An Overview of the Quiet Short-Haul Research Aircraft Program

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RESEARCH AIRCRAFT PROGRAM

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INTRODUCTION

The Quiet Short-Haul Research Aircraft (QSRA) is a new research aircraft which NASA will use as a flight facility for advanced flight experiments in terminal area operations. Because the nature and use of research aircraft by NASA are frequently misunderstood, the following discussion is presented to clarify the subsequent description of the QSRA and its use as a research facility.

NASA research aircraft are not prototypes and frequently they are not experimental aircraft. For example, the Kuiper Airborne Observatory, which is operated by Ames Research Center, is a standard Lockheed/USAF C-141 modified to carry a telescope and other airborne scientific experiments. Other research aircraft such as the X-15 series are highly experimental in nature, but are not prototypes for future aircraft. Occasionally, an aircraft built as a prototype is used as a research aircraft; examples are the Boeing "Dash Eighty," which was the 707 prototype and the USAF AMST prototypes. These aircraft were used or planned to be used by NASA for flight research after completing their prototype missions. All of these aircraft had a common denominator: as research aircraft their mission was one of data gathering, and indeed, this is usually the primary mission of NASA research aircraft. For this reason, NASA frequently views research aircraft as facilities, just as a wind tunnel or a simulator is considered a test facility.

The data resulting from the QSRA flight research program will be used by the United States aircraft industry to establish design criteria and by regulatory agencies to establish certification criteria for advanced STOL aircraft. This is important from a national point of view since aircraft exports exert an important positive influence on the U.S. balance of payments. In addition, QSRA flight data will lead to improved air transportation at reduced noise levels and with less air traffic congestion.

Another characteristics of many NASA research aircraft is lower cost than that typically associated with a prototype development. Limited budgets and fiscal responsibility dictate that research capability must be maximized relative to cost, and experience with research airplane projects has led to certain approaches developed to minimize their cost. These include:

1. Use of an existing airframe where possible
2. Use of "off-the-shelf" hardware
3. Use of goals instead of requirements

4. In-house participation where appropriate
5. Cost consciousness at all organizational levels
6. Soft tooling
7. Informal documents

The application of these concepts to the QSRA will be discussed later.

HISTORICAL BACKGROUND

NASA has conducted research with powered-lift airplanes since the 1950s. The first jet STOL research airplane developed by NASA was the Augmented Jet Flap STOL Research Airplane (ref. 1) developed in the early 1970s. This was an austere program which consisted of a modification of an existing deHavilland C-8A Buffalo, powered by two modified Rolls Royce Spey engines. It recently completed 500 hr of highly successful flight research and after a major inspection has been placed back in service for futher work. Its performance is representative of the first generation of jet STOL aircraft with an approach lift coefficient in the 3.5 to 4.0 range. Its major limitation is high levels of sideline noise.

A second, more ambitious jet STOL research airplane program, initiated in the early 1970s was the Quiet Experimental STOL airplane (QUESTOL). Three preliminary design studies and a design competition (won by Lockheed-Georgia) were completed before this project was cancelled in January 1973 due to budgetary limitations. The QUESTOL was planned as a four-engine, externally blown-flap STOL airplane, powered by four General Electric TF-34 turbofan engines.

In January 1974, a decision was made to embark on an austere jet STOL research aircraft which would feature very low sideline noise levels and "next generation" performance (approach lift coefficient of 4.5 to 5.5). Preliminary design contracts were awarded the Boeing Commercial Airplane Company and the Lockheed-Georgia Company to study an augmented jet-flap concept and a hybrid upper surface blowing concept. These studies were not competitive in the sense that they did not form the basis for the selection for the winner of the subsequent hardware competition. Each design team operated independently, and only at an industry-wide conference at the end of the study was the work of one team revealed to the other. In this way, NASA was able to obtain two independent approaches to the problem. The results of these studies were presented to industry in September 1974 (refs. 2, 3), and a request for proposal for detail design, fabrication, and test of the QSRA was issued in November 1974. Important excerpts from the initial statement of work are given in table 1. Boeing, Douglas, and Lockheed responded to the request for proposal and after a lengthy evaluation, the Boeing Commercial Airplane Company was awarded the hardware contract in March 1976.

The QSRA made its first flight on schedule—July 6, 1978. The aircraft departed Boeing Field in Seattle to go to Paine Field in Everett, Washington in order to begin its initial 17.5-hr flight-test program. Although the primary objective of this program was to demonstrate the airworthiness of the

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aircraft and its systems, the last 2 to 2.5 hr were devoted to internal and external noise measurements. This initial flight test program proceeded very smoothly and was accomplished 1 month ahead of schedule, allowing the aircraft to be delivered in August instead of in September of 1978 as originally planned. Figure 1 shows the aircraft on final approach into Moffett Field, California where 9.5 hr were flown in order to verify data system operation at Ames and to provide pilot familiarization and training. After a thorough inspection of the aircraft and its engines, the second phase of the NASA flight research program was begun in November at Ames where the propulsive-lift, handling, and acoustic characteristics are being investigated, with improvement modifications as required.

MANAGEMENT APPROACH

The total funding for the QSRA was established at $29 million in January 1974. At the start of the project, a firm commitment was made to complete the project within the available funds. Since these funds had to cover costs for all studies, test, engine and airframe procurement, and proof-of-concept flight tests, an austere and innovative management approach was required. The approximate distribution of the available money is given in table 2.

Scope Versus Cost

The techniques discussed in the Introduction were all applied to the task of developing a technically meaningful project within the budgetary limitations. An important aspect of living within the budget was definition of the scope of the project, which was largely accomplished during the preliminary design studies. Within limits, a project such as QSRA can "cost what you want it to cost." This is due to the fact that many features, while highly desirable, are not essential. An example of this occurred during the preliminary design studies. An article in a trade magazine indicated that $32 million were available for the QSRA project. The first cost estimates, independently prepared by the two study contractors, were for about $30 million. A special trip was made to NASA project managers to explain the distribution of funds as shown in table 2. The second round cost estimates were about $20 million. Both estimates were legitimate; the difference was in the scope and detail of the tasks to be accomplished.

There is, however, a lower limit beyond which a technically meaningful cost cannot be implemented. Some fortunate circumstances contributed to the completion of the QSRA project within the available funds. These included: (1) the availability of a suitable airplane, the deHavilland C-8A, for modification; and (2) the availability of suitable engines which could be configured for use in the QSRA.

Airframe Acquisition

The C-8A was obtained at no cost, through appropriate government channels, from the National Center for Atmospheric Research (NCAR). The physical size and the T-tail configuration of the C-8A made it an ideal airframe for modification into an advanced STOL aircraft and prior experience with a similar modification, the Augmented Jet Flap STOL Research Aircraft (AWJSRA), further enhanced its desirability.

When the Fairchild A-10 airplane was selected as the winner of the United States Air Force AX fly-off competition, the two Northrop A-9A airplanes were transferred to NASA for a possible flight research program. A later decision not to fly the two prototype airplanes made the engines, equipment, and spares from this program available for QSRA use. Six Lycoming YF-102 engines and four accessory power packages were salvaged from the A-9A program together with many other miscellaneous components. The YF-102 engines, although relatively immature prototype engines, were almost ideal for the QSRA. They are high by-pass ratio, geared-fan engines that generate 33,410 N (7,500 lb) of thrust at low noise levels.

The use of the C-8A and the YF-102 engines was an important first step in minimizing the cost of the QSRA project, but many additional cost-reduction factors were necessary. They included: in-house participation, cooperative approach, detailed tracking of costs, and a full appreciation of the importance of cost at all organizational levels.

In-House Participation

The approach to in-house participation was to let NASA do that which NASA could do best and to let Boeing do those things which Boeing could do best. The large-scale wind-tunnel model is an excellent example of this concept. Early in the program, a large-scale, powered wind-tunnel model was identified as a project requirement. Ames Research Center has a long history of constructing large powered models for research in the Ames 40- by 80-Foot Wind Tunnel. Boeing, on the other hand, had a detailed knowledge of the details of the QSRA design. In order to take advantage of the expertise of each organization, Boeing was assigned the task of designing the model and NASA assumed responsibility for fabricating and instrumenting the model.

Another example of a NASA in-house program was the engine program. An extensive ground test program was completed by the Lewis Research Center in which both performance and acoustic data were acquired in support of the QSRA design effort. Lewis also managed the program to refurbish and update the flight engines.

Cost Consciousness

It is beyond the scope of this paper to discuss the details of QSRA management beyond the examples that have already been presented. However, no discussion of QSRA management would be complete without emphasizing the

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importance of the outstanding cooperation between the Boeing project team and the NASA Project Office and the detailed tracking of costs accomplished by both these groups. The Boeing project control group tracked cost for 38 work breakdown structure elements on a weekly basis at the peak of the project. These data were provided in a timely manner to the NASA Project Office and were on display in a control room in the Boeing project area. Thus, project personnel to the lowest organizational levels were made aware of cost performance. The NASA Project Office was consulted whenever transfers were made from the Boeing management reserve. In this way, project funds were not expended to correct minor performance deficiencies that were not important to NASA, and available resources could be concentrated on important problems.

A paper planned for later publication by the QSRA project personnel will deal with this subject in depth.

IN-HOUSE PROGRAMS

Wind-Tunnel Tests

The need for accurate, large-scale, wind-tunnel testing of the specific powered-lift airplane configuration had been identified in studies previous to the QSRA contract award (ref. 4). In order to support the QSRA design effort, and to reduce costs and risk by utilizing NASA talent and facilities, an existing large-scale, wind-tunnel model was modified to be aerodynamically similar to the QSRA and tested in the Ames 40- by 80-Foot Wind Tunnel. This 0.55-scale model was used to provide aerodynamic and loads data for the QSRA design, and the control stability data for the flight simulation program.

Wind-tunnel model—The QSRA wind-tunnel model is shown mounted in the Ames 40- by 80-Foot Wind Tunnel, in figure 2. This model is powered by five JT-15D turbofan engines. Four of these engines are mounted above the wing; the fifth, mounted in the fuselage, provides boundary-layer control (BLC) air. The model has three trailing-edge flap systems. Upper-surface-blown flaps are located directly behind the engines, with double-slotted flaps outboard of these and blown ailerons at the wing tips. The entire leading edge is blown for boundary-layer control, including the area between the nacelle and fuselage. Although the leading edge flaps were fixed, the trailing-edge flap systems and spoilers could be remotely actuated during the test runs.

This model had over 600 pressure and temperature measuring points in order to provide airloads and temperature design data for the QSRA. Engine thrust levels were measured under static conditions with flaps up and correlated with fan speed. These correlation equations were used to determine thrust levels during the wind-tunnel test points. The corrected mass flows were obtained from ideal mass flows, calculated by using the average static pressure at the farthest downstream inlet measuring point and the test section total temperature and pressure. This ideal flow was corrected for pressure recovery and inlet losses by assuming a 0.98 correction factor.

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Aircraft design contributions—The wind-tunnel tests of this model made a number of important contributions to the final QSRA design. These tests defined the airload data used in the QSRA structural design, showing that these loads were slightly different in location and magnitude than those predicted using YC-14 data, particularly on the fuselage near the wing leading edge. These tests also verified the mixed flow nozzle and propulsion system simulation which was based on Langley JT-15D tests simulating the YC-14 propulsion system. The tests defined the BLC system requirements, showing that blowing was necessary at all times along the leading edge during high angle-of-attack operations, resulting in a redesign of the QSRA's BLC system. These tests defined and verified the effectiveness of the control surfaces and the effects of engine-out and other failure conditions, providing a data base for the flight simulation. Finally, these tests defined a serious nacelle/wing aerodynamic interference problem and provided a simple, effective, low-cost solution for the aircraft design, by showing that several small vortex generators could eliminate the boundary-layer separation at this interface. A more detailed summary of the test data is contained in references 5-7.

