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A FULL AUTHORITY DIGITAL ELECTRONIC CONTROL SYSTEM FOR MULTI-ENGINE ROTORCRAFT

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ABSTRACT

Conventional engine control systems for turbine-powered rotorcraft have become increasingly complex in the process of striving for optimized performance of the power plant and aircraft. Traditionally, the only method of achieving this goal was to increase the level of functional sophistication within the control through nonelectronic techniques.

Using a proposed RAF application as an example, this paper reviews the basic requirements and need for incorporation of a full authority digital electronic control system on an existing twin-engine military helicopter. The unique selection process and component configuration are discussed which involved international collaboration among several organizations utilizing the latest concepts in electronic technology. The technical details and functional performance of the digital electronic control system are described relative to fulfilling the particular requirements of a tandem rotor helicopter. Finally, operational and installation features of the engine control system, such as reliability, maintainability, diagnostics, history recording, health monitoring, aircraft incorporation and cost-of-ownership are summarized to ensure that the original design philosophy and goals of the program would be satisfied.

1. INTRODUCTION

For approximately thirty years, regulation and operation of gas turbine-powered rotorcraft have been satisfactorily accomplished with hydropneumatic and hydromechanical engine control systems. However, during this time period, the natural evolution of fuel control systems produced mechanical and electronic hybrid descendents that became significantly more costly and complex than their ancestors. Designers have also discovered there is a practical limit to the level of sophistication for these control systems relative to installation volume, weight, accuracy constraints, and more importantly, the inability to implement complex control functions or to provide an interface with aircraft requirements.

As an example, a typical multi-engine rotorcraft, utilizing state-of-the-art hydromechanical control systems, may exhibit the following limitations or problems:

- Marginal starting during hot relights and cold ambients
- Slow or mismatched engine acceleration time
- Engine compressor stall or surge
- Mismatch of engine torques under load
- Rotor speed droop during transient maneuvers
- No safety features or failure mode protection
- Lack of self-check or diagnostic capability
- No engine fault history recording
- High pilot and cockpit workload

A comparatively recent solution to this dilema has been the introduction of the full authority digital electronic control (FADEC) for both fixed and rotary wing applications. For the first time, an engine control system has the capability to provide self-checking and diagnostics, to record and store information, to interface with the real world and to make intelligent decisions based on an accurate transfer of data.

2. SELECTION PROCESS

A unique proposal team collaboration was established among Lycoming, Chandler Evans (CECO) and Hawker Siddeley Dynamics Engineering (HSDE) to offer a state-of-the-art FADEC system using the latest concepts in electronic control technology.

CECO was awarded a contract in 1982 to provide a FADEC system for the Lycoming ALF-502 turbofan engine, while HSDE had been selected by Rolls Royce in 1983 to develop and manufacture an electronic control system for the GEM turboshaft engine. CECO and HSDE have been participating in a contractual business arrangement since 1979, wherein they agreed to jointly develop, manufacture and market electronic control systems for both commercial and military gas turbine engines. This arrangement has included a free and open technology exchange between the two companies in addition to protection of proprietary data and selection of place of manufacture. After analyzing system requirements for a multi-engine helicopter, a derivative FADEC system was conceived that represents a technical marriage of the CECO fuel metering unit and the HSDE electronic control unit. In this manner, a user would obtain relevant qualification activity by similarity and "on-shore" commonality of the electronic control.

To take full advantage of this innovative technology, a FADEC technical proposal was submitted to the UK Ministry of Defence (MoD) describing a full authority digital electronic control system for the RAF Chinook HC Mk1 medium-lift helicopter manufactured by Boeing Vertol (Figure 1). The rotorcraft is powered by two Lycoming T55-L-712E gas turbine engines (Figure 2) currently employing conventional hydromechanical fuel controls.

Figure 1
RAF CHINOOK HC Mk1 HELICOPTER

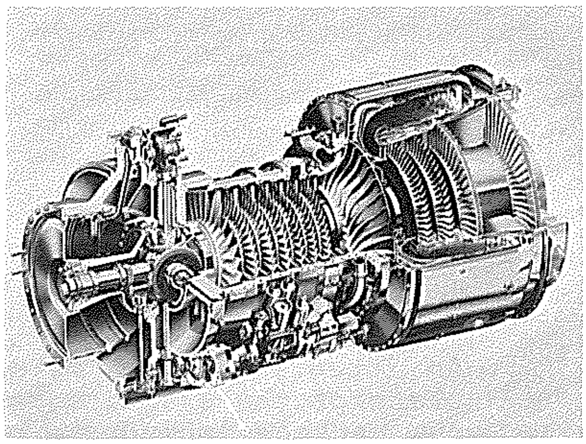


Figure 2
LYCOMING T55-L-712 TURBOSHAFT ENGINE

3. COMPONENT CONFIGURATION

The current engine control system used on the RAF HC Mk1/T55-L-712E application represents a 25 year old design philosophy that has historically exhibited certain limitations or problems. Using state-of-the-art digital technology, the proposed CECO/HSDE Model EMC-32T electronic fuel control system was designed to provide improved functional performance, reduced pilot workload, increased system reliability, reduced maintenance tasks and a significant reduction in cost-of-ownership over the existing control.

The engine-supplied FADEC, shown in Figure 3, consists of three major elements that are designed to minimize the functional and mechanical differences from the existing engine/airframe installation.

- An airframe-mounted digital electronic control unit (DECU) that also contains a built-in diagnostic fault display.

