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INTRODUCTION

The ability to achieve rapid and reliable airstarts is crucial to the safe operation of modern jet aircraft. The NASA Ames Research Center's Dryden Flight Research Facility is currently testing prototype Pratt and Whitney F100 Engine Model Derivative (EMD) engines in an F-15 aircraft. The F100 EMD has a thrust increase of approximately 15 percent over the standard F100 engine. It incorporates a redesigned fan, improved materials in the hot section, and a redesigned augmentor fuel distribution system. The F100 EMD also incorporates the digital electronic engine control (DEEC) system. The DEEC, described in ref. 1, incorporates closed loop airstart logic which was evaluated on a standard F100 engine (ref. 2), and resulted in a significant improvement in airstart envelope. For the first flight tests of the F100 EMD in March–June, 1983, similar airstart logic was used and similar airstart results were obtained (ref. 3). In the F100 EMD flight evaluation flown in July–September, 1983, modifications to the airstart logic were evaluated. This report describes the F100 EMD engine, the DEEC, the modifications to the airstart logic, and the airstart results before and after the logic modifications.

NOMENCLATURE

CIVV	compressor inlet variable vanes
DEEC	digital electronic engine control
EMD	engine model derivative
FTIT	fan turbine inlet temperature, $^{\circ}$C
HP	pressure altitude, m
JFS	jet fuel starter
M	Mach number
N1	engine fan speed, rpm
N2	engine core speed, percent (100 percent is 14,000 rpm)
PB	main burner pressure, N/cm^2
PLA	power lever angle, deg.
PS2	engine inlet static pressure, N/cm^2
PT6M	mixed turbine discharge pressure, N/cm^2

RCVV	rear compressor variable vanes
SEC	secondary engine control
T	airstart time, time from pressurization to idle N2, sec
TT2	engine inlet temperature
t	time, sec
WF	engine fuel flow, kg/hr
WF/PB	fuel flow-burner pressure ratio

DESCRIPTION OF APPARATUS

The F-15 aircraft (fig. 1) is a single seat, high performance, all weather air superiority fighter capable of Mach 2.5. It is a twin engine airplane with a high-mounted sweptback wing, twin vertical stabilizers, and large horizontal stabilizers. The F-15 has been modified to be a general test bed aircraft. During the first phase of the flight test program, an F100 EMD engine was installed in the left side of the F-15. During the second phase, the EMD engine used in Phase I was installed in the right side, and another F100 EMD was installed in the left side.

The F100 EMD engine (figs. 2 & 3) is a twin spool, low bypass ratio, augmented turbofan. It has a three stage fan driven by a two stage low pressure turbine. The fan has five percent greater airflow capability and seven percent more pressure rise than the standard F100 fan. The ten-stage high pressure compressor is driven by a two-stage high pressure turbine. The turbines incorporate single crystal blades and vanes, allowing a higher operating temperature than the standard F100 engine. Compressor bleed is used only during starting. The variable camber inlet guide vanes and rear compressor variable vanes allow for higher performance over the operating envelope. Variable augmented thrust is provided by a mixed flow, sixteen-segment afterburner. The mixed flow is exhausted through a variable area convergent-divergent nozzle. During Phase I, F100 EMD engine serial number P680350 was used, and for Phase II, F100 EMD engine serial number P680585 was added. Both engines are pre-production test models. Airstarts were conducted with both P680350 and P680585.

An important feature of the EMD engines is the DEEC unit. The DEEC is a full-authority digital electronic control system with a simple integral hydromechanical secondary engine control. The DEEC replaces the functions of the supervisory electronic engine control and the hydromechanical unified fuel control on the F100 engine. The DEEC system, shown in figure 4, receives inputs from: a) the airframe through throttle position (PLA) and Mach number (M); b) the engine through pressure sensors PB, P6TM, PS2, temperature sensors TT2 and FTIT, and rotor speed sensors N1 and N2; and c) the control system through feedback resolvers that indicate variable vane (RCVV, CIVV) positions, metering valve positions (fuel flow for primary and augmented thrust modes), and exhaust nozzle positions. This information is used by the DEEC controllor to a) schedule the compressor bleeds and position the variable vanes through actuators in open-loop system; b) control the primary and augmented fuel flows in a closed-loop system; and c) control the nozzle in a closed-loop system.

The DEEC computer is a 16 bit, 1.2 microsecond cycle time micro-computer with 10.5k available memory. The entire electronic unit is fuel cooled, and is engine mounted.

The DEEC secondary engine control (SEC) is a hydromechanical engine fuel control. It is mechanically integrated within the gas generator fuel metering hardware of the DEEC. In the event of a critical DEEC failure, or at the pilot's option, the SEC system can be engaged. The SEC inputs are PLA, TT2, PS2, and RCVV position. Based on these parameters, the SEC system controls the engine fuel flow, the RCVV position, and the compressor start bleed.

The Jet Fuel Starter (JFS) is a small auxiliary gas turbine power unit which can be coupled to the F100 engine. The JFS is used to accelerate the high compressor for engine starting on the ground. It may also be used in flight at altitudes below 7000 m. The JFS disengages automatically when 50-percent N2 is achieved.

Pressures, temperatures, rotor speeds, fuel flow, and positions of variable geometry are measured at various positions in the F100 EMD engine. Engine parameters important to this report are PLA, N2, PB, FTIT, and WF. All parameters are input into a pulse code modulation (PCM) system during the test flights. The digital PCM data are recorded on an onboard tape recorder and also telemetered to the ground for real time display in the control room.

DEEC Airstart Logic

In the event of an engine shutdown or flameout, the DEEC monitors several parameters to insure a successful airstart. An open-loop lightoff fuel flow is metered into the combustor until lightoff is detected. Once lightoff has been detected by the DEEC by an increase in FTIT, fuel flow and compressor bleeds are controlled by the closed-loop logic shown in figure 5. This logic attempts to maintain a desired N2 rate by varying fuel flow. The desired N2 rate is a function of PT2, TT2, and M. If the fuel flow is too high, the compressor may stall, resulting in a "hot start" or the combustor may blowout from an overrich fuel-air ratio. If the fuel flow is too low, the energy available will not be sufficient to overcome the losses in the engine and the accessory power drain, resulting in a "hung start". The DEEC airstart logic maintains the scheduled N2 rate subject to a bias if FTIT exceeds a temperature limit. The minimum fuel flow, set by a stop in the fuel metering valve, is approximately 115 kg/hr. The compressor bleeds are held open until a scheduled value of N2 is achieved.

DEEC logic 4.2.2, which is an updated version of logic 4.2.1, incorporates many changes, including several to the airstart logic. These are shown in Table 1. Logic 4.2.2 increased the N2 rate schedule, biased lightoff fuel flow and trim rate slew out by PT2, raised the percentage N2 before the start bleeds closed, and reduced the FTIT limit during airstarts. These changes help to prevent hot starts and significantly reduce airstart times.

TEST PROCEDURE

Tests were performed to compare the airstart capability of the F100 EMD engine with logic 4.2.2 to the capability of the former logic, 4.2.1. The three types of airstarts examined are 40-percent spooldown, 25-percent spooldown, and JFS assisted. For all airstarts the normal F-15 power requirements for the engine and accesories were present.

The spooldown airstart is achieved in a four step procedure: 1) engine shutdown, 2) pressurization, 3) light, and 4) acceleration of the engine to idle speed. The engine shutdowns were mostly performed from the intermediate power setting. The compressor rotor was then allowed to wind down (spooldown) to a predetermined percentage of maximum core speed. For the evaluation of EMD airstart capability, values of 40-percent N2 and 25-percent N2 were used. The pressurization step was accomplished when the pilot returned the throttle to the idle power setting to begin the start cycle. This pressurized the fuel system and fuel began to flow to the combustor. Approximately 8 seconds later, the fuel reached the combustor nozzles and was ignited (light). The fuel flow was modulated by the DEEC to maintain the desired N2 rate until the scheduled idle speed was reached and the airstart sequence was completed. Airstart time, T, is calculated from the time of pressurization to the time when idle N2 is reached in the above procedure.

The JFS assisted airstart is accomplished by coupling the jet fuel starter to the high compressor rotor through a gearbox. The JFS may be engaged at any N2 speed from 0 to 30-percent. The pressurization step may be initiated at a core speed of 12-percent or greater. The JFS disengages automatically at 50-percent N2.

Of the 35 primary DEEC airstarts attempted during the test flights, 18 were 40-percent spooldown, 12 were 25-percent spooldown, and 5 were JFS-assisted.

During the airstart tests the pilot used one engine for the test and maintained the desired altitude and airspeed with the other engine. Airspeed was held within 4 knots and altitude within 30 m of the desired test condition. Test day temperature varied as much as ± 10°C from standard day temperatures. More details of the test procedure can be found in reference 1.

RESULTS AND DISCUSSION

Spooldown Airstarts

Figure 6 is a time history of an EMD DEEC logic 4.2.2 airstart at 250 knots calibrated airspeed and an altitude of 10,700 m. The pilot initiated the airstart procedure by shutting down the engine at t = 11 sec. The core speed, N2, immediately began to spool down with a rapid drop in fan turbine inlet temperature (FTIT). The core reached 40-percent rpm at t = 34 sec, at which time the pilot moved the throttle to idle, which pressurized the fuel system and initiated the airstart sequence. The fuel began to flow through the fuel manifold, however FTIT and N2 continued to drop until t = 42 sec when the fuel reached the combustor and was ignited as indicated by the rise in FTIT. The DEEC closed-loop logic then modulated the fuel flow to achieve the desired rate of acceleration of the engine core. N2 increased uniformly until t = 60 sec, then increased its acceleration. FTIT increased along with the increased N2 rate while fuel flow, WF, was decreasing, indicating a sudden increase in the efficiency of the main combustor. This increase in burner efficiency has been noted previously at high altitude conditions. Idle rpm was reached at t = 79 sec. The airstart time, T, defined as the time from pressurization to idle, was 45 sec.

Figure 7 shows a 40-percent spooldown airstart at the same flight conditions of 250 knots and 10,700 m, but with DEEC logic 4.2.1. The pilot shutdown the engine at t = 11 sec. Fuel flow quickly went to zero, while core speed and FTIT dropped rapidly for the first few seconds, then more slowly. The engine reached 40-percent N2 at t = 31 sec, at which time pressurization occurred. Engine rpm and FTIT continued to drop, reaching 30-percent and 412°C respectively at t = 42 sec, when the fuel mixture ignited. The compressor rpm increased uniformly until t = 63 sec, when N2 rate increased due to the increase in combustor efficiency, as previously noted in figure 6. Idle rpm was reached at t = 93 sec. The airstart took 62 sec compared to 45 sec for DEEC logic 4.2.2, shown in the previous figure.

Spooldown to a lower percentage N2 increased the airstart time considerably. Figure 8 shows an airstart with DEEC logic 4.2.2 at the same flight conditions as figure 6, 250 knots and 10,700 m. The difference is a 25-percent spooldown instead of a 40-percent spooldown. The pilot shutdown the engine at t = 13 sec and pressurized at t = 66 sec. The engine spooled down to 23-percent N2 and FTIT was 325°C when the fuel ignited at t = 75 sec. The engine reached idle speed at t = 123 sec. The total airstart time was 57 sec compared to 45 sec for the same logic at the same flight conditions but for a 40-percent spooldown airstart.

Figure 9 is another comparison between logic 4.2.2 and 4.2.1. It shows the same spooldown percentage and flight conditions as figure 8 but this time with logic 4.2.1. The pilot shutdown the engine at t = 10 sec and pressurized at t = 59 sec. Engine rpm and FTIT dropped to 21 percent and 285°C respectively at t = 70 sec when the burner light occurred. The engine reached idle at 130 sec. The airstart time was 71 sec compared to the time of 57 sec for the same airstart with DEEC logic 4.2.2.