Configuration optimization—A continuing benefit of these wind-tunnel tests is in the use of this data base and the model as a tool for further configuration development and optimization. As an example, the early wind-tunnel tests showed that although blowing was essential along the leading edge at high angles-of-attack, only very small amounts were required to keep the flow attached over the wing. In subsequent tests, a slotted leading-edge flap was fabricated and tested to determine what performance penalties, if any, were associated with removing the outboard leading edge BLC system (ref. 5). Although performance improved slightly, there was a loss of about 4° in angle-of-attack margin. One of the projected studies to be made with the QSRA will be to verify in flight the effect of replacing the outboard leading edge BLC system with a slotted flap, a change that would considerably simplify the aircraft pneumatic system. This change will be made, however, only after a thorough documentation of the flying characteristics of the basic configuration.

Engine Ground Tests

As discussed previously, the QSRA is powered by the Lycoming YF-102 engines acquired from the A-9A aircraft program. Although these are relatively immature prototype engines, they had met all of their performance goals during the AX program, and had demonstrated operational reliability. The QSRA, however, required a much more complex engine installation with a confluent flow exhaust system and with a bleed air schedule requiring up to 10% of core airflow at low power settings. These QSRA requirements were so far beyond the existing engine performance data base that there were questions regarding engine operation and its effect on cost and aircraft safety. In addition, the ambitious acoustic goals of the QSRA required an extensive acoustic data base in order to develop an adequate low-noise nacelle design within cost constraints. It became obvious that it was necessary to develop these data bases in order to minimize program cost and risk, and again it was clearly an area where NASA talent and facilities could be used most effectively.

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Vertical Lift Fan Facility—The Lewis Research Center Vertical Lift Fan Facility is an outdoor engine test stand sheltered by a service building which is moved away on tracks before testing. The engine is suspended beneath the thrust measuring system, which can be pivoted around a vertical axis for operational flexibility. A frame work extending from the thrust measuring system is used to mount inlet and exhaust hardware separately from the engine. The engine centerline was 2.9 m (9.5 ft) above the ground; the facility, with the baseline confluent flow YF-102 mounted on the thrust stand, is shown in figure 3. The area beneath the engine is paved with concrete and asphalt out to the acoustic data microphones which are located on a 30-m (100 ft) radius circle over a 160° arc from the inlet centerline. The control room is located about 152 m (500 ft) from the stand and affords a good view of the engine inlet.

Propulsion design refinements—The engine ground test contributed to the final QSRA aircraft design in a number of different ways. The tests were used to define the engine base-line performance for the confluent flow configuration and to update the engine performance prediction deck. These tests defined the transient operating characteristics of the engine and the effect of BLC system failures on the engine stability and safe operation. These tests showed that the engine was unable to accelerate from low power settings under high core bleed conditions, requiring the design of a BLC control system that limits core bleed to power settings where the engine can be safely operated. New acceptance test procedures were developed as a result of these ground tests in order to ensure adequate, stable, and safe engine operation when installed in the QSRA. Finally, a special test was run to verify the design and adequate operation of the fan bleed air S-duct and its flow characteristics at the ejector inlet (ref. 8).

Acoustic design refinements—Acoustic performance is a second area where the Lewis test program made significant contributions to the QSRA design. These tests developed all of the acoustic data base for the YF-102 engine, providing a measure of the component noise levels and their directivity. The induct fan tones and their location relative to the duct walls were determined along with their mode shapes and other design data. Acoustic design simplifications eliminating splitter rings and engine spinner treatment were verified, eliminating considerable cost and performance penalties. The effect of wing shielding was determined and, finally, special techniques were developed to determine the contribution of combustor noise (ref. 9).

Flight Simulation

The Ames Flight Simulator for Advanced Aircraft (FSAA) was used to define those combinations of flight conditions, aircraft configuration, control power, and control rates that would ensure acceptable handling qualities for both normal operation and in various single or multiple failure occurrences in either propulsion or flight control systems.

FSAA—The FSAA is a six-degree-of-freedom motion simulator with very high fidelity motion and visual cues. It has two pilot stations and room for an observer in the cab. It was configured to closely approximate the flight

deck of the QSRA with similar instruments, throttles and controls. A pilot's eye view of the simulation is shown in figure 4. Experience with the FSAA has shown that realistic, accurate simulations can be made and, indeed, the pilot ratings of 2-3 for normal operation at low speed and 4-5 for a single failure were verified in flight.

Simulation design refinements—These simulations showed a need for several design changes to improve handling qualities under a variety of STOL operations and simulated failure conditions. The need for longitudinal stability augmentation and direct lift control was identified, as was a change in horizontal stabilizer incidence. A requirement was also determined for automatic retraction of the upper surface blown flaps to reduce drag during go-around. Pilot procedures and handling qualities were also defined for operations with one or more engines inoperative, and for situations where electrical power was lost, or hydraulic or boundary-layer control systems had failed. Steep curvilinear landing approach operating procedures were investigated for noise abatement.

Further details of the QSRA flight simulations, the QSRA mathematical model, and the results of these simulations are contained in references 10-12.

AIRPLANE DESCRIPTION

The general arrangement of the QSRA is shown in figure 5 and a photograph of the airplane is shown in figure 1. The fuselage is that of a deHavilland C8-A Buffalo with structural reinforcement in the aft fuselage and new fairings at the wing-body intersection. The C-8A empennage was used without structural or aerodynamic modification. SAS actuators were added to both the rudder and the elevator and a hydraulic actuator was added for power actuation of the elevator. The C-8A landing gear was modified to increase the sink rate capability of the aircraft.

The QSRA wing was designed and fabricated by Boeing with a wingspan of 22.4 m (73.5 ft), a wing area of 55.74 m^2 (600 ft^2), and a quarter chord sweep of 15°. Figure 6 shows the wing being attached to the fuselage at the Boeing Development Center in Seattle. The center section of the wing is sealed to form two integral fuel cells which contain a total of 4535.9 kg (10,000 lb) of Jet A-1 (JP-5) fuel. Fixed leading edge flaps are blown by a mixed flow boundary layer control system. The trailing edge on either side of the centerline consists of two upper surface blowing (USB) flaps, a double-slotted flap, and a drooped, blown aileron.

The flaps and ailerons are supported by external beams and linkages. In keeping with the austere nature of the program and the low-speed environment of the QSRA, these are not faired. The main landing gear is fixed and is attached to the underside of the wing between the two nacelles. The wing is attached to the fuselage by the same pin joints as those used in the original C-8A. This provided a significant cost saving but it did require the addition of 418.7 kg (923 lb) of ballast in the tail.

Propulsion System

The QSRA main propulsion system consists of four AVCO-Lycoming YF-102 (QSRA) engines mounted in above-the-wing nacelles (fig. 5). These prototype engines, acquired from the A-9A program, were extensively refurbished and updated in a program managed by the Lewis Research Center. The principal elements of this update include a fan containment ring, combustor case high-pressure air bleed ports, new oil coolers, and improved shafting material.

Powerplant—A cutaway view of the engine is shown in figure 7. The low-pressure spool incorporates a single-stage fan which provides bypass and core air to the engine. The core airflow is further compressed by a single-stage supercharger attached to the fan. The fan is driven by a two-stage, uncooled turbine through a single planetary reduction gear (2.3 speed ratio) located in the fan module.

The gas producer section of the engine is essentially a T-55 core with slight modifications. The high-pressure components include an axial/centrifugal compressor, a reverse-flow combustor, and a two-stage, air-cooled turbine to drive the compressor. The high-pressure compressor has seven axial stages followed by a centrifugal stage. It features variable inlet guide vanes (VIGV's) and a sixth-stage bleed band to minimize the possibility of compressor stall during transient operations.

The engine weighs 5412 N (1215 lb) and has a basic diameter of 1.077 m (42.4 in.) with an overall length of 1.621 m (63.8 in.) including the fan spinner, while the fan has a diameter of 1.024 m (40.3 in.). The engine geometry and unstalled performance are shown in figure 8.

Nacelle structure—The nacelle layout is shown in figure 9 and the major external nacelle structural components are shown in figure 10. The external nacelle is composed of two main assemblies, the structural cowl and nozzle assembly and the engine build-up assembly. The structural cowl and nozzle assembly is attached to the wing front spar, forming the structural nacelle and pylon. The engine build-up assembly is then mounted to this structure and forms the front half of the nacelle. The nose cowl is attached to the engine as shown in figure 11 and forms the inlet and outer nacelle. In addition to the nose cowl, a core cowl and the primary nozzle are installed as part of the engine buildup. Engine driven accessories are airframe-mounted in the nose cowl, resulting in this area being one of the three primary fire zones in the nacelle. Other fire zones are the core cavity and the outer fan case. Fire protection behind the nacelle is provided by an external heat shield attached to the upper surface of the wing, together with the use of heat-resistant materials in the wing flaps and trailing edge. In addition, the primary nozzle is canted upwards allowing cooling fan air to be drawn between the wing surface and the high-temperature jet in normal operation.

Exhaust nozzle—The QSRA/YF-102 exhaust system is a confluent-flow design with both primary and fan streams discharging through a common D-shaped exit nozzle having an aspect ratio of 3.5. As indicated in figure 12, the core exhaust diffuses as it passes through the primary nozzle and then mixes with

the surrounding fan stream, exiting through the D-shaped upper-surface blowing nozzle. The core nozzle is canted upward 9.4° relative to the engine center-line to minimize the heat effects on the wing and flaps.

The flow areas in the fan-duct and core-nozzle exit plane (mixing plane) are chosen to provide adequate performance without significantly affecting surge margins. The main control on surge margins and engine match, however, is provided by the final exit area of the D-nozzle, which is designed to spread the exhaust into a thin sheet, which is then turned by the Coanda effect over the USB flaps, providing lift.

The QSRA D-duct design has mixing plane areas of 0.44 m^2 (682.5 in.^{2}) and 0.156 m^2 (250 in.^{2}) for the fan and core airstreams, respectively. The D-nozzle was designed so that the exit area could be increased as much as 10%, if needed, from an effective area of 0.42 m^2 (650 in.^{2}) which was 7.5% under the assumed baseline area. Subsequent calculations showed that there would be adequate surge margins at this area, however, and that no nozzle trim would be needed. Measured results discussed in a later section showed that indeed this was the case.

Acoustic treatment—The location of the nacelle acoustic liners is shown in figure 12. These liners are located in two different nacelle areas, the fan duct and the inlet. The fan duct liners, which are located on both the structural cowl and on the core cowl, are composed of perforated aluminum face sheets bonded to an aluminum honeycomb core with solid aluminum outer backing sheets. These panels cover about 0.75 m (30 in.) of duct length and are estimated to provide about 12 PNdB of aft fan attenuation. These panels serve as an integral part of the cowl structure and are load-carrying in addition to providing sound attenuation.

The second area of the nacelle that is lined is the inlet. The inlet acoustic panels are double-layer construction with perforated aluminum face sheet and septum with aluminum honeycomb cores and a solid aluminum backing sheet. The lower acoustic panel honeycomb cores are slotted and drain holes are provided in the outer sheet to prevent water accumulation and possible freeze damage.

BLC System

A unique feature of the QSRA is the mixed-flow boundary-layer control (BLC) system for the wing leading edges and ailerons. Air for the BLC system is bled from both the fan and the engine core and mixed in an ejector. A schematic of this system is shown in figure 13.

The BLC air is distributed by cross-ducting from each engine to the oppo-site side of the wing leading edge or aileron surfaces. Interconnecting ducting and check valves are installed between the two BLC system manifolds; they are located externally under the wing outboard of the outboard nacelles. The aileron ducting is located in a cavity aft of the rear spar; however, the leading edge ducting had to be located externally behind the leading edge flaps and crosses over inside the fuselage, under the wing. As was previously

discussed, these ducts may be simplified, in a future test period, to eliminate some of the external ducts. The BLC ducting is arranged so that each engine feeds a separate part of the BLC system, as shown in table 3. This arrangement provides a degree of automatic roll compensation in the event of the loss of a critical (outboard) engine.

Key elements in the BLC system are the mixing ejector and servo-regulator valve which are located as shown in figure 14. The ejector, which is shown in the insert of figure 15, has a fixed-geometry mixing section with an elliptical center body, and 42 circumferentially distributed ejector nozzles. These convergent-divergent nozzles, with length-to-diameter ratios of 5:1, limit the high-pressure bleed to a nominal 10% of the engine core flow, and fan bleed is limited to 3% due to duct size. Figure 15 shows the effect of this ejector design on net blowing momentum of the aileron nozzles. The upper curve represents the performance of the ejector without any pressure regulation. The servo-regulator valve limits the downstream duct pressure to a preset value, however, and the regulated system follows the lower curve of figure 15, yielding a nearly constant value of blowing momentum over the entire engine thrust range. This valve regulates high-pressure flow from the compressor so that it is zero at high power settings where the fan pressure ratio is high, and about 10% of the core airflow at low power settings. Although there is a loss in engine thrust at the 10% bleed airflow, it only occurs when a low-thrust level is commanded by the pilot. At high-thrust setting, the thrust loss is less than 1% due to BLC system losses.

