NASA Technical Memorandum 86748

NASA-TM-86748
19850023807

Performance Improvements of a Highly Integrated Digital Electronic Control System for an F-15 Airplane

Terrill W. Putnam, Frank W. Burcham, Jr., Mary G. Andries, and James B. Kelly

August 1985

National Aeronautics and
Space Administration

NASA Technical Memorandum 86748

Performance Improvements of a Highly Integrated Digital Electronic Control System for an F-15 Airplane

Terrill W. Putnam and Frank W. Burcham, Jr.
Ames Research Center, Dryden Flight Research Facility, Edwards, California
Mary G. Andries and James B. Kelly
Pratt and Whitney, Government Products Division, West Palm Beach, Florida

1985

National Aeronautics and
Space Administration
Ames Research Center
Dryden Flight Research Facility
Edwards, California 93523

N85-32120 #

Performance Improvements of a Highly Integrated Digital Electronic Control System for an F-15 Airplane

Terrill W. Putnam[*] and Frank W. Burcham, Jr.[**]
NASA Ames Research Center
Dryden Flight Research Facility
Edwards, California

Mary G. Andries[†] and James B. Kelly[‡]
Pratt and Whitney
Government Products Division
West Palm Beach, Florida

Abstract

The NASA highly integrated digital electronic control (HIDEC) program is structured to conduct flight research into the benefits of integrating an aircraft flight control system with the engine control system. A brief description of the HIDEC system installed on an F-15 aircraft is provided. The adaptive engine control system (ADECS) mode is described in detail, together with simulation results and analyses that show the significant excess thrust improvements achievable with the ADECS mode. It was found that this increased thrust capability is accompanied by reduced fan stall margin and can be realized during flight conditions where engine face distortion is low. The results of analyses and simulations also show that engine thrust response is improved and that fuel consumption can be reduced.

Although the performance benefits that accrue because of airframe and engine control integration are being demonstrated on an F-15 aircraft, the principles are applicable to advanced aircraft such as the advanced tactical fighter and advanced tactical aircraft.

Introduction

The capability of high-performance airplanes may be significantly improved by the use of integrated propulsion-flight control systems. Engines powering high-performance airplanes are currently operated with a stall margin large enough to accommodate the worst-case combination of inlet distortion, throttle transient, and engine-to-engine variation. Operation with this large stall margin requires the engine thrust to be reduced over what could be obtained if a smaller stall margin could be used. By providing airframe and flight control information to the engine, the smaller engine stall margin may be used most of the time. With the advent of digital engine control systems, digital flight control systems, and data buses, it may be practical to integrate the engine and flight control systems and implement an adaptive engine control system (ADECS), in which the engine control margins are continuously adjusted to match the needs of the airplane. For example, airframe data could be used to allow the engine to operate at higher performance levels (uptrim) at times when the inlet distortion is low and the full engine stall margin is not required. It may also be desirable to obtain additional engine stall margin (downtrim) during certain flight maneuvers, such as during a short takeoff and landing rollout with reverse thrust where reingestion could cause an engine stall, or for extreme attitude flight, such as might be used for fuselage pointing. In addition, operation at higher engine pressure ratios but at reduced temperatures may be desirable for longer engine life.

NASA Ames Research Center's Dryden Flight Research Facility, in cooperation with other government agencies, is conducting a program called highly integrated digital electronic control (HIDEC). The HIDEC prime contractor is McDonnell Douglas Corporation, with major subcontracts to Pratt and Whitney Aircraft for engines and Lear Seigler Incorporated for flight control computers. This program will develop and evaluate new digital engine control technology that is integrated with the airplane digital flight control system. As part of the HIDEC program, an adaptive engine control system (ADECS) mode will be implemented. This paper provides a brief description of the HIDEC system, ADECS modes, performance benefits predicted, steady-state and dynamic simulation results, and future plans. A companion paper will describe the HIDEC system, hardware, software, bench and ground tests, and flight results of system performance (Ref. 1).

Nomenclature

ADECS	adaptive engine control system
CAS	control augmentation system
DEEC	digital electronic engine control
DEFCS	digital electronic flight control system
EMD	engine model derivative
EPR	engine pressure raio, PT6M/PT2
F	thrust, lb
FTIT	fan turbine inlet temperature, deg C
HIDEC	highly integrated digital electronic control
KA2	instantaneous total pressure distortion factor for the F100 engine
M	Mach number

---

[*] Chief, Aeronautics Branch. Member, AIAA.

[**] Chief, Propulsion Section. Member, AIAA.

[†] Senior Analytical Engineer.

[‡] Assistant Project Engineer.

PT2	fan inlet total pressure, lb/in^2
PT6M	mixed turbine discharge total pressure, lb/in^2
TSFC	thrust specific fuel consumption
TT2	engine inlet total temperature
t	time, sec
UART	universal asynchronous receiver transmitter
WA	fan airflow, lb/sec
α	angle of attack, deg
β	angle of sideslip, deg
Δ	change in parameter
σ	standard deviation

Airplane

The NASA F-15 airplane (Fig. 1) is being used for the HIDEC program. The F-15 is a high-performance air superiority fighter with excellent transonic maneuverability and a maximum Mach capability of 2.5. It is manufactured by the McDonnell Douglas Corporation and is powered by two F100 afterburning turbofan engines. The F-15 airplane has also been used for the evaluation of the digital electronic engine control (DEEC) system on the F100 engine, and the F100 engine model derivative (EMD) engine. The F-15 is equipped with variable-geometry external compression inlets. The flight control system consists of a mechanical flight control system and a high-authority electronic control augmentation system.

Engine

The F100 EMD engine[2] is an upgraded version of the F100-PW-100 engine that presently powers the production F-15 airplanes. These engines are built by Pratt and Whitney Aircraft and have a company designation of PW1128. The engine incorporates a redesigned fan, revised compressor and combustor, single-crystal turbine blades and vanes, a 16-segment augmentor with light-off detector, and a digital electronic engine control (DEEC).