Airstarts at lower airspeeds took longer because of the reduced energy of the inlet flow, lower burner pressure, and lower stall margin. Figure 10 shows a 40-percent spooldown airstart at an airspeed of 200 knots and an altitude of 10,700 m. Shutdown occurred at t = 9 sec and the system was pressurized at t = 26 sec. The fuel ignited at t = 35 sec when rpm was 31 percent and FTIT was 400°C. The engine reached idle at t = 84 sec for an airstart time of 58 sec. This may be compared to the 250 knot airstart in figure 6 which had an airstart time of 45 seconds. Also this may be compared to the same airstart performed with DEEC logic 4.2.1 which had an airstart time of 92 sec, indicating a reduced time for logic 4.2.2 by 37 percent.

Airstarts were performed at different altitudes to test the effect of altitude on airstart times. Figure 11 is a 40-percent spooldown airstart at 250 knots and an altitude of 7,600 m. The pilot shutdown the engine at t = 7 sec and pressurized at t = 22 sec. The engine spooled down to 31 percent and FTIT reached 500 °C before the light occurred at t = 30 sec. The engine reached idle speed at t = 55 sec for an airstart time of 33 sec. This may be compared to the airstart at 10,700 m which took 45 sec. The same airstart as figure 11 but for DEEC logic 4.2.1 had a time of 48 sec. The modifications in DEEC logic 4.2.2 reduced the airstart time by 31 percent.

JFS-Assisted Airstarts

The JFS was utilized to test for faster airstart times at conditions within the JFS envelope. Figure 12 shows a time history of a JFS-assisted airstart at an airspeed of 170 knots and an altitude of 7,000 m. The pilot shutdown the engine at t = 3 sec and engaged the JFS at t = 41 sec, when N2 was at 13 percent. The JFS accelerated the compressor, and the pilot advanced the throttle to idle at t = 46 sec. The JFS continued to accelerate the compressor and the light occurred at t = 56 sec. The compressor quickly accelerated to 50 percent. When the JFS disengaged, the N2 rate dropped off for a few seconds, then increased again, and idle was reached at t = 83 sec. The airstart time was 37 sec, compared to a 25-percent spooldown at similar conditions of 175 knots and 7,600 m, which took 76 sec.

The same JFS-assisted airstart at an altitude of 7000 m and an airspeed of 170 knots was performed with DEEC logic 4.2.1. The airstart time was 60 sec. DEEC logic 4.2.2 improved this airstart time to 37 sec, a decrease in time of 38 percent.

Summary of Airstart Times

Comparisons of the airstart times for DEEC logic 4.2.1 and 4.2.2 are shown in figures 13 and 14 for 40-percent spooldown airstarts and 25-percent spooldown airstarts respectively. The results show a large improvement in DEEC logic 4.2.2 over 4.2.1. In figure 13, the 40-percent spooldown airstart times for the DEEC logic 4.2.1 range from 52 sec at 250 knots and 7,600 m to 133 sec at 7,600 m and 175 knots. These times were taken from reference 3. For DEEC logic 4.2.2, however, airstart times range from 33 sec to 62 sec for the same conditions. Thus the modified logic reduced the airstart times 37 percent to 53 percent. The largest decrease in times came at the lower airspeeds. This is not surprising since the modified logic calculates fuel flow rate as a function of airspeed. This results in the large improvements in the airstarts at low airspeeds.

The 25-percent spooldown airstart results shown in figure 14 are similar. Times for DEEC logic 4.2.1 ranged from 56 sec at 3050 m and 250 knots to 170 sec at 7600 m and 175 knots. Times for DEEC logic 4.2.2 ranged from 39 sec to 83 sec at the same conditions. This was a reduction in time of 30 percent to 51 percent. Again, the greatest reduction in times was for the slower airspeeds.

Unsuccessful Airstarts

The F100 EMD experienced four unsuccessful airstarts during the flight evaluation of the 4.2.2 logic. Two of these were hot starts, in which the engine lit normally, but the FTIT exceeded the engine starting temperature limit. The other two were "blowouts" in which the combustor flame blew out and did not reignite.

Figure 15 shows the time history of an airstart in which a combustor blowout occurred. This happened on a 25-percent spooldown airstart at an altitude of 10,700 m and an airspeed of 200 knots. The shutdown occurred at t = 10 sec and the system was pressurized at t = 47 sec. N2 and FTIT increased normally until t = 81 sec when the blowout occurred. The pilot waited 12 sec to see if the burner would relight, after which he shutdown the engine, terminating the airstart test, and increased airspeed. He pressurized again at t = 101 sec and N2 accelerated very rapidly to idle. Figure 16 is a plot of N2 versus fuel-flow to burner pressure ratio, WF/PB, which closely resembles fuel-air ratio. It shows that when the blowout occured at N2 = 31.5 percent, WF/PB was 44. This mixture appears to be too rich for the low pressure and temperature present in the combustor causing a rich blowout. The DEEC logic does not recognize blowouts and continued to increase fuel flow until the pilot terminated the airstart. Thus, in figure 16, WF/PB continued to increase during the spooldown after blowout, preventing a relight. One other blowout occurred at 225 knots and an altitude of 12,200 m for the same reasons as above.

Figure 17 shows the time history of a hot start at an altitude of 10,700 m and an airspeed of 175 knots. At t = 2 sec the pilot shutdown the engine and then pressurized at t = 18 sec. The light occurred at t = 29 sec. N2 did not increase and even with the fuel flow at its minimum value, the FTIT continued to increase, indicating a compressor stall on the lightoff. When the FTIT reached 750°C at t = 44 sec, the pilot discontinued the test by shutting down the engine and increasing airspeed, eventually reaching 300 knots. FTIT and N2 quickly dropped until the pilot repressurized at t = 51 sec. Then N2 quickly accelerated to idle.

The fourth unsuccessful airstart, a 40-percent spooldown at 200 knots and 10,700 m, also resulted in a hot start. The test was repeated since the new logic was designed to prevent hot starts. It was successful. A plot showing an overlay of the successful and unsuccessful airstarts at this condition is shown in figure 18. It shows that spooldown rate and initial fuel flow are very similar but there is some difference in FTIT. Prior to the hot start, the engine had been at intermediate power for a longer time, significantly increasing FTIT, and resulting in a hotter compressor. When the airstart was initiated, the light was normal, but after about 5 sec, the N2 rate dropped off to zero while the FTIT continued to climb, indicating a stall. As FTIT exceeds 700°C the fuel flow was reduced but with the stalled compressor, recovery was not possible. The pilot shutdown the engine, increased airspeed, and successfully completed the airstart.

Summary of Spooldown Airstart Success

Figure 19 summarizes the successful and unsuccessful airstarts for EMD DEEC logic 4.2.2 and logic 4.2.1. Airstarts below 10,700 m were all successful with logic 4.2.2. At 10,700 m, three were unsuccessful; one a blowout at 200 knots and 25-percent, one a hot start at 175 knots, and the third, a 40-percent spooldown airstart at 200 knots that was successfully repeated. The blowout at 12,200 m and 225 knots was not unexpected since the airstart was conducted at the upper limit of the airstart envelope.

Comparing the unsuccessful airstarts of logic 4.2.2 to those of logic 4.2.1, two significant differences appear. One is the now successful airstart at 3050 m and 175 knots which failed with logic 4.2.1. The success is due to the revised N2 schedule and the other improvements in Table 1. The second difference is the blowouts which occurred at high altitude. Flight testing of airstarts with logic 4.2.1 were never conducted at 12,200 m, thus rendering it impossible to make a comparison. Blowouts occurring with logic 4.2.2 were probably due to the higher N2 rate schedules that resulted in a higher fuel-air ratio.

CONCLUDING REMARKS

A series of airstarts were conducted in an F-15 airplane with two prototype Pratt and Whitney F100 Engine Model Derivitive engines equipped with Digital Electronic Engine Control systems utilizing logic 4.2.2. The airstart envelope and the time required for airstarts were defined. Comparisons were made between the original logic, 4.2.1, and the modified 4.2.2 logic.

Spooldown airstarts with the 4.2.2 logic were more successful at lower altitudes than were those with logic 4.2.1. Spooldown airstart times ranged from 33 sec at 250 knots to 83 sec at 175 knots. 4.2.2 logic improved the airstart time by 31 percent to 53 percent, with the most improved times at slower airspeeds. JFS-assisted airstarts were conducted at 7000 m and airstart times were significantly faster than unassisted airstarts. The effect of altitude on airstart times was small.

The 4.2.2 logic, having higher N2 rate schedules, did result in more unsuccessful airstarts at the upper part of the airstart envelope at very low airspeeds. Combustor blowouts and hot starts occurred at test conditions where the 4.2.1 logic would have been able to make a very slow but successful airstart.

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1. Myers, L.P., : Flight Test of a Full Authority Digital Electronic Engine Control in an F-15 Airplane. AIAA Paper 81-1501, July, 1981.

2. Licata, S.J., and Burcham, F.W. : Airstart Performance of a Digital Electronic Engine Control System in an F-15 Airplane. NASA TM 84908, April, 1983.

3. Cho, T.K., and Burcham, F.W. : Preliminary Flight Evaluation of F100 Engine Model Derivative Airstart Capabilities in an F-15 Airplane. NASA TM 86031, July, 1984.

	DEEC SOFTWARE RELEASE	
	4.2.1 (MAR-JUNE 1983)	4.2.2 (JULY-SEPT 1983)
N2 RATE SCHEDULE	BASE	INCREASED
LIGHTOFF FUEL FLOW	f(FTIT)	f(FTIT, PT2)
TRIM RATE SLEW OUT	f(M)	f(M, PT2)
START BLEED CLOSURE	56-percent N2	61-percent N2
FTIT LIMIT DURING STARTS	760°C	704°C

TABLE 1. Significant differences in airstart logic between software release 4.2.1 and 4.2.2.

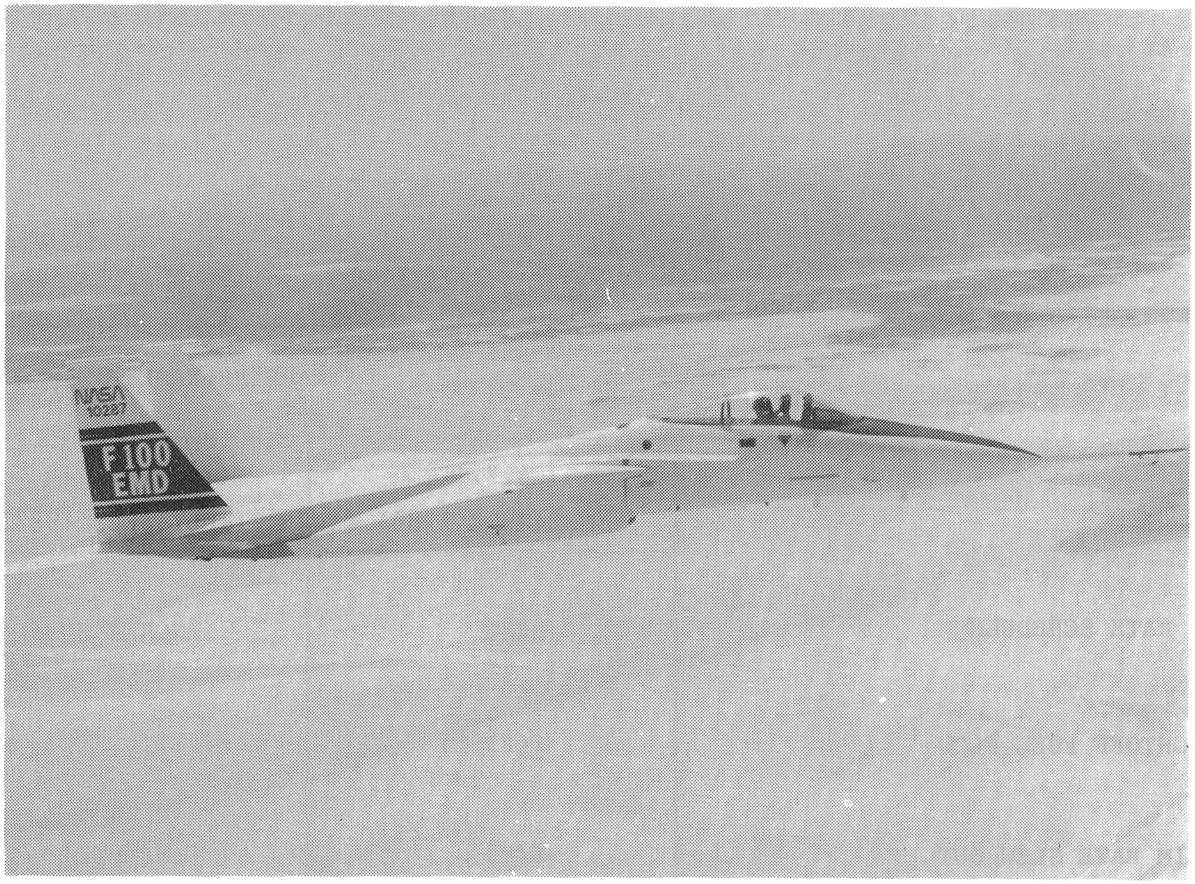


Figure 1. Photograph of the F-15 airplane.