Flight Controls

The flight control surfaces are shown schematically in figure 16. All wing trailing edge surfaces are electrically controlled (fly-by-wire) except the ailerons. The spoilers, double-slotted flaps, and USB flaps are electrically commanded and hydraulically powered; the ailerons are mechanically controlled and hydraulically powered. Both the rudder and elevator are C-8A components which are mechanically controlled and both are hydraulically powered.

Flap system—The USB flaps are deployed to the 30° position with the pilots flap lever. A thumb switch located in the throttle handle for the No. 1 engine controls USB flap position from 30° to the full deflection of 66°. This provides the pilot with a convenient means of varying USB flap setting, during a landing approach, as a means of glide path control. Deployment of the double-slotted flaps is controlled by a separate lever on the pilot's console. The aileron droop is slaved to the double-slotted flaps. The USB flaps, the spoilers, and the double-slotted flaps are all individually actuated by digital, electronically controlled, hydraulic actuators. This allows any flap or spoiler to be actuated independently of any other by proper preprogramming. This feature provides maximum research capability for the QSRA. As initially configured, the QSRA pilot has the capability to command assymetric deployment of the double-slotted flaps to trim engine-out rolling moment.

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Stability augmentation system—The QSRA has a single channel, three-axis limited authority series type stability augmentation system (SAS). The roll and yaw axes are stabilized by a simple analog system similar to the one used in the Augmented Jet Flap STOL Research Airplane. The longitudinal SAS is a rate-command, attitude-hold system. It uses a General Electric MCP-701A digital computer to provide both pitch SAS functions and to control the direct lift control system and certain other logic functions. When the direct lift control (DLC) function is selected, the spoilers are deployed to about -13°. An increase in thrust (thrust levers forward) causes the spoilers to retract, and a decrease in thrust causes them to extend beyond the nominal -13° angle. After each excursion from the -13° position, a washout circuit gradually returns the spoilers to the -13° position until the throttle is once again moved. At go-around thrust levels, the DLC system is automatically disabled and the spoilers are retracted.

Additional information on the QSRA configuration and systems is contained in reference 13.

AIRCRAFT PERFORMANCE

Although a large number of ground and flight tests have been performed to determine the QSRA's operating characteristics, many of these data are still being analyzed at this writing. Therefore, many of the aircraft performance curves presented are based on predicted, wind-tunnel, or simulation results. Most of the ground test data have been analyzed, however, allowing a comparison of the predicted and measured characteristics of the propulsion and BLC systems. In addition, sufficient flight data have been checked to verify that the airplane performance is close to that predicted, and these flight results will be commented on in the presentation of the individual data curves.

Propulsion System

Most of the measurements of propulsion system characteristics were made during the Boeing ground test. The primary objectives of this ground test were: (1) to determine the component map characteristics and to verify adequate surge margins (nozzle trim); (2) to measure engine performance with and without the BLC system operating; (3) to trim and adjust the engine fuel controls for idle, takeoff power, and acceptable acceleration characteristics; and, (4) to measure flaps-up thrust and flaps-down turning. In order to meet these objectives, a large number of data points were taken and analyzed for each engine; however, it will only be possible to present a small representative sample of the data here. Four summary plots will be presented. Two deal with engine thrust relationships, one with the location of the engine operating lines on the fan map, and the fourth with the acceleration characteristics of the engines with the BLC bleed schedule.

Thrust characteristics—The relationship of the engine thrust with fan speed is shown in figure 17, which also shows the relationship between fan and core speed for these engines. This curve is based on the ground test

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results of all four of the engines (the results had less than ±1% scatter). The correlation between the predicted performance is very good above 72% of the corrected core speed but very poor at lower core speeds; hence, this curve gives better results than computer deck and will be used for performance estimation in the flight test program. As measured in the ground test, the inboard engines have about 3% less installed thrust than the outboard engines which have a maximum installed thrust of 30,068 N (6,750 lb). The effect of ambient temperature at sea level on this maximum installed thrust is shown in figure 18. These takeoff data are shown for no-bleed and ECS-bleed only because the high pressure bleed is normally shut off at this power setting. One additional item to note is the restricted zone shown in figure 17. This restriction results from a resonance problem in the sun gear at a fan speed of 55.5%. Although this resonance has a very sharp peak, the restricted operating band has been set between 50 and 60% to prevent excessive excursions into this zone, particularly near the resonance peak. This band causes a basic problem in the aircraft operation by forcing the STOL flight idle setting to be at a nominal 60% which is about 5-6% higher than is desirable. AVCO-Lycoming is working on a redesign of the sun gear to eliminate this resonance problem and expects to have a solution some time in 1979.

Fan operation—Figure 19 shows test data from all four engines plotted on the YF-102 fan map. This map includes predicted operation for a range of relative nozzle areas with the base area corresponding to the untrimmed nozzles. The test data were plotted using fan pressure ratio and corrected bypass flow as primary parameters with corrected fan speed as a secondary parameter. The test data indicated good correlation with predictions up to fan speeds of 70%; at higher speeds, these data indicated a nozzle under-area condition of up to 2%. This nozzle area spread was considered good in light of the rather limited instrumentation and hence a decision was made to operate without additional nozzle trim. The upper limit for fan operation used during the A-9A program's YF-102 acceptance tests is also shown in the figure for reference.

Engine acceleration—Engine accelerations were initially conducted on all engines starting at three fan speeds—48, 53, and 60%—which encompassed the predicted STOL flight idle range. Adjustments were made, to the fuel controls of all the engines, to increase the acceleration schedule in order to increase the acceleration rate with the Boeing high-pressure bleed schedule. Figure 20 shows the thrust versus time for accelerations from 53% fan speed for all the engines with the final fuel control adjustment. All of the engines accelerate to 65% thrust in approximately the same time; however, from that point on engine No. 2 was markedly slower and took several more seconds than the other engines to come up to the 95% thrust point. This slowness is due to an interaction with the BLC system, where the valve on engine No. 2 begins to close at a higher speed and appears to close at a slower rate. This results in higher bleed rates at a given fan speed for engine No. 2 which reduces the acceleration rate at higher fan speeds. Engine No. 1 also exhibits this characteristic but to a much lesser extent than engine No. 2.

Initially, these accleration data were to be used to establish the STOL idle detent position which corresponded to a fan speed of 53%. However, due to the problems discussed in the previous section, the throttle has no flight

idle detent and normal STOL landing operation is at 60% of fan speed. Because of the geometry of the overhead throttle system, the 60% setting forms a "natural" flight idle position.

Engine stability—Stability tests were conducted on all engines to demonstrate acceptable inlet operation and acceptable surge margins with increased fuel control acceleration schedules. These tests were conducted with all bleeds off and the fuel flow increased by 5% (TEST position for compressor surge detection). To check stability under severe operating conditions a series of transients, consisting of rapid accelerations, decelerations, and Bodies, were performed on the engines. No adverse engine operation was noted and the engines operated surge-free during this entire series of tests.

One final stability test was conducted on the engine in order to check inlet and fan operation at high angles of attack. A wind machine was positioned to provide a 36 m/s (72 knot) wind at 51° to the inlet centerline which was estimated to be the most critical inlet inflow condition. Tests were run on engines Nos. 1 and 2 using the same procedures as in the previous tests and also with the engines at ground idle (low mass flow) in a crosswind, which is the worst condition for inlet separation. Again no adverse engine operation was detected.

BLC System Performance

An evaluation of the ground-test data showed that the BLC system performance was essentially as predicted with the amount of net blowing momentum better than or equal to predicted levels at both STOL idle and takeoff power. The operation of the high-pressure regulator valve was stable with the pumping performance of each ejector compatible with its system demands. The performance of the aileron system was in excellent agreement with calculated performance, both with and without the regulator valve working (fig. 15). The only deviation from this curve occurred at thrust settings above 70% where system performance was slightly higher than that predicted. The test results showed that system losses at the design point were in good agreement with predictions, the losses being 5.2 and 6.5 % of the mixing total pressure for the leading edge and aileron systems, respectively.

During the BLC system tests, the only significant problem that was encountered was the inability of the pneumatically powered section of the pressure regulator valve to remain closed during engine starts, leading to long start times and poor engine acceleration characteristics. This lack of pneumatic power was a result of lower bleed duct pressures than preducted which are believed to be caused by higher losses in the engine bleed ports and high-pressure ducting. This problem was solved by placing a motorized valve in series with the regulator valve which ensures a positive closure during low-speed engine operation.

Additional information on the engine operation and ground test can be found in references 14-16.

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Flight Performance

As a part of the management approach discussed earlier in this paper, rigid performance requirements were not imposed on Boeing, the airplane prime contractor. However, ambitious performance goals were established at the start of the project and current predictions indicate that most of these will be met or exceeded. The reason for the high-performance levels is to provide the QSRA with the maximum amount of research capability. Propulsive-lift, roll acceleration, approach capability, and low community noise are technology targets that were emphasized by NASA and that were of primary importance in the development of the QSRA design. Some of the more significant performance capabilities of the QSRA are summarized in table 4.

Lift capability—One of the primary performance goals, a minimum usable approach lift coefficient (C_L) of 4.6, is expected to be exceeded by about 16% after allowance has been made for commercial flight safety margins. Figure 21 compares the lift performance of the QSRA to that of a standard medium commercial jet transport (the B-727) and to the Boeing Advanced Military STOL Transport (YC-14). The high-lift capability for the QSRA was achieved by applying propulsive-lift and leading edge BLC, as discussed previously. This four-engine configuration permits a larger span USB flap and reduces adverse yaw and roll moments with one engine inoperative, thus yielding the improvement in lift over the twin-engine YC-14. The actual flight data indicate that the QSRA performance is nearer to prediction at the higher angles of attack than to the wind-tunnel data. The reasons for this are complex, but are believed to be due to the fact that the QSRA USB performance configuration has not been truly optimized yet and performance is expected to improve as more is known about the flow over the USB portion of the wing.

Another performance area which is vital to the QSRA research mission is the roll control responsiveness of the airplane. The QSRA roll acceleration is compared to that of several other airplanes in figure 22. This high QSRA roll control effectiveness is achieved by incorporating blown ailerons, minimizing roll inertia, minimizing engine-out rolling moment, and by the assymetric use of the double-slotted flaps for trim. This roll-control power is important because much of the research flying will be done with one of the outboard (critical) engines shut down under unfavorable conditions in order to develop criteria for future STOL aircraft. This curve has not been verified in flight at this time but will be explored during the next phase of flight testing at Ames.

STOL operating envelope—The STOL operating envelope of the QSRA with all engines operating is shown in figure 23 and the envelope with the critical engine (either outboard engine) inoperative is shown in figure 24. These figures show the aerodynamic capability of the airplane. Pitch control limitations of the present configuration prevent operation at full USB flap deflection, at 100% thrust, and at low speeds. Similarly, directional control considerations limit the minimum speed with an engine out in a go-around configuration. However, future modifications to the QSRA empennage, which are presently under consideration, will make it possible to explore all corners of the envelope. The existing configuration can safely operate at a lift coefficient of 5.5 while maintaining speed, angle of attack, maneuver, and

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go-around climb margins. When the thrust is increased to 100% in a go-around situation, the USB flaps are autmoatically retracted to the go-around setting. As shown in figure 24, this permits a climb angle of +2° (equivalent to a rate of climb of 1.22 m/s (240 ft/min)) at an approach lift coefficient of 5.5 with the critical engine inoperative. As the speed is allowed to increase, the climb angle increases to over +6°.

