AIAA 81-2625R

Selected Results from the Quiet Short-Haul Research Aircraft Flight Research Program

John A. Cochrane,* Dennis W. Riddle,† Victor C. Stevens,‡ and Michael D. Shovlin‡
NASA Ames Research Center, Moffett Field, California

The quiet short-haul research aircraft (QSRA) was developed as a research aircraft that would provide high levels of STOL performance at low levels of community noise. The QSRA is a C-8 Buffalo, modified to incorporate a new propulsive-lift wing powered by four Lycoming YF-102 turbofan engines. During 3 years of flight research, the STOL performance and the low-noise characteristics of the QSRA have been confirmed, and several benefits and applications of the concept have been investigated. Maximum lift coefficients in excess in 10 have been demonstrated in flight and the advantages of upper-surface blowing in reducing takeoff distance over a wide range of thrust-to-weight ratios has been documented.

Introduction

THE National Aeronautics and Space Administration has been engaged in propulsive-lift research for more than 30 years. During this time, numerous techniques for developing propulsive lift have been investigated. During the late 1960s, the upper-surface-blowing (USB) technique was conceived at the Langley Research Center. Numerous wind tunnel investigations were conducted at Langley[1-4] and subsequently at the Ames Research Center.[5-8] Following two parallel preliminary design studies, a contract was awarded to the Boeing Commercial Airplane Company to design and build the quiet short-haul research aircraft (QSRA) for use by Ames Research Center in terminal-area flight research. The QSRA made its first flight on July 6, 1978 and was delivered to Ames Research Center on Aug. 3, 1978.

The airplane has been engaged in a flight research program since that time and has undergone several significant modification programs. Figure 1 provides configurational and dimensional details. The QSRA is a de Havilland C-8A Buffalo modified with a new propulsive-lift wing and powered with four Lycoming YF-102 turbofan engines. The configuration uses the upper-surface-blowing technique to develop high levels of lift at low noise levels. A detailed description of the QSRA in the "as delivered" configuration is contained in Ref. 9, and a description of the airplane as presently configured is contained in Ref. 10. This configuration is the result of both developmental flight test and several extensive modification programs.

The NASA flight program began immediately after the QSRA was delivered to Ames Research Center. Initial flights were conducted at Moffett Field, but most of the research flights were conducted at the NASA flight research facility at the Naval Auxiliary Landing Field, Crows Landing, California.

This paper presents selected results from the first 3 years of the QSRA flight research program.

Roll-Control Power

A high level of roll-control power was a specific design goal of the QSRA. Therefore measurements of roll acceleration were accomplished early in the program. Figure 2 shows the results of the measurements of roll acceleration of the QSRA in its original configuration. The technique used to obtain these data was to establish a roll rate in one direction and then to reverse the direction of roll with the desired deflection of the control wheel. The data in Fig. 2 are for a USB flap deflection of 50 deg, which is the normal approach configuration. The goal for the QSRA was a roll acceleration, with all engines operating, of 0.8 rad/s^2 at a lift coefficient of 4.6. At the design wing loading of 80 lb/ft^2, this corresponds to an approach speed of about 72 knots. Note that the QSRA meets the goal with the full-wheel deflection of about 80 deg. Note also that the spoilers contribute approximately one-half of the QSRA's roll-control power.

During flight evaluations with an outboard engine inoperative, it was noticed that pilots had a tendency to develop a pilot-induced oscillation (PIO) in roll. It was determined that this was a result of the roll trim point being very close to the point at which the spoilers started to deploy, based on the original roll-control gearing used in the QSRA. Figure 3 shows the QSRA roll acceleration as a function of wheel position for the original gearing and the effect of two modifications to the QSRA. The solid line shows the response of the QSRA to the original spoiler gearing. Note that the spoilers started to deploy at a wheel deflection of 30 deg. Fairings were added to the double-slotted-flap support brackets during a modification program. These fairings improved the flow through the flap slots and thus increased the lift that they were generating. This in turn made the spoilers more effective since they had a higher level of lift to "spoil." This effect is shown in Fig. 3 by the dashed line. Although the roll-control power was increased by this effect, the discontinuity in the airplane response to control wheel deflection also became more pronounced.