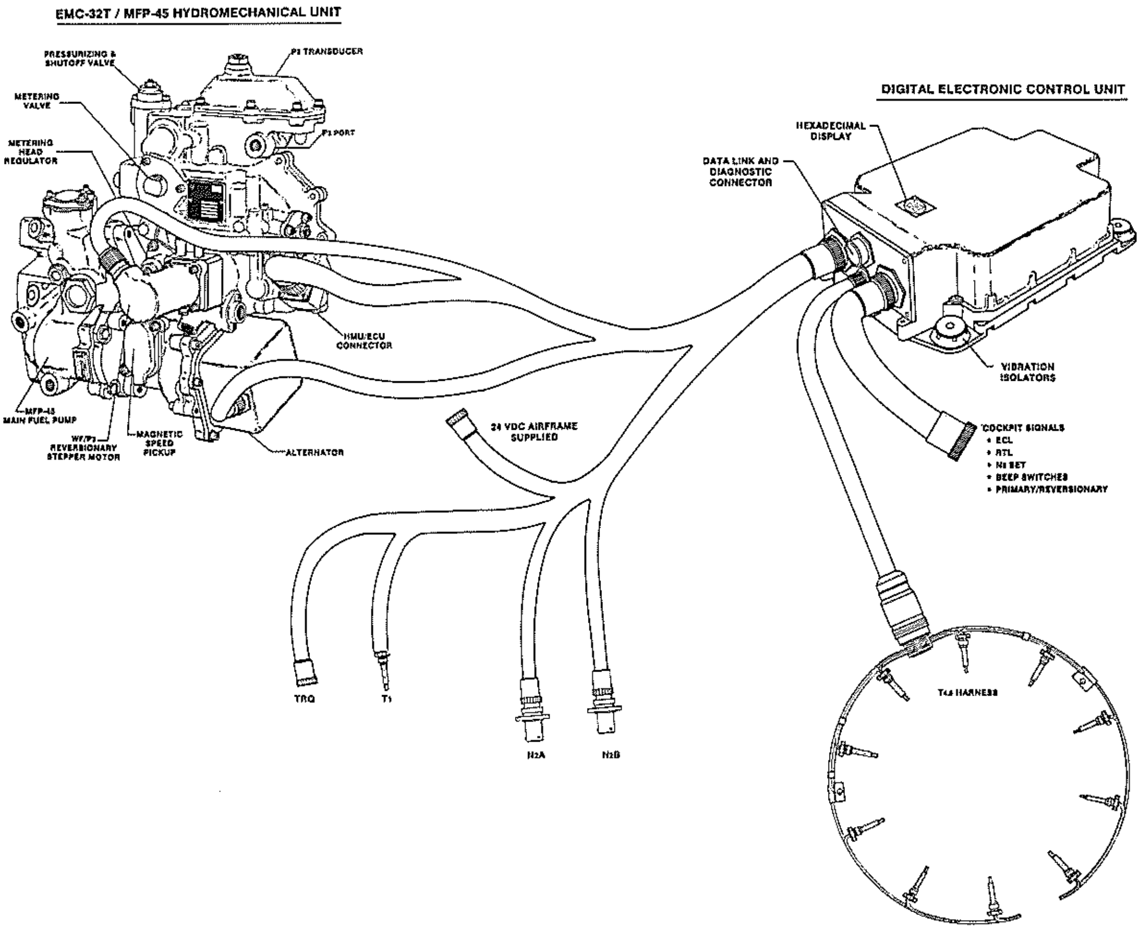


Figure 3 FULL AUTHORITY DIGITAL ELECTRONIC CONTROL SYSTEM

- An integrated fuel metering unit (HMU) which mounts in place of the existing hydromechanical fuel control. The new package includes a gearbox-driven high pressure fuel pump and alternator in addition to an electromechanical primary metering unit and manual reversionary fuel control.

- A set of electrical harnesses which connect the electronic control, electromechanical components, engine sensors and cockpit signals.

The EMC-32T FADEC system, depicted in the block diagram of Figure 4, describes component configuration and shows the relationship between control/engine/airframe interface signals.

The digital electronic control unit will be installed inside the fuselage on the aft cabin side wall utilizing vibration isolators. Connections to the DECU include a compressor discharge pressure (P3) pneumatic signal pressure line and four electrical connectors to the HMU and engine sensors, measured power turbine inlet temperature (T4.5) thermocouple harness, airframe/cockpit signals and serial data communication output port.

