PROPULSION CONTROL TECHNOLOGY

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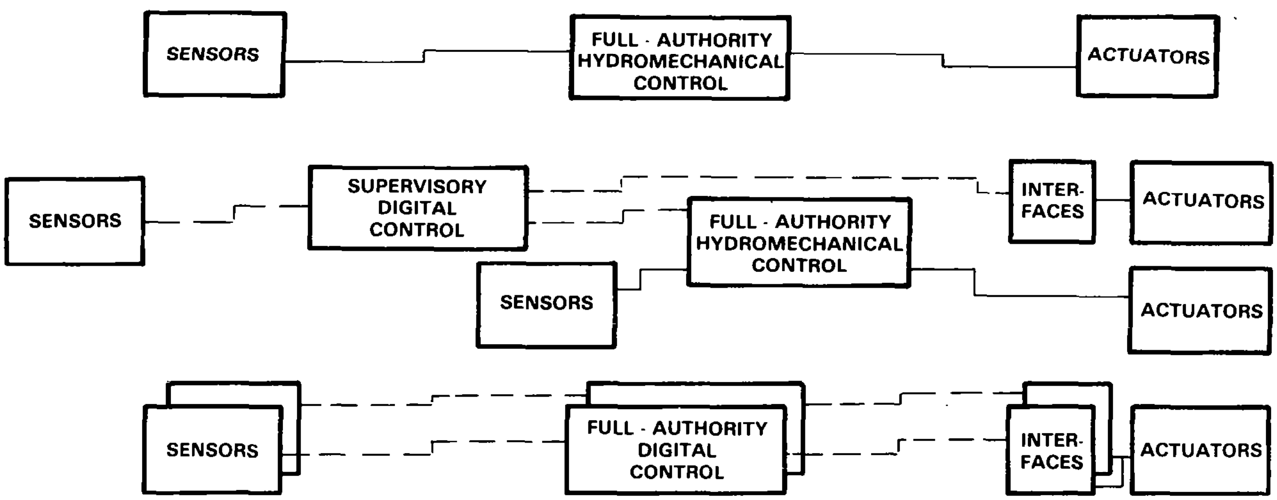
Turbine Engine Control Evolution

Control systems for both commercial and military gas turbine engines are being transitioned in an orderly fashion from pure hydromechanical to full-authority digital electronic control in order to obtain the associated operational and performance benefits. Additional benefits will be available with further advancements in electronic control system technology and through increased integration with aircraft systems. At Pratt & Whitney, supervisory digital electronic control systems are in current operational service, and full-authority digital electronic control systems will be in service on upcoming models of commercial and military engines.



Digital Electronic Control Systems Are Incorporated in Pratt and Whitney Military and Commercial Engines

Supervisory digital electronic control systems are in current operational service on the F100 engine in F15 and F16 aircraft and on the JT9D-7R4 engine in Boeing 767 and Airbus A310 aircraft. Full-authority digital electronic control systems have been developed for the F100 engine, available for future F15 and F16 aircraft and for the PW2037 engine in the Boeing 757. The PW2037 engine and control system will be certified by the end of 1983. Pratt & Whitney is also developing a full-authority digital electronic control system for its new PW4000 engine which will be available for future versions of all wide-bodied aircraft.

