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Quiet Propulsive Lift for Commuter Airlines

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INTRODUCTION

The commuter airlines are a dynamic and vital segment of the U.S. air transportation system. Scheduled passenger and cargo service is provided safely and at reasonable cost to an increasing number of communities. Using small aircraft such as the deHavilland Twin Otter, Beech 99, and Nord 262, profitable operations have been possible in some markets with range or passenger density too low to economically support the large aircraft operated by other carriers. Public acceptance of this service has led to average annual growth rates during the 1970's of over 10% in passenger enplanements and about 30% in cargo tonnage carried by the commuters.⁽¹⁾ Continued rapid growth is projected by the industry and the FAA in the "new era" of commuter operations resulting from the Airline Deregulation Act of 1978.

The traveling public will be well served by a continuation of the service responsible for commuter airline growth in the past: high frequency operations, with service to small community airports as well as the major hub airports. The majority of commuter passengers are connecting with certificated air carrier flights. Therefore, they require convenient access to the major airline terminals. This requirement, coupled with high frequency of service and rapid traffic growth, is placing heavy burdens on the major airports. Some airports are already limited in the number of landing slots available, and many more will become so in the next decade.

Commuter airline operating costs are very sensitive to aircraft delays. Because the average stage length is very short, a three minute average delay can increase their airplane operating costs by as much as 10%. Thus, continued service to small communities and the future financial success of the commuters depends on their ability to cope with increasing airport congestion as well as rising fuel costs, noise curfews, and other operating constraints.

One way of alleviating the airport congestion problem is to operate short haul systems separate from the long haul systems as much as possible. This was proposed in 1971, along with the use of STOL airplanes capable of using small runways at close-in STOL ports, for high density short haul operations.⁽²⁾ The concept of downtown STOL ports has been slow to gain acceptance in the U.S. because of public concern over safety, noise, and pollution in the airport vicinity. Yet, the Canadian demonstration service between small downtown airports in Ottawa and Montreal was highly successful in terms of both passenger demand and community acceptance.⁽³⁾ The demonstration proved that fast, reliable, and convenient intercity air transportation can be achieved.

An alternative means of using short field aircraft to relieve airport congestion is being proposed by U.S. commuter airlines. That is the use of small runways at the major airports, with ATC patterns separate from the long haul aircraft.⁽⁴⁾ Some airports, such as Washington National, regularly use separate traffic patterns for commuters and

general aviation aircraft, leaving the long runways free for large jets. Individual short runways already exist at many of the hubs, including Los Angeles, Seattle, and others. Some airports have sufficient space for adding short runways, even though longer conventional runways could not be built. At others, it is possible to use the stub end of an existing long runway or a taxiway.

Application of this operating concept requires air traffic control procedures for safe dual-pattern operations, and maneuverable, short field aircraft with the range, passenger capacity, and performance to assure economic viability. By placing orders for the new 50 passenger deHavilland DHC-7, several of the leading U.S. commuter airlines have expressed confidence in such an operation. The Ransome Airlines proposal to use the DHC-7 in dual pattern operations at Washington National is one example. Service with this aircraft is expected to expand in response to growth in passenger demand from small communities to the hubs and on short haul hub-to-hub routes. The low fuel consumption per seat mile and low noise of the DHC-7 enhance its attractiveness to the operators.

If the Ransome experiment succeeds in relieving congestion at Washington National, use of the dual pattern concept will increase at other major airports. Moreover, the availability of higher speed aircraft with the terminal-area performance of the DHC-7 would permit future extension of this operating concept to longer stage lengths.

Increasing demand may in time warrant the development of short to mid range jet transports designed specifically for efficiency at short stage lengths and incorporating operating systems designed to reduce congestion and noise. Due to block time savings, such aircraft may be economically competitive even though fuel consumption is higher than that of turboprop STOL aircraft.

Propulsive lift is one of the most efficient ways of achieving high terminal-area performance (high maneuverability, steep flight paths, low approach speeds, short field length, and low community noise levels) combined with high cruise speeds. However, numerous questions remain unanswered regarding the technical and economic feasibility of civil propulsive-lift aircraft. This paper describes NASA's Quiet Short-Haul Research Aircraft, and the program to develop technology to support future design and certification of practical, quiet propulsive-lift transports.

