NASA Technical Paper 1692

Static and Transient Performance of YF-102 Engine With up to 14 Percent Core Airbleed for the Quiet Short-Haul Research Aircraft

Jack G. McArdle, Leonard Homyak, and Allan S. Moore

JUNE 1980

NASA

NASA Technical Paper 1692

Static and Transient Performance of YF-102 Engine With up to 14 Percent Core Airbleed for the Quiet Short-Haul Research Aircraft

Jack G. McArdle, Leonard Homyak,
and Allan S. Moore
Lewis Research Center
Cleveland, Ohio

National Aeronautics
and Space Administration

Scientific and Technical
Information Office

1980

Summary

The steady-state and transient performance of the YF-102 turbofan engine with core airbleed was measured on an outdoor static test stand. The test configuration included a bellmouth inlet and a confluent-flow exhaust system similar in size to the Quiet Short-Haul Research Aircraft (QSRA) exhaust system. For the steady-state tests the engine operated satisfactorily with core bleed up to 14 percent of the core inlet flow. For the transient tests the engine accelerated and decelerated satisfactorily with no core bleed and with core bleed up to 11 percent of the core inlet flow (maximum tested). For some of the tests the core bleed flow rate was scheduled to vary with fan discharge pressure to simulate the QSRA bleed requirements. No stability, surge, stall, overtemperature, combustor flameout, or other operating problems were encountered in any of the tests. Steady-state and transient engine performance data are presented in graphs, and fuel control trajectories for typical transient tests are shown.

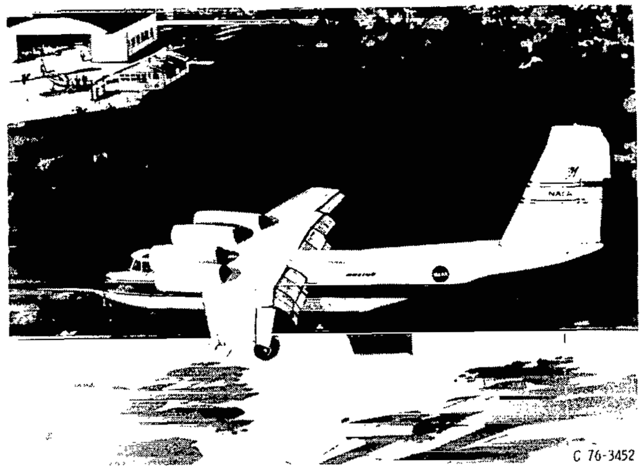


Figure 1. - Artist's sketch of QSRA airplane in approach configuration.

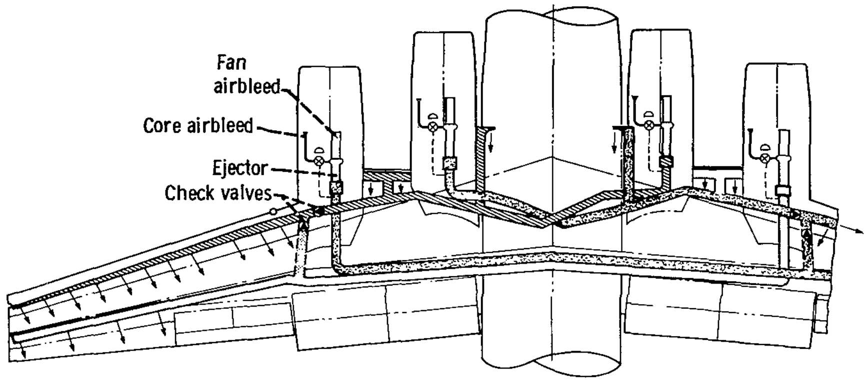
Introduction

As part of the NASA Quiet Short-Haul Research Aircraft (QSRA) Project, an airplane using the upper-surface-blowing (USB) propulsive lift concept has been built. The airplane is shown in figure 1. Its purpose is to conduct flight research into takeoff, approach, and landing modes of vertical- or short-takeoff and landing (V/STOL) operation. The airplane and its preliminary performance characteristics are described in references 1 and 2.

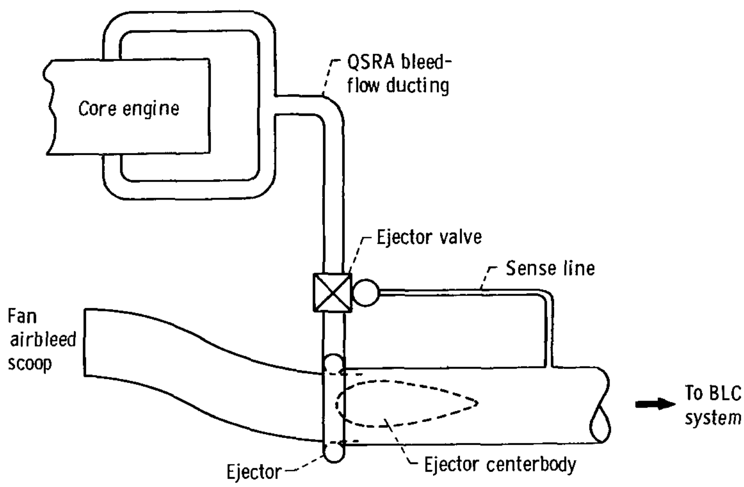
One of the important features of the QSRA airplane is the use of engine bleed air in a wing boundary-layer-control (BLC) system (shown schematically in fig. 2(a)). Air bled from each of the outboard engines is blown over the aileron on the opposite wing, and air bled from each inboard engine is blown over the leading edge on the opposite wing. For each engine, air is taken from both the bypass (fan discharge) duct and from the gas generator (core engine). These flows are mixed in an ejector, as shown in figure 2(b), to provide a "constant momentum" supply to the BLC system. This method requires a large quantity of core airbleed (about 10 percent of the core inlet flow) at low power settings because the fan-discharge pressure is low, and no core bleed at high power settings because the fan-discharge pressure is high enough for the BLC system without pressure boost from the ejector. The fan bleed is about 3 percent of the bypass airflow and is obtained from a fixed-area scoop in the bypass duct (ref. 3). The core bleed is obtained from a manifold on the engine combustor housing. The quantity of core bleed is controlled by the ejector valve (as shown in fig. 2(b)). The valve senses pressure in the ejector-exit duct and meters the core bleed air to provide the desired duct pressure.

As described previously, about 10 percent of the core airflow is bled from the engine at low power settings. This reduces engine thrust and, because of lower acceleration fuel flow margin, can lessen the ability of the engine to accelerate to high power. The reduced thrust is not a problem for the QSRA, but quick reliable engine acceleration is needed for flight safety.

The QSRA is powered by four YF-102 engines manufactured by the Avco Corporation, Lycoming Division, of Stratford, Connecticut, originally for use on the Northrup A-9A aircraft. At the conclusion of the A-9A program at Edwards Air Force Base, the YF-102 engines were obtained by NASA. Five of the engines were refurbished at the factory for use on QSRA. At the same time some configuration changes, including the addition of the core airbleed manifold, were made (ref. 4). One of these engines was sent to NASA Lewis Research Center to



(a) Schematic layout. The two ducts indicated by dashed lines only connect leading- and trailing-edge systems in the event of engine failure.



(b) Schematic of ejector to mix core and fan airbleeds.

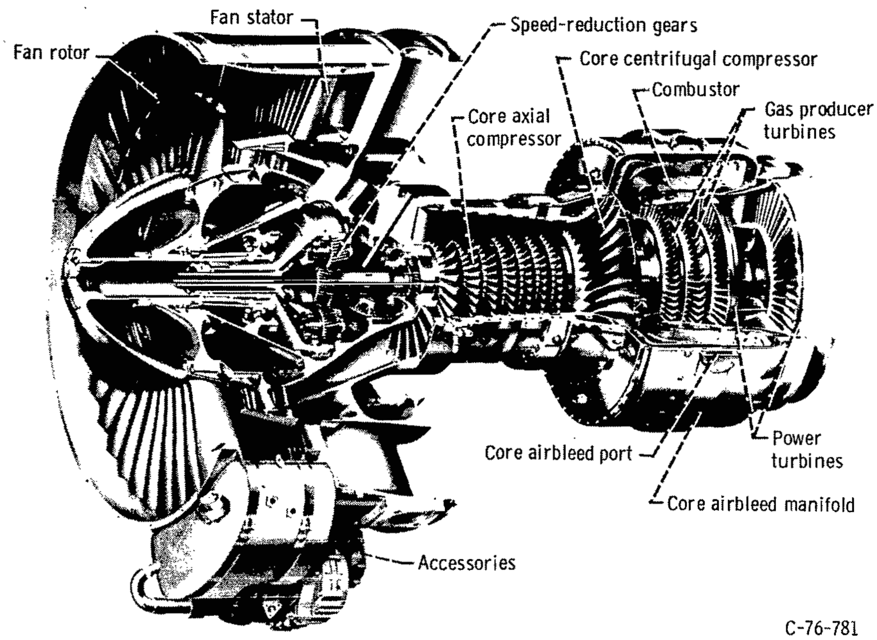
Figure 2. - QSRA boundary-layer-control (BLC) system.

obtain test data for use in design of the QSRA propulsion system and noise-suppression treatment. Results of some of the tests are reported in references 3 and 5 to 7. The tests that assess the steady-state and dynamic performances of the engine with only core bleed (no fan bleed) are reported herein. These tests were performed to demonstrate that the YF-102 engine can meet the QSRA core bleed and engine acceleration requirements. The report describes pertinent engine and fuel-control characteristics and presents results of steady-state tests with core bleed up to 14 percent of the core inlet flow. Also, results are given for engine acceleration and deceleration tests, both without core bleed and with core bleed ratios (defined here as core bleed flow rate divided by core inlet flow rate) up to 11 percent. For some of the tests the core bleed ratio was approximately constant during the transient, while for other tests the core bleed ratio varied to simulate QSRA operation. All in all, the tests exercised the engine at or beyond the applicable QSRA requirements. All tests were conducted on an outdoor static test stand with a bellmouth inlet and a confluent-flow exhaust system similar in area to the QSRA exhaust system.

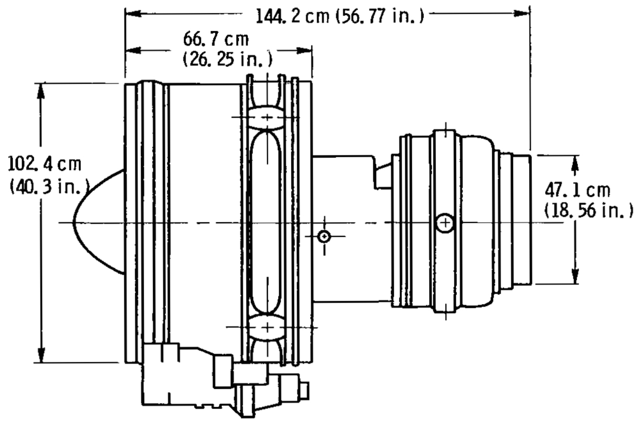
Apparatus

Engine

The Lycoming YF-102 engine (complete designation YF102-LD-100 (QSRA updated), Lycoming Model No. ALF 502A), is a twin-spool turbofan powerplant. Illustrative drawings of the engine are shown in figure 3. The core engine consists of a combination seven-stage axial, single-stage centrifugal



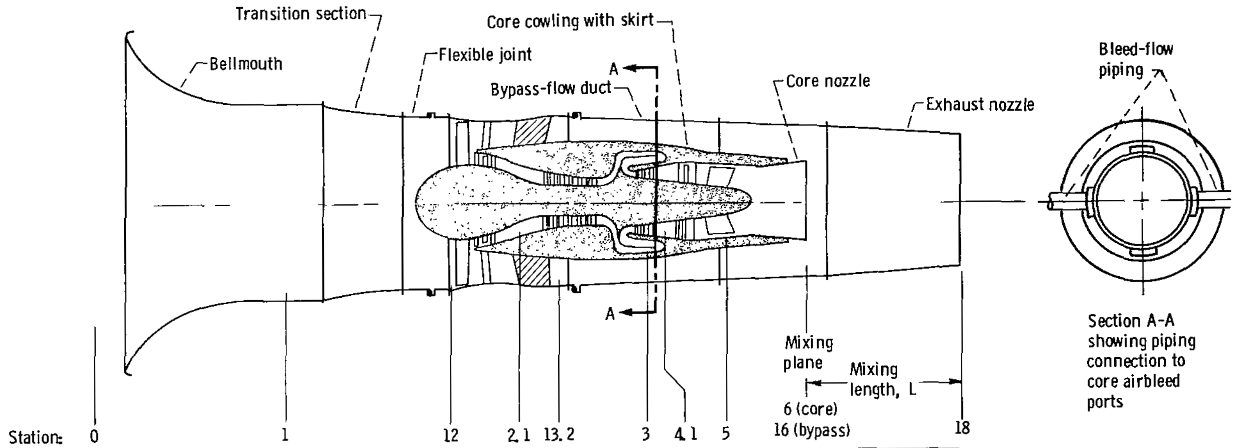
(a) Cutaway sketch.



