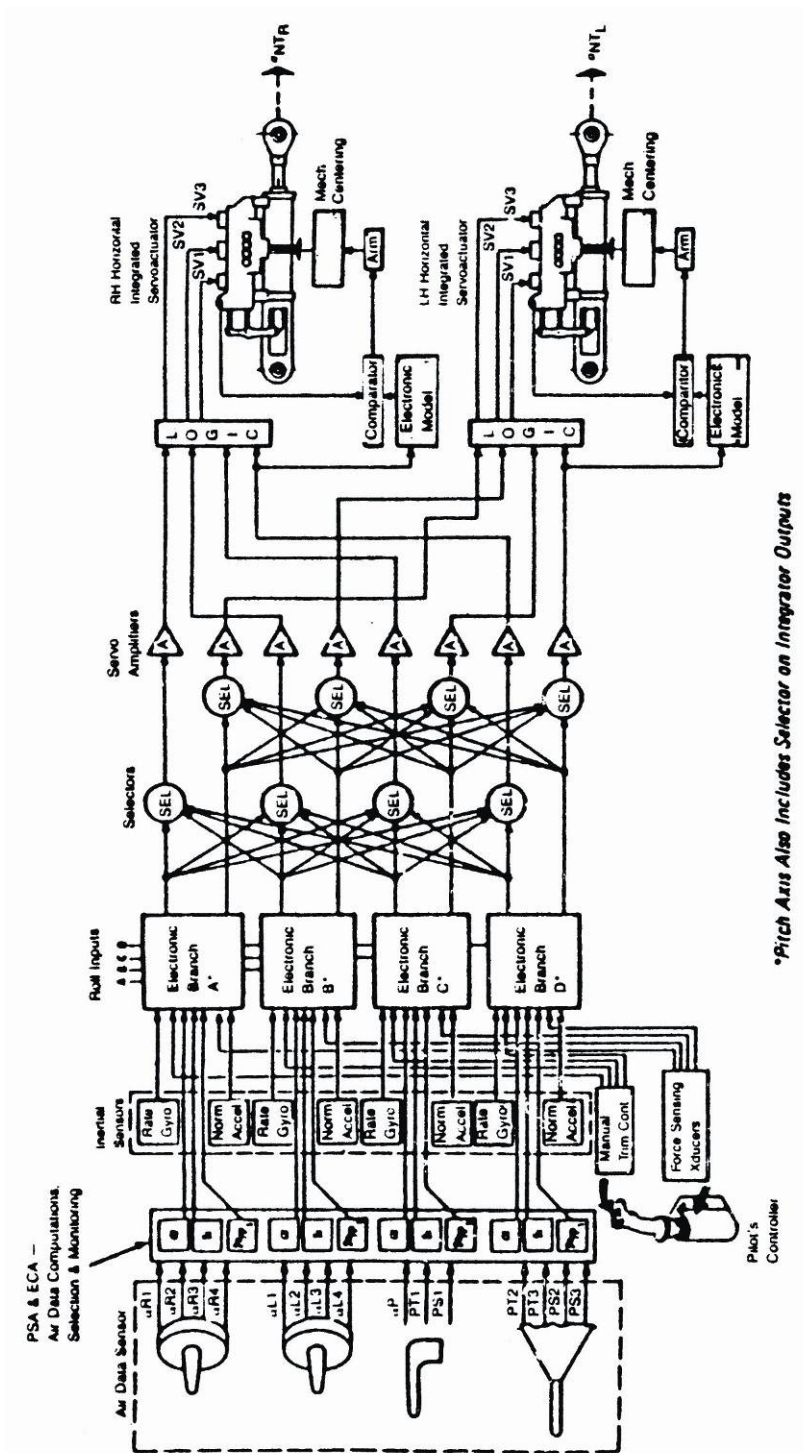


Figure 7 - General dynamics/Lockheed Martin F-16 Fighting Falcon, pitch axis electronic redundancy

3.1.2.2 System Description of the F-16 C/D Digital Flight Control System

The Digital Flight Control System (DFLCS) was incorporated beginning with the F-16 C/D Block 40 Aircraft. The upgraded system consolidates the analog FLCC and the ECA into a Digital Flight Control Computer along with other system enhancements. Figure 8 shows the DFLCS components and locations. Figure 9 is a functional Block Diagram of the DFLCS.

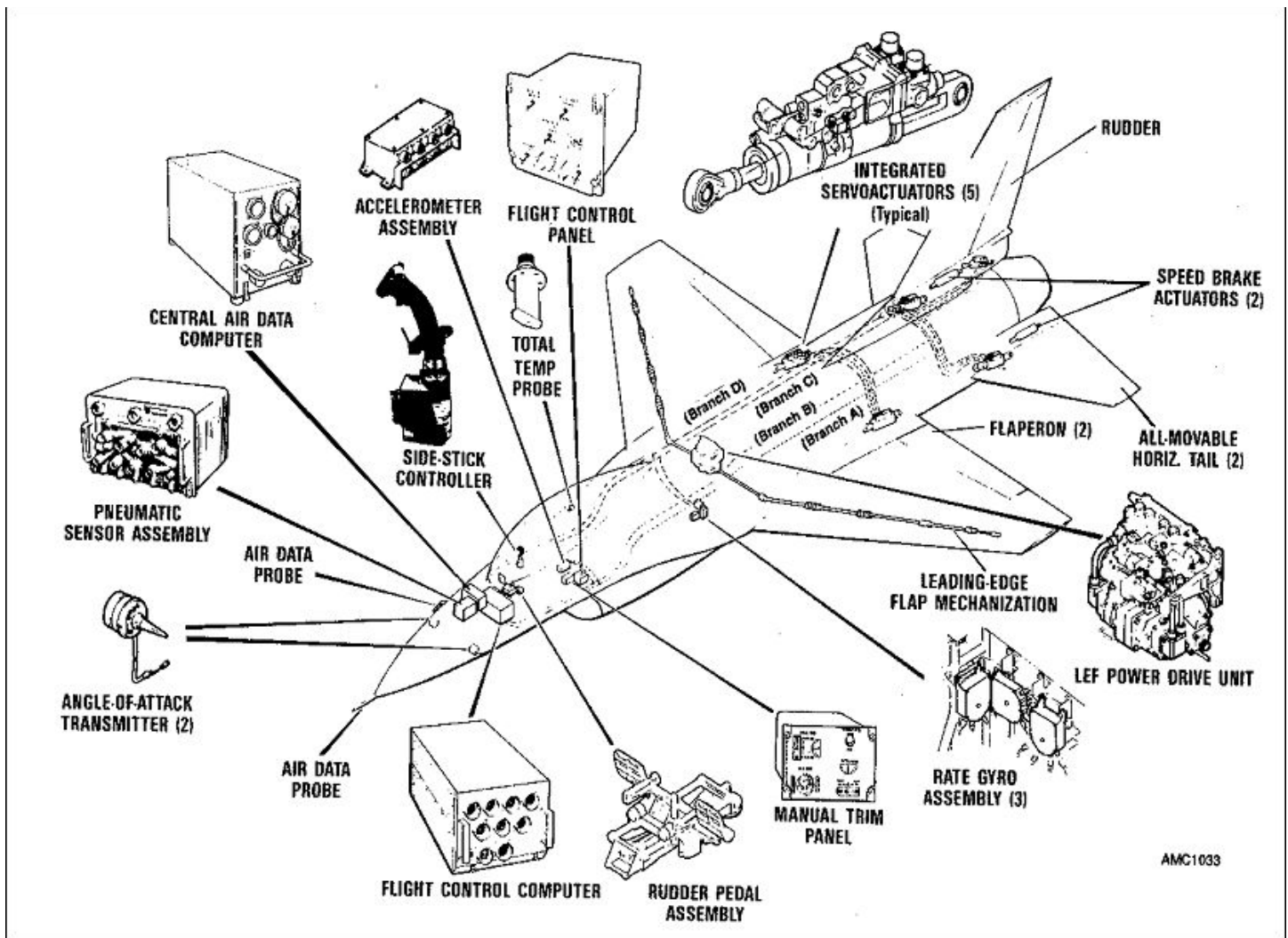


Figure 8 - Lockheed Martin F-16 Fighting Falcon, digital flight control system components