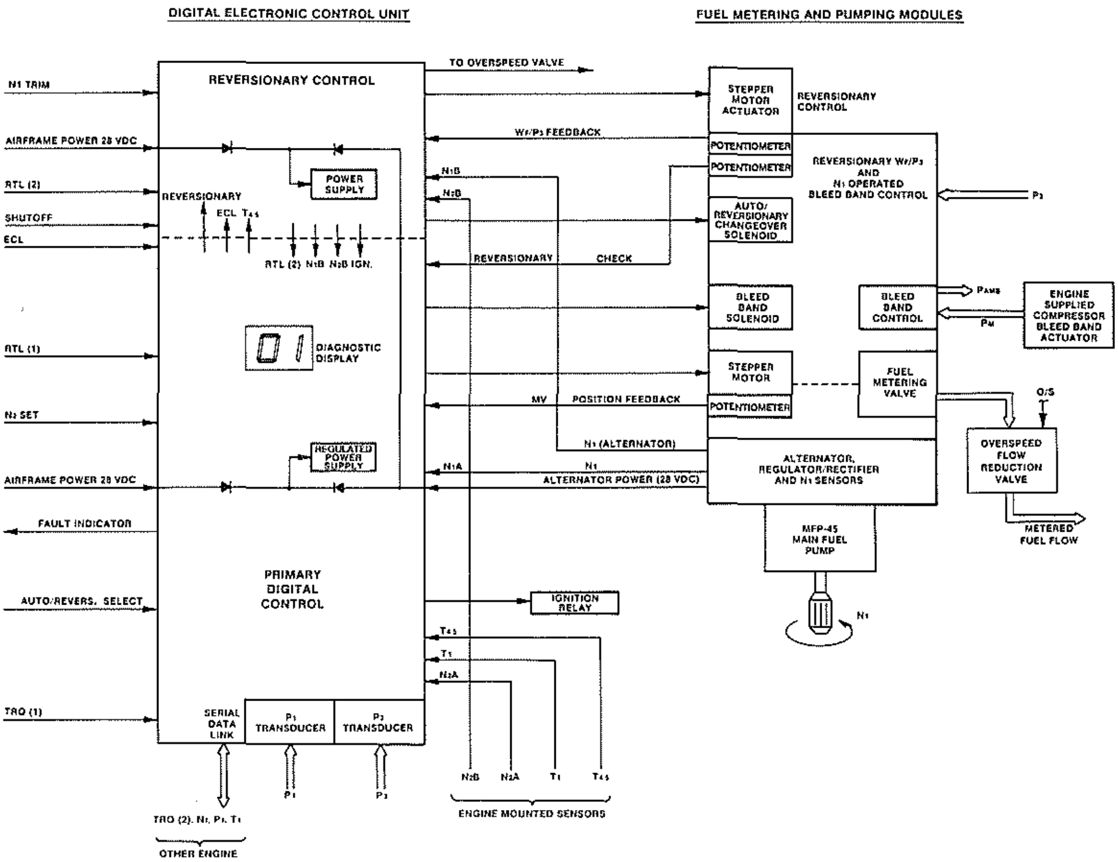


Figure 4 FADEC INTERFACE BLOCK DIAGRAM

The fuel metering and pumping unit mounts on the engine gearbox in the exact location of the present hydromechanical fuel control and fuel pump. Connections to the HMU inlcude three fuel lines at the inlet, discharge and seal drain ports, three electrical connectors for the alternator, reversionary control and primary control, and two pneumatic lines for the P3 sensors and the compressor interstage air bleed actuator signal. With the exception of electrical connectors, only minor changes to the current engine plumbing are required for this installation.

With a few exceptions, all control/engine/airframe interface signals utilize primary and secondary parameters that require virtually no installation changes to the engine or airframe. This is easily accomplished because cumbersome interface hardware can be integrated directly into the FADEC via electrical harnesses.

4. SYSTEM REQUIREMENTS AND FUNCTIONAL PERFORMANCE

The FADEC system will provide all functions available in the current hydromechanical control at a superior level of performance. In addition, it incorporates advanced features to enhance operation and performance of both the T55-L-712E engine and the HC Mk1 helicopter while reducing pilot and cockpit workload.

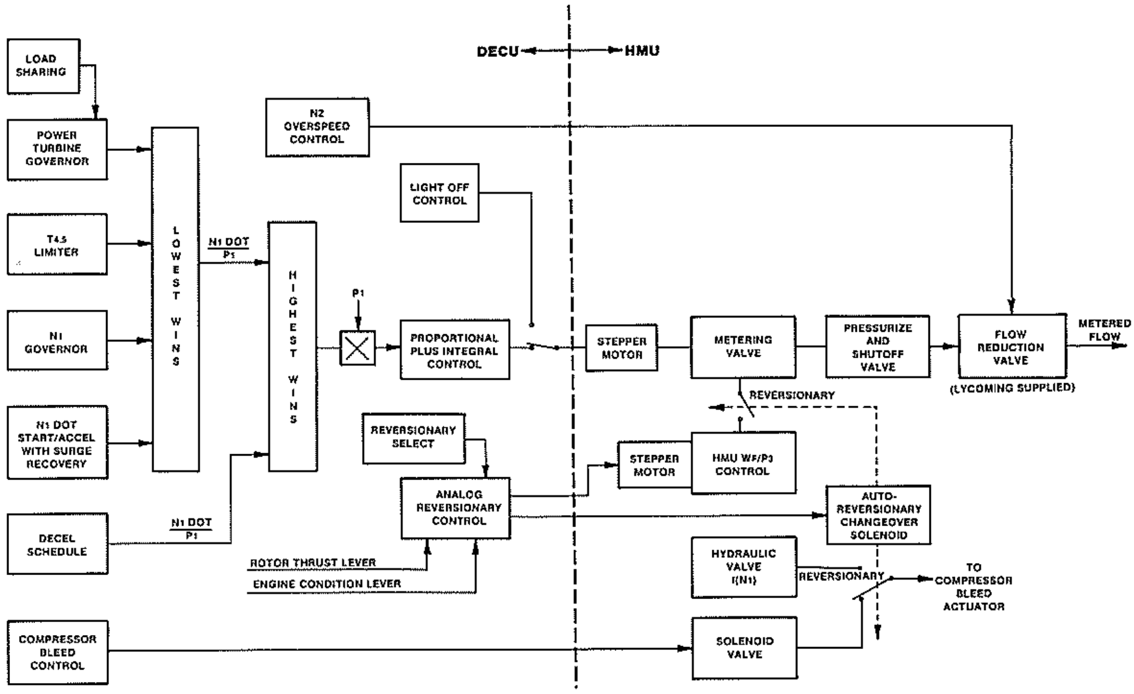


Figure 5 FADEC SIMPLIFIED FUNCTIONAL BLOCK DIGRAM

As shown in the simplified functional diagram of Figure 5, all the control loops of the primary FADEC control are decoupled by lowest/highest wins gates and operate by modulating the demanded engine parameter to a proportional-plus-integral controller. This configuration provides a constant interval, or isochronous control, on all control modes, eliminates the problem of integrator windup and through the proportional action, delivers a fast transition between steady running and transient fuel flow limits to minimize helicopter rotor speed (NR) excursions.

