Paper 10

BACKUP CONTROL AIRSTART PERFORMANCE ON A DIGITAL ELECTRONIC ENGINE CONTROL-EQUIPPED F100 ENGINE

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SUMMARY

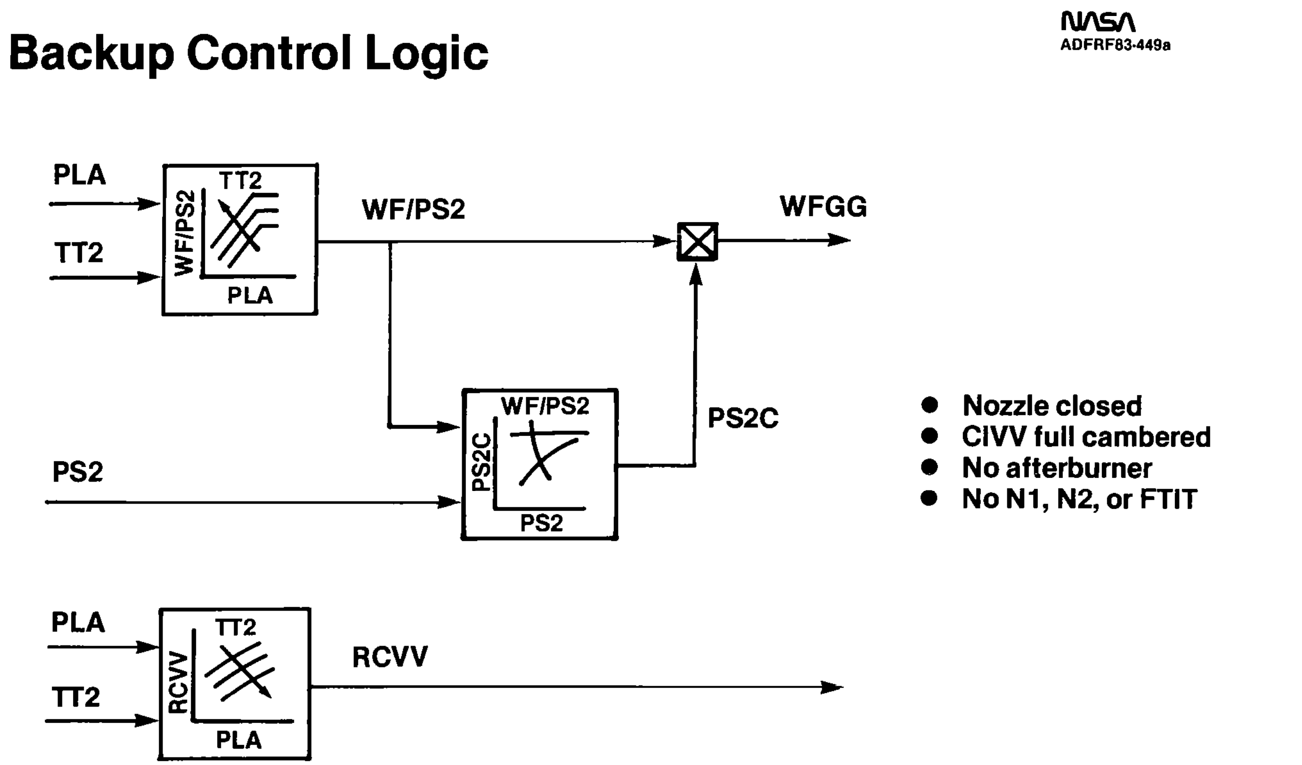
The airstart capability of a backup control (BUC) was tested for a digital electronic engine control- (DEEC-) equipped F100 engine, which was installed in an F-15 airplane. Two airstart schedules were tested. The first was referred to as the group I schedule and the second, or revised schedule, was referred to as the group II start schedule.

Using the group I start schedule, based on a 40-sec timer, an airspeed of 300 knots was required to ensure successful 40- and 25-percent BUC mode spooldown airstarts. If core rotor speed (N2) was less than 40 percent, a stall would occur when the start bleeds closed — 40 sec after initiation of the airstart. All jet fuel starter- (JFS-) assisted airstarts were successful with the group I start schedule.

For the group II schedule, the time between pressurization and start bleed closure ranged between 50 sec and 72 sec, depending on altitude. All airstarts were successful above approximately 200 knots giving a 75- to 100-knot reduction in required airspeed for a successful airstart. Forty-percent spooldown airstarts were successful at 200 knots, at altitudes up to 10,650 meters, and were successful at 175 knots at altitudes up to 6100 meters. Idle rpm was lower than the desired 65 percent for airstarts at higher altitudes and lower airspeeds. All JFS-assisted airstarts were successful.

BACKUP CONTROL LOGIC

The BUC logic is shown below. In the BUC mode, the compressor inlet variable vanes (CIVV) go to the full camber position, the nozzle closes, and augmentation is cancelled. The BUC schedules fuel flow (WF) and the rear compressor variable vane (RCVV) position, based on fan inlet total temperature (TT2), power lever angle (PLA), and fan inlet static pressure (PS2). There are no rpm (fan rotor speed (N1), core rotor speed (N2)) or fan turbine inlet temperature (FTIT) inputs to the BUC. More information on the BUC is presented in reference 1 and Paper 9. Airstarts conducted on the same engine with the digital control system are discussed in reference 2 and Paper 8.

