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I am submitting herewith a thesis written by Arthur D. Waurio entitled "The Automatic Flight Control System Of The S-3B Viking Aircraft and the Intergration of the Digital Flight Data Computer." I have examined the final copy of this thesisfor form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science in Aviation Systems.

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THE AUTOMATIC FLIGHT CONTROL SYSTEM OF THE S-3B VIKING AIRCRAFT AND THE INTEGRATION OF THE DIGITAL FLIGHT DATA COMPUTER

A Thesis
Presented for the
Master of Science
Degree
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Arthur Douglas Waurio
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DEDICATION

THE CARRIER EXPERIENCE

"It gave me moments of fear and loneliness,
kinship and challenge, joy and victory.
It was a part of me then and it is a part
of me now. I am certain it will be with me
'til the end of my days."

Anonymous



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ABSTRACT

The S-3 airplane's Automatic Flight Control System (AFCS) was designed and developed during the early 1970's. The AFCS was documented as unreliable during developmental flight tests and continues to be considered unreliable without any major improvements since the S-3A Viking was introduced into the Navy in 1974. The AFCS in the S-3 aircraft is composed of numerous components with several deficiencies related to performance and reliability. The Flight Data Computer (FDC), the major component in AFCS, is the least reliable component and has been implicated in inciting several aircraft mishaps. As a result of one mishap investigation, all roll modes of Autopilot System (APS) were disconnected in all S-3 aircraft. Maintenance has also been identified as a problem. The original estimate for the FDC Mean Flight Hour Between Failure (MFHBF) was 500 hours, but the actual MFHBF has proven to be much less and requires an expensive support and logistics network. Current MFHBF for the FDC is now below 40 hours which has seriously impacted aircraft reliability and its ability to perform missions in support of the Navy Carrier Battle Group.

This study reviews each of the major components and functionality within the AFCS of the S-3 aircraft. Although the S-3B and ES-3A are different models of the original S-3, for this study both aircraft are considered the same since their flight control systems and AFCS are almost identical. Several aspects of current AFCS status, failures, deficiencies, and trouble shooting are noted which indicate that the AFCS system has many performance, reliability, and maintenance problems. Current operational status and reliability of the S-3 AFCS has severely affected aircraft readiness prior to flight and has eliminated several APS modes for pilot relief and tactical mission maneuvering. Maintenance and troubleshooting efforts are long and tedious

without an effective means to isolate AFCS related failures. The current AFCS Built-In-Test (BIT) is not being used by fleet maintenance personnel because it has minimal credibility and does not isolate failed AFCS components. Besides the FDC, many other AFCS components are considered undependable and contribute to overall system unreliability.

There is currently a program to replace the Flight Data Computer (FDC) with a new form, fit, functional replacement called the Digital Flight Data Computer (DFDC). It has been designed to correct many known reliability issues and deficiencies of the current S-3 AFCS. If properly designed, the DFDC could become the most reliable component in the AFCS, be used to isolate other component failures in minimal time, and enhance S-3 AFCS flight qualities and mission performance. However, without improving other components of the AFCS, the enhancements given by the DFDC will not become apparent without a dramatic increase in reliability of each of the other AFCS problem components and the availability of spare AFCS parts in the supply system. Although the MFHBF of the DFDC is forecasted by the manufacturer as being greater than 2000 hours, conservative in-house estimates indicate an MFHBF of approximately 310 hours. This, combined with the fact that the original builder of the DFDC will also be the depot level repair facility, does not guarantee quality performance, reliability, and workmanship. The builder has an inherent interest in producing more units and repairing failed units. Without some kind of production reliability acceptance testing or contractual agreement for DFDC reliability, the Navy will travel down the same familiar path it has taken with the failed FDC.

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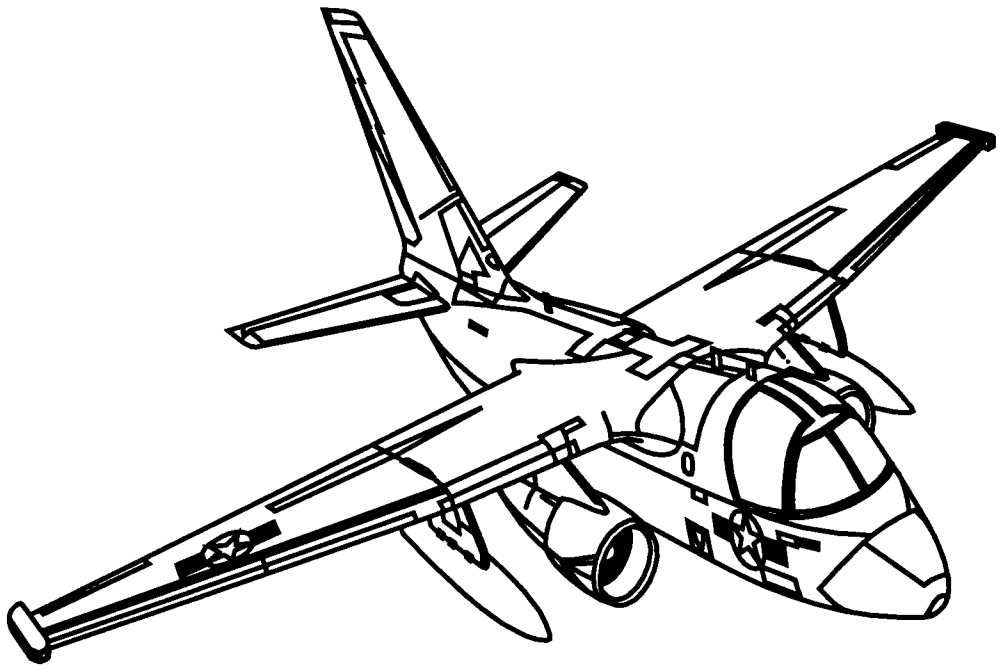
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LIST OF ABBREVIATIONS

AC	Alternating Current
ACLS	Automatic Carrier Landing System
AFCS	Automatic Flight Control System
AGL	Above Ground Level
ALT	Altitude
AOA	Angle Of Attack
AOB	Angle Of Bank
APC	Approach Power Control
APS	Automatic Pilot System
APS	Autopilot System
ASW	Anti-Submarine Warfare
ATS	Automatic Thrust System
AUTO	Automatic
AWCLS	All-Weather Carrier Landing System
BIT	Built-In-Test
CLA	Control Logic Assembly
CMPTR	Computer
COMP	Computer
CSS	Control Stick Steering
DAMP	Damper
DC	Direct Current
DFDC	Digital Flight Data Computer
DLC	Direct Lift Compensation
EFCS	Emergency Flight Control System
EHV	Electro-Hydraulic Valve
EMI	Electromagnetic Interference
ESV	Engage Solenoid Valve
FCF	Functional Check Flight
FCT	Flight Control Test
FDC	Flight Data Computer
FMS	Flight Mode Selector
FMS	Flight Mode Selector
FQIP	Flying Qualities Improvement Program
HDG	Heading
HSI	Horizontal Situation Indicators
IAFC	Interim Airframe Change
IAS	Indicated Airspeed Hold
LSO	Landing Signal Officer
LVDT	Linear Variable Differential Transformer
MAD	Magnetic Anomaly Detection
MAF	Maintenance Action Form
MAN	Manual
MESL	Minimum Essential System
MFHBF	Mean Flight Hour Between Failure
NALDA	Navy Aviation Logistic Data Analysis

NATOPS	Naval Air Training And Operating Procedures Standardization
NAV SEL	Navigation Select
NAWC-AD	Naval Air Warfare Center Aircraft Division
NDCR	Navigation Data Converter Repeater
NDS	Navigation Display Selector
PFCS	Primary Flight Control System
PRAT	Production Reliability Acceptance Testing
PTA	Pitch Trim Actuator
RVDTs	Rotary Variable Differential Transducers
SDR	System Design Review
STCS	Speedbrake And Trim Control System
STCU	Speedbrake And Trim Control Unit
STRNG	Steering
TACAN	Tactical Air Navigation
TPC	Thrust Pitch Compensation
UHF	Ultra High Frequency
VAC	Volt AC
VAST	Versatile Avionics Shop Test
VDI	Vertical Display Indicators
WRAs	Weapon Replaceable Assemblies

I. INTRODUCTION



S-3B Viking

BACKGROUND

Although Anti-Submarine Warfare (ASW) remains one of the many primary missions for the S-3B, the recent increases in mission tasking have dramatically emphasized the versatility of the Viking in areas of surface and electronic surveillance, mine warfare, long-range identification and targeting, Harpoon delivery, intelligence gathering, counter-narcotics operations, and tanking. The evolution of the S-3B as a multi-mission war-at-sea platform and the ES-3A as a reconnaissance platform are perhaps the most significant enhancements to the capabilities of

carrier aviation in the last ten years. The unique surveillance sensors, data fusion processing, and electronic data targeting capabilities of carrier-based S-3B's and ES-3A's are designed to exploit opportunities in radar, optical electronics, and acoustic surveillance. All 132 S-3B's and ES-3A's are equipped with APS-137 Inverse Synthetic Aperture Radar (ISAR), ALR-76 Electronic Support Measures (ESM), and Forward-Looking Infrared (FLIR). The ES-3A is also equipped with the ALD-9 low band phase measuring Direction Finding (DF) system, ALR-82 ESM, and highly sensitive ALR-81 manual ESM system. All S-3B and ES-3A aircraft are integrated through a common aircraft system interface and all sensors can be operated by each of the three sensor operators [1, p. 16-17]. A quotation from RADM Philip A. Dur, USN, Commander, Cruiser-Destroyer Group Eight for the USS Saratoga Battle Group on 4 November 1992 expresses the importance of S-3's as an asset to the Carrier Battle Group:

> "It is no exaggeration to say that S-3B's have demonstrated more versatility in ASW / ASUW / EW and strike support than I have ever seen from a single weapons system. Your enduring value to the battle group is a matter of record."

The versatility of the S-3B and ES-3A has been proven and is definitely a part of the future of the Navy's Carrier Battle Group. Although the S-3 platform is highly reliable, it does need critical mission systems and flight control upgrades for it to be fully capable in the future. Without these upgrades, the platform will be unable to support missions for the Carrier Battle Group because of technology becoming obsolete or the aircraft platform itself becoming unreliable or unsupportable. This upgrade is extremely important given that the service life of the S-3's have been extended to the year 2015.

The author of this thesis has served as the Project Officer and Test Pilot for the U.S. Navy S-3 Digital Flight Data Computer (DFDC) Team from August 1994 to present. The purpose of the

DFDC program is to develop and deploy a digital replacement for the Flight Data Computer (FDC) that will provide stability augmentation, autopilot, and autothrottle functions for the S-3B and ES-3A aircraft. The author helped plan, test, and document several test and evaluation milestones for the DFDC program that included simulation evaluations, collecting baseline data, and deficiency verification. The author was the "Fleet Representative" pilot for several flight and simulator evaluations for the DFDC program. Simulator evaluations ranged from confirming aircraft flight control and handling characteristics to verifying flying qualities from control law changes in simulation software. Flight tests were conducted to verify certain S-3 AFCS deficiencies to support DFDC efforts, and to help determine if existing FDC control laws needed to be changed for incorporation into the DFDC. The author was also the pilot for collecting baseline data for the S-3B aircraft to be used for simulator validation, improving control law definition, and to verify outstanding deficiencies of the Automatic Pilot System (APS) and Automatic Carrier Landing System (ACLS). During all flight testing the author was deeply involved in managing aircraft test programs, priorities, and maintenance in direct support of DFDC project milestones. The author was also the pilot and project officer for the DFDC team efforts including specification review, statement of work, work breakdown structure, and system design review.

PURPOSE

The purpose of this thesis was to identify performance deficiencies and system limitations in the Automatic Flight Control System (AFCS) of the S-3B Viking aircraft, and subjectively evaluate the future overall performance of the Automatic Flight Control System with the integration of the Digital Flight Data Computer.

DESCRIPTION OF AIRCRAFT

The S-3B and ES-3A is a subsonic, four-place, high-wing, twin-engine, multi-mission airplane manufactured by Lockheed Aeronautical Systems Company for land and carrier based missions. Airplane gross weight ranges from 30,000 to 52,500 lbs depending on the fuel, internal and external store load. The airplane is powered by two wing pylon-mounted General Electric TF34-400 high bypass ratio turbofan engines rated at 9,275 lbs of static sea level thrust each. Each wing has leading and trailing edge flaps with two external store pylons located inboard of the wing fold station. Flight control surfaces include upper and lower wing spoilers and ailerons for lateral control, an elevator for longitudinal control, and a rudder for directional control. The primary flight control system (PFCS) is operated by control sticks and rudder pedals, is irreversible, and is hydraulically-powered. The reversible emergency flight control system (EFCS) engages automatically in the event of a dual hydraulic system failure. The automatic flight control system (AFCS) provides relief to the pilot via automatic pilot and automatic thrust systems. Photographs and illustrations of the S-3B and ES-3A aircraft are displayed in Figures B-1, B-2, and B-3.

GENERAL DESCRIPTION OF AFCS SYSTEM

The AFCS controls the aircraft during all basic maneuvers in order to relieve the pilot from the routine piloting tasks of flying the aircraft during its many missions. The AFCS system operates automatically but has two control panels for pilot interface and system performance monitoring. The system receives dual inputs from various sensors, monitors, interlocks and computers. It blends and smoothes these inputs to control the aircraft in the pitch, roll, yaw, and thrust axes. As shown in Figure 1 [2, p. 2-248], the AFCS is comprised of two separate

subsystems: the automatic pilot system (APS) and the automatic thrust system (ATS). Both of these subsystems are packaged in the flight data computer (FDC) and are powered by the same dual power supplies.

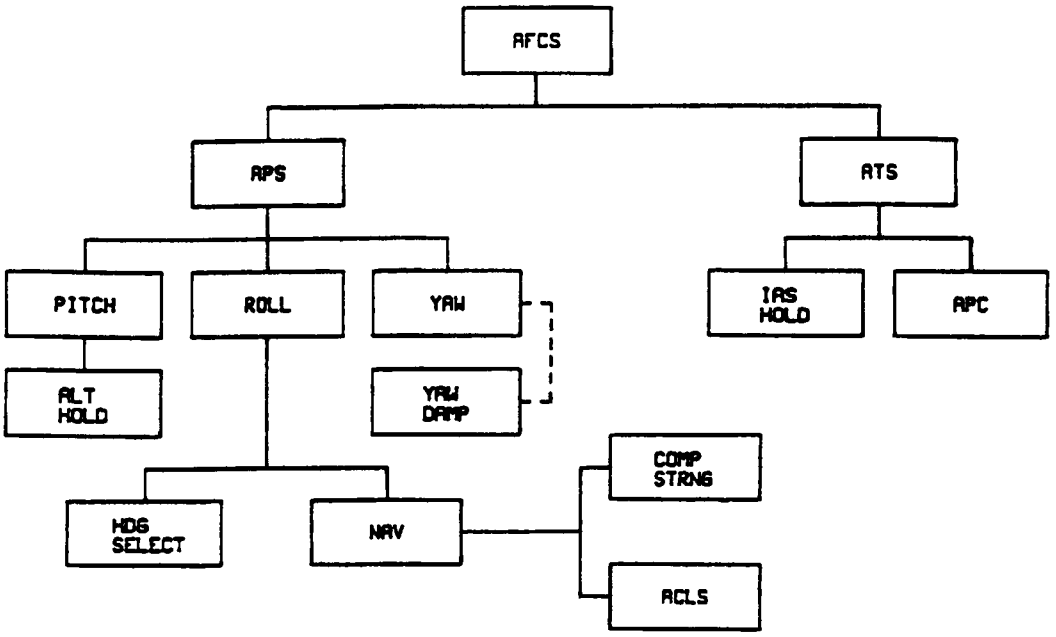


Figure 1
Automatic Flight Control System

The AFCS uses dual redundant computing and servo channels and full-time monitors. The system was designed to constantly monitor AFCS operation and, in the event of a system failure, disengage in such a manner that no physical input goes to the affected controls. Pilots are notified of the failure by advisory, warning, or caution lights. In addition, the AFCS was designed as a fail-passive system and fail-safe in all subsystems to prevent hard-over control inputs as a result of a single failure. This design is particularly important during low altitude ASW operations and carrier approach and landing. The fail-safe system monitors and detects

any single failure within the system including the sensing, computing, and servo commands of the subsystems. Upon detection of the failure, the affected AFCS subsystem automatically disengages with no critical deviations from the flight path and with appropriate visual warning of the disengagement to aircrew. Once the system is disengaged, the AFCS provides the capability to re-engage the APS and the ATS in a single-channel, non-fail-safe mode. The Altitude Hold mode is monitored in both dual and single channel operation for fail-safe status at all times [3, p. 38].