These operating envelopes have been partially verified in the initial Boeing flight test and also in the Ames flight test. Values of airplane drag are slightly higher than those predicted and performance at the very high flap settings (over 63°) indicates that there is some flow separation and slightly lower turning angles than were attained in wind-tunnel tests. However, as discussed earlier, it is believed that configuration optimization and a better understanding of propulsive-lift aerodynamics will allow the airplane to eventually exceed performance predictions at the highest STOL flap settings. This flow field has been explored to a minor extent (tufts) during the first series of Ames tests and will be explored in great depth in the next phase of the Ames flight research program.

Approach angle—A short-field airplane requires a steep descent capability (high approach angle) in order to minimize the required airspace in the terminal area, as well as to minimize community noise effects. The USB nozzle and flaps of the QSRA have been designed to provide exceptionally high flow turning of the engine exhaust, yielding high lift approach lift coefficients (> 5.5) which enable this aircraft to achieve very steep approaches with full safety margins. Figure 25 gives a comparison of the QSRA STOL capabilities and the descent angle and ground roll of a conventional transport aircraft landing. At the same distance from the airport, the QSRA is more than twice as high as the conventional airliner and it is able to stop on the runway before today's commercial transports complete their flare and touch down on the runway. The landing and takeoff performance of the QSRA has been verified during the initial flight test with ground roll distance of 202.4 m (664 ft) during a maximum performance takeoff and of less than 167.6 m (550 ft) during a STOL landing.

Because noise attenuates rapidly with distance, the higher approach altitude of the QSRA is a big factor in reducing community noise effects; this height can be increased even more by landing toward the center of the runway. Another technique that may reduce community noise effects, by keeping the noise completely within the airport boundaries during takeoff, is a spiral or circling approach and departure. Simulation studies have shown that the QSRA noise can be confined to the boundaries of a typical general aviation airport, and flight test has shown that the QSRA is capable of a 337.1-m (1106 ft) radius departure with a 30° bank angle with an increase in altitude of 884 m (2900 ft) after a full 360° turn.

Acoustic Performance

One of the primary goals of the QSRA program was to have a 90-EPNdB community noise impact area of no more than 2.5 km^2 (1 mile^2) for a 668,182-N (150,000 lb) commercial airplane based on QSRA technology. Figure 26 shows

how this goal compares with the noise-impact area of a current medium short-haul commercial transport (B-737, DC-9). The actual noise levels of the QSRA were measured during the final phase of the Boeing flight-test program, extrapolated, and compared to the program goals. The maximum effective perceived noise level (EPNL) measured on the 152.4-m (500 ft) sideline during takeoff was 93.5 EPNdB and the goal was 92 EPNdB; during landing it was 89 EPNdB and the goal was 90 EPNdB. As can be seen, the values are slightly higher during takeoff and slightly lower during landing. (It should be noted that these takeoff and landing noise levels are based on a 152.4-m (500 ft) sideline and hence the takeoff noise is substantially greater than that which would be measured in accordance with FAR 36.) Several major differences exist between the QSRA and any potential transport aircraft based on the QSRA technology, with the most important of these being the high drag configuration of the QSRA during takeoff, due to the absence of fairings and retractable landing gear, and the fact that the QSRA has nonretractable vortex generators and nozzle doors in the takeoff and cruise configuration. The clean transport configuration would result in a takeoff/climbout speed increase from the 90 knot QSRA speed to about 130 knots, resulting in a decrease in the takeoff sideline noise level to approximately 91.5 EPNdB. Based on this clean configuration QSRA, a 668,182-N (150,000 lb) commercial transport would have a 90 EPNdB noise impact area of 7.03 km^2 (2.8 $mile^2$) compared to the QSRA goal of 2.51 km^2 (1 $mile^2$). These noise extrapolations are preliminary results based on a limited data base and are believed to be considerably larger than the noise areas that will be achievable by a commercial transport based on the QSRA technology. This belief is based on a number of factors, discussed in the following sections, that can be eliminated in any future transport if they are isolated as significant noise sources (e.g., nonretracting vortex generators).

Data analysis—The data were analyzed by the systems and methods used in FAR-36 noise certifications, with 1/3 octive band spectra integrated over 0.5-sec periods at increments of 0.5 sec. Computer processing mated acoustic data with the airplane position as determined optically and with the flight profile data, synthesizing flyover noise time histories for the various reference flight profiles.

Far field results—The community noise level data result from measurements made with a precision of about ±1 EPNdB in the EPNL measurements and about ±2 PNdB in PNL measurements. The noise levels along the flight path are higher with the USB flaps retracted than they were with a 30° flap setting and the sideline noise levels were relatively unaffected by flap configuration. Although airframe noise was present in some measurements, it did not significantly influence the PNL and EPNL noise levels. The measured noise exceeded predictions, with the higher levels appearing to be related to a random aerodynamic noise generated by interaction of turbulence within the jet flow with the wing trailing edge. It is believed that one possible source of this noise may be the vortex generators. In addition, a large, low-frequency (200 Hz) component seems to be the result of engine installation effects.

An additional anomaly appeared in some of the data for retracted USB flap that was taken at a different time than the rest of the data. The levels of this data point appeared to be essentially the same as the 30° flap data. This lower far-field noise level was corroborated by near-field measurements

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discussed in the next section. There is no reasonable explanation of this anomaly at this time but subsequent testing of the QSRA will investigate this effect.

Near-field measurements—Near-field noise measurements were made with eight microphones flush-mounted on the fuselage exterior surface and four located inside the aircraft. These measurements showed that noise levels increased uniformly with engine power levels, approximating a 40 log V_J relationship, with maximum exterior noise levels of about 150 dB. The interior noise levels with inboard engines shut down were about 10 dB less than with all engines operating, especially in locations where flow attachment and fuselage scrubbing occurred. The maximum measured interior noise levels were 118 dB in the aft cabin at high power settings. It should be noted that the fuselage interior is untreated and is not representative of the noise levels that would exist in a similar commercial transport aircraft.

Data significance—The acoustic data presented in this section are preliminary and do not represent a complete analysis or a good data base. Rather, they represent a starting point from which to build a more complete understanding of propulsive-lift aircraft noise, and to develop the required flight experiments that will provide a technology base for future transports based on QSRA program goals. As has occurred in several other areas, the QSRA acoustic configuration has not been optimized. Optimization of the configuration can be expected to reduce the noise levels from those measured in these tests. It should be noted that a reduction in measured noise level of only 2 dB will result in noise impact area reduction of approximately 60%. Additional data on the QSRA flight tests and acoustic tests are given in reference 17.

FUTURE PLANS AND EXPERIMENTS

Initial Tests and Configuration Optimization

The initial NASA flight program at Ames Research Center will last for approximately 1½ years and will be devoted to envelope documentation with configuration optimization as required. As discussed in several previous sections, small changes in the configuration or flow field can have a significant effect on propulsive-lift aircraft performance. During these initial tests, a series of experiments will be performed to define the flow field and the effect of this flow field on the QSRA powered-lift performance. For example, a number of experiments will be performed to determine the effect of vortex generator size and location on the QSRA aerodynamic performance and far-field acoustics. Aerodynamic performance will be documented and compared to a reference baseline as provided by a relatively sophisticated mathematical model of the QSRA and by the use of flow-visualization techniques such as tufts. The acoustic measurements will be cross correlated with near-field measurements in order to isolate and identify the sources of the noise, and these experiments will be augmented with small scale tests as required. In addition, alternative flight profiles will be evaluated in order to further reduce community noise impact areas.

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One interesting modification under consideration is the replacement of the present blown leading edge with an unblown leading edge slat. Wind-tunnel tests described earlier showed that an unblown leading edge would degrade performance by reducing the angle-of-attack margin 4° to 5° (ref. 18). If this can be verified in flight, future designers of high-performance STOL aircraft will have a firm technical base for the selection of blown versus unblown leading edges.

Another modification planned for the QSRA is to increase the gross weight to 267,273 N (60,000 lb). This will provide a wing loading of 4795 N/m² (100 lb/ft²) and give the QSRA the capability of operating over a range of wing loadings from 3117 to 4795 N/m² (65 to 100 lb/ft²) to increase its research versatility.

Flight Experiments

After the initial NASA flight research program and configuration optimization, the QSRA will be made available for the flight-experiments program. In the initial sections of this paper, the concept of a research aircraft being a facility for flight research was discussed. When the QSRA enters the flight-experiments phase it will fulfill this goal and become a national facility for flight research. Research personnel within NASA are planning a program of flight experiments. Some of the experiments will be accomplished as in-house efforts; others will be done jointly with other government agencies, for example, the development of certification criteria for future STOL aircraft. In other cases, the work will be contracted, particularly when the experiment involves structural modification to the airplane or the development and installation of new equipment. The QSRA is, however, a national flight facility. As such, it is available to the aeronautical community in the same way that a NASA wind tunnel or simulator is available.

QSRA workshop—On November 29 and 30, 1978 a workshop will be held at Ames Research Center in order to provide industry, universities, and government agencies with information on the capabilities of the QSRA and to provide a mechanism by which participation in the flight experiments program can be implemented. It is hoped that this procedure will lead to broad participation by the aeronautical community in the QSRA flight research program.

Although the flight-experiments phase will not "officially" begin for several years, it is believed that many experiments, particularly, self-contained experiments, can be flown on the QSRA during the initial flight tests. In addition, some experiments, such as acoustic measurements and correlation of small-scale testing with the QSRA, can and should be done concurrently with the early flight program. For example, one series of acoustic experiments which is under consideration involves the use of Ames' quiet noise measuring airplane, the YO-3A, to make free-field acoustic measurements of the QSRA flap and inlet noise. A number of other experiments are planned in various research areas such as avionics, computer control systems, inlet flow fields, acoustics, structural vibration, and aerodynamic performance.

Flight demonstration—Another activity in the early planning stages is demonstration flights at airports in the San Francisco Bay Area for potential users of the technology. This would include airline and airport officials and technical personnel from interested aircraft manufacturers. The QSRA will not carry passengers because it is qualified only for a crew of two research pilots. However, flight demonstrations will expose potential users of this technology to the short-field capability, the maneuverability, and the low community noise levels of which the QSRA is capable. Late in the initial flight program, it is also planned that qualified pilots from other organizations will be invited to fly and evaluate the QSRA with a NASA research pilot as an "instructor-pilot." This was done successfully with the Augmented Jet Flap STOL Research Airplane and will be repeated with the QSRA.

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TABLE 1. – QSRA INITIAL GOALS AND REQUIREMENTS
(PARTIAL LIST)

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Requirements

- Day, VFR operation only

- Crew of two research pilots only

- Modification of GFE C-8A Buffalo

- Use of four GFE YF-102 engines

- Hybrid upper surface blowing propulsive lift concept

Goals

- Approach lift coefficient – 4.6 (steep approach with margins)

- Approach path of -7.5° with margin for gusts, wind, etc.

- 90 EPNdB combined takeoff and landing footprint area, when scaled to 668,182 N (150,000 lb) of 2.5 km^2 (1 $mile^2$)

- Minimum duration of test mission—50 min

- Minimum wing loading at gross weight = 3117 N/m^2 (65 lb/ft^2)

- Maximum cruise speed 160 knots

- Wing/nacelle configuration representative of cruise at M = 0.74.