The manual reversionary control modulates the basic engine parameter of fuel flow (Wf) divided by compressor discharge pressure (P3) to provide a ratio unit (Wf/P3) schedule. This parameter is varied by the engine condition lever (ECL) for engine starting and via the rotor thrust lever (RTL) in the flying region. Speed and temperature limiters reduce Wf/P3 to preclude engine surge, overtemperature and overspeed. Therefore, rapid engine power excursions are allowed and considerable aircraft maneuverability is retained with the reversionary control.

Although advantages of FADEC's have been well documented over the years, outstanding performance highlights of the EMC-32T control system are summarized in the following sections.

Engine Starting and Acceleration

Historically, starting has been one of the most problem-plagued areas of the gas turbine engine's operating regime. Stagnated or hung starts, overtemperature and failure to obtain ignition are all problems that continue to occur.

Incorporation of an electronic control system permits engine operation at a near optimum start mode. Control of engine acceleration rate, or time derivative of N1 speed (NDOT) with measured power turbine inlet temperature (T4.5) limiting, inherently overcomes all of the problems stated above. The result is consistent, predictable starts that minimize thermal stresses of hot section components. After operation has been stabilized at idle speed, the control mode for both accelerating and decelerating the engine is an ambient temperature (T1) and altitude-biased (P1) closed-loop acceleration rate control (NDOT/P1). Additionally, an NDOT control is insensitive to fuel type, a hot or cold engine and inaccuracies in the fuel metering system.

Surge Avoidance and Recovery

Gas turbine engines inadvertently experience surge because of inlet distortion, foreign object damage or engine degradation. During surge, a typical NDOT/P1 control tries to overcome the engine hesitation by increasing fuel flow in an attempt to maintain the demanded acceleration rate. This usually drives the engine deeper into surge.

However, in the EMC-32T control, the time derivative of compressor discharge pressure (P3DOT), is used to detect the onset of surge. When P3DOT drops during an engine acceleration or NDOT stagnates during a start, a surge detector circuit is activated. The compressor bleed valve is snapped open, the engine is decelerated momentarily and then reaccelerated to the new operating condition at a rate proportional to the severity of the surge. When the new steady state condition is achieved, as detected by stabilized operation on the N1 speed governor, the surge detector is reset and normal operation resumes.

The FADEC acts to avoid surge through its precise control of the engine during the transient conditions where surge is most likely to occur. Altitude and inlet temperature compensation of the closed-loop NDOT control mode, together with the closely coordinated control of the compressor interstage bleed, provide maximum surge margin for the engine throughout the flight envelope. These techniques have been thoroughly demonstrated during flight testing of the ALF-502 turbofan derivative of the T55 turboshaft engine.

Power Turbine Speed Governing and Control

An increasing amount of evidence has been accumulated in recent years which strongly suggests that current engine control systems have caused pilots to be hesitant about flying a helicopter to the designated safe limits of its capability. Excessive transient rotor speed droop, delayed engine torque recovery, large settling rotor speeds and torque overshoots significantly increase pilot workload.

To overcome these problems, the FADEC system selects rapid anticipation of power recovery and provides fast transition from the isochronous steady running line to the engine acceleration/deceleration fuel flow limits. Equally important to helicopter handling qualities is a smooth engine torque application. Therefore, control system gains must be high to restrict rotor speed droop, but also need to be low at specific times to preclude transient excursions which also affect pilot workload.

Torque Sharing and Power Management

A majority of twin engine helicopters use hydromechanical or electromechanical devices to manage power and limit available torque with varying degrees of accuracy and repeatability.

Communication of electrical torque meter signals from each engine allows the electronic control to provide accurate and responsive torque matching and limiting functions. Twin-engine torque sharing is accomplished by upgrading the speed demand to the isochronous power turbine governor of the low torque engine. This causes the low torque engine to spool up in power disrupting the torque balance on the rotor system. The resulting increase in rotor speed spools down the high torque engine via the power turbine speed control loop until both engine torques are matched at the reference rotor speed. By always upgrading the low engine via the torque sharing channel, a high torque engine can never be spooled down to match a deteriorated or failed engine.

