FLIGHT TESTING THE DIGITAL ELECTRONIC ENGINE CONTROL
IN THE F-15 AIRPLANE

Lawrence P. Myers
NASA Ames Research Center
Dryden Flight Research Facility
Edwards, California

SUMMARY

The digital electronic engine control (DEEC) is a full-authority digital engine control developed for the F100-PW-100 turbofan engine; it has been flight tested on an F-15 airplane at the NASA Ames Research Center's Dryden Flight Research Facility (DFRF). The objectives of the flight test were to evaluate the DEEC hardware and software throughout the F-15 flight envelope. New real-time data reduction and data display systems were implemented. New test techniques and stronger coordination between the propulsion test engineer and pilot were developed which produced efficient use of test time, reduced pilot work load, and greatly improved quality data. The engine pressure ratio (EPR) control mode was demonstrated. Nonaugmented throttle transients and engine performance were satisfactory.

The figure below shows the instrumentation system for the F-15. Starting at the top, airframe parameters, such as altitude, airspeed, and Mach number were recorded directly. Several engine parameters were recorded and are shown in detail on the next figure. The DEEC computer outputs a serial digital data stream that is processed through an interface box to make the signal compatible with the pulse code modulation (PCM) system. A breadboard diagnostic unit was used on the ground for interrogating and powering the DEEC without starting the engine. Finally, the data was recorded onboard the aircraft and also telemetered to the ground for recording and real-time analysis and display.

F-15/DEEC Instrumentation System

NASA
DFRF83-421
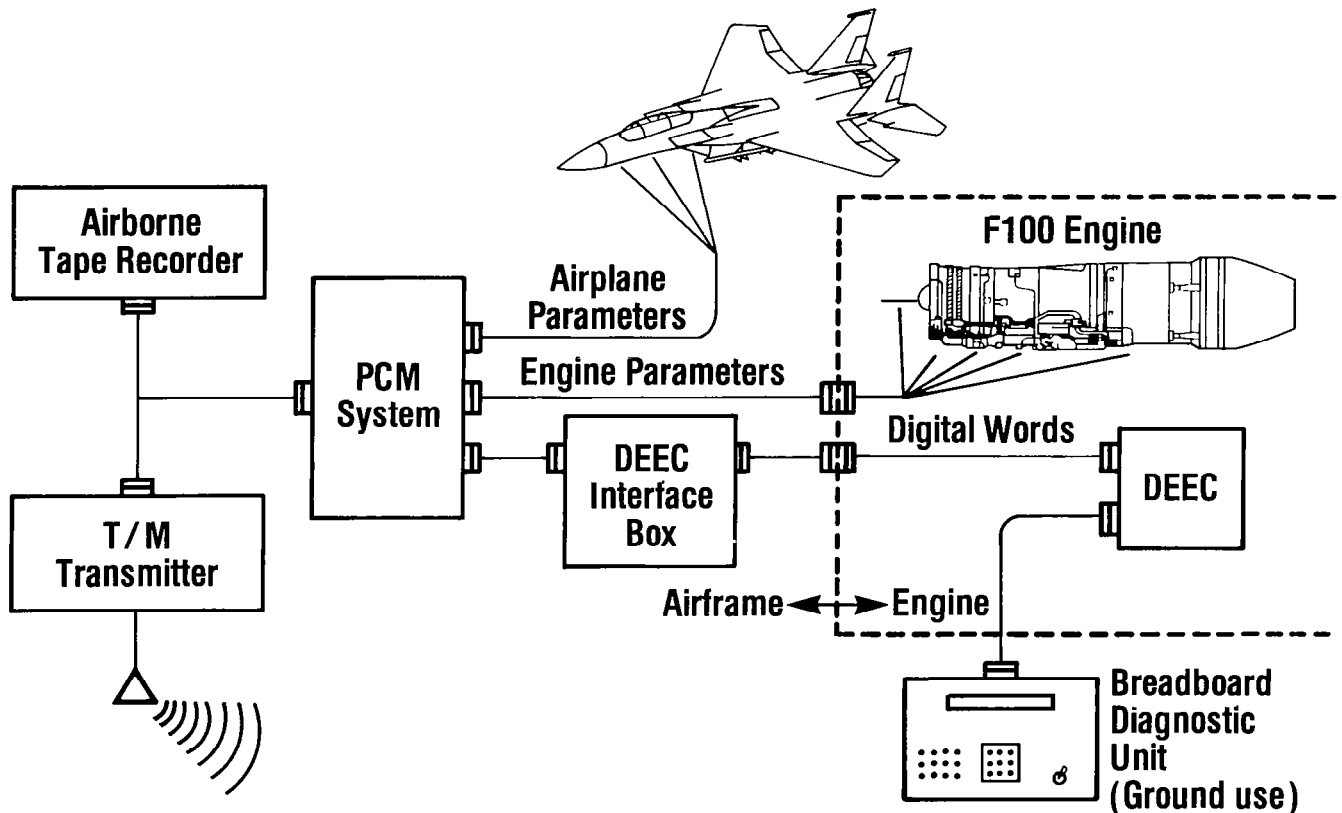
FLIGHT INSTRUMENTATION

Shown on this figure are engine parameters recorded on the data system. A continuous serial digital word from the DEEC computer was also recorded. High frequency response parameters such as burner pressure (PB), augmentor static pressure (PAB), turbine discharge pressure (PT6), and the augmentor segment fuel pressures were recorded at 200 samples per sec. The other engine and aircraft parameters were recorded at 20 samples per sec. The various parameters were filtered before digitization by the PCM system to prevent aliasing error.