The AFCS consist of sensors, computers, monitors, interlocks, displays, selector controls, flight station instruments, lighting panels, aircraft flight controls, and engine controls (Figure B-4). The computer, sensor, and data signals are transmitted into the Flight Data Computer (FDC) and the Navigation Data Converter Repeater (NDCR). Command signals are transmitted from the Flight Mode Selector (FMS) panel and the Navigation Display Selector (NDS) panels into the Navigation Data Converter Repeater (NDCR), which interfaces with the flight data computer. The NDCR transmits information signals to the vertical display indicators (VDI) and horizontal situation indicators (HSI), which are linked with the flight mode selector panel and the flight data computer. The flight data computer and the Speedbrake and Trim Control Unit (STCU) transmit command signals to the servos for autothrust, aileron, elevator, rudder, speedbrake, spoiler, and pitch trim operation. In addition, the flight data computer transmits information and warning signals to the failure annunciator panels and the ACLS discrete word panel. The AFCS controls and indicators are located on the flight mode selector panel, the Flight Control Test (FCT) panel, the failure annunciator panels, the aircraft control sticks, the throttle levers, and the head-up annunciator panels (Figure B-5). Figure B-6 depicts the flow of signals and data

between the controls and indicators along with the flow of inputs from various sensors and computers [2, p. FO-13].

AUTOMATIC CARRIER LANDING SYSTEM

The Automatic Carrier Landing System (ACLS) provides a reliable capability for final approach and landing of carrier-based aircraft. The system operates during daylight or darkness, under conditions of severe weather and sea state with no system limitation because of low ceilings and visibility. The system utilizes a precision tracking radar and computer aboard the carrier. The radar provides precise position data on the approaching aircraft with respect to the carrier. This data, along with data on pitch, roll, yaw, and deck motion of the carrier are supplied to the computer. The computer constantly calculates the desired position of the aircraft and generates a control signal that is transmitted to the aircraft by the data link system [2, p. 2-268].

The data link receiver is an airborne part of the Automatic Carrier Landing System (ACLS), sometimes referred to as the All-Weather Carrier Landing System (AWCLS), which receives and decodes pitch and roll commands from a shipboard computer for control of the AFCS during an automatic carrier landing. The ACLS also provides a second channel of vertical and lateral displacement information through the NDCR to the flight instruments [2, p. 2-268]. Currently S-3 aircraft are capable of conducting Mode 1A approaches using the Automatic Carrier Landing System to 200 feet and 1/2 mile. During Mode 1A approaches, the AFCS uses automatic pilot system (APS) and automatic thrust system (ATS) to conduct an Automatic Carrier Landing System approach by information via data link and other aircraft sensors. The approach is automatically controlled to a minimum of 200 feet and 1/2 mile at which point the pilot is required to manually take over and fly the remainder of the approach.

DESCRIPTION OF AFCS SYSTEM EQUIPMENT

FLIGHT DATA COMPUTER

The FDC (Figure B-7) located in the right internal avionics bay is by powered aircraft 115 VAC and 28 VDC. The FDC contains printed circuit plug-in modules, and uses a cold-plate cooling design to maintain component temperatures within acceptable limits. Two FDC power supply modules (one per channel) are used to provide all other AC and DC excitation voltages required by AFCS components. External connection to the FDC is provided by three dual 106 - pin connectors. Two additional connectors are provided for shop maintenance to interface with the Versatile Avionics Shop Test (VAST) equipment [4, p. 18].

Located on the front panel of the FDC are 10 magnetically latching Built-In-Test (BIT) indicators used for fault isolation of the following Weapon Replaceable Assemblies (WRAs): FDC, channel No. 1 rate gyro, channel gyro. 2 rate gyro, channel No. 1 accelerometer, channel No. 2 accelerometer, autothrust servo (engine No. 1), autothrust servo (engine No. 2), pitch servo, roll servo, and yaw servo. Also on the front panel is an elapsed-time and a ground-test-flight switch. Although the FDC is a dual-channel unit, it is capable of single channel operation. In dual-channel operation, comparator circuitry continuously monitors both channels. This circuitry automatically disengages the AFCS if an out-of-tolerance difference occurs between channels.

SPEEDBRAKE AND TRIM CONTROL UNIT

The Speedbrake and Trim Control Unit (STCU) interfaces with the FDC during manual pitch and roll trim operation, automatic pitch trim operation, speedbrake control, Direct Lift

Compensation (DLC), and DLC / Pitch Compensation. In the Pitch Attitude and Altitude Hold mode of APS, the STCU automatically trims the aircraft in pitch by moving the horizontal stabilizer. The STCU incorporates a monitoring circuit which will automatically disengage a malfunctioning channel, or both channels, and send a disconnect signal to the Flight Control Test (FCT) panel for display. The system is dual channel but provides for single channel operation after a first failure in each of the subsystems (pitch, roll and speedbrake). Subsequent to a first failure, both channels of the failed subsystem are automatically disengaged. The pilot may then re-engage either channel of the failed subsystem to isolate the failure and resume single channel operation. Failures in any subsystem are indicated by the corresponding BIT indicator on the Speedbrake and Trim Control Unit, by indicators on the Flight Control Test panel, and by the annunciator located on the master caution panel [5, p. 2-3]. The STCU is located in the right internal avionics bay as displayed in Figure B-8.

NAVIGATION DATA CONVERTER REPEATER

The Navigation Data Converter Repeater (NDCR) interfaces the flight displays and the AFCS with the various navigation subsystems by converting digital signals to analog signals or analog signals to digital signals. Within the AFCS the NDCR converts information from computer navigation subroutine and the ACLS data link system. Specific information converted from digital to analog is for the vertical display indicators (VDI), horizontal situation indicator (HSI), and aircraft platform sources. The NDCR is located in the right internal avionics bay as displayed in Figure B-9.

RATE GYROS

Two rate gyros (one per channel) are installed in the right bomb bay (Figure B-10). Each gyro assembly contains three rate gyros (roll, pitch, and yaw); the rate gyros are physically identical but differ in their spin axes. Each rate gyro is driven by a motor supplied from a 1600-Hz inverter. The 1600-Hz inverter supplies a 1600-Hz signal to the wheel speed monitor (comparator), which also receives a phase signal from the motor. The wheel speed monitor provides a validity signal to the FDC. A BIT circuit is incorporated to detect a failure in a rate gyro and to send a BIT failure indication to the FDC for display for fault indications to maintenance personnel [4, p. 18].

ACCELEROMETER

Two accelerometers (one per channel) are installed in the right bomb bay (Figure B-10). Each accelerometer contains three subassemblies which are used to sense normal, lateral, and longitudinal accelerations. Normal and longitudinal accelerations are interfaced with the automatic pilot system (APS) and automatic thrust system (ATS) while lateral acceleration is not used. Electromagnetic forces are used to counter the acceleration forces of a mass within the accelerometer. The electrical current required to maintain the mass in its original or null position is sent to the FDC. The BIT circuitry is connected up-line of the torque to test and monitor the accelerometer and to send a failure indication signal to the FDC for display. The subassemblies are identical units, except that the normal (or vertical) acceleration sensing unit is biased by the interconnecting wiring to operate at approximately +1.0 g [4, p. 18-19].

FLIGHT CONTROL TEST PANEL

The Flight Control Test (FCT) Panel (Figure B-11) contains the AFCS and Speedbrake and Trim Control System (STCS), single-channel selection toggle switches, and the channel and axis status indicators. The status indicators consist of two amber lights in each channel. When the lights are on, the channels are not enabled. The lights are used in conjunction with a toggle switch which is used to change the status of the channel; when the indicator light is on, the channel is disabled, and when the indicator light is off, the channel is enabled. The eight lower lights and four switches are used for AFCS functions. The six upper lights and three switches are used for trim functions. The AFCS functions, which are controlled and annunciated by these switches and indicators, are channel No. 1 and channel No. 2 of the pitch, roll, yaw and thrust axes. The STCS functions controlled are channel No. 1 and channel No. 2 of pitch trim, roll trim, and speedbrake. Three lever-lock switches are used to control primary hydraulic power to channel No. 1 primary power servos, No. 2 primary power servos, and to channels No. 1 and No. 2 spoiler servos, respectively. A five-position Magnetic Anomaly Detection (MAD) select toggle switch is used for MAD maneuver axis selection and a MAD START switchlight is used to initiate the maneuver in the selected axis. A TEST switchlight is used to initiate AFCS self-tests, using the AFCS Built-In Test (BIT). The TEST switchlight has a split lens. The upper half of the lens comes on and indicates AUTO during the automatic portion of BIT tests and the lower half of the lens comes on and indicates MAD during the manual portion of BIT tests [4, p. 3].

FLIGHT MODE SELECTOR PANEL

The Flight Mode Selector (FMS) panel (Figure B-12) contains the basic engage switching functions for all AFCS axis and modes of operation. Separate switches are used for pitch, roll,

and yaw Autopilot System (APS) engagement to provide the capability for split-axis operation. Solenoid-held toggle switches are used for pitch, roll, and yaw APS engage: altitude hold mode engage: heading select and heading navigate mode engage; and ATS, IAS, or APC mode engage functions. A navigation select (NAV SEL) rotary switch allows the aircrew to select any one the three aircraft navigation systems: All-Weather Carrier Landing System (AWCLS), Tactical Air Navigation (TACAN), and Computer (CMPTR). Moving the NAV SEL switch knob in and out operates switch which controls the slaving function of the pilot and copilot Horizontal Situation Indicators (HSI's). Miniature PITCH, ROLL, and YAW axis indicators (located above the respective APS) are used to indicate APS axis synchronization. In manual flight mode, the miniature control axis indicators move off center when a change in aircraft control surface position occurs. Once the flight control inputs are neutralized, the indicator will return to the center position which informs the pilot that the AFCS may be engaged without an abrupt control transient. With the AFCS engaged, the indicators show the relationship between actual flight control surface position with respect to neutral flight control surfaces position [4, p. 3].

HYDRAULIC SERVO ASSEMBLIES

The APS controls the three hydraulic powered servos: the elevator, the aileron, and the rudder. The three power servos are used by both the APS and the manual flight control system. The difference between the APS and manual operation is that when the APS is engaged, an electrical command signal is used to move the servo and manual operation is directly controlled by pilot control inputs. The APS can control each of the three servos in parallel mode but can operate only the elevator and rudder servo in the series mode. In the parallel mode (Figure B-13), the hydraulic valves actuate the autopilot cams in the servo to provide mechanical

movement of the control stick and rudders when the APS is engaged (mechanical feedback). Series mode of APS offers no mechanical feedback to the pilot (Figure B-14).

PITCH TRIM ACTUATOR

The Pitch Trim Actuator (PTA) is an electrically powered linear actuator consisting of two motors to allow the pilot to trim the horizontal stabilizer on the S-3 aircraft. Both motors are used for normal operation; however, if one should fail, the other will trim the horizontal stabilizer at half the normal rate. The actuator operates on 115 VAC power from the Speedbrake Trim Control Unit (STCU) [4, p. 4].

AUTOTHRUST SERVO

Automatic Thrust Servos (ATS) are on each of the aircraft engines. Each autothrust servo is mounted near the fuel control unit, and its output shaft is mechanically linked to the engine throttle linkage through a spring bungee linkage. The autothrust servos control engine throttle position upon commands from the FDC. The autothrust servo is made up of two motors (torquers), two follow-up Rotary Variable Differential Transducers (RVDTs), a gear train, and an override clutch. The RVDTs, which are connected to the output shaft, send autothrust output shaft position signals to the FDC [4, p. 20].

AIRCRAFT CONTROL STICKS

Each pilot and copilot control (Figure B-15) contains pitch and roll force sensors. The pitch and roll force transducers are crystal strain gauges bonded to a bending beam in the control stick.

When APS is engaged and a force is applied to either the pitch or roll axis of the control stick, the bending beam is deformed causing the crystal strain gauges to vary the voltages within the electronic circuitry. The crystal strain gauges, which consisting of four crystals each, act as bridges consisting of four variable resistors. As the crystals deform, resistance values across segments of each bridge change, resulting in changed steering signals to the FDC that are proportional to the amount of deformation. Sheering signals that are proportional to the roll and pitch forces applied to the control stick by the pilot or copilot to initiate attitude changes are generated when one or more APS modes are engaged. This mode is known as Control Stick Steering (CSS) [4, p. 20]. The AFCS disengage switch on each control stick provides for emergency disengagement of the APS. Various other switches are provided on the control stick grips for non-AFCS functions. The nosewheel steering switch on the pilot control stick will disengage the ATS, as well as engage and disengage nosewheel steering.

CONTROL LOGIC ASSEMBLY

The Control Logic Assembly (CLA) is a solid-state control device designed to permit or inhibit the functioning of controlled systems and subsystems. The assembly receives and combines electrical inputs from switches, relays, and sensors to solve predetermined logic equations. The solution to these logic equations is the output used to control solid-state driver switches that, in turn, control the various functions [2, p. 2-73]. The left and right Control Logic Assemblies (CLA) interface with the AFCS to provide weight-on-wheels logic to disengage the APS and ATS automatically at touchdown, and to inhibit initiation of preflight tests during flight. Gear down logic is provided to prevent engagement of the IAS hold mode when the

landing gear is lowered. Flap position logic for proper gain scheduling of the AFCS and hydraulic pressure logic for proper system interlock and preflight testing are also provided.

AUTO / MAN BIT

The Flight Data Computer (FDC) Built-In Test (BIT) exercises and tests the major components in the Automatic Flight Control System. The BIT is initiated by pressing "Test" on the Flight Control Test Panel as shown in Figure B-11. The automatic (AUTO) portion of the AFCS BIT consists of checking all sensors for validity, aircraft discrete interlocks, a FDC self test, analog signals, and memory checks. The manual (MAN) portion of the AFCS Bit consists of checking the Roll, Yaw and Pitch servos. It also checks critical AFCS switches located in the Flight Control Test Panel, Failure Annunciation Panels, and the Pilot/Copilot Upper Control Sticks. Failures during the AUTO/MAN BIT are indicated by failure annunciation on the Flight Control Test Panel and fault indicators located on the front panel of the FDC [6, p. 1-4].

S-3 AFCS AND FLEET OPERATIONS

The S-3 AFCS as always been plagued by system unreliability, poor flying qualities, and uncommanded control inputs. Unexplained nuisance disconnects, the inability to engage various modes of the APS, and undesirable control feedback to the pilot have all contributed to the AFCS as a problem flight control system in the S-3. Several aircraft mishaps have occurred in which there have been uncommanded lateral hardovers at low altitudes causing loss of aircraft and in most cases, loss of the entire crew. Except for one aircraft mishap, all have occurred in the carrier environment precluding easy recovery of the aircraft for accident investigations.

The flight control servos utilized in the S-3 airplanes are capable of operating the control surfaces in either a hydraulic powered mode or an unpowered emergency flight control system (EFCS) mode. Each servo has dual hydraulic system capability. In the powered mode, the servo can be operated by the pilot or the automatic flight control system (AFCS). For the AFCS to operate the servo, the engage solenoid valve (ESV) for each system must be opened to port pressure to the electro-hydraulic valve (EHV) (Figure B-16). The ESV, which is controlled by the AFCS, is unmonitored as to its position whether AFCS is engaged or not. If the ESV fails open (passive) and allows hydro pressure to the EHV, then any signal at the proper power level to the EHV, no matter what the source, will cause the servo to make a control system input. If the ESV fails closed in a passive manner, the EHV will be unable to make any control system inputs [7, p. 1].

An S-3B was conducting touch and go landings when it experienced an uncommanded left roll during a turn to crosswind after departure from the runway. The crew of two ejected safely as the aircraft passed through 90°-100° left wing down angle of bank. The aircraft crashed into a wooded area near the airport. The airplane had been on a Functional Check Flight (FCF) following an aileron servo change. During prelaunch checks, a number of navigation and AFCS discrepancies were noted but were not considered serious enough to prevent conducting the Functional Check Flight. The wreckage was removed from the accident site and reassembled in a local hangar for investigation purposes. The fact that all significant system components were recovered, and the flight crew was available, it provided the first real opportunity for an in depth investigation into the uncommanded roll problem that has plagued the fleet [8, p. 22].

The basic cause of this mishap was attributed to a left roll hardover command from the Automatic Flight Control System (AFCS) Flight Director Computer (FDC) being supplied to the

aileron servo at a time when a hot short condition had energized the AFCS engage solenoid valve (ESV) on the aileron servo. The hardover signal provided by the FDC was caused by shorted pins on one of the FDC test connectors. The hot short to the engage solenoid valve was provided by an intercircuit short between the AFCS yaw damper engage switch and the roll AFCS mode switch in the AFCS flight mode selector panel. Neither of these faults by themselves are monitored and are passive in nature, together they cause the servo to go full hard over and the pilot does not have the ability to remove the initial hardover input with full opposite stick. This is because the hardover resulting from these failures gives a series command signal to the servo and the pilot cannot provide an overriding input. The pilot can only cancel out all or part of this series command depending upon the amount of stick travel available at the time of the hardover [8, p. 22].