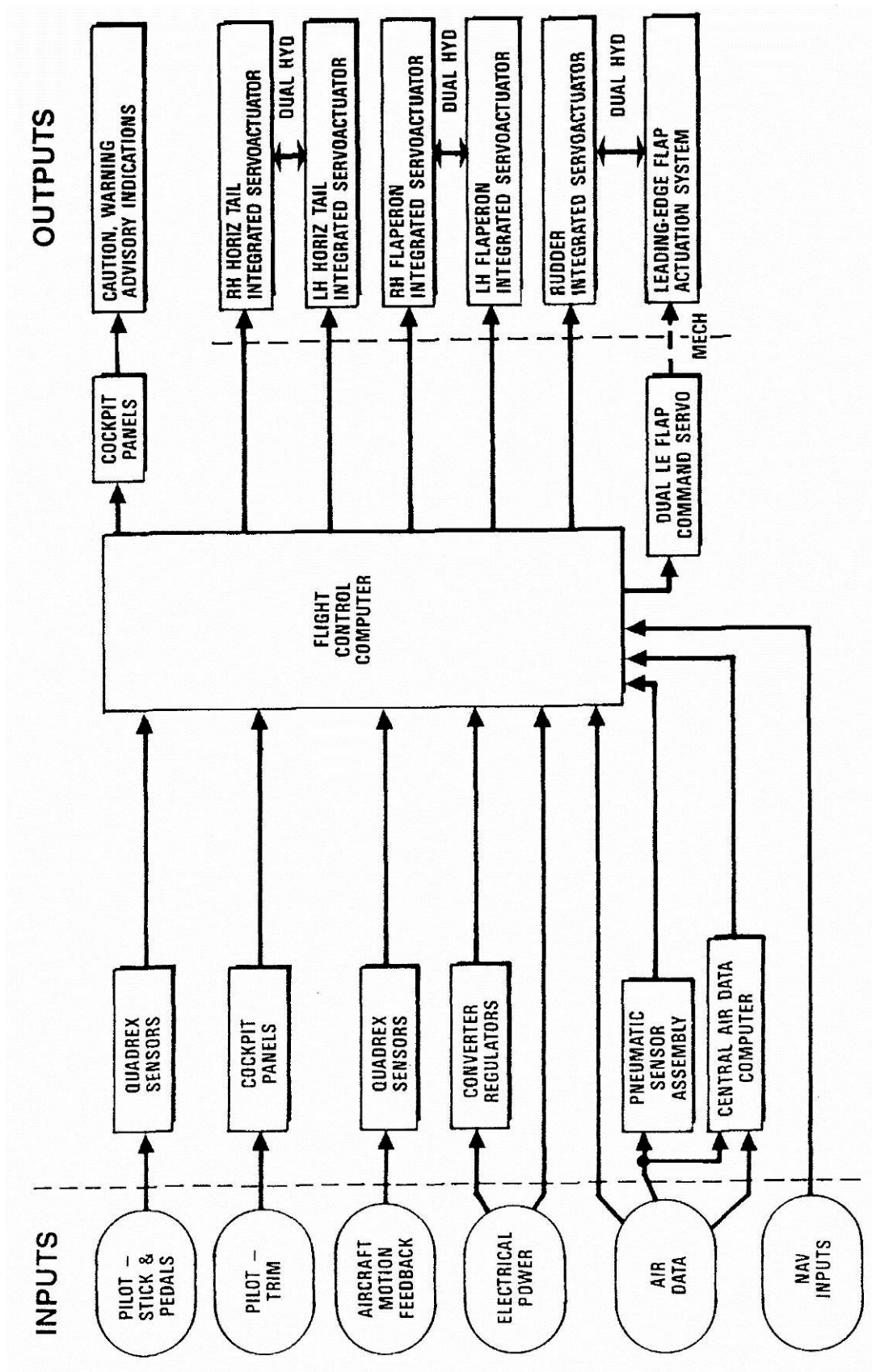


Figure 9 - Lockheed Martin F-16 Fighting Falcon, digital FLCS functional block diagram

3.1.3 McDonnell-Douglas F/A-18A-D Hornet

3.1.3.1 F/A-18A-D Aircraft Flight Controls Systems

The F/A-18A-D Hornet is a high performance fighter aircraft with a digital control-by-wire (CBW) primary flight control system. The quadruplex digital flight control system provides all of the conventional stability and control functions as well as autopilot and coupled data link modes. The major factor in the F/A-18A-D flight control system design philosophy was to provide a highly reliable, survivability, and safe aircraft with minimum system degradation with loss of any component.

3.1.3.2 System Description

The F/A-18A-D flight control system is a control augmentation system (CAS) configuration which is implemented using fly-by-wire techniques. A functional diagram of the flight control system is shown in Figure 10. All primary control law computations are performed by the four digital computers working in parallel (quadruplex redundancy). The computers use inputs from analog cockpit controls and motion sensors to compute commands to the redundant electrohydraulic servoactuators which provide the desired surface deflection and aircraft response. Aircraft control is provided by two ailerons, two rudders, two stabilators, two leading-edge flaps, and two trailing-edge flaps. The flight control system redundancy provides two-fail-operate capability for the primary control functions. Backup modes include mechanical control for the two stabilator control surfaces and fly-by-wire analog position control of the aileron and rudder control surfaces.

3.1.3.3 F/A-18A-D Flight Control System Mechanization

Reliability and survivability considerations in consonance with the F/A-18A-D aerodynamic configuration were used to establish the redundancy levels for each control function. Control functions which are critical from a flying qualities or safety standpoints were designed with two-fail-operate/fail-safe capability. These functions include primary control commands, motion sensors, and stabilator and trailing edge flap actuators. Less critical functions or control surfaces with aerodynamic redundancy were designed with fail-operate/fail-safe capability. The redundancy selected for all of the major flight control system components is shown in Figure 11.

A major factor in the F/A-18A-D design philosophy is to provide maximum system capability with the loss of any control function. The backup modes are analog DEL control of the ailerons and rudder, and mechanical control of the integrated stabilator surface actuators. The aileron and rudder analog DEL mode can only be engaged following three digital processor failures. Reversion to the stabilator servoactuator mechanical backup mode will occur in the event of any one of the following failure conditions:

- Three pitch or roll stick sensor failures
- Three digital processor failures
- Three computer power supply failuresTwo generator and two battery failures
- Three servoactuator electrical failures

The mechanical control system schematics are shown in Figures 12 and 13.

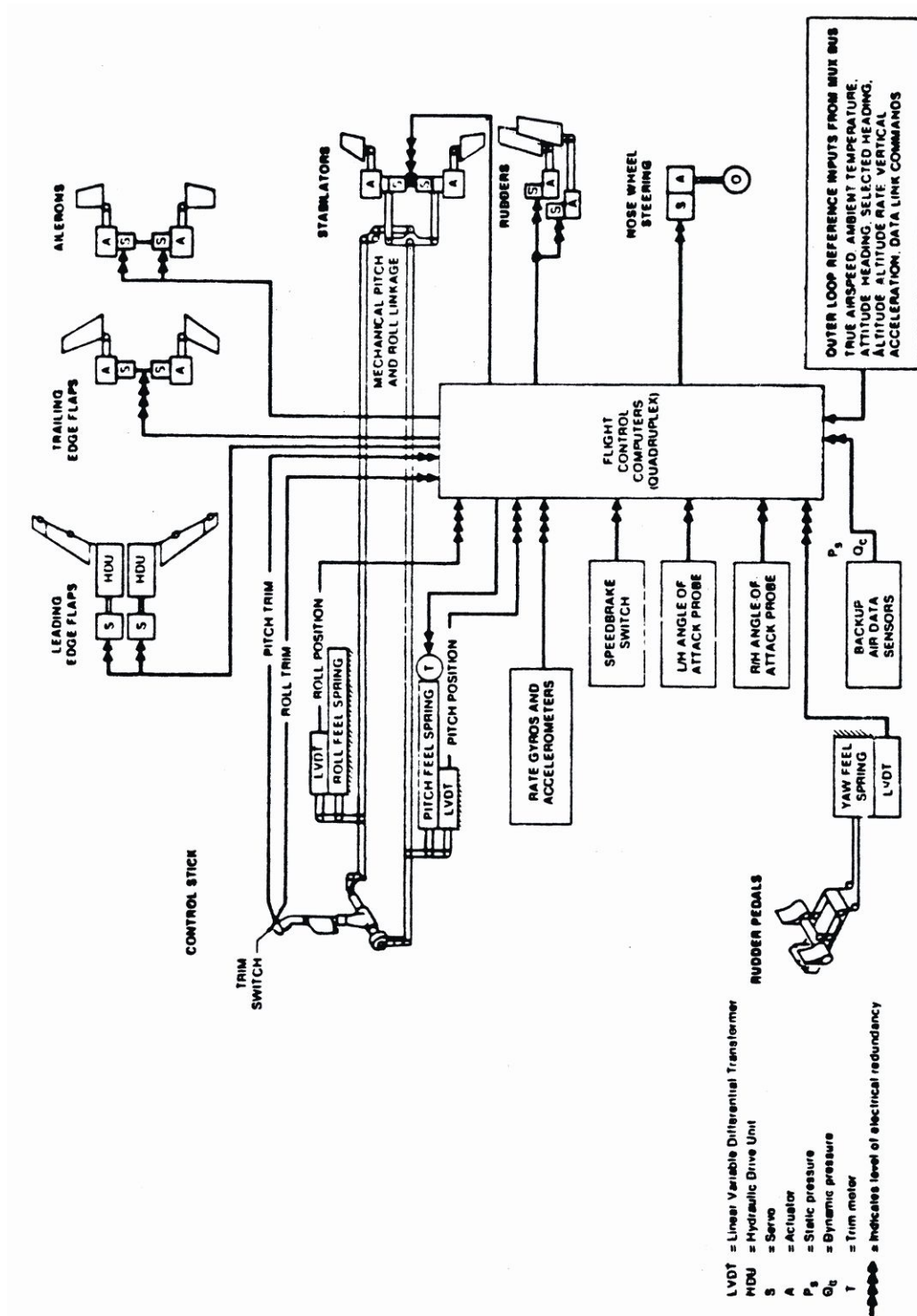


Figure 10 - McDonnell-Douglas F/A-18A-D Hornet, flight control system functional diagram