THE ROLE OF NASA

The role of NASA in aeronautics is to provide a technical foundation that will enable the nation to exploit advances in aircraft technology for the development, welfare, and security of the U.S. and its citizens.⁽⁵⁾ This entails broad-based research in aerodynamics, propulsion, structures, flight dynamics, avionics and operating systems technology. Both ground facilities and research aircraft are employed. NASA strives to identify the potential benefits of technical advances in order to guide the direction of its programs. This is accomplished in part through interface with regulatory agencies such as FAA, with aircraft and airport operators, and with the aircraft manufacturing industry. NASA demonstrates promising technical advances and promotes technology transfer, but generally does not participate directly in prototype aircraft development.

What is NASA doing to improve short haul aircraft capabilities? One program, the Small Transport Aircraft Technology (STAT) Program at Ames Research Center, is specifically addressed to the needs of the commuter and local service airlines. The objective of STAT is to identify and demonstrate the cost-effective application of advanced technology to future small (15 to 60 passengers), short haul (50 to 1000 miles) transport aircraft. The STAT Program will focus on improving the economy, performance, energy efficiency, environmental compatibility, and safety of aircraft operating over short stage lengths in a low altitude environment.

Another program oriented toward short haul is the Quiet Propulsive-Lift Technology (QPLT) Program. In the early 1970's a need was perceived

for quiet STOL aircraft technology to provide a potential solution to the problems of airport congestion and noise experienced in the late 1960's. NASA established the QPLT Program to develop this technology. The objective of the QPLT Program is to furnish the U.S. Government and aviation industry with flight data which can be used to develop design methods and certification criteria for practical, quiet, propulsive-lift aircraft. This will help develop options for future U.S. short haul transportation and will reduce the technical risk associated with the design, development, and certification of quiet STOL aircraft.

It is not NASA's intent with either STAT or QPLT to define regulatory requirements or to influence decisions by the manufacturers or airlines whether or not to utilize the technology. It is NASA's intent to provide the technical data from which realistic assessments of performance and operating economics may be made for advanced short haul aircraft.

THE QSRA

A major element of the QPLT Program is the Quiet Short-Haul Research Aircraft (QSRA) Project at Ames. The QSRA is a new research aircraft built for NASA by the Boeing Commercial Airplane Company. The QSRA will be used for flight experiments in terminal-area operations. It utilizes a hybrid upper surface blowing (USB) propulsive-lift concept to achieve significant improvements in low speed performance and very low community noise levels. Figure 1 depicts the USB concept. It depends on the Coanda effect to turn the engine exhaust airflow over a simple curved flap. This action converts a large part of the thrust to lift while also entraining additional airflow over the wing to increase the aerodynamic lift. The USB concept was first investigated by NASA in 1959, and is used on the Boeing YC-14 airplane in addition to the QSRA.

The QSRA is a modified deHavilland C-8A Buffalo, with a new swept wing and nacelles, and 4 AVCO-Lycoming YF-102 turbofan engines. The gross weight capability ranges from 40,000 to 60,000 lb, permitting research at wing loadings from 67 to 100 lb/sq. ft. The QSRA is not a passenger carrying aircraft; the fuselage contains research instruments, fuel tanks, and the aircraft hydraulic and electrical systems hardware. Figure 2 shows the QSRA in final approach at Moffett Field, California. The USB flaps generally are deflected from 50 to 66° for landing approach. The corresponding touchdown speeds range from 67 to 55 knots, resulting in stopping distances as low as 550 ft. with no head wind and without reverse thrust.

For optimum utilization, a short-field airplane requires a steep approach angle to minimize the required air space in the terminal area, as well as to minimize community noise. The USB nozzle and flaps on the QSRA have been designed for exceptionally high turning of the engine exhaust flow to permit 7.5° approach angles with full safety margins. Figure 3 compares the approach angle and landing ground roll for current commercial airliners to the QSRA capability. The height of the QSRA approach path one mile from the runway is over twice that of conventional airplanes. Since noise attenuates rapidly with distance (height) the higher approach altitude is a very big factor in reducing the noise impact on the community. The height over the community can be increased even more by landing the QSRA toward the center of the runway if using conventional runways.

The performance values listed in Table I were demonstrated during the initial 40 research flights. The QSRA has exceptional low speed performance, providing high versatility for research in terminal area operations. Design changes are being investigated to further demonstrate the potential to reduce the takeoff noise.