The DEEC[3] is a key part of the HIDEC system. It is a full-authority digital control with an integral hydromechanical backup control. It regulates the gas generator and augmentor fuel flows, the compressor bleeds, the variable inlet guide vanes, the variable stators, and the variable exhaust nozzle. For the HIDEC program, the DEEC has been modified to accept inputs from the airplane, in addition to inputs from the many engine sensors.

The DEEC logic for the F100 EMD incorporates two closed loops that eliminate the need for periodic engine trimming. In the first of these loops, fan airflow (WA, a function of fan speed) is controlled by gas generator fuel flow. The airflow loop is active for all power settings. The other closed loop is the engine pressure ratio (EPR) loop. EPR is the ratio of turbine discharge to fan inlet pressure and is directly related to thrust. The EPR mode is only active for power settings of intermediate and above and is the control loop used in the ADECS mode. The DEEC logic also limits fan turbine inlet temperature (FTIT) and fan and core rotor speeds.

Two computer simulations of the F100 EMD engine are being used in the HIDEC program, a nonlinear aerothermal steady-state engine performance program, and a linear state-variable transient engine program. The steady-state model provides accurate values for many engine parameters including engine thrust, fuel flow, fan and core stall margins, and the DEEC parameters. Its inputs are inlet pressure, temperature, and power setting. The linear state-variable transient model of the F100 EMD provides realistic dynamic response characteristics for engine transients but less accurate for steady-state values.

HIDEC System

The HIDEC system is described in detail in Ref. 1; hence, only a brief description is provided here. The equipment installed on the F-15 airplane for the HIDEC program is shown in Fig. 2. The F100 EMD engines tested at NASA Ames-Dryden are used, together with the DEEC engine controllers. A digital electronic flight control system (DEFCS) is installed in the airplane and accommodates the HIDEC computations. A digital interface and bus control unit and a cockpit control and display are also installed. A telemetry uplink from ground-based computers is available. The F-15 airplane is fully instrumented and equipped for propulsion and flight control integration research.

A block diagram of the HIDEC system on the F-15 is shown in Fig. 3. The various digital systems on the airplane communicate with each other through a digital interface and bus controller. This unit permits the HIDEC system to communicate with the equipment on the F-15 H009 data bus, the universal asynchronous receiver transmitter (UART) data bus, and the 1553 bus. The DEEC controllers on each engine communicate with the HIDEC system by means of the UART bus. The normal throttle inputs to the DEEC controllers and the backup engine controls from the cockpit will be maintained.

The DEFCS is a digital implementation of the analog control augmentation system (CAS) currently on the F-15. It is a dual-channel fail-safe high-authority system which operates in conjunction with a mechanical flight control system. The DEFCS replaces the analog computations in the CAS and has data bus input and output capability in MIL Standard 1553 format. It is programmable in higher order language and currently has 80 percent excess capacity available for other control computations. For the early phases of the HIDEC program, the HIDEC control laws will be implemented in the unused portion of the DEFCS computers.

The pilot communicates with the HIDEC system through a cockpit control and display panel. The normal pilot stick, rudder, and throttle inputs are handled as they are in the standard F-15.

The NASA uplink system is also Mil 1553 compatible and can be used to provide data to the HIDEC system. This permits control algorithms to be processed in a ground-based computer, if desired.

Most of the airframe data required by the HIDEC system is available from the equipment currently installed and communicating on the F-15 H009 data bus, shown at the top of Fig. 3. Included are the air data computer, the inertial navigation set, the horizontal situation indicator, the attitude and heading reference set, and the central computer unit. The navigation control indicator panel is used to input data into the inertial navigation system and can also be used for keyboard entries into the HIDEC system.

For future system expansion, an additional on-board computer is employed. This computer is Mil 1553 compatible and provides additional flexibility and computational power.

The NASA data system monitors parameters on the Mil 1553 bus as well as other parameters that are recorded directly. These data are recorded onboard and also telemetered to the ground for real-time display, analysis, and use in control law computations that may be uplinked to the airplane.

ADECS Mode Description and Methodology

The ADECS mode may modify the engine performance in several ways. One way is to increase the EPR, with the resulting increase in thrust and temperature. Another way is to increase EPR at constant temperature. A third way is to increase EPR but reduce temperature to maintain constant thrust.

A simplified block diagram of the ADECS EPR uptrim is shown in Fig. 4. Airframe and flight control system data are used to provide an indication of the stall margin required, and the ADECS logic then trades the excess stall margin for improved performance. During a maneuver which significantly increases inlet distortion, the logic downtrims EPR to regain the required stall margin.

A typical fan map, shown in Fig. 5, illustrates how various uptrim modes can be effected. Holding the fan speed and hence airflow constant, while closing down the exhaust nozzle, results in an increase in fan pressure ratio that is directly related to EPR and also thrust. Similarly, EPR can be increased while holding fan turbine inlet temperature (FTIT) constant with a resultant smaller increase in thrust. Finally, thrust can be held constant while decreasing FTIT and airflow with concurrent improvements in engine life. The normal operating line is below the optimum fan efficiency line at the higher fan speeds; hence, an EPR uptrim improves the fan efficiency. Limits on engine speeds, temperatures, and nozzle area are part of the engine control logic, and they provide practical limits on the amount of available uptrim.

The first ADECS mode to be implemented utilizes EPR upmatch to obtain maximum jet engine performance. Engine pressure ratio (EPR) is increased by closing the nozzle while maintaining constant airflow until either the stability or performance limit is reached. If the fan inlet turbine temperature limit is reached, and if there is additional performance to be gained by continuing to upmatch at constant FTIT with reduced airflow, the upmatch is allowed, but only if the stability limit is not exceeded.