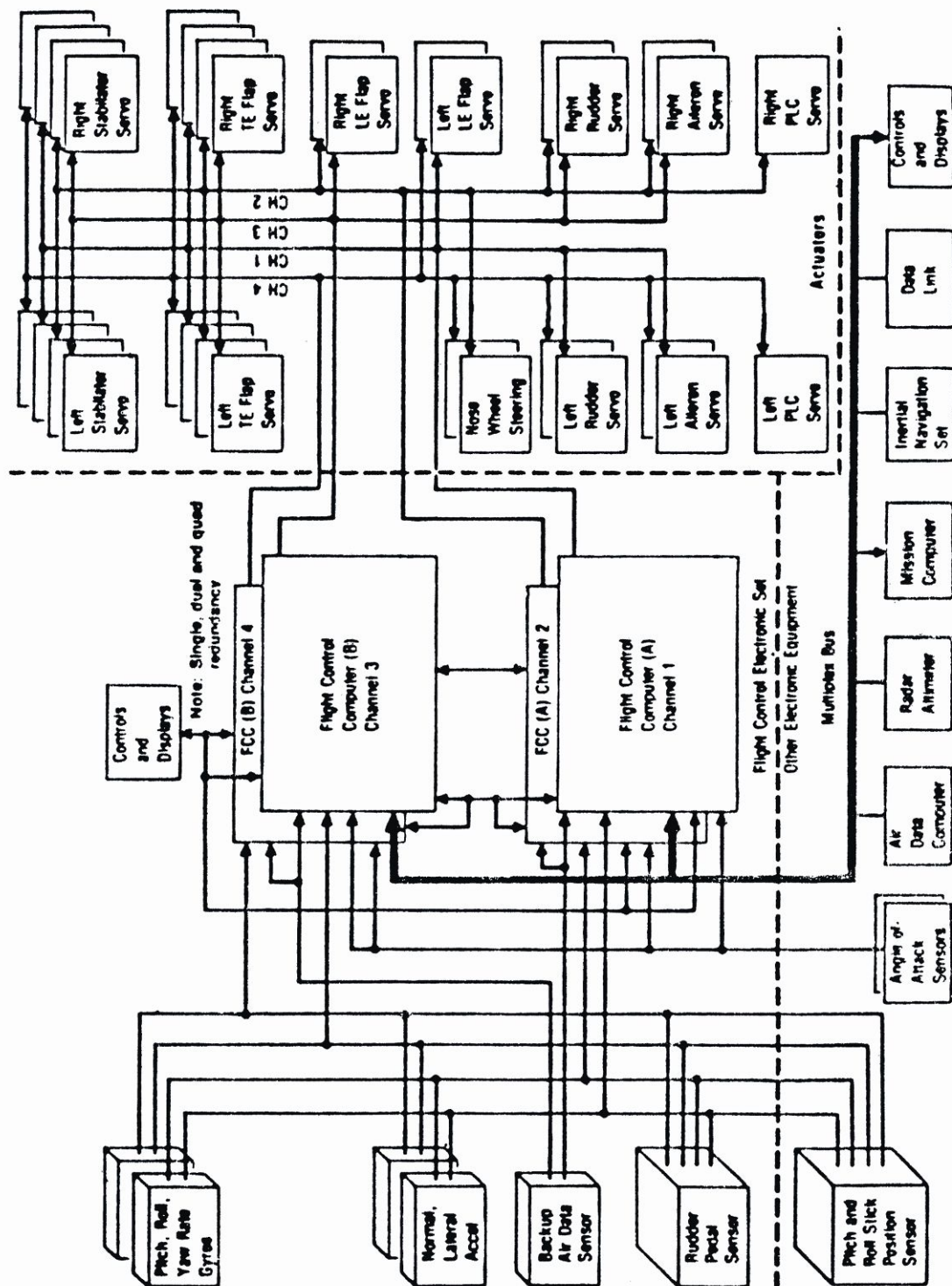


Figure 11 - McDonnell-Douglas F/A-18A-D Hornet, flight control electronic set interface

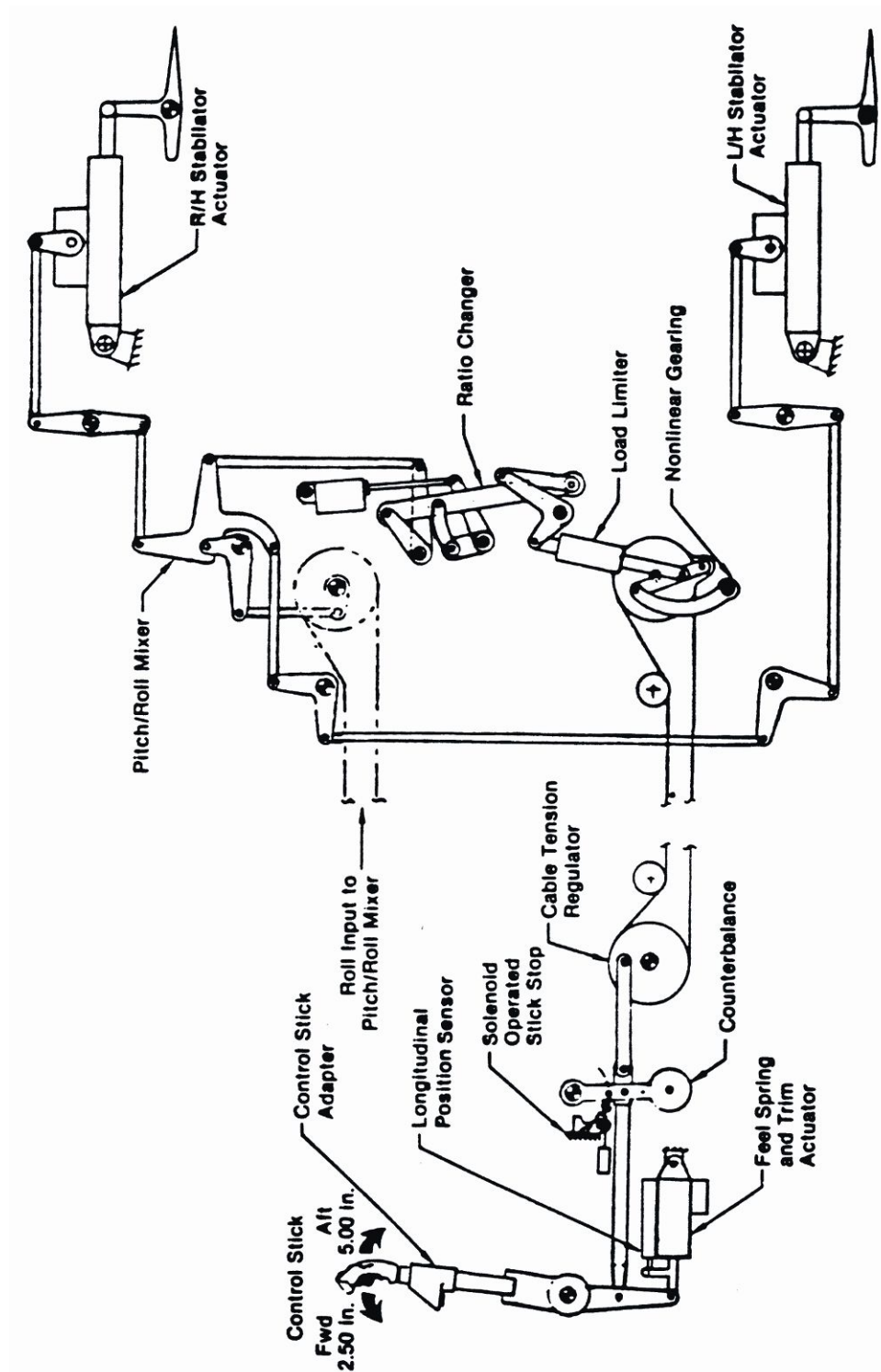


Figure 12 - McDonnell-Douglas F/A-18A-D Hornet, longitudinal control system schematic

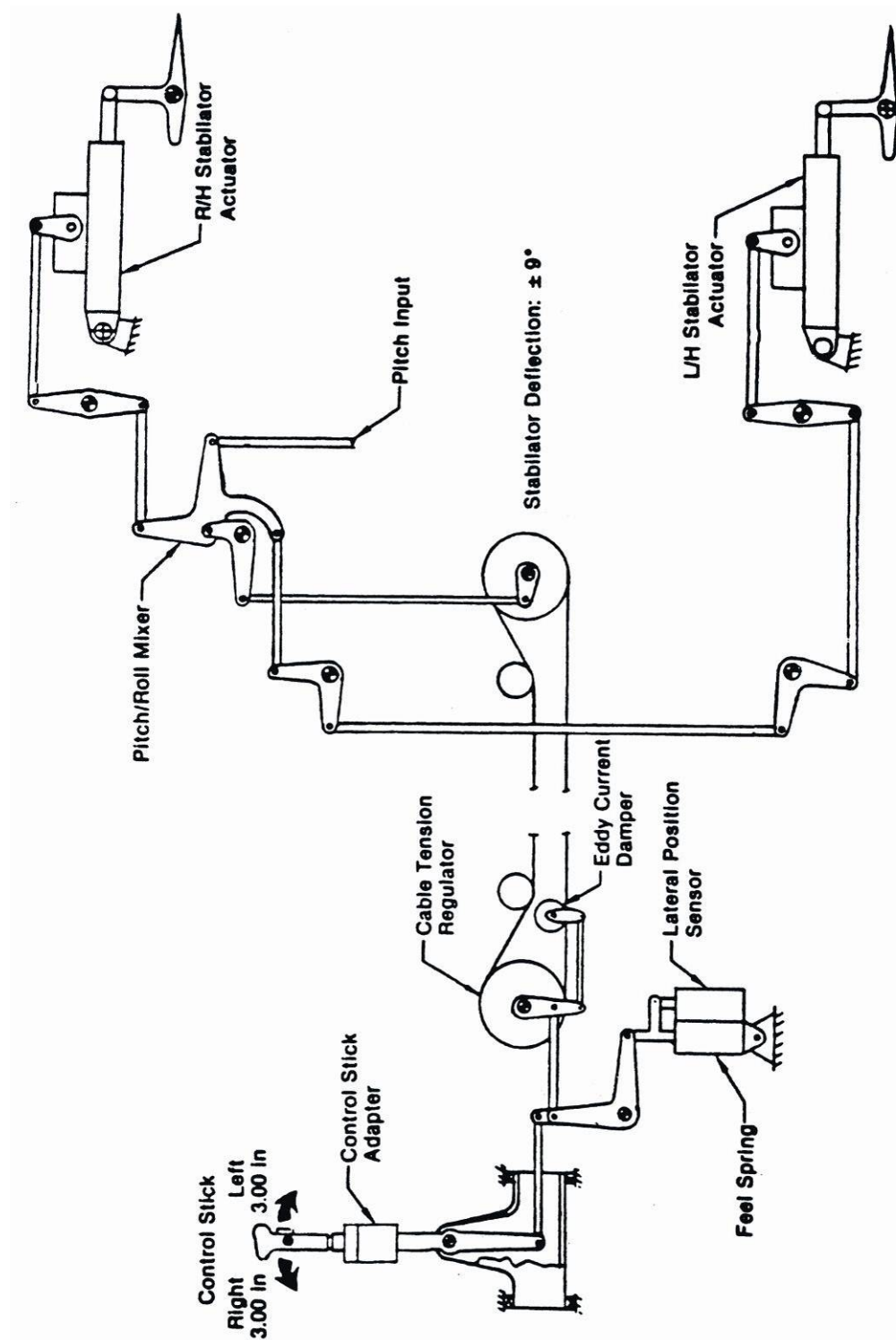


Figure 13 - McDonnell-Douglas F/A-18A-D Hornet, lateral control schematic

In the area of aircraft power systems, equal concern was present in the areas of both hydraulic and electrical supplies. Incorporation of reservoir level sensing and switching valves resulted in all actuators having at least two normal sources of hydraulic pressure or a normal source backed up through a switching valve to a second source. The stabilator has one of the two chambers backed up through a switching valve; therefore, three hydraulic supply failures must occur before total stabilator control is lost.