The excellent maneuverability of the QSRA would permit dual pattern operations with a minimum of traffic interference. An example of this is shown in Figure 4, an artist's concept of QSRA operations at Los Angeles International Airport. In this illustration, arrivals from the north use the VFR corridor to transit the four CTOL runways with a 270° turn to descend from the crossing altitude and align with the STOL

runway for a landing to the west. On departure the reverse procedure is used. The small turning radius of QSRA permits the turn to final to be made without interference with the CTOL traffic and also helps to concentrate the relatively low noise over the airport property. It is not the intent of this illustration to advocate a traffic pattern such as that shown, but rather to illustrate the flexibility possible with an aircraft based on QSRA technology.

Low community noise was emphasized in the design of the QSRA. The Lycoming YF-102 engine has a relatively high bypass ratio (6 to 1) which is conducive to low noise. The installation was designed to attenuate the engine noise by including tuned acoustic linings in the inlet and fan duct as shown in Figure 5. In addition, engine placement above the wing provides noise shielding to ground observers. These design features result in an extremely quiet airplane, as exemplified by comparing the 90 EPNdB footprint of a current jet commercial airliner (Figure 6) to that of a QSRA derivative of the same gross weight as the commercial airliner. At Los Angeles International Airport, the 90 EPNdB footprint of a medium transport using QSRA technology would be nearly all contained within the airport boundaries.

Of more interest to the commuter airline industry is the noise footprint of a 40 to 50 passenger QSRA derivative. Since the QSRA itself is a modified deHavilland C-8A Buffalo (41 passengers), it is of a representative size and gross weight. Figure 7 shows the 90 EPNdB footprint of the QSRA (50,000 lb gross weight) superimposed on the San Jose Airport. The noise reaching the surrounding community would be well below the 90 EPNdB level.

PERFORMANCE TRADEOFFS

The potential benefits of QSRA technology for relief of airport noise and congestion are easily recognized. However, fuel consumption is a major concern to potential users of propulsive-lift aircraft due to the relatively high thrust to weight requirement. As fuel prices increase, this concern becomes more pronounced.

The QSRA was designed for one primary purpose: terminal area research. As a cost reducing measure, it has fixed landing gear, fixed wing leading edge, and other drag-producing features. In addition, it uses the existing DHC-5 fuselage and tail structure, which were not designed for high speed flight. Consequently, QSRA cruise speed is low, fuel consumption is high, and the aircraft cannot provide answers to the questions of future propulsive-lift aircraft fuel economy.

Previous design studies have shown that propulsive lift is probably the most fuel-efficient way to achieve high cruise speed (400 kts. or greater) in combination with short field operations (under 3000 ft.).⁽⁶⁾ Moreover, various performance tradeoffs are possible to reduce fuel consumption of future propulsive-lift aircraft. Whereas the research mission of the QSRA requires extremely high levels of performance, commercial versions will be designed for maximum operating economy consistent with each particular application. If the short field capability and terminal area maneuverability requirements are less than that of QSRA, the fuel economy will be better.

Many factors enter into the determination of an airplane's fuel efficiency. Two important factors are aerodynamic efficiency and propulsive efficiency. These depend on design features such as wing

size and the type of propulsion system, which in turn determine performance characteristics such as ride quality, cruise speed, and low speed maneuverability.

Aerodynamic efficiency is based on the zero lift drag of the airplane and the drag due to lift (induced drag). At high speeds, drag due to compressibility effects also becomes significant. One way in which cruise drag may be minimized is to cruise the airplane at a speed which corresponds to the maximum ratio of lift to drag $(L/D)_{\max}$. The maximum lift-to-drag ratio for an airplane occurs when the induced drag is equal to the zero lift drag. In order to fly at a lift coefficient which is compatible with minimum cruise drag and still maintain high cruise speeds, a high wing loading is required.

An airplane equipped with conventional mechanical flaps is limited to a maximum usable approach lift coefficient of approximately 1.8 when commercial aircraft safety margins are considered. When the high wing loading required for efficient cruise is combined with landing approach lift coefficient of 1.8 and the attendant high landing speed, landing field lengths in excess of 5000 ft. result. In addition, because of the high approach speeds, the turn radius required when maneuvering in the vicinity of the airport is proportionately increased.

If, however, QSRA propulsive-lift technology is applied to an airplane with a wing loading which is optimized for high speed cruise, both landing field lengths and approach turn radius are dramatically reduced. Figures 8 and 9 illustrate these advantages. Referring to Figure 8 for example, if a cruise speed of 400 knots is selected, the

landing field length with QSRA technology would be 2000 ft. while with mechanical flaps the landing field length would be 5500 feet.