The 50 DEEC digital words were updated at eight samples per second. The DEEC digital data included pressures and temperature throughout the engine, position requests and feedback, internal calculations, and eleven 16-bit diagnostic words.

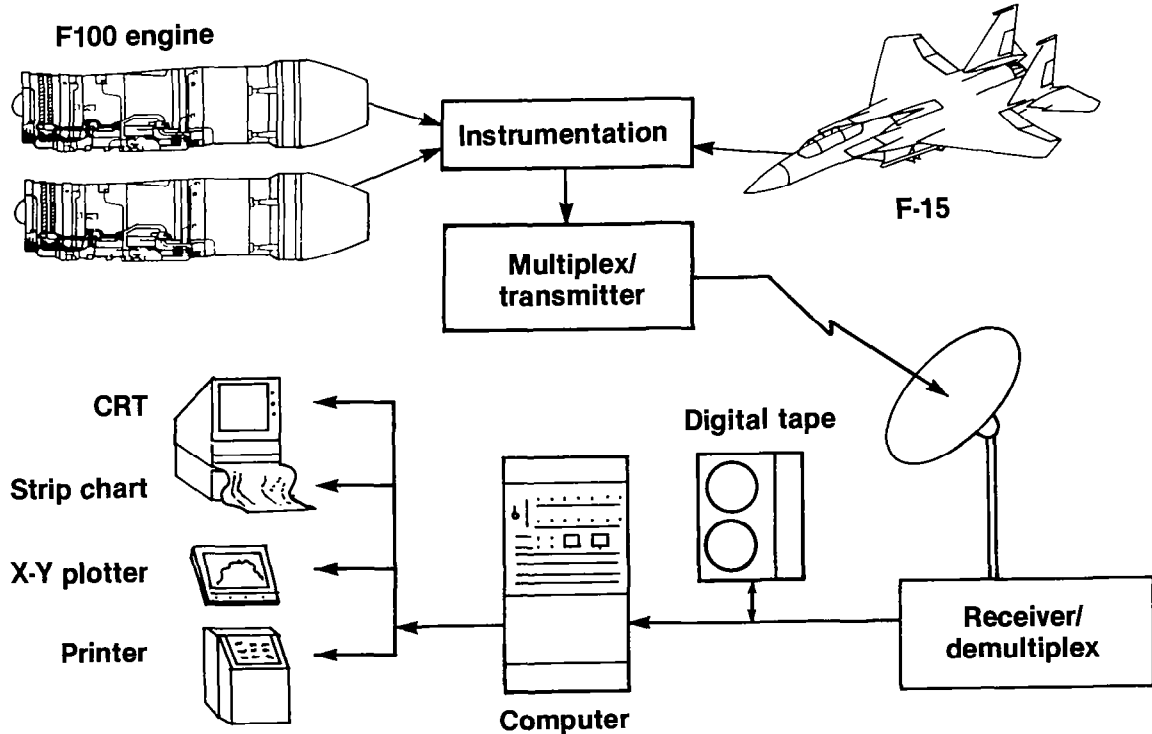# DEEC FLIGHT INSTRUMENTATION

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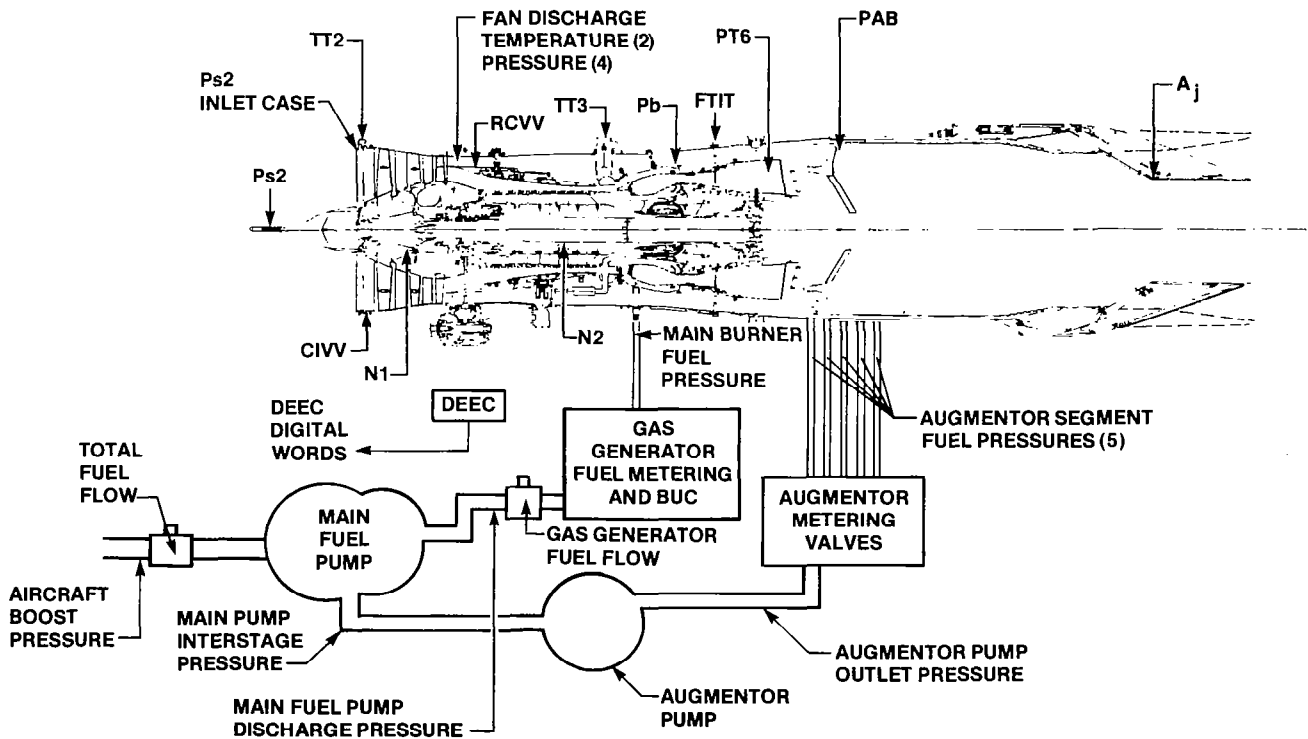
Data from the test airplane and engine were taken from the telemetry signal and processed in real time by using a series of digital computer programs. The raw data was converted to engineering units and various computations were performed. The 11 DEEC diagnostic words were displayed on a color cathode ray tub (CRT). In-flight thrust was also calculated and displayed. The four methods of displaying the processed data were: CRT, eight-channel strip charts, X-Y plotters, and tabulated hard-copy listings.