Batteries back up the normal FCS electrical power input. These batteries automatically power the FCS if the primary sources are lost.

The specification for electrical supplies, MIL-STD-704, allows 50 ms interruptions of power. This would not affect most analog systems; however, loss of power for that long could scramble the memory of a digital system. Therefore, a 7-second "hold-up" circuit was put into the computer power supplies to connect them directly to the batteries for 7 seconds if the voltage to these supplies falls below 16 V for more than 5 μ s.

3.1.4 Grumman F-14 Tomcat

The Grumman F-14 Tomcat is a variable sweep air superiority fighter utilizing a Type III mechanical-power augmented flight control system with integral stability and command augmentation (SAS and CAS). A dual-channel, fail-safe stability augmentation system (SAS) is employed in pitch and roll and a three channel fail-operational SAS in yaw. The control system allows for operation at subsonic and supersonic flight while providing performance and agility characteristics necessary for close in air combat superiority.

3.1.4.1 System Description

The F-14 control system encompasses the use of automatically programmed variable wing sweep along with twin rudders and all moveable horizontal stabilizers for pitch and roll control and wing spoilers for low speed roll performance enhancement. Wing leading and trailing edge flaps are automatically programmed for maneuver enhancement and automatic scheduling of the wing is programmed as a function of speed and altitude. This Mach Sweep Programmer allows utilization of all the inherent advantages of a variable sweep rather than limiting combat operations to a fixed wing sweep position.

Each vertical tail is toed-in 1 degree and has a 30% chord full span rudder. Rudder deflection is limited thru an infinitely variable device which is controlled as a function of aircraft speed and altitude. The all-moveable horizontal stabilizer can be deflected symmetrically between 10 degrees TED and 33 degrees TEU for pitch control and differentially ± 12 degrees for roll control. Maximum deflections are limited to 15 degrees TED and 35 degrees TEU. Additional roll control is provided by four wing spoilers for wing sweep angles less than 57 degrees.

Stability augmentation and other automatic functions to the primary control surfaces are processed through the Automatic Flight Control system (AFCS). These functions are roll command augmentation (CAS), pitch, roll, and yaw stability augmentation, automatic rudder interconnect (ARI), pitch/roll autopilot, Mach trim control, spoiler control, roll, and yaw authority controls and built-in test (BIT). The system consists of: dual roll and pitch rate gyros, three yaw rate gyros, three lateral accelerometers, three AFCS computers (pitch, yaw, roll), and one AFCS control panel.

3.1.4.2 F-14 Flight Control Systems Mechanizations

Control stick motion is transmitted to the hydraulic power actuator via a completely mechanical linkage arrangement (see Figure 14) consisting solely of pushrods and bellcranks to the pitch roll/mixer where it branches to the port and starboard stabilizer actuators. The longitudinal control system is designed to provide nonlinear stick to stabilizer relationship so that stick sensitivity levels provide acceptable aircraft handling qualities.

Artificial feel is provided to the pilot through a spring-loaded cam and roller assembly, fore and aft bobweights and a sprashpot. The assembly is designed to provide distinct breakout force plus two force gradients over the range of control stick displacement. The bobweight function provides the pilot with normal acceleration force cues. The sprashpot (eddy current damper) augments control system damping by generating forces proportional to the control stick velocity.

Lateral control (Figure 15) of the aircraft is effected by differential displacement of all the moveable horizontal stabilizer where full stick displacement provides ± 7 degrees differential horizontal stabilizer. The SAS/CAS provides an additional ± 5 degrees differential via the AFCS. Four sets of spoilers, commanded differentially, assist in roll control for wing sweep positions of less than 57 degrees. During power approach (flaps down), vertical glide path correction (Direct Lift Control) can be made (at pilot option) by proportional symmetric displacement of all the spoilers without changing angle of attack or engine power settings. Pitching moments generated by symmetrical spoiler deflection are compensated by coupled symmetrical horizontal stabilizer deflection.

A mechanical pitch/roll mixer assembly algebraically sums pitch and roll commands, and a lateral authority control device restricts differential commands to the stabilizer as a function of dynamic pressure.

Full rudder pedal corresponds to proportional full deflection of the dual rudders. The artificial feel system mechanized by a spring roller-cam assembly is mechanically similar to the longitudinal feel system. The feel spring force gradient is nonlinear with the force rate decreasing with increasing pedal displacement. A rudder pedal shaker motor emitting high frequency, low amplitude oscillations via a shaker mass imbalance to the left rudder pedal is installed to warn the pilot of excessive angle of attack during approach. Infinitely variable rudder stops restrict the rudder pedal travel as a function of dynamic pressure (Figure 16).