Stability Audit

The HIDEC logic definition is based on PW1128 engine-inlet stability audit methodology. The stability audit considers all destablilizing factors that reduce the fan stall margin from the basic level available between the steady-state operating point and the undistorted stall line. Stall margin is defined here as the percentage difference between stall and operating pressure ratio divided by a reference operating pressure ratio at constant airflow.

Fan stall margin is effected by changes in the nominal stall line and operating line pressure ratios. The nominal stall line can be reduced by Reynolds number effects, inlet distortion, and variations from engine to engine. The fan operating pressure ratio is affected by augmentor transient back pressure and control tolerances. The PW1128 engine computer simulation was used in conjunction with the automated stability audit to assess the fan stability during high-power augmentor transients. The random effects (control tolerance, engine-to-engine stall line variations, and the random part of augmentor back pressure) are "root-sum-squared" to get a 2-σ worst-case engine stability audit.

The desired fan operating line is determined on the basis of an optimization of stall margin, augmentor operability, and performance requirements. DEEC control of the desired fan pressure ratio as a function of airflow operating line is achieved by scheduling EPR as a function of corrected fan airflow. EPR is controlled by a variation of exhaust jet nozzle position to obtain a desired mixed turbine discharge total pressure value (PT6M) for the corresponding value of fan inlet total pressure (PT2).

Inlet Distortion

The inlet distortion factor (KA2) system of the F100 engine is used for accurate correlation of the engine stall margin loss with distortion produced by screens and aircraft inlets. The KA2 system is based on the proven principle that fan stall margin loss resulting from any total pressure distortion pattern can be calculated. This assumes that the surge line effects of the classical components (that is, pure radial and pure circumferential profiles) of the pattern are known and proper distortion indices are used. The circumferential and radial fan distortion factors are combined into one factor, KA2, which therefore represents the stall margin loss for any complex pattern.

The major aircraft inlet distortion effect on engine stability during high-power augmentor transient operation is maximum time-variant inlet pressure distortion. This distortion combines the effects of steady-state pressure distortion and random turbulence.

The airplane manufacturer has processed F-15 inlet model data to determine the maximum time-variant distortion for the PW1128. Generally, the distortion is minimal for angle-of-attack condition of approximately $\alpha = 4.0$, and the distortion increases for variations about this position. Similarly, the distortion level tends to increase with angles of sideslip (β) for the leeward inlet. This is as expected because the forward section of the aircraft fuselage shields the inlet and therefore results in higher distortion.

The F-15 inlet data were correlated so that a calculated value of the distortion factor KA2 could be obtained for any angle of attack, angle of sideslip, airflow, and Mach number (M). Generally, the data were characterized at a nominal condition, and partial derivatives were used to calculate the value for off-nominal condition.

The basic ADECS principle involves defining the engine stability match point (engine and fan pressure ratio at a given airflow) for the minimum distortion condition as a function of flight conditions (M and altitude). This stability match point is used as a base, and downmatch is requested by the aircraft control to accommodate distortion other than the minimum. This is accomplished with the aid of the PW1128 engine simulation and stability audit with each source of fan stall margin loss allocated.

The stability match-point pressure ratio is set by starting with the fan stall pressure ratio and reducing the pressure ratio by an amount equivalent to the loss due to Reynolds number effects, minimum distortion condition loss, and $-2\text{-}\sigma$ random losses (engine-to-engine stall line variations and control tolerance). The match point thus defined is further reduced by 4 percent to provide the remaining conservative stall margin. The resulting stability match was determined for the engine and was defined similar to the standard DEEC scheduling methods (EPR as a function of fan speed and total inlet pressure).

As previously discussed, during flight, the HIDEC system computes online the distortion factor, KA2, for the actual angles of attack and sideslip at the Mach number and airflow conditions. This distortion factor is then used to compute the corresponding reduction in match point from the stability match required to offset the distortion difference relative to the minimum level. The resulting match point satisfies stability criterion. The stability schedules are stored in the DEFCS in the form of tables of EPR uptrim as a function of corrected fan speed and PT2. For engine protection, the stability schedules are also stored in the DEEC.

Maximum Performance Logic

The performance schedule is developed to allow EPR upmatch only where there are performance benefits. The performance schedule is also a function of corrected fan rotor speed and PT2. This schedule is necessary for conditions in which ample stability margin exists but other engine constraints have been predicted to be reached before the stability limit. Under these conditions, continued EPR upmatch can result in a performance loss rather than an improvement.

During the performance schedule generation, EPR upmatch at constant airflow to the FTIT limit was allowed. EPR upmatch was continued at constant FTIT only when performance benefits were demonstrated. Other engine operating constraints, such as high compressor rotor speed, main burner pressure, and high compressor exit temperature, were observed. The amount of EPR upmatch communicated to the DEEC is determined by selecting minimum requirements for EPR upmatch from the performance schedule and the stability schedule criteria.

A detailed flow diagram of the implementation of the ADECS logic is given in Ref. 4. For the HIDEC program, the performance schedules are implemented in the flight control computer, while the stability schedules are in both the flight control computer and the DEEC.

Performance Predictions

Performance predictions were made utilizing the PW1128 steady-state simulation. Figures 6(a) and 6(b) show contour plots for percent thrust increase for intermediate and maximum afterburning power. The thrust increases vary throughout the flight envelope because of the various performance limitations encountered. The major thrust benefits are in the subsonic regime of the flight envelope where substantial FTIT margin is available and where airflow levels are high. Continued EPR upmatch at constant FTIT after the FTIT limit is reached provides additional performance benefits.

Reduced benefits of EPR upmatch is exhibited at supersonic flight conditions where less FTIT margin is available for EPR upmatch. Here, upmatch at constant FTIT reduces performance because maintaining fan corrected airflow is more beneficial than increasing the fan pressure ratio and reducing the airflow. For intermediate power operation at some flight conditions, performance is limited because, as a result of minimum nozzle area limitations, the desired EPR upmatch cannot be achieved. At maximum power, large thrust increases for some flight conditions are observed because of the initiation of additional augmentor segments. The additional segments are allowed because of higher operating pressures in the augmentor with the EPR upmatch.