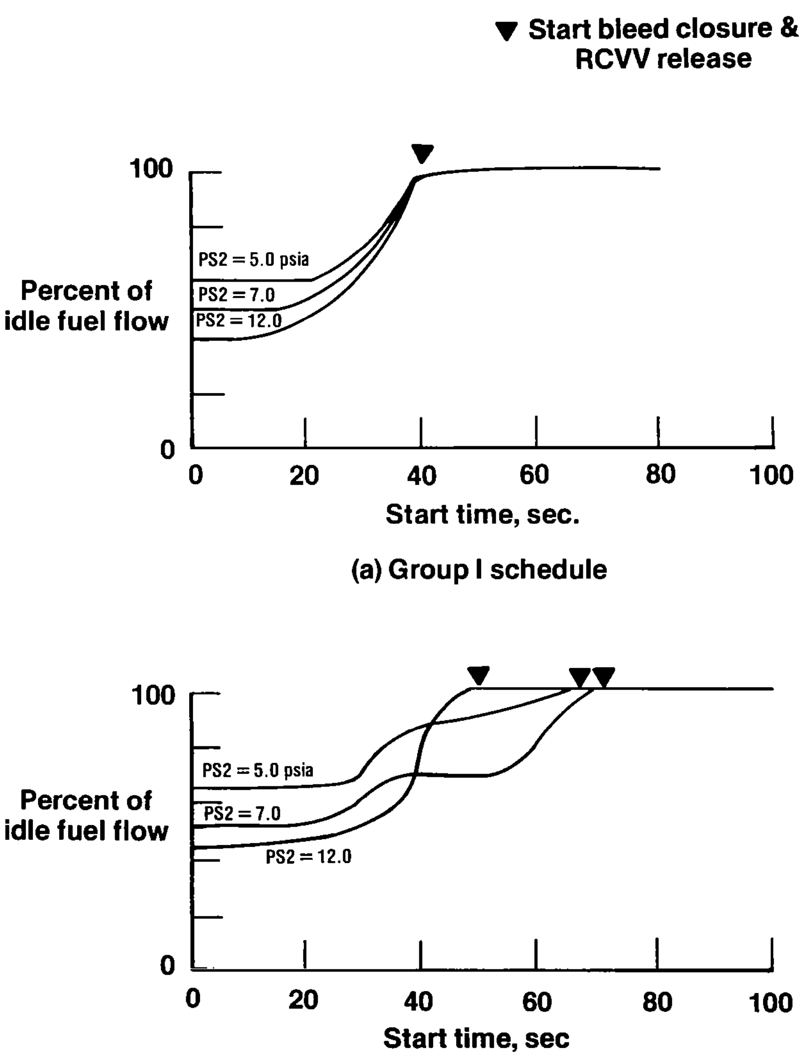


The BUC airstart logic is an automatic schedule derived from a cam in the backup control. The start cam schedules a percentage of the idle fuel flow biased by PS2. The RCVV and compressor bleeds are held in the cambered and open positions.

Two start schedules were tested – the group I schedule and a revised schedule called group II. For the revised schedule, the initial fuel flow was slightly higher, and the elapsed time to start bleed closure and RCVV release was dependent on PS2, whereas the group I schedule released the RCVV and closed the start bleeds after approximately 40 sec for all values of PS2.