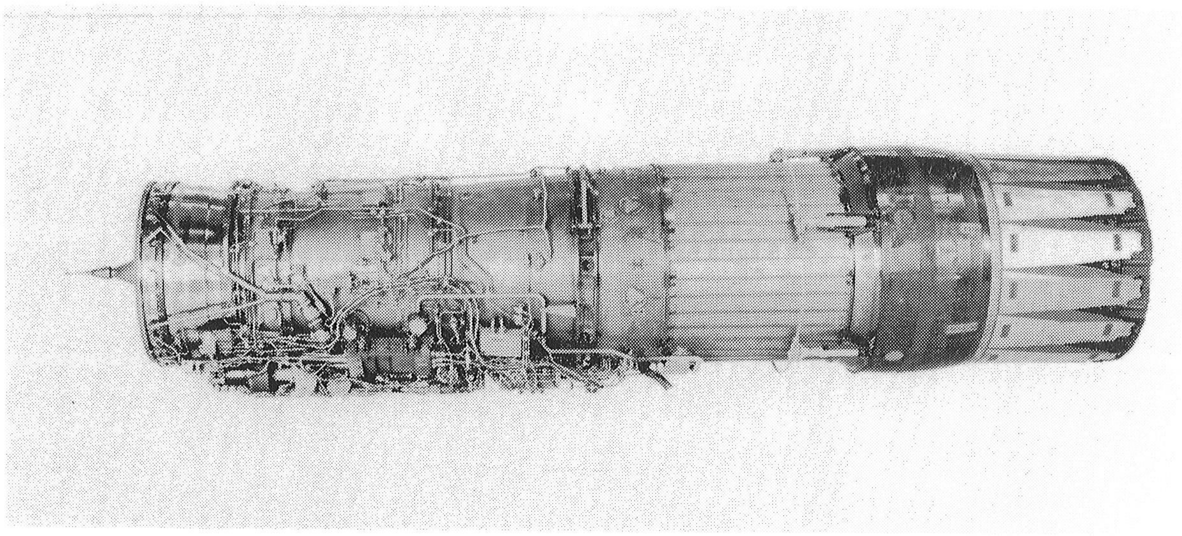


Figure 2. Photograph of the F100 EMD test engine.