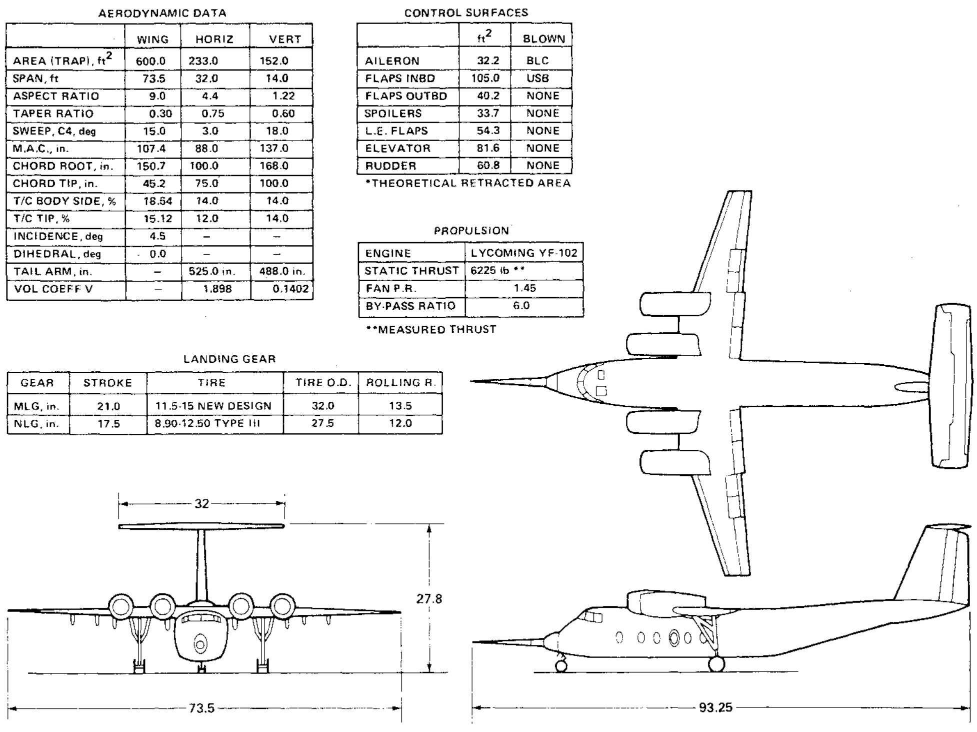
Engine-out approaches were more difficult to perform with precision because of the difficulty the pilot had in maintaining bank angle. It was decided to reprogram the spoilers so that this sharp discontinuity would be eliminated. The spoilers on the QSRA are controlled by a fly-by-wire system, so the modification required only a simple circuit change. The dotted line in Fig. 3 shows the result of this modification. The spoilers deploy as soon as the control wheel is deflected, and the trim point is reached at a smaller wheel deflection and without the previous discontinuity. Subsequent flight evaluations proved that this modification greatly improved the precision with which bank angle could be maintained during engine-out landing approaches. Use of asymmetric, double-slotted flaps to trim out the engine-out rolling moment, in conjunction with the improved spoiler gearing, resulted in a nearly neutral wheel required for typical engine-out landing approaches.

Presented as Paper 81-2625 at the AIAA/NASA Ames V/STOL Conference, Palo Alto, Calif., Dec. 7-9, 1981; submitted Dec. 17, 1981; revision received June 21, 1982.

*Manager, Quiet Short-Haul Aircraft Office. Member AIAA.

†Aerospace Engineer.

‡Aerospace Engineer. Member AIAA.



AERODYNAMIC DATA

	WING	HORIZ	VERT
AREA (TRAP), ft^2	600.0	233.0	152.0
SPAN, ft	73.5	32.0	14.0
ASPECT RATIO	9.0	4.4	1.22
TAPER RATIO	0.30	0.75	0.60
SWEEP, C4, deg	15.0	3.0	18.0
M.A.C., in.	107.4	88.0	137.0
CHORD ROOT, in.	150.7	100.0	168.0
CHORD TIP, in.	45.2	75.0	100.0
T/C BODY SIDE, %	18.54	14.0	14.0
T/C TIP, %	15.12	12.0	14.0
INCIDENCE, deg	4.5	–	–
DIHEDRAL, deg	0.0	–	–
TAIL ARM, in.	–	525.0 in.	488.0 in.
VOL COEFF V	–	1.898	0.1402

CONTROL SURFACES

	ft^2	BLOWN
AILERON	32.2	BLC
FLAPS INBD	105.0	USB
FLAPS OUTBD	40.2	NONE
SPOILERS	33.7	NONE
L.E. FLAPS	54.3	NONE
ELEVATOR	81.6	NONE
RUDDER	60.8	NONE

*THEORETICAL RETRACTED AREA

PROPULSION

ENGINE	LYCOMING YF-102
STATIC THRUST	6225 lb **
FAN P.R.	1.45
BY-PASS RATIO	6.0

**MEASURED THRUST

LANDING GEAR

GEAR	STROKE	TIRE	TIRE O.D.	ROLLING R.
MLG, in.	21.0	11.5-15 NEW DESIGN	32.0	13.5
NLG, in.	17.5	8.90-12.50 TYPE III	27.5	12.0

Fig. 1 QSRA configuration and dimensional details.

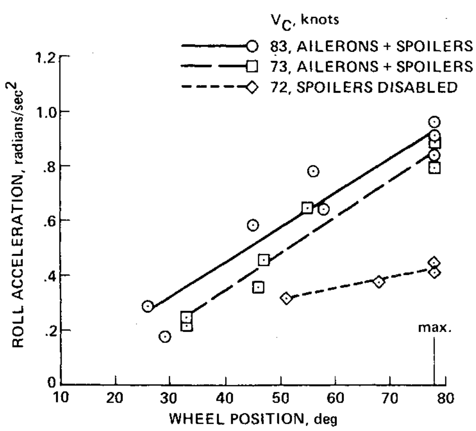


Fig. 2 QSRA roll acceleration performance.

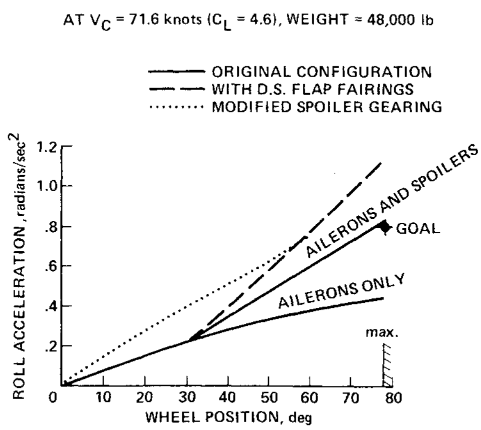


Fig. 3 Effect of spoiler gearing change.