BUC Airstart Fuel Flow Schedule

NASA DFRF83-460



(a) Group I schedule

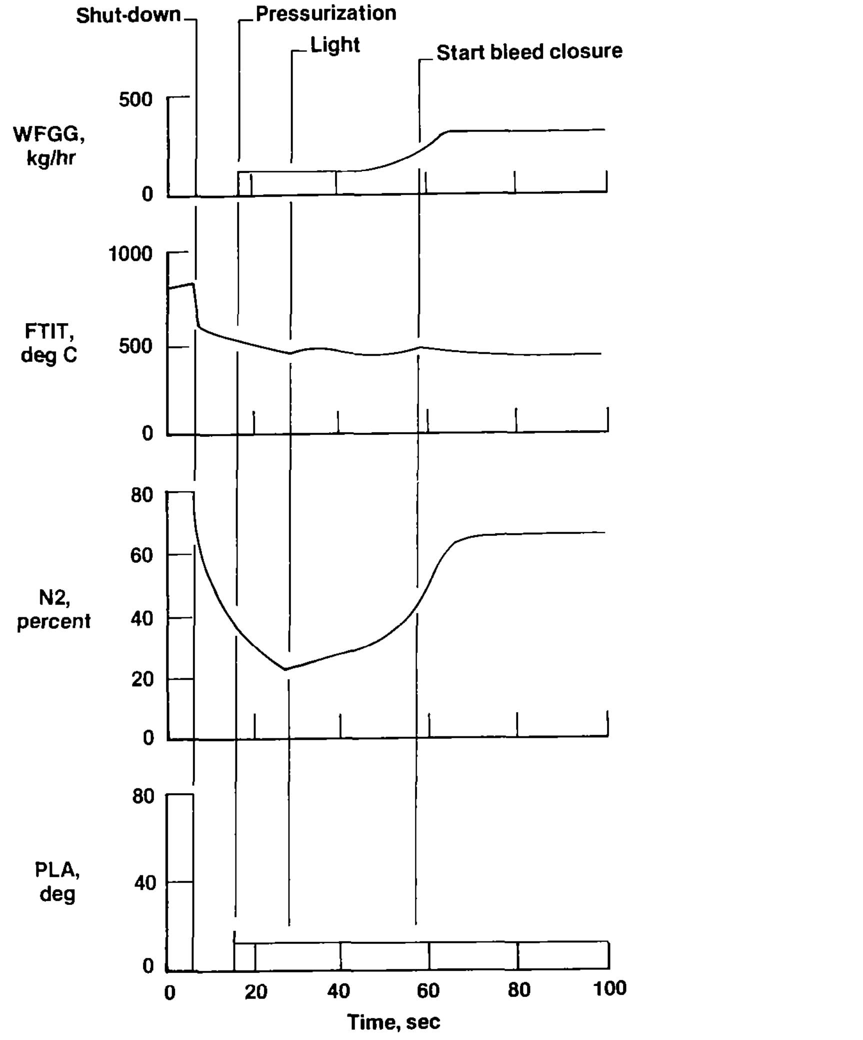
(b) Group II schedule

SUCCESSFUL BUC SPOOLDOWN AIRSTART
GROUP I

This figure presents a time history of a successful, 40-percent spooldown airstart, using the group I start schedule. The start was conducted at an altitude of 4600 meters and an airspeed of 310 knots. Start bleed closure and RCVV release occurred 40 sec after pressurization, as indicated by the drop in FTIT. However, N2 was approximately 43 percent and was still increasing to an idle condition. Although this start was successful, it is apparent the start timer elapsed before the start was complete.

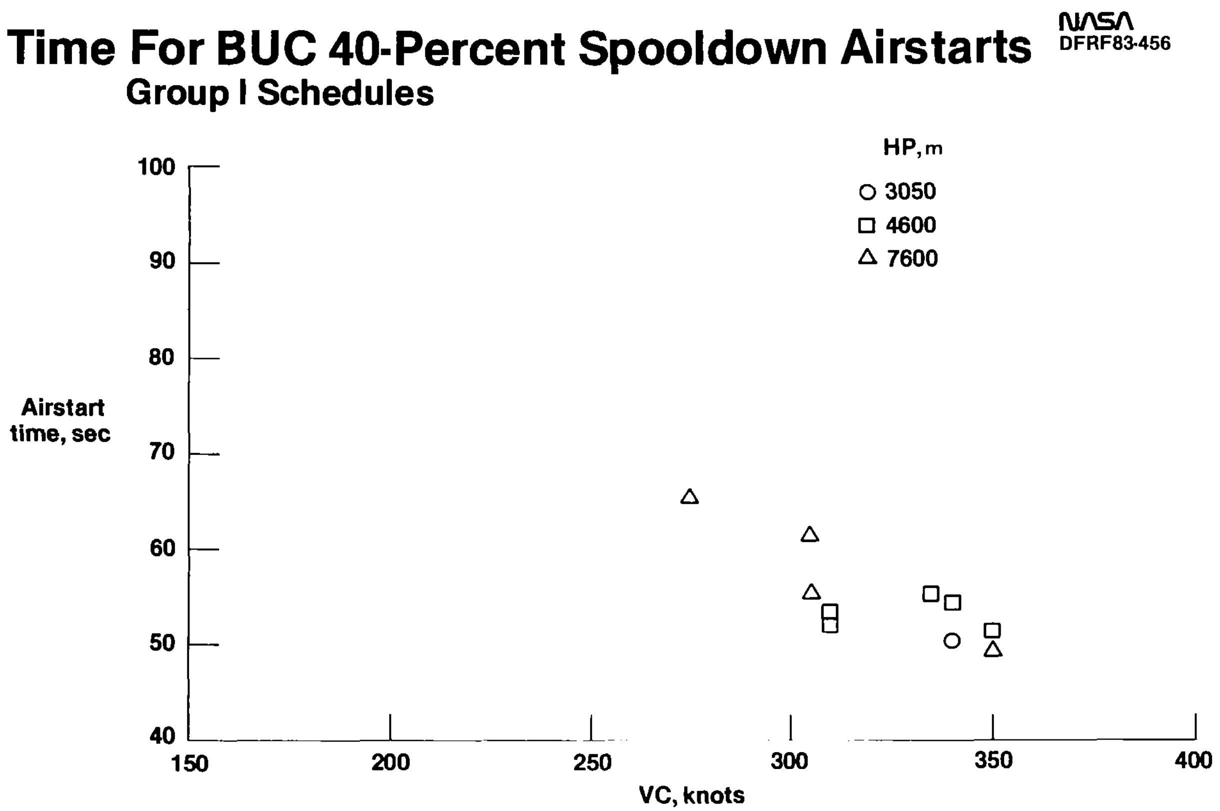
Successful BUC Spooldown Airstart

Group I Schedules
310 Knots



BUC 40-PERCENT SPOOLDOWN AIRSTART TIMES
GROUP I

With the group I start schedule, the time required for successful spooldown airstarts is primarily a function of airspeed, with no significant altitude effects. Airstart times were generally in the 50- to 60-sec range. JFS-assisted airstart times ranged from 40 sec to 65 sec.