F-15 DEEC Real-Time Data System

NASA
DFRF83-558a

Figure labels: F100 engine, Instrumentation, F-15, Multiplex/transmitter, CRT, Strip chart, X-Y plotter, Printer, Computer, Digital tape, Receiver/demultiplex

MISSION CONTROL ROOM

The NASA mission control room, shown below, is equipped for real-time monitoring and control of research flights. For the F-15 DEEC flights, the 12 eight-channel strip charts, seven CRT displays, two X-Y plotters, and seven status light displays were used to display DEEC test data. Test engineers and technicians monitored the data and fed appropriate information to the flight controller and the research test engineer. A series of television cameras with long range optics, displayed overhead, was used for visual tracking of the airplane. Radar data on space position of the aircraft was plotted on the large consoles at the far right of the room.

STRIP CHARTS

The 12 eight-channel strip charts were the primary source of the data in monitoring the DEEC system performance. The research test engineer sat in front of the strip charts which displayed the critical engine parameters necessary to conduct an efficient and safe flight evaluation. The test engineer assisted the pilot during test maneuvers by monitoring engine conditions and requesting throttle transients at the correct revolutions per minute (RPM) values or time. The engineer assessed the results and requested that test points be repeated or deleted as appropriate. He also monitored data on the CRT and diagnostic displays. With all of the data displays, the test engineer had access to virtually all the DEEC information in real time.


Strip Charts

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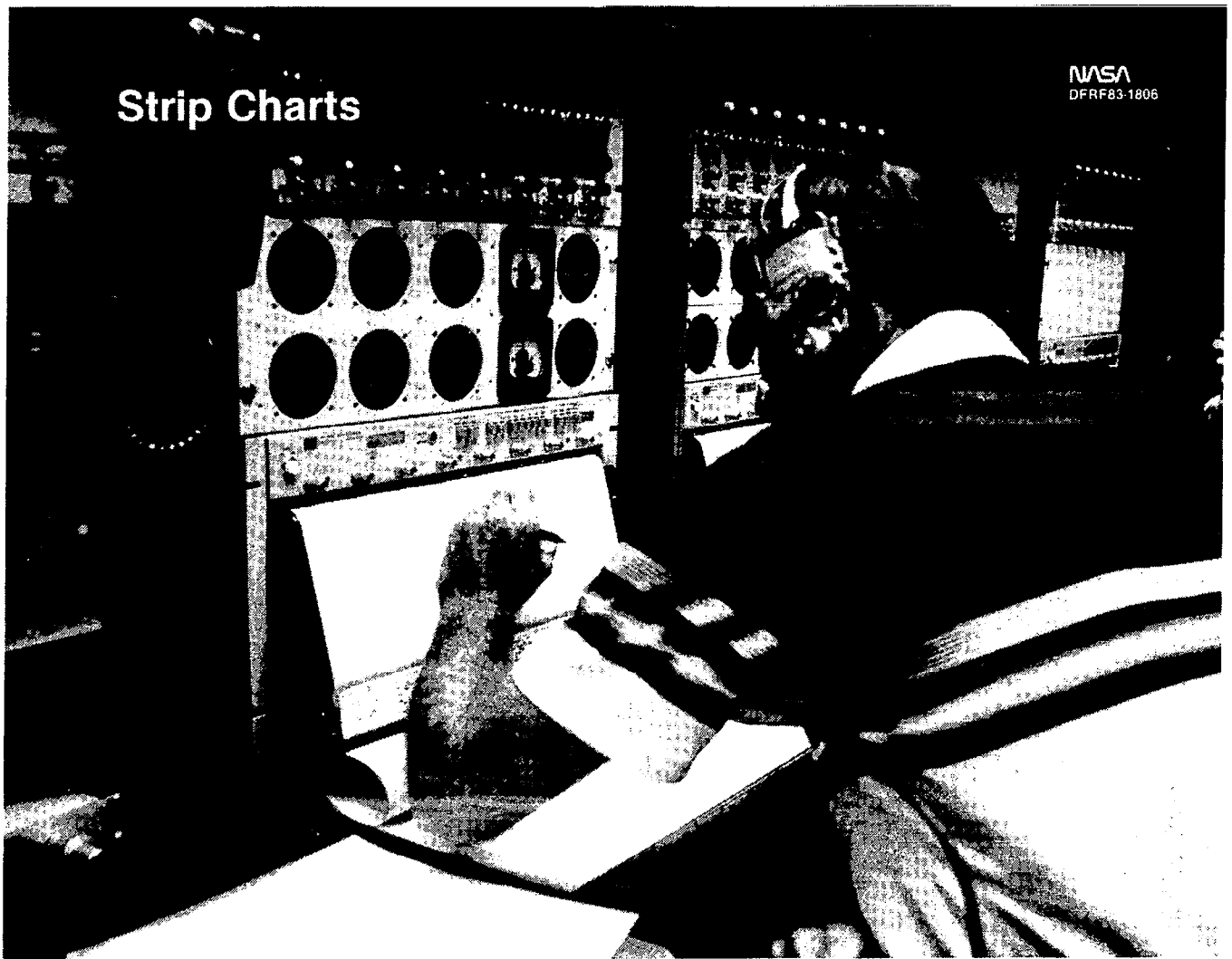
Two basic types of throttle transients were used: the throttle snap, a rapid single-direction movement from one stabilized power setting to another, and the bodie, which begins with a snap in one direction, followed closely by a snap in the other direction before stabilization.