Performance levels vary on the basis of inlet distortion. For minimum distortion and low angles of attack and sideslip, maximum performance benefits are observed. Conversely, for maximum distortion and high angles of attack and sideslip, reduced performance benefits are observed. Figure 7 illustrates the thrust increase at maximum power for varying levels of angle of attack and sideslip. At nominal flight conditions, a thrust increase in excess of 5 percent is shown. Even at extreme values of α and β, the thrust increase is still in excess of 3 percent.

As discussed previously, the DEEC receives the command for the desired amount of EPR upmatch based on the stability and performance limitations. If the EPR upmatch is requested at idle, the request is ramped in but no effect is observed until the engine transitions to EPR control at power settings near intermediate. The transition to EPR control logic provides transition to the higher EPR upmatch levels. If the EPR upmatch is requested when the engine is on EPR control, the amount of EPR upmatch is ramped in as a function of time.

Because the stability audits utilize the stall margin for augmentor sequencing back pressures, augmented transients require EPR downmatch during sequencing. The EPR downmatch is based on predicted EPR excursions during augmentor sequencing at various flight conditions. The EPR downmatch is slewed out to the requested upmatch level after augmentor sequencing is completed and maximum power is attained.

Uptrim time histories of thrust are shown in Fig. 8 for Mach 0.8 and an altitude of 30,000 ft, with and without uptrim. In Fig. 8(a), for a throttle snap from 45 deg to intermediate power, the upmatch is ramped in at $t = 1.2$ sec. A smoother transient response is observed with EPR uptrim, in addition to the faster acceleration and higher thrust. In Fig. 8(b), a throttle snap from 45 deg to maximum power, the EPR upmatch at $t = 1.2$ sec is reduced during augmentor sequencing and is subsequently returned to the full upmatched EPR at $t = 8$ sec.

Constant-Thrust Mode

A constant-thrust engine mode could be implemented to improve the thrust specific fuel consumption (TSFC) and to increase engine life by reducing turbine temperature. This constant-thrust mode is being considered for future HIDEC testing. The temperature and fuel consumption reductions possible for intermediate power at Mach 0.6 and an altitude of 20,000 ft are shown in Fig. 9. The 2.5- to 3.0-percent improvement in TSFC is important and can be translated into increases in aircraft range. In addition, the reduction in fan turbine inlet temperature of 50 deg is significant in terms of increased life and durability of the engine. The range of temperature reductions achievable for various altitudes and speeds is indicated by the shaded area in Fig. 10.

Advanced Integration Concepts

The integration of the propulsion and flight control system provides the design engineer with many new options for meeting new or multiple mission design requirements. The next logical element of the aircraft control system to be integrated is the inlet. On an airplane such as the F-15, the variable geometry inlet not only determines the quantity and quality of the air delivered to the engine, but it also affects the lift, drag, and stability of the airplane. Figure 11 indicates conceptually how the inlet might be integrated by means of HIDEC logic. The inlet variables would be commanded to their optimum positions depending on the particular requirements, such as airframe, engine, or a combination of both.

Finally, the concept of a performance-seeking control would optimize propulsion system variables in such a way that either excess thrust or aircraft range would be maximized. Figure 12 is a block diagram of how such a performance-seeking control might be implemented. A state-variable model of the engine would be utilized, together with models of the inlet and exhaust nozzle. Optimization logic would then compute commands for the various propulsion system variables depending on flight conditions such as speed, accelerations, altitude, attitude, dynamic pressure, and aircraft configuration. These commands would be sent to the various propulsion system elements with the resultant states fed into the models to update the models. This process would continue until the performance index was optimum. Such a system would be capable of accommodating engine degradation, nonstandard-day atmospheric conditions, and various external stores configurations. This technology may be of great importance to supersonic cruise vehicles that are highly sensitive to small changes in propulsion system performance.

Concluding Remarks

A brief description of the highly integrated digital electronic control (HIDEC) system has been presented with a more detailed discussion of the adaptive engine control system (ADECS) mode. Results of simulation and analysis showed significant improvement of the excess thrust capability of the F-15 aircraft with the use of ADECS. Transient thrust response was also demonstrated to be greatly improved with ADECS. Although the performance benefits that accrue because of airframe and engine control integration are being demonstrated on an F-15 aircraft, the principles are applicable to advanced aircraft such as the advanced technical fighter and advanced technical aircraft.

References

[1]Baer-Riedhart, J. and Landy, R. J., "Highly Integrated Digital Electronic Control - Digital Flight Control, Aircraft Model Identification and Adaptive Engine Control," AIAA-85-1877, Aug. 1985.

[2]Myers, L. P. and Burcham, F. W., Jr., "Preliminary Flight Test Results of the F100 EMD Engine in an F-15 Airplane," AIAA Paper 84-1332, June 1984.

[3]Burcham, F. W., Jr., Myers, L. P., and Walsh, K. R., "Flight Evaluation Results of a Digital Electronic Engine Control System in an F-15 Airplane," AIAA Paper 83-2703, Nov. 1983.

[4]Yonke, W. A., Terrell, L. A., and Myers, L. P., "Integrated Flight/Propulsion Control: Adaptive Engine Control Mode," AIAA Paper 85-1425, June 1985.