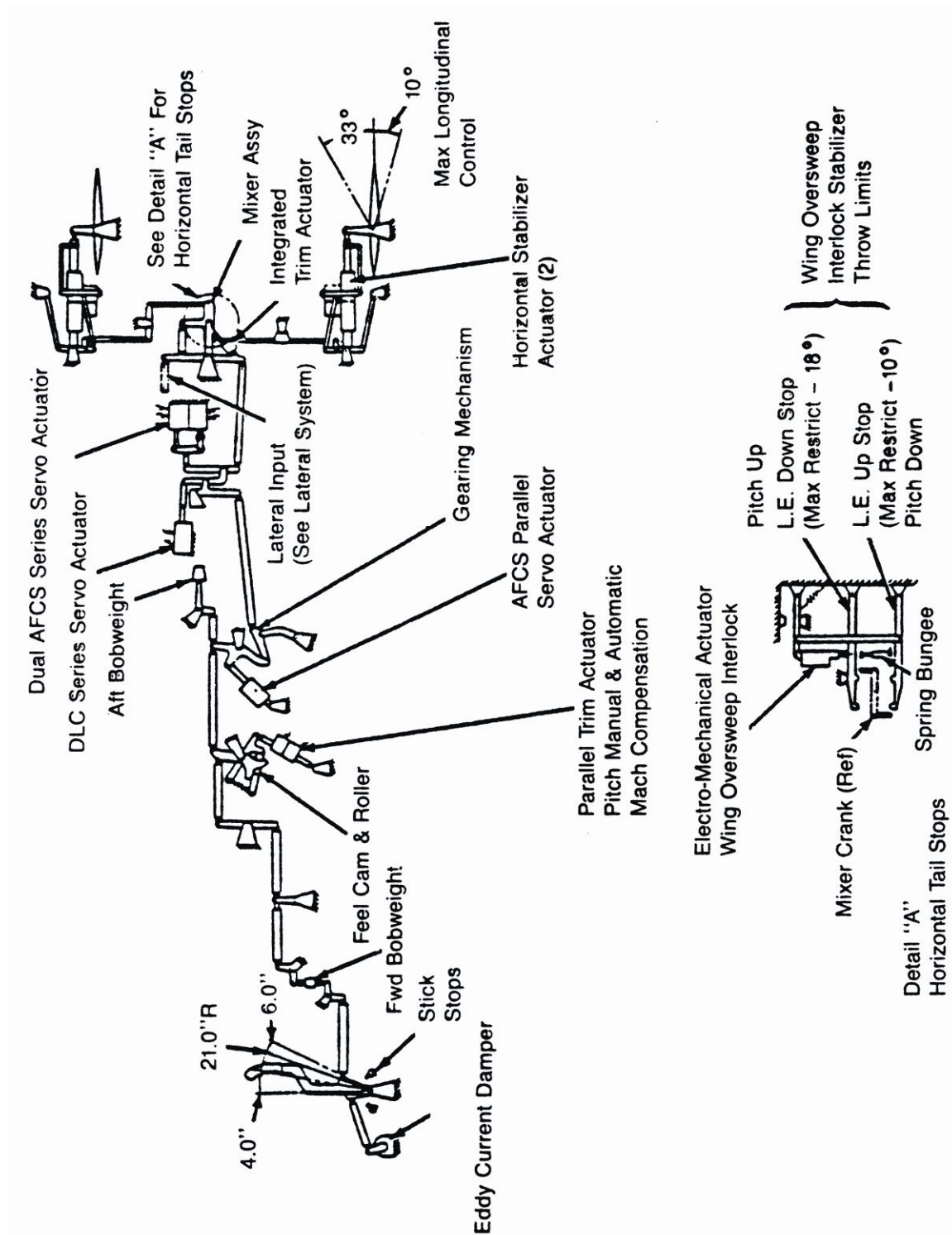


Figure 14 - Grumman F-14 Tomcat, longitudinal control system schematic

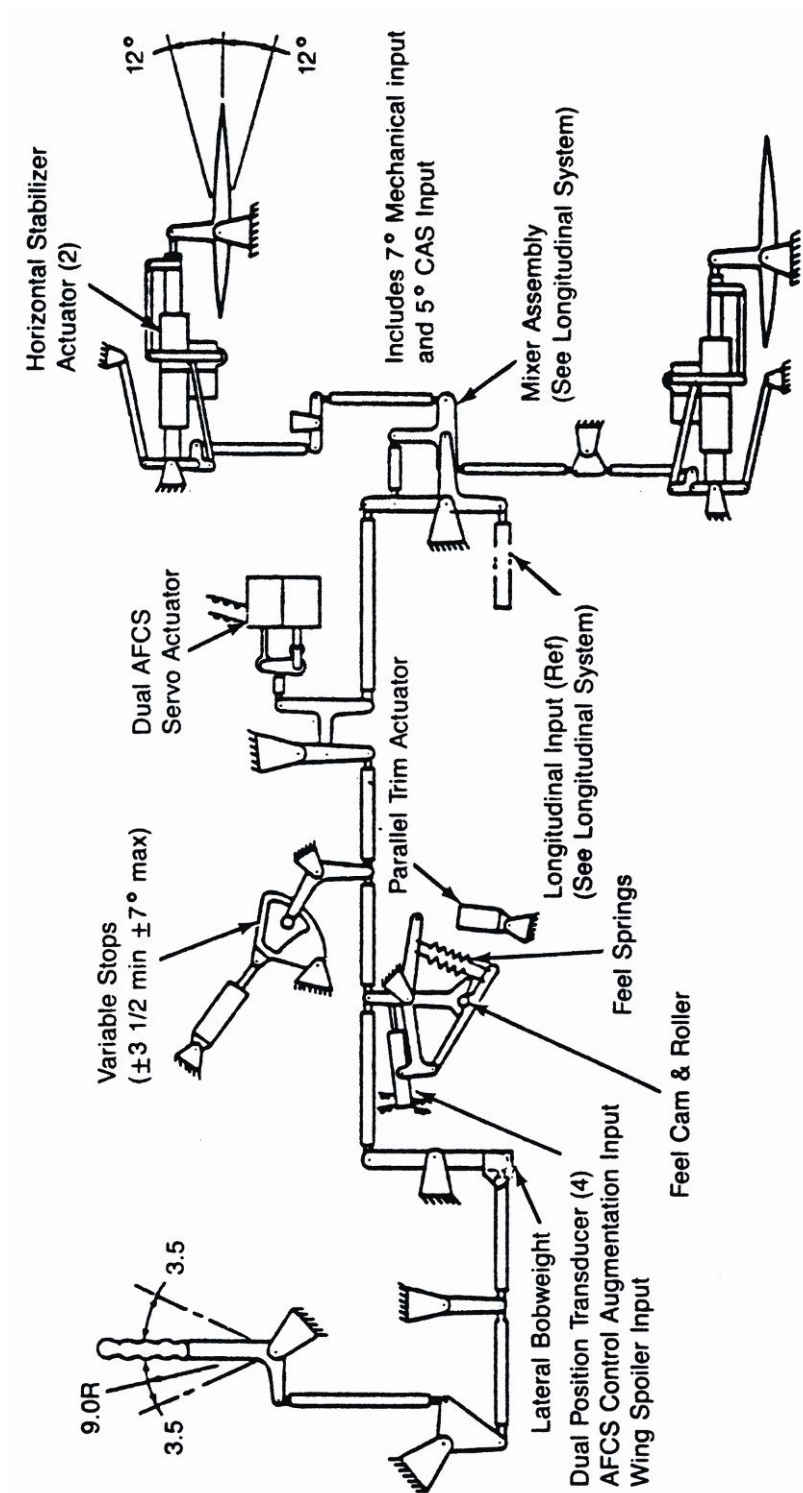


Figure 15 - Grumman F-14 Tomcat, lateral control system schematic

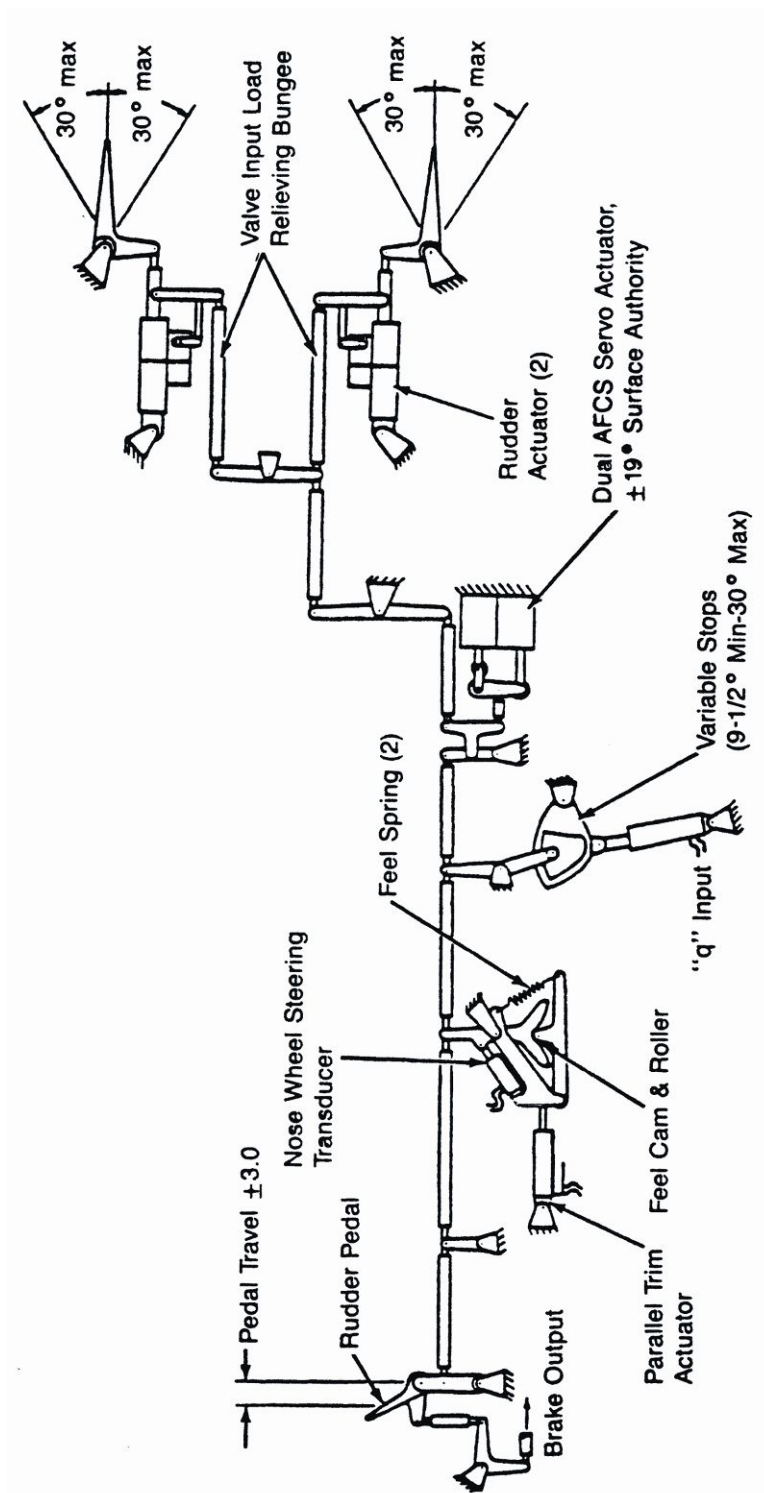


Figure 16 - Grumman F-14 Tomcat, directional control system schematic

The Stability Augmentation System (SAS) assists the natural damping of the aircraft. The pitch SAS augments the basic airframe characteristics by providing proportional, closed loop, position control of dual electrohydraulic series servoactuators. The demodulated phase sensitive dc signal of the gyro proportional to pitch rate is fed to a high pass washout filter. The filter prevents the passage of steady state signals representing pitch rate. This permits the pilot to command steady state pitch rates with the SAS damping higher perturbations. Dual channels with cross-channel monitoring and in-line servo monitors are used. In addition to SAS, the roll AFCS provides roll command augmentation (CAS). The command roll rate is compared to the sensed roll rate and their difference is amplified and applied to the roll series servoactuator.

3.1.5 Republic Aviation F-105 Thunderchief

The Republic Aviation F-105 Thunderchief was a supersonic, Mach 2 capable, fighter-bomber used by the United States Air Force.

3.1.5.1 System Description

The F-105 utilized a Type III irreversible mechanical hydro-power augmented flight control system with integral Stability Augmentation. The flight control system was comprised of single string controls components that included pushrods and cables. The primary flight control actuators were a dual tandem design receiving hydraulic power from two independent hydraulic systems (Systems 1 and 2). The control systems included artificial feel bungees and cams, trim actuators and eddy-current dampers. The vertical stabilizer was equipped with flutter dampers.

3.1.5.2 System Mechanization

3.1.5.2.1 Pitch Control System Description

The pitch-control system shown in Figure 17, is provided to facilitate horizontal maneuvering of the aircraft. Pitch control is accomplished by manually or automatically varying the deflection of the hydraulically-actuated horizontal stabilizer. Manual control is obtained by movement of the magnetically-damped control stick or the pitch-trim switch. During normal operation, fore and aft movement of the stick positions the control valve in the stabilizer power actuator. Movement of the control valve from its neutral position directs hydraulic pressure to one side of the power-actuator cylinder which is connected to the stabilizer. The stabilizer-power actuator is irreversible, that is, the air load at the stabilizer surface will not produce a load at the stick. Control feel is simulated by an artificial-feel-spring capsule roller which is in contact with a cam. Movement of the roller along the cam varies the load felt by the pilot in proportion to the deflection of the stick. Two autopilot actuators are connected to the pitch controls: a series actuator which acts as a fixed link in the control system when the autopilot is inoperative; a parallel actuator which positions the control stick during remote-command flight. Automatic-mechanical-advantage ratio is obtained by the continuously variable mechanical-advantage shifter change which provides a predetermined ratio between stick movement and surface travel in relation to aircraft speed and altitude. A warning system is incorporated in the shifter to signal when the horizontal stabilizer is in the wrong ratio for altitude and airspeed, or for extending the landing gear. The pitch-trim system permits the pilot to compensate for various conditions affecting aircraft pitch during flight. A single push-type takeoff-trim switch is incorporated to trim the stabilizer, rudder, and ailerons to neutral by a single action. Complete trim of all surfaces to neutral is indicated by the takeoff-trim light. The pitch-control system is normally pressurized by both the NO.1 and NO.2 flight control-hydraulic systems with either one capable of operating the system by itself. Emergency operation is provided by the ram-air pump which pressurizes the NO.1 system. The continuously-variable-mechanical-advantage shifter is powered by the primary DC bus and is protected by the mechanical-advantage circuit breaker.