For augmented transients, a series consisted of an intermediate-to-maximum-to-intermediate throttle sequence, followed by idle-to-maximum-to-idle snaps. No attempt was made to allow the augmentor manifolds to drain completely between transients. When stalls or blowouts occurred at a given test point, the transient was repeated until the same result was achieved in two out of three trials. Augmentor transients were performed in the upper left-hand corner with maximum segment 1 limiting and, with the override switch, with full augmentation.

The throttle transient series shown below illustrates a typical transient sequence. The propulsion engineer monitoring this strip chart called the throttle sequence to the pilot. The engineer analyzed the data to determine when the engine stabilized and called for the next step in the series. This technique reduced the pilot workload and greatly improved the quality of data. The pilot concentrated on holding speed and altitude, using the right engine to compensate for the changing thrust of the test engine.
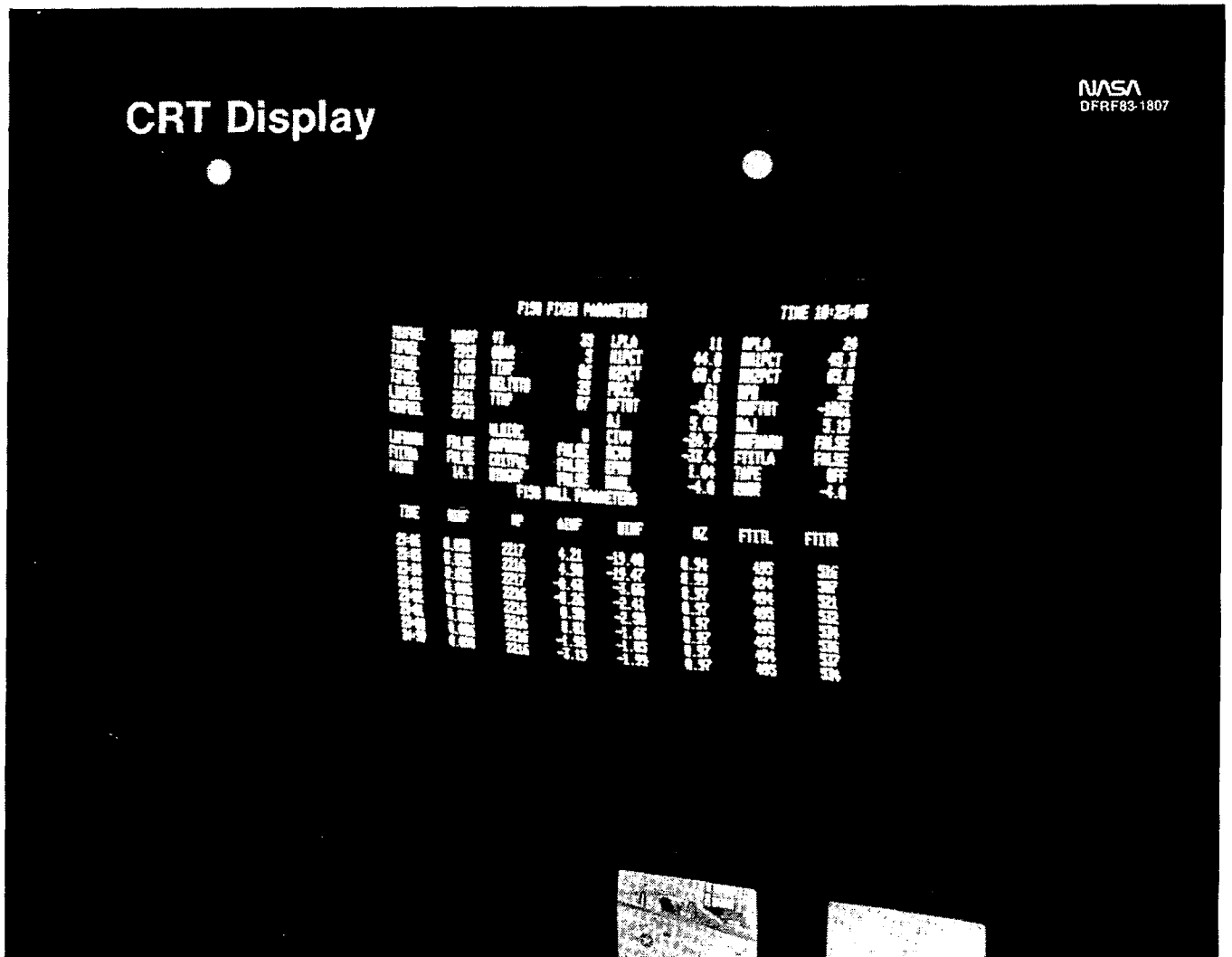
# DEEC Throttle Transient Series