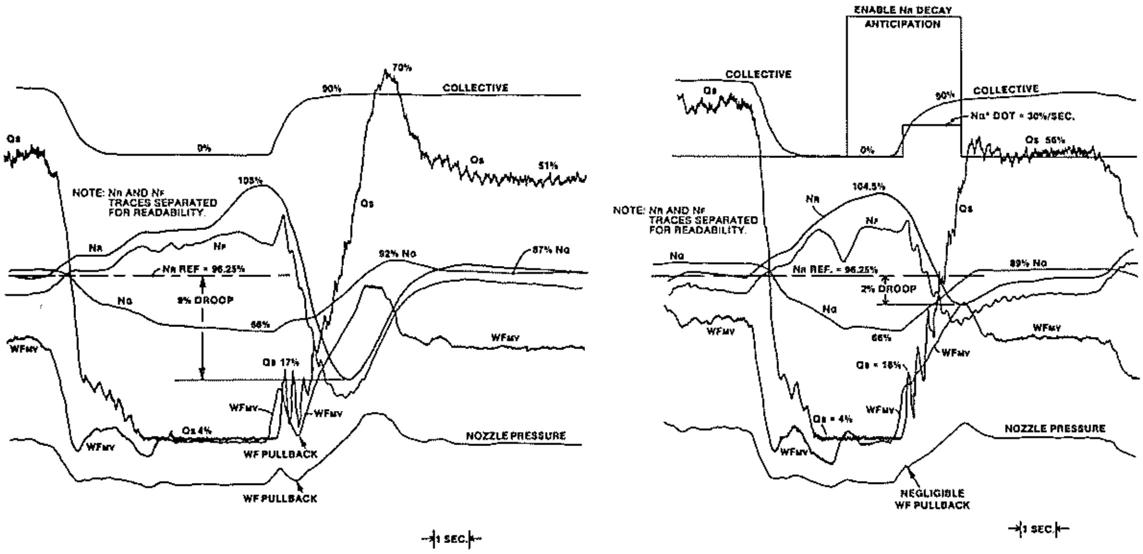
Backup protection is provided by matching gas generator speeds. Therefore, if a torque signal should fail, both FADEC systems switch over to the N1 speed sharing mode which operate in an identical manner to that described above.

Helicopter Rotor Thrust Control

Sophisticated control logic is required for optimized performance during various transient maneuvers such as waveoffs or rollouts following a quick turn which require a significant power recovery from split torque needles. To prevent rotor droop, the engine must be accelerated in the presence of an overspeeding but decaying rotor speed.

The control resolves this problem by utilizing the decoupled decay rate of rotor speed (NRDOT) to proportionately demand a gas generator acceleration rate during and immediately following a split needle condition. By utilizing rotor speed decay anticipation, a considerably improved transient rotor speed control system can be obtained. The proposed NR rate anticipator does not attempt to predict rotor load, it simply gives the engine a head start and then allows the more intelligent governor logic to assume control.

Recent flight testing of an advanced technology CECO FADEC system has demonstrated the effectiveness of this approach. Representative engine traces are shown in Figure 6, comparing the rotor decay anticipation feature with the baseline control operation.



WAVEOFF FROM AUTOROTATION WITH THE BASELINE FADEC CONTROL

WAVEOFF FROM AUTOROTATION WITH ROTOR DECAY ANTICIPATION

Figure 6 ROTOR SPEED DECAY CHARACTERISTICS

Reversionary Control

An analog electronic reversionary control with hydromechanical backup is provided in the unlikely event of a failure of the primary digital control. The reversionary control modulates required engine Wf/P3 ratio units via a dedicated stepper motor in the HMU which is optimized by analog electronic trimming devices.

Switchover to the reversionary control is accomplished manually via a cockpit switch or automatically when the primary control registers a hard fault. In either case, the primary metering valve stepper motor is deenergized, thereby holding fuel flow, and engine power, "frozen" at the present operating condition. In the fly region, the reversionary stepper motor is immediately driven to the rotor thrust lever (RTL) scheduled Wf/P3 value which tracks the current operating condition of the engine. Engine transient overshoots at switchover are held to a minimum by the RTL load-matching schedule.

In the start mode, engine fuel flow is modulated by the engine condition level (ECL) versus Wf/P3 schedule. The full range of ECL motion is used to insure desensitized modulation, and the T4.5 and T4.5DOT limiters are in place to preclude hot starts.

To summarize, the reversionary analog and manual backup control provides full engine power modulation, surge, overtemperature and overspeed protection, and incremental N1 speed trimming to compensate for various operating conditions, including deteriorated or damaged equipment. Therefore, the pilot has the capability to pull rapid RTL maneuvers and retain considerable aircraft maneuverability while in the reversionary mode.

5. TECHNICAL DESCRIPTION

Digital Electronic Control Unit

The digital electronic control unit (DECU) will be installed within the fuselage on the aft cabin side wall and vibration isolators provide damping at the mounting points. The DECU is of rugged construction, designed for use in the airframe-mounted environment. Conformal coating of the printed circuit boards and flexible interconnections between the boards are among the design features incorporated to provide vibration protection. A design summary of the DECU is listed in Table I.

The electronic assembly shown in Figure 7 is housed in an environmentally sealed cast aluminum enclosure. It has been designed to withstand an operational ambient range from -54 degrees C to +85 degrees C. The DECU is designed to meet the Electromagnetic Compatibility (EMC) requirements of MIL-STD-461B and FS(F) 510. The aluminum enclosure provides shielding for the circuit boards and internal components, while a ground strap maintains an electrical ground path from the enclosure. EMC filtering is used to bypass all electrical transients and noise. Internal shielding provides isolation between EMC filtering, power supply and control circuit areas. Protection against lightning induced transients is through the selection of filtering components with sufficient surge ratings.

The DECU interfaces with the engine, HMU and airframe to control fuel flow through stepper motor positioning of the metering valve in the HMU. The electronic control contains all input and output signal processing circuitry, digital microprocessor, power supplies, pressure transducers, etc., required to provide the specified control functions. These primary functions are implemented through a programmable digital computer. The Intel 80186 microprocessor has been chosen as the central processing unit (CPU) for the system and it operates at a 6 MHz clock rate and offers a full 16-bit data bus and 20-bit address bus. Computations required for the various control funtions are performed sequentially with the computer program directing the controller to scan the input signals, make calculations and supply output commands in a predetermined order.