Supervisory

- **F100 — F15, F16**
- **JT9D-7R4 — B-767, A310, A300-600**

Full Authority

- **PW2037 — B-757**
- **F100 DEEC — F15, F16**
- **PW4000 — B-767, B-747, A310, A300, MD100**

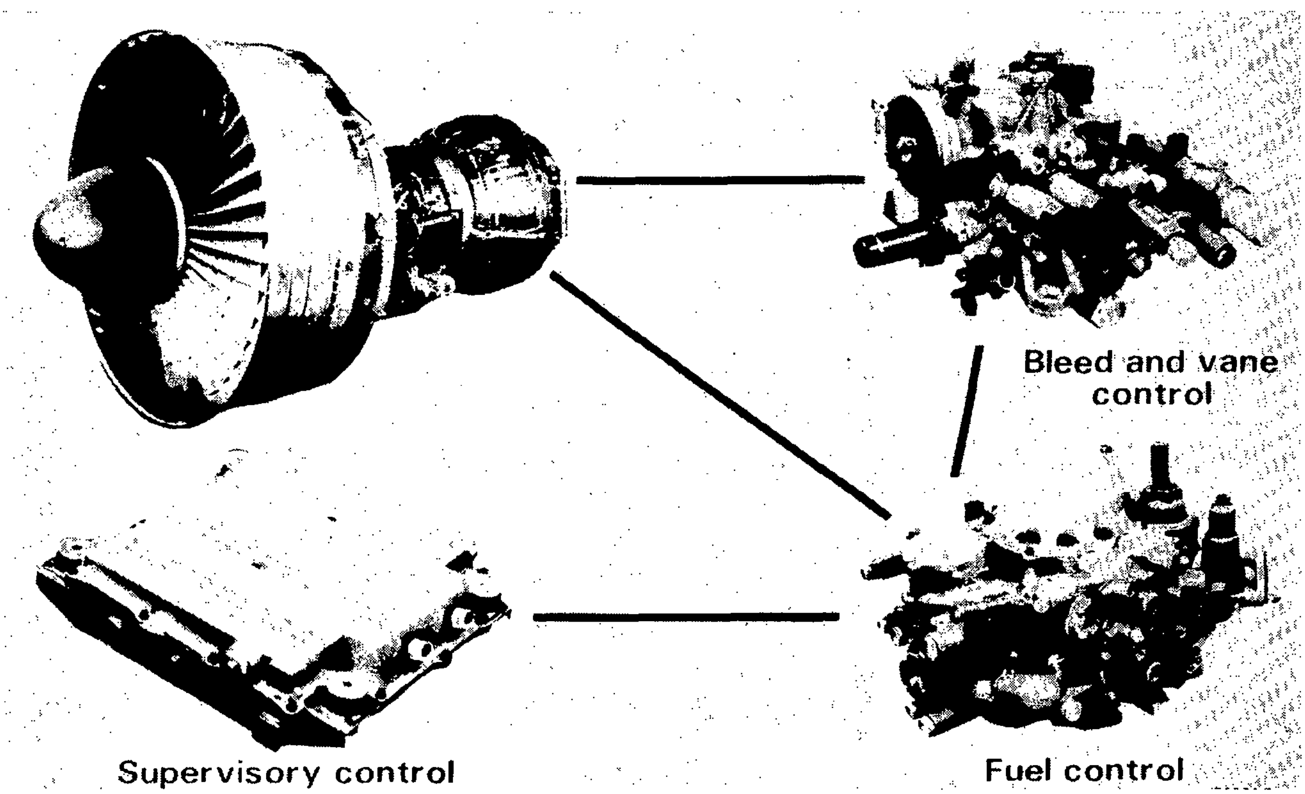
Electronic Control System Has Substantial Experience

Pratt & Whitney's digital electronic control systems have substantial operational and test experience. The current supervisory control system for the F100 engine has over 1.5 million hours of in-service operating time. The JT9D-7R4 engine's supervisory control system, recently introduced into service on Boeing 767 and Airbus A310 aircraft, has over 130,000 hours of operating time in revenue service. Pratt & Whitney has also conducted or participated in, with NASA and the Air Force, a number of electronic control system technology development and demonstration programs dating from the early 1970's. These programs have played a key role in developing digital electronic control system technology to a state of readiness for incorporation in production engines. With the advent of the full-authority electronic control system, continuing technology programs are required to obtain the benefits of control system technology advancements.

F100 supervisory	— 1,500,000+ flight hours, F15 and F16 engines
JT9D-7R4 supervisory	— 767 airline service; 130,000+ engine hours
JT8D EEC reliability evaluation	— 300,000+ hours on 727 aircraft
JT8D EPCS, 1975	— Boeing demonstration at Boardman, Oregon
TF30 IPCS, 1975	— F111 flight test at Edwards AFB
F100 DEEC, 1978	— F100 altitude test at Tullahoma
F401 FADEC, 1979	— F401 altitude test at NASA Lewis
JT9D EPCS, 1980	— 747 flight test at Boeing
F100 DEEC, 1980	— F15 flight test
F100 DEEC, 1983	— F15 flight test
F100 DEEC, 1983	— F16 flight test
PW2037 full authority, 1983	— Ground, altitude and flight test

JT9D Supervisory Electronic Control System

The JT9D-7R4 Supervisory Electronic Control System incorporates a conventional hydromechanical control system coupled with a digital electronic control which trims the hydromechanical control to provide accurate control of the desired engine power setting. Digital communication links with the cockpit provide simplified cockpit power setting procedures. The electronic control for the JT9D engine is mounted on the engine's fan case and is air cooled. Design of the electronic control was completed in the late 1970's, and the engine was introduced into service in 1982 on Boeing's 767 aircraft and in 1983 on Airbus' A310 aircraft. Operation of the JT9D-7R4 control system is similar to that of the F100 supervisory control system.