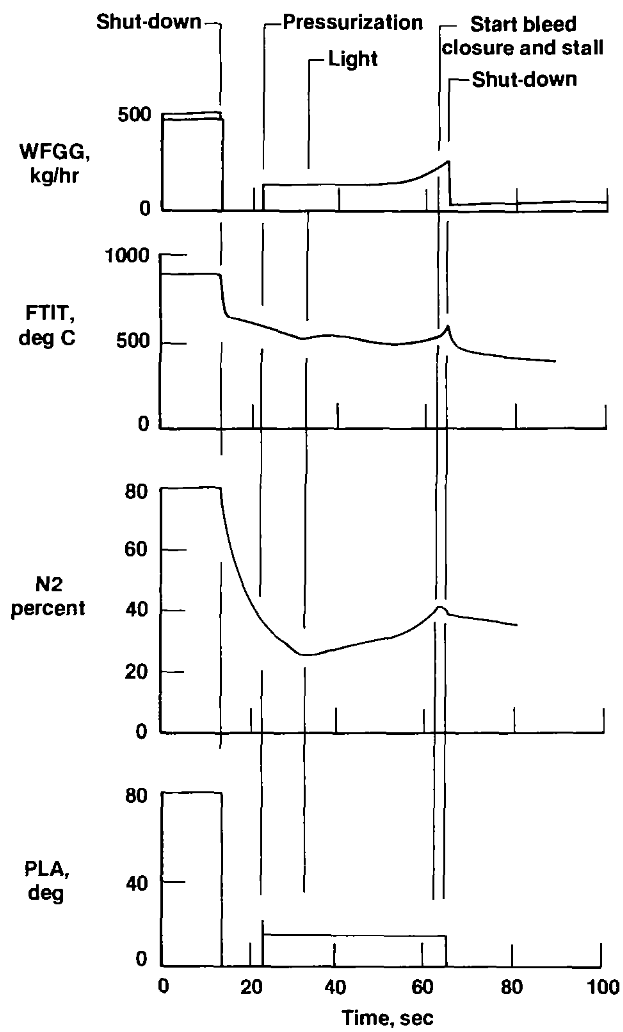
This figure presents a 40-percent spooldown airstart at 4600 meters and an airspeed of 280 knots. This case resulted in a stall rather than a successful airstart. The stall occurred 40 sec after pressurization at a rotor speed of approximately 38 percent, when the start bleeds closed and the RCVV released, effectively lowering the stall margin. This start was unsuccessful because the rotor acceleration was slower, due to the lower inlet pressure and fuel flow (WF).

In general, if N2 was less than 40 percent when the timer elapsed, stalls occurred.