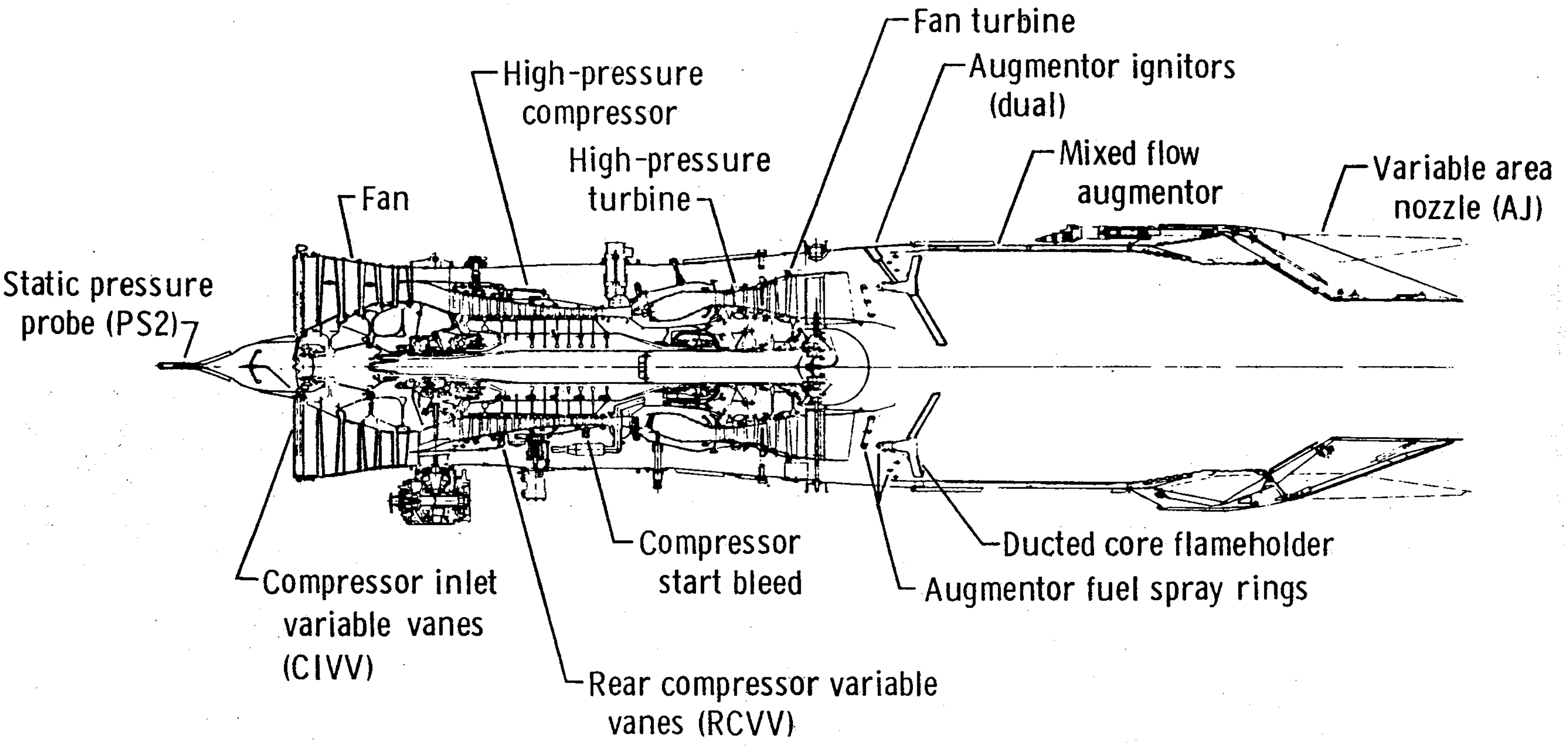


Figure 3. Cutaway view of the F100 EMD engine

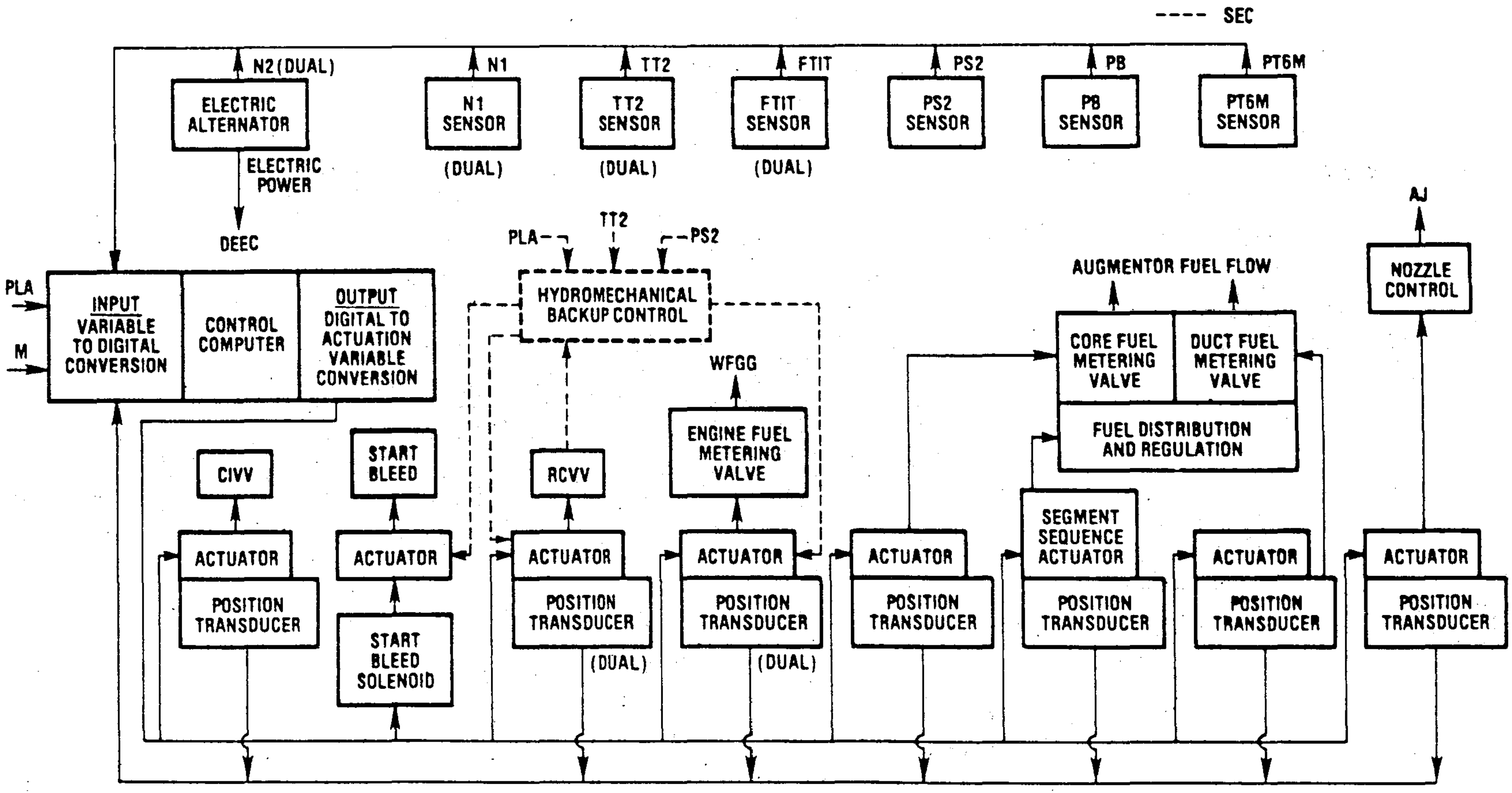


Figure 4. Block diagram of the F100 EMD/DEEC control system

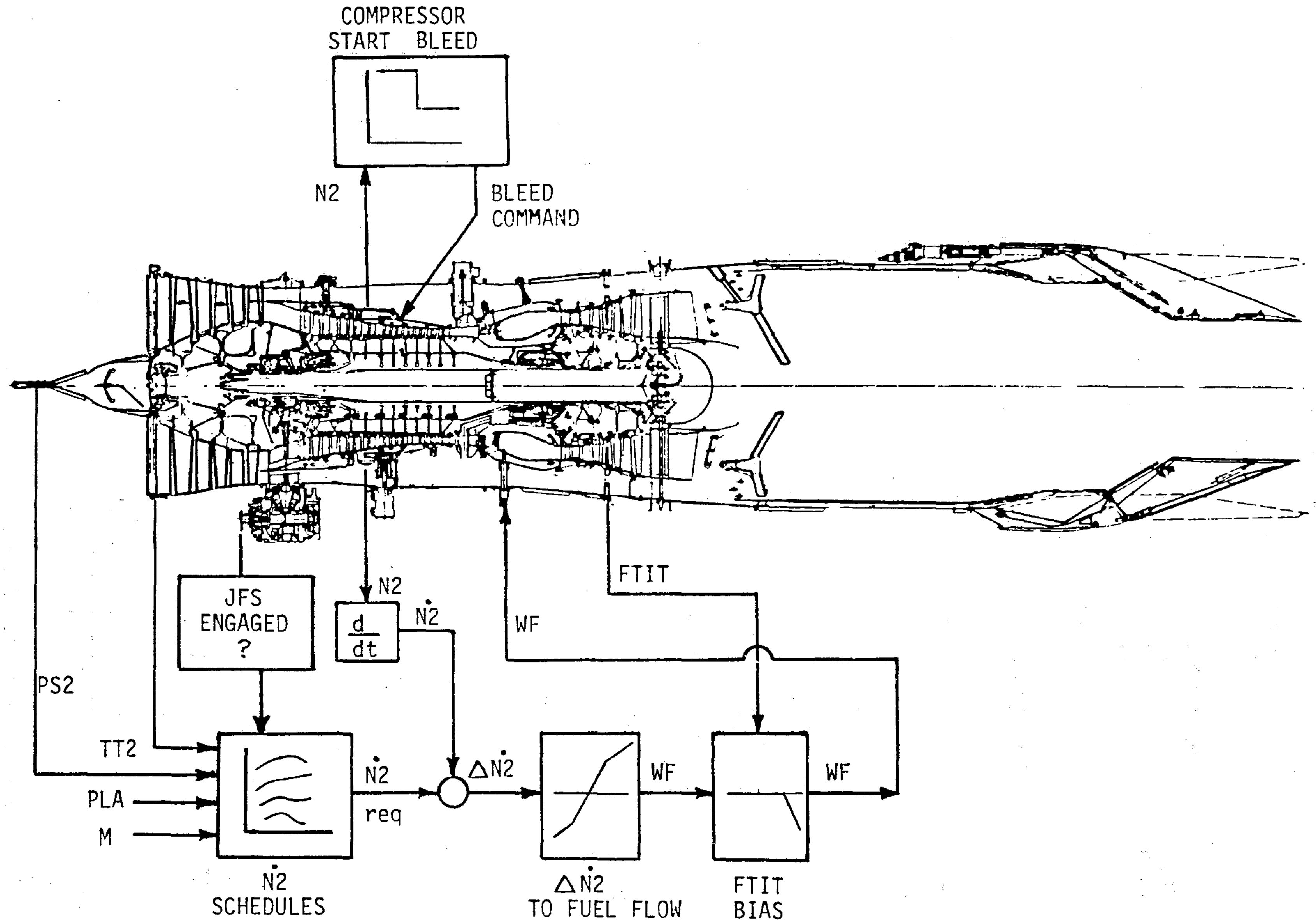


Figure 5. F100 EMD/DEEC airstart logic

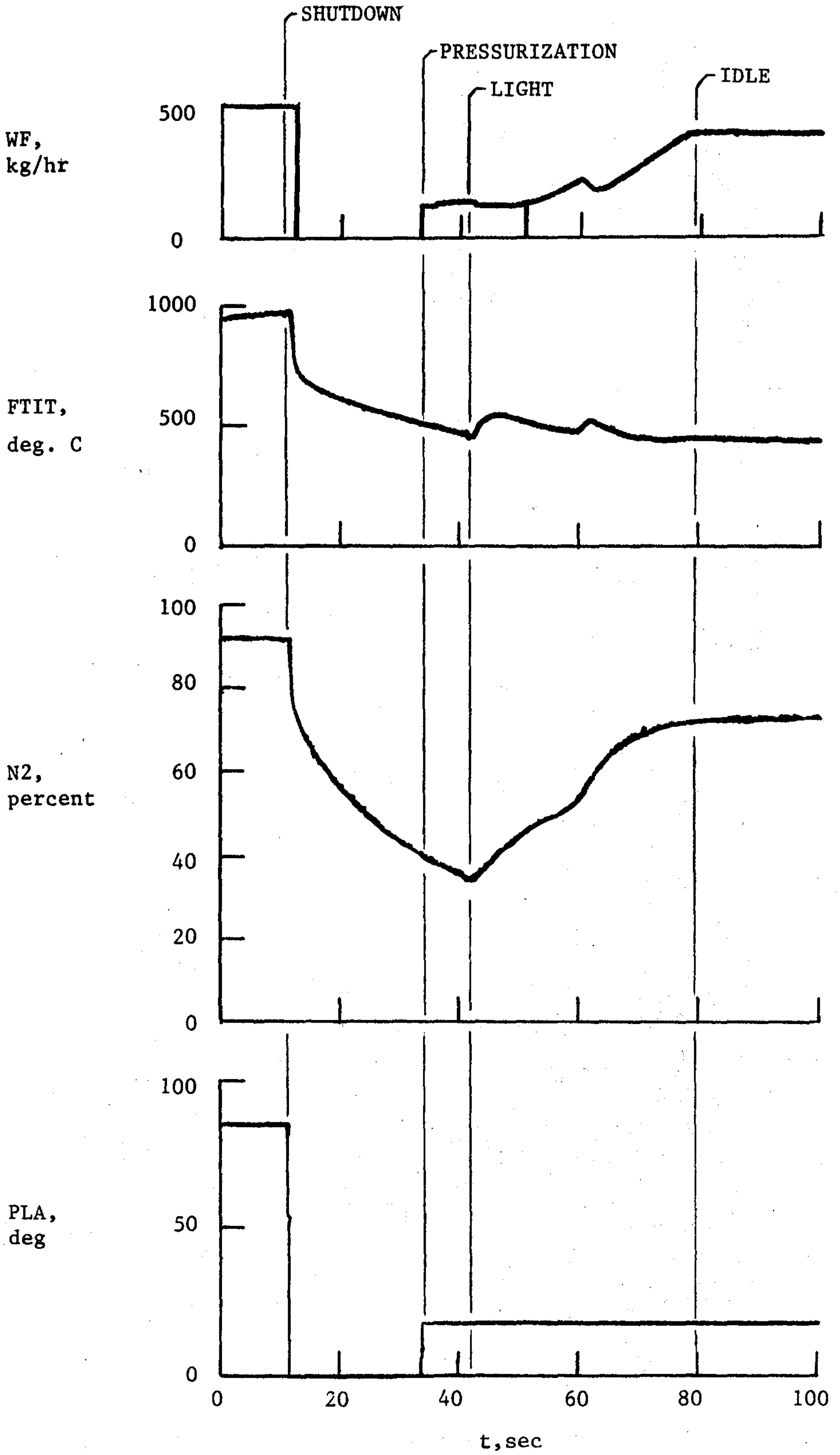


Figure 6. F100 EMD 40-percent spooldown airstart. DEEC logic 4.2.2, VC = 250 knots, HP = 10,700 m.

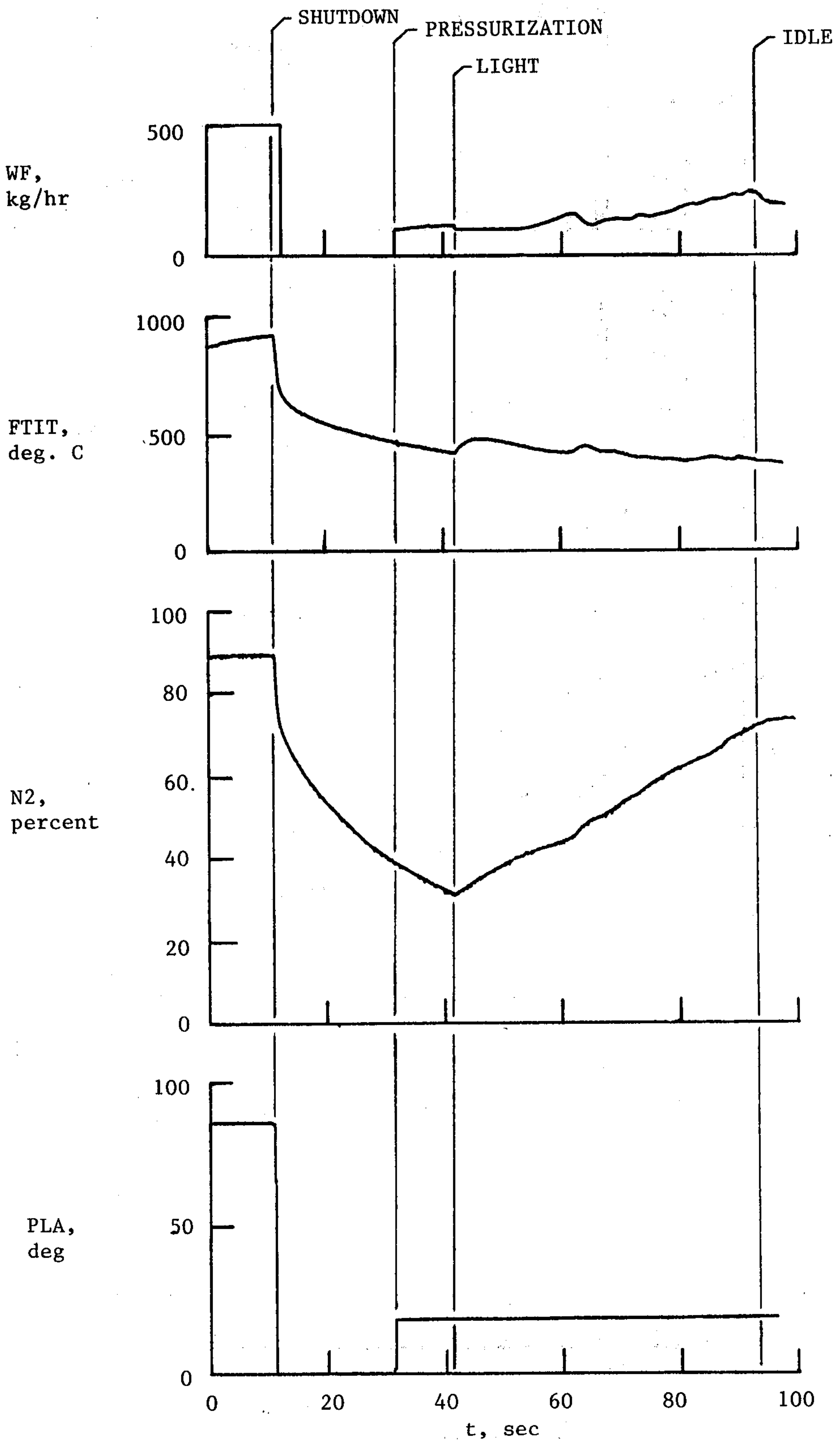


Figure 7. F100 EMD 40-percent spooldown airstart.
DEEC logic 4.2.1, VC = 250 knots, HP = 10,700 m.