Interface circuits between sensors and the microcomputer convert both analog voltage and frequency signals into digital form for use by the microprocessor. Analog voltage signals are routed via a multiplexer under microprocessor control to an analog-digital converter. Engine inlet pressure (P1) and compressor discharge pressure (P3) are measured by transducers within the DECU and their signals are fed to the CPU via this interface route.

Table I DESIGN SUMMARY
Digital Electronic Control Unit

Weight	10.7 lbs. (4.9 Kg)
Installation	Airframe-mounted, vibration isolators at mounting points.
Construction	Cast aluminum housing and cover with EMI seal
Ambient Temperature	-54 Degrees C to +85 Degrees C
EMC, Lightning Compatibility	Per MIL-STD-461B and FS(F) 510
External Connectors	MIL-C-83723, Series 3
Power Supply	Switching mode pulse width modulated type using stamped aluminum shield.
Circuit Boards	Four multilayer boards
P1 Transducer	Semiconductor strain gage
P3 Transducer	Bonded strain gage bridge
Internal Connections	Multilayer flexible cables
Reversionary Control	Electronic RTL vs. Wf/P3 with T4.5 over-temperature limiting.
Computer	Intel 80186 Microprocessor based design
RAM	2K x 16 Bits, expansion to 4K
ROM	16K x 16 Bits, expansion to 32K
EEPROM	2K x 8 Bits
Diagnostic Display	2 Hexadecimal digits
Serial Communication	Via RS423 data port
Overspeed Protection	Interface with engine fuel reducing valve

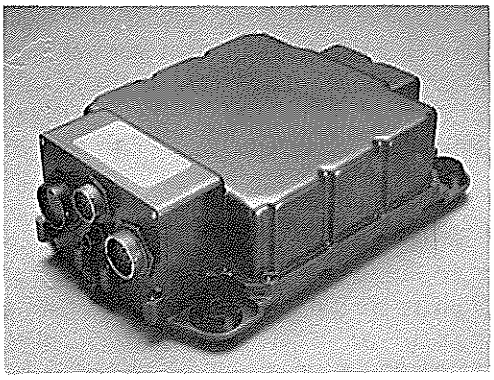


Figure 7
DIGITAL ELECTRONIC CONTROL UNIT

Fault information is stored by the processor in electrically alterable read only memory (ROM) during engine operation. Readout of this stored information by maintenance personnel will materially assist in the identification and correction of faults existing or experienced during the last engine run. The fault identifying readout is in the form of a two-digit, hexadecimal display visible through a transparent window in the DECU case.

Engine operational history data is maintained within the DECU and available through an RS423 serial communication port. Among the data available is:

- Total engine operating hours
- Number of engine starts
- Duration and extent of engine limit exceedance values

Such data may be logged, reset or entered, via the RS423 link, as required by both engine and DECU maintenance schedules.

Ground testing of the DECU is carried out using the RS423 serial port connected to a compatible terminal. This terminal will be able to invoke built-in test routines for the purposes of interrogating the fault store and displaying raw or processed parameter information.

Fuel Metering Unit

The new fuel metering and pumping unit (HMU), shown in Figure 8, mounts on the engine gearbox in the exact location of the present hydromechanical control. The HMU installs as a piggyback arrangement consisting of the CECO EMC-32 fuel metering unit and MFP-45 main fuel pump, which includes a three-phase alternator. A design summary of the HMU is listed in Table II.

Table II DESIGN SUMMARY

Hydromechanical Unit

Weight	31.6 lbs. (14.4 Kg)
Installation	Engine-mounted, in place of current hydromechanical control.
Gear Pump Rating	8,100 PPH at 700 PSID 100% N1 (4,200 RPM) 675 PPH at 150 PSID, 10% N1 (420 RPM)
Boost Stage	Pressure Regulated Jet Inducer 770 - 9,260 PPH
Dry Lift	*1 Foot minimum* at 15% N1
Vapor Liquid Ratio	0.45 at engine inlet
Metering Valve:	Rotary flat plate design
• Rating	0 - 2,470 PPH
• Electromechanical Drive	4-phase stepper motor (2)
Compressor Air Bleed:	
• Automatic Mode	Solenoid Valve
• Reversionary	Hydromechanical valve

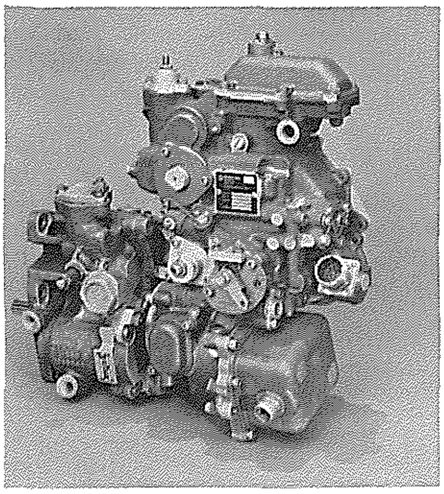


Figure 8
HYDROMECHANICAL CONTROL UNIT

N1 Engine Speed Sensing:	
• Primary	Magnetic Sensor
• Secondary	Alternator winding
• Reversionary	Hydromechanical
Reversionary Control	Automatic or pilot-selected. Maximum and Minimum Wf/P3 and P3 Limits versus RTL. Protection in both automatic and reversionary modes.
Alternator	Integral voltage regulator that meets power requirements at idle and above.