(b) Side envelope.

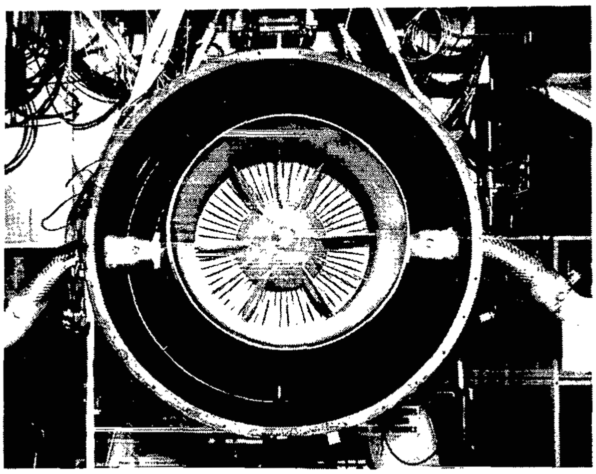
Figure 3. - Lycoming YF-102 turbofan engine.

compressor driven by a two-stage axial turbine and external atomizing combustor. An interstage bleed valve (ISBV) vents air from the sixth axial stage as required to prevent compressor stall. The valve consists of slots in the compressor case, covered by a tight-fitting circumferential metal band. The band is fixed at one end, and held in place by a pneumatic actuator at the other end. To open the valve, the actuator is stroked to loosen the band, and air pressure forces the band more-or-less uniformly away from the slots. The ISBV is open at low power settings and during rapid thrust transients and is automatically closed by a mechanical computer in the fuel control. The front fan and one supercharging stage are driven by a two-stage, free-type, coaxial, power turbine through a 2.3 to 1 speed-reducing gear system. Maximum rating performance at sea-level-static conditions, with ideal inlet and exhaust systems and with no airbleed or power extraction, is 33 360 newtons (7500 lb) thrust (minimum), 7600 rpm fan speed (maximum), and 6.2 (nominal) bypass ratio. Maximum rating is defined by the manufacturer as the performance at a

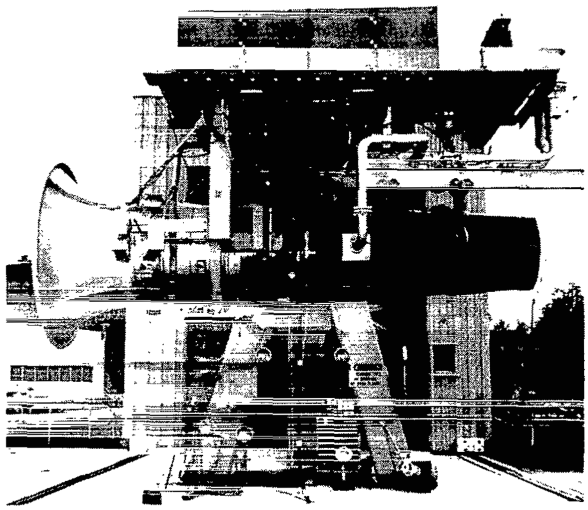


Core-nozzle area		Exhaust-nozzle area		Bypass-flow-duct area at mixing plane		Mixing length, L	
cm^2	in^2	cm^2	in^2	cm^2	in^2	cm	in.
1687	261.5	4803	744.4	4451	689.9	91.4	36.0

(a) Configuration sketch and dimensions.



(b) Bleed piping in bypass duct.



(c) Engine ready for testing.

Figure 4. - Engine configuration for core airbleed tests.

measured gas temperature (MGT) of 1194 K (2150° R) or at any of several other defined mechanical limits during off-design operation. The MGT is the average temperature sensed by 10 thermocouples spaced throughout the flow passage at the power turbine inlet.

Test Configuration

The engine configuration for these tests is shown in figure 4. The air inlet system (fig. 4(a)) consisted of a bellmouth and transition section supported from the test stand and connected to the engine by a flexible joint. The bellmouth, previously used on another test program, was 193 centimeters (76 in.) in diameter at the inlet and had a straight exit section 112 centimeters (44.0 in.) in diameter. The transition section reduced the airflow passage to 101.6 centimeters (40.0 in.), the diameter of the engine inlet. The flexible joint included a soft Neoprene seal, and prevented transfer of large inlet system loads to the engine.

The exhaust system was the same as the Basic Confluent-Flow Exhaust System (C-1) reported in reference 7. The nozzle and flow passage areas and lengths are similar to the QSRA exhaust system. The exhaust system consisted of a core cowling, a core engine nozzle, and a bypass-flow duct ending in an exhaust nozzle for the combined core and bypass flows. The core cowling was the same as used on the A-9A airplane, except that small scoops were installed over the existing ventilation ports at the forward end to force air into the engine space. Also, a 33-centimeter (13-in.) aft skirt was added to the cowling to smooth the flow passage over the core nozzle.

The core nozzle is intended to diffuse the core flow to produce a satisfactory static-pressure match with the bypass flow at the mixing plane. To this end the nozzle consisted of a divergent cone attached to the shell of an A-9A core nozzle downstream of the straightening vanes. The exit diameter was 46.35 centimeters (18.25 in.).

The bypass-flow duct was made up of steel extensions and adapter spools and included a flexible joint near the engine fan frame mounting flange. The exhaust nozzle was 78.20 centimeters (30.79 in.) in exit diameter, providing 4803 square centimeters (744.4 in^2) geometric flow area. The geometric area in the bypass duct at the mixing plane was 4451 square centimeters (689.9 in^2).

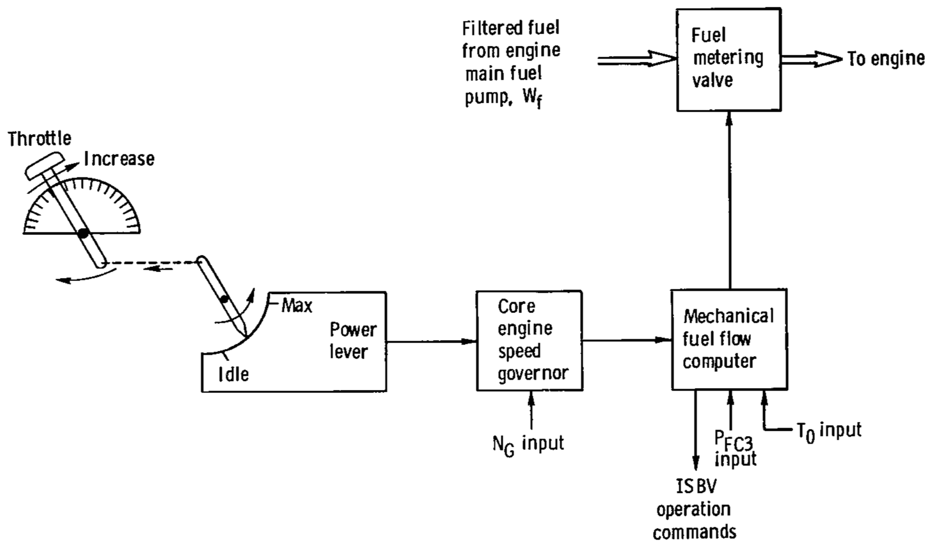
The core bleed was taken from the two 5.1-centimeter (2.0-in.) diameter ports on the horizontal centerline of the engine bleed manifold. The flow piping was enlarged to 7.6 centimeters (3.0 in.) in diameter as it crossed the bypass flow duct and joined the test stand airbleed flow system through corrugated flexible pipe. A photograph of the piping in the bypass duct is shown in figure 4(b), and one of the engine ready for testing is shown in figure 4(c).

Fuel Control

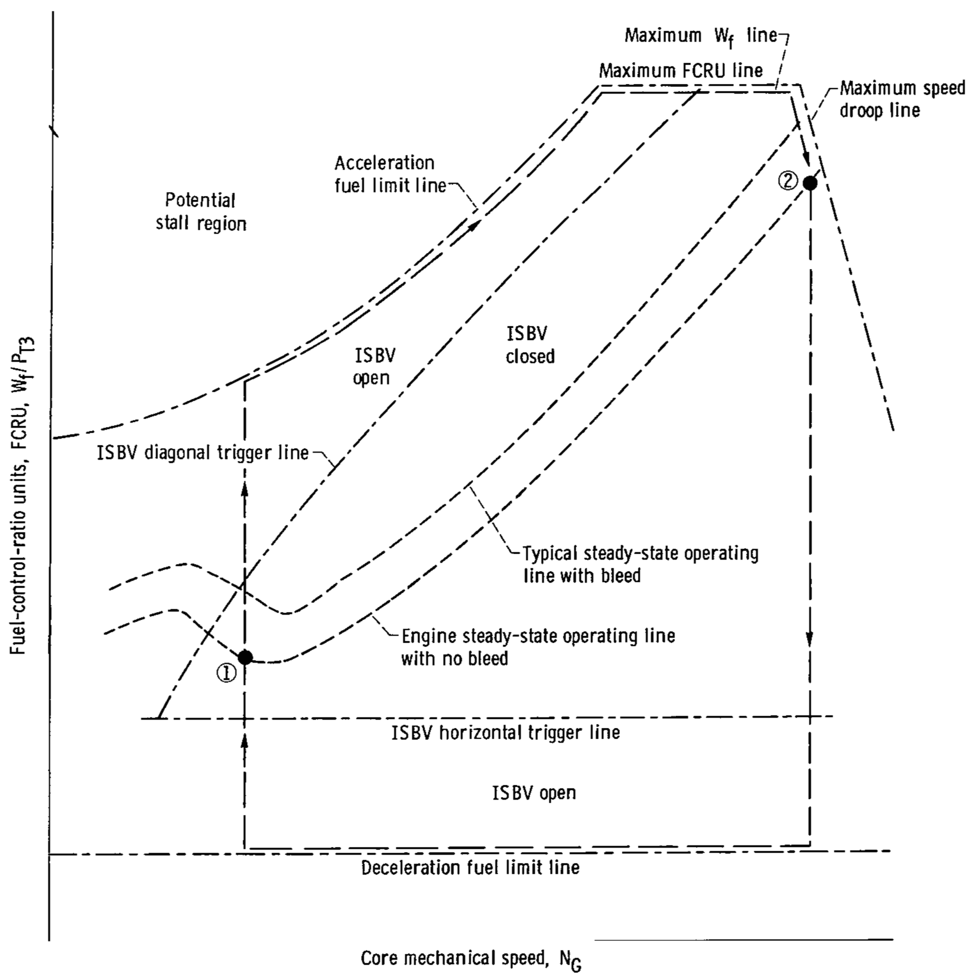
The YF-102 engine fuel control is the hydromechanical Hamilton-Standard Model JFC31-19. It is mounted on the accessory gearbox beneath the engine and is driven by gears from the core compressor shaft. The control components important for the core bleed tests (shown schematically in fig. 5(a)) are the governor and the mechanical computer. The governor sets core speed according to the power-lever position. The computer determines the fuel flow rate. The computer also limits fuel flow at extreme operating conditions and varies the limits slightly with changing engine inlet air temperature. In addition, the computer controls operation of the interstage bleed valve (ISBV) to prevent compressor stall at low power settings and during rapid transients. The fuel control also performs other necessary functions not discussed herein because they are not relevant to the core airbleed tests.