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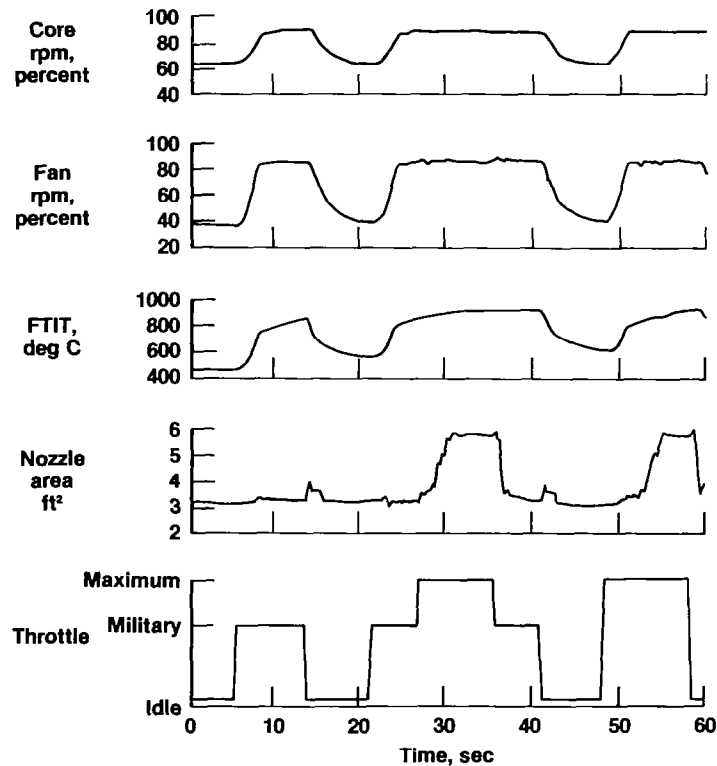
This figure shows a sample of the data available on the CRT. Each CRT has two data formats and a color graphics panel that can be individually selected by the engineers at the console. The long-range optics television pictures are displayed below the CRT.

COLOR GRAPHICS PANEL

The color graphics panel is the third format on the CRT and is an 11 by 16 array. Eleven of the DEEC serial digital words were used for diagnostic words, each having 16 discrete bits. Each bit represented a discrete fault or failure in not only the DEEC computer, but the entire DEEC control system. The colors used to display the discrete bits were: gray, if the bit was not set; yellow, if the bit was set, but advisory in nature; and red, if the bit was set and the fault or failure should have caused an automatic transfer to the backup control (BUC).