_____

TABLE 2. - QSRA FUNDING DISTRIBUTION

Preliminary design studies	$ 2,000,000
Wind tunnel and engine tests	1,000,000
Engine program	2,000,000
Airplane detail design and fabrication	22,000,000
Proof-of-concept flight test	2,000,000
Total funding available	$29,000,000

TABLE 3. - BLC FLOW DISTRIBUTION

Engine position	BLC segment
1	Right aileron
2	Right leading edge
3	Left leading edge
4	Left aileron

TABLE 4.- QSRA PREDICTED PERFORMANCE

Approach lift coefficient (steep approach with margins)	5.5
Approach path with margin for wind, gusts, etc.	-7.5°
Duration of STOL test mission	102 min
Landing field length at 213,370 N (48,000 lb) (W/S = 3836 N/m² (80 lb/ft²)) (1.67 factor over 10.7-m (35 ft) obstacle)	426.7 m (1400 ft)
Takeoff field length at 668,182 N (150,000 lb) (10.7-m (35 ft) obstacle with critical engine inoperative (CEI) at decision speed)	403.9 m (1325 ft)
Turn radius at 30° bank angle	213.4 m (700 ft)
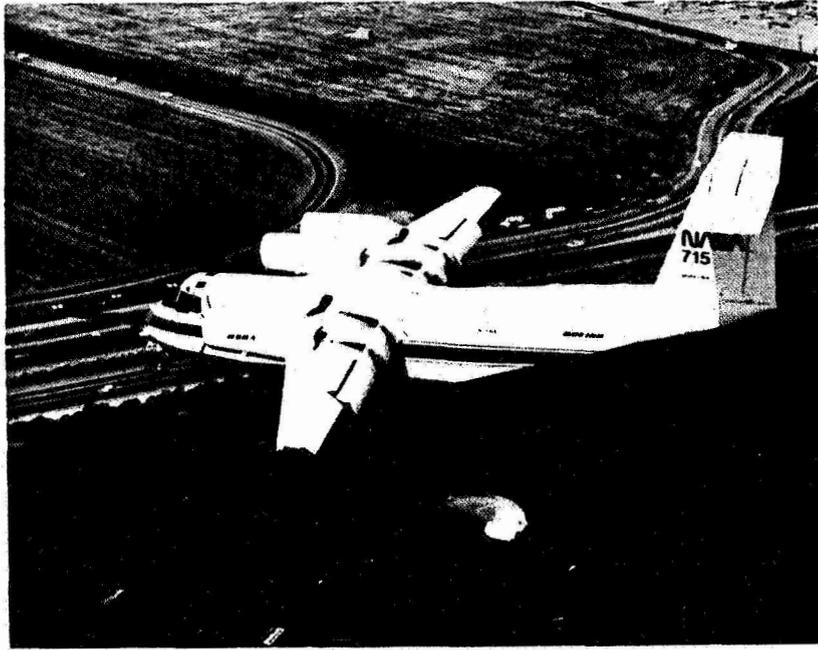
Figure 1. – The Quiet Short-Haul Research Airplane (QSRA) performing a STOL
approach prior to landing at Ames Research Center.

Figure 2. – The 0.55–scale QSRA model mounted in the Ames 40– by 80–Foot
Wind Tunnel.

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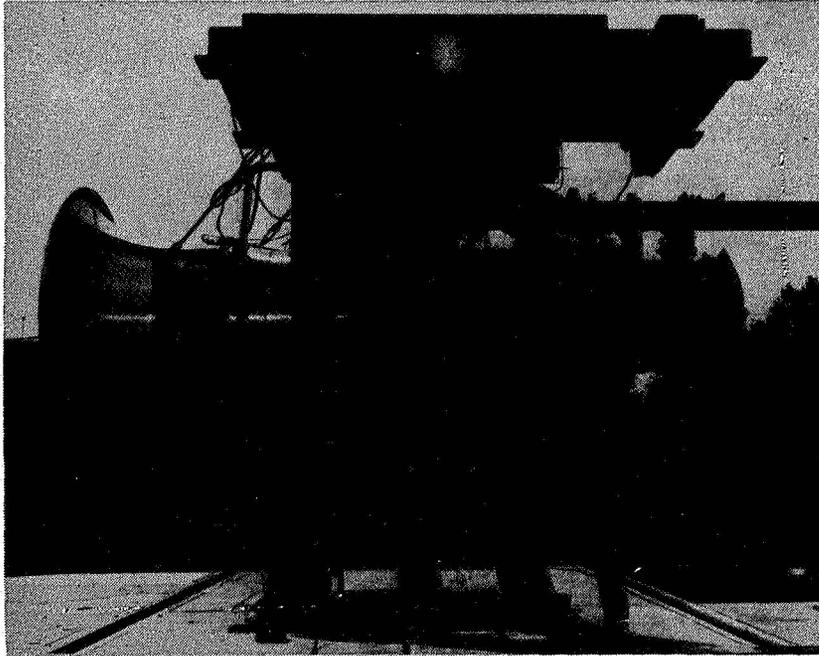
Figure 3. – The YF-102 (QSRA) engine installed in the Lewis Vertical Lift Fan
Facility in preparation for confluent flow baseline testing.

Figure 4. – Pilot's view from the cab of the Ames FSAA during the QSRA flight simulation.

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TOGW, lb	50,000	222260 N
WING AREA, ft^2	600	55.74 m^2
WING LOADING, lb/ft^2	83	3987.4 N/m^2
ASPECT RATIO	9	
THRUST/WEIGHT	.60	
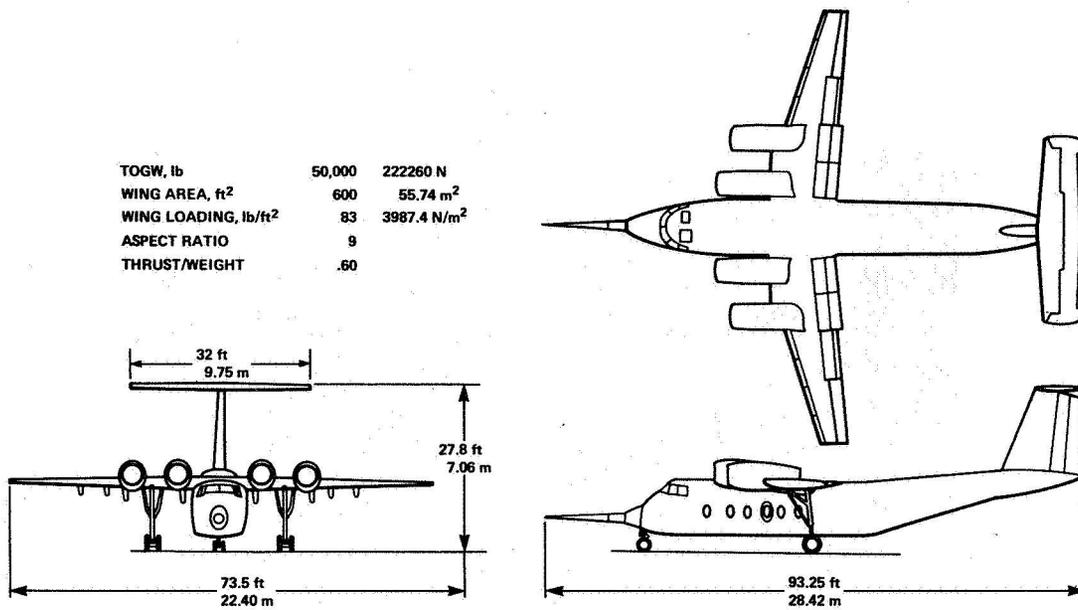
Figure 5. – The QSRA airplane layout.
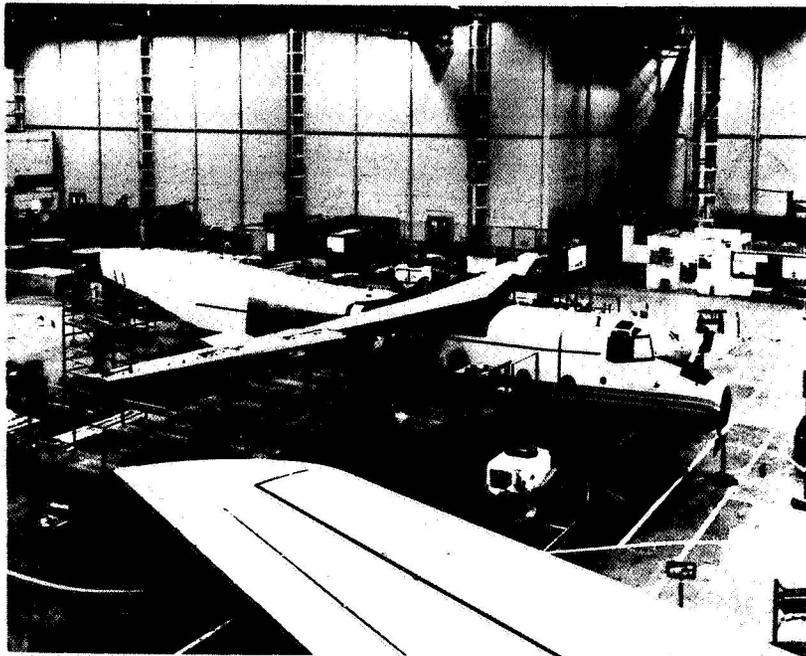
Figure 6. – The QSRA wing and fuselage under construction at the Boeing Developmental Center in Seattle, Washington.

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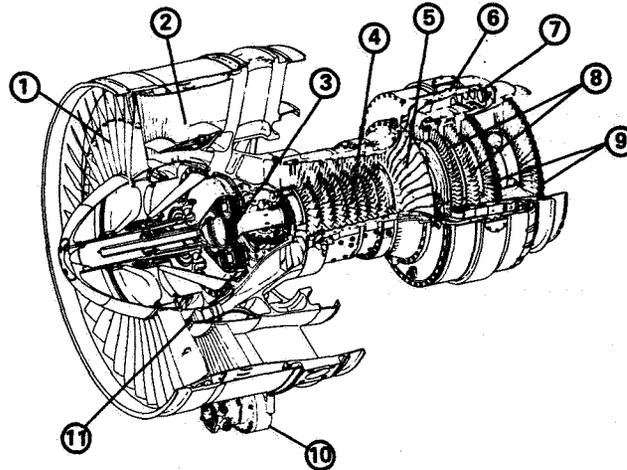
1. FAN STAGE
2. FAN STATOR
3. REDUCTION GEAR ASSEMBLY
4. CORE AXIAL COMPRESSOR
5. CORE CENTRIFUGAL COMPRESSOR

6. CUSTOMER BLEED PORTS
7. COMBUSTOR
8. GAS PRODUCER TURBINES
9. POWER TURBINES
10. ACCESSORY GEARBOX
11. SUPERCHARGER

Figure 7. – A cutaway view of the YF-102 (QSRA) engine which was built by AVCO-Lycoming Division.

56.77 in.
1.442 m

26.25 in.
0.667 m

40.3 in.
1.024 m

18.56 in.
0.471 m

N_L 7600 (FAN)
(POWER TURBINE 17600)

N_H 19660

SFC   0.41

MGT   1665°F 907°C
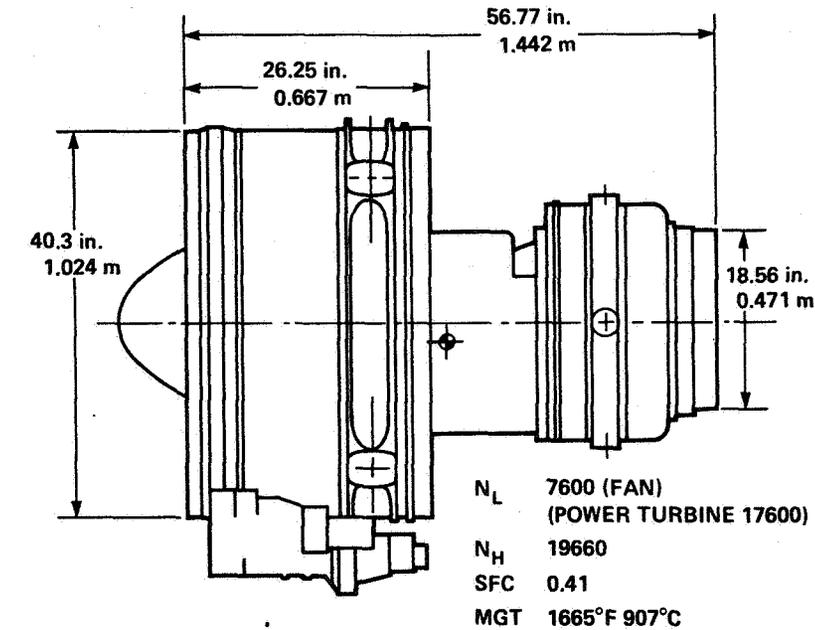
MAX. THRUST	7500 lb	33409.1 N
WEIGHT DRY	1215 lb	551.1 kg
TOTAL AIRFLOW	267 lb/sec	121.1 kg/sec
CORE AIRFLOW	37 lb/sec	16.8 kg/sec
B.P.R.	6.2	

Figure 8. – YF-102 (QSRA) engine layout.