The MFP-45 pumping unit is a jet-induced gear pump, qualified for use on the ALF-502 engine. Over 250 of these pumps have been delivered in production. The pump includes a single-element gear stage, jet inducer, high pressure relief valve, a self-relieving control bypass screen and a bypass pressure regulator which maintains proper pressure levels for jet pump operation. Materials were selected based on CECO's successful experience with several high-production, high-time pumps.

The heart of the primary fuel metering section is the stepper motor-operated flat plate metering valve. The flat plate rotary metering valve is an inherently contaminant insensitive device by virtue of its wiping action. Valve position is measured by a potentiometric transducer and fed back to the DECU for closed-loop control. This design eliminates the close fitting, contaminant sensitive and expensive parts normally associated with servo operated spool-type metering valves. It improves reliability by minimizing fuel contamination problems and by eliminating the additional hardware associated with high performance torque motor-operated electrohydraulic servos. Moreover, adding 100 pounds per hour (PPH) to the pump capacity at cranking speed to support a servo, increases pump power dissipation by over 1 HP at rated speed.

The reversionary fuel metering mechanism operates to schedule Wf/P3 as a function of the rotational position of the stepper motor. The scheduled Wf/P3 is then multiplied by P3 to give altitude sensitive control of engine metered fuel flow (Wf). This function is performed at high force levels through the use of fuel operated Wf/P3 and P3 servomechanisms and a mechanical multiplier. The multiplier output, representative of fuel flow, drives the metering valve to the desired angular position, thereby providing proper metered fuel flow to the engine. The reversionary mode is automatically activated upon fault detection or loss of electrical power or it can be selected by the pilot via a cockpit switch.

A three-phase alternator provides the control system with a dedicated power source. A rotor and stator, together with separate rectification and power conditioning, provide electrical power for the fuel control electronics unit and associated electromechanical actuators. The alternator is integrally mounted on the HMU package to minimize volume and weight. Included in the alternator package is an independent single phase speed sense winding for N1 speed sensing.

The compressor interstage air bleed control operates to vent the signal pressure in the control chamber of the engine-mounted bleed band actuator. Control is provided in either the primary or reversionary mode of operation by two ball valves arranged in series to vent the air bleed actuator signal pressure.

6. OPERATIONAL AND ECONOMIC ADVANTAGES

In addition to providing outstanding operation of the total aircraft/power plant combination by providing precise limiting and protection functions to optimize system performance, the EMC-32T FADEC offers important features not currently available with hydromechanical fuel controls.

Reliability, Maintainability and Diagnostics

FADEC reliability improvements were predicted by using analyses based on the failures rates of similar components currently in service in the same or similar environments, and data from international sources. It has been determined that the proposed FADEC is over five times more reliable than the existing control system.

The incorporation of built-in test and diagnostic features in the FADEC facilitates direct diagnosis and maintenance of both the DECU and electromechanical components within the HMU. Readout, via an alphanumeric, hexadecimal display on the DECU, aids maintenance personnel in identifying faults experienced during the last engine run. More specific fault identification and cumulative fault history can be examined using separate test equipment. The FADEC system provides on-condition maintenance, with no scheduled overhaul time. Additionally, the system offers module interchangeability and the elimination of all field adjustments.

History Recording and Health Monitoring

Provisions have been made within the FADEC for the addition of pre-flight and post-flight engine data gathering features to provide high level engine health monitoring functions.

- Time, temperature and cycle counts for timed bands of engine operation.
- Duration and extent of engine limit exceedance both during normal operation and emergency conditions.
- Engine failure detector warning to reduce pilot reaction time.
- Power to hover assurance check for any specific ambient condition.

This information can be supplied by the FADEC via illumination of cockpit lights on the maintenace panel, interrogation with a comprehensive hand-held diagnostic terminal, or complete extraction of historical data via a serial data communication port connected to a compatible external terminal.

Aircraft Installation

A survey of airframe/engine interface hardware reveals that many electrical components, such as control boxes, actuators, droop eliminators and relays, can be deleted or functionally incorporated within the FADEC system via an electrical harness (Figure 9). To preserve the configuration of the current HC Mk1 cockpit layout, existing instrumentation, engine condition quadrants and thrust control levers have been retained.

Primary pilot functions, such as engine power selection and thrust control, are operationally identical to the present aircraft whereas new secondary functions, such as power turbine speed selection, fault indication lights, and reversionary control switches are incorporated into existing cockpit panels that have been vacated by obsoleted functions (Figure 10). Because airframe modifications will be limited to minor changes within the cockpit, the same operating modes are retained and pilots will not have to go through an extensive retraining process.

1. POWER TURBINE N_2 CONTROL ACTUATOR (2)
2. GAS PRODUCER N_1 CONTROL ACTUATOR (2)
3. ENGINE GAS PRODUCER N_1 CONTROL BOX (2)
4. ENGINE CONDITION CONTROL RELAY (2)
5. EMERGENCY ENGINE CONDITION CONTROL RELAY
6. ENGINE CONDITION CONTROL RESISTOR
7. ENGINE POWER TURBINE (N_2) CONTROL BOX (2)