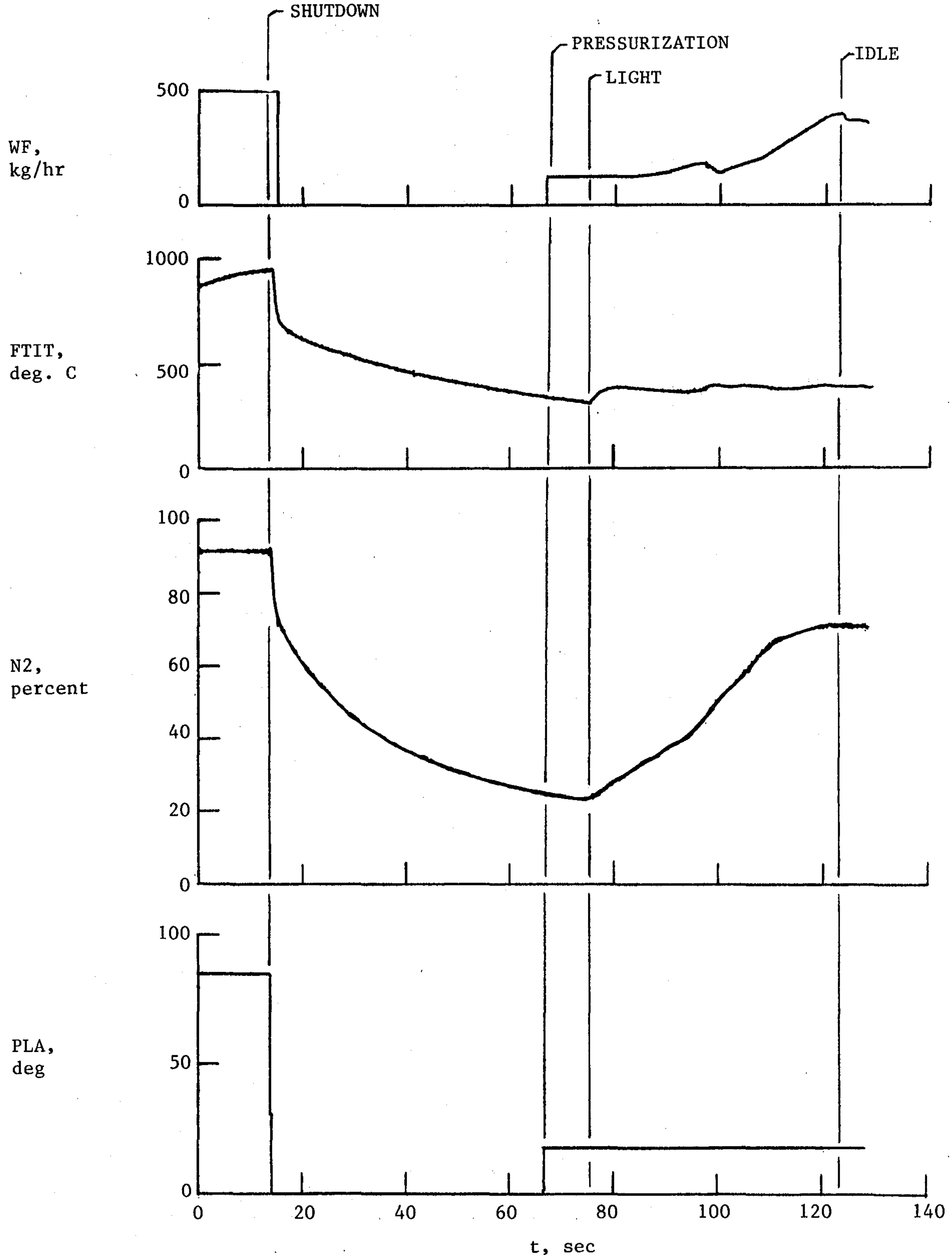


Figure 8. F100 EMD 25-percent spooldown airstart.
DEEC logic 4.2.2, VC = 250 knots, HP = 10,700 m.

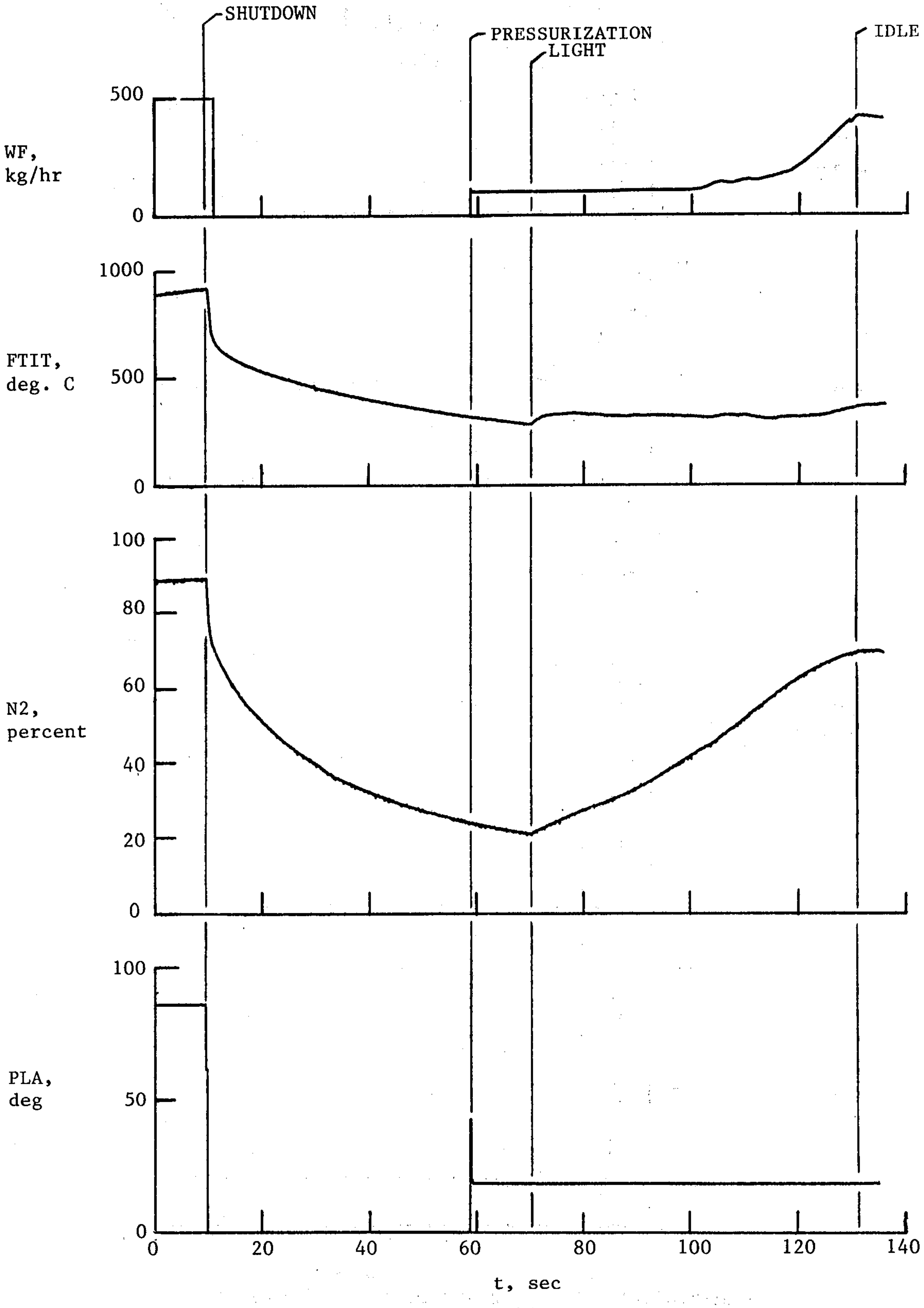


Figure 9. F100 EMD 25-percent spooldown airstart.
DEEC logic 4.2.1, VC = 250 knots, HP = 10,700 m.

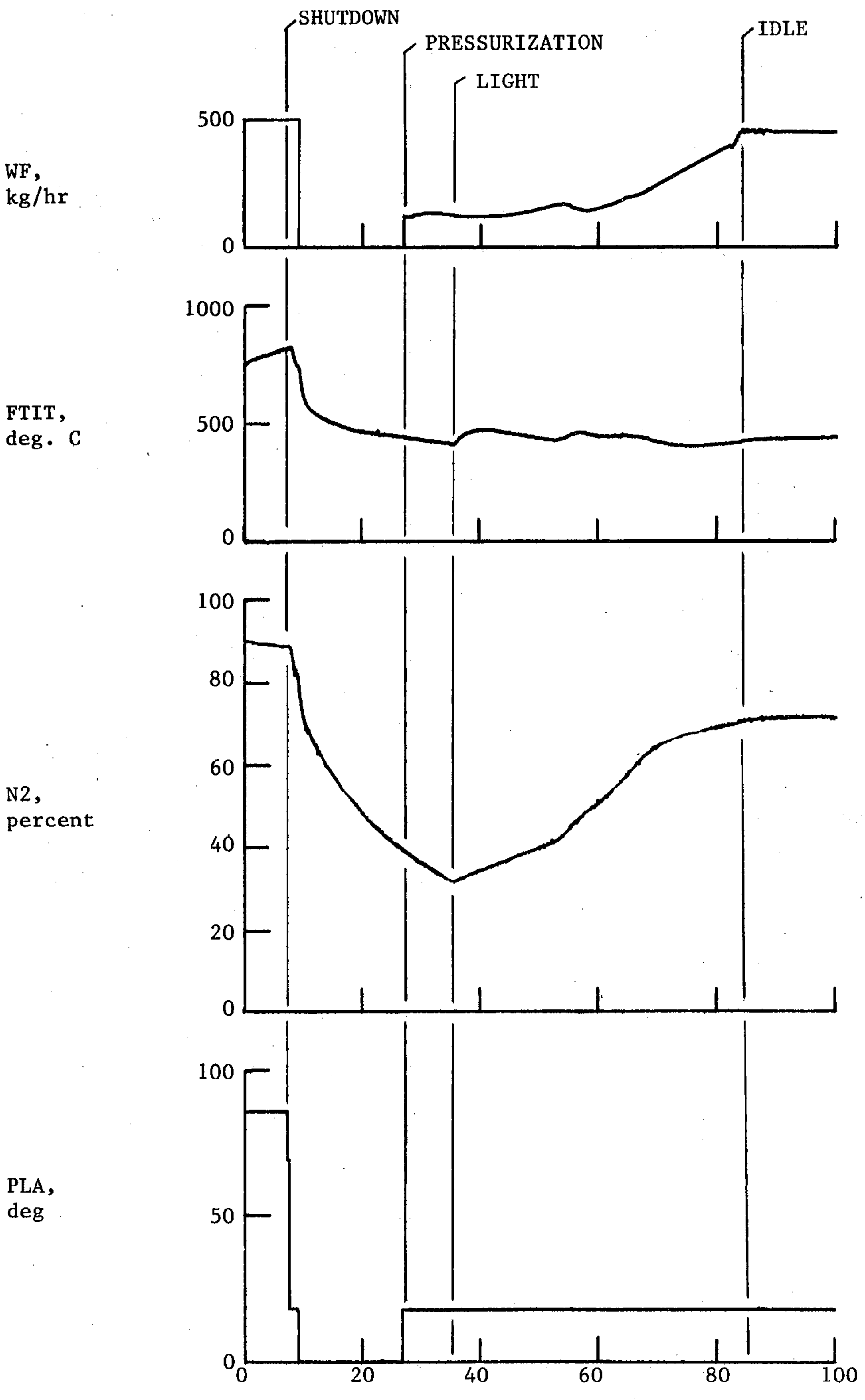


Figure 10. F100 EMD 40-percent spooldown airstart. DEEC logic 4.2.2, VC = 200 knots, HP = 10,700 m.