99
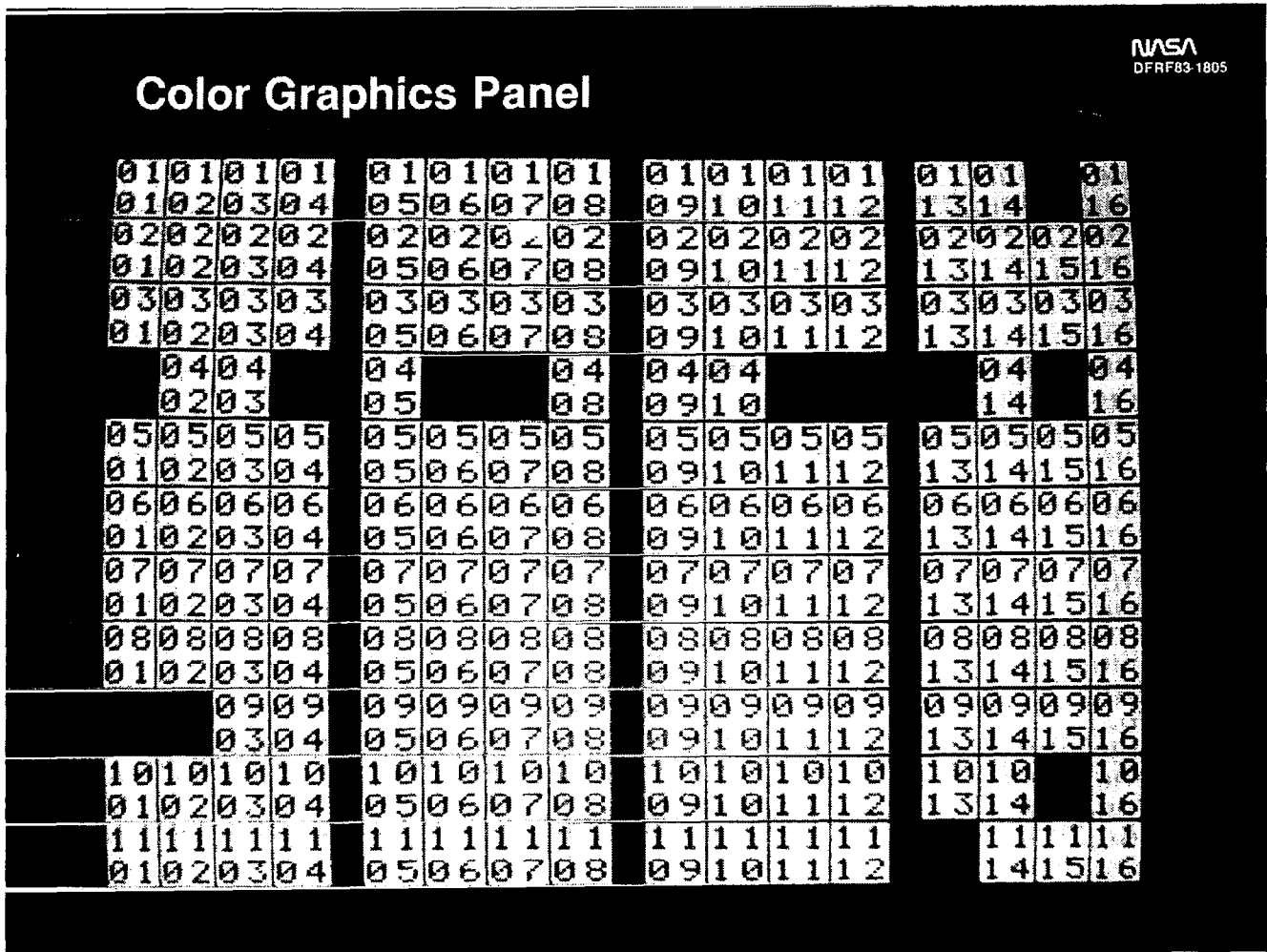
The DEEC test program consisted of four phases. On the chart below, each phase is illustrated with a number in a block. To the left of the block is the configuration or change from the previous phase, and to the right is the number of flights and major evaluation of the phase. The four DEEC test phases were completed in one and one-half years.