First generation propeller-driven STOL airplanes achieved good low speed performance by use of large wings which were strut braced and combined with fixed landing gears. These configurations were most suitable for low speed cruise and even at modest cruise speeds had relatively poor aerodynamic efficiency. Other factors being equal, fuel consumption increases with the cube of the velocity. However, since these aircraft operated at cruise speeds under 200 knots, their fuel efficiency was acceptable. In addition, low cruise speeds permitted the use of reciprocating engine and turboprop power plants which have good propulsive efficiency at low speeds.

As stage lengths increase, low speeds become less acceptable to the passenger and adversely affect aircraft productivity. High speed jet aircraft reduce transit time and provide better ride quality because of generally higher wing loadings and higher operating altitudes. However, to achieve these improvements, conventional jet transports sacrifice the low speed performance and maneuverability required for dual pattern short haul operations like that shown in Figure 4.

Propulsive lift permits good low speed maneuverability with a high wing loading (80 to 100 PSF). This is efficient for high speed cruise and also provides a smoother ride in turbulent air. In addition, QSRA uses advanced high bypass ratio turbofan engines which have inherently low fuel consumption.

Thrust to weight of an aircraft based on QSRA technology will depend on design field length. Generally, the thrust to weight will be 0.40 to 0.60 (uninstalled) for FAR field lengths ranging from 2500 to 1500 feet, respectively. This is a higher thrust to weight than large commercial aircraft use, but is comparable with the thrust to weight of some modern business jet aircraft. The higher thrust to weight of a propulsive-lift aircraft can be used to advantage by cruising at higher altitudes at the design cruise speed if stage length permits.

The amount of propulsive lift designed into an aircraft can be tailored for each application. With USB flaps retracted, an airplane based on QSRA technology provides conventional operating characteristics, with Mach 0.7 to 0.8 cruise speeds and excellent ride comfort. If field lengths of 3500 to 4000 ft. are acceptable, the thrust to weight ratio would approach that of conventional transports, thus providing good fuel efficiency and operating economics. Yet, shorter field performance could be achieved by offloading payload when necessary. This operational flexibility could make propulsive lift very attractive to short haul airlines who need to operate both in the congested hubs and small airports.

QSRA FLIGHT EXPERIMENTS

The QSRA will be used in a comprehensive flight research program to answer a number of technical questions related to the operational feasibility of future jet R/STOL short haul transportation. Experiments will be conducted with the following objectives:

- (a) Establish design criteria to assess the best compromise with respect to wing loading, propulsive-lift, and flight control systems.
- (b) For flight operation at approach lift coefficients of 3.5 to 5.5, determine requirements and criteria for approach path performance, stability and control, handling qualities, and operational safety margins.
- (c) Obtain technical information required to establish operational criteria relative to approach flight path control precision, touchdown dispersion, field length requirements, runway acceptance rates, terminal area spacing, wake turbulence, gust effects and ride comfort, crosswind and shear effects, terminal area operating procedures, ground handling, and STOLport geometry.
- (d) Establish functional and performance requirements for guidance and navigation systems, air traffic control interface requirements, and the inter-relationships between the aircraft, pilot, airborne avionics, and other elements of the short haul transportation systems.

- (e) Investigate advanced nav/guidance concepts and operational techniques such as steep, circling approaches and departures for low noise in nonautomated flight modes.
- (f) Provide the on-going NASA/FAA study of STOL certification criteria and tentative airworthiness standards with test-case, relevant flight experience for high propulsive-lift performance levels and for advanced flight control concepts and displays; establish the effects on landing distance of pilot control techniques, abuses of flare techniques and flare entry conditions.
- (g) Study methods for alleviation of propulsive-lift noise and structural loads.
- (h) Investigate ground proximity effects on aerodynamics and stability and control at very high lift coefficients.
- (i) Investigate alternative configuration options to improve and simplify USB design, including consideration of constraints imposed by cruise performance considerations.
- (j) Where appropriate, serve as an inflight demonstrator of STAT program technology, such as actuators developed for potential use in an all electric controlled aircraft.

The QSRA experiments program will include FAA participation. Guest pilot evaluations are planned, as are operational demonstrations (without passengers) at a limited number of airports. Principal investigators from outside of NASA may also propose flight and ground research experiments to be conducted on or related to the QSRA, which will be regarded as a national flight research facility.