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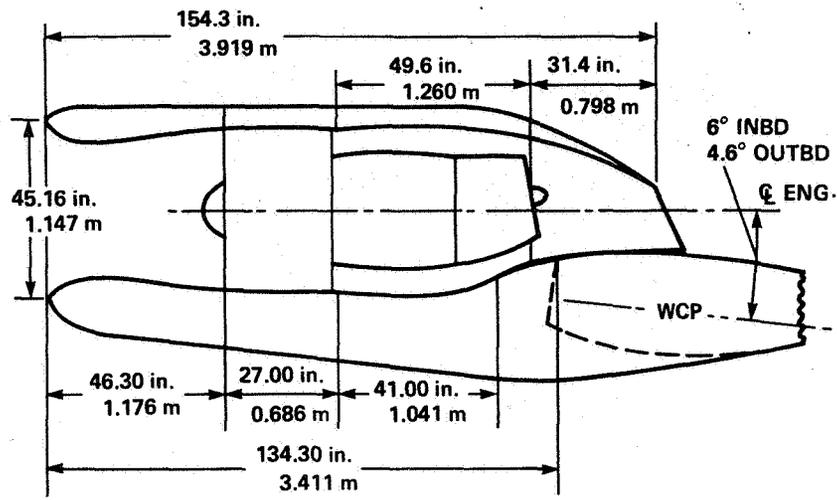
Figure 9. – The QSRA nacelle layout.
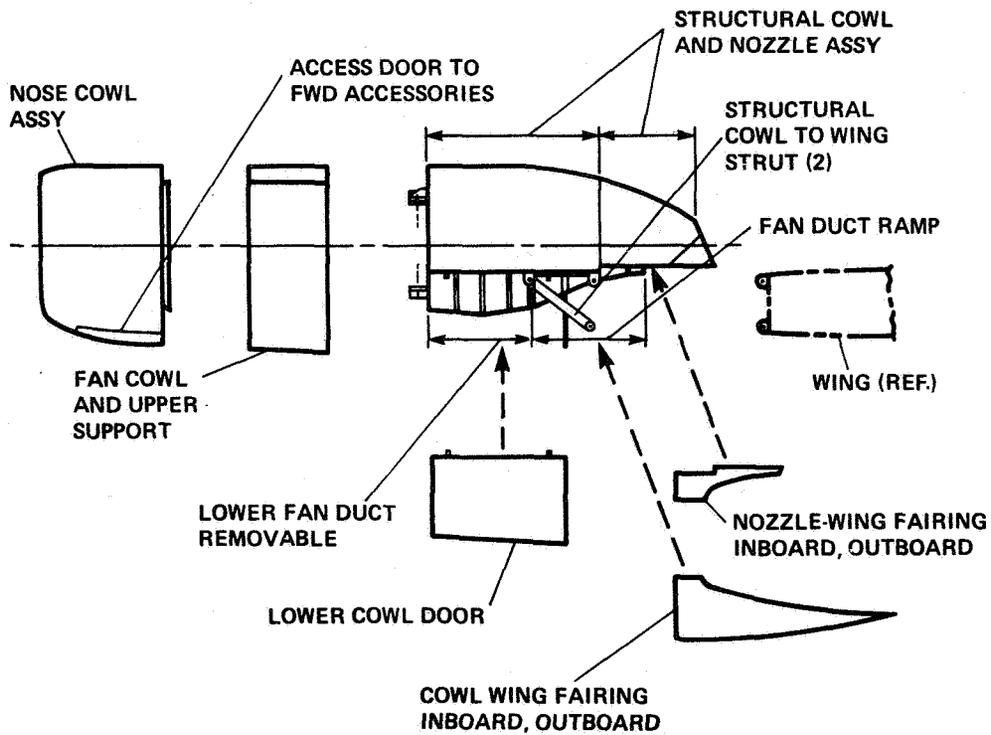
Figure 10. – View of the QSRA nacelle main structural elements.

30
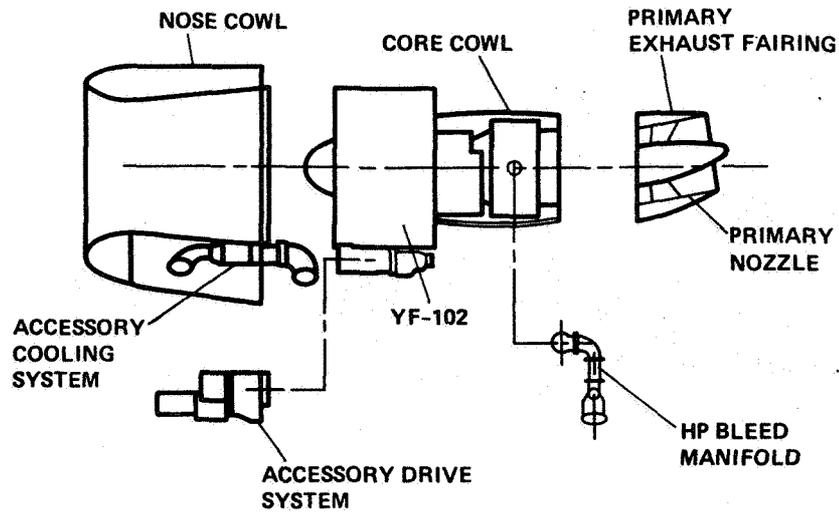
Figure 11. – The engine build up showing the YF-102 (QSRA) engine installed in an assembly consisting of the engine, core cowl, inlet, and primary nozzle.
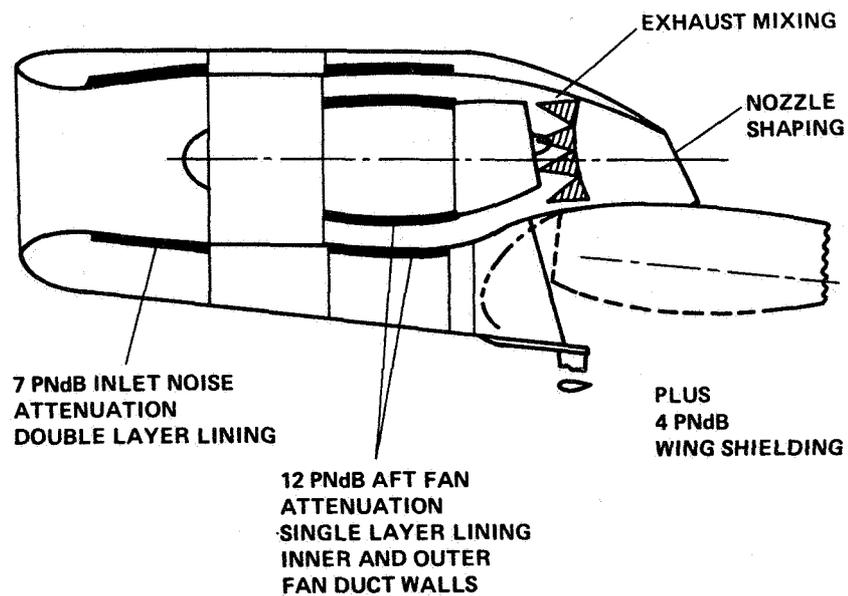
Figure 12. – Location of the acoustic lining panels in the QSRA inlet and aft fan flow passages.
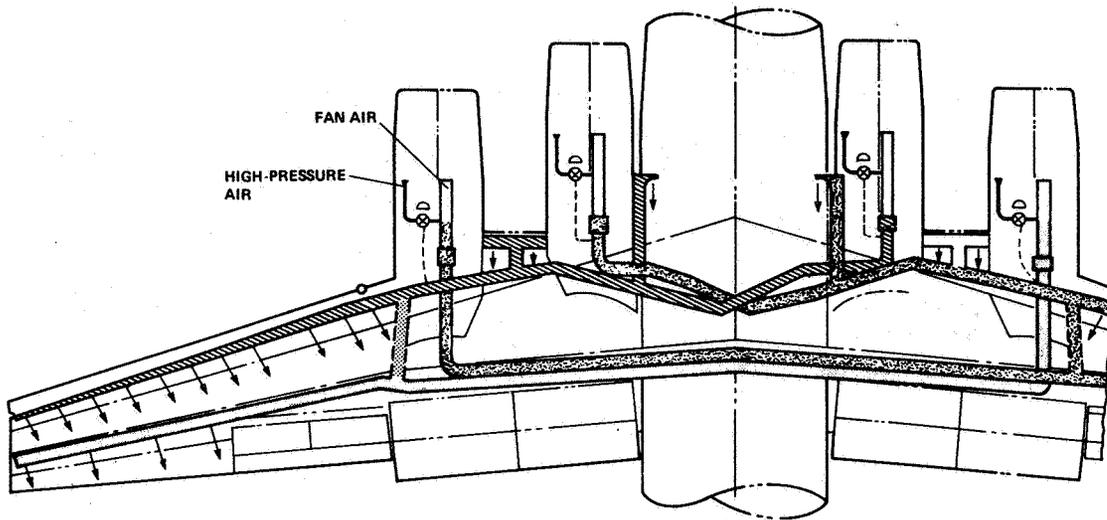
Figure 13. – The layout of the QSRA boundary-layer control (BLC) system.
The two phantom line ducts only connect the leading and trailing edge
systems in the event of an engine failure.
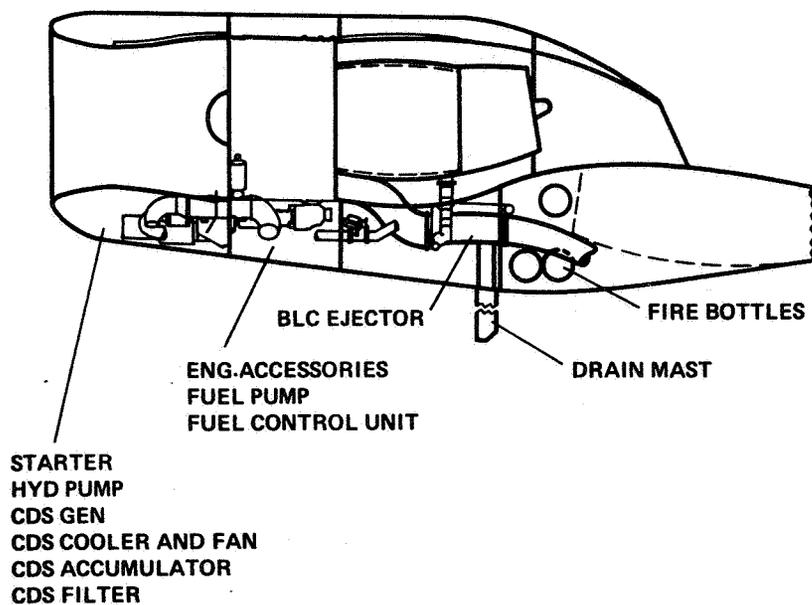
Figure 14. – Systems layout in the QSRA nacelle.
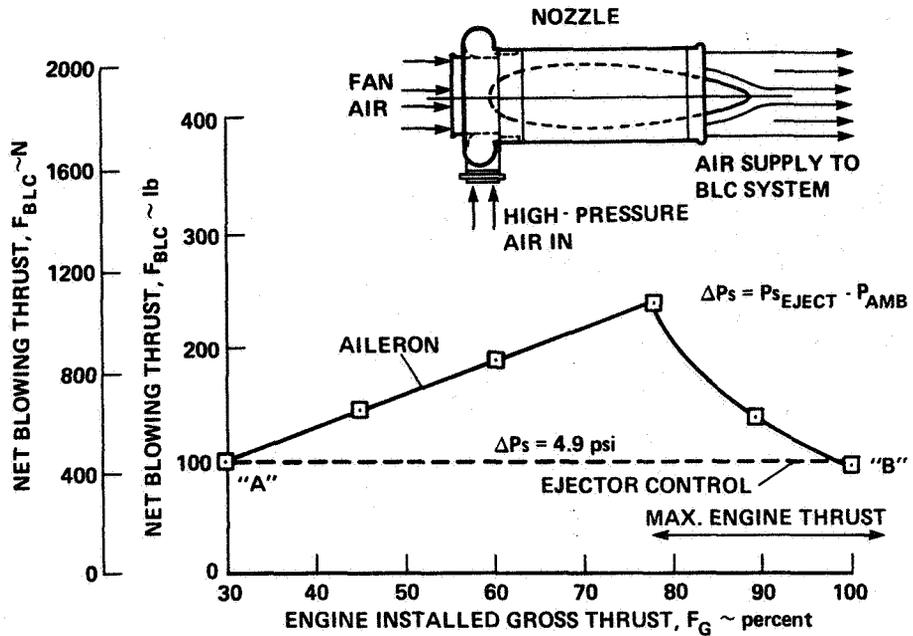
Figure 15. – The performance of the QSRA aileron BLC system shown as a function engine thrust. The BLC ejector which combines the fan and core air from the engine to provide the BLC system air flow is shown in the insert.
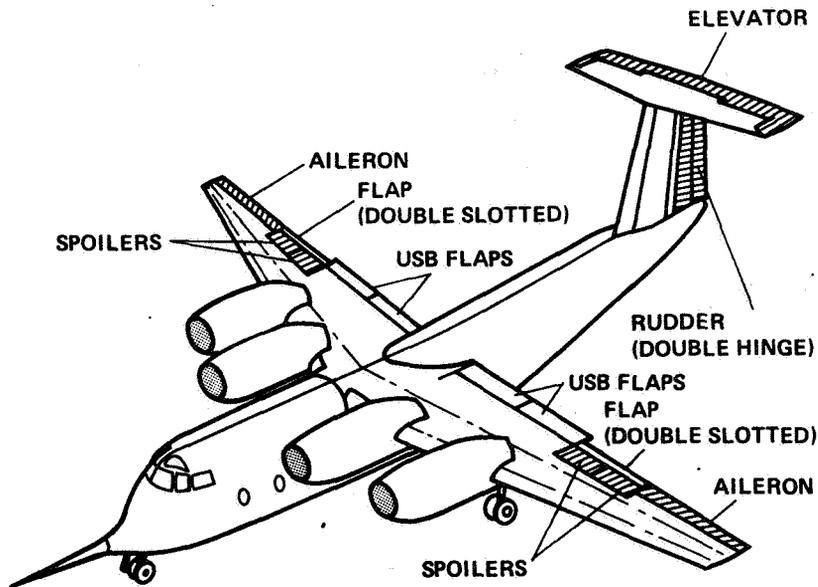
Figure 16. – Location of the QSRA main flight controls.
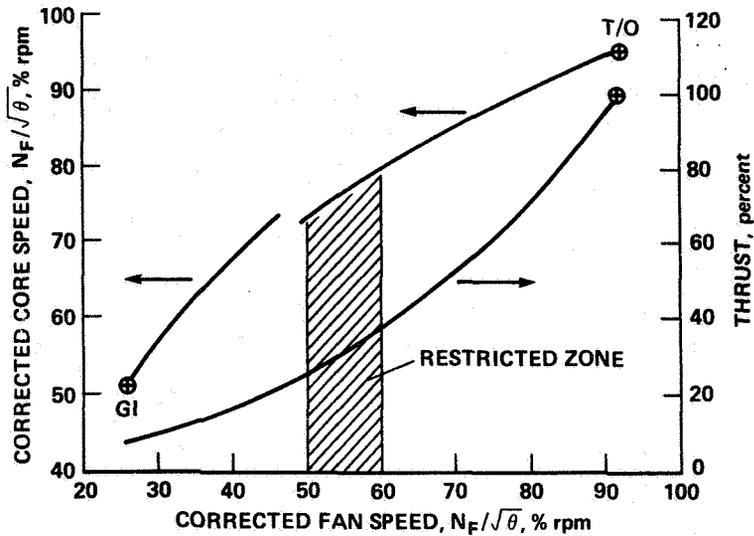
Figure 17. - The relationship of the fan and core compressor speeds with each other and with engine thrust level for the YF-102 (QSRA) engine.
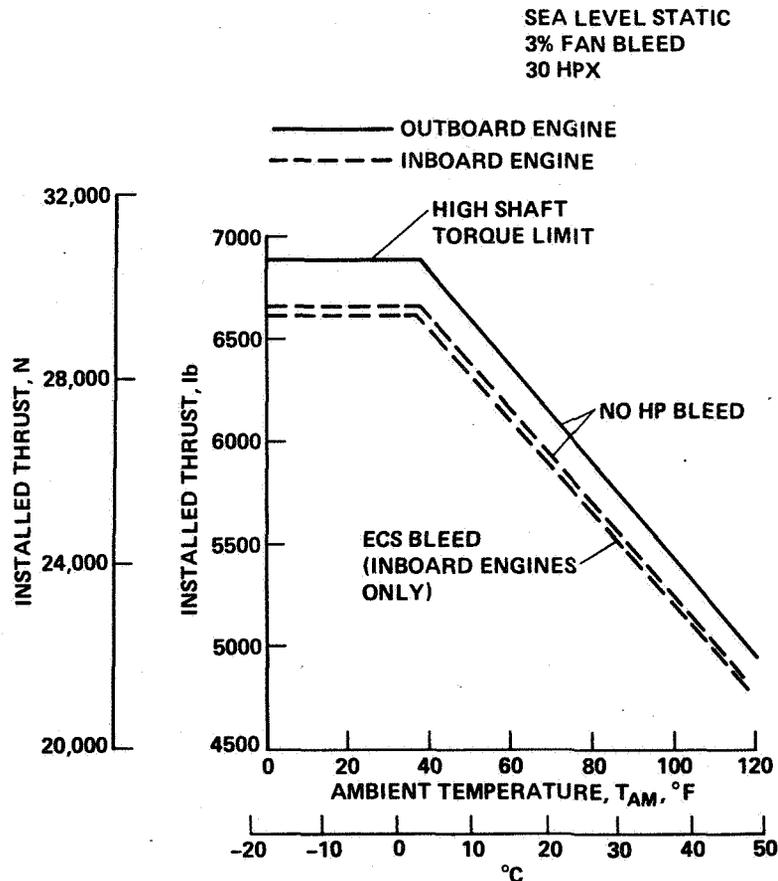
Figure 18.- The effect of ambient temperature on the YF-102 (QSRA) engine thrust. The engine is torque-limited at the lower temperatures and environ-ment control system (ECS) bleed is only taken from the inboard engines.