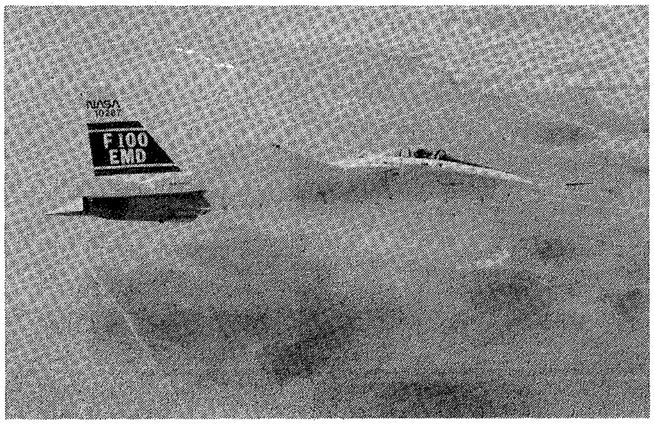


Fig. 1 NASA F-15 research plane.

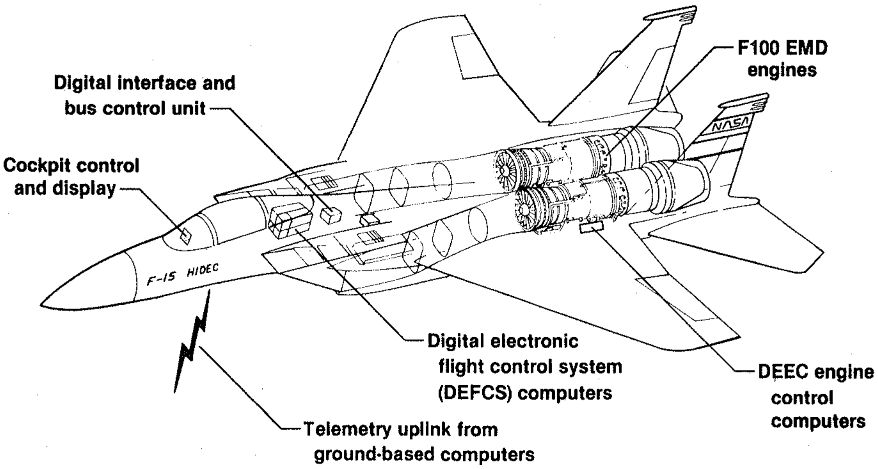


Fig. 2 HIDEC system elements.

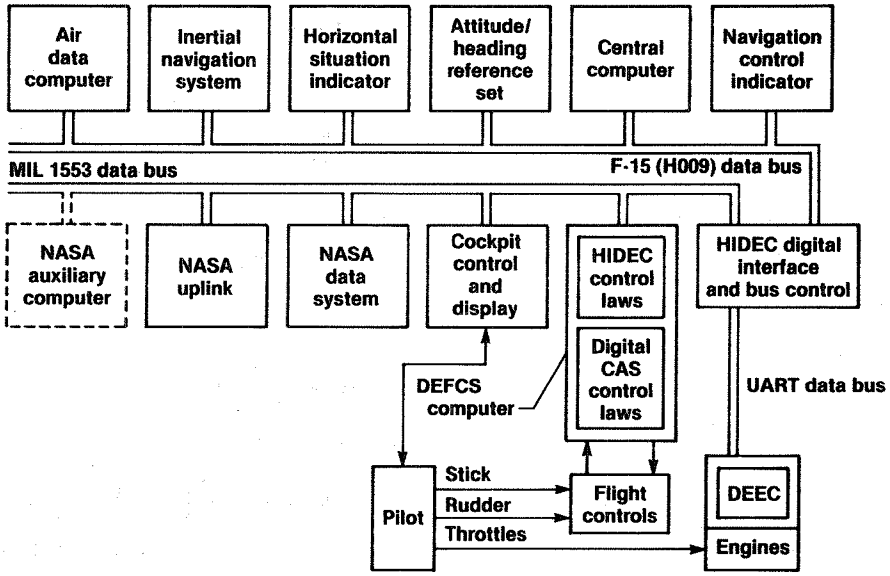


Fig. 3 HIDEC system block diagram.

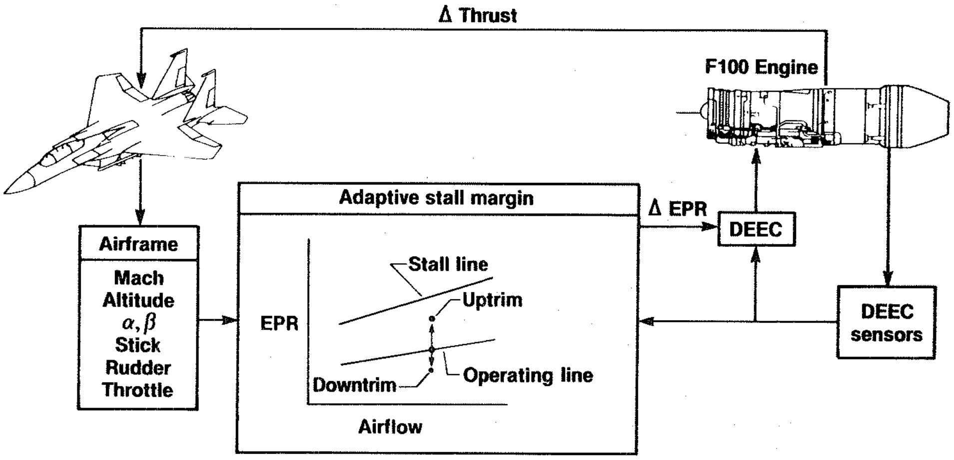


Fig. 4 HIDEC adaptive engine control system.