Elevator Stall

In the course of evaluating the lift performance of the QSRA, an elevator stall phenomenon was discovered. Figure 4 shows the evidence of the elevator stall based on flight data. At the top of Fig. 4, elevator deflection is plotted against angle of attack. At an angle of attack of about 8 deg there is an abrupt change in the slope of the curve. Further deflection of the elevator provides only a small increase in angle of attack. Similarly, in the lower half of Fig. 4, the curve of lift coefficient vs angle of attack exhibits an abrupt break at the same angle of attack. In this case, the lift coefficient increases suddenly. The reason for this sudden increase is the stalling of the elevator, which reduced its download, thus increasing the apparent net lift of the aircraft. The aircraft is no longer trimmed when this occurs and the nose starts to pitch downward.

This phenomenon occurs only with large deflections of the USB flaps and with the engines at maximum power. Generally, the maneuver must be accomplished at altitudes below 5000 ft in order to provide sufficient engine thrust. The motion of the airplane when elevator stall occurs is gentle. The nose pitches slowly downward, much in the manner of a wing stall of a well-behaved light aircraft. Recovery is accomplished by reducing elevator deflection and USB flap deflection. Although the maneuver is quite safe at altitude, it could have serious consequences in a wave-off maneuver close to the ground. Pilots first checking out in the QSRA have encountered a "wheelbarrowing" tendency when the go-around was attempted by adding full engine thrust without first retracting the USB flaps. The nature of the elevator stall was investigated by tufting the underside of the horizontal tail. Figure 5 shows the horizontal tail with near maximum elevator deflection. The tufts indicate that the flow on the stabilizer is attached, but the flow on the elevator is separated.

As a result of these observations, the incidence of the horizontal stabilizer was reset to be 3 deg more negative. Although this modification did provide some increase in the maximum available pitch control power, the increase was not sufficient to eliminate the elevator stall phenomenon. Therefore elevator stall is always demonstrated (at altitude) to new pilots checking out in the QSRA, and they are instructed in the proper procedure for accomplishing a wave-off or a

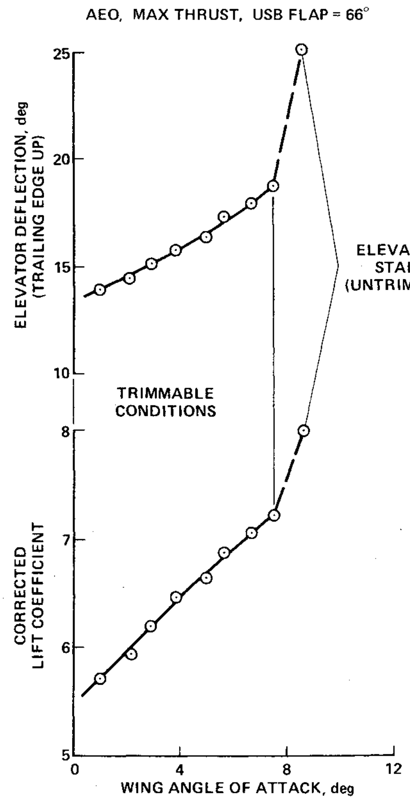


Fig. 4 QSRA elevator stall.

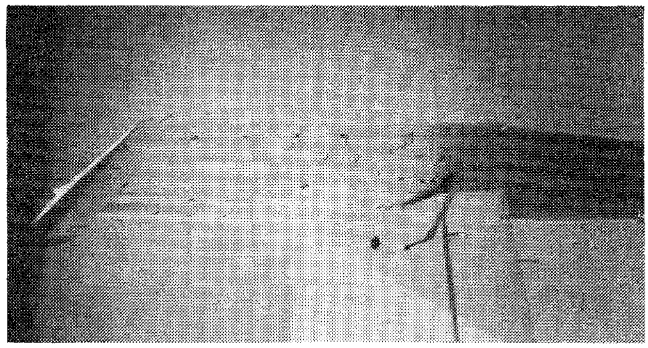


Fig. 5 Tuft photograph: elevator stalled.

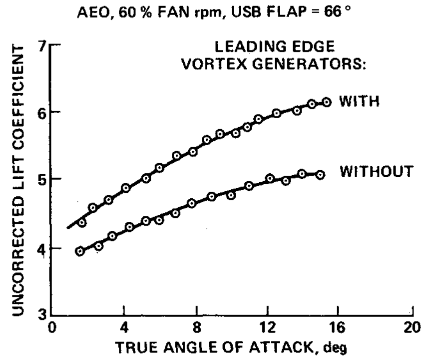


Fig. 6 Effect of leading-edge vortex generators.

touch-and-go landing. In an operational airplane (compared with the austere research airplane) a properly designed, trimmable stabilizer would eliminate this problem. A throttle-flap interconnect is another approach to solving the problem. Such an interconnect was, in fact, installed on the QSRA originally. However, it was disconnected to permit full exploration of the airplane's envelope for research purposes.

Effect of Leading-Edge Vortex Generators

Vortex generators are located behind the engines on the QSRA to aid in spreading the flow and to enhance flow-turning at large USB flap deflections. Initially, the design of the vortex generator pattern was developed during the large-scale wind tunnel program in the 40×80-ft wind tunnel at Ames.[8] Differences in the bypass ratio of the engines used on the wind tunnel model and those used on the aircraft made it necessary to redevelop the vortex-generator installation on the airplane. This was accomplished through a flight program, during which lift measurements were combined with various flow-visualization schemes to determine the optimum pattern. After it had been determined that the flow behind the engine nozzles was satisfactory, it became apparent that further improvement was required. The flight research program was then directed to the area between the engine nacelles. Development work in the 40×80-ft wind tunnel had shown this to be a critical area.