Unsuccessful BUC Spooldown Airstart

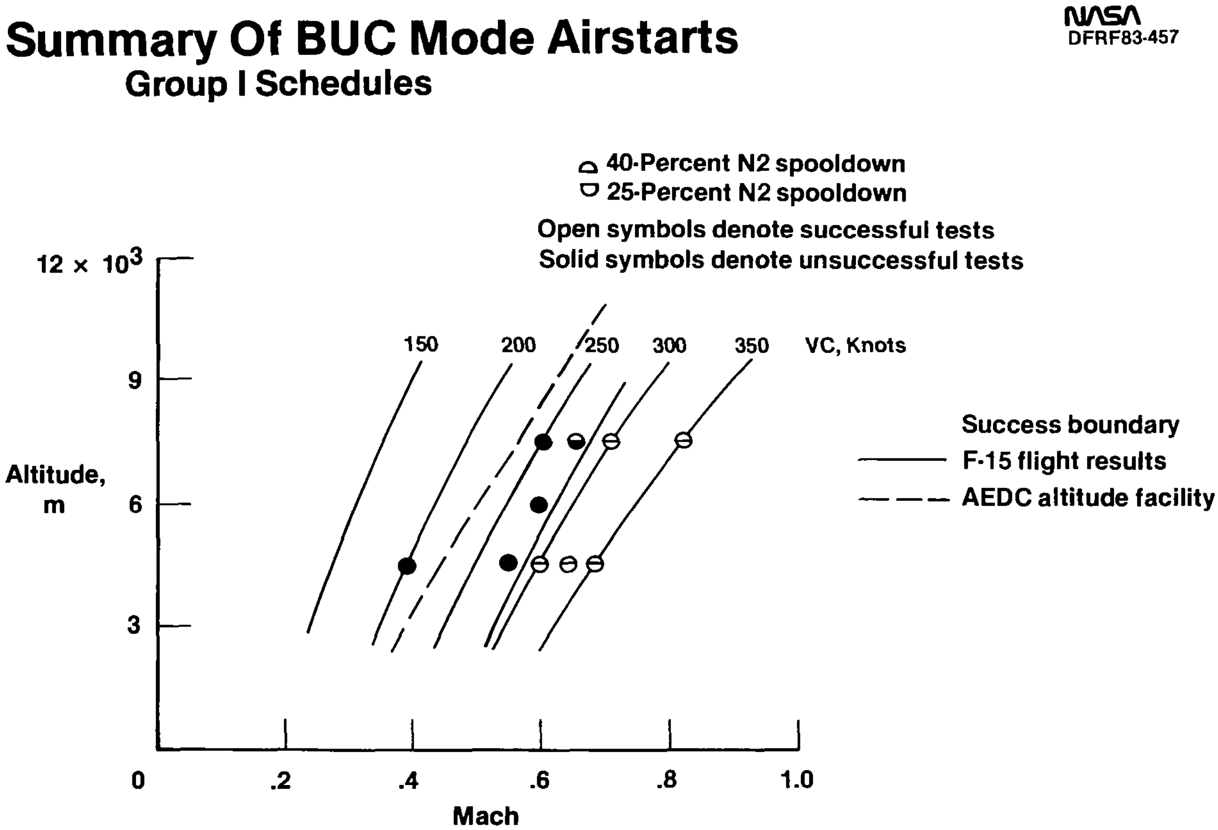
NASA DFRF83-458

Group I Schedules
280 Knots



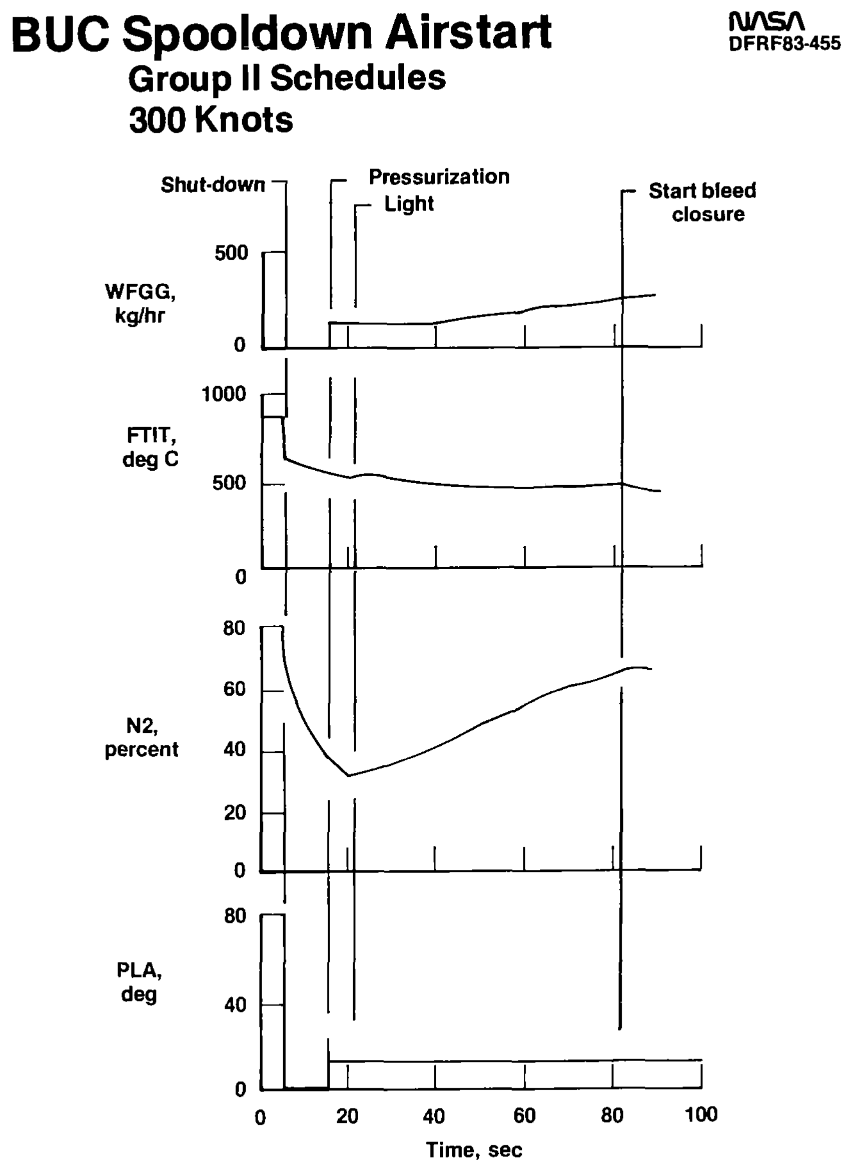
SUMMARY OF GROUP I BUC MODE AIRSTARTS

The group I flight summary chart shows that BUC mode spooldown airstarts below 300 knots, at any flight altitude, were unsuccessful except for a 40-percent spooldown airstart at 275 knots and 7600 meters. Also shown is a success line established during altitude facility testing at the Arnold Engineering Development Center (AEDC) (ref. 3). BUC mode airstarts were successful at airspeeds that were approximately 50 knots lower than in flight. However, there were no horsepower or bleed extractions during the altitude facility testing.



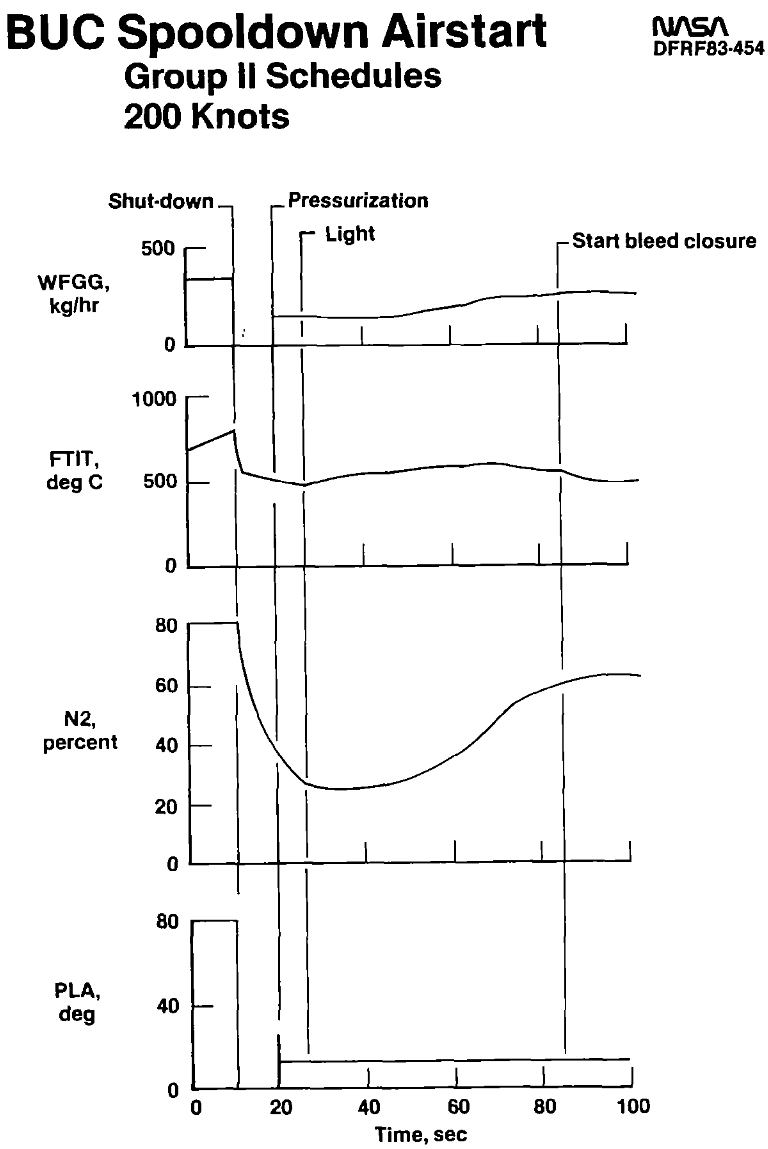
BUC SPOOLDOWN AIRSTART, 300 KNOTS
GROUP II