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YF-102 FAN
BYPASS MAP

$100\% \dfrac{N_F}{\sqrt{\theta}} = 7600\,rpm$

O ENG. 1 (YF01)
△ ENG. 2 (YF02)
□ ENG. 3 (YF03)
◇ ENG. 4 (YF05)

**RELATIVE NOZZLE AREA
FROM UNTRIMMED NOZZLE**

SURGE LINE

UPPER LIMIT FOR ENGINE
ACCEPTANCE TESTS DURING
A-9 PROGRAM

+2%
93.7%
-2%   0%
+4%
88.8%

ROTATING STALL LINE

78.9%

69.1%

ESTIMATED STEADY STATE
OPERATING LINES (S.L.S.)

49.3%

39.5%

29.6%

FAN PRESSURE RATIO, Pt/Pt_0

1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05

40 60 80 100 120 140 160 180 200 220

CORRECTED BYPASS AIRFLOW, $\dfrac{W\sqrt{\theta}}{\delta}$, lb/sec

20 30 40 50 60 70 80 90 100
kg/sec
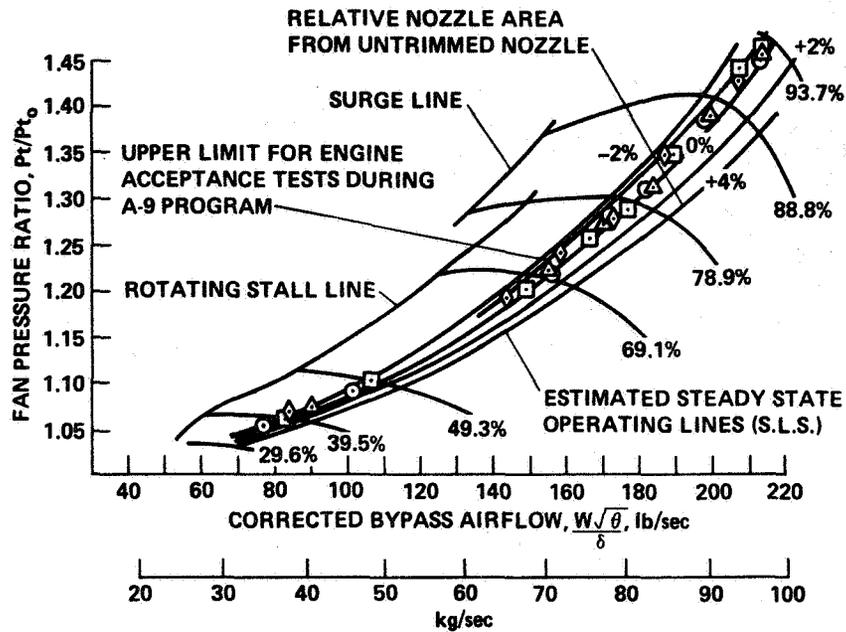
Figure 19. – The YF-102 (QSRA) engine fan map. Results of the installed engine ground tests, which indicate that there is adequate operating margin for each engine, are shown.

MAX. THRUST, percent

100
80
60
40
20

ENG. 3
ENG. 4
ENG. 2
ENG. 1

BLC BLEED "ON"
STD DAY
S.L.S.

0 2 4 6 8 10 12
TIME, sec
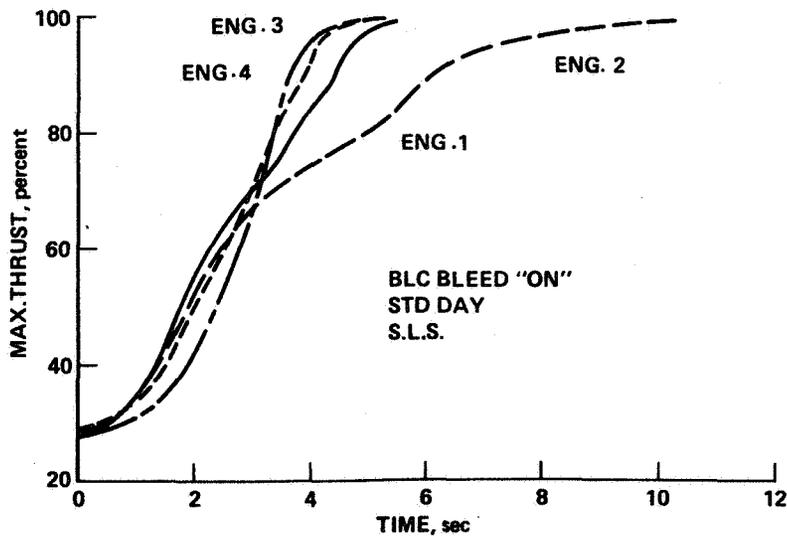
Figure 20. – The acceleration time history for each of the QSRA engines. Note the effect of the slightly out-of-phase BLC valve operation on the acceleration of engine No. 2.