The limits and functions of interest here are shown in figure 5(b), wherein fuel-control-ratio units (FCRU's) are plotted as a function of core engine mechanical speed. Fuel-control-ratio units are defined as the ratio of fuel flow rate W_f to core compressor discharge pressure P_{T3}. On the YF-102 engine a wall pressure P_{FC3} from the centrifugal-compressor diffuser casing is used instead of P_{T3}. (For the engine tested at NASA, a calibration showed that P_{FC3} was 0.93 P_{T3} over the whole operating range.) Also in figure 5(b) fuel-control limits and functions, set by mechanical devices in the computer, are shown by dot-dashed lines. Engine operating lines, which are the variation of FCRU's with speed for any particular set of conditions, are shown by dashed lines. Several fuel flow limits are shown in the figure. The acceleration fuel limit line is adjusted to make the engine responsive to rapid power-lever changes but to avoid the potential stall region. The maximum fuel flow line limits flow to a safe value and is the limit usually encountered at low altitude. The maximum FCRU line is the limit usually encountered in high-altitude flight. The maximum speed droop line limits core speed. The deceleration fuel limit line prevents combustor flameout during rapid deceleration.

Regions marked in figure 5(b) show where the ISBV is open or closed. If the engine operating line crosses one of the trigger lines, the fuel control commands the ISBV to change state. The change of state is not sudden; the action occurs in a modulation range of 2 to 3 percent of the core speed around the trigger line. The locations of the trigger lines are adjustable. For the tests reported herein, both trigger



(a) Schematic showing only components related to core airbleed tests.



(b) Performance characteristics for ideal engine and control behavior.

Figure 5. - YF-102 engine fuel control.

lines were set within specification, but the diagonal trigger line was moved to the left as far as possible so that the ISBV would close at the lowest permissable core speed.

Typical engine steady-state (or very slow transient) operating lines are shown in the figure. For no core bleed the line is in the "ISBV open" region at low power settings, dips to a lower FCRU value as it crosses the diagonal trigger line, and rises to its highest value at maximum power. The dip in the operating line as it crosses the diagonal trigger line occurs because P_{T3} increases as the ISBV closes, thus causing the numerical FCRU value to decrease. For significant core bleed, the operating line has the same shape as the no-bleed line but is displaced toward higher FCRU.

Engine dynamic operating lines, called trajectories, trace the ideal FCRU path during a rapid (throttle-burst) acceleration from point 1 to point 2, and a rapid (throttle-chop) deceleration from point 2 to point 1. At point 1 the ISBV is closed. For the rapid acceleration the power-lever advance calls for higher core speed, so fuel flow increases. Simultaneously, the fuel control causes the ISBV to open. As the engine accelerates, the trajectory follows the acceleration fuel limit line and the maximum FCRU line. The ISBV closes again as the diagonal trigger line is crossed. The trajectory follows the maximum speed droop line down to the core speed associated with the new power lever position. For the rapid deceleration, fuel flow drops to the deceleration fuel limit line as soon as the power lever is retarded. The ISBV opens when the horizontal trigger line is crossed. When the core engine reaches the speed associated with the new power-lever position, fuel flow returns to the steady-state value, and the ISBV closes.

Test Stand Bleed Flow System

A schematic diagram of the core bleed flow system is shown in figure 6(a). As indicated in this figure and in figure 4(b), air was drawn from two of the ports on the engine core airbleed manifold. The bleed flow went to a 10.2-centimeter (4-in.) diameter header located above the engine. Core bleed flow was controlled by two pneumatically operated valves mounted from the header. Either of these valves could be controlled manually. In addition, the larger valve, a 7.6-centimeter (3-in.) quick-acting tapered plug valve, could be driven from an open-loop control system. The measured valve characteristics were 0.9-hertz natural frequency and 1.1-second full-stroke actuation time. The core bleed flow rate was measured by vertical conical exhaust nozzles downstream of the valves. Forces produced by these nozzles were normal to the engine centerline, and therefore did not contribute to the measured engine thrust.

The open-loop control system was used to control core bleed during all transient tests. The system sensed fan discharge pressure and converted that signal to a position command according to a predetermined program set in the analog computer. Fan pressure was chosen as the input variable because it was judged to provide the best available simulation of the QSRA ejector-mixer bleed demand. (Neither fan bleed nor the ejector-mixer were used in the present tests.) Fan pressure was obtained from one tube of an instrumentation rake at station 13.2. The particular tube was selected to provide a pressure typical of the average fan discharge pressure through the whole operating range.

Figure 6(b) is a photograph showing the test stand setup.

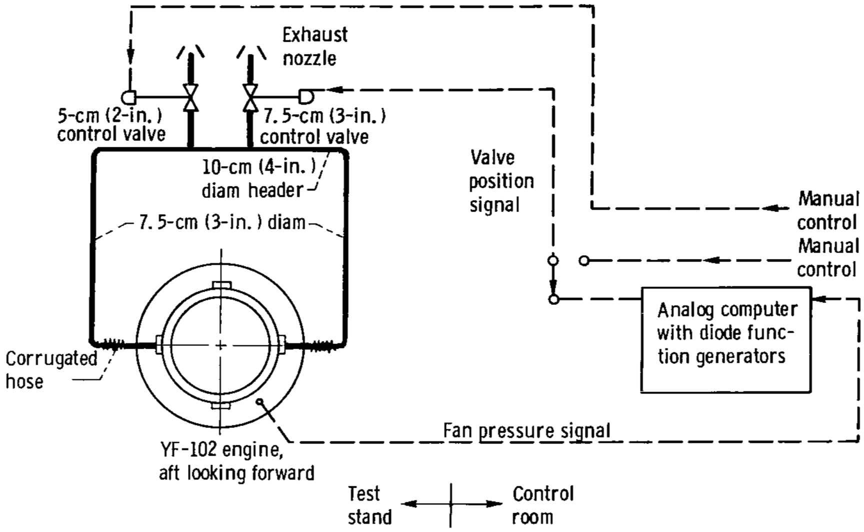
Instrumentation and Data Processing

The instrumentation used during these tests is summarized in table I. For the steady-state tests (table I(a)), the instrumentation is basically the same used for the tests reported in reference 7. The raw data for each test reading consisted of two scans of the complete instrument list. Most of the instrumentation was sampled once per scan (scan duration was approximately 15 sec), but net thrust and fan speed were sampled many times to obtain better average values. The raw data were recorded on the Lewis central data system and processed on a digital computer with a program specially written for these tests. The program averaged and listed the data, corrected results to standard temperature and pressure, and computed airflows and other performance parameters. Parameters and symbols used in this report are defined in appendix A.

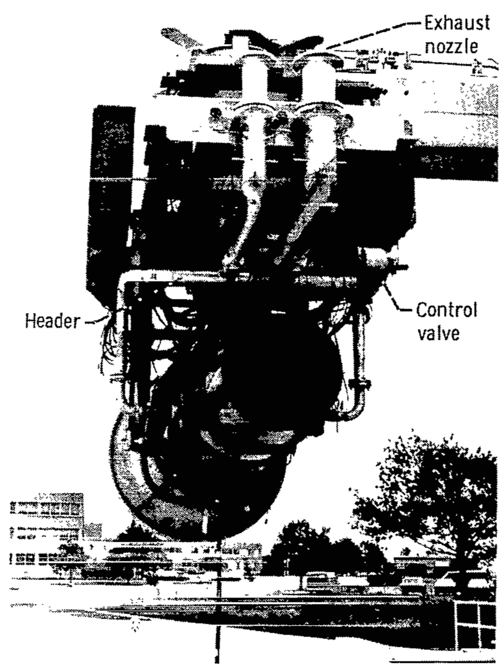
For the transient tests (table I(b)) selected measurements were recorded on an eight-track strip chart at 2.5 centimeters per second (1.0 in./sec) paper speed. Data were read directly from the chart using the steady-state recorded data to calibrate each track. Performance parameters were computed manually from these data.

Test Facility

All tests were conducted at the Vertical Lift Fan Facility (VLF) at the NASA Lewis Research Center. This facility is an outdoor engine static test stand sheltered by a service building which is moved away on tracks before testing. The engine is shown ready for testing in figures 4(c) and 6(b). The engine was suspended beneath the thrust measuring system,



(a) Core bleed flow system schematic, showing control system.



(b) Test stand setup.

Figure 6. - Core bleed flow system.

which can be pivoted around a vertical axis for operational convenience. Frameworks extending from the thrust measuring system were used to mount inlet and exhaust ducts and other hardware separately from the engine. The engine centerline was 2.9 meters (9.5 ft) above the ground. The control room was about 150 meters (500 ft) from the engine.

Procedure

For the tests reported herein, the day-to-day ambient temperature T_0 varied between 14° and 29° C (57° and 85° F). Most of the transient data were obtained when the ambient temperature was between 18° and 28° C (65° and 83° F).

TABLE I. - ENGINE PERFORMANCE INSTRUMENTATION

(a) Steady-state tests[a]

Station	Total pressure	Wall static pressure	Lip static pressure	Total temperature	Wall temperature
	Number of sensing points				
0				6	
1		4			
2.1	[b]2	2		2	
3	1	1		2	
4.1				[c]1	
5	15	3		6	
6		3	2		2
13.2	40			20	
16		4			
ISBV flow	[d]1				
Inlet to test-stand bleed-system piping (P_{bp})		1		1	
Inlet to bleed system exhaust nozzles		2		2	

(b) Transient tests

The following measurements were recorded on a strip chart at 2.5 cm/sec (1 in/sec) paper speed:
- Power lever position
- Core speed
- Net thrust
- Core bleed flow-control valve position
- Combustor housing wall pressure, P_{w3}
- Fan-discharge total pressure[e]
- ISBV flow[d]
- Measured gas temperature (MGT)

[a]Miscellaneous measurements: Net thrust; fan speed; core speed; fuel flow rate; (core) inlet guide vane position; ambient atmospheric and wind conditions; engine health measurements.
[b]Two integrating rakes; each was a single pressure measurement from 10 sampling ports spaced across the flow passage.
[c]Single output from 10 thermocouples spaced throughout flow passage, all wired in parallel. This measurement is also called measured gas temperature (MGT).
[d]Tube located to sense flow pressure at bleed band; pressure greater than under-cowling ambient pressure indicates ISBV is open.
[e]One tube from station 13.2 rake, chosen to be typical of average fan-discharge pressure over whole operating range.

Steady-state Tests

Data were obtained for the steady-state tests over a range of core speeds from near idle to maximum rating. Maximum rating always occurred when MGT reached 1194 K (2150° R). For each reading the bleed flow control valves were adusted manually to the desired position. The engine throttle was set to provide the desired core speed. After the engine had "settled out" for 2 minutes, a performance data reading was recorded and processed as described in the "Instrumentation and Data Processing" section of this report.

In presenting the test results, it is necessary to refer to "corrected maximum MGT". Corrected MGT is $MGT/\theta^{1.022}$, as recommended by the engine manufacturer. For the ambient temperatures at the time the tests were performed, the corrected MGT at maximum rating was approximately 1139 K (2050° R). This value is used herein to describe performance at maximum rating. Where necessary, the data have been interpolated or extrapolated to determine the performance at 1139 K.

Bleed Flow System Calibration for Transient Tests

Using the larger bleed-flow-control valve only, performance data were obtained for several different valve positions as described in the procedure for steady-state tests. From the resultant data, the core bleed ratio $W_B/W_{2.1}$ was plotted against the fan-discharge pressure ratio, $P_{T13.2}/P_{T0}$ for each valve position. The data from these graphs were cross-plotted to show valve position as a function of core bleed ratio for several values of the fan discharge pressure ratio, as shown in figure 7. On the test day, the desired bleed schedule was superimposed on the crossplot, and appropriate intersections were determined to set up the diode function generators in the analog computer.