Figure 6 compares the relative lift performance of the QSRA with and without vortex generators at the leading edge in the area between the nacelles. Flow separation at the leading edge between the nacelles results in lifting of the engine exhaust jet sheet, which degrades flow-turning performance. Various vortex-generator patterns were evaluated until the desired performance was achieved. It should be noted that such configurational details are highly dependent on the particular airplane design and must be individually tailored to the application. In the case of the QSRA, the support brackets for the leading-edge flap between the nacelles significantly influenced the design of the vortex-generator pattern. The key point is that the quality of the flow at the leading edge has a very large effect on the flow-turning performance at the trailing-edge USB flaps.

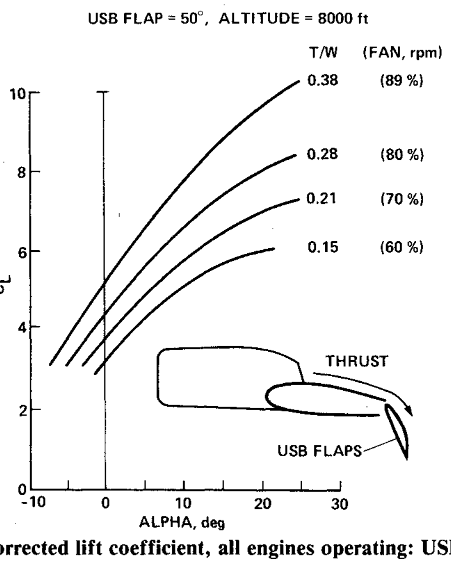


Fig. 7 Corrected lift coefficient, all engines operating: USB flaps at 50 deg.

Lift Performance

When satisfactory levels of performance were achieved and the handling qualities were considered to be satisfactory, the flight program effort was concentrated on documenting airplane characteristics and the best techniques for flying high-performance, precision, STOL landing approaches. Figure 7 presents the lift performance of the QSRA with the USB flaps set at 50 deg and with all engines operating. The 50-deg setting on the USB flaps was determined to be the optimum. Greater flap deflections resulted in less net lift, because of the elevator downloads required to trim the airplane; they also resulted in a more nose-down pitch attitude. Note that the lift coefficient at maximum angle of attack and maximum fan rpm reached a maximum value in excess of 10. Although the airplane would not be flown on landing approaches in this corner of its envelope, it does provide substantial margin over the normal approach lift coefficient of 5.5.

Figure 8 shows the effect of flap deflection on the lift performance at a constant thrust setting. Note that the maximum lift coefficient with the USB flaps at 30 deg approaches the maximum lift coefficient shown in Fig. 7. Figure 9 is based on the same data set as Fig. 8, but flight-path angle is plotted in Fig. 9 as a function of approach speed. The data in this figure were acquired at approximately 8000 ft. Note that with 50 deg of USB flap, the QSRA can barely maintain level flight at full thrust at 65 knots; however, at 30 deg of USB flap a climb flight path of about +6 deg can be maintained. At this speed, further retraction of the USB flaps results in less climb gradient. Thus, at the normal approach speed of 65 knots, 30 deg of USB flaps is close to the maximum powered lift-drag ratio.

The USB flaps on the QSRA are mechanized so that a thumbswitch on the throttle is used to command USB flap deflections greater than 30 deg. Thus, when a go-around is desired, the pilot simply pushes this switch forward while advancing the throttles. As the flaps retract to the 30 deg position, there is little loss in lift but a large increase in climb capability. In addition, pitching moment is reduced as the engines come up to full thrust, thus eliminating the possibility of encountering the elevator stall discussed earlier. These data, together with pilot comments, led to the standard go-around procedure used on the QSRA: retract the USB flaps to 30 deg and then advance the throttles to maximum thrust.

Sea-Level Flight-Path Performance

The format used to present the data contained in Fig. 9 is the basic method of presenting the performance of STOL aircraft in the landing configuration. A major problem with powered-lift STOL aircraft is the generation of sufficient lift with engine thrust while still being able to maintain a steep approach path. The ability to accomplish this is related to the flow-turning, which in the case of the QSRA, is accomplished as a result of the Coanda effect on the flow over the USB flaps.

Another problem with powered-lift airplanes is the difficulty of measuring performance in flight. This problem arises because performance is heavily thrust-dependent and thrust varies with altitude. To further complicate the problem, lift performance is highly dependent on thrust coefficient, which varies with velocity. Thus, when an angle-of-attack sweep is accomplished at altitude, even though the engine thrust is relatively constant, the thrust coefficient varies greatly as the airplane slows down. To relate the lift performance to wind tunnel data, which are presented for lines of constant thrust coefficient, it is necessary to perform angle-of-attack sweeps at several power settings and to cross-plot the resulting data. Thus in order to construct a velocity flight-path diagram referenced to sea level, it is necessary to acquire and process a large amount of flight data.

Figure 10 presents such a diagram for the QSRA with the USB flaps at the 50-deg setting and an aircraft weight of 48,000 lb. This is a valuable diagram for presenting the approach performance of a powered-lift STOL airplane. The QSRA normally flies STOL approaches at 65 knots along a −6 to −7.5 deg flight path. Note the characteristics of the airplane at this design point. Fan speed is 70%, which is slightly more than half the available thrust ($T/W \approx 0.27$). Pitch attitude is approximately level, and the angle of attack is about 10 deg. This is a desirable situation because little rotation is required to place the airplane in a landing attitude, and the angle-of-attack margin is about 20 deg. Note also that the lines of constant pitch attitude are nearly vertical but that the lines of constant angle of attack have a significant slope. These data explain the need to fly landing approaches in the QSRA at constant pitch attitude rather than at the more conventional constant angle of attack. By using this technique, changes in thrust provide for glide-slope tracking with minimal excursions in airspeed, and changes in pitch attitude control airspeed.