INTERIM AIRFRAME CHANGE 244

As a result of this mishap, the investigation caused the implementation of Interim Airframe Change 244 (IAFC 244) which disables the roll axis of the AFCS. This IAFC was intended to preclude engagement and operation of the roll axis of the AFCS installed in all S-3 type, model, and series aircraft and was determined necessary as a result of flight control system anomalies that have been discovered during ground testing after the mishap investigation mentioned above [9, p. 1]. This Interim Airframe Change has been and will remain in effect until the AFCS can be modified and tested to assure that the passive and hot short type of failures cannot cause an uncommanded control input. As a result, incorporation of IAFC 244 has resulted in the loss of the following Automatic Pilot Systems (APS) modes since January 1992 [10, section 3, p. 4]:

- Roll Attitude / Heading Hold
- Heading Preselect
- Computer Guidance

- Approaches (Mode 1A) with Automatic Carrier Landing System (ACLS)
- Roll and MAD Compensation Maneuvers

The following modes of APS are still available in the S-3 aircraft:

- Pitch APS / Pitch APS and Altitude Hold
- Indicated Airspeed Hold (IAS) and Approach Power Control (APC)
- Direct Lift Control (DLC) and Thrust Pitch Compensation (TPC)
- Yaw damper turn coordinator

AFCS SAFETY OF FLIGHT LIMITATIONS

Other known hazards or problems with the S-3 AFCS have been well documented within the S-3B Naval Air Training and Operating Procedures Standardization (NATOPS). Several of the S-3 AFCS failures that pertain directly to safety of flight and operation of the S-3B are listed below:

- Certain AFCS failures can result in uncommanded maneuvers, even if the AFCS is not engaged [2, p. 2-248].
- The APS should not be engaged in any mode if the pitch, roll, or yaw trim and synchronization indicators on the FMS panel are not centered. A hardover signal may be present in the AFCS. The APS should not be engaged in any mode if indicator movement has occurred with APS disengaged. In this case, indicator movement may be an indication of failure(s) affecting the AFCS [2, p. 2-251].
- With Interim Airframe Change No. 244 incorporated, the aircraft shall not be flown if roll channel 1 and/or 2 lights are not illuminated [2, p. 2-254].
- Single-channel pitch, roll, and heading hold modes of the APS are unmonitored and some system failures could cause hardovers. Therefore, single-channel operations below 1,000 feet AGL are not recommended except when dictated by mission requirements. If mission

completion requires low-altitude, single-channel APS operations, the pilot should closely monitor system operation and be ready to take control in the event of the hardover malfunction [2, p. 2-259].

- Single-channel pitch hardover at speed greater than 250 KIAS will cause excessive structural loads. Operation of the AFCS is limited to 250 KIAS in the single-channel pitch mode [2, p. 2-260].

AFCS DEFICIENCIES

Several undesirable characteristics of the S-3 AFCS have been documented during AFCS flight tests. Many of the these undesirable characteristics have been attributed to poor engineering design and electrical failures of the Flight Data Computer (FDC). Other problems such as nuisance APS disconnects, unreliability, and poor flying qualities with APS engaged can be attributed to poor system and component design [3, p. 29]. For example, the APS system characteristics during Control Stick Steering (CSS) and stall were not designed properly to maximize aircraft performance and safety. Likewise, the APS yaw damper turn coordinator system logic design degrades aircraft flying qualities during approaches and touch and go's. With APS modes engaged, nuisance disconnects continue to happen when there is moderate turbulence, aircraft is commanded into an AOB, or for other unknown reasons.

During initial flight tests and prior to IAFC 244, the APS with Control Stick Steering (CSS) was considered virtually unusable for precise maneuvering tasks because of high breakout forces, stick jerks, kickbacks, shallow longitudinal stick force gradient, response lags, and high lateral stick force gradient. These CSS shortcomings made moderate to aggressive maneuvering and high gain tasks with precise control very unpredictable [3, p. 9]. Safety of flight qualities in

the design of the pitch APS were not considered. The automatic pitch trim feature in the pitch APS mode commands the horizontal stabilizer trailing edge up during an approach to stall. When the aircraft stalls, the aircraft is in a full nose up trim condition making stall recovery more difficult, delaying recovery, and requiring the pilot to use a different recovery procedure. This undesirable feature, which is also apparent during accelerated stalls, also aggravates accelerated stall recovery procedures [3, p. 24].

Two of the logic flaws of the FDC have always been the disengagement of yaw damper turn coordinator mode of the APC with weight on wheels and disengagement during coupled ACLS approaches. Without a yaw damper turn coordinator the S-3 has a lightly damped Dutch Roll characteristic resulting in undesirable flying qualities during moderate to aggressive maneuvering or turbulent conditions. This logic design could impact flight safety especially during critical phases of flight like touch-and-goes, bolters, or take-offs. Any time there is a momentary weight on wheels signal to the FDC, the aircrew must re-engage the yaw damper turn coordinator. For coupled ACLS carrier approaches, the ACLS uncouple logic completely disengages the yaw APS and yaw damper turn coordinator during an ACLS waveoff, system uncouple, or downgrade (required at 200' or on LSO call). This undesirable flying quality combined with total disengagement of an ACLS coupled approach, causes the pilots workload to shift from monitoring a fully automatic approach to manually flying the remainder of the approach or executing a wave-off. Disengagement or losing yaw APS and yaw damper turn coordinator happens at a very inopportune time, forcing the pilot to re-engage the yaw damper turn coordinator or accept degraded line-up control during one of the most critical points of an approach [11, p. 1].

Another AFCS system flaw has been its design and control in the longitudinal axis making it unusable throughout the terminal phase of the coupled approach. During dual-channel and single-channel AFCS operation there is insufficient longitudinal control authority for ACLS approaches. This causes dramatic longitudinal oscillations above and below glideslope with ± 3 units Angle of Attack (AOA) precluding safe automatic (Mode I) landings [12, p. 1]. This system limitation prohibits coupled ACLS approaches below 200 feet and with 1/2 mile for safety of flight reasons.

ELECTROMAGNETIC INTERFERENCE

Electromagnetic Interference (EMI) in wire bundles and connections have also contributed to numerous unintentional APS disconnects and uncommanded control inputs. The AFCS bomb bay harness provides electrical connection between the Flight Data Computer (FDC) and the rate gyroscope assemblies, accelerometers, and pitch rate sensor. Operational experience has shown that the rate gyroscope assembly is susceptible to UHF EMI conducted along the AFCS bomb bay harness. The EMI causes uncommanded flight control response and unintentional AFCS disconnects during UHF radio transmissions when using the bottom antenna on the aircraft with AFCS is engaged. This affect has been determine to be caused by poor wiring and connections in combination with the aircraft bomb bay forming a resonant cavity for electromagnetic interference with the bomb bay doors open or closed [13, p. 2].

CURRENT FLEET OPERATIONS

Again, there have been several aircraft mishaps which the AFCS has been suspected in giving uncommanded flight control inputs. These are catastrophic failures that have caused several

alterations in aircraft maintenance procedures as well as causing interim air-frame (flight control) changes, and changes to in-flight emergencies procedures. Overall, these changes have reduced the numbers of incidents which uncommanded flight control inputs have had on catastrophic mishaps. Even though these catastrophic events have seemed to diminish, the S-3 AFCS is still plagued with performance and system deficiencies. Many components are unreliable and contribute to overall system degradation, limiting the pilot's availability of APS, and making trouble shooting and repairing AFCS failures very difficult.

MISSION IMPACTS

Current operational status and system reliability of the S-3 AFCS has severely affected aircraft flight readiness resulting in several mission sorties being aborted due to system failures. During carriers operations the S-3 aircraft must have dual channel pitch trim, single channel roll trim, single channel speedbrakes, and single channel yaw damper turn coordinator. All of these flight control systems are required according to the Minimum Essential System List (MESL) for the S-3 aircraft. Any one of these failures will delay launching the aircraft until that failure can be isolated and repaired. Deck space on board a carrier is also a very precious commodity during carrier operations. If an aircraft is not ready to launch for its required mission, that aircraft then becomes a liability and must be moved out of the way to launch and recover other aircraft. If the aircraft is not ready, the time required to conduct launch and recovery evolutions during carrier operations would increase, making the carrier more vulnerable and easier to target by hostile forces. Without the minimum AFCS subsystems and the trim flight control systems operational, the aircraft will not launch for its mission. This would also impact the carrier's effectiveness by providing one less asset to conduct mission sorties.

Once airborne, most missions can be completed with AFCS failures but it will always have some impact on mission effectiveness. Without a yaw damper turn coordinator, flying qualities of the aircraft degrade due to lightly damped Dutch Roll characteristic. Aircraft performance while tanking, bombing, and landing onboard the carrier are seriously affected. During each of these missions precise aircraft control is necessary but without the yaw damper turn coordinator precise control in all three axes becomes difficult. Another problem experienced without a yaw damper turn coordinator during long Anti-Submarine Warfare (ASW) missions at low altitudes has been aircrew sickness and vertigo. The inherent nature of maneuvering without AFCS yaw combined with moderate to heavy turbulence has created this undesirable effect.

New mission capabilities have increased work load for all aircrew and have raised some concern about fatigue. This can especially be true for the pilot after long missions that end with a landing on a carrier. Unlike the S-3 cockpit, modern cockpits in other tactical aircraft have incorporated automatic engine and weapon monitoring systems, navigation systems, auto-pilots, and landing systems to ease pilot workload. In the S-3, the pilot must continually fly the aircraft without relief for extended periods (4-6 hours). With IAFC 244, the pilot is unable to interface the AFCS with the mission computer to get relief during aircraft transit or tactical phases of a mission. This definitely becomes a safety factor during low altitude maneuvering at night for extended periods of time.

Overall, the AFCS in it current status does not help relieve the pilot of tasks during flight except for Pitch / Altitude Hold APS modes. Disconnecting the roll AFCS channel resulted in loss of operational capability for the S-3B, particularly the long duration low altitude ASW mission at night. Without Roll / Heading Hold APS modes, the pilot may become over-tasked.

Primary concentration is focused on flying the aircraft whereas the mission becomes secondary. The pilot's inability to contribute tactically impacts the entire mission of the S-3B.

One of the aircraft sensors called Magnetic Anomaly Detection (MAD) requires a fully operational AFCS including roll axis to conduct MAD calibrations. The MAD system detects submarines by measuring changes (anomalies) in the earth's magnetic field created by the submarine. This system has been in the fleet for over 35 years and it continues to be an effective means to localize and track a submarine for an attack solution. However, the MAD system needs to be compensated due to the influences of the airplane's fixed magnetic fields and magnetic fields generated (or changed) during maneuvers [14, p. 2]. Prior to IAFC 244, the AFCS would automatically perform MAD compensation maneuvers in the pitch, roll, and yaw axis. Manually flying the MAD compensation maneuvers are very difficult, time consuming, and ineffective. As a result of IAFC 244 , MAD compensations have not been properly conducted on S-3B aircraft since January 1992. This has severely degraded MAD system performance and has rendered it nearly obsolete.

CURRENT STATUS OF AUTO/MAN BIT

The S-3B Viking AFCS was designed in the early 1970's with the theory that pilots would engage various modes of AFCS right after takeoff, fly a majority of the mission with AFCS engaged, and then conduct an approach to landing with AFCS. Although many parts of the AFCS system are analog, the initial design of the pre-flight AUTO/MAN BIT (or AFCS BIT) was to be conducted prior to every flight and give sufficient confidence that the AFCS was free of failures and ready for flight. The AFCS BIT proved to be ineffective and over the years maintenance personnel then concluded the BIT was not checking system components properly

and the information from the test was unreliable and unclear. For example, after conducting an AFCS BIT test several times in succession on the same aircraft, totally different fault codes indicating subsystem failures would be indicated after each BIT. Removing and replacing the FDC generally resulted in the same results: inconclusive fault codes indicating failures. Therefore, the AFCS BIT has not been looked upon as a reliable means of troubleshooting AFCS failures [15, p. 2].

Currently the AFCS AUTO/MAN BIT is not being used in the fleet prior to any flights except for FCF's. The AUTO/MAN BIT conducted on the ground and the in-flight check of the AFCS are still portions of the S-3B FCF profile, but both are ineffective because the roll axis of the APS is disengaged. Failures during the AFCS BIT are noted and then reported to maintenance without any real maintenance action taken to repair them. Fleet squadrons are still conducting AFCS BIT's, but fault indications are not clearly indicating the proper maintenance repair. Currently in all the fleet squadrons, the AFCS AUTO/MAN BIT has minimal credibility and does not determine Go / No Go criteria prior to flight.

For the AFCS BIT to be an effective tool, it must be able to detect AFCS and related flight control system component failures dependably and accurately. Obviously failures related to the flight control system status, electrical failures that could result in uncommanded control surface movement, or failures within the FDC are all critical. But every failure must clearly indicate a specific component for easily trouble shooting and repairing the problem. Until the AFCS BIT is redesigned to specify failed components and become a reliable test, the overall general opinion of the AFCS BIT will not change.

ORGANIZATIONAL LEVEL MAINTENANCE

Maintenance completed in the squadron level is called "Organizational Level" or O-level maintenance. O-level maintenance is performed by an operating unit on a day-to-day basis in support of its own operations. The O-level maintenance mission is to maintain assigned aircraft and aeronautical equipment in a full mission capable status while continually improving the local maintenance process. O-level maintenance is usually accomplished by maintenance personnel assigned to aircraft in general maintenance functions including inspections, servicing and handling, on-equipment corrective and preventive maintenance (which includes repair, removal, and replacement of defective components), and record and log all maintenance completed for each aircraft [16, p. 7-1].

CURRENT AFCS FAILURE RATES IN THE FLEET

Typically, the level of knowledge for all fleet maintenance personnel on each of the aircraft systems is excellent. If an aircraft is designed properly from the beginning, maintenance procedures for fixing failures in any of the aircraft systems should be easy to follow, easy to perform, and logical. The ease of performing all maintenance procedures directly affects the immediate and long term impact on aircraft reliability, aircraft readiness, mission effectiveness, safety, and outlook or perception others have for that aircraft community. Obviously the opposite is true if an aircraft system has poor component reliability and has difficult trouble shooting and repair techniques. With difficult maintenance procedures the aircraft's reliability, readiness, and safety are all impaired.

For Navy maintenance personnel, in-depth technical knowledge about the inner workings of a component is not required, but overall system knowledge is required for trouble shooting and repairing failures. When referring to the proper maintenance manuals, the standard procedures for fixing a failure within the S-3 AFCS is to first trouble shoot the failure, identify the failure, and then repair the failure or remove / replace the failed component. Usually most AFCS failures are corrected by "reseating" a component, reconnecting canon plugs, or replacing the component with a new component. Currently with IAFC 244 disengaging all modes of roll APS, the typical AFCS failures in the fleet squadrons are only related to yaw damper turn coordinator, Pitch / Altitude Hold, and the AutoThrust System. Only a complete failure of the yaw damper turn coordinator will down an aircraft for safety reasons and all other failures will prevent the pilot from using various relief modes of APS. The other APS systems that are disengaged are simply not maintained because there is no requirement. Since the roll axis of APS has not been used for over four years, the personnel expertise and knowledge on maintaining the system in many cases have already left the squadrons.

Recent flight testing of the S-3 AFCS conducted at Naval Air Warfare Center Aircraft Division at Patuxent River, MD required data to be collected for AFCS related deficiencies. Testing was completed to verify flying qualities and to confirm or eliminate past documented AFCS deficiencies. Several of these deficiencies could have been corrected by the installation of an improved central air data computer and flight control changes resulting from the Flying Qualities Improvement Program (FQIP). The test team required this baseline information in order to focus efforts to correct confirmed deficiencies in a program design to replace the current Fight Data Computer (FDC) [17, p. 2].

Prior to flight testing, the test aircraft needed IAFC 244 to be removed and the AFCS needed to be "groomed" for proper operation. This was done to ensure all modes of APS were fully operational and to limit any potential risk of catastrophic failures while airborne. The removal of IAFC 244 was relatively easy and accomplished by of a set of jumper cables that connected the original roll axis up to the AFCS. Grooming consisted of ground testing with full electrical and hydraulic power available and attitude sources turned on, then initiating an AFCS AUTO/MAN BIT. Prior to the actual groom effort the test team collected known, or thought to be known, "good" components for all AFCS related parts from the Navy supply system to support trouble shooting efforts. Parts that were collected were rate gyros, accelerometers, and STCU's. Several "Golden" FDC's were also collected specifically tested, and known to be good in all axes for ground and flight testing.

Trouble shooting, identifying, and fixing failures in the S-3 AFCS is not an easy task. As is generally the case, the initial trouble shooting during the groom effort was very difficult because the AFCS AUTO/MAN BIT only indicates of a failure in an AFCS axis or channel and not a specific component failure. An AUTO/MAN BIT done several times in a row without any component swapping resulted in different failure indications at the completion of the test. Logical trouble shooting proved to be very difficult with a BIT that was unreliable because it would often give different failure indications.