Transient Tests

When the desired core bleed schedule was set in the diode function generators, the engine was run with the computer controlling the bleed flow. In a similar manner to the procedure for steady-state tests, the engine throttle was adjusted to provide the desired

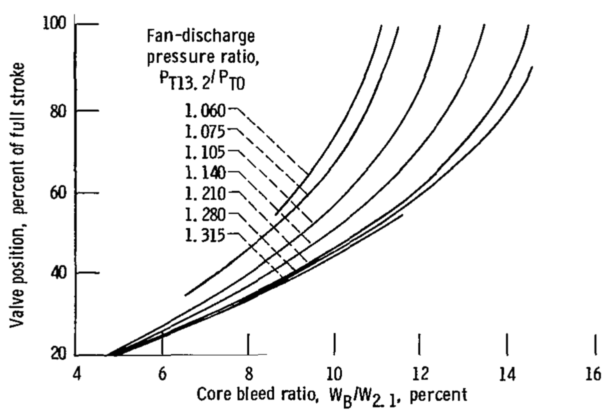


Figure 7. - Open-loop bleed-air control system calibration data.

beginning and end core engine speeds for the transient, and throttle stops were set at each of these speeds. For the transient the throttle was snapped between the stops. Each transient test was performed at least twice. Acceleration and deceleration times from all applicable test data were averaged to provide final results.

Transient tests were performed for no core bleed and for each of the core bleed schedules shown in figure 8. In this figure the dashed lines indicate the desired schedules. The symbols show the core bleed ratio measured when setting the throttle stops for the transient tests. For the QSRA bleed schedules 1 and 2, a 1 percent additional bleed above that allocated for the BLC system has been included at low power settings. This was done to simulate the power extraction expected during flight by hydraulic pumps, generators, etc., which could not be included in these tests. No allowance has been made at high power settings because the expected power extraction will not affect engine behavior significantly.

Results and Discussion

Steady-State Performance

The relation between corrected core bleed flow rate and core bleed ratio, at several corrected core speeds and at corrected maximum MGT, is shown in figure 9. The solid symbols in this and following figures indicate that the ISBV is open, as determined by the total-pressure tube sensing flow at the bleed band (see table I). For all power settings from approximately flight idle (defined by the manufacturer as 13 300 rpm corrected core speed) to corrected maximum MGT (maximum rating), more than 11 percent core bleed ratio was obtained. At corrected maximum MGT, over 14 percent (corresponding to 1.88 kilograms per second (4.15 lb/sec)), corrected core bleed flow rate was obtained. The figure also shows that the range of satisfactory engine operation with core bleed is limited; operation is not permissable in region I because maximum MGT would be exceeded.

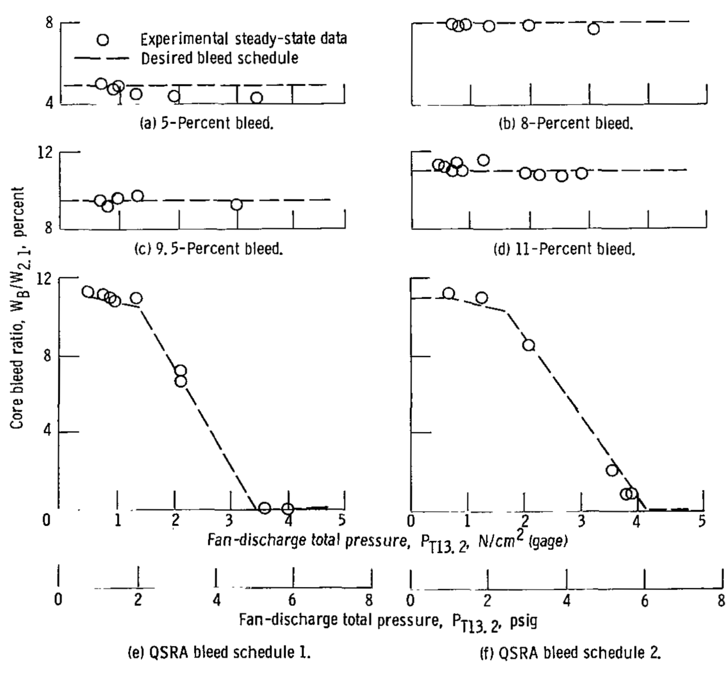


Figure 8. - Bleed schedules for transient tests.

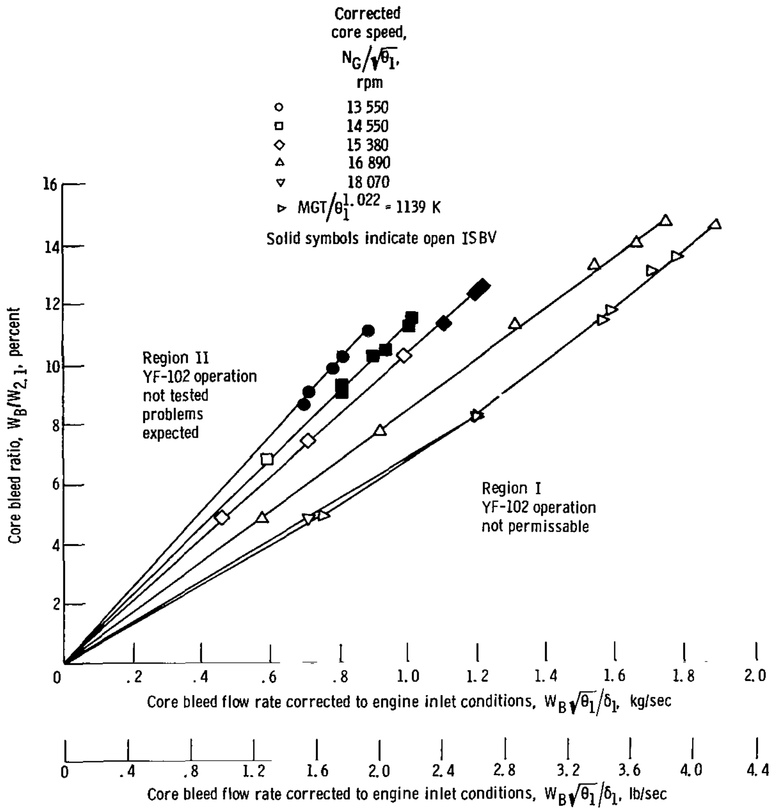


Figure 9. - Core bleed ratio for several corrected core speeds.

In the untested region II, problems such as unacceptably slow transient acceleration and compressor surge would be encountered.

Performance over a large range of core speed is presented in figure 10. Data are shown for the bleed-flow-control valve set at a fixed position, and for no core bleed (valve closed). At low speed the ISBV is open; for the data with core bleed the ISBV begins to close at about 14 250 rpm. As it closes, many of the performance parameters undergo conspicuous changes from their smooth trends. For example, core bleed ratio jumps up because core bleed flow rate increases as the compressor-discharge pressure increases. Thrust increases when the ISBV closes mainly because fan speed increases due to resulting greater turbine flow.

A comparison of the performance with core bleed with the performance with no bleed in figure 10 shows that the core inlet flow rate is practically the same whether there is bleed or not. This indicates that for moderate core bleed ratios, represented by these data, turbine flow is reduced by an amount nearly equal to the bleed flow. The turbine flow, as in most engines, is controlled by choke conditions at the inlet stators; for this case flow is reduced by lower pressure and increased temperature.

Other comparisons of interest in figure 10 include MGT, fan speed, thrust, compressor-discharge pressure, FCRU's, and thrust specific fuel consumption. For core bleed MGT is significantly greater than without bleed in order to provide energy to drive the engine at the same core speed. However, at high core speeds the fan speed and, consequently, thrust are a little less for bleed; this may be related to a change in power-turbine characteristics because of off-design operation. Compressor-discharge pressure decreases

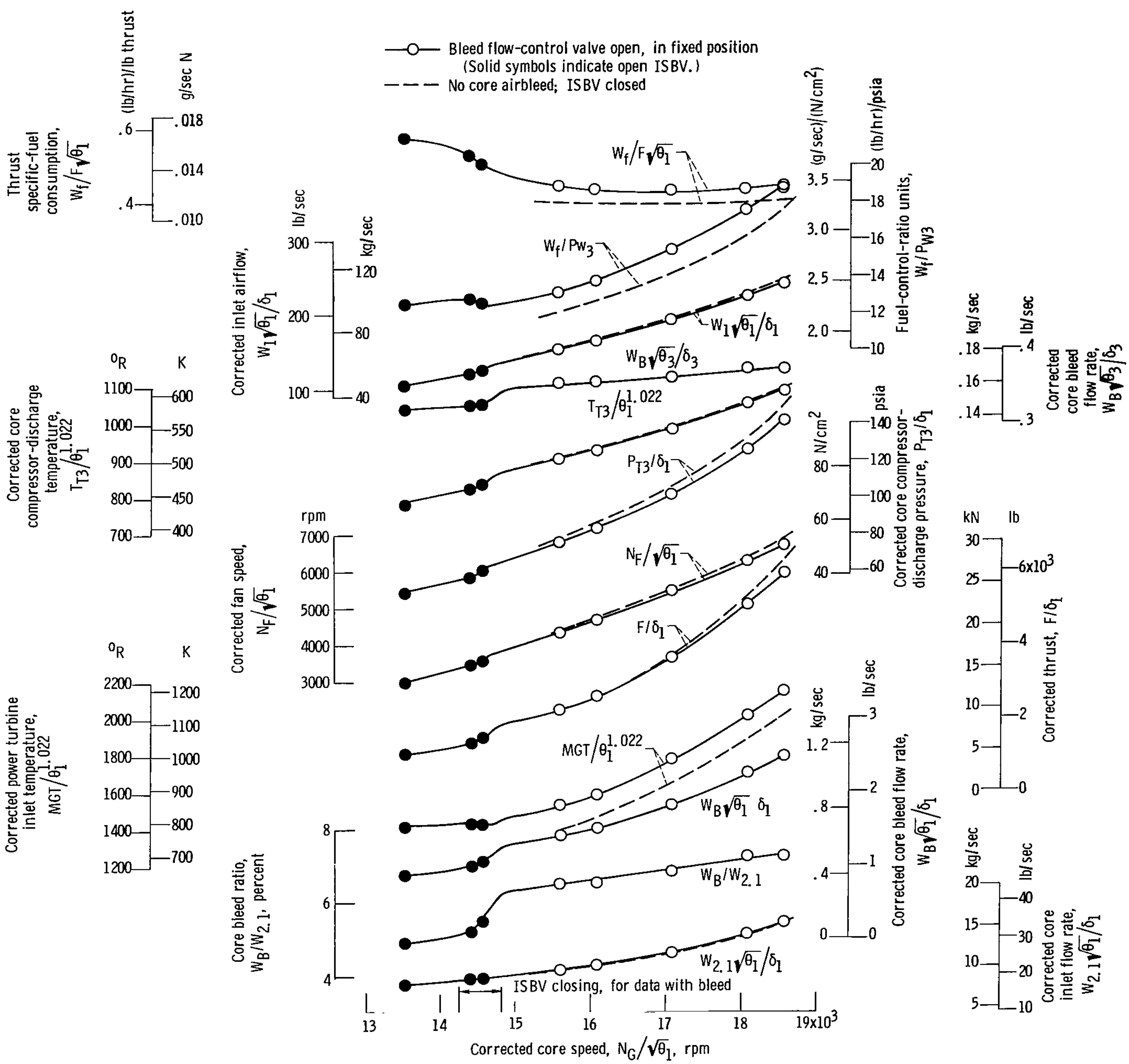


Figure 10. - Engine performance with bleed flow-control valve in fixed position, and with no core airbleed.

for core bleed because the compressor operating line is lowered. The FCRU's increase for core bleed because compressor-discharge pressure decreases. The thrust specific-fuel consumption improved significantly for core bleed after the ISBV closes, but is always worse than without bleed because power (in the form of highly compressed air) is extracted from the engine.

Condition of core bleed air. – The maximum available core bleed pressure is shown in figure 11 as a function of corrected bleed flow rate for several corrected core speeds, corrected maximum MGT, and core bleed ratios up to 12 percent. The maximum available pressure is the measured compressor-discharge total pressure P_{T3}. It depends mainly on core speed, as expected, and falls off slightly as core bleed flow rate is increased. Bleed flow at this pressure could be obtained from a specially installed total-pressure scoop in the combustor housing. But, when flow is taken from the existing ports on the core airbleed manifold, the pressure is less. This effect is shown in figure 12, which gives the ratio of pressure in the external piping P_{bp} to P_{T3} as a function of the core bleed flow rate corrected to station 3 conditions.