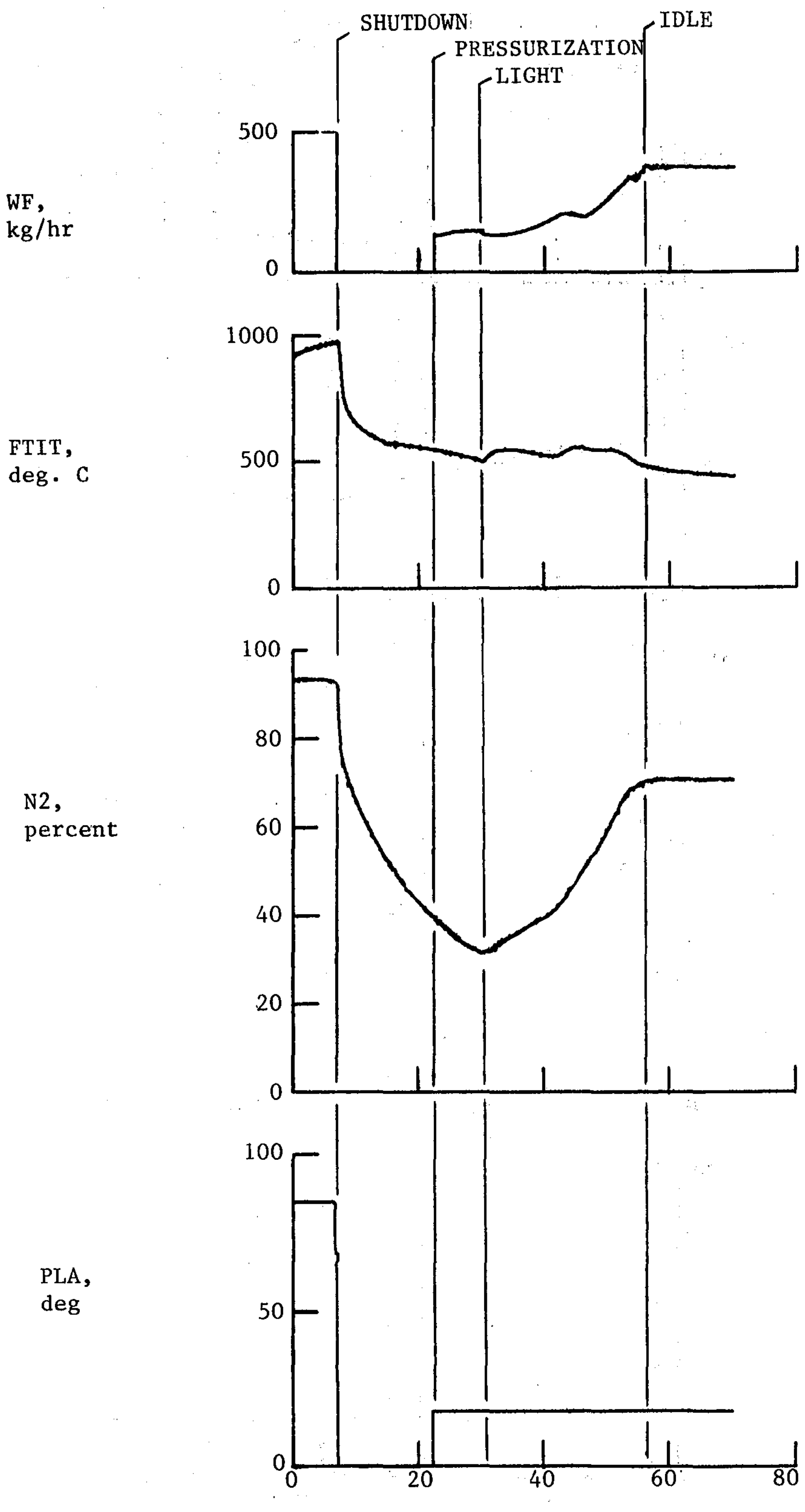


Figure 11. F100 EMD 40-percent spooldown airstart.
DEEC logic 4.2.2, VC = 250 knots, HP = 7,600 m.

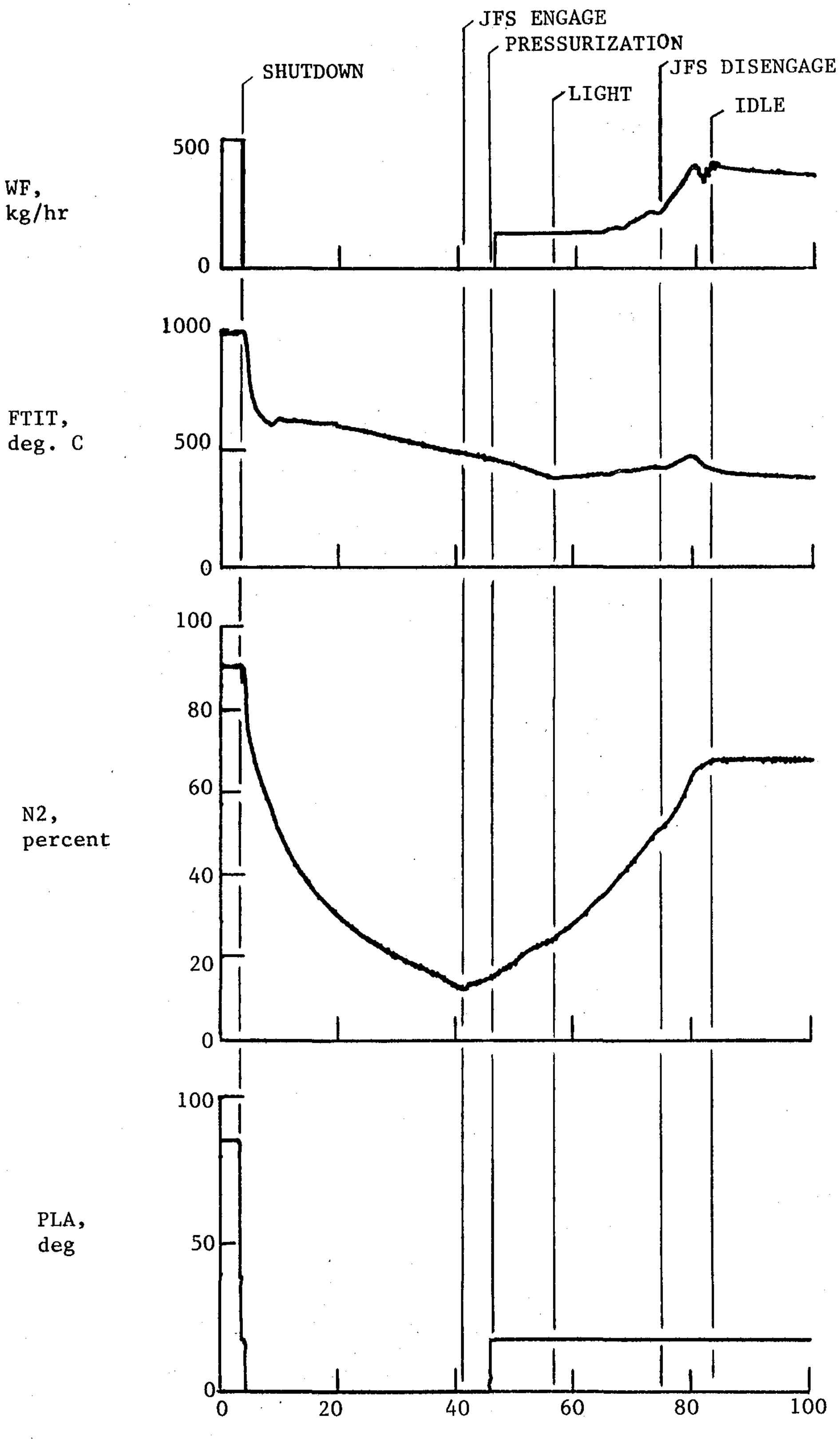


Figure 12. F100 EMD JFS assisted airstart.
DEEC logic 4.2.2, VC = 170 knots, HP = 6,100 m.

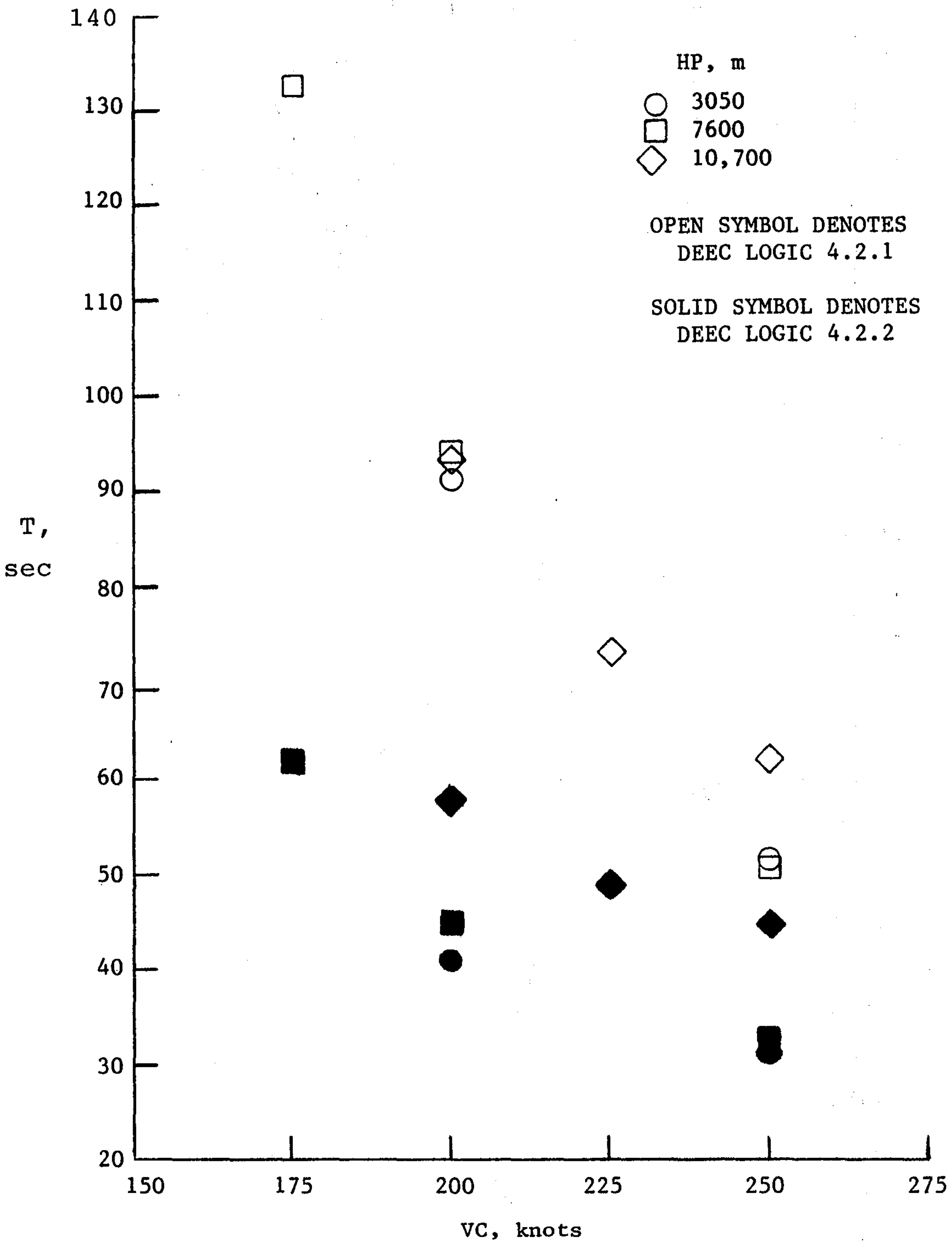


Figure 13. Comparison of DEEC logic 4.2.1 to 4.2.2 and effect of airspeed on airstart time for 40-percent spooldown airstart.