F-15/DEEC Test Program

NASA
DFRF83-651a

1981	1982	1983	84

Flight clearance configuration [1] 6 flights, nonaugmented, airstarts

**Augmentor improvements** [2] 12 flights, ULHC augmentor

[   ] PSL tests, Lewis

Nozzle instability fix group II BUC [3] 7 flights, ULHC augmentor BUC evaluation

LOD, fast acceleration [4] 5 flights, thrust, ULHC augmentor

The DEEC was evaluated in a series of 30 flights totaling 35.5 hours. On three flights, aerial refuelings were used to extend test time. A maximum Mach of 2.36 was reached at 40,000 ft. Climbs to 60,000 ft were made to determine upper limits of augmentor operation. More than 200 nonaugmented and almost 1000 augmented throttle transients were accomplished as well as 155 airstarts and 125 manual transfers to the backup control.
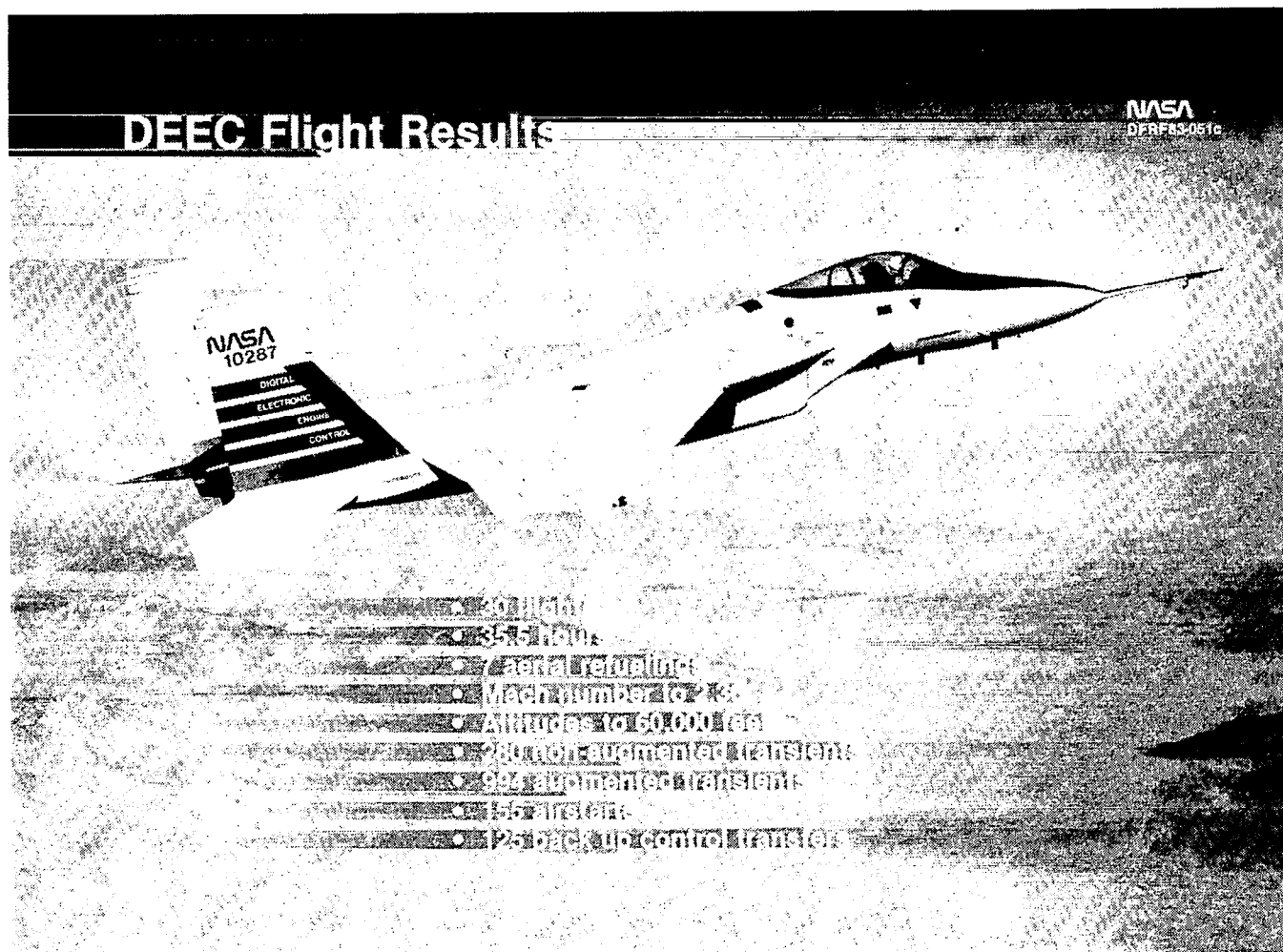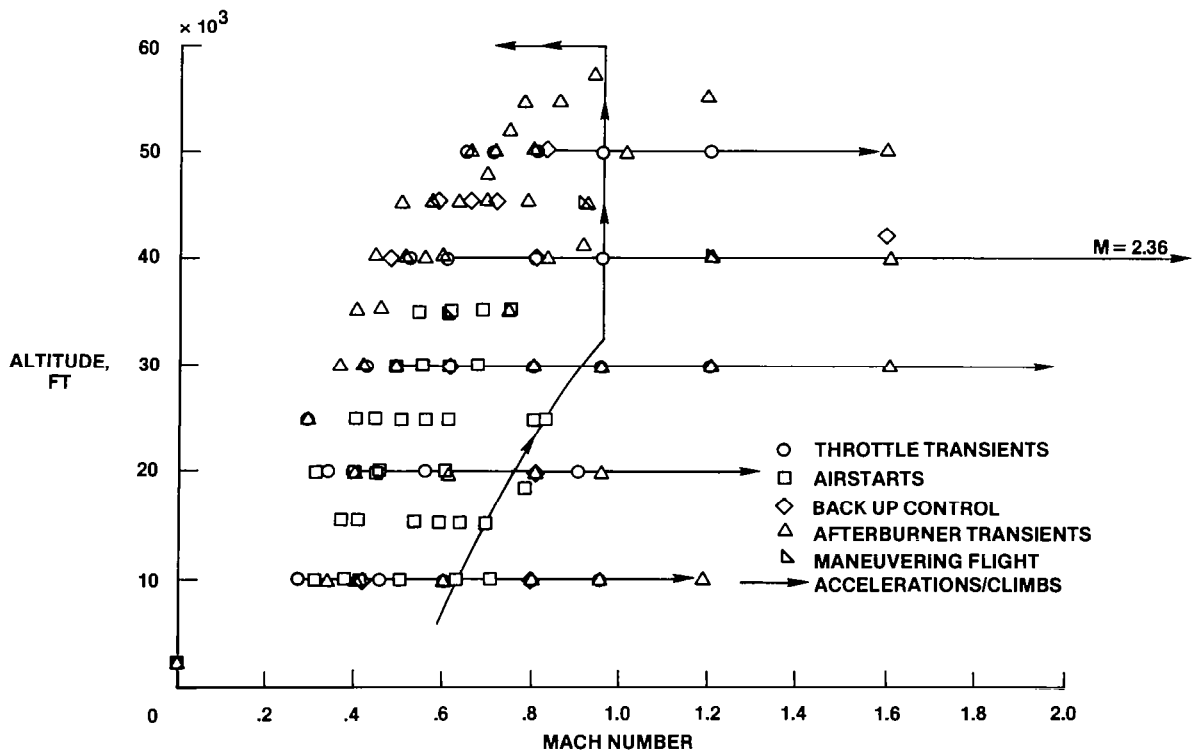
The DEEC flight test points are shown in the figure below. The test program concentrated on the upper left hand side of the F-15 envelope to determine the operability limits. For points in which stabilized speed and altitude were required, the pilot used the right engine to control speed while the left engine was evaluated.

In maneuvering flight, large angles of attack and sideslip (up to about 25° and 15°, respectively) were flown and throttle transients were performed. Airplane accelerations in intermediate and maximum power were flown at several altitudes. Transfers to backup control were made at the conditions indicated.