A spooldown airstart, using the group II schedule, was flown at similar flight conditions to one flown with the group I schedule. Even though the group I schedule provided a successful start at these conditions (300 knots and 6100 m) the group II schedule closed the start bleeds later, taking approximately 63 sec from pressurization to start bleed closure. This allowed N2 to accelerate to values in excess of 63 percent, a near-idle condition.



BUC SPOOLDOWN AIRSTART, 200 KNOTS
GROUP II

A spooldown airstart at 200 knots and 4600 meters, using the group II schedule, allowed a successful start where it would have been unsuccessful using the group I schedule. Although this start was termed successful, the idle N2 value was approximately 60 percent, which was lower than the desired idle speed of 65 percent. In this case, the pilot would have to advance the throttle slowly while accelerating the engine from 60 to 65 percent.



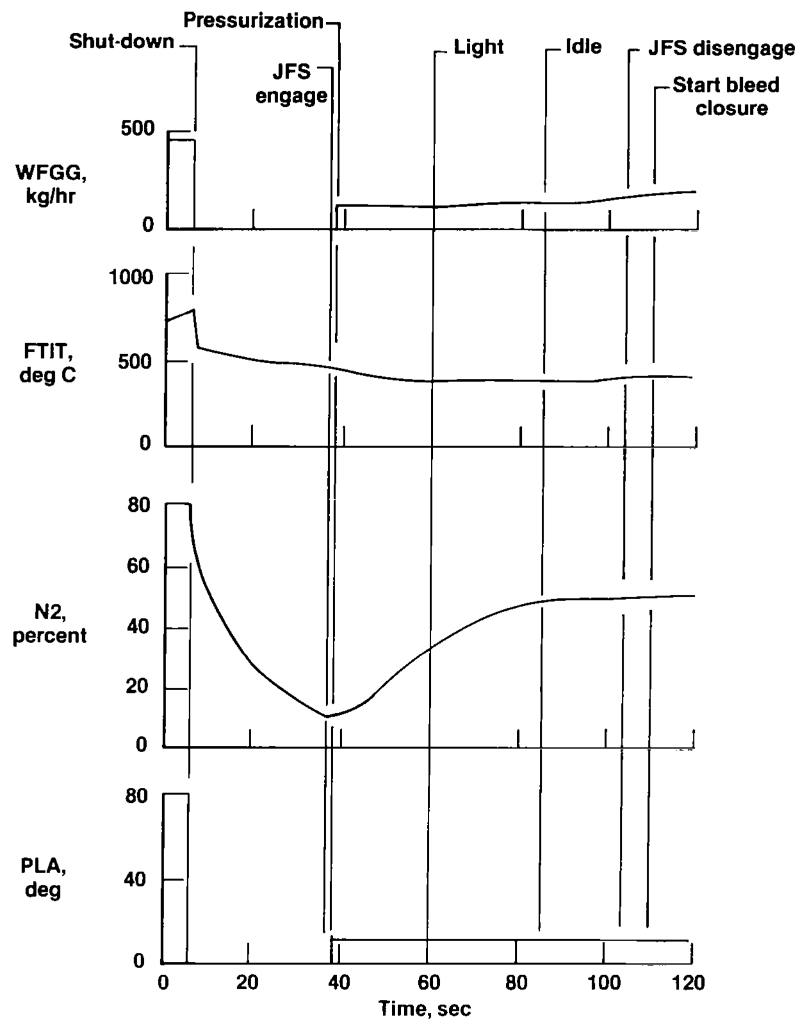
JFS-ASSISTED BUC AIRSTART

This time history of a JFS-assisted airstart shows the relatively rapid increase in N2 even at an airspeed as low as 150 knots. The airstart is termed successful, but the idle speed of 50 percent is much lower than desired.