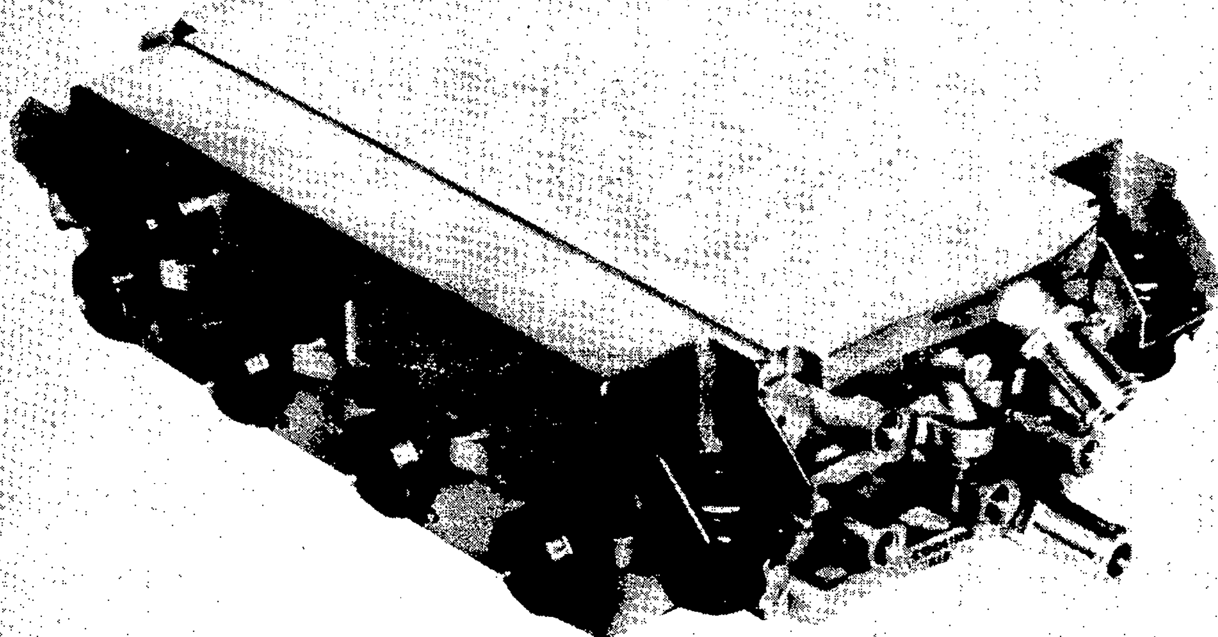


PW2037 Control System

The PW2037 Control System incorporates a dual-channel, full-authority digital electronic control and utilizes full redundancy of all inputs and outputs. As with the JT9D-7R4 supervisory control system, digital communication links with the cockpit provide for optimum aircraft/engine control communication and simplified power setting procedures. The electronic control design was completed in 1981 and incorporates advancements in circuit integration which provide for a substantial increase in functional capacity, compared to the supervisory control, with a significantly less than proportional increase in parts count. Engine and control system certification will be completed in December, 1983, and introduction into service on Boeing's 757 aircraft is scheduled for November 1984.