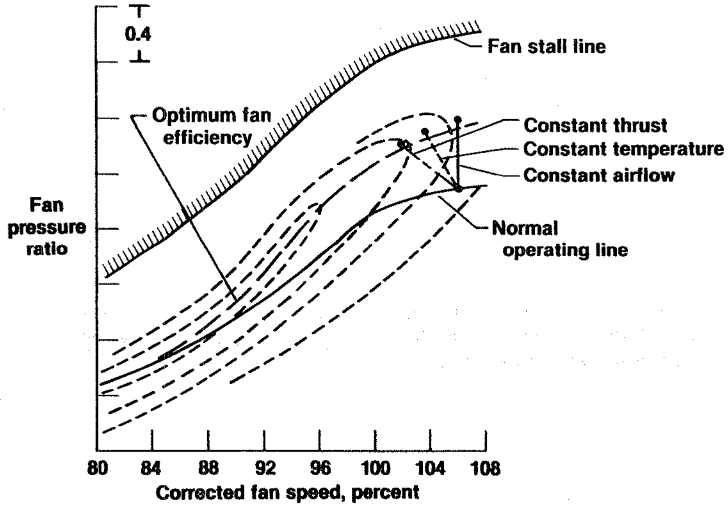
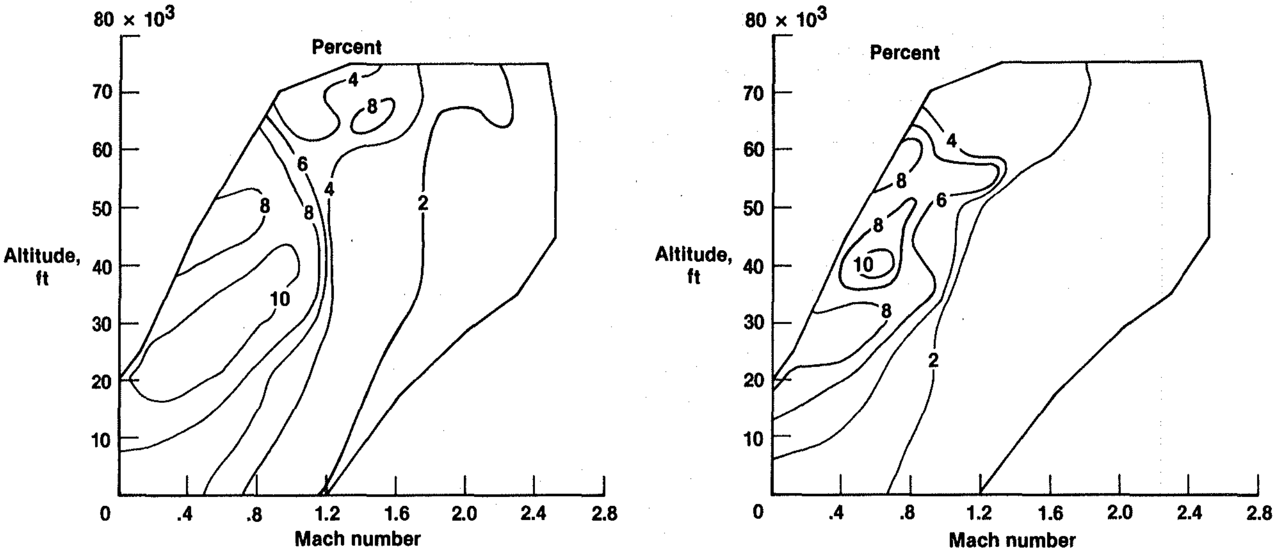


Fig. 5 HIDEC adaptive engine control system uptrims.



(a) Intermediate power. *(b) Maximum power.*

Fig. 6 Increase in net installed thrust.

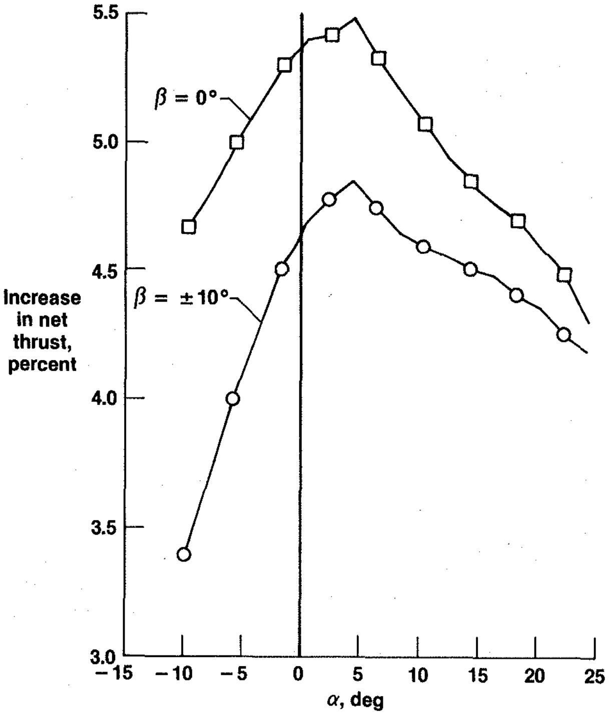
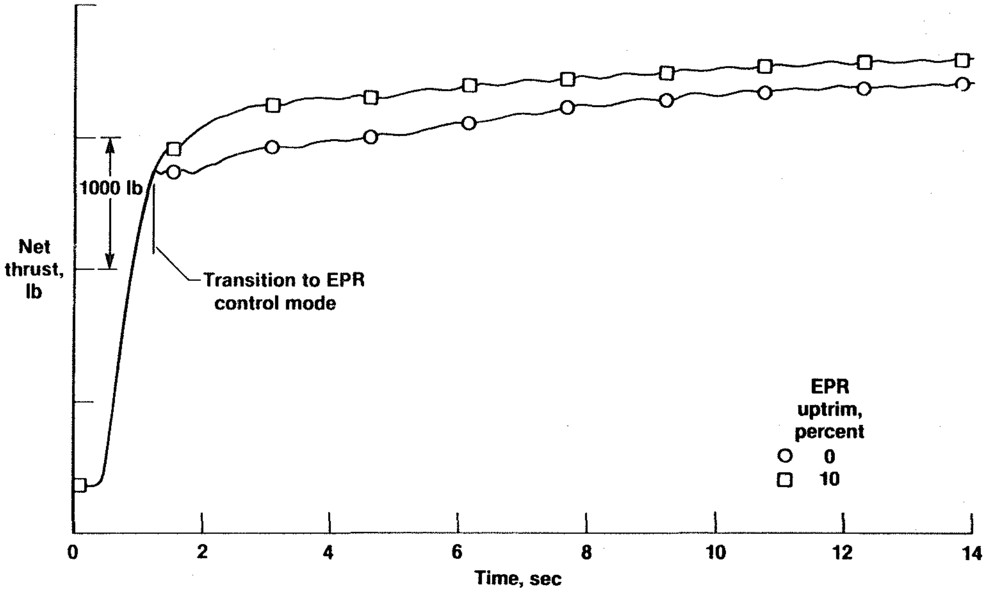
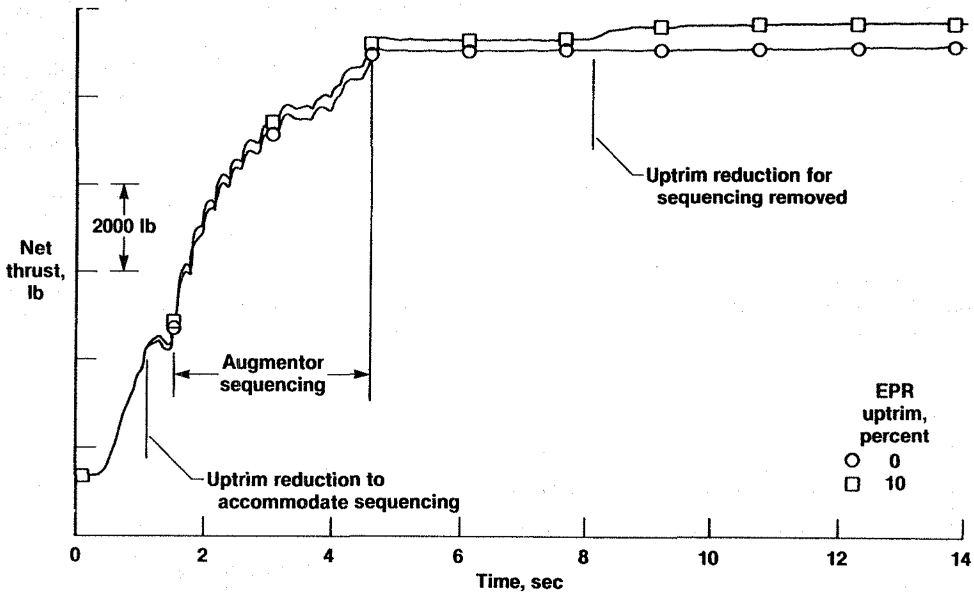