DEEC TEST POINTS FLOWN

NASA
DFRF81-269c

ALTITUDE, FT vs MACH NUMBER

O   THROTTLE TRANSIENTS
□   AIRSTARTS
◇   BACK UP CONTROL
△   AFTERBURNER TRANSIENTS
◮   MANEUVERING FLIGHT
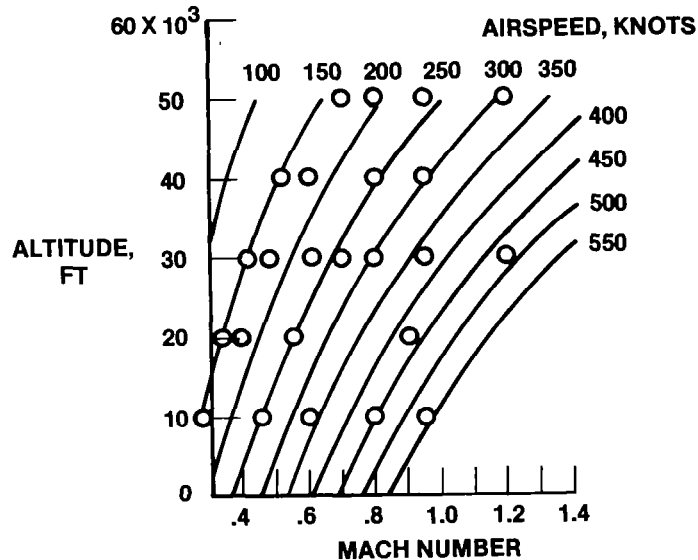——▶ ACCELERATIONS/CLIMBS

M = 2.36

NONAUGMENTED THROTTLE TRANSIENTS

Nonaugmented throttle transients in the DEEC primary mode consisted of snaps and bodies. Throttle transients were idle-intermediate and were performed from a Mach 0.6 at 50,000 ft to Mach 1.2 at 30,000 ft. During the transients no anomalies or engine limitations were encountered. The part-power small-transient response of the DEEC was evaluated in formation flying and aerial refueling, and was satisfactory.

Overall nonaugmented transient performance was excellent, particularly since this was the first flight evaluation of the DEEC system.

NON AUGMENTED THROTTLE TRANSIENTS

NASA
DFRF82-343

- SNAP ACCELERATIONS
- SNAP DECELERATIONS } 100 PERCENT SUCCESSFUL
- BODIES
- NO AUTOMATIC TRANSFERS TO BACKUP CONTROL

- NO STALLS
- NO ENGINE LIMITS EXCEEDED
- PILOTS LIKED RESPONSE

One of the most important features of the DEEC system is the capability to maintain a desired engine performance level without adjusting or trimming the engine. The DEEC maintains a desired performance by use of an EPR control mode as previously described. Approximately 100 hours of altitude-cell, sea level, and flight tests have been accomplished on the P063 with the DEEC system, without the need to retrim the engine. EPR plotted against corrected fan rotor-speed data from altitude-cell, sea level, and flight tests are shown in the lower left hand figure. This figure indicates that the engine maintained a desired performance level throughout the ground and flight tests.

During the flight-test phase, new software logic packages were provided. The DEEC computer was removed from the engine and replaced by another computer with different software without the need to adjust or trim the engine or remove the engine from the airplane.

The lower right hand figure indicates the possible savings of the U.S. Air Force if DEEC control systems were installed on one-half of the F-16 fleet, with a total savings of $150 million.
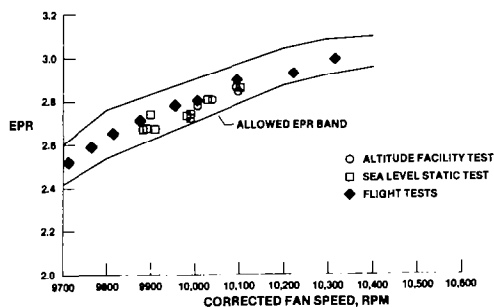
DEEC - NO TRIM

NASA
DFRF82-952

- **CLOSED LOOP CONTROL COMPENSATES FOR CHANGES IN ENGINE CONDITION, CONTROL TOLERANCES, AND FUEL CHARACTERISTICS**

- **ELIMINATES THE NEED FOR PERIODIC RETRIMMING**

DEEC TEST RESULTS

DEEC MILITARY POWER EPR CHECKS

O ALTITUDE FACILITY TEST
□ SEA LEVEL STATIC TEST
◆ FLIGHT TESTS

ALLOWED EPR BAND

EPR

CORRECTED FAN SPEED, RPM

SAVINGS TO U.S.
(BASED ON DEECS ON 1/2 OF F-16 FLEET)

- **FUEL - $40 MILLION**

- **LABOR - $10 MILLION**

- **ENGINE HOURS - 50,000**

- **VALUE OF ENGINE HOURS - $100 MILLION**

With the real-time data and displays available, the test engineers in the control room had access to virtually all the DEEC information in real time. The test program involved large numbers of throttle transients to determine the operability of the DEEC. A propulsion engineer, watching a strip chart, called the throttle sequence to the pilot. The engineer analyzed the data to determine when the engine had stabilized and called for the next step in a throttle transient series. This technique reduced the pilot workload and greatly improved the quality of data.

The EPR control mode feature was demonstrated; engine performance remained at an acceptable level without trimming or adjusting the engine throughout the ground and flight program.

Nonaugmented throttle transients and engine performance were satisfactory; the DEEC maintained control without exceeding any engine limits.

NASA
DFRF83-647a

Summary

- **Real-time data and displays extremely valuable**

- **Propulsion engineer assistance to pilot made more productive and efficient test time**

- **No trim verified—substantial savings shown**

- **All nonaugmented throttle transients successful**