Spoiler Performance

Four spoiler panels are located just forward of the double-slotted flaps on the QSRA (two panels per side). These spoilers, which are controlled by a "single thread" fly-by-wire system, serve four functions. First, they are geared to the roll-control system and augment the blown ailerons in providing roll control of the airplane. Second, they can be used as speed brakes, with deployment being proportional to deflection of the speed-brake lever in the cockpit. Third, this same lever can also be used to deploy the spoilers to maximum deflection on the ground for a lift-dump function. And fourth, the spoilers can be used in a direct-lift-control (DLC) mode to improve glide-slope tracking (heave response). In the DLC mode, the spoilers are biased up to −13 deg and move from that position in response to throttle movement. An increase in throttle retracts the spoilers; retarding the throttle causes them to deploy to a maximum of 26 deg. A 1-second washout circuit returns the spoilers to the −13 deg position after each

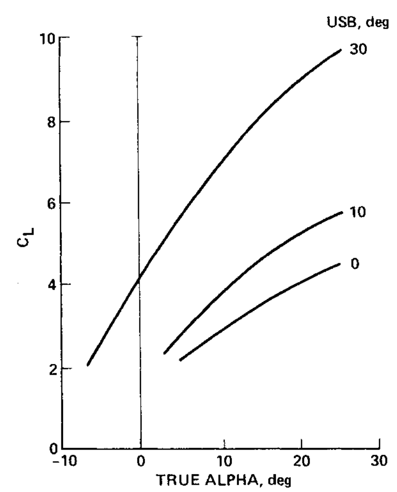


Fig. 8 Effect of USB flap setting on lift coefficient at maximum thrust.

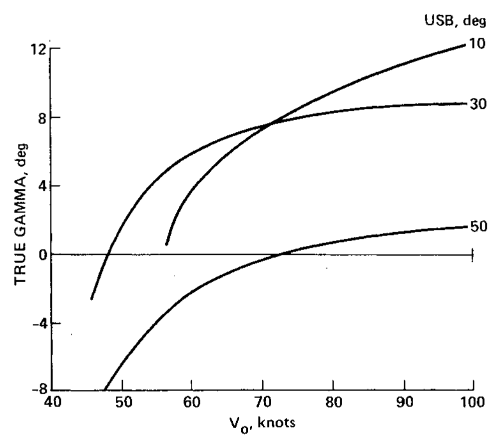


Fig. 9 Effect of USB flap setting on flight path at maximum thrust.

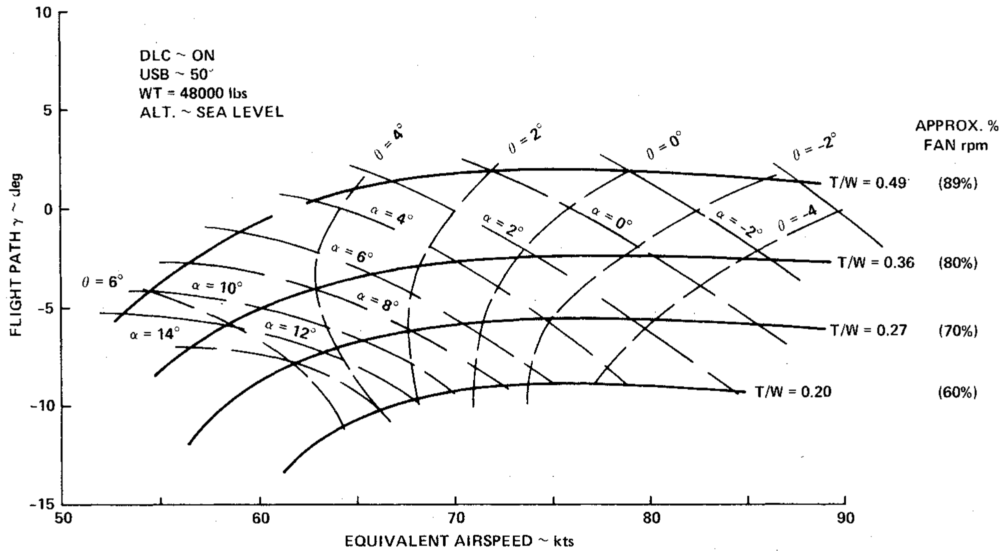


Fig. 10 Flight path vs velocity diagram: landing configuration.

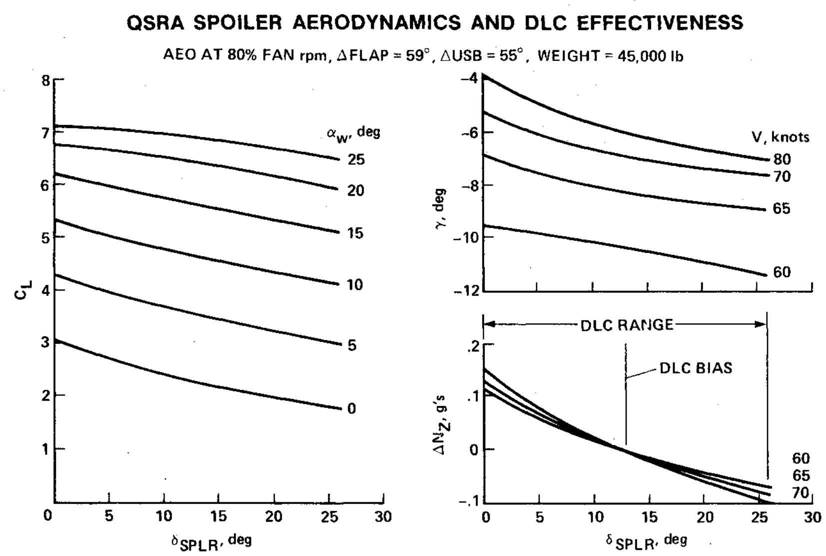


Fig. 11 QSRA spoiler performance.