PW2037 CONTROL SYSTEM

Electronic Engine Control



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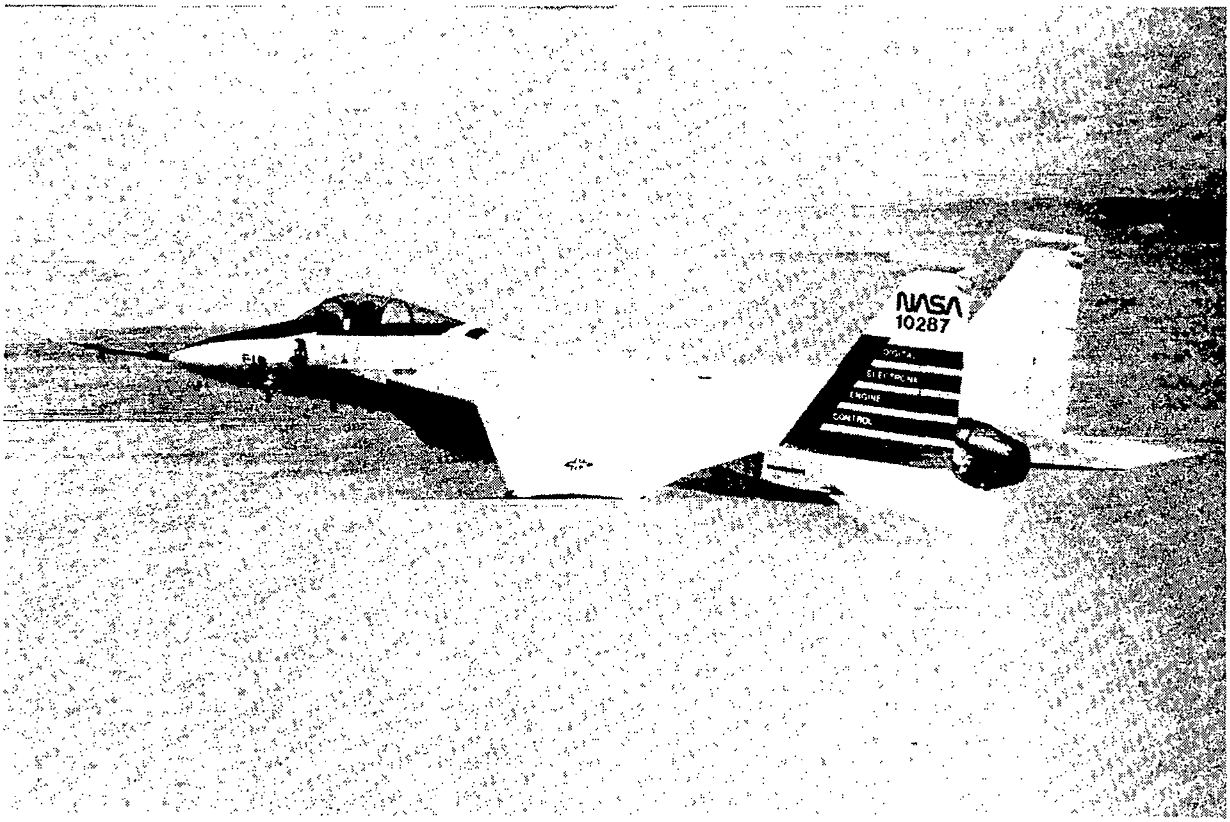
- **Dual-channel Full-Authority Digital Electronic Control (FADEC)**
- **Dual redundancy of all inputs and outputs**

F100 Digital Electronic Engine Control (DEEC) System

A full-authority digital electronic control system has been developed for the F100 engine. This control system incorporates a single-channel electronic control and provides hydromechanical backup capability to meet mission reliability requirements for single-engine applications. The electronic control design incorporates the same electronic component technology as the PW2037 control. DEEC control systems have successfully completed sea level and altitude engine testing and flight testing on NASA's F15 and Air Force F16 aircraft.



Propulsion Control: Research Needs and Opportunities

Significant advances in propulsion control system technology have led to the near-term incorporation of full-authority digital electronic controls in production engines. Substantial propulsion system benefits can be obtained through continuing advancements in control system technology. Integration of aircraft and engine control systems and functions can provide optimized hardware configurations and control modes. Development and application of optical interfaces, high-temperature electronics, and continuing advancements in large-scale circuit integration are likely candidates for electronic control design improvements to provide size, weight, and reliability benefits. Continuing development of advanced sensor and actuator concepts is required to evaluate potential benefits of optical interfacing and design concepts for increased reliability. NASA has sponsored a number of programs concerned with the development of advanced concepts for detection, isolation, and accommodation of sensor faults. Continuing work is required in this area to develop optimum redundancy management concepts. Adaptive control modes can contribute to more predictable system operation and may show significant benefits for integrated aircraft/engine control modes. Improvements in propulsion system modelling techniques become increasingly important as advanced propulsion system design concepts are developed for performance and operability improvements. Finally, software tools and documentation/testing concepts need to be developed for a high-level-language-based software development methodology which can meet regulatory agency certification requirements.

- **Aircraft/propulsion control system integration**
- **Optics**
- **High-temperature electronics**
- **Large-scale integration**
- **Sensor and actuator concepts**
- **Redundancy management**
- **Adaptive control modes**
- **Propulsion system modelling**
- **High-level-language-based software methodology**