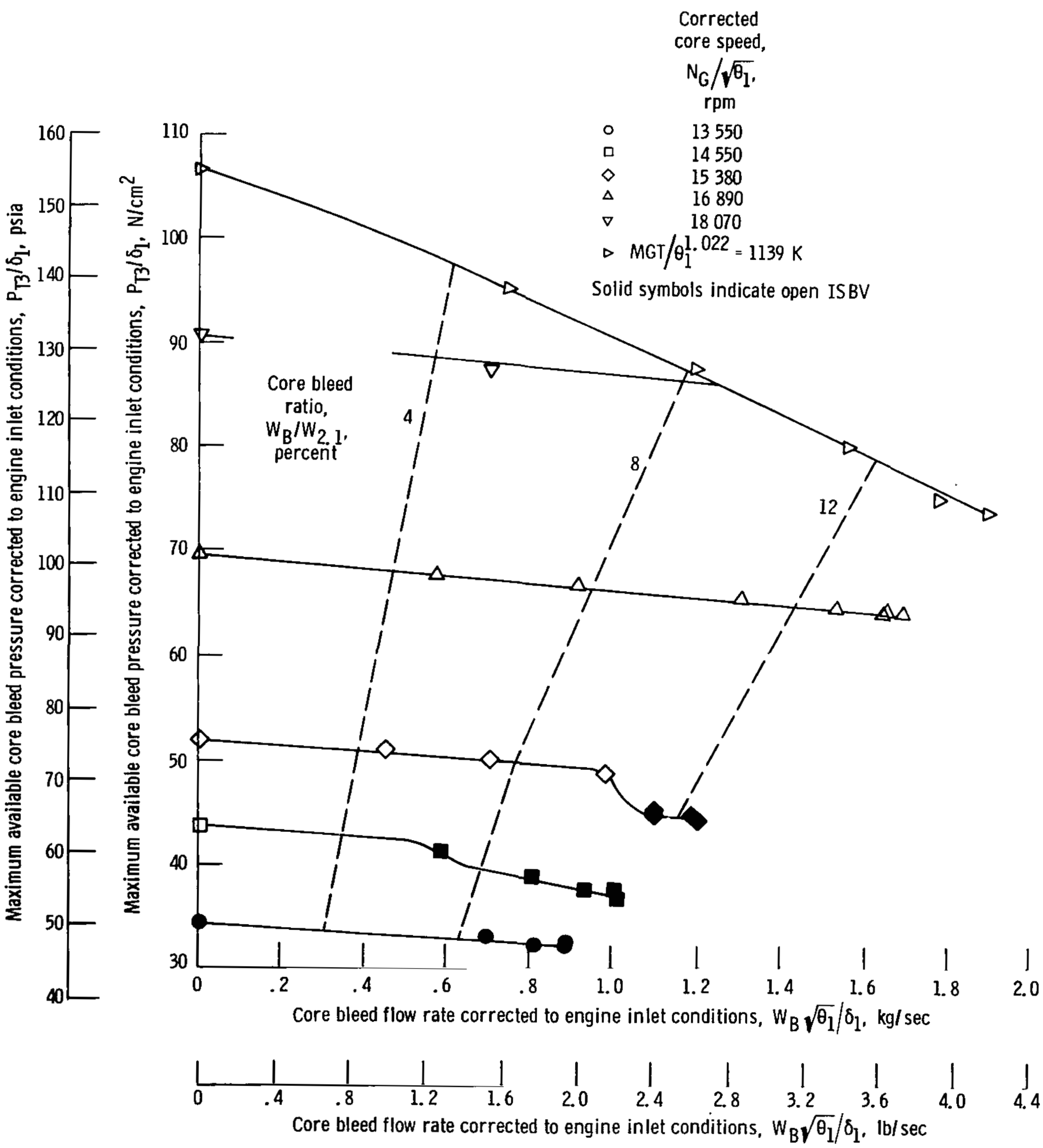


Figure 11. - Maximum available core bleed pressure.

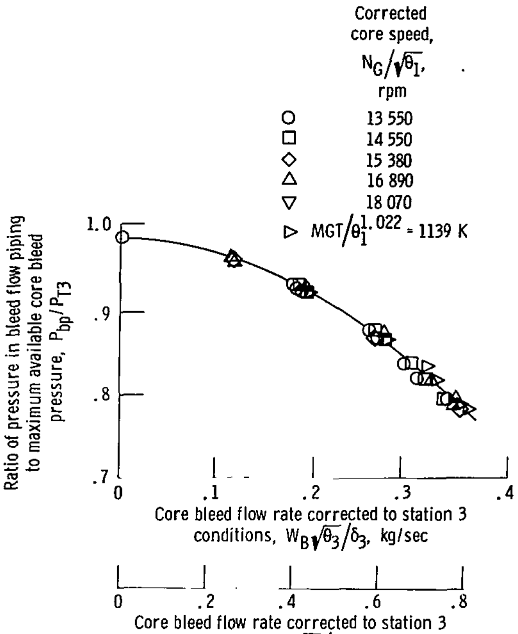


Figure 12. - Usable core air bleed pressure. P_{bp} is pressure in test stand bleed-flow piping, about 30 cm (1 ft) downstream of engine bleed flow port.

For the case of no bleed flow, the maximum P_{bp} is the combustor housing wall pressure P_{w3}, which is about 0.985 P_{T3}. With core bleed, P_{bp} is reduced still further because of pressure drop in the manifold.

The maximum core bleed temperature is shown in figure 13 in the same format as figure 11. This temperature is the measured compressor-discharge total temperature T_{T3}. Although not included in the figure, the data showed that the core bleed temperature in the bleed piping T_{bp} was about 6° C (10° F) less than T_{T3} because of heat loss in the manifold and the NASA supplied bleed flow piping crossing the bypass flow duct.

From the results presented in this section, the engine operation necessary to meet given core bleed requirements can be calculated easily using P_{T3} and T_{T3} from the manufacturer's estimated engine performance computer program.

Effects of core bleed on engine performance. – The effects of core bleed flow rate on fan discharge pressure ratio, corrected thrust, and corrected MGT are presented in figures 14 to 16, respectively. The fan-discharge pressure ratio is here defined as $P_{T13.2}/P_{T0}$, where, as indicated in figure 4(a), $P_{T13.2}$ is the average pressure in the bypass duct just ahead of the fan nozzle mounting flange. As shown in figure 14, for any given corrected core speed, the fan-discharge pressure ratio drops off slightly as core bleed flow rate is increased, until the

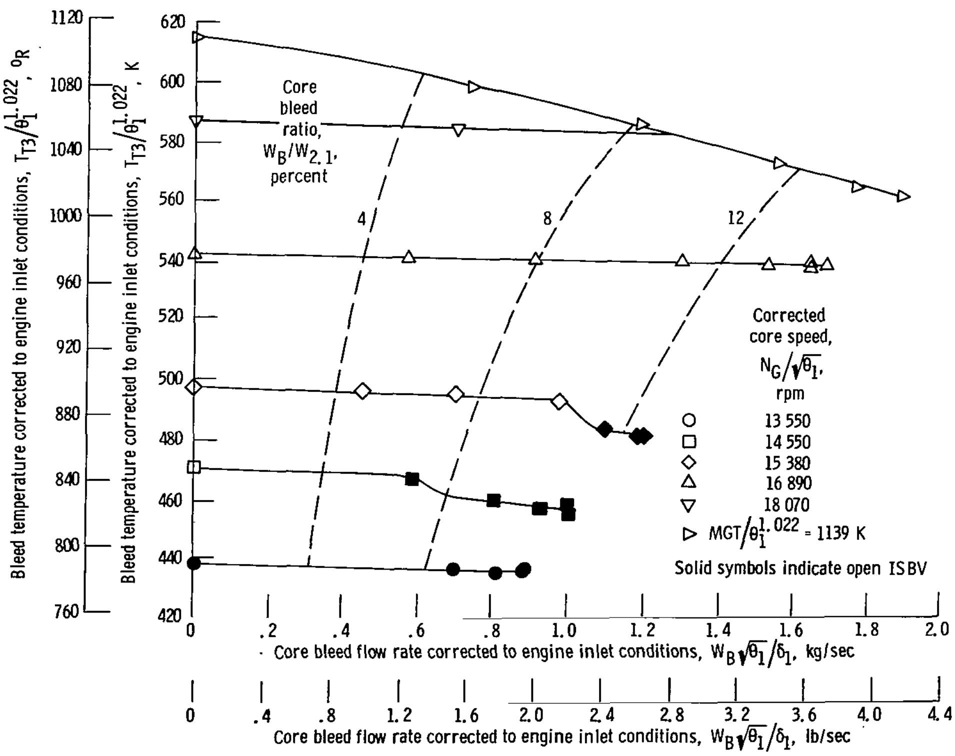


Figure 13. - Core airbleed temperature.

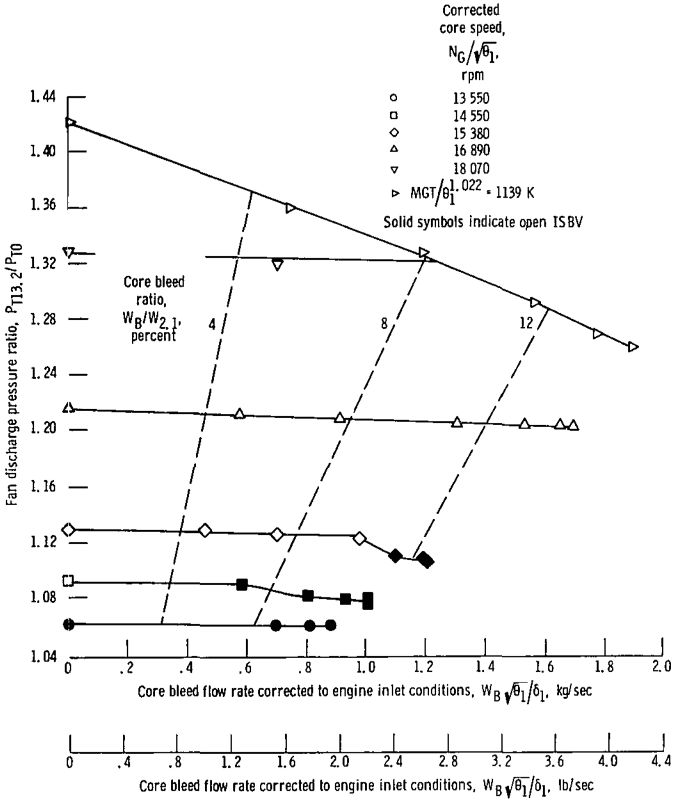


Figure 14. - Effect of core air bleed on fan discharge pressure ratio.

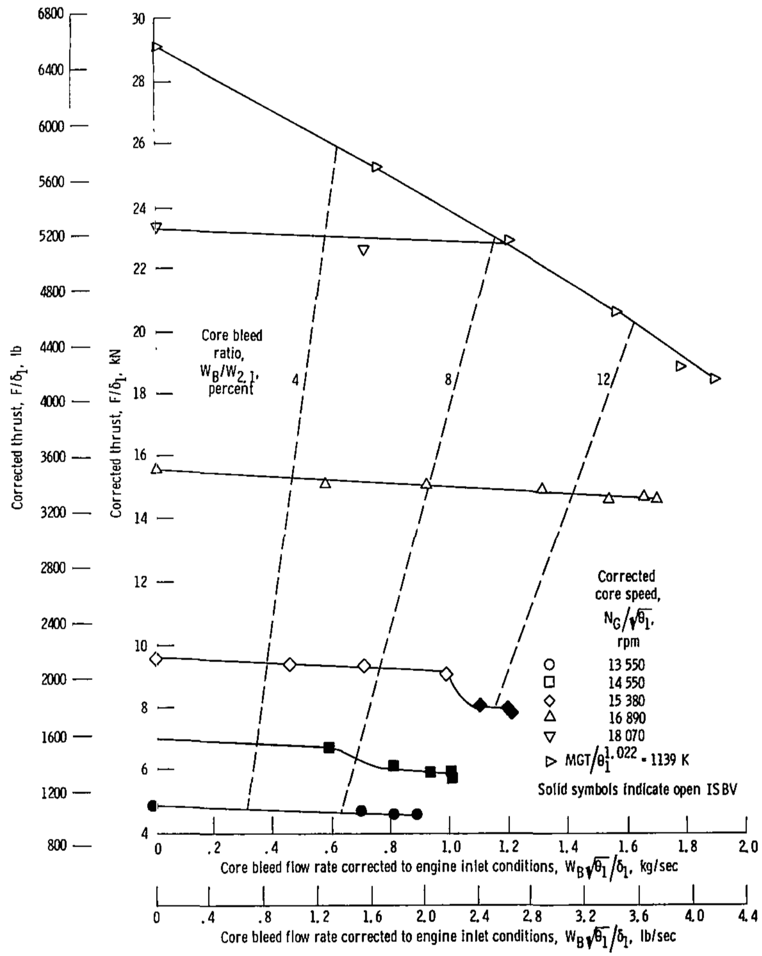


Figure 15. - Effect of core air bleed on thrust.