The AFCS components also proved to be quite unreliable. The quality of the AFCS components themselves did not always assure logical results during the groom effort. Many times after a component was swapped out with a known bad component (expecting truth data), the same failure or lack of failures would be indicated. Although most of the AFCS components

came directly from the Navy supply system and were tested for safety of flight functionality for the Powered Flight Control System (PFCS), concerns were brought up that these components were not being tested for their functionality in regard to roll axis APS. Some of these parts included the pilot's control stick, the navigation data converter repeater (NDCR), and the aileron hydraulic servo. Other components are known to have a low Mean Flight Hour Between Failures (MFHBF) and were considered tainted or unreliable after several long days of testing. Some of these components included the rate gyros, the Speedbrake Trim Control Unit (STCU) and the Flight Data Computer (FDC). Aircraft wiring became a common failure item for component subsystems that had not been used for several years. Many subsystems had electrical shorts causing failures and were found only after many tedious hours of trouble shooting. Overall, the combination of an old system design, difficult trouble shooting, unreliable AFCS components, and lack of system operation for several years made the AFCS groom effort very difficult and time consuming.

RELIABILITY AND MAINTAINABILITY

The problems associated with grooming the S-3 AFCS and making it fully system capable has raised many doubts about the reliability of several AFCS components and the overall system maintainability. Although the groom effort for AFCS testing was primarily conducted on one aircraft, other groom efforts on other fleet and Naval Air Warfare Center S-3's have produced similar results. The test team has become acutely aware of many problems with the design, logic, and components of the AFCS and believes many of these problems will be very similar to other fleet S-3 aircraft AFCS's. This concern will become readily apparent as a replacement for the Flight Data Computer (FDC) is introduced into the fleet and IAFC 244 is removed.

The Navy has a computer system called the Navy Aviation Logistic Data Analysis (NALDA) designed to track all aircraft parts and work required to complete maintenance action items for all S-3 aircraft. Although the NALDA system can be very helpful, it does have some limitations. For instance, detailed information for a specific part failure on an aircraft is not available; only a generic repair for the failure is annotated in the data base. Detailed information on the correction would have to be obtained from the original squadron initiating the Maintenance Action Form (MAF). However, part number, general types of failures, man hours required for the repair, and number of mission aborts are available in a relatively short period of time and can be used for analysis. Another limitation is that the data is approximately 4-5 months behind the time when the actual maintenance action was completed. Reasons for this limitation are related to the time required by other maintenance levels to determine the exact reason for failure, fix the component, and then enter this information into the NALDA data base.

For this study, information for S-3 AFCS components was obtained from the NALDA data base on 6 May 1996 and represents failures during an 18-month time period from 1 July 1994 to 31 December 1995 [18]. Information on the total number of failures, failures that were repairable, failures that required component removal, man hours, and total number of aborted flights for each component are contained in Table A-1 and A-2. Although all are critical flight components, Table A-1 primarily represents AFCS components. Table A-2 represent components whose secondary function supports the S-3B AFCS, but are critical "safety of flight" components for flight controls, electrical controls, and navigation. Information on flight hours and number of sorties for the S-3 aircraft during an 18-month period are presented in Table A-3. The information for AFCS components Mean Flight Hours Between Failures (MFHBF) are presented with component reliability in Table A-4. The following equations were used to

determine component and system reliability and MFHBF using flight hours and failures for the FDC.

HoursFlt = Total Number of Flight Hours in 18-Month Period
Failures = Total Number of FDC Failures in 18-Month Period
Sorties = Total Number of Sorties in 18-Month Period

$$MFHBF = \frac{\text{HoursFlt}}{\text{Failures}} = \frac{74466.4}{1964} = 37.9$$

$$\textit{Mission Time} = \frac{\textit{HoursFlt}}{\textit{Sorties}} = \frac{74466.4}{33287} = 2.24 \text{ hours}$$

Assumption: For every 2 hours 15 minutes of flight time at least 15 minutes is spent on the ground during start, taxi, and shutdown.

Therefore average mission time will be: t = 2.5 hours

R = Reliability
λ = Failure Rate
t = Mission Time

$$\lambda = \frac{1}{MFHBF} = \frac{1}{37.9} = .0264$$

$$R = e^{-\lambda t} = e^{-(.0264)2.5} = .9362\ \%$$

Detailed calculations for all AFCS component MFHBF and reliability are presented in detail in Table A-5.

Looking at Table A-1, one of the most striking component failures is the Flight Data Computer (FDC). The Flight Data Computer has the highest number of failures and overall requires the highest number of maintenance man hours to correct aircraft failures in the AFCS. Although it takes approximately 5-10 minutes to remove a defective FDC and replace it with a new FDC, average man hours to replace a FDC is 5.2 hours. This is a result of current trouble

shooting techniques that indicate general axis and channel of APS failures but do not immediately specify a component failure. Since the FDC is conducting the BIT, it should have an accurate self BIT which readily notifies maintenance personnel of a FDC failure. The FDC has also caused a relatively high number of mission aborts due to failures and has the lowest MFHBF and component reliability of 37.9 hours and 0.936 respectively as shown in Table A-4.

Other problem components in Table A-1 are the rate gyros, accelerometers, automatic throttle servos and AFCS wiring. The rate two gyros have a high failure rate (adjusted MFHBF of 288.6 hours) that requires component removal and replacement. Rate gyros have the third highest number of failures and the third highest number of man hours to repair and/or fix the failure. Although the accelerometers have a relatively low failure rate, both the accelerometer and AFCS related wiring require 10.4 and 11.3 man hours respectively to trouble shoot a failure and repair the component or wiring on the aircraft. Again, current trouble shooting indications do not point to the failed AFCS component and many hours are wasted investigating AFCS failures.

Table A-2 represents failures of peripheral AFCS components which have secondary functions to support the S-3 AFCS, but are also critical components for flight controls, electrical controls, and navigation. The total number of failures for each component is listed from the data base for the 18-month time frame. After looking at each of the generic write-ups of the component failures in the NALDA data base, several failures were subtracted from the total failures once it was determined the failure could not impact the AFCS. The remainder could not be determined if they were genuine AFCS failures or related to other systems. Although the total number of possible AFCS failures in Table A-2 is not precise, these could not be excluded from the data base as possibly impacting the AFCS. Again, many of the peripheral AFCS components

are also used in other aircraft systems which are critical, and a failure of one of these components will also prevent the aircraft from launching for its mission.

Looking at Table A-2, several conclusions can be determined about the peripheral AFCS components. The Speedbrake Trim Control Unit (very similar to the FDC) has a very high number of failures and has resulted in the greatest number (24) of mission aborts. Although it takes approximately 10-15 minutes to remove a defective STCU, the average man hours to repair or remove a defective STCU is 3.8 hours. This fact simply points out another AFCS component that is difficult to trouble shoot or confirm actual operational status. The MFHBF and component reliability are 111.3 hours and 0.98 respectively, indicating the STCU is the second least reliable component in the AFCS, and requires the second highest number of man hours to repair and/or fix the failure.

The Navigation Data Converter Repeater (NDCR) also has a high failure rate, but reviewing the generic write-up in the NALDA data base, one is unable to determine if the failure would have a direct impact on the AFCS. This failure data is the least accurate since the NDCR interfaces with many other aircraft components. The only way to determine actual impact of the NDCR on the AFCS would be to read each Maintenance Action Form (MAF) from the originating squadron. At this time, the status of the interface between the NDCR and the roll APS in all fleet aircraft is unknown.

The Pitch Trim Actuator (PTA) is another failure item with a high number (11) of aborted missions. A PTA is a critical safety component for proper operation of the longitudinal flight controls and has secondary functions which could impact, degrade, or eliminate the availability

of Pitch APS in AFCS operation. An average of 14.3 man hours are required if the PTA has to be removed.

The data in Table A-2 does not reflect AFCS failures for the Pilot's Control Stick. The failures in the data are probably related to trim control features or other switches that failed and required the stick to be removed. The Pilot's Control Stick for the operation of CSS is another one of the unknowns if roll axis APS were to be engaged in the S-3. The crystal strain gauge sensors that are in the control stick have not been used in years and many doubt if the aircraft in the fleet would have any control sticks that would be operational for roll axis Control Stick Steering (CSS). At NAWC-AD, every time a groom effort commenced, the pilot's control stick needed to be replaced in preparation for AFCS deficiencies test flights.

All hydraulic servos have approximately the same failure rate and all require extensive maintenance man hours to remove and replace. Obviously, all hydraulic servos are critical safety items for proper operation of the flight controls and any AFCS functions are secondary. The aileron servo however, has been electrically disconnected with the IAFC 244 and the data in the Table A-2 only indicates flight control failures, not AFCS failures. At this time the status of all aileron servos for AFCS functionality in each aircraft is unknown. It is expected that when IAFC 244 is removed from fleet aircraft, the AFCS functionality of the aileron servos in support of the roll axis APS will not be important enough to spend the numerous man hours and aircraft down time to replace the aileron servo.

The Mean Flight Hours Between Failures (MFHBF) and calculated component reliability for all AFCS components are presented in Table A-4. All data has been collected from NALDA for

an 18-month period ending on 31 December 1995 [18]. Although most AFCS have a relatively high reliability factor and MFHBF, the MFHBF only represents complete failures in which that component had to be repaired or removed. It does not take into consideration the number of AFCS failures that fail only under certain unique conditions or a failure which only happens occasionally or intermittently and are considered as nuisance disconnects by the aircrew.

However, for system integrity, all AFCS components have to be considered together in series for all axes of APS and ATS to work at a 100% operational level. As shown in Table A-4 and A-5, a system reliability of 0.8695 was calculated after figuring out the reliability of each component. This also equates to an AFCS MFHBF of 17.88 hours. In other words, there is a likely chance that every 18 hours there will be a degradation or complete failure in the S-3 AFCS. This is unsatisfactory when considering that the S-3B and ES-3A are critical to the carrier battle group and are flying 2-3 hours per sortie, four times a day. To improve overall AFCS performance some of these failures could be eliminating by redesigning and replacing the FDC, STCU, and rate gyros. Other AFCS components, because of their current failure rates, are not considered as crucial for improving the overall AFCS reliability and performance. Some of these components are the NDCR, Pilot's Control Stick, and Aileron Servo. However, these components will not be fully operational when IAFC 244 is removed and the roll APS is engaged, resulting in much higher failure rates than are currently present in the fleet.

II. RESULTS AND DISCUSSIONS

WHY REPLACE THE FDC

The Flight Data Computer (FDC) has been the least reliable component of the AFCS and has been cited as a causal factor of at least one aircraft mishap. Currently the FDC roll channels have been permanently disabled until a replacement FDC is introduced into the fleet. As already stated, the FDC is the primary component in the AFCS but has many problems associated with reliability, performance, and maintenance trouble shooting. After a FDC failure is determined at the squadron or operational level, the FDC is then sent to an intermediate maintenance level of repair. Intermediate levels receive approximately 36 FDC's a month. Repairs generally consist of replacement of FDC components like computer boards or power supplies. Of the 642 FDC failures in the 18-month study period, 604 were repaired at the intermediate level. If repairs can not be done at the intermediate level, the FDC is then sent to a depot maintenance level of repair. If an FDC is beyond capable repair, it is taken out of the supply system at the depot level. Depot levels are receiving FDC's at a rate of 2 per month and the average turnaround time for these repairs is approximately 90 days [19].

The original FDC target MFHBF was 500 hours, but over the years the MFHBF has always been low and has even decreased to less than 40 hours. Overall, approximately $180 million has been spent to buy and repair approximately 968 FDC's over the last 16 years [20] [21]. Currently there are only 374 FDC's to support all of the 132 S-3 aircraft. Although there are many reasons for FDC being taken out of the supply system, the main reason is that most are beyond repair. For this reason the FDC has become too expensive and unsupportable and a new program called

the Digital Flight Data Computer (DFDC) has been initiated to replace this high failure component.

DIGITAL FLIGHT DATA COMPUTER

The new DFDC will be designed as a form, fit, and functional replacement for the current S-3 FDC. The DFDC will be located in the right internal bay and will be supplied by two channels of basic AC and DC power from the aircraft's 115 VAC three phase power supply and the 28 VDC power supply. The DFDC will include several Built-In-Test (BIT) provisions and will have as a minimum Mean Flight Hour Between Failure (MFHBF) of 2000 hours. The self contained BIT according to the Detailed Specification of the DFDC, will accomplish failure detection and isolation to a Weapon Replaceable Assembly (WRA) without the assistance of ground support equipment at the squadron level. In addition, the BIT will provide the pilot or ground crew the capability to assess the functional equipment performance and to identify failed modes in order to determine operational readiness or ability to complete a mission [22, p. 58-59]. The DFDC will be designed with a Power-Up BIT and Continuous BIT to identify system integrity failures and to isolate these WRA failures with a detection accuracy of 98% and 95% respectively [23, p. 69].

Currently there is a plan to buy only 120 new DFDC's. The program has been funded by the Navy and in April 1996 the first System Design Review (SDR) was held with the Navy, contractor, and subcontractor present. The primary purpose of the meeting was to review and ensure program requirements, verify plans for implementing requirements, and to evaluate current progress. Initial production of the DFDC will start in June 1998 with a rate of 2-3 DFDC units per month. A schedule presented in Table A-6 projects expected Test and Evaluation

milestones for the DFDC program with testing being completed in July 1999. Production DFDC's are projected to be introduced into the fleet starting in July - August 1999.

IMPROVEMENTS

The DFDC will undoubtedly improve the current status of the S-3 AFCS by replacing the old FDC. A reliable DFDC with a thorough system of self tests and maintenance BIT's will decrease trouble shooting and man hours required to repair AFCS failures. If designed properly, the DFDC would become the highest MFHBF component and would isolate other component failures within the system. In less than 5 minutes, an inexperienced maintenance personnel could initiate a BIT and then focus all repair efforts on a failed component that the DFDC identified. Less time would be required to isolate and repair the failed component, decreasing aircraft down time and improving the overall AFCS system reliability and readiness.

As DFDC's are introduced into the fleet, each aircraft will be able to re-engage the roll APS systems of AFCS. Basic APS modes like roll attitude, heading hold, and computer guidance will largely improve pilot relief and enable the pilot to concentrate or participate more in mission tasks. Removing IAFC 244 will also allow ACLS Mode 1A approaches to be conducted to 200' and 1/2 mile. Although it is still too early to determine if the new DFDC will be qualified for coupled approaches to touch down on a carrier deck, a coupled approach would at least give the pilot an option to allow the AFCS to fly an automatic approach until the pilot manually takes over. This option can improve overall situational awareness and safety during night or inclement weather approaches. Additionally, removing IAFC 244 will resolve the problem of MAD compensations and will improve the MAD systems for localizing and tracking submarines.

Lastly, the DFDC will improve system reliability when airborne and could enhance the S-3 AFCS flight qualities. The inability to select various modes of APS and the annoying APS disconnects could possibly disappear as component and overall system performance improves. With a dedicated effort to improve control laws, eradicate past deficiencies, and confirm software changes with flight testing, there is an excellent chance to improve the APS flying qualities. The digital design also permits future changes to be incorporated via software instead of requiring expensive hardware redesigns.

DFDC ISSUES

The DFDC as a replacement for the FDC shows great promise in areas of component reliability, performance, and BIT's. However, the contractor who is designing and manufacturing the DFDC is the contractor that developed similar systems in the Navy F/A-18 and Air Force A-10. Table 1 presented below shows the aircraft, system designed, designed MFHBF, and actual/predicted MFHBF for the F/A-18, A-10, and S-3 [22, p. 155] [23, p. 1-32].

Table 1
Design and Actual Mean Flight Hour Between Failure

Aircraft	System Component	Contractor Reported MFHBF	Actual MFHBF
F/A-18	Flight Control Computer	2,200	201
A-10	LASTE (Autopilot)	16,000	359
S-3	DFDC	*2,000	*310

* estimated

In each of the F/A-18 and the A-10, the actual MFHBF according to [18] was less than 10% of the reporting MFHBF by the manufacturing company. Team members from NAWC-AD Reliability and Maintenance (R&M) department who are very familiar with the DFDC program are predicting the DFDC MFHBF to be around 310 hours. They are estimating the MFHBF by using a computer program developed by Naval Air Systems Command to predict system reliability. Their estimate is based on a statistical model that uses a large historical data base of predicted and actual MFHBF from previous Navy procurement programs [20] [21]. As a result, the indicative 310 MFHBF is much lower than the expected 2000 hours and will impact overall component reliability. Realistically, any MFHBF below 1000 hours for the DFDC is unjustifiable for the amount of time, money, and effort that has been expended to replace the FDC.

Even when estimating an MFHBF of 2000 hours for the DFDC the overall system failure does not improve dramatically. Table 2 presented below lists AFCS system reliability with different MFHBF's for the DFDC [18] [20] [22, p. 155]

Table 2
AFCS System Reliability

Component	MFHBF (Hours)	Reliability Component (2.5 Hours)	Reliability System	MFHBF System (Hours.)
FDC	37.9	.9362	.8695	17.9
DFDC Navy Estimate	310	.9920	.9213	30.5
DFDC Contractor Estimate	2000	.9988	.9276	33.3

Best case, overall AFCS system reliability increases from the current 17.9 hours to 33.3 with a 2000 hour MFHBF DFDC. The least reliable component within the AFCS is being replaced but a design that is in series with other unreliable components prohibits thorough systematic improvements without replacing the entire system. With a new DFDC, AFCS failures will occur at less than 1/2 the rate (MFHBF 17.9 vs. 33.3 hours) that is currently in the fleet.