throttle movement. This 1-s time-constant blends with the response of the engines in the approach thrust range. Figure 11 presents the performance of the QSRA spoilers as measured in flight. Notice that at approach speeds the deflection range of the DLC system provides a vertical acceleration of $\pm 0.1g$. Notice also that at the normal 65-knot approach speed, the DLC provides a flight-path variation of about ± 1 deg.

Engine-Out Performance

Figure 12 presents the engine-out characteristics of the QSRA at an altitude of 8000 ft, with a gross weight of 53,000 lb, and with the USB flaps deflected to 55 deg. Note that lift considerations would define the critical engine as the inboard engine, because the maximum lift with an outboard engine inoperative is about three-fourths of a unit greater than with an inboard engine inoperative. This characteristic is also reflected in a greater descent angle with the inboard engine inoperative. However, the amount of control-wheel deflection required to trim the engine-out rolling moment is significantly greater in the case of an inoperative outboard engine. Thus the inboard engine is critical from a performance point of view, and the outboard engine is critical when control is considered.

Acoustic Measurements

Low noise was a major consideration in the design of the QSRA. The initial QSRA noise tests were conducted by Boeing at the Bayview Airport, near Seattle, Washington, in July 1978. Since the QSRA envelope had not been fully expanded and because of budgetary limitations, the noise characteristics of the QSRA were not fully documented at that time. A second noise test was conducted at the NASA Crows Landing Facility, Crows Landing, California, in January 1979. This test was devoted to measuring noise levels with USB flap deflections of less than 30 deg, evaluating a spiral climb departure technique on community noise, and determining the effect of trailing-edge vortex generators on the noise signature.

Thirteen test conditions were investigated with the vortex generators removed. A comparison with the July 1978 test data showed that the vortex generators did not have a significant effect on the noise levels. At high USB flap deflections, the noise levels were higher with the vortex generators removed, probably because of flow separation resulting from less efficient flow-turning. It was determined that the direct-lift-control (DLC) system and the leading-edge boundary-layer control system contributed between 2 and 3 dB to the noise levels at approach power.

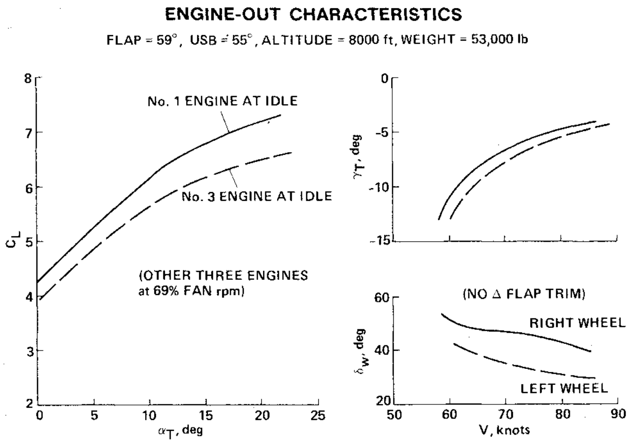


Fig. 12 QSRA engine-out characteristics with USB flaps at 55 deg.

Analysis of the data also showed that USB flap trailing-edge noise was the dominant source. The tests showed that the spiraling departure technique resulted in a 90 EPNdB contour that is nearly circular in diameter and has an area of about 3.4 square miles. Although this is a larger area than that which would result in a straight-in approach and a straight-out departure, the noise is concentrated over the airport area. Details of the January 1979 noise investigation are reported in Ref. 11.

Small-scale model tests and ground tests on a single USB flap indicated that significant noise reductions could be achieved with this modification of the USB flap trailing edge to a sawtooth configuration.

Noise measurement tests required flights at low speed near the runway. Therefore it was necessary to evaluate the effect of the sawtooth trailing edges on the airplane aerodynamics at altitude to insure that no undesirable flight characteristics developed as a result of the installation. Comparison of the airplane performance and handling qualities with the sawtooth trailing edge installed to the baseline airplane did not reveal any adverse aerodynamic characteristics. The noise tests were accomplished at Naval Auxiliary Landing Field, Crows Landing, California. Laser tracking provided precision location measurements of the airplane over the microphones located on the runway and on poles next to the runway. A series of runs was made with the sawtooth trailing edges installed and then repeated with the devices removed for a baseline comparison. Some of the results of this research are presented in Fig. 13. A noise reduction of about 2 dB is documented by these data. A detailed report on this research program is contained in Ref. 12.