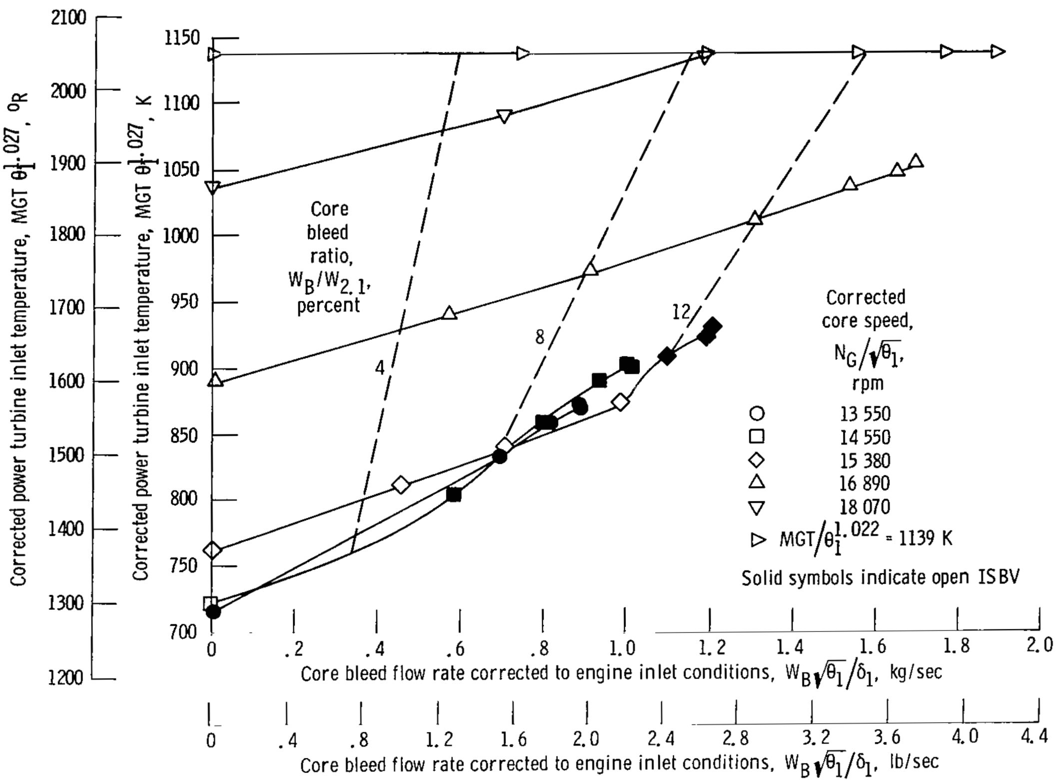


Figure 16. - Effect of core air bleed on corrected measured gas temperature.

ISBV opens. When the ISBV opens, the pressure ratio falls to a new lower value. Corrected thrust (fig. 15) varies in a similar manner, as expected, because the fan moves toward lower speed on the fan map operating line as bleed flow rate is increased. At zero bleed and corrected maximum MGT, the corrected thrust was reduced about 900 newtons (200 lb) when compared with the data in reference 7. This reduction is caused by pressure loss due to the round (NASA supplied) bleed flow piping crossing the bypass duct. The corrected MGT (fig. 16) increases as core bleed flow rate is increased for a given corrected core speed in order to provide sufficient energy to keep the speed constant.

The effect of core bleed flow rate on thrust specific-fuel consumption is shown in figure 17. The data show that even a small amount of core bleed is costly in terms of fuel consumption, especially when the ISBV is open.

Transient Performance

Before transient data were taken, two fuel-control adjustments were made to optimize engine acceleration response for the QSRA airplane. The adjustments were made to the acceleration fuel limit line and to the ISBV diagonal trigger line. These lines are shown in figure 5(b). The acceleration fuel limit line was set to meet the QSRA requirement that the engine accelerate from 15 600 rpm corrected core speed (QSRA flight idle speed) to maximum rating in 3.0 seconds using the QSRA bleed schedule 1. This adjustment required making engine acceleration tests until the desired setting was found by trial-and-error. During some of these preliminary tests, the engine accelerated very slowly (20 or 30 sec to maximum rating), or not at all, due to combinations of large core bleed at low power settings and low acceleration fuel limit. The final setting was higher than the factory setting, but was judged to be safely away from the potential stall region. The second fuel-control adjustment made was to move the ISBV diagonal trigger line to the left edge of the factory tolerance. This was done so the ISBV would close at the lowest permissable core speed, and thus tend to improve engine acceleration performance.

No other fuel-control adjustments were made. The two adjustments just described do not affect overall engine steady-state performance.

Throttle-burst accelerations. – For the throttle-burst accelerations performed, the power lever was advanced to its new position in about 0.6 second. The

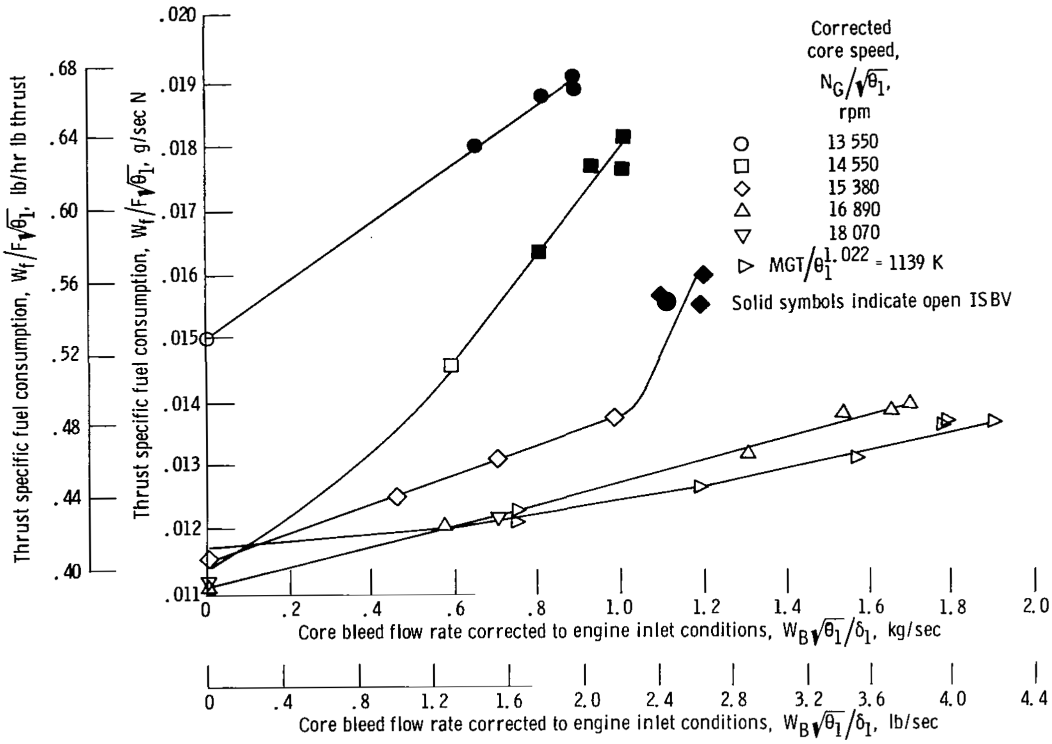


Figure 17. - Effect of core air bleed on thrust specific fuel consumption.

engine acceleration time from a given starting corrected core speed is shown in figure 18 for all the core bleed schedules tested. This figure summarizes the results of 109 tests. Engine acceleration time is defined here as the time required for the engine to accelerate to 95 percent of thrust at the corrected maximum MGT for the bleed schedule used. All tests were performed at ambient temperatures of 18° to 29° C (64° to 85° F). The effect of changing ambient temperature on acceleration time was not measured, but the effect should be small for the range of temperatures existing during the tests.

Acceleration time (fig. 18) is always least for no core bleed. With core bleed, acceleration time increases significantly for core bleed ratios greater than 9.5 percent, and for starting corrected core speeds less than about 15 000 rpm. For all tests the YF-102 engine performed without surge, stall, overtemperature, or other indication of unsatisfactory behavior.

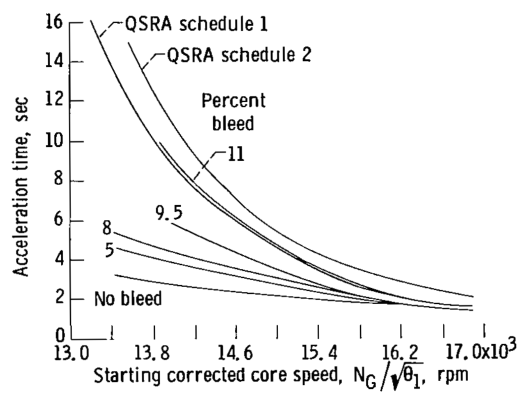


Figure 18. - Engine response time for throttle-burst accelerations. Acceleration time is time for engine to accelerate to 95 percent of maximum rating thrust for that bleed schedule.

A typical strip-chart recording from a throttle-burst acceleration test with the QSRA bleed schedule 1 is shown in figure 19. Each of the eight channels is labeled. Power-lever position is used only as an indication of the transient "start". The other measured quantities change smoothly during the transient time, except the ISBV flow-indicator measurement (see table I). The ISBV is open at the start of the transient, and the measurement indicates flow. The flow increases as core speed and compressor discharge pressure (as indicated by P_{w3}) increase, then varies in response to a combination of increasing compressor-discharge pressure and valve modulation, then finally closes as the diagonal trigger line is crossed.

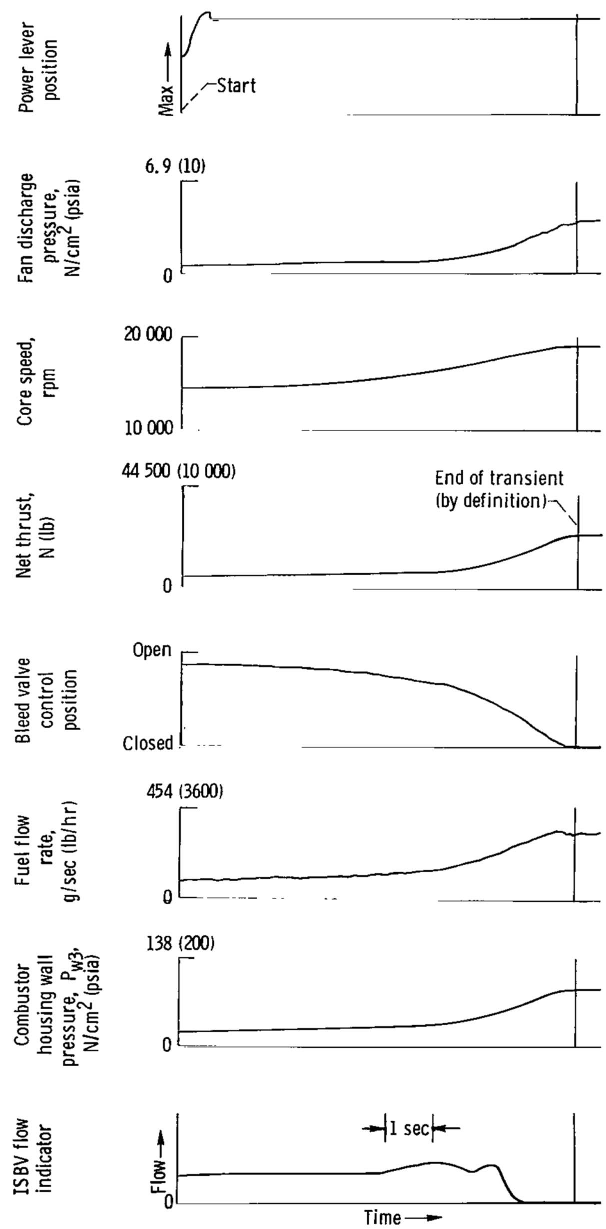


Figure 19. - Strip-chart data for throttle-burst acceleration with QSRA bleed schedule 1.