Fig. 7 Increase in net thrust allowed at Mach 0.8 and 45,000-ft altitude, as a function of angles of attack and sideslip.



(a) Snap to intermediate power.



(b) Snap to maximum power.

Fig. 8 Transient-thrust response, with and without EPR uptrim, at Mach 0.8 and 30,000-ft altitude.

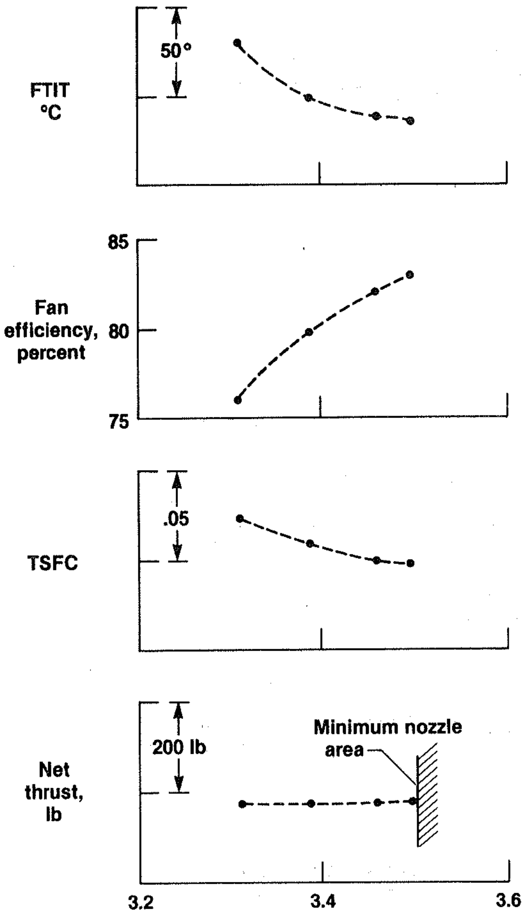


Fig. 9 ADECS constant-thrust mode uptrim for intermediate power at Mach 0.6 and 20,000-ft altitude.

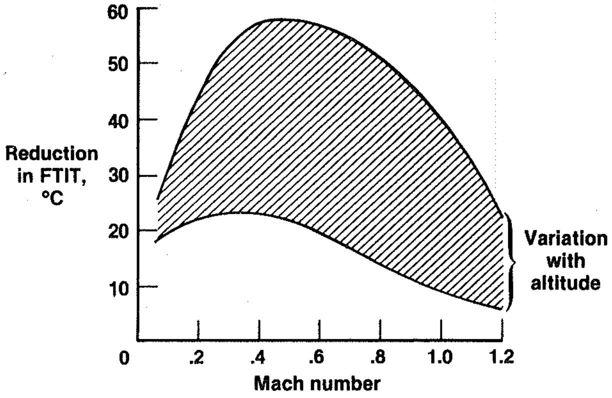


Fig. 10 Reduction of fan turbine inlet temperature for intermediate power at constant thrust as a function of altitude and speed.