JFS Assisted BUC Airstart

Group II Schedules
150 Knots

NASA
DFRF83-453



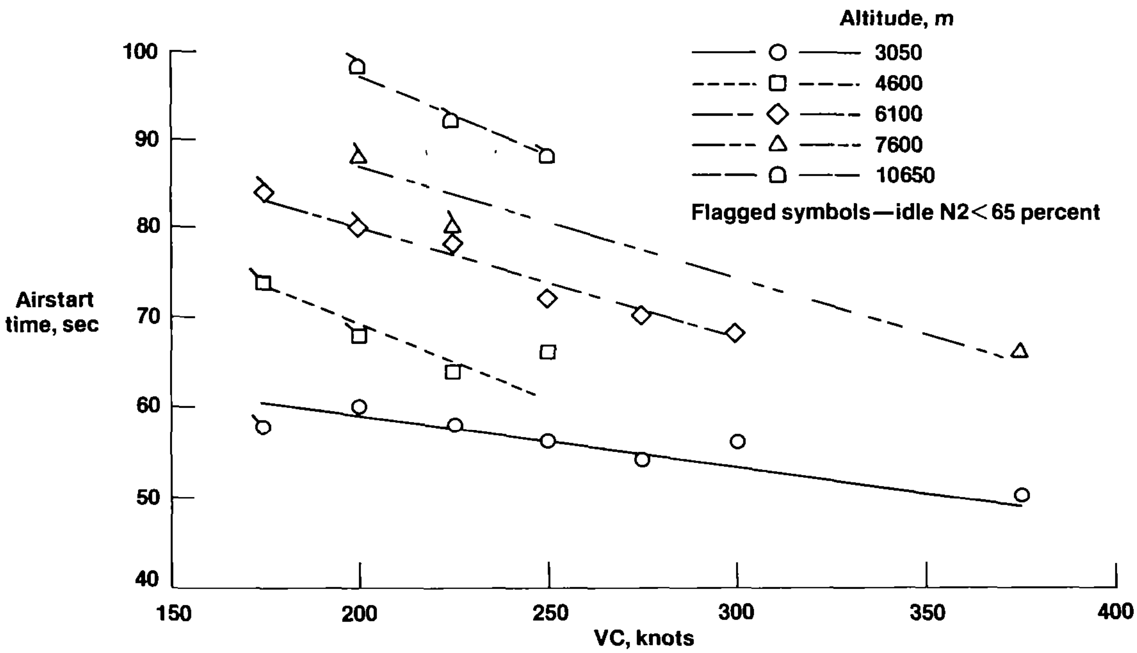
BUC SPOOLDOWN AIRSTART TIMES
GROUP II

For both 40- and 25-percent spooldown airstarts, the revision caused the airstart time to become more altitude-dependent rather than totally airspeed-dependent as evidenced with the group I start schedule. This is a result of biasing the time to start bleed closure by PS2. Also shown are airstarts in which the idle rpm was less than the desired 65 percent.

Time For BUC 40 Percent Spooldown Airstarts

Group II Schedules

NASA DFRF83-450

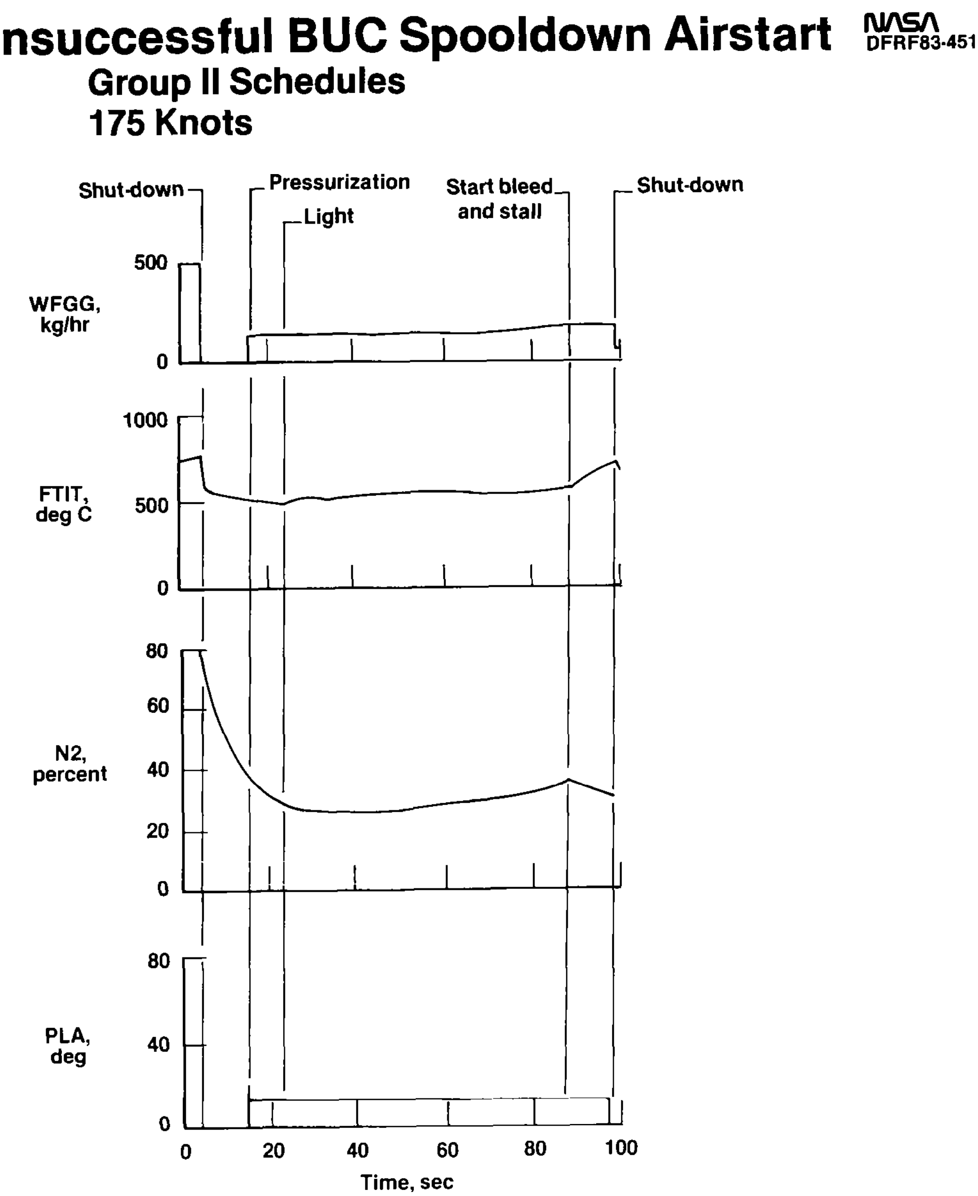


UNSUCCESSFUL BUC AIRSTART
GROUP II

This figure presents a time history of an unsuccessful 40-percent spooldown airstart at 175 knots and 7600 meters. In this case, the scheduled fuel flow was too low to accelerate the core to a sufficient speed before the bleeds closed. The result was a stall and the pilot shut down the engine.