Reduced-Thrust Takeoff Program

Analytical studies of QSRA wind tunnel data indicated that substantial levels of lift resulting from supercirculation phenomena were developed by the QSRA high-lift system, even with the USB flaps retracted (takeoff configuration). Total engine exhaust flow-turning in this configuration was estimated at 18 deg because of wing incidence (4.5 deg) and the contour of the upper surface of the wing (13.5 deg). Since substantial amounts of propulsive lift were being generated with very little turning of the thrust vector (and thus little reduction in horizontal acceleration force) it was theorized that superior takeoff performance could be achieved with an upper-surface-blowing propulsive-lift airplane. Although a conventional airplane could achieve the vertical component of thrust (lift) due to the 18 deg of flow-turning, the USB airplane develops about 17% additional lift as a result of supercirculation phenomena. Configurations with more distributed upper-surface blowing could generate even greater amounts of supercirculation lift. Analytical investigations indicated that USB technology could significantly reduce takeoff distances even at conventional thrust-to-weight ratios and wing loadings. Alternatively, at takeoff distances equal to those of conventional airplanes, the USB propulsive-lift technology could accommodate larger payloads, according to the analysis.

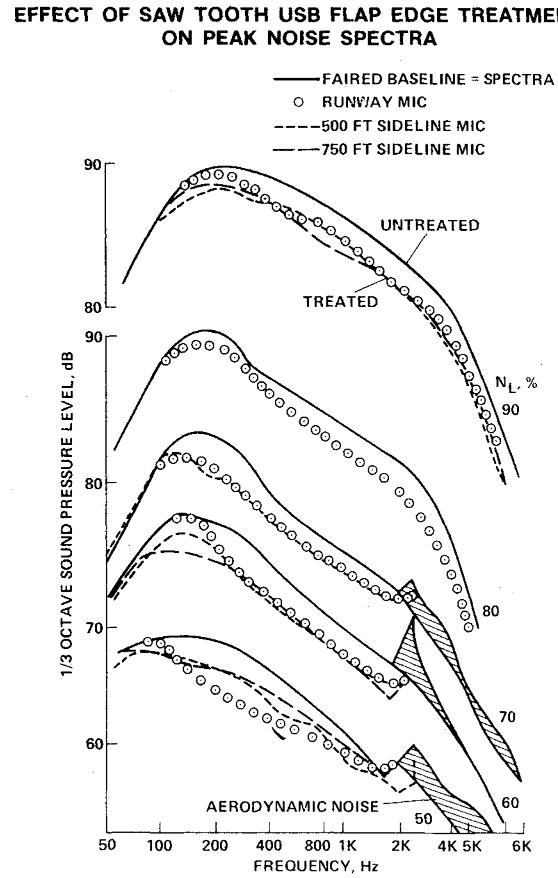


Fig. 13 Effect of serrated trailing edge on noise.

The general conclusion drawn from the analysis was that conventional jet transport aircraft could benefit significantly from the application of USB propulsive-lift technology, without any increase in thrust-to-weight ratio. The importance of this conclusion led to the initiation of a comprehensive flight investigation into the takeoff performance of the QSRA over a range of thrust-to-weight ratios and wing loadings. This flight program required about 6 months to complete, including the time required for ground calibration of the QSRA's engines. More than 500 precision takeoffs were performed during the program. The program proved conclusively that significant takeoff performance benefits could be derived from the USB propulsive-lift technology. Based on civil aviation criteria (Fig. 22 in Ref. 13), reductions in takeoff field length were of the order of 30%; based on USAF criteria (Fig. 23 in Ref. 13), the reductions were as great as 60%. This program is reported in detail in Ref. 13.

Figure 14, completed after Ref. 13 was published, is based on data from this program. Figure 14 compares the measured QSRA takeoff performance with the published takeoff performance of a number of business jet aircraft with a relatively wide range of wing loadings. Note that at a wing loading of 80 lb/ft^2, the QSRA requires about 20% less runway than one of the current business-jet aircraft with a wing loading of 40 lb/ft^2. At equal wing loadings, the QSRA would require only half the takeoff runway of the conventional business jet. In addition to the shorter runway requirement, the higher wing loading of the QSRA provides better ride qualities in turbulence and greater cruise efficiency at medium altitudes. Of all potential users of this technology, the business-jet operator would seem to be one with a need for

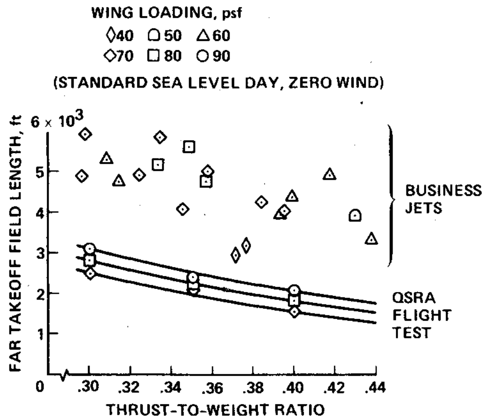


Fig. 14 Comparison of QSRA takeoff performance with current business jet aircraft.

an aircraft that could combine short runway operation at low noise levels with efficient high-speed cruise performance—precisely the features that this technology makes available.

Other Important Results

Two very significant QSRA flight programs—the Joint Navy/NASA QSRA Flight Research Program and the QSRA Evaluation Pilot Program—are not reported here because of space limitations. However, they are of sufficient importance that they both merit a brief comment. During the Joint Navy/NASA QSRA Flight Research Program, comprehensive ground-based tests were followed by 4 days of operations aboard the U.S.S. Kitty Hawk at sea. Unarrested landings and non-catapult takeoffs were accomplished by three pilots over a wide range of conditions. This program is reported in Refs. 10, 14, 15, and 16.