The warning system is powered by primary DC power through the master-caution system circuit breaker. Power for the trim system is from the primary DC bus and it is protected by the pitch-and -roll-trim circuit breaker. The takeoff-trim circuit is powered by the secondary DC bus and is protected by the takeoff-trim circuit breaker.

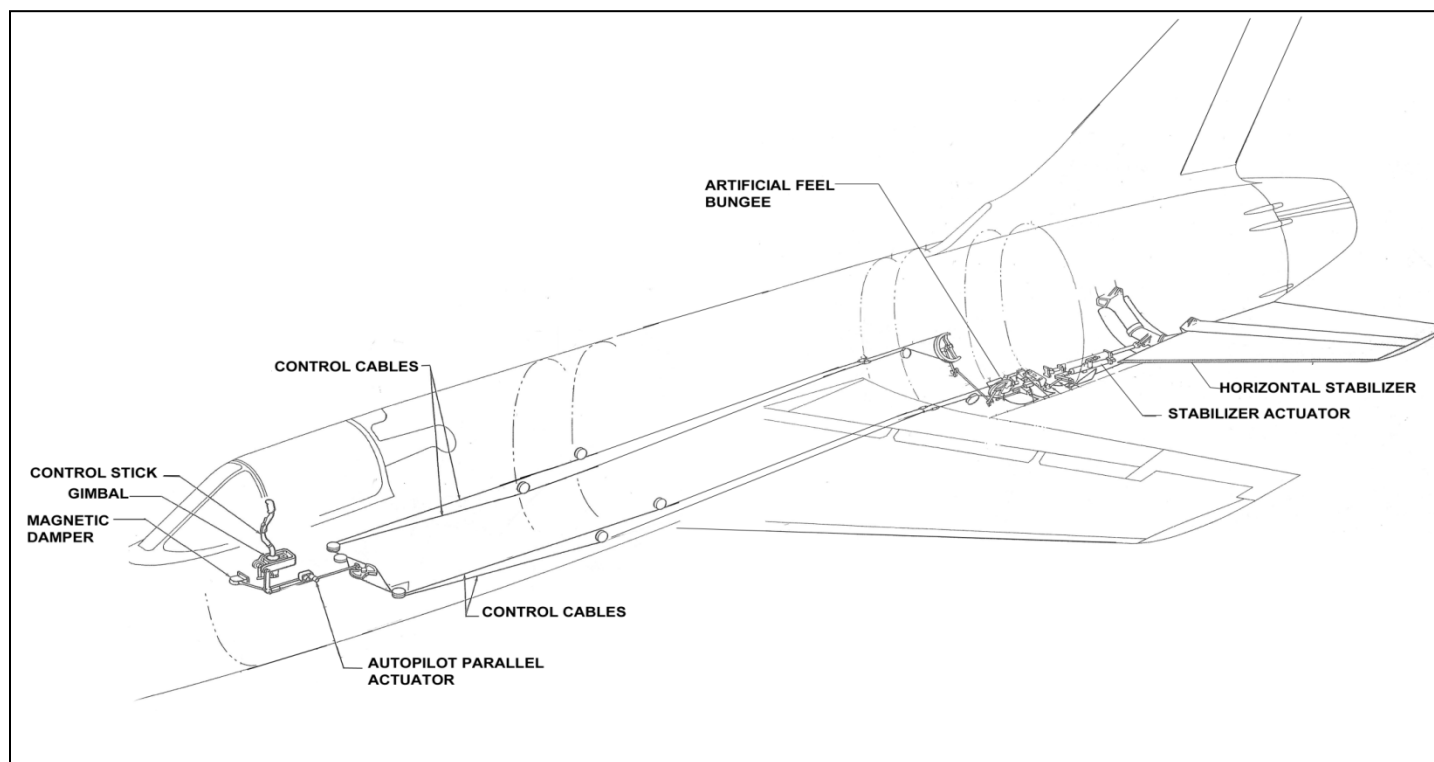


Figure 17 - Republic Aviation F-105 longitudinal flight control system

3.1.5.2.2 Roll Control System Description

The roll-control system shown in Figure 18, regulates the hydraulic pressure applied to position the ailerons and spoilers as required to control air craft maneuvers in a lateral plane. The spoilers function through the entire aircraft speed range, and the ailerons operate in the low-speed range only. The ailerons are rendered inoperative in the high-speed range by a lockout system that mechanically nullifies aileron response to the linkage in each wing. The control system utilizes five, tandem, hydraulic actuators, two aileron power actuators, two spoiler power actuators, and stick booster that operate on pressure supplied by both the number one and number two flight-control hydraulic systems. Either system is capable of operating the controls independently. The control system that interconnects the actuators to the control stick serves to displace the actuator control valves causing the actuators to respond to pressure to position the flight-control surfaces. For descriptive purposes the controls can be divided into two systems, one responds to the control stick or parallel autopilot actuator to displace the stick booster control valve and the other responds to the stick booster or autopilot series actuator to displace the control valve on the aileron and spoiler power actuators.

Control-stick deflection for lateral maneuvers is transmitted through control rods, tension regulators and a cable system to position a quadrant in the aft quadrant-control assembly in the bomb bay. The tension regulators serve as the forward cable quadrants and compensate for tension variations caused by temperature changes. The quadrant in the aft quadrant-control assembly is connected to and positions the stick-booster control valve causing the booster to follow the stick. The trimable-feel device connected to this quadrant, applies an increasing spring load that opposes stick deflection from a selected neutral position. The electric trim actuator responding to cockpit controls establishes the neutral-feel position with the stick deflected as required to provide aircraft lateral trim.

A thermal heater blanket around the trim actuator prevents freezing of condensation. Control-stick deflection is limited by adjustable mechanical stops in the trimable-feel device linkage and in the control-stick base. The autopilot parallel actuator is connected to the right cable-tension regulator and during autopilot-automatic mode, positions the control stick and connected controls to accomplish automatic maneuvers. An idler assembly in the aft quadrant control assembly provides an interconnecting link that permits surface control response to either the stick booster or autopilot series actuator. When the autopilot is inoperative, the idler is rotated about a pivot point established by the inoperative series actuator, by the stick booster. Idler motion transmitted through rods and torque shafts positions the drum of the lost-motion device in each wing.

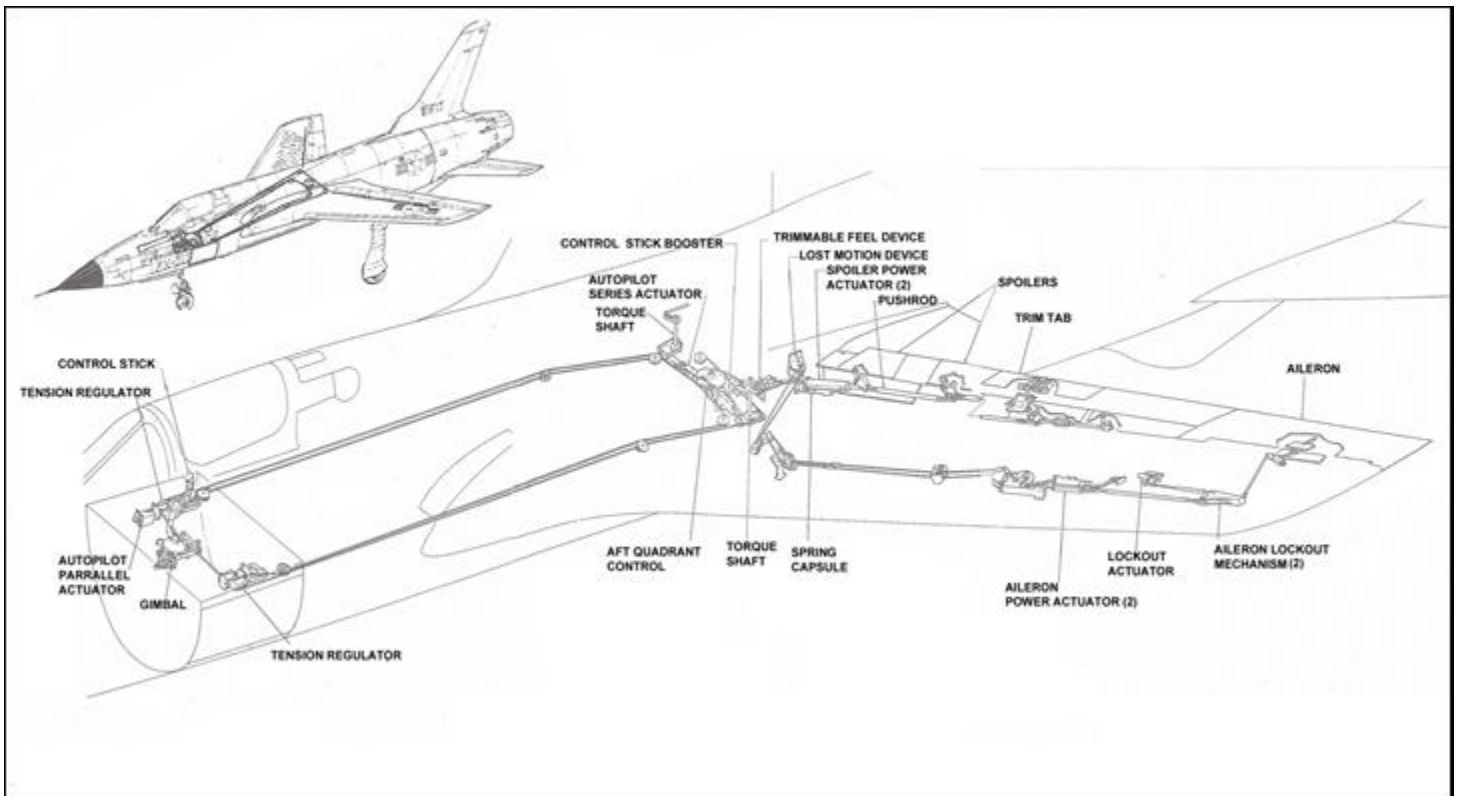


Figure 18 - Republic Aviation F-105 lateral flight control system

As illustrated in Figure 19, the lost-motion-device-drum rotation in one wing transmits stick-booster-actuator displacement to both the aileron-and spoiler-actuator-control valves and, in the opposite wing, transmits actuator displacement to only the aileron-actuator-control valve. Lost motion-device-drum rotation is conveyed to the aileron-actuator valve through a cable and pulley system and to the spoiler -control valve through a rod and idler. When the autopilot functions to provide lateral stability, the autopilot series actuator functions to position the controls in place of the inoperative stick booster. The series actuator force is transmitted to the surface controls through an idler assembly in the aft quadrant-control assembly. During this mode of operation, the idler rotates about a pivot point established by the inoperative and neutralized stick booster. The push-pull force of the spoiler actuator is conveyed to the five, individually hinged, segments of the spoilers through a series of interconnected push-pull rods, cranks, and links.