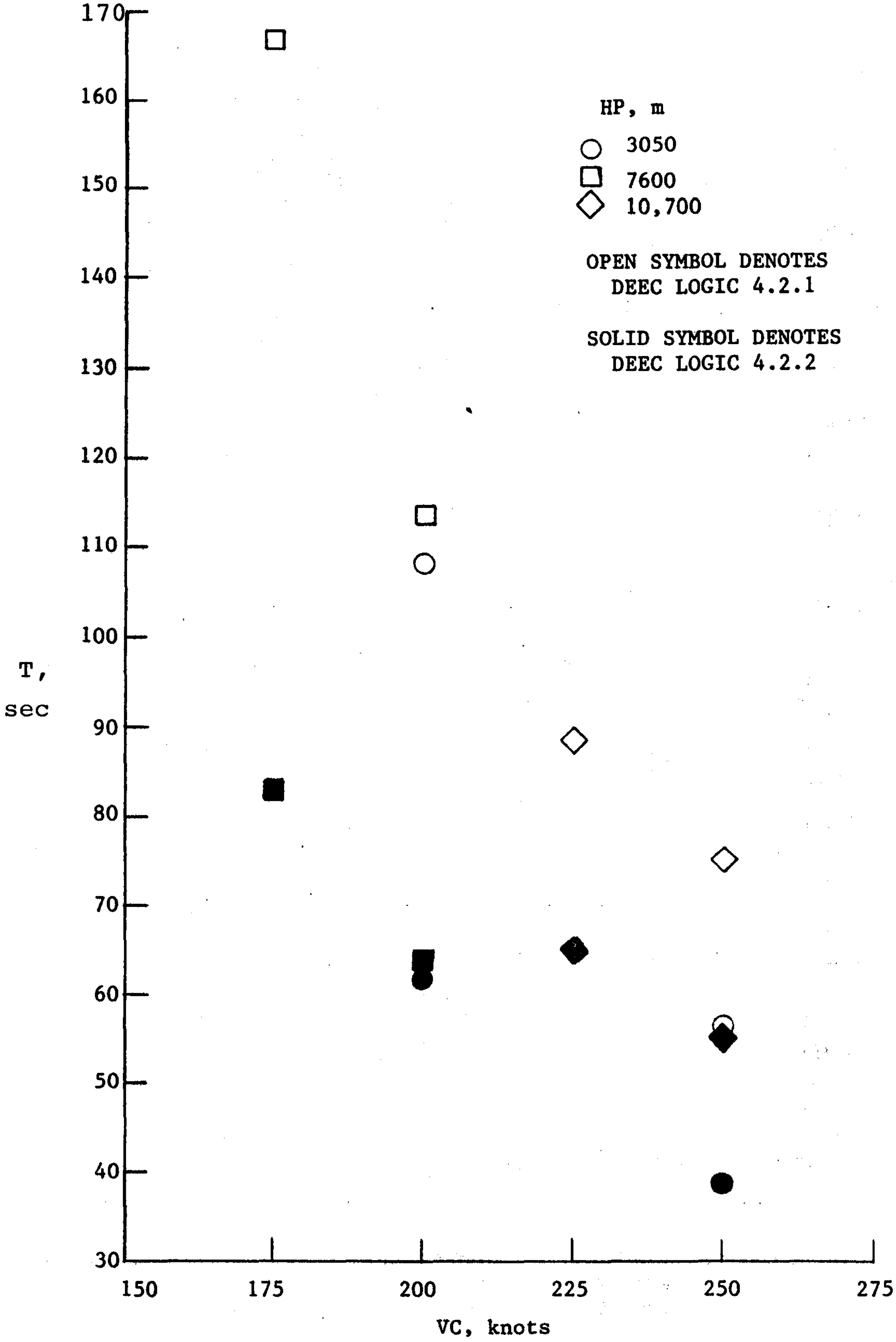


Figure 14. Comparison of DEEC logic 4.2.1 to 4.2.2 and effect of airspeed on airstart time for 25-percent spooldown airstart.

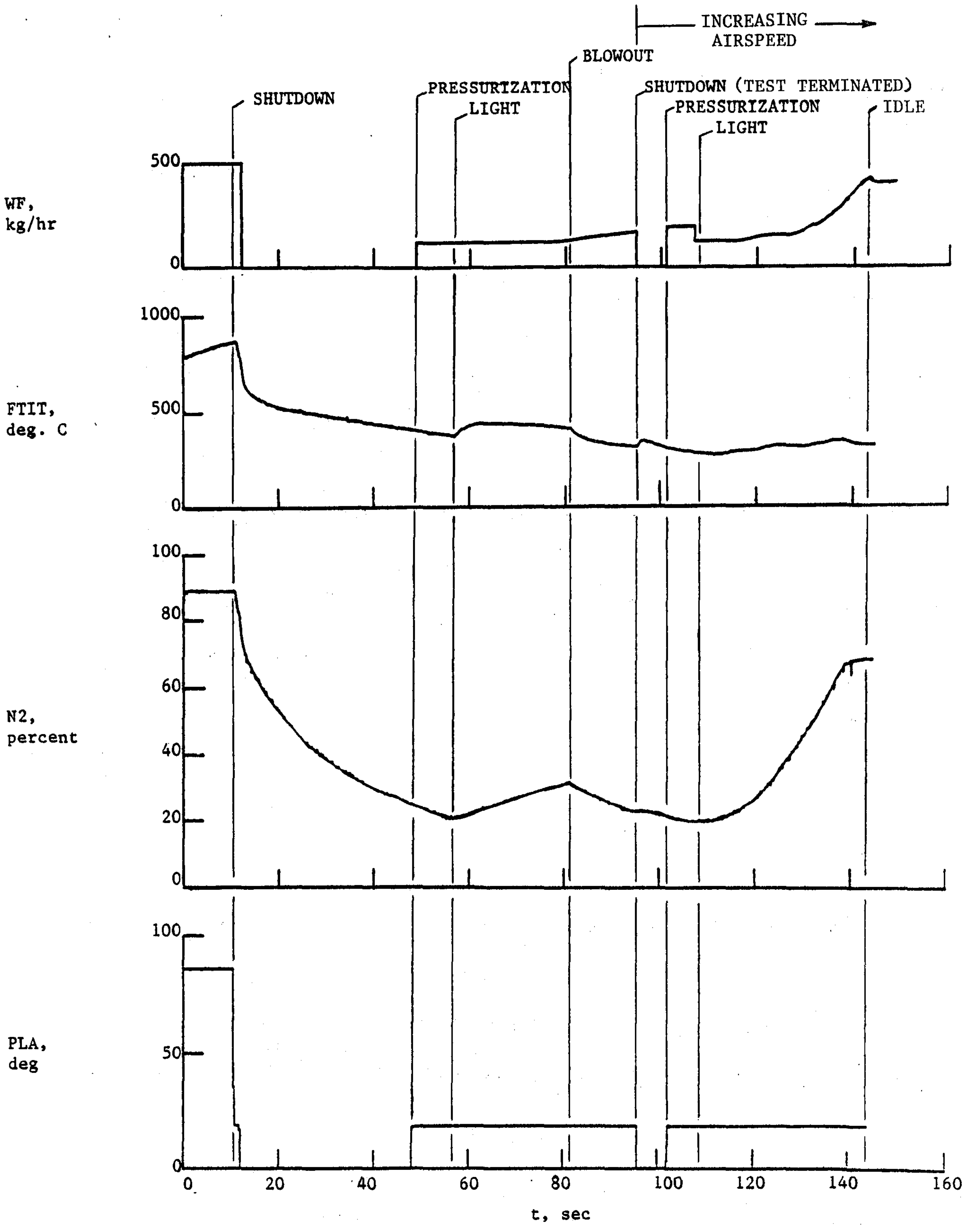


Figure 15. F100 EMD 25-percent spooldown "blowout".
DEEC logic 4.2.2, VC = 200 knots HP = 10,700 m.

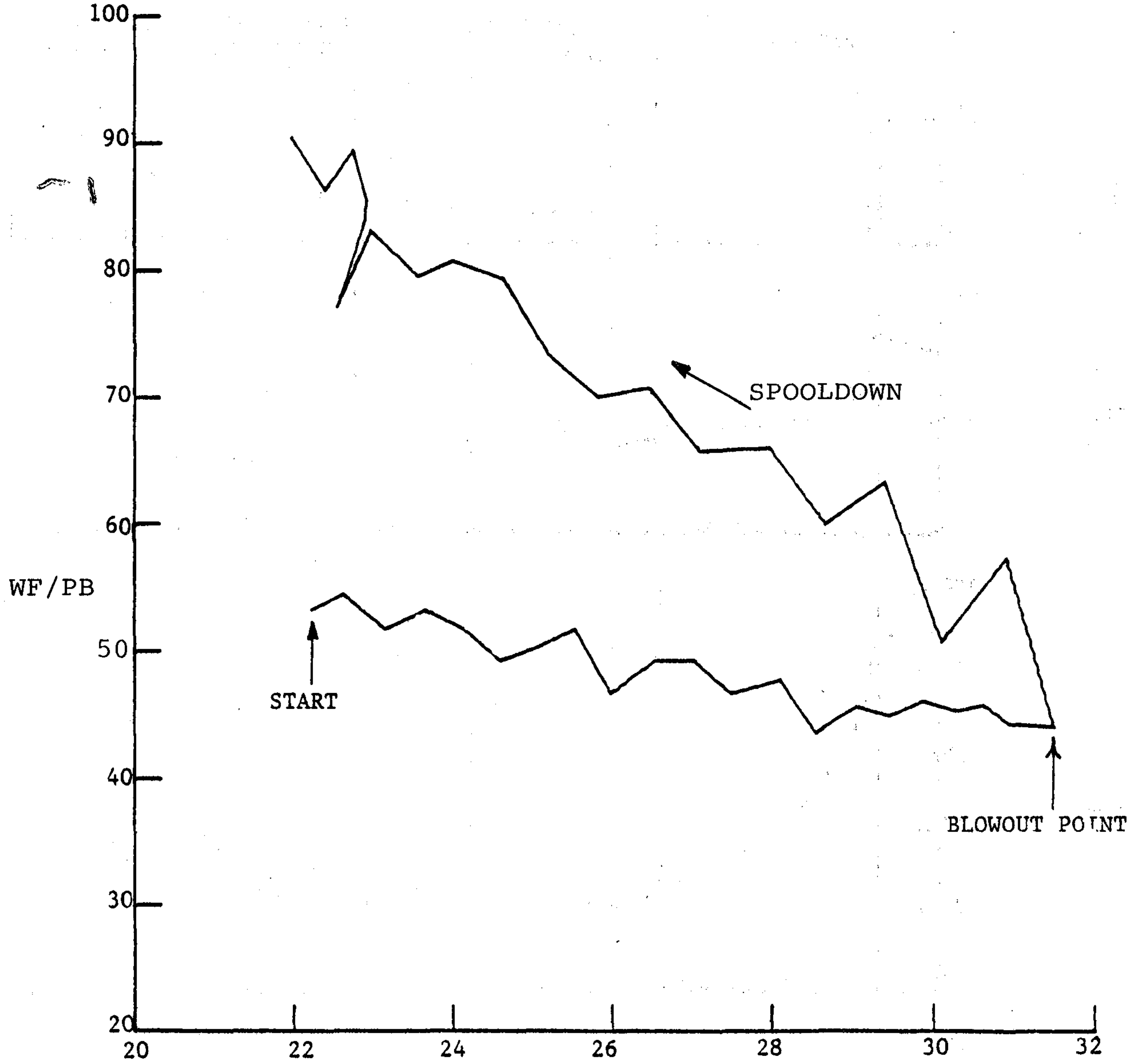


Figure 16. F100 EMD 25-percent spooldown airstart.
Fuel-Air Ratio vs. N2, Combustor Blowout.
DEEC logic 4.2.2, VC = 200 knots HP = 10,700 m