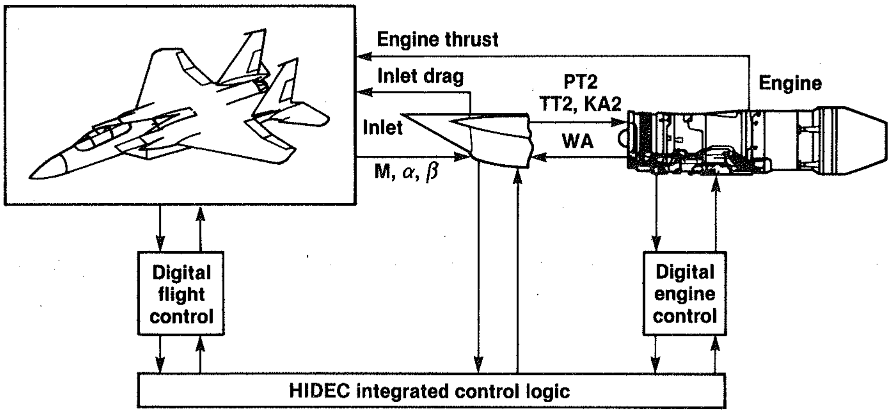


Fig. 11 HIDEC system with inlet control added.

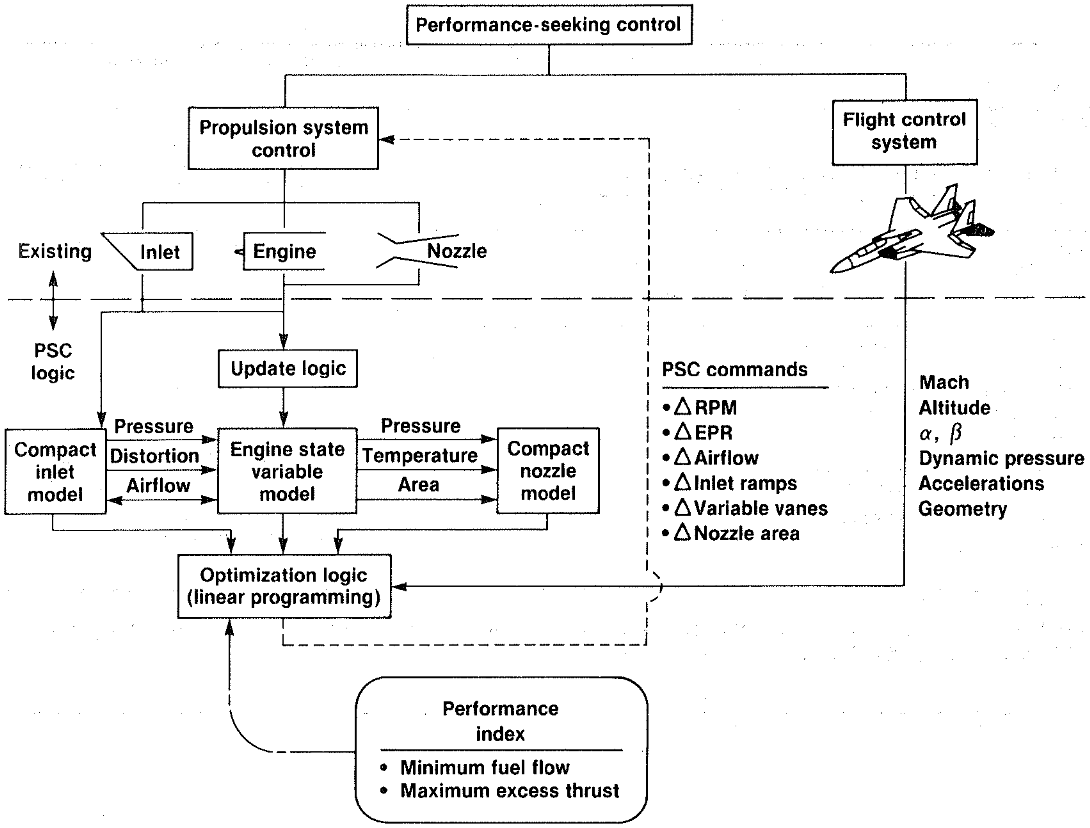


Fig. 12 Performance-seeking control.

1. Report No.
NASA TM-86748

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle

Performance Improvements of a Highly Integrated
Digital Electronic Control System for an F-15 Airplane

5. Report Date
August 1985

6. Performing Organization Code

7. Author(s)
Terrill W. Putnam and Frank W. Burcham, Jr. (NASA)
Mary G. Andries and James B. Kelly (Pratt and Whitney)

8. Performing Organization Report No.
H-1312

9. Performing Organization Name and Address
NASA Ames Research Center
Dryden Flight Research Facility
P.O. Box 273
Edwards, CA 93523

10. Work Unit No.
RTOP 533-02-02

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared as AIAA Paper 85-1876 for presentation at the AIAA Guidance and Control Conference, Snowmass, Colorado, August 19-21, 1985

16. Abstract

The NASA highly integrated digital electronic control (HIDEC) program is structured to conduct flight research into the benefits of integrating an aircraft flight control system with the engine control system. A brief description of the HIDEC system installed on an F-15 aircraft is provided. The adaptive engine control system (ADECS) mode is described in detail, together with simulation results and analyses that show the significant excess thrust improvements achievable with the ADECS mode. It was found that this increased thrust capability is accompanied by reduced fan stall margin and can be realized during flight conditions where engine face distortion is low. The results of analyses and simulations also show that engine thrust response is improved and that fuel consumption can be reduced.

Although the performance benefits that accrue because of airframe and engine control integration are being demonstrated on an F-15 aircraft, the principles are applicable to advanced aircraft such as the advanced tactical fighter and advanced tactical aircraft.

17. Key Words (Suggested by Author(s))
Control systems
Engines
F-15 aircraft
Integrated control
Propulsion control

18. Distribution Statement
Unclassified — Unlimited

STAR category 07

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
12

22. Price*
A02

*For sale by the National Technical Information Service, Springfield, Virginia 22161.

End of Document