Aileron actuator force is applied to the aileron through a control-rod system which utilizes the aileron-lockout mechanism as a crank.

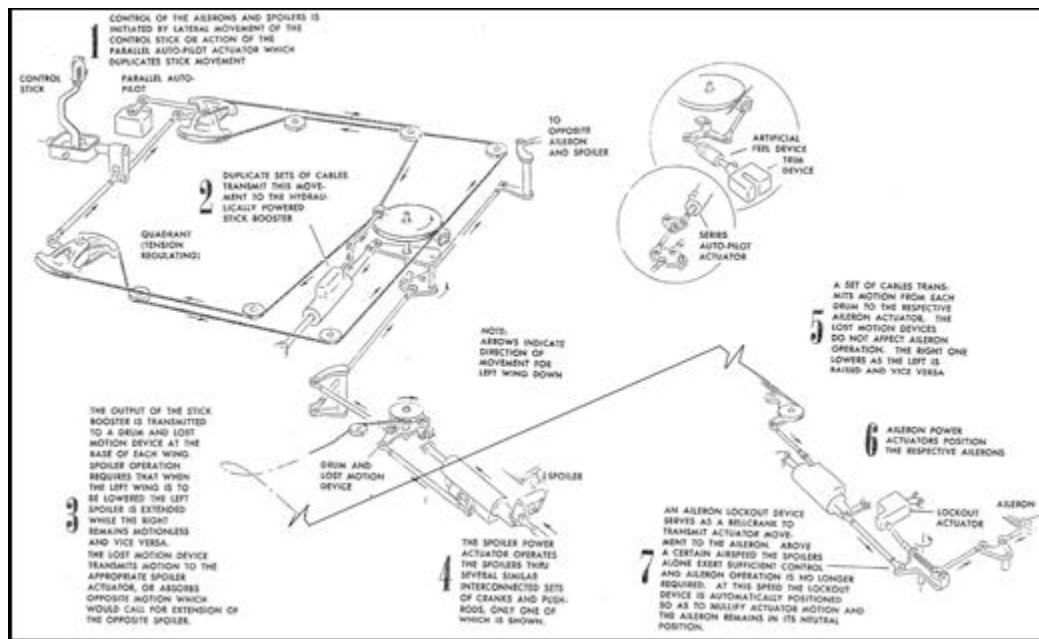


Figure 19 - Republic Aviation F-105 roll-control system schematic

3.1.5.2.3 Directional Control System Description

As illustrated in Figure 20, a dual hydraulic-power actuator, controlled by the cockpit-rudder pedals through a cable and linkage system, deflects the rudder. The power actuator utilizes pressure supplied by both flight-control-hydraulic systems and can function when either is inoperative. The rail-mounted-rudder pedals are connected through a cable system to a quadrant assembly in the aft fuselage which, in turn, is connected, through a series of levers and rods, to the control valve of the power actuator.

The cable-actuated-quadrant assembly includes adjustable mechanical stops, shown in Figure 21, that limit normal rudder deflection. An automatic-rudder stop that reduces the rudder deflection limits during high-speed operation, and an artificial-feel device that imposes a load on the rudder pedals as they are deflected from neutral position. Rudder trim is accomplished by an actuator in the quadrant assembly that selects a neutral-feel position of the artificial feel device with the rudder deflected, as required. Buzz dampers, installed at the rudder hinge line, provide hydraulic restriction that eliminates high-frequency-low-amplitude oscillation of the rudder surface because of high speed. An autopilot series actuator serves as a fixed link in the controls between the quadrant and the power actuator, when the autopilot is inoperative.

The electrical system consists of the trim-actuator controls responding to switches in the cockpit, the automatic-rudder-stop controls that respond to airspeed variations, and a rudder-stop-warning system that indicates when the rudder deflection limits are not correct for the existing airspeed.

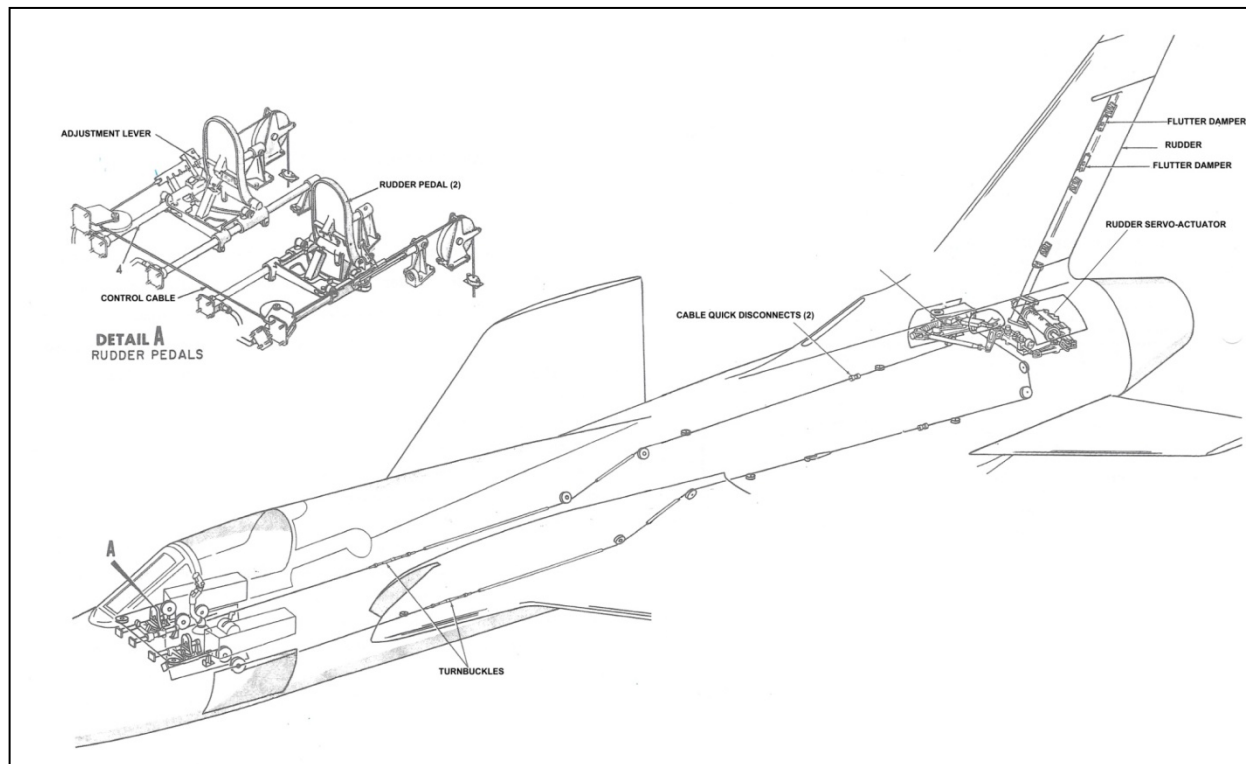


Figure 20 - Republic Aviation F-105 directional flight control system

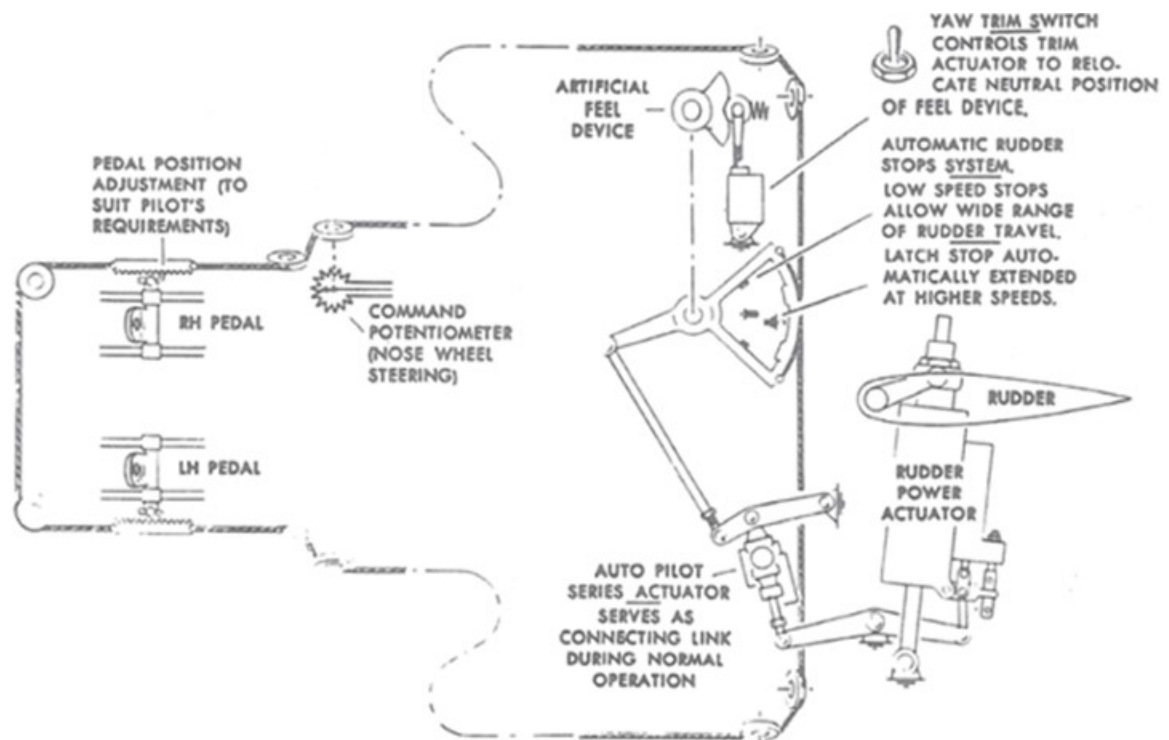


Figure 21 - Republic Aviation F-105 directional control system schematic

3.2 Attack Aircraft

3.2.1 Fairchild Republic A-10 Thunderbolt II

The Fairchild Republic A-10 Thunderbolt II (Figure 22) is a twin engine close air support attack aircraft. The surfaces used to effect pitch, roll, and yaw are the traditional elevators, ailerons, and rudders which are controlled by a mechanical primary flight control system (Figure 23).