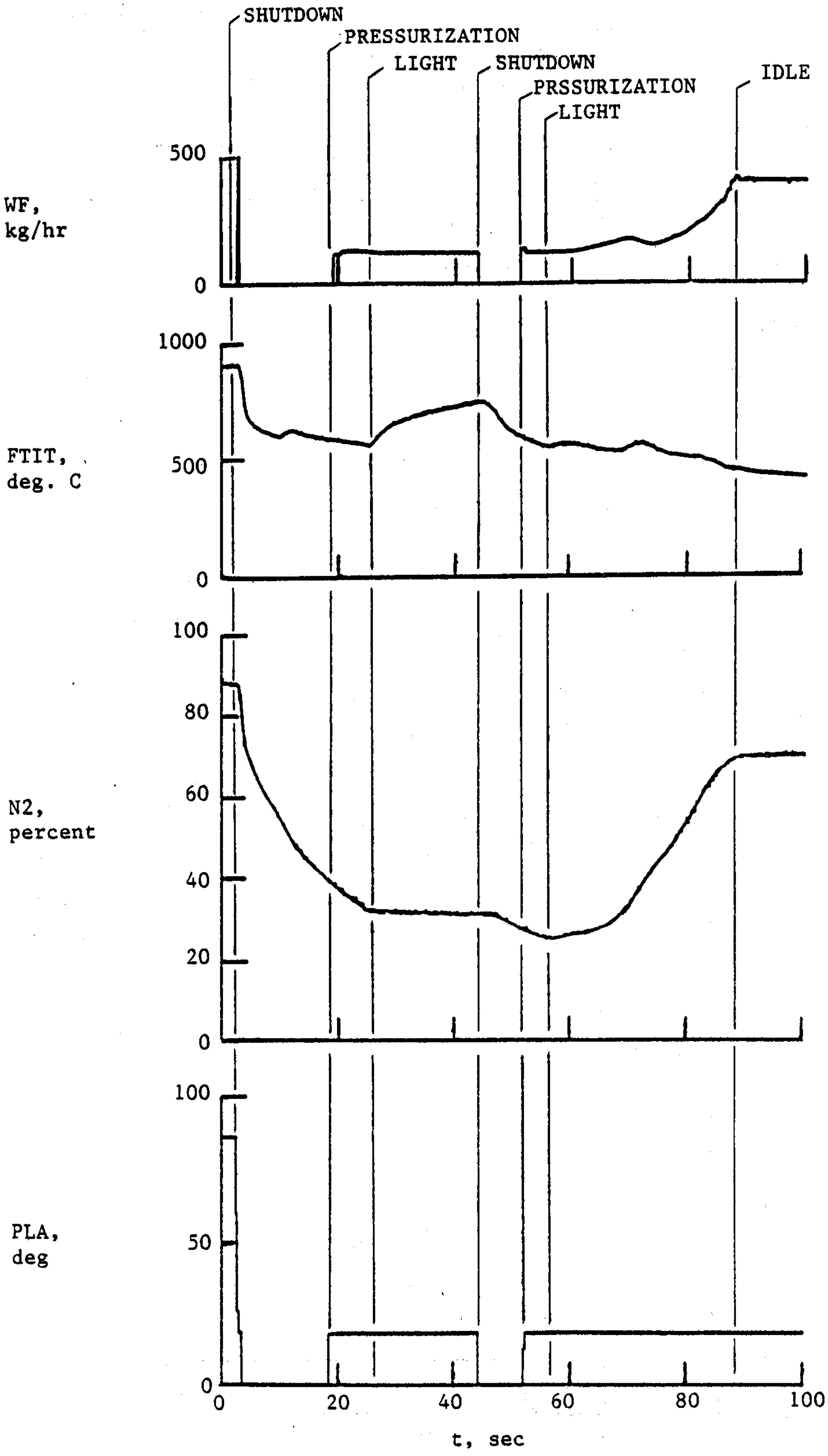


Figure 17. F100 EMD 40-percent spooldown "hot"start.
DEEC logic 4.2.2, VC = 175 knots HP = 10,700 m.

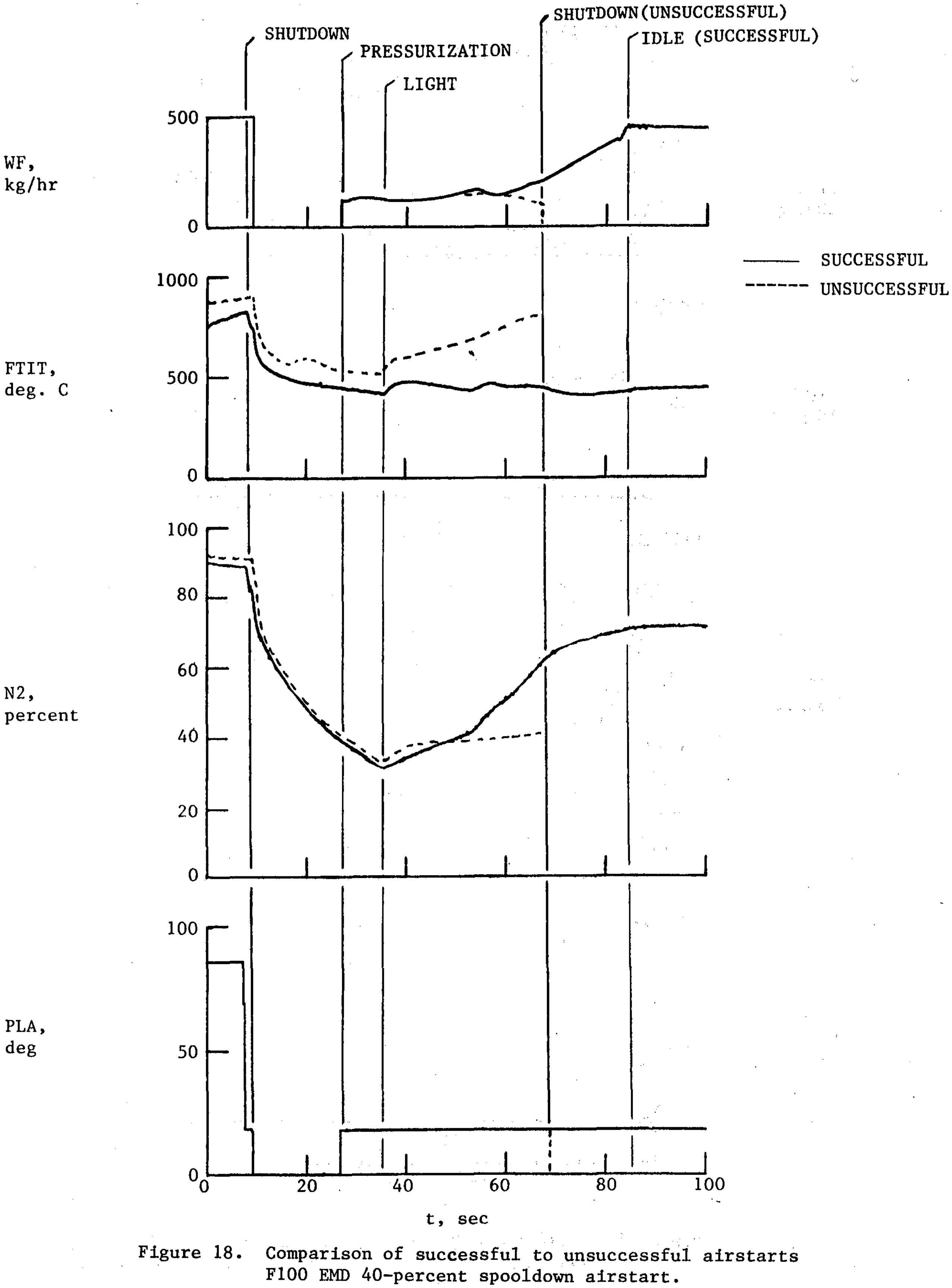
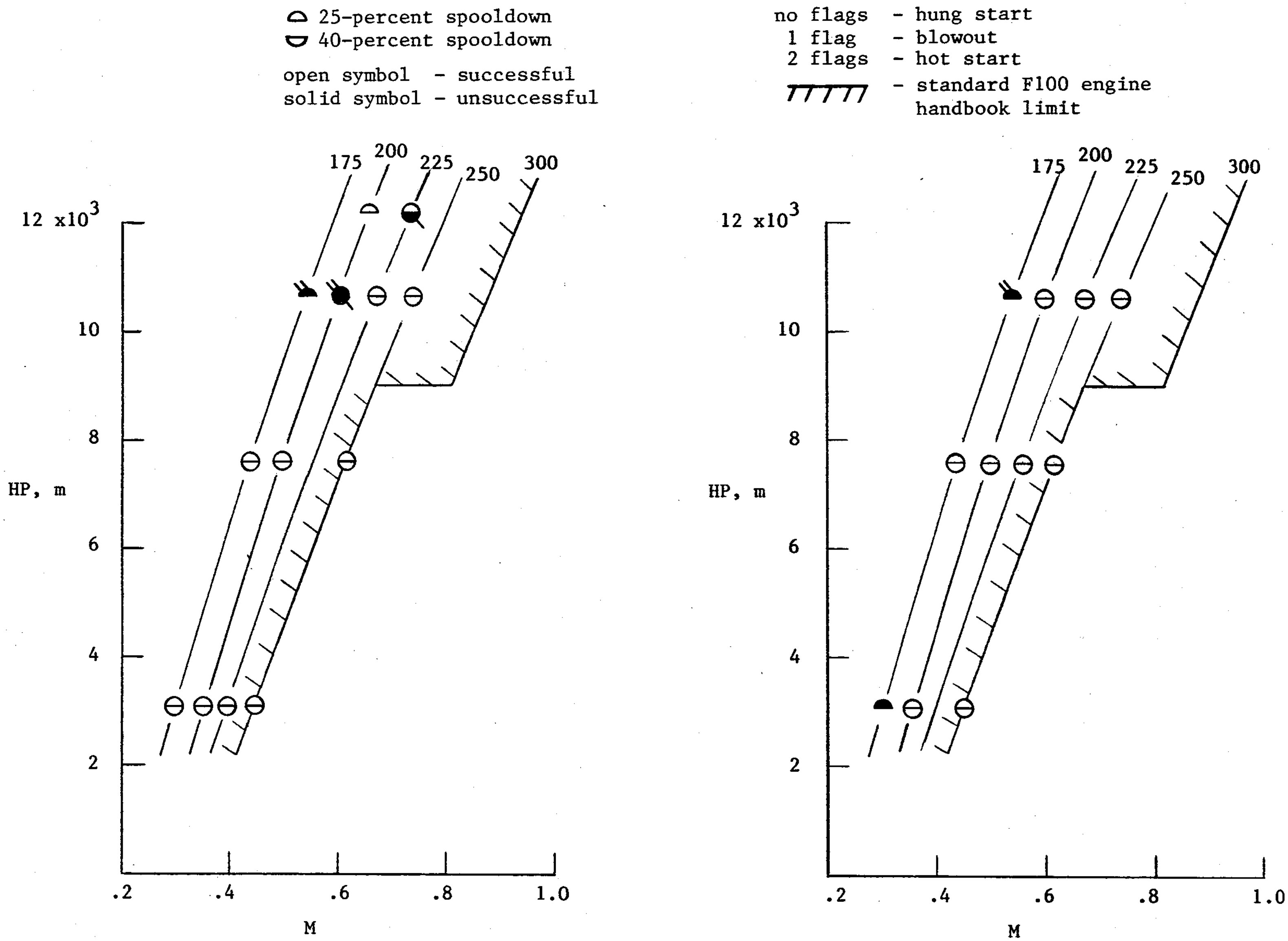


Figure 18. Comparison of successful to unsuccessful airstarts F100 EMD 40-percent spooldown airstart. DEEC logic 4.2.2, VC = 200 knots HP = 10,700 m.



DEEC logic 4.2.2

DEEC logic 4.2.1

Figure 19. Summary of EMD spooldown test success.

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16. Abstract

A series of airstarts were conducted in an F-15 airplane with two prototype Pratt and Whitney F100 Engine Model Derivative engines equipped with Digital Electronic Engine Control (DEEC) systems. The airstart envelope and the time required for airstarts were defined. Comparisons were made between the original airstart logic, and modified logic which was designed to improve the airstart capability. Spooldown airstarts with the modified logic were more successful at lower altitudes than were those with the original logic. Spooldown airstart times ranged from 33 seconds at 250 knots to 83 seconds at 175 knots. The modified logic improved the airstart time from 31 percent to 53 percent, with the most improved times at slower airspeeds. Jet fuel starter (JFS)-assisted airstarts were conducted at 7000 m and airstart times were significantly faster than unassisted airstarts. The effect of altitude on airstart times was small.

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