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- TRIMMED LIFT BASED ON WIND-TUNNEL DATA
- FLAPS IN APPROACH ATTITUDE
- ALL ENGINES OPERATING
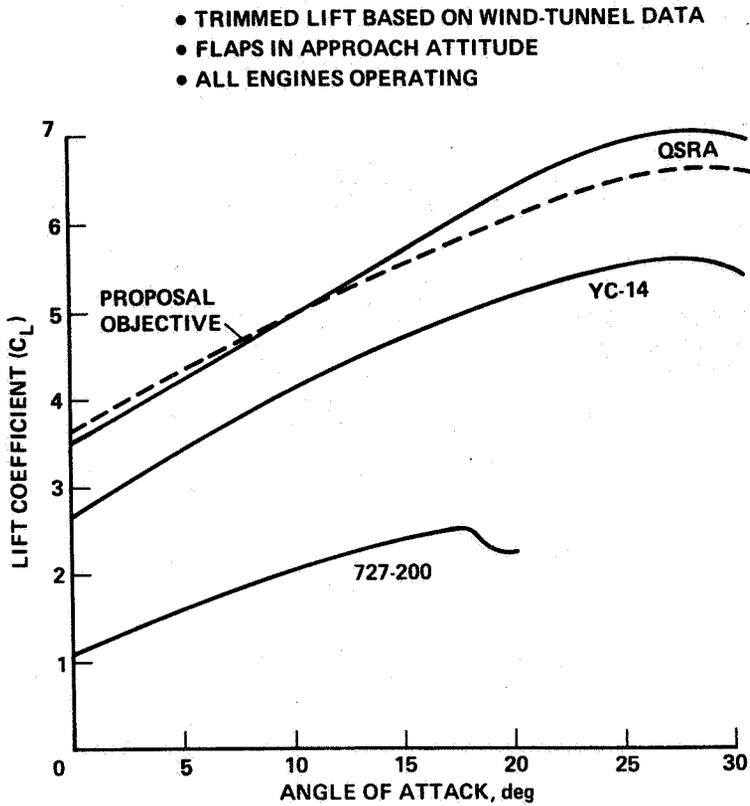
Figure 21. - Comparison of the powered-lift performance of the QSRA with a conventional transport and with an advanced STOL transport.
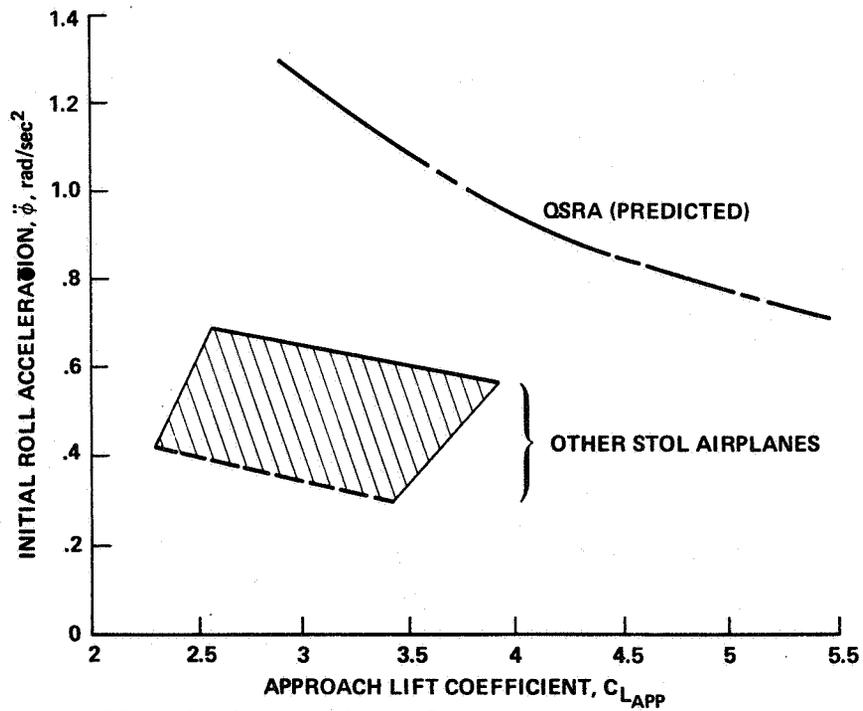
Figure 22.- The predicted QSRA roll performance compared with previous STOL airplanes.
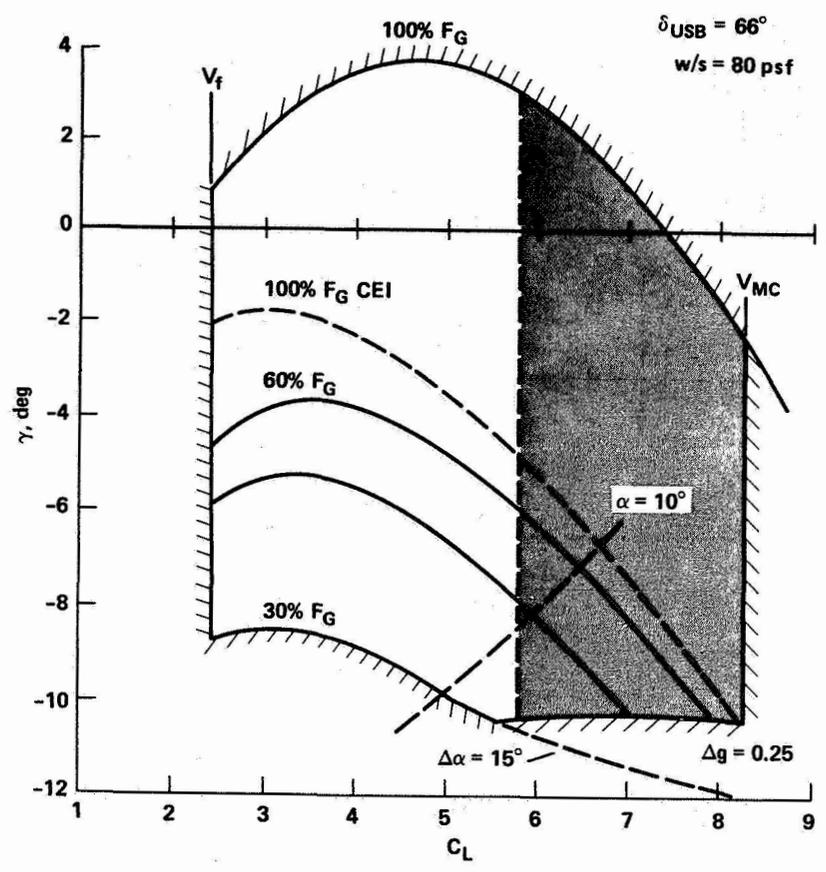
Figure 23. – Approach performance of the QSRA showing flight safety margins.
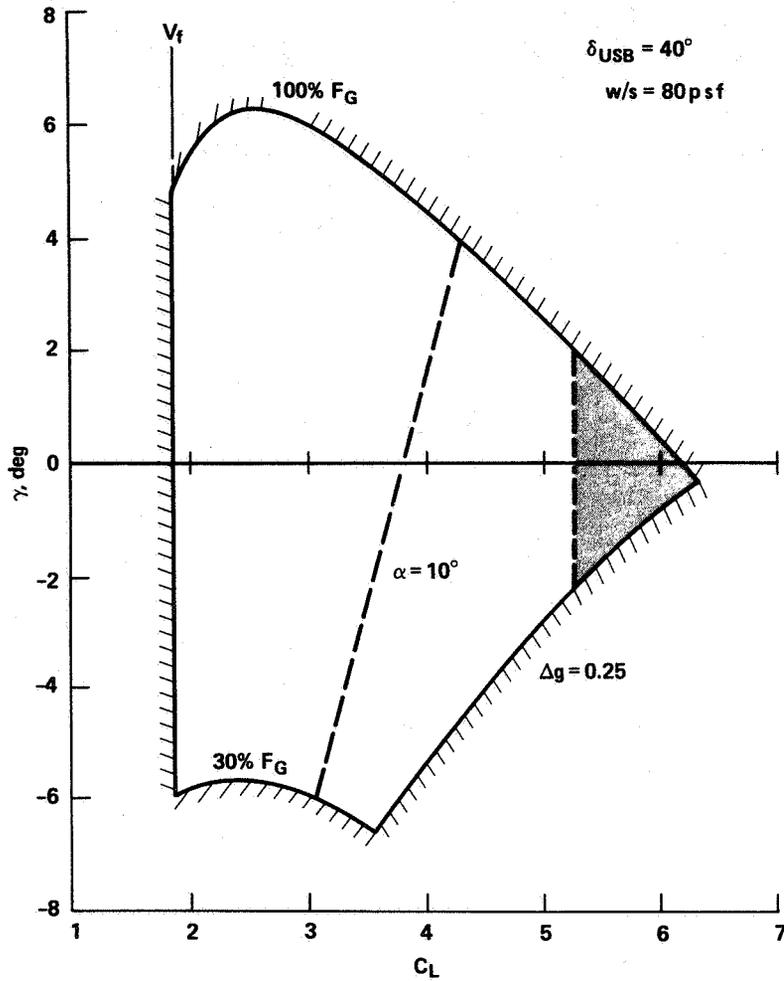
Figure 24. – Performance of the QSRA after a critical (inboard) engine has failed and the QSRA is reconfigured for go-around.
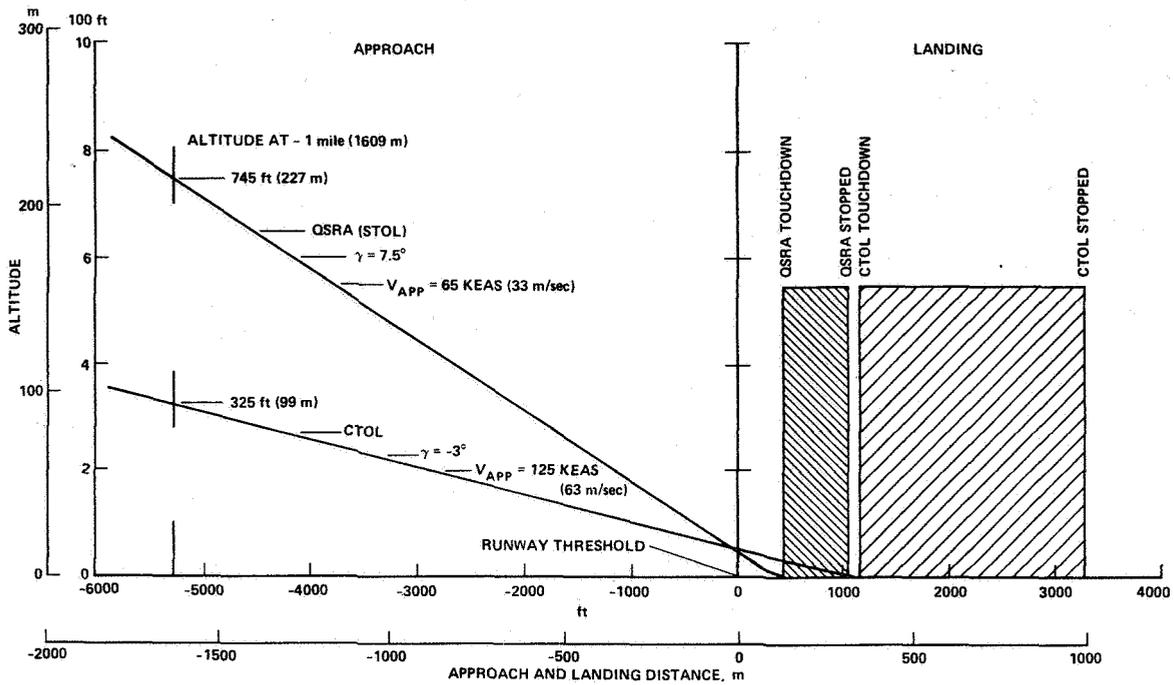
Figure 25. – The STOL landing capability of the QSRA compared to
a conventional approach and landing.

90 EPNdB FOOTPRINTS
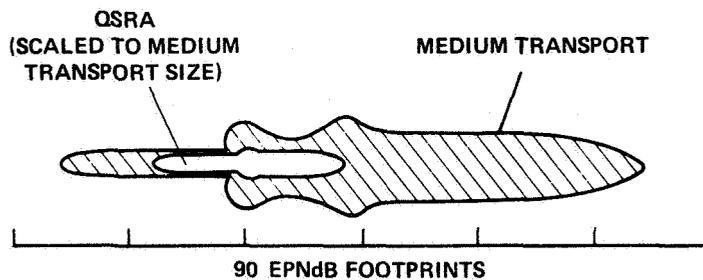
Figure 26. – A comparison of the noise impact areas of a current medium trans-
port aircraft and of the same size transport which meets the QSRA noise
goals.   There is approximately an 80 to 90 percent
reduction in community noise impact.

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15. Supplementary Notes

16. Abstract

An overview of the Quiet Short-Haul Research Aircraft (QSRA) Program is presented, with special emphasis on its propulsion and acoustic aspects. The historical background and management approach which led to a successful, low-cost research aircraft, capable of high levels of low-speed performance and very low community noise impact, are discussed. A description of the NASA technical participation in the program including wind-tunnel testing, engine ground tests, and advanced aircraft simulation is given. The aircraft and its systems are described and, measured performance, where available, is compared to program goals. Although most program goals were met or exceeded, preliminary data indicate that additional research and development are needed in some areas of which acoustics is an example. Some of these additional research areas and potential experiments using the QSRA to develop this technology are discussed. The concept of the QSRA as a national flight-research facility is explained and future plans and programs utilizing it for this purpose are described.

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