The only way to improve the AFCS system reliability without totally redesigning the system would be to replace all of the higher failure rate items in the system. These would include the FDC, STCU, and the rate gyros. The mission aborts in 18 months for the STCU and rate gyros combined was three times (27) the mission aborts for just the FDC (9). As a minimum, these three components need to be replaced. Other components status such as the aileron servo, NDCR, and pilot's control stick are completely unknown and will not be known until IAFC 244 is removed. If these components prove to be become higher failure rate items, the squadrons will rush to acquire these parts in the supply inventory (particularly the aileron servo), and diminish all spares in stock. Other squadrons with the same failure will not be able to obtain their part as a back log of parts will develop. To solve this problem now, depot levels need to double check quality control and guarantee all AFCS components, especially the aileron servo, control stick, and NDCR for reliability in their secondary (AFCS) functions.

The actual schedule of production DFDC's will be between 2-4 units per month. With FDC's performance and reliability deteriorating, DFDC are needed for replacement without delay. Most likely a squadron will be targeted for the first set of new component installations. Once the DFDC's become available, that squadron will install the new component and expect great results

from a new digital component advertised as solving all of the AFCS problems. This will not be the case, however, due to all of the inherent problems in the AFCS. Given the fact that the MFHBF of the DFDC has increased and trouble shooting techniques become easy, there will be some marked improvements. But, the overall system performance (including all modes of roll APS) will not change due to inherent series system design and several other components with inferior performance and reliability. Without a dedicated effort to groom aircraft after DFDC's are installed, the roll modes of APS will not be available for the aircrews.

Once a DFDC is installed in an aircraft, it should be used for trouble shooting all axes. At this point a prearranged "groom team" stacked with quality spare AFCS parts should attack the faulty components and deliver the aircraft with an AFCS that is fully operational back to the squadron. Once that aircraft is completed, the next aircraft in line should be groomed for that squadron. Without a hydraulic servo or PTA actuator change, the groom process should take about 2-4 days depending on the status of the AFCS components, some (roll axes) of which have not been used for over 7 years. Integrating the DFDC with a dedicated groom team must be employed. Their knowledge and expertise will ultimately bring each aircraft's AFCS up to an operational level more quickly and with less effort than sporadic, haphazard undertaking at the squadron level.

The production schedule of the DFDC's is tentatively slow. The aircrew, the maintainers, and supply personnel all need this enhancement now to improve aircraft readiness and safety. As scheduled, the first production unit will not be introduced into the fleet for at least three years. Meanwhile, exorbitant man hours efforts will continue or possibly increase from maintenance, supply, and depot level repair personnel. The DFDC is already late and should have been

introduced into the fleet years ago when it was documented as unsupportable during original testing in 1974 [24, p. 1]. From 1974 to the current date, the failure rate of the FDC's has been so high that 968 FDC's have been purchased to support the S-3 aircraft over the years [20] [21]. The original contractor probably profited from producing (by a factor of 7) an unreliable product which is flight critical in a Navy aircraft. On the other hand, producing only 120 DFDC's to support the current 132 aircraft is not realistic and another unit buy is required for supply spares while the units are at the depot level for repairs. At a minimum the Navy will need to purchase at least 162 units to support each of the fifteen squadrons with DFDC spares during logistic and repair delays after the units fail.

One specific reason for the slow production of the DFDC units is money. During these last several years the Navy defense budget has decreased and will continue to decrease for at least the next two to three years. This will continue to affect all Navy programs (except for a few high visibility aircraft platforms) in the Test/Evaluation, systems improvement, and obsolescent part replacements. The lack of funding has forced the Maritime Surveillance Aircraft Program Office for the S-3 to lengthen the entire DFDC program in order to spread the limited annual budget or funding into the "out years," ultimately slowing the program and delaying the results of a final product. As with every program, the program manager has to manage money and risk. A manager could save money in one area but a complete evaluation of risks associated with failures, delays, and cancellations must be taken into account. However, when there is a requirement for a program but a lack of funding, either the program is canceled because it can't be done or that manager is forced to take higher risks. One such area that is considered "high risk" is the area of reliability and maintenance, an already known problem through the entire existence of the FDC.

One possible solution to ensure product quality would be to use a technique called Production Reliability Acceptance Testing (PRAT). PRAT is a technique employed to ensure that the contractor can produce, on a continuing basis, equipment that meets the specified reliability requirements. It provides a means of identifying when a contractor's processes and procedures have changed, resulting in a production lot of equipment not meeting reliability requirements [25]. Therefore, PRAT can be considered an insurance policy for reliability and maintenance that prevents substandard equipment from entering the fleet. Lastly, because the contractor knows that he must pass a PRAT test, he is far more motivated to seriously consider reliability and maintenance during the design process. Currently, the government is assuming all the risk in the DFDC program without any recourse if the DFDC has a much lower MFHBF than the expected 2000 hours. A Product Reliability Acceptant Test must be considered to legally hold the contractor to what was originally outlined in the contract. If the DFDC has reliability problems, then the contractor should be forced by a "PRAT clause" to reduce the cost for repairs or provide additional units to support the program. The implementation of PRAT will ensure that the operational availability of the fleet is not degraded and the warranty will ensure that any latent design deficiencies that may be discovered will have to be corrected by the contractor at no cost to the government.

Current repair facilities for the FDC are the Navy's intermediate and depot levels of maintenance. However, repair facilities of the DFDC will be quite different. Once a DFDC is removed from an aircraft at the squadron level, it will be sent directly to the original manufacturing contractor. The contractor will then be paid for each DFDC they repair and will then send it back into the Navy supply system. A simple or complex repair would cost the Navy the same price. Without a quality control check like PRAT, there is nothing to protect the Navy

in the long run from the contractor designing a component with a much lower than advertised MFHBF. From the contractor's point of view, more revenue could be generated by a product that has a lower MFHBF if that company could also benefit from the repair process. Not only does that company have the possibility of profiting as a repair facility, but could also profit when the MFHBF is low and more units are required to support all aircraft. This would require the production lines to open again for another buy at an increased cost. Without PRAT, what is the motivation for a company to produce a highly reliable AFCS component when that company is the only producer of a critical component in an aircraft platform? Currently the Navy is accepting the DFDC without a contractual warranty or minimum MFHBF. With that mind set, the DFDC will probably follow its predecessor and become extensively over-priced with low reliability.

III. CONCLUSIONS AND RECOMMENDATIONS

The S-3 AFCS has always been plagued by system unreliability, poor flying qualities, and uncommanded control inputs. The FDC which is the primary component in the AFCS has also been implicated in one aircraft mishap resulting in an IAFC 244 which has eliminated several modes of AFCS. All of the these undesirable characteristics have been attributed to poor AFCS system and component design, especially the FDC. The FDC has the highest failure rate in the AFCS and has affected aircraft flight readiness due to system reliability. With the FDC becoming extremely expensive to repair and support, a new DFDC will undoubtedly improve the current status of the S-3 AFCS.

If a new DFDC is designed properly, it could become the highest MFHBF component, isolate other component failures within the system, allow aircrew to engage all modes of the AFCS, and permit future changes via software because of its digital design. However, the MFHBF detailed specification of 2000 hours will likely be more in the range of 310 hours. Although an MFHBF of 310 hours is better than the current FDC, it will not greatly improve the overall status of the S-3 AFCS. Even with a high MFHBF for the DFDC, the overall system will still have a relatively low MFHBF of approximately 34 hours. The overall system performance will not change due to inherent series system design and several other components with inferior performance and reliability. The only way to greatly improve overall AFCS system reliability would be to replace all of the other higher failure rate components in the system like the STCU, rate gyros, NDCR, PTA, control stick, and aileron servo. As a minimum, prior to DFDC incorporation into the fleet, depot levels need to double check quality control and guarantee all AFCS components. All

aircraft must then be groomed by a dedicated groom team to bring each aircraft's AFCS up to an operational level more quickly than if done at the squadron level.

The people who need the DFDC are the maintenance, logistics, and aircrew personnel. As presently scheduled, the first production unit will not be introduced into the fleet for at least three years while uncounted man-hours are wasted trouble shooting and repairing AFCS failures. Meanwhile, mission effectiveness, aircraft readiness and overall safety continue to degrade. It is extremely important that a quality product be delivered to the fleet. The DFDC should, at a minimum, maintain the advertised 2000 MFHBF and pass Product Reliability Acceptance Testing to eliminate past reliability problems associated with the FDC. This would allow personnel, funding, and assets to be used on other programs to enhance the S-3 aircraft safety, readiness, and mission effectiveness.

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APPENDICES

APPENDIX A

TABLES

Table A-1
Primary Automatic Flight Control System Component Failure Rates

	Flight Data Computer(FDC)	Rate Gyro	Auto Throttle Servos(ATS)	Flight Mode Selector Panel	Accelerometer	AFCS Wiring
Total Number of AFCS Related Failures	1964	516	188	88	54	n/a
AFCS Failures That Were Repairable	1322	154	90	55	17	112
Man Hours For AFCS Failures That Were Repairable	3095.9	514.1	415.4	90.4	191.5	1162.3
Average Man Hours For AFCS Failures That Were Repairable	2.3	3.3	4.6	1.6	11.3	10.4
Failures That Required AFCS Component Removal	642	362	98	33	37	n/a
Man Hours For Failures That Require AFCS Component Removal	3329.1	1440.6	433.5	96.7	127.6	n/a
Average Man Hours For Failures That Require AFCS Component Removal	5.2	4.0	4.4	2.9	3.4	n/a
Total Number Of Aborts Due To AFCS Failures	9	3	1	0	0	1

Source: Navy Aviation Logistic Data Analysis System (NALDA), Department of the Navy, 1 May 1996.

Table A-2
Peripheral Automatic Flight Control System Component Failure Rates

	Speed Brake Trim Control Unit (STCU)	Navigation Data Converter Repeater	Left Hand Control Logic Assembly	Right Hand Control Logic Assembly	Control Stick	Pitch Trim Actuator (PTA)	Aileron Servo	Elevator Servo	Rudder Servo
Total Number of Failures	699	498	130	260	71	160	*80*	60	54
Total Number of Possible AFCS Failures	597	455	114	214	*n/a*	132	*n/a*	10	20
AFCS Failures That Were Repairable	320	254	47	79	12	27	*47*	4	12
Man Hours For AFCS Failures That Were Repairable	1211	572	165	360	38.7	115	*398*	24	93
Average Man Hours For AFCS Failures That Were Repairable	3.8	2.3	3.5	4.6	3.2	4.3	8.5	6.0	7.8
Failures That Required AFCS Component Removal	277	201	67	135	59	105	*33*	6	8
Man Hours For Failures That Require AFCS Component Removal	1044	645	301	1112	241.8	1504	*926*	132	143
Average Man Hours For Failures That Did Not Require AFCS Component Removal	3.8	3.2	4.5	8.2	4.1	14.3	*28.1*	22.0	17.9
Total Number Of Aborts Due To AFCS Failures	24	3	6	12	0	11	*6*	2	3

Underlined data is not accurate for AFCS failures.

Source: Navy Aviation Logistic Data Analysis System (NALDA), Department of the Navy, 1 May 1996.

Table A-3
Average Number of Flight Hours and Sorties for S-3 Aircraft

Month And Year	Average Number Of Aircraft Reporting	Total Flight Hours	Number Aircraft Of Sorties
Jul 94	115.4	3410.7	1657
Aug 94	118.8	3693.7	1733
Sep 94	114.7	4386.3	1829
Oct 94	118.2	3413.8	1588
Nov 94	115.6	4342.5	1896
Dec 94	119.2	3560.3	1497
Jan 95	115.3	4296.9	1899
Feb 95	101.1	3618.0	1658
Mar 95	112.5	4389.6	2004
Apr 95	109.7	4214.0	2045
May 95	113.6	3883.9	1693
Jun 95	108.6	4635.7	1987
Jul 95	115.4	4417.3	1828
Aug 95	115.6	5006.0	2204
Sep 95	113.7	5006.3	2241
Oct 95	114.9	4418.7	2013
Nov 95	110.5	3987.3	1875
Dec 95	108.4	3785.4	1640
Total	113.4	74466.4	33287

Report Period: Jul 94 thru Dec 95
Prepared: 06 April 1996

Source: Navy Aviation Logistic Data Analysis System (NALDA), Department of the Navy, 1 May 1996.

Table A-4
AFCS Component MFHBF and Reliability

Component	Quantity	MFHBF (source NALDA)	λ	Reliability (2.5 hr mission)
Flight Data Computer*	1	37.9	.0264	.9362
Speedbrake Trim Control Unit	1	111.3	8.98 x 10-3	.9778
Navigation Data Converter Repeater	1	149.5	6.69 x 10-3	.9834
Right Control Logic Assembly	1	286.4	3.49 x 10-3	.9913
Rate Gyro*	2	288.6	3.47 x 10-3	.9914
Pitch Trim Actuator	1	465.4	2.15 x 10-3	.9946
Left Control Logic Assembly	1	572.8	1.75 x 10-3	.9956
Auto Thrust Servo*	2	792.2	1.26 x 10-3	.9968
Flight Mode Selector Panel*	1	846.2	1.18 x 10-3	.9970
Aileron Servo	1	930.8	1.07 x 10-3	.9973
Elevator Servo	1	1241.1	8.06 x 10-4	.9980
Rudder Servo	1	1379.0	7.25 x 10-3	.9982
Control Stick**	2	2097.6	4.76 x 10-4	.9988
Accelerometer*	2	2758.0	3.63 x 10-3	.9991
AFCS System Overall	--	17.88	.056	.8695

* Integral AFCS system component ** ES-3A has one control stick this model assumes 2

From Table A-3: HoursFlt = Total Number of Flight Hours in 18-Month Period
Failures = Total Number of FDC Failures in 18-Month Period
Sorties = Total Number of Sorties in 18-Month Period

$$MFHBF = \frac{\text{HoursFlt}}{\text{Failures}} = \frac{74466.4}{1964} = 37.9$$

$$\textit{Mission Time} = \frac{\textit{HoursFlt}}{\textit{Sorties}} = \frac{74466.4}{33287} = 2.24 \text{ hours}$$

Assumption: For every 2.25 Hours of flight time at least 15 minutes for start, taxi, and shutdown.

Therefore average mission time will be: t = 2.5 hours

R = Reliability λ = Failure Rate t = Mission Time

$$\lambda = \frac{1}{MFHBF} = \frac{1}{37.9} = .0264$$

$$R = e^{-\lambda t} = e^{-(.0264)2.5} = .9362\ \%$$

Source: Navy Aviation Logistic Data Analysis System (NALDA), Department of the Navy, 1 May 1996.

Source: Ritchie, Chris, Personal conservations and notes, 4.1.6.2 System Engineering Reliability and Maintenance Branch, Naval Air Warfare Center, Patuxent River, Maryland. 1 May 1996.

Table A-5
Calculations for System Reliability and MFHBF for the AFCS

Definitions:

MFHBF	=	Mean Flight Hours Between Failure	R	=	Reliability
λ	=	Failure Rate	Q	=	Unreliability = 1 - R
AFCS	=	Automatic Flight Control System	s	=	subsystem
PTA	=	Pitch Trim Actuator	rg	=	rate gyroscope
STCU	=	Speedbrake and Trim Control Unit	acc	=	accelerometer
CLA	=	Control Logic Assembly	es	=	Elevator Servo
FMSP	=	Flight Mode Selector Panel	rs	=	Rudder Servo
FDC	=	Flight Data Computer	as	=	Aileron Servo
NDCR	=	Navigation Data Converter Repeater	t	=	mission time
ATS	=	Auto Throttle Servo	CS	=	Control Stick
DFDC	=	Digital Flight Data Computer			

Assume t = 2.5 hrs For every 2.25 hours flight time at least 15 minutes for start, taxi, and shutdown.