Throttle-burst trajectories constructed from strip-chart data are shown in figure 20 for several core bleed schedules. The fuel-control limits, ISBV diagonal trigger line, and steady-state operating lines have the same meaning as described previously. The ordinate scale shows FCRU's expressed in terms of P_{w3}, since that pressure was measured in the tests. (This is acceptable, because P_{w3} is proportional to P_{FC3} and P_{T3}.) The values shown for the fuel control limits are the best values determined from factory setup data (adjusted to P_{w3}) and the test data. In general, the trajectories are consistent with the ideal performance shown in figure 5(b). For the 11 percent schedule and the QSRA bleed schedule 1, the steady-state operating line lies nearly on the acceleration fuel flow limit line at the starting core speed shown. Consequently, not much fuel margin is available to accelerate the engine, resulting in the long acceleration times shown in figure 18. At the beginning of the no-bleed (fig. 20(a)) and 11 percent bleed (fig. 20(c)) trajectories, the measured FCRU overshoots the acceleration fuel limit line. This may be due to the instrumentation, which was intended originally only for steady-state measurements. The fuel flowmeter was not close coupled to the engine, and the overshoot may be caused by flow phenomena in the long connecting line. Also, the P_{w3} transducer was located at the end of a relatively long sense line, and, therefore, the measured P_{w3} may lag the actual P_{w3} for rapid pressure changes. Another difficulty appears in the no-bleed trajectory (fig. 20(a)): The trajectory lies below the acceleration fuel limit line, whereas the other trajectories accurately adhere to the line. The reason for this discrepancy is not known.

The corrected thrust buildup associated with throttle-burst accelerations is shown in figure 21. These data were also obtained from strip charts. The high core bleed schedules are slow to accelerate at the beginning of the transient, but acceleration improves at about 8800 newtons (2000 lb) corrected thrust (about 16 000 rpm corrected core engine speed). This is the speed range at which the ISBV begins to modulate toward the closed position.

Throttle-chop decelerations. – For the throttle-chop decelerations performed, the power lever was retarded to its new position in about 0.2 second. The engine deceleration time from a given starting corrected core speed is shown in figure 22 for all of the core bleed schedules tested. Engine deceleration time is defined here as the time required for the engine to decelerate to 105 percent of the thrust produced at 14 600 rpm corrected core speed for that core bleed schedule. Deceleration time is generally less than acceleration time and is more dependent on the core bleed than on starting speed. The fastest deceleration time is for no core bleed; longer times are measured when there is large core bleed, and consequent opening of the ISBV at the diagonal trigger line, at lower core speed. The longest time was about 2.5 seconds for the QSRA bleed schedules 1 and 2 and the 11 percent bleed schedule.

A typical strip-chart recording for a throttle-chop deceleration with QSRA bleed schedule 1 is shown in figure 23. All parameters except thrust and fuel flow

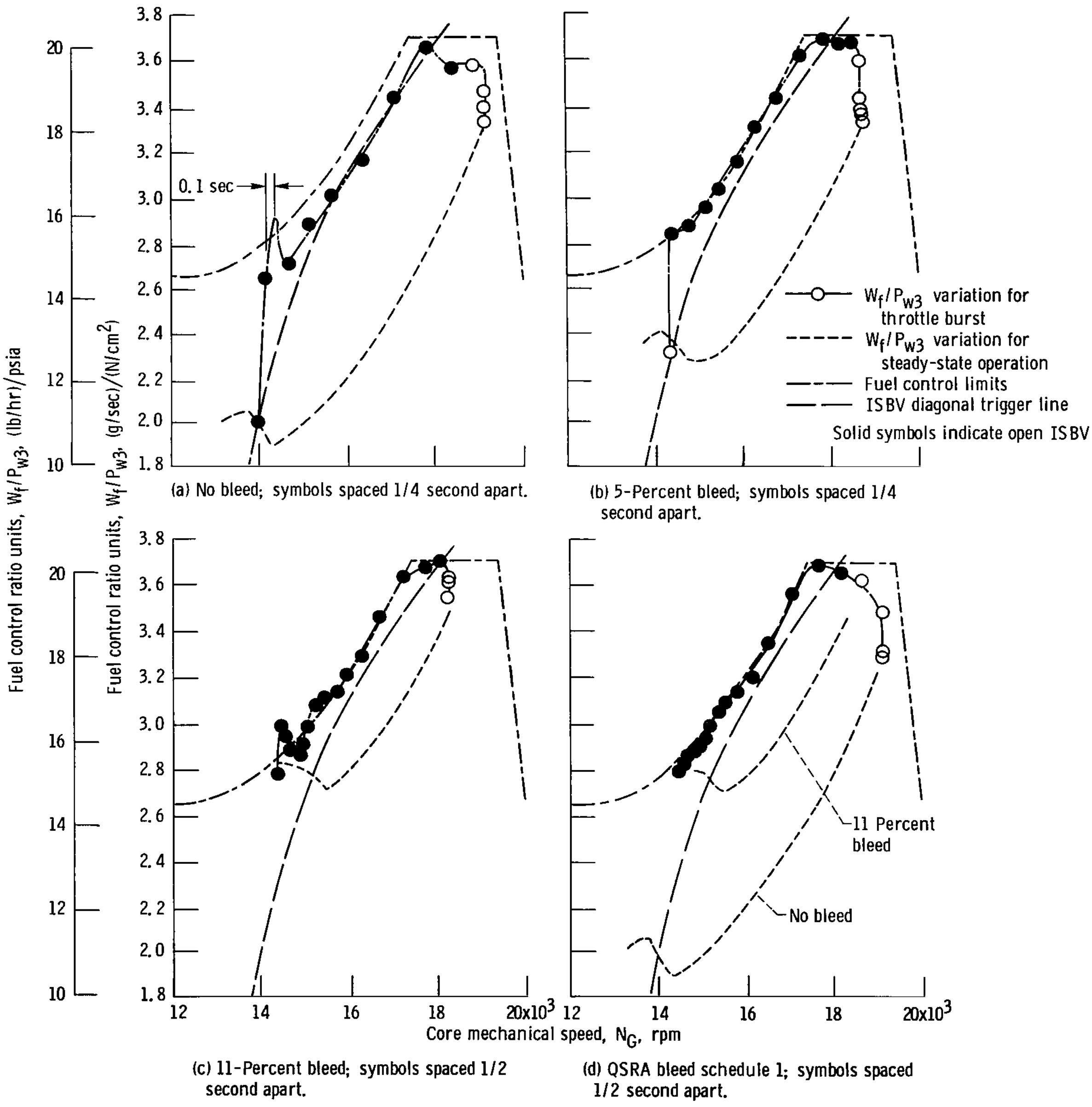


Figure 20. - Fuel control trajectories for throttle-burst accelerations with several bleed schedules.

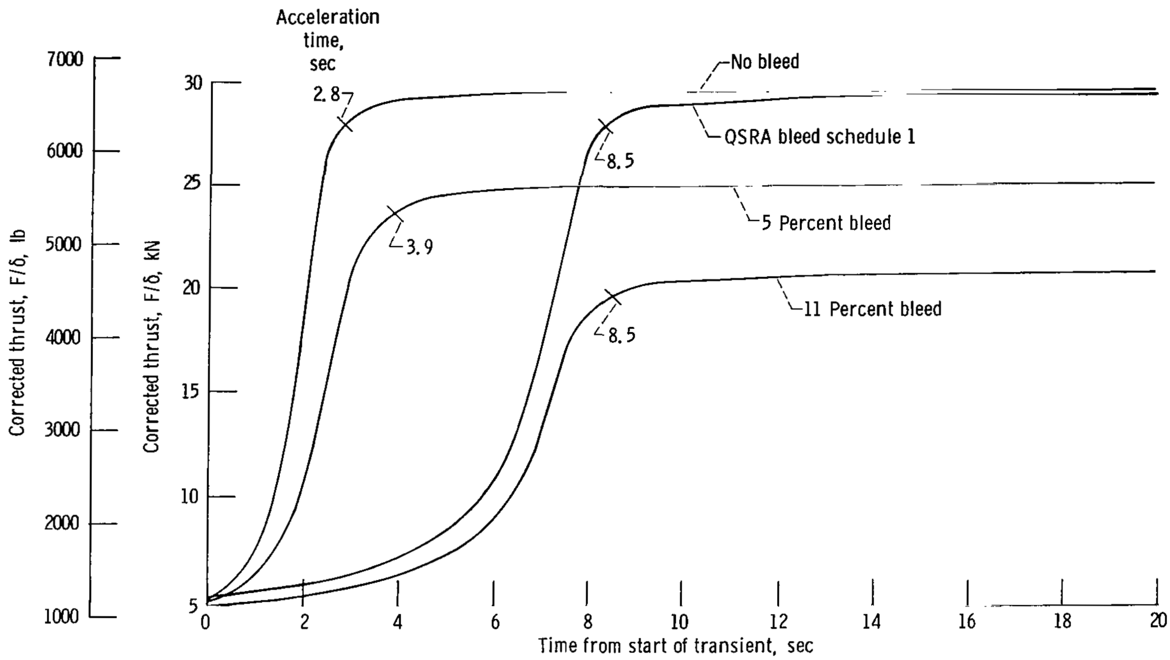


Figure 21. - Thrust buildup during throttle-burst accelerations for several bleed schedules. Acceleration from 14 100-rpm corrected core speed to 1139 K (2050° R) corrected maximum MGT.

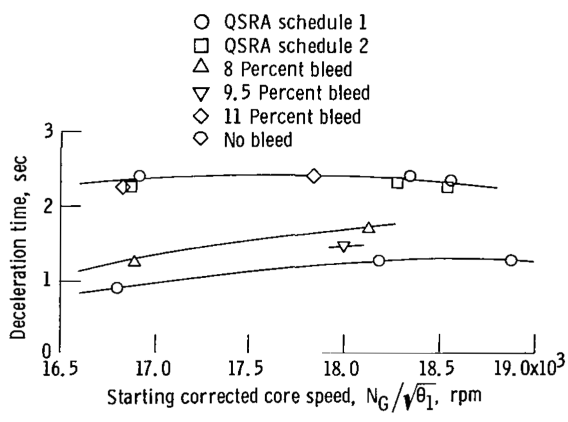


Figure 22. - Engine response time for throttle-chop decelerations. Deceleration time is time for engine to decelerate to 105 percent of thrust produced at $N_G\sqrt{\theta_1}$ = 14 600 rpm.