3.2.1.1 System Description

The flight control system is a Type III irreversible power control which reverts to Type I (reversible mechanical control system) with the loss of both hydraulic systems. Loss of either hydraulic system will still retain full powered control response. Loss of both systems automatically engages the manual reversion mode that has performance for moderate maneuvers and safe landings. The linkages consist of push-pull rods, cables, and cranks configured for straight parallel paths with low friction and minimum connections (Figure 23). Artificial feel is provided by redundant spring/cam devices located at each surface actuator. Redundant stability augmentation systems (SAS) are provided to enhance tracking and minimize trim transients for speed brake deployment in pitch, and to reduce sideslip in yaw during abrupt roll maneuvers. The roll axis does not employ a SAS. Redundant pilot control capability is provided through separate transmission paths for the pitch, roll, and yaw commands. In addition, the elevators and rudders have dual control surfaces and actuators while the ailerons are equipped with tandem hydraulic actuators.

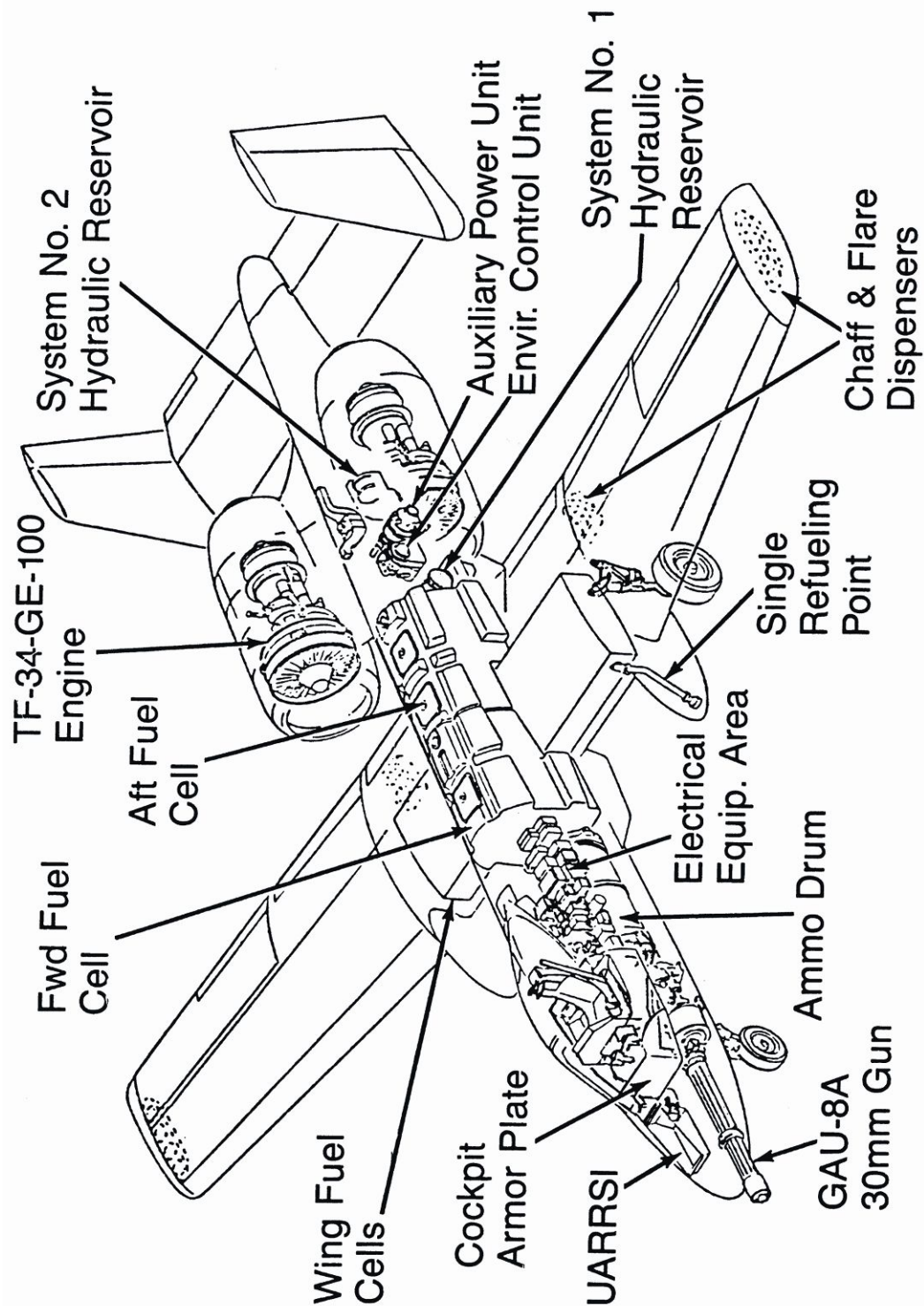


Figure 22 - Fairchild Republic A-10 Thunderbolt II, internal arrangement

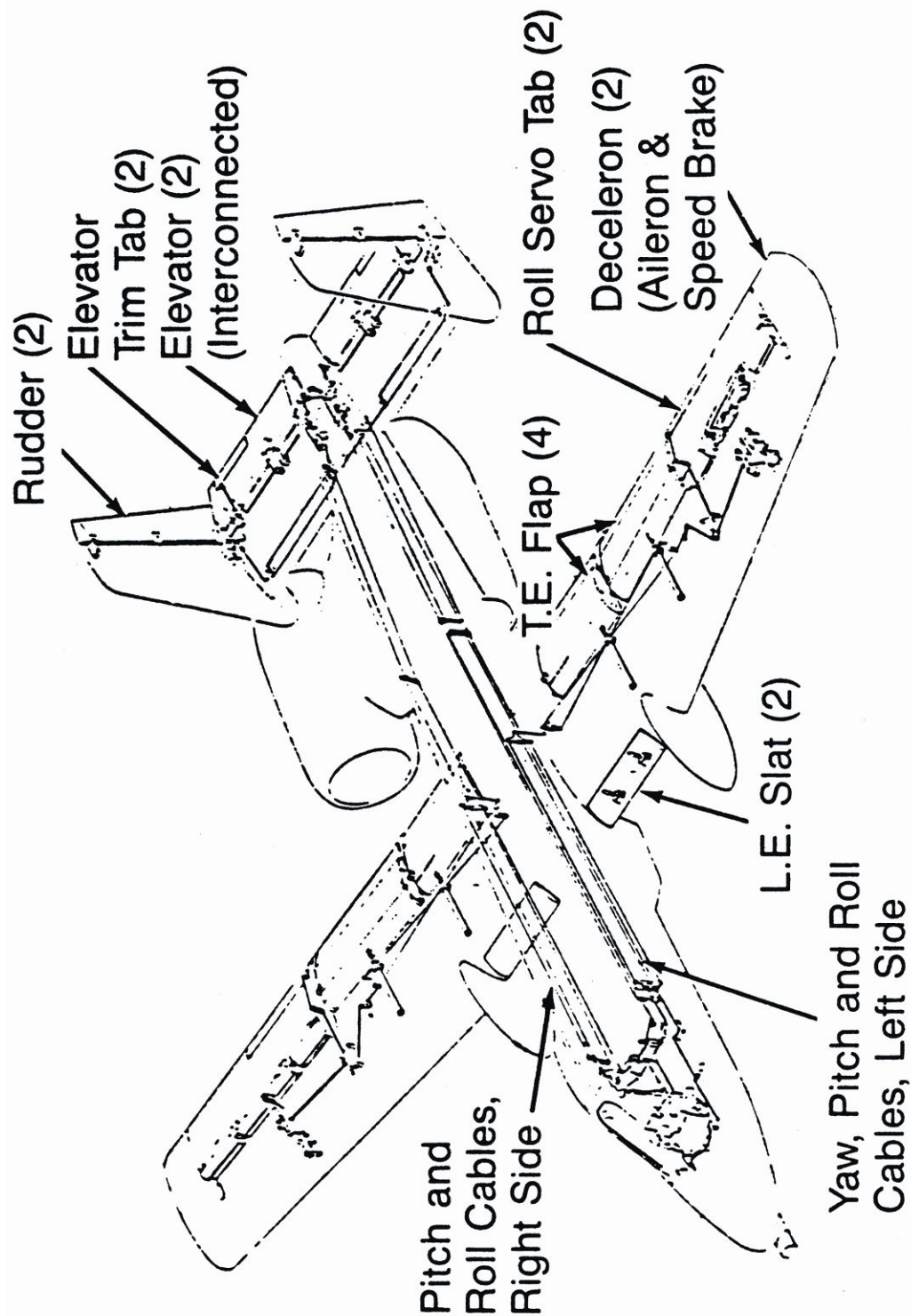


Figure 23 - Fairchild Republic A-10 Thunderbolt II, flight control subsystems