For the rate gyros 1 of 2 must be operative: $R_{s(rg)} = 1 - Q_{(rg)}^2$

For the accelerometers 1 of 2 must be operative: $R_{s(acc)} = 1 - Q_{(acc)}^2$

For the control stick 1 of 2 must be operative: $R_{s(cs)} = 1 - Q_{(cs)}^2$

$R = e^{-\lambda t}$ For a series system, the reliability equation for the AFCS system is:

$$R_{(afcs)} = R_{s(es)} \times R_{s(pta)} \times R_{s(stcu)} \times R_{s(as)} \times R_{s(rs)} \times R_{s(lcla)} \times R_{s(rcla)} \times R_{s(fmsp)} \times R_{s(rg)} \times R_{s(acc)} \times (R_{s(ats)}^2) \times R_{s(fdc)} \times R_{s(cs)} \times R_{s(ndcr)}$$

$$R_{(afcs)} = R_{s(es)} \times R_{s(pta)} \times R_{s(stcu)} \times R_{s(as)} \times R_{s(rs)} \times R_{s(lcla)} \times R_{s(rcla)} \times R_{s(fmsp)} \times (1 - Q_{(rg)}^2) \times (1 - Q_{(acc)}^2) \times (R_{s(ats)}^2) \times R_{s(fdc)} \times (1 - Q_{(cs)}^2) \times R_{s(ndcr)}$$

Using Reliability Values from Table A-4:

$$R_{s(afcs)} = .9980 \times .9946 \times .9778 \times .9973 \times .9982 \times .9956 \times .9913 \times .9970 \times (1 - .0086^2) \times (1 - .0009^2) \times (.9968^2) \times .9362 \times (1-.0012^2) \times .9834$$

Reliability for the AFCS system: $R_{s(afcs)} = .8695$

$$MFHBF_{(afcs)} = \frac{2.5}{(.8695)(\ln)} = 17.88 \text{ hours}$$

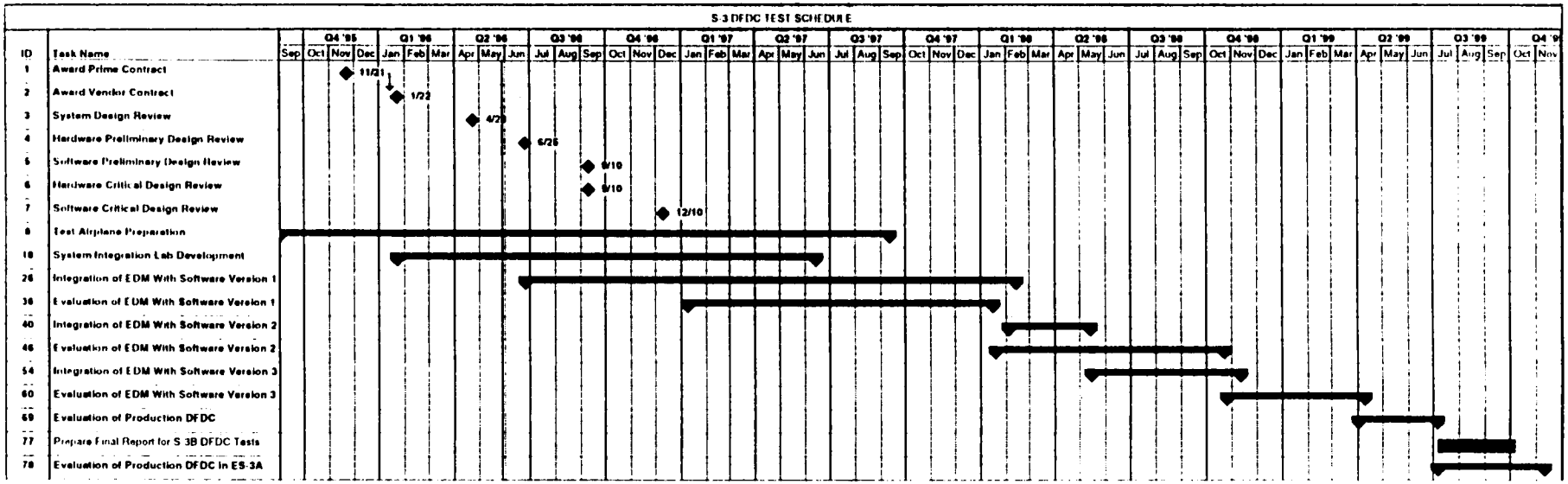
Assume a DFDC with the spec time MFHBF = 2000 then: $R_{s(afcs\ w/DFDC)} = .92754$

$$MFHBF_{(afcs\ w/DFDC)} = \frac{2.5}{(.92754)(\ln)} = 33.24 \text{ hours}$$

Source: Navy Aviation Logistic Data Analysis System (NALDA), Department of the Navy, 1 May 1996.

Source: Ritchie, Chris, Personal conservations and notes, 4.1.6.2 System Engineering Reliability and Maintenance Branch, Naval Air Warfare Center, Patuxent River, Maryland. 1 May 1996.

Table A-6
DFDC Test and Evaluation Schedule



Source: S-3 DFDC Team, Naval Air Warfare Center Aircraft Division, Patuxent River Maryland, 15 May 1996.

APPENDIX B

FIGURES



Figure B-1
S-3B Viking Aircraft

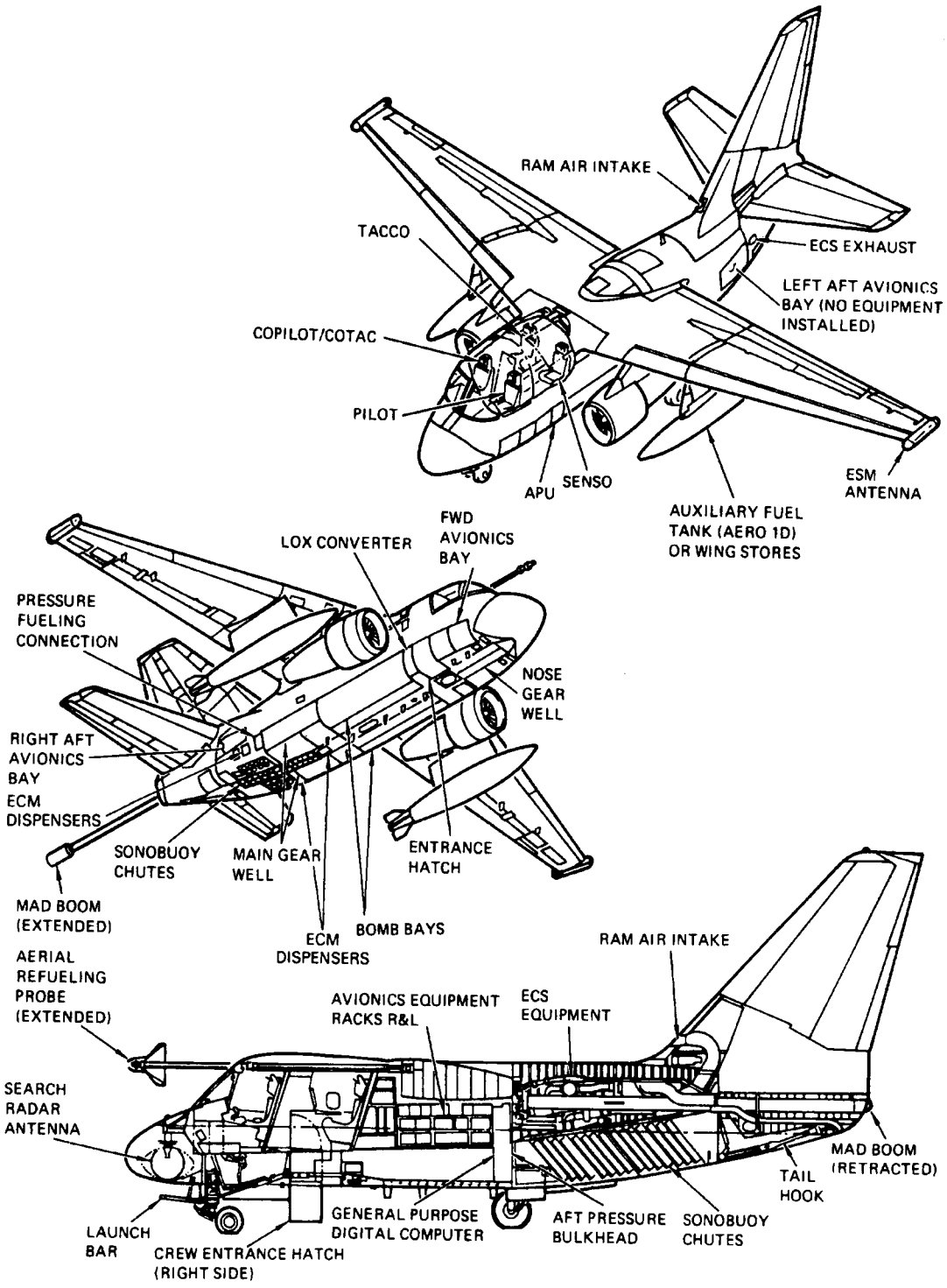


Figure B-2
S-3B Aircraft General Arrangement

Source: NAVAIR 01-S3AAB-1, NATOPS Flight Manual Navy Model S-3B Aircraft, Department of the Navy, 1 October 1993.



Figure B-3
ES-3A Shadow Aircraft

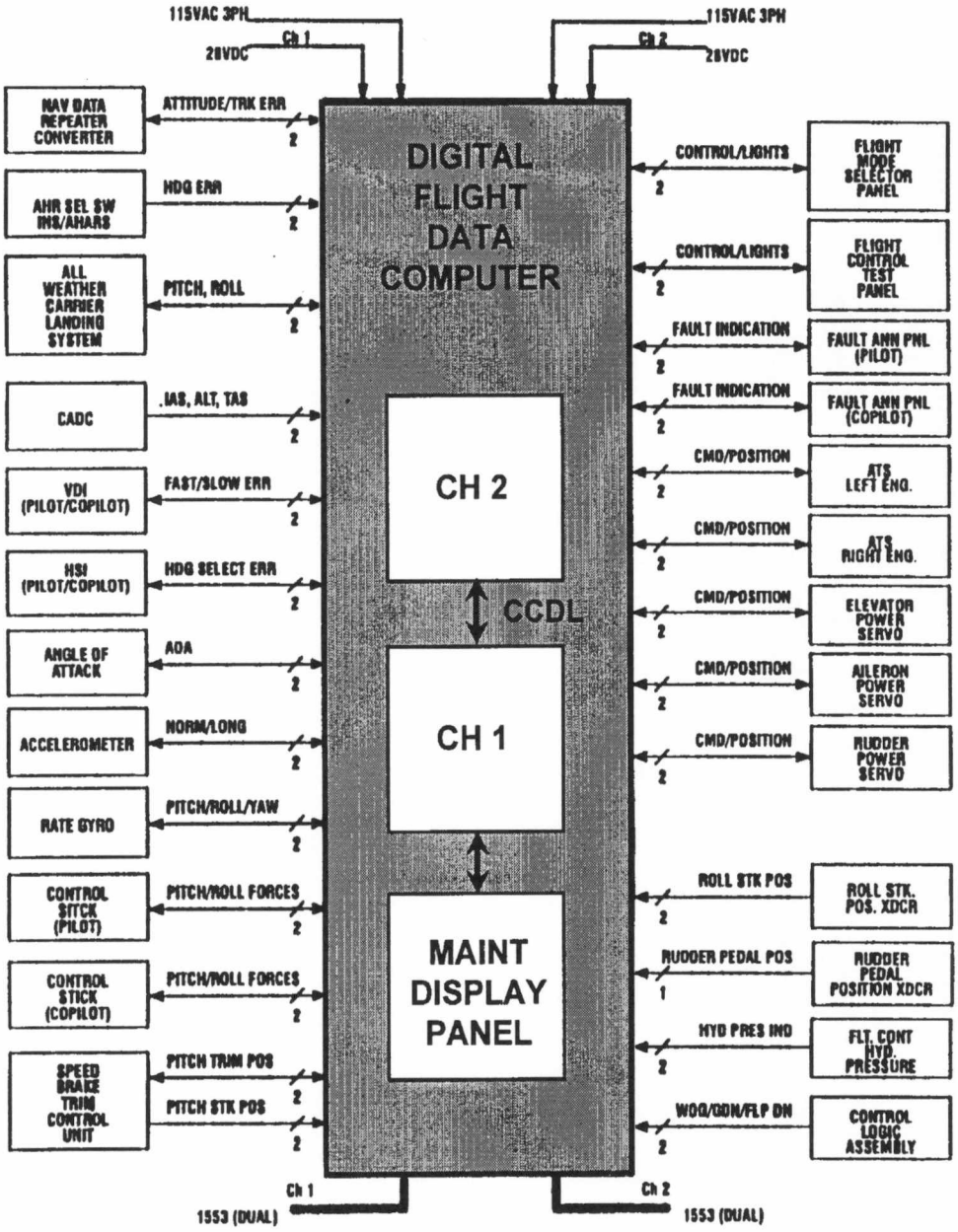


Figure B-4
AFCS Component Block Diagram

Source: Lockheed Martin Control System, S-3 DFDC System Design Review, Binghamton, NY, 23-24 April 1996.

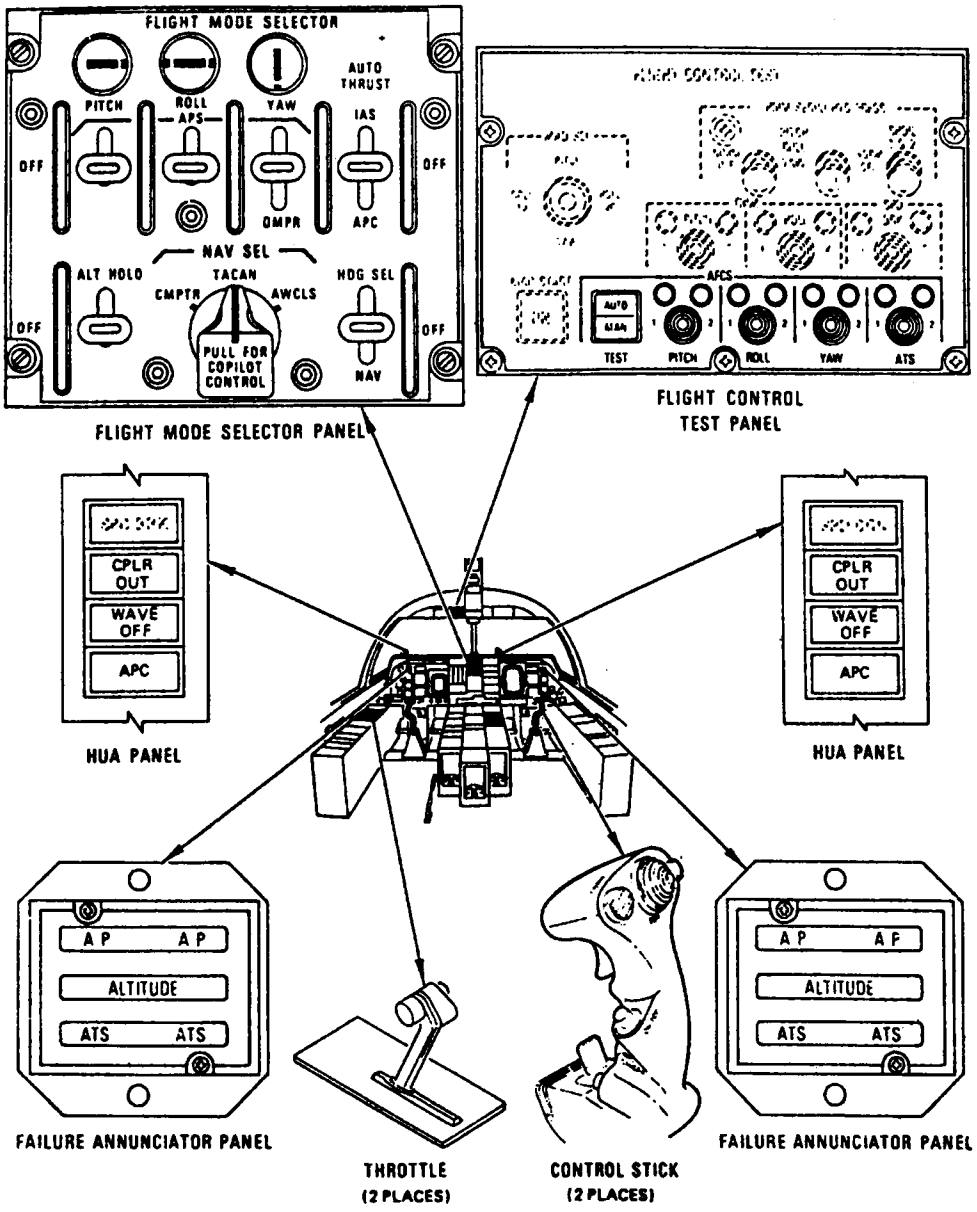
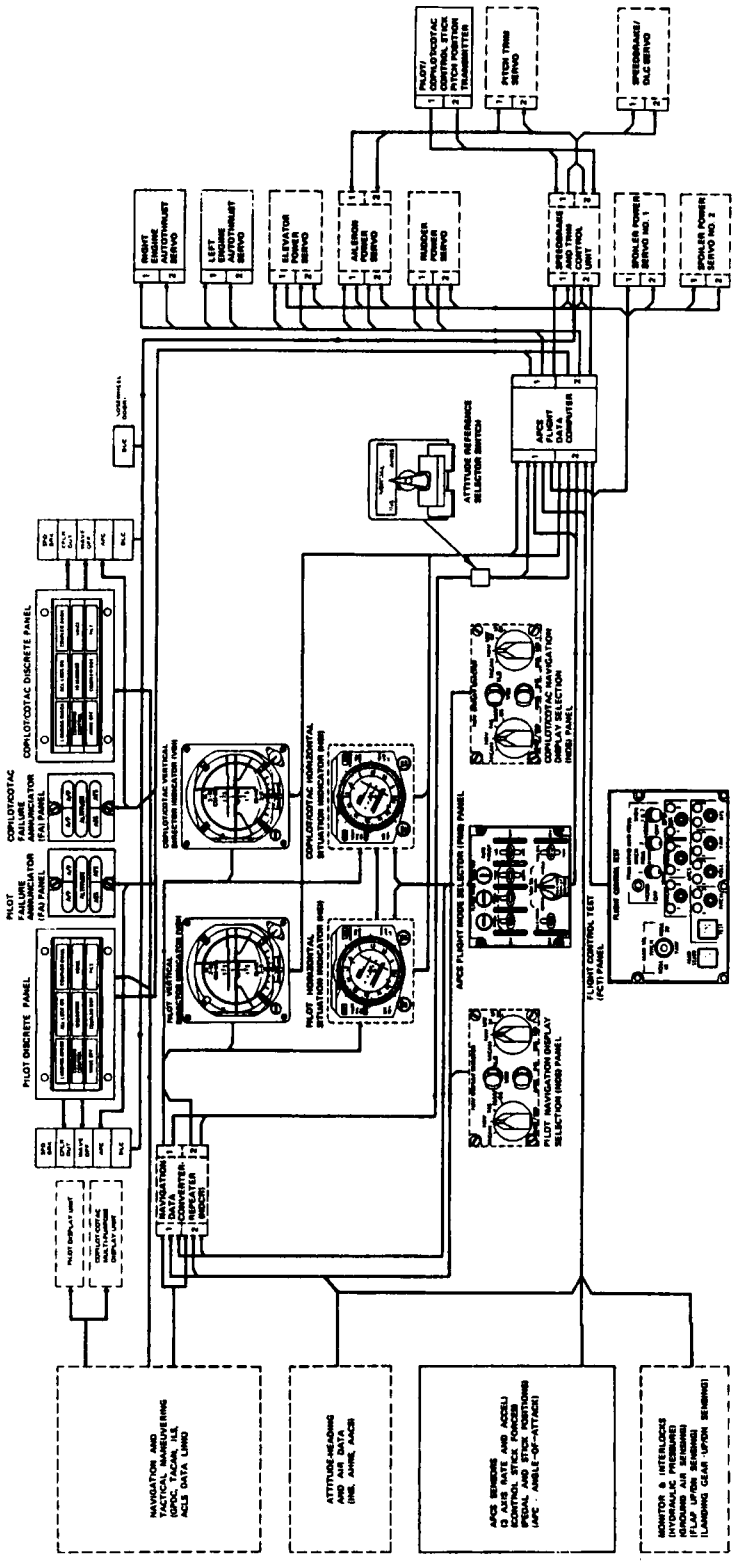