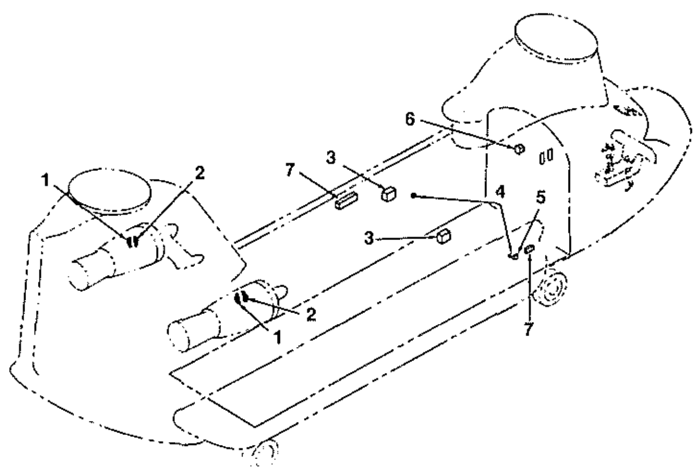


Figure 9 HC Mk1 AIRCRAFT HARDWARE DELETIONS

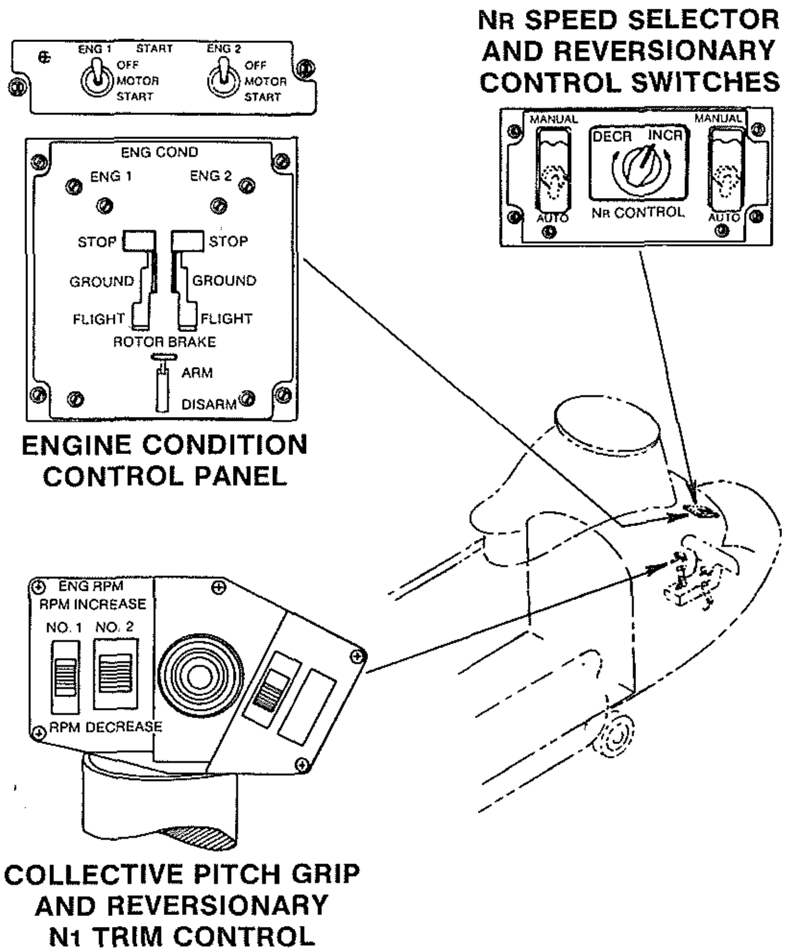


Figure 10 HC Mk1 COCKPIT LAYOUT WITH FADEC

Cost of Ownership

The FADEC unit cost, in the current economy, is approximately half of the cost for the current bill of material control, based on a projections for a typical production buy. Retrofit costs, including harnesses and minor modifications to the cockpit, are predicted to be lower than typical scheduled overhaul costs for the existing hydromechanical fuel control.

A life cycle cost analysis has been completed to compare FADEC system cost-of-ownership relative to the current hydromechanical control. This analysis reflected initial investment as well as operational and support costs of the installed configuration. The inherent maintainability and higher reliability of the FADEC translates to a direct maintenance cost per hour reduction by an order of magnitude. This reduction extends to substantial cost of ownership savings when projected over a 20-year operational life for the current fleet size. Furthermore, substantial savings will be realized for the HC Mk1 aircraft after removing costly and unreliable components from the airframe and incorporating their functions into the FADEC system.

7. SUMMARY

The proposed EMC-32T FADEC system is based on substantially identical units currently being developed and qualified for Lycoming and Rolls Royce engines. Therefore, not only is the technical risk extremely low due to the redundancy of parallel qualification programs, but the user also obtains "on-shore" commonality to the FADEC for an existing UK application.

System safety was paramount in the basic control design. There is a hierarchy of safe failure conditions in the electronics unit that includes a "fail frozen" reversionary mode in the unlikely event of a primary control failure. An automatic transition is made to the manual reversion system that contains compensation for altitude and load demand, in addition to compressor surge recovery.

The FADEC provides on-condition maintenance with no scheduled time between overhaul (TBO), a significant improvement of mean time between defects (MTBD), control system diagnostics, complete component interchangeability, elimination of field adjustments and capability for future functional growth and engine health monitoring functions. All of the above features were incorporated to substantially improve both reliability and maintainability levels over the current hydromechanical control.

Cost of ownership is significantly reduced by offering a low production procurement cost, an even lower direct maintenance cost per hour and a reduced unit repair cost. Total system costs are further reduced by removing expensive airframe/engine interface hardware and integrating these functions directly into the FADEC system.

Incorporating a full authority digital electronic control system on the HC Mk1/T55-L-712E application will allow considerable removal of airframe/engine interface hardware which, in turn, will substantially improve reliability and dispatch capability of the aircraft and reduce pilot workload.

A FADEC system comprised of a functionally simple fuel metering unit and a powerful state-of-the-art digital electronic control unit provides a very cost effective, maintainable and modern technology solution to today's operational problems.