Unsuccessful BUC Spooldown Airstart

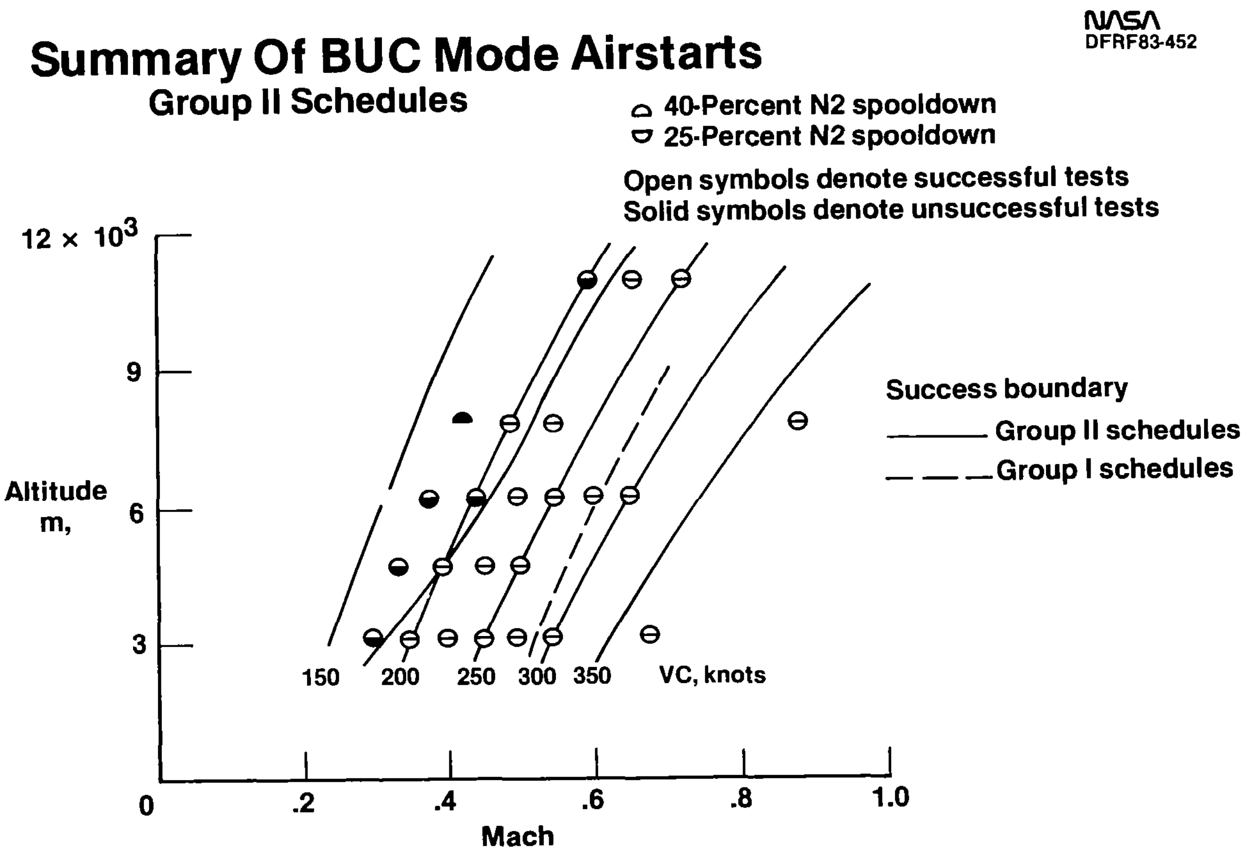
Group II Schedules
175 Knots



SUMMARY OF GROUP II BUC MODE AIRSTARTS

A summary of successful and unsuccessful 40- and 25-percent spooldown airstarts is shown in order to summarize the effectiveness of the group II start schedule. The solid line establishes a success boundary for these airstarts. All starts attempted above 225 knots were successful. Forty-percent spooldown airstarts were successful above 200 knots at all altitudes tested, and were successful at 175 knots below 6100 meters.

The success boundary established from the group I summary chart is indicated by the broken line and shows the improvement gained by revising the start schedule. Essentially, the revision decreased the airspeed required for a successful BUC mode airstart by approximately 75 knots.



REFERENCES

1. Myers, Larry; Mackall, Karen; and Burcham, F. W., Jr.: Flight Test Results of a Digital Electronic Engine Control System in a F-15 Airplane. AIAA Paper 82-1080, June 1982.

2. Licata, S.; and Burcham, F. W. Jr., The Airstart Performance of a Digital Electronic Engine Control System on a F-15 Airplane. NASA TM-84908, 1983.

3. Ewen, J. S.; and Walter, W. A.: F100 Engine Model Derivative Program/Initial Engine Altitude Test Report. Pratt and Whitney Aircraft Report PWA FR-14785, July 1981.