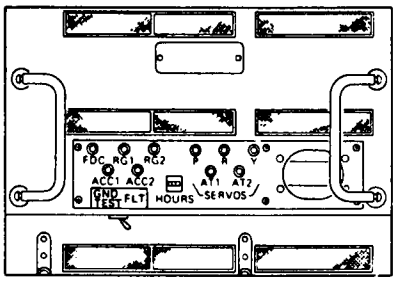
Figure B-5
AFCS Controls and Displays

Source: NAVAIR 01-S3AAB-1, NATOPS Flight Manual Navy Model S-3B Aircraft, Department of the Navy, 1 October 1993.

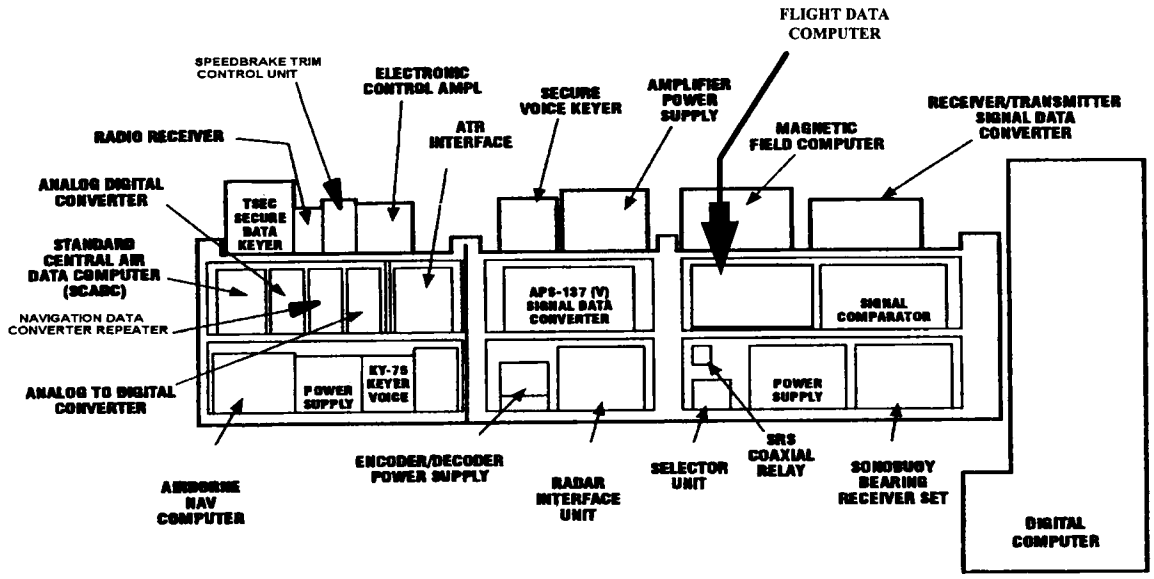


Source: NAVAIR 01-S3AAB-1, NATOPS Flight Manual Navy Model S-3B Aircraft, Department of the Navy, 1 October 1993.

Figure B-6
AFCS System Diagram



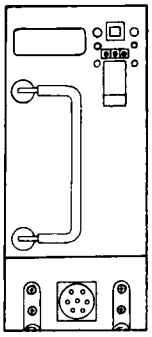
Flight Data Computer



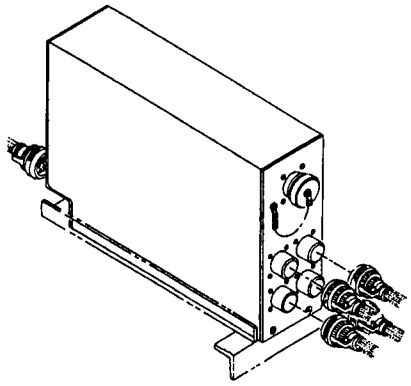
Right Internal Avionics Bay

Figure B-7
Flight Data Computer and Location

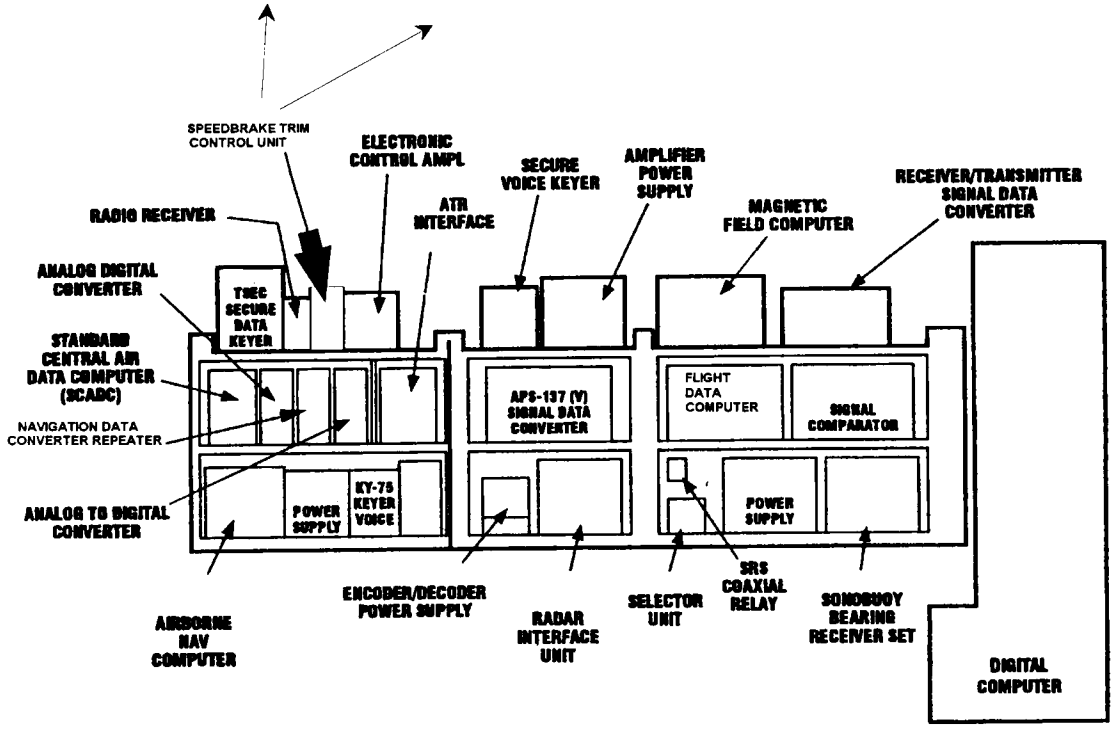
Source: NAVAIR 01-S3AAA-2-2.14, Organizational Maintenance Principles of Operation of the Automatic Flight Control Set AN/ASW-33, Department of the Navy,1 January 1992.



Front



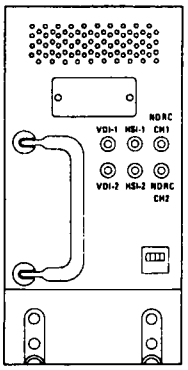
Back



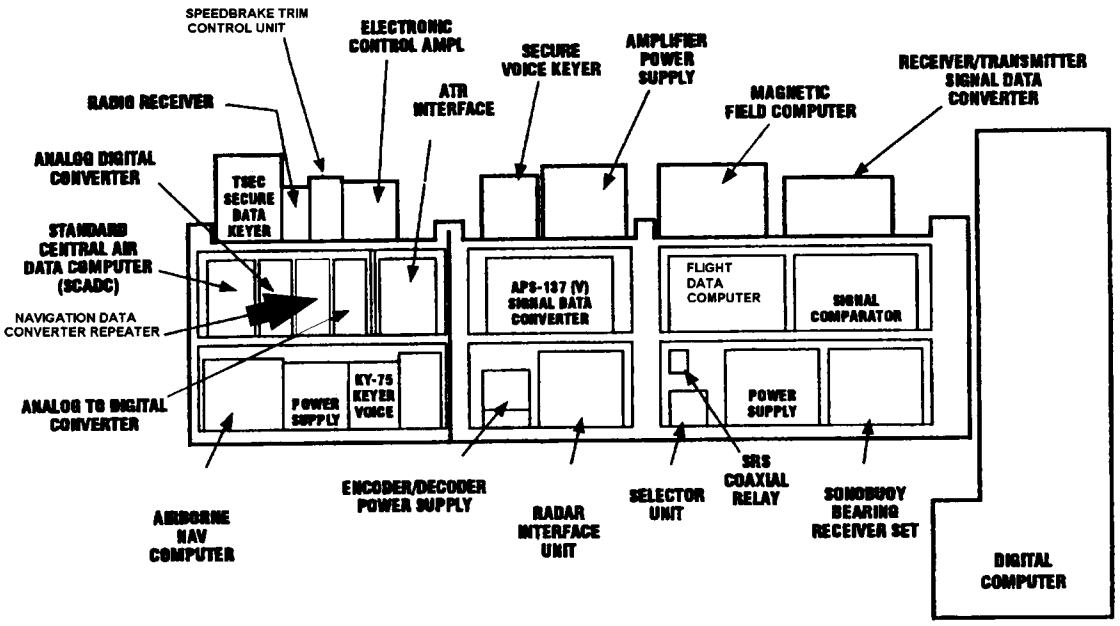
Right Internal Avionics Bay

Figure B-8
Speedbrake Trim Control Unit and Location

Source: NAVAIR 01-S3AAA-2-2.14, Organizational Maintenance Principles of Operation of the Automatic Flight Control Set AN/ASW-33, Department of the Navy,1 January 1992.



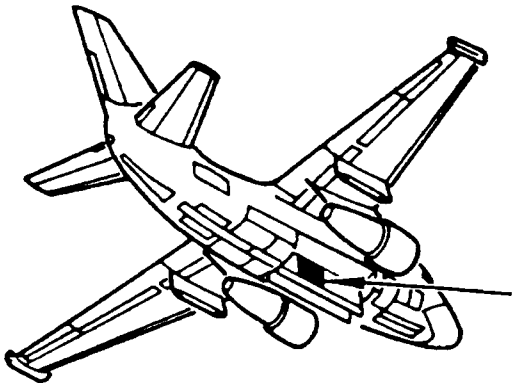
Navigation Data Converter Repeater



Right Internal Avionics Bay

Figure B-9
Navigation Data Converter Repeater and Location

Source: NAVAIR 01-S3AAA-2-2.14, Organizational Maintenance Principles of Operation of the Automatic Flight Control Set AN/ASW-33, Department of the Navy,1 January 1992.



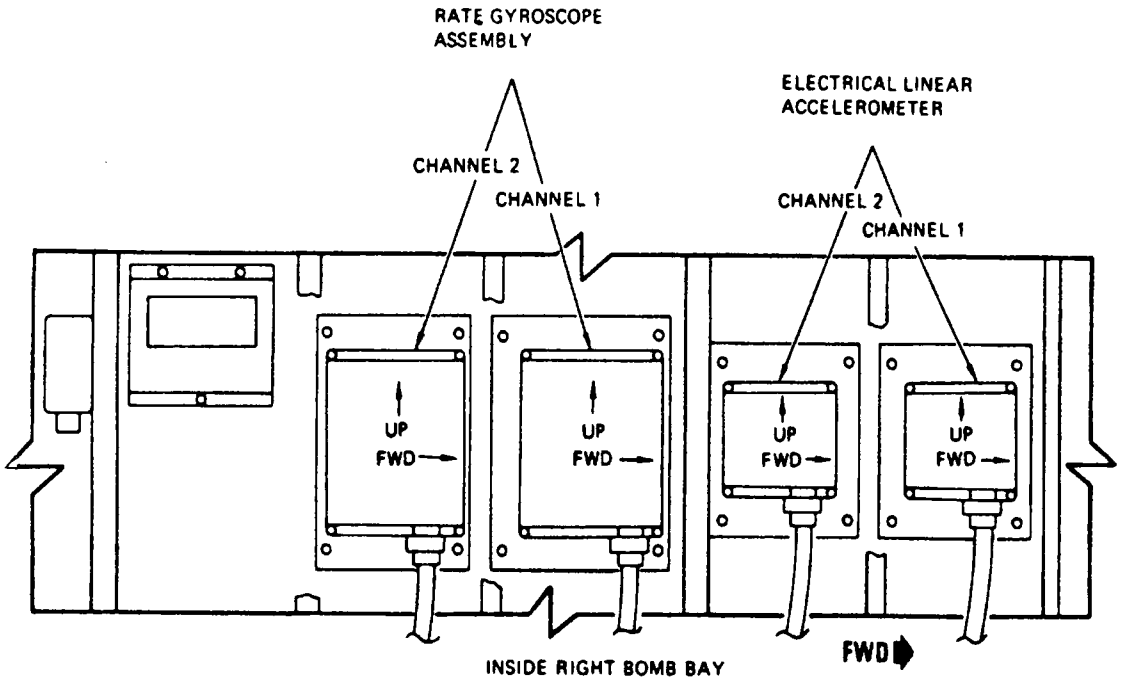


Figure B-10
Rate Gyro and Accelerometer Location

Source: NAVAIR 01-S3AAA-2-2.14, Organizational Maintenance Principles of Operation of the Automatic Flight Control Set AN/ASW-33, Department of the Navy,1 January 1992.

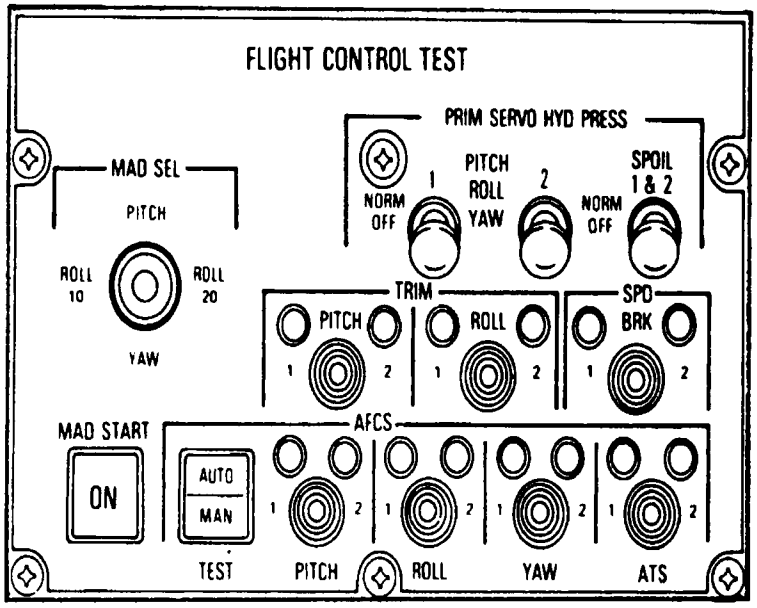


Figure B-11
Flight Control Test Panel

Source: NAVAIR 01-S3AAB-1, NATOPS Flight Manual Navy Model S-3B Aircraft, Department of the Navy, 1 October 1993.