In the QSRA Evaluation Pilot Program, which will be the subject of a future report, 28 pilots were exposed to a full day of briefings followed by 2 days during which each pilot flew the QSRA for a total of 3 hours (two flights). The first flight was for familiarization with the flight characteristics of the QSRA and for learning how to make high-performance STOL landings with all engines and systems operative. On the second flight, each pilot was exposed to various failure modes during high-performance STOL landing approaches. At the end of the program, each pilot flew a high-performance STOL approach with one engine inoperative and with the stability augmentation system turned off. These data strongly contradict the widely held opinion that high-performance propulsive-lift airplanes are difficult to fly.

Concluding Remarks

The first 3 years of the ongoing QSRA flight research program have yielded technical results that substantiate the high performance available with the propulsive-lift technology incorporated in the QSRA. Maximum lift coefficients in excess of 10 have been demonstrated in flight, and steep STOL approaches are routinely flown at lift coefficients of 5.5 with an engine inoperative. The importance of vortex generators located behind the engine nozzles and at the leading edge between the engine nacelles has been documented. Noise research has documented the low noise characteristics of the QSRA and its technology. The use of special "treatment" of the USB flap trailing edge to reduce noise has been demonstrated in flight. The benefits of propulsive-lift in improving takeoff performance or increasing payload or both have been demonstrated in a comprehensive flight program. And the capability of pilots with a variety of backgrounds to fly an airplane incorporating this technology at high-performance levels without extensive training or special experience has also been demonstrated. Flight research with the QSRA is continuing, and it is anticipated that this ongoing program will provide significant additional data and understanding of the benefits of advanced propulsive-lift technology.

Acknowledgments

The authors wish to acknowledge the contributions of the other members of the Quiet Short-Haul Aircraft Office and personnel of the Ames Research Center Aircraft Operations Division who are assigned to this project. In particular, we wish to recognize the contributions of Robert Innis and James Martin, who have been the QSRA project pilots since its first flight, and Dalton Mountz, who has been the QSRA crew chief since fabrication was completed. Without their efforts, this paper and the accomplishments reported herein would not have been possible.

References

[1] Phelps, A.E. and Smith, C.C. Jr., "Wind Tunnel Investigation of an Upper Surface Blown Jet-Flap Powered-Lift Configuration," NASA TN D-7399, 1973.

[2] Smith, C.C. Jr., Phelps, A.E., and Copeland, W., "Wind Tunnel Investigation of a Large Scale Semi-Span Model with an Unswept Wing and an Upper Surface Blown Flap," NASA TN D-7526, 1974.

[3] Parlett, L.P., "Free-Flight Wind Tunnel Investigation of a Four Engine Swept Wing Upper Surface Blown Transport Configuration," NASA TM X-71,932, 1974.

[4] "Wind Tunnel Investigation of Aerodynamic Performance, Steady and Vibratory Loads, Surface Temperatures, and Acoustic Characteristics of a Large Scale Twin Engine Upper Surface Blown Jet Flap Configuration," NASA TN D-8235, 1977.

[5] Aoyagi, K., Falarski, M., and Koenig, D.G., "Wind Tunnel Investigation of a Large-Scale Upper Surface Blown Flap Transport Model Having Two Engines," NASA TM X-62,296, 1973.

[6] Aoyagi, K., Falarski, M.D., and Koenig, D.G., "Wind Tunnel Investigation of a Large Scale Upper Surface Blown Flap Model Having Four Engines," NASA TM X-62,419, 1975.

[7] Carros, R.J., Boissevain, A.G., and Aoyagi, K., "Aerodynamic Characteristics of a Large Scale Hybrid Upper Surface Blown Flap Model Having Four Engines," NASA TM X-62,460, 1975.

[8] Nickson, T.B., Youth, S., and Middleton, R., "Large Scale Wind Tunnel Investigation of the Quiet Short-Haul Research Aircraft (QSRA)," NASA CR-152,350, 1980.

[9] Cochrane, J.A. and Boissevain, A.G., "Quiet Short-Haul Research Aircraft—Current Status and Future Plans," AIAA Paper 78-1468, 1978.

[10] Queen, S. and Cochrane, J., "QSRA Joint Navy/NASA Sea Trials," *Journal of Aircraft*, Vol. 19, Aug. 1982, pp. 655-660.

[11] Bohn, A.J., "Community Noise of the Quiet Short-Haul Research Aircraft," NASA CR-166,301, 1982.

[12] Bohn, A.J. and Shovlin, M.D., "Upper Surface Blowing Noise of the NASA Ames Quiet Short-Haul Research Aircraft," *Journal of Aircraft*, Vol. 18, Oct. 1981, pp. 826-832.

[13] Riddle, D.W., Innis, R.C., Martin, J.L., and Cochrane, J.A., "Powered-Lift Takeoff Performance Characteristics Determined from Flight Test of the Quiet Short-Haul Research Aircraft (QSRA)," AIAA Paper 81-2409, 1981.

[14] Stevens, V.C., Riddle, D.W., Martin, J.L., and Innis, R.C., "Powered-Lift STOL Aircraft Shipboard Operations: A Comparison of Simulation, Land-Based and Sea Trial Results for the QSRA," AIAA Paper 81-2480, 1981.

[15] Martin, J.L. and Strickland, P.B., "Shipboard Trials of the Quiet Short-Haul Research Aircraft (QSRA)," Paper presented to the Society of Experimental Test Pilots, Los Angeles, Calif., 1980.

[16] Queen, S.J., Strickland, P.B., Senn, C.P., and Webb, C.E., "Shipboard Trials of the NASA Quiet Short-Haul Research Aircraft (QSRA)," Naval Air Test Center Technical Report SA-51R-81, Naval Air Test Center, Patuxent River, Md., Oct. 1981.