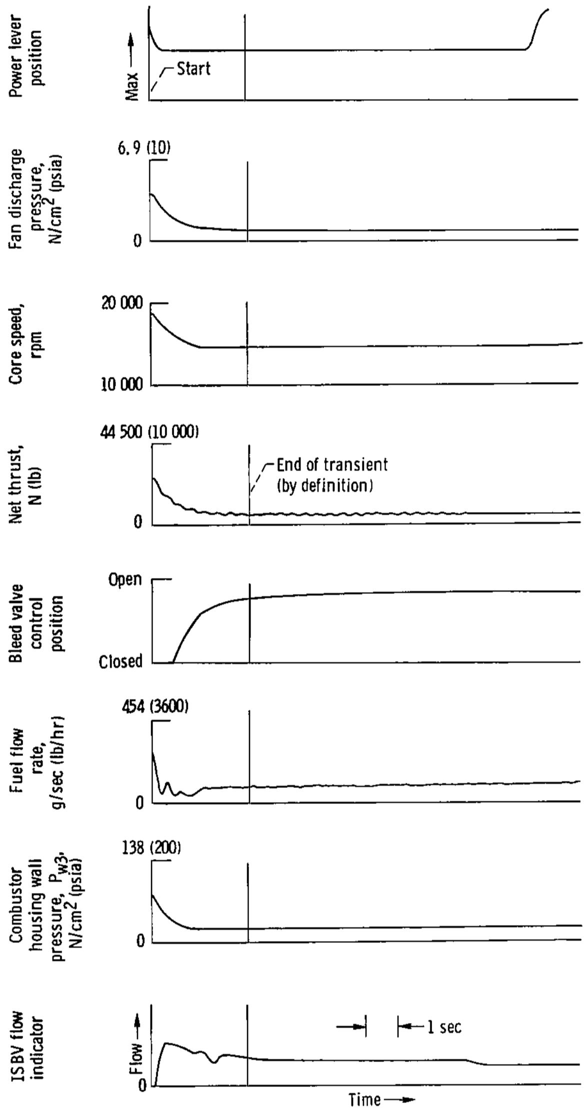


Figure 23. - Strip-chart data for throttle-chop deceleration with QSRA bleed schedule 1.

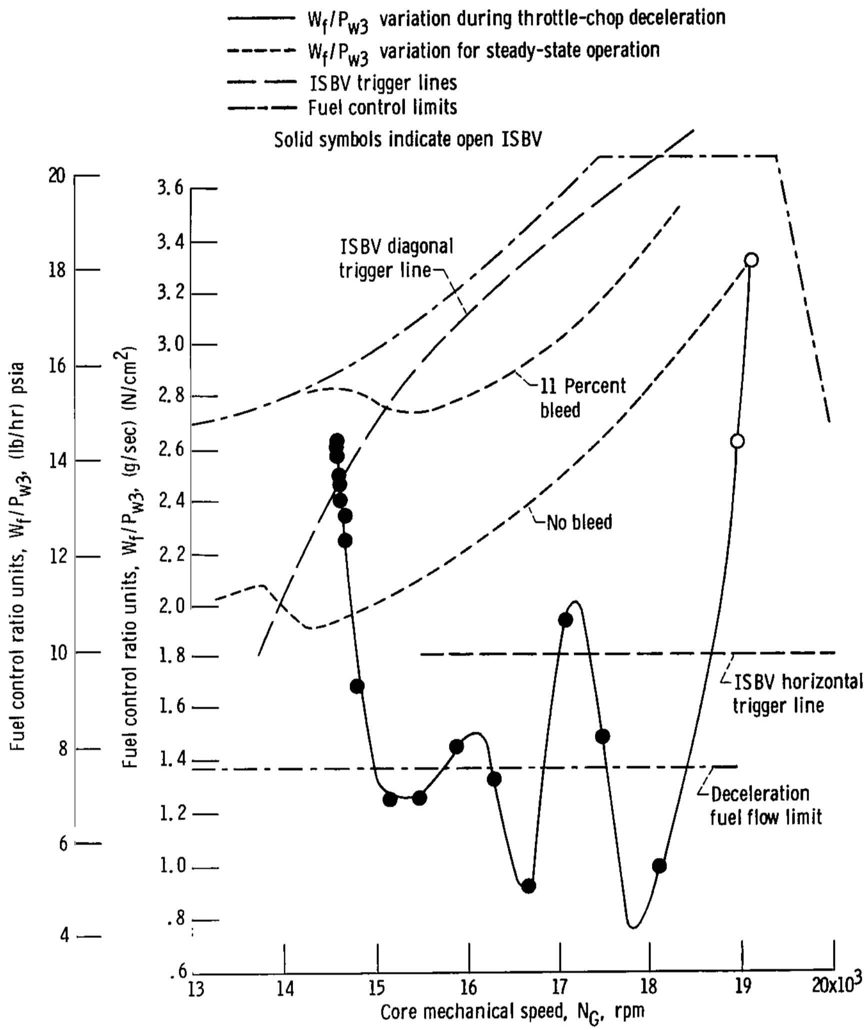


Figure 24. - Fuel control trajectory for throttle-chop deceleration with QSRA bleed schedule 1 symbols spaced 1/8 second apart.

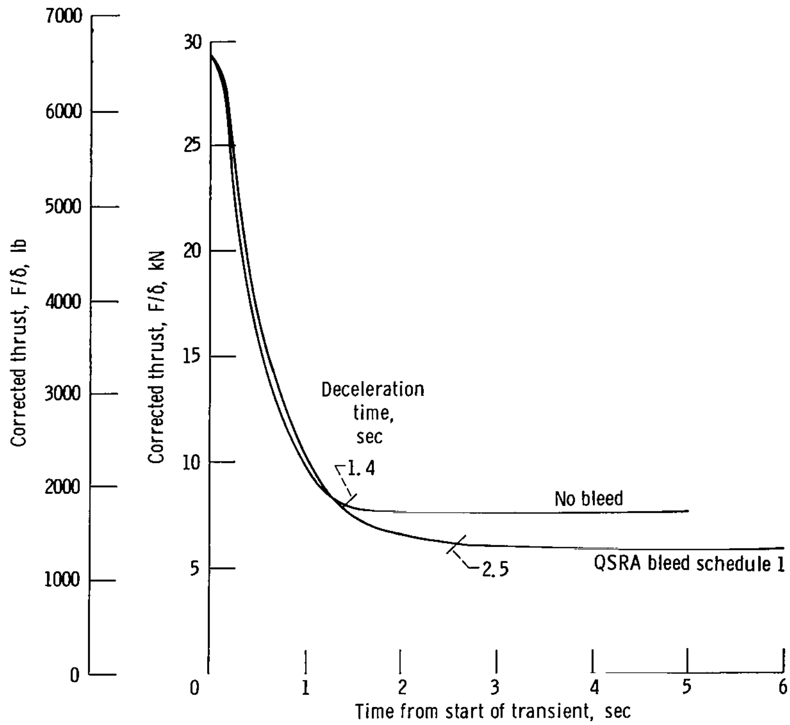


Figure 25. - Thrust decay during throttle-chop decelerations. Deceleration from 1139 K (2050° R) corrected maximum MGT to 14 600 rpm corrected core speed.

respond in the expected manner. The 3-hertz oscillation superimposed on the thrust measurement is the response of the test stand structure to a sudden reduction in thrust load, and has been observed in other engine tests on this stand. The oscillation does not affect any of the other measurements. The fuel flow quickly drops to a low value, then makes several oscillations before settling out at the new steady-state flow rate. It was not determined if this result is characteristic of the fuel control or the test-stand fuel system. In either case, no combustor flameout was encountered during any of the transient tests.

A deceleration trajectory for the same test as the previous figure is shown in figure 24. The trajectory is generally consistent with the ideal performance discussed with figure 5(b); the fuel flow oscillations noted in the previous paragraph are reflected as trajectory oscillations about the deceleration fuel flow limit line.

The thrust decay for typical throttle-chop decelerations are shown in figure 25. Corrected thrust falls off very quickly at the start of the transient, then not as rapidly as the final core speed is approached. The less rapid decay near the end of the transient is the main reason for longer deceleration times for the large core bleed schedules shown previously.

Summary of Results

As part of the QSRA propulsion system development, the YF-102 engine was tested to determine steady-state and transient performance with core airbleed. Tests were performed on an outdoor static test stand at ambient temperatures between 14° and 29° C (57° and 85° F), and with a confluent exhaust system similar in size to the QSRA exhaust system. The tests exercised the engine at or beyond the applicable QSRA requirements. The most important results of the tests are as follows:

1. The engine operated satisfactorily with steady-state core bleed up to 14 percent of the core inlet air flow. As a result of this bleed, engine thrust was reduced significantly, but no stability or mechanical engine operating problems were encountered.

2. After setting the engine fuel control to meet QSRA acceleration requirements at the QSRA flight idle power setting, the engine was tested to determine its transient performance characteristics. For some of the tests, the core bleed was scheduled to vary with fan discharge pressure, to simulate the QSRA bleed requirements. The engine accelerated and decelerated satisfactorily over the whole operating range with no core bleed and with core bleed up to 11 percent of the core inlet airflow (maximum tested). No surge, stall, overtemperature, combustor flameout, or other operating problems were encountered.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 16, 1979,
769-02.

Appendix – Symbols

A geometric flow area, cm^2 (in^2)
D diameter, cm (in.)
F measured thrust, N (lb)
N rotational speed, rpm
P pressure, N/cm^2 (lb/in^2)
T temperature, K (°R)
W flow rate, kg/sec (lb/sec); for fuel flow rate only, g/sec (lb/hr)
δ ratio of pressure to standard-day pressure, 10.132 N/cm^2 (14.696 lb/in^2)
θ ratio of temperature to standard-day temperature, 288.2 K (518.7° R)

Subscripts:

B bleed flow
bp bleed piping
F fan
f fuel
FC fuel control
G gas generator (core engine)
T total
w wall

Note: A number following a subscript designates an engine station (see fig. 4(a)).

References

1. Cochrane, J. A.; and Boissevain, A. G.: Quiet Short-Haul Research Aircraft Current Status and Future Plans. AIAA Paper 78-1468, Aug. 1978.
2. Shovlin, M. D.; and Cochrane, J. A.: An Overview of the Quiet Short-Haul Research Aircraft Program. NASA TM-78545, 1978.
3. Gunnarson, D. W.; and McArdle, J. G.: Inlet and Duct for the QSRA Boundary Layer Control System. J. Aircr., vol. 16, no. 5, May 1979, pp. 303-308.
4. Engine Specification, YF102 (QSRA Updated) Lycoming Model No. ALF 502A Turbofan Engine. Specification No. 124.36D, Avco Lycoming Division, 1976.
5. Clark, B. J.; McArdle, J. G.; and Homyak, L.: Measured and Predicted Noise of the Avco-Lycoming YF-102 Turbofan Engine. AIAA Paper 79-0641, Mar. 1979.
6. Reshotko, M.; et al.: Core Noise Measurements on a YF-102 Turbofan Engine. AIAA Paper 77-21, Jan. 1977.
7. McArdle, J. G.; Homyak, L.; and Moore, A. S.: Static Test Stand Performance of the YF-102 Turbofan Engine with Several Exhaust Configurations for the QSRA Aircraft. NASA TP-1556, 1979.

1. Report No.
NASA TP-1692

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle STATIC AND TRANSIENT PERFORMANCE OF YF-102 ENGINE WITH UP TO 14 PERCENT CORE AIRBLEED FOR THE QUIET SHORT-HAUL RESEARCH AIRCRAFT

5. Report Date
June 1980

6. Performing Organization Code

7. Author(s)
Jack G. McArdle, Leonard Homyak, and Allan S. Moore

8. Performing Organization Report No.
E-184

10. Work Unit No.
769-02

9. Performing Organization Name and Address
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

11. Contract or Grant No.

13. Type of Report and Period Covered
Technical Paper

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

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The steady-state and transient performance of the YF-102 turbofan engine with core airbleed was measured on an outdoor static test stand. The test configuration included a bellmouth inlet and a confluent-flow exhaust system similar in size to the Quiet Short-Haul Research Aircraft (QSRA) exhaust system. For the steady-state tests, the engine operated satisfactorily with core bleed up to 14 percent of the core inlet flow. For the transient tests the engine accelerated and decelerated satisfactorily with no core bleed and with core bleed up to 11 percent of the core inlet flow (maximum tested). For some of the tests the core-bleed flow rate was scheduled to vary with fan discharge pressure, to simulate the QSRA bleed requirements. No stability, surge, stall, overtemperature, combustor flameout, or other operating problems were encountered in any of the tests. Steady-state and transient engine performance data are presented in graphs, and fuel-control trajectories for typical transient tests are shown.

17. Key Words (Suggested by Author(s))
Engine airbleed; Performance task; Transient performance; Turbofan engines; Fuel controls; QSRA; YF-102

18. Distribution Statement
Unclassified - unlimited
STAR Category 07

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	25	A02

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

NASA-Langley, 1980

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

THIRD-CLASS BULK RATE

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

U.S.MAIL

4 1 1U,A, 060680 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LABORATORY
ATTN: TECHNICAL LIBRARY (SUL)
KIRTLAND AFB NM 87117

NASA

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return