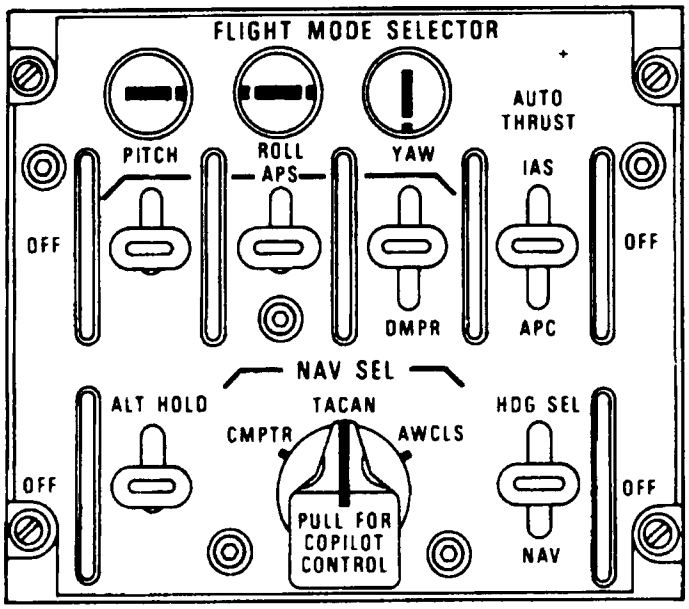


Figure B-12
Flight Mode Selector Panel

Source: NAVAIR 01-S3AAB-1, NATOPS Flight Manual Navy Model S-3B Aircraft, Department of the Navy, 1 October 1993.

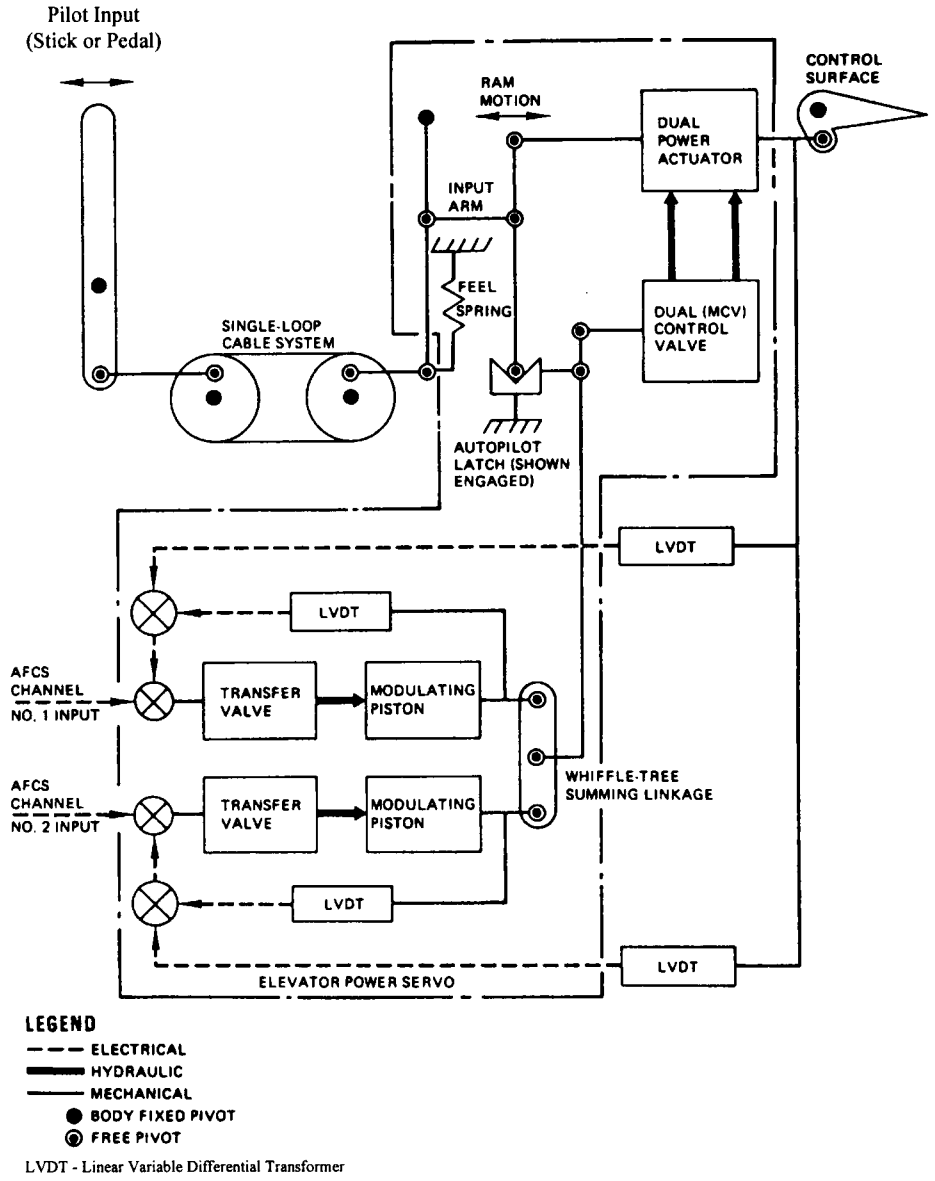
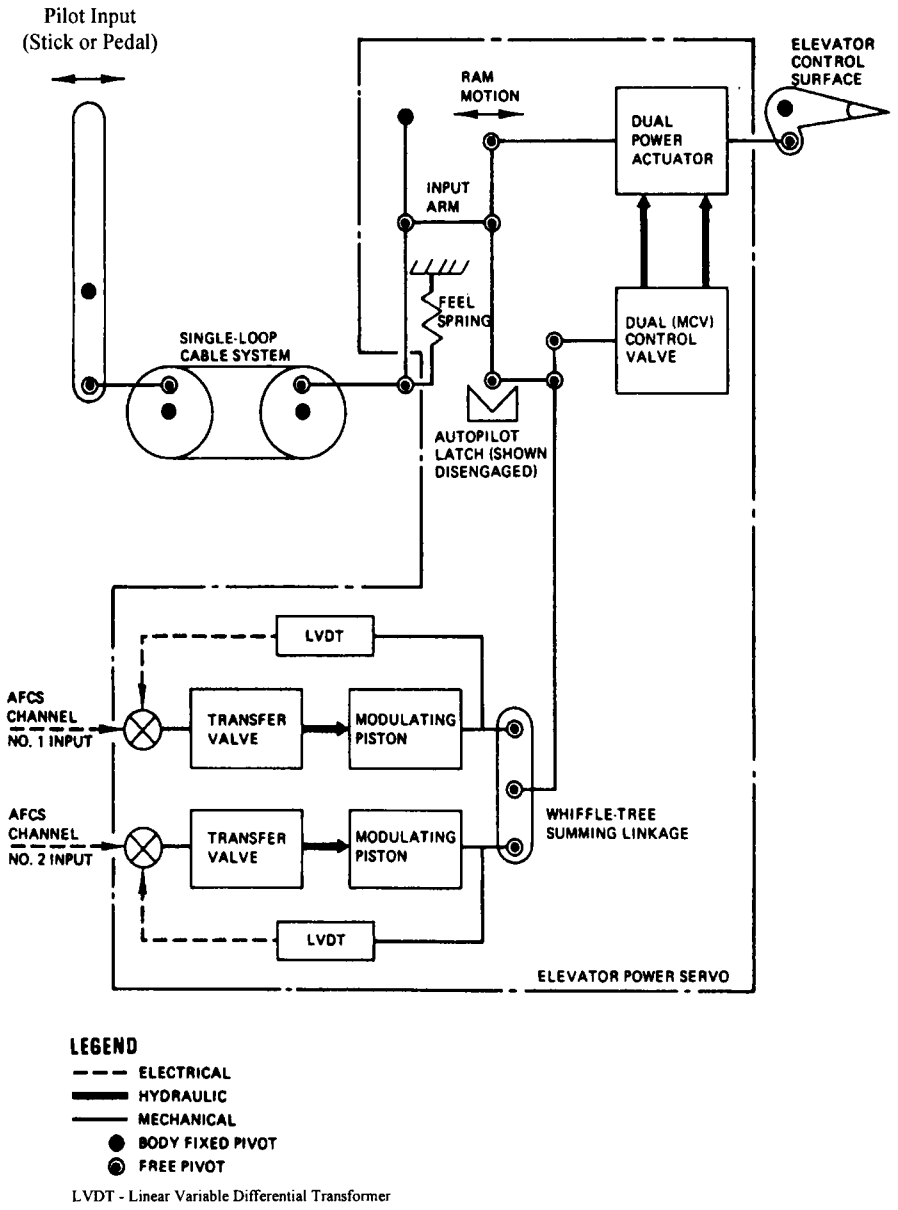


Figure B-13
AFCS Parallel Mode Block Diagram

Source: NAVAIR 01-S3AAA-2-2.14, Organizational Maintenance Principles of Operation of the Automatic Flight Control Set AN/ASW-33, Department of the Navy 1 January 1992.



LVDT - Linear Variable Differential Transformer

Figure B-14
AFCS Series Mode Block Diagram

Source: NAVAIR 01-S3AAA-2-2.14, Organizational Maintenance Principles of Operation of the Automatic Flight Control Set AN/ASW-33, Department of the Navy 1 January 1992.

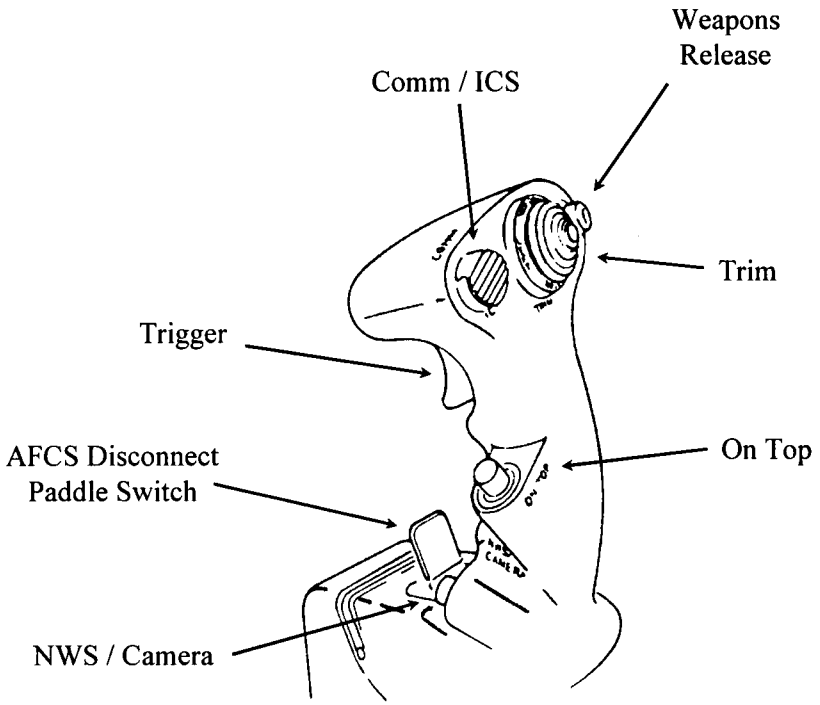


Figure B-15
Aircraft Control Stick

Source: NAVAIR 01-S3AAB-1, NATOPS Flight Manual Navy Model S-3B Aircraft, Department of the Navy, 1 October 1993.

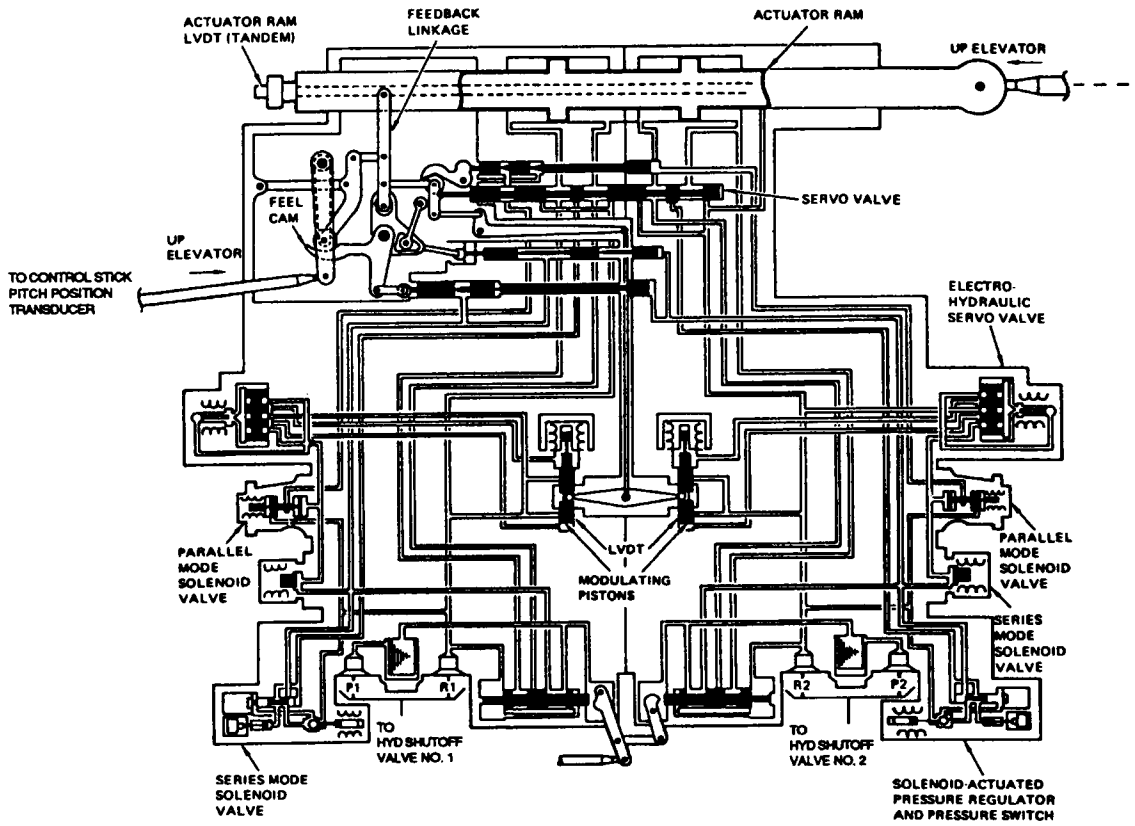


Figure B-16
Typical Elevator Servo Showing
Engaged Solenoid Valves and Electro-Hydraulic Valve

Source: NAVAIR 01-S3AAA-2-2.14, Organizational Maintenance Principles of Operation of the Automatic Flight Control Set AN/ASW-33, Department of the Navy, 1 January 1992.

VITA

Arthur Douglas Waurio was born in McHenry, Illinois on 17 June 1964. He is a native of Bessemer, Michigan and graduated from A.D. Johnston High School in May 1982. That following summer, he entered Great Lakes Maritime Academy at Northwestern Michigan University in Traverse City, Michigan. In August of 1983 he transferred to State University of New York Maritime College. On 10 May 1987, Arthur received a Bachelor of Engineering degree in electrical engineering, a Third Mate's Coast Guard License, and was commissioned as an Ensign in the United States Navy. In August of 1987 he started flight school and then received his "Wings of Gold" and was designated a Naval Aviator on 7 July 1989. After completion of Fleet Replacement Pilot Training he reported to VS-30 in Jacksonville, Florida in July 1990. From August, 1990 to March, 1991, he was deployed with Carrier Air Wing 17 on the USS Saratoga in direct support of Operation Desert Shield and Desert Storm. He made a second deployment on the USS Saratoga in May of 1992 that returned November of 1992 after supporting Adriatic operations in Bosnia-Herzegovina.

He was accepted to United States Naval Test Pilot School at Patuxent River, Maryland and started in class 105 in June 1993. After graduating in June 1994, he was assigned as S-3B Test Pilot and Project Officer at Naval Force Test Squadron which is part of the Naval Air Warfare Center Aircraft Division at Patuxent River. Arthur enrolled in the Masters of Science program at the University of Tennessee, Knoxville in 1994 where he intends to receive a Masters degree in Aviation Systems. He has accumulated over 2000 flight hours, 283 carrier arrested landings, and flown 25 different aircraft. Arthur currently resides in Patuxent River, Maryland with his wife, Pamela, and two sons, Matthew and Nicholas.