CONCLUDING REMARKS

Deregulation is bringing the operating environment of the commuter airlines and certificated carriers closer together. If the expected short haul traffic growth materializes, the commuters will gradually begin operating larger aircraft and over longer stage lengths. If the Ransome Airlines demonstration of DHC-7 service in a dual traffic pattern at Washington National is a success, acceptance of quiet STOL will grow among the airlines, the public, and the airport authorities. These factors may combine to create a need for future short haul aircraft with the versatility and terminal-area performance of the DHC-7 and cruise speeds approaching that of jet transports. Currently only 20% of the nation's airports have runways that are sufficiently long to permit the landing of modern jet transport aircraft; it is estimated, however, that 80% of the nation's airports could be utilized if there existed a fleet of quiet short-to-medium range aircraft capable of efficiently using 2,000 to 5,000 foot runways.

NASA's research program in propulsive lift was spawned in the 1960's, an era of airport congestion and noise problems. Airline interest in jet STOL waned as fuel prices increased and airport congestion decreased during the early 1970's. However, public interest in the Ottawa-Montreal STOL demonstration and the growing number of orders for the DHC-7 aircraft suggest that the age of STOL may have arrived. Quiet STOL or RTOL aircraft, using separate runways and dual traffic patterns

at major airports and existing runways at small airports, could significantly increase the air transportation system capacity with a minor impact on the airport community.

NASA's QSRA is a very quiet high performance research aircraft. Its technology provides several benefits: low community noise levels, increased safety (low landing speeds), and operational versatility (steep flight paths, high maneuverability, short field performance). This technology could provide partial solutions to some of the concerns which have plagued air transportation in recent years.

To the general public, the major concern is aircraft noise and pollution, and hence, there has been resistance to building additional airports or expansion of existing airports. QSRA technology is one solution. To the passenger, delays and inconvenience were not the problem during most of the 1970's that they were during the 1960's. However, this will again become a serious problem in the 1980's as traffic demand exceeds available runway or terminal capacity. The airlines must consider the economics of delays due to airport congestion, noise curfews, and other operating constraints. QSRA technology is one solution.

Future commuter aircraft may or may not use QSRA technology. The advantages of block time savings and improved ride quality available with the jet must be weighed against the fuel economy of the turboprop. The QSRA program will not answer the question of optimum speed and range, nor is it intended to influence the economic decisions of the aviation community. But it will help provide options for future U.S.

short haul transportation. It will reduce the technical risk of developing civil and military propulsive-lift transports, and will provide data with which regulatory agencies can establish realistic certification criteria if commercial applications materialize.

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TABLE I
DEMONSTRATED QSRA PERFORMANCE

$C_{L_{max}}$ (All Engines Operating)	8.9
$C_{L_{approach}}$	5.5
V_{min}	50 kt.
Approach Flight Path	7.5°
FAR Field Length	1500 ft.
Turn Radius	600 ft.
Ground Roll (zero wind)	
Takeoff	650 ft.
Landing	550 ft.
90 EPNdB Footprint	1.0 sq. mi.
500 ft. Sideline Noise	
Takeoff	93 EPNdB
Landing	89

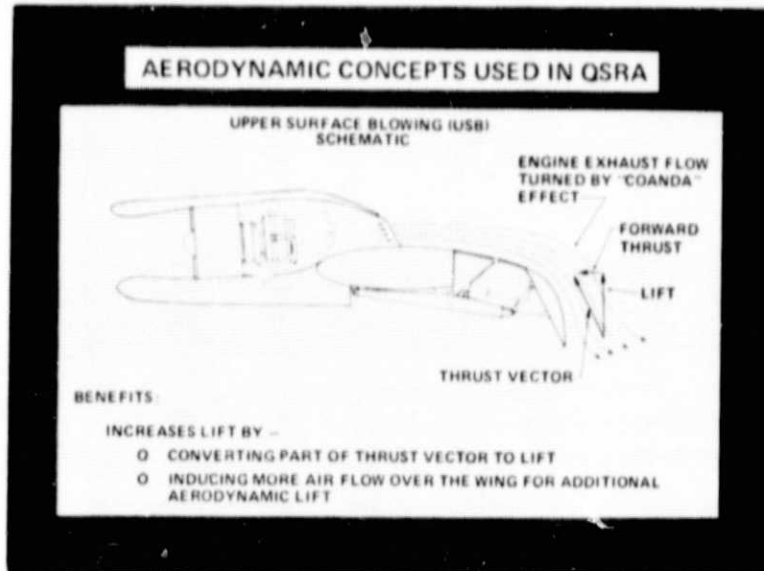


Figure 1. Upper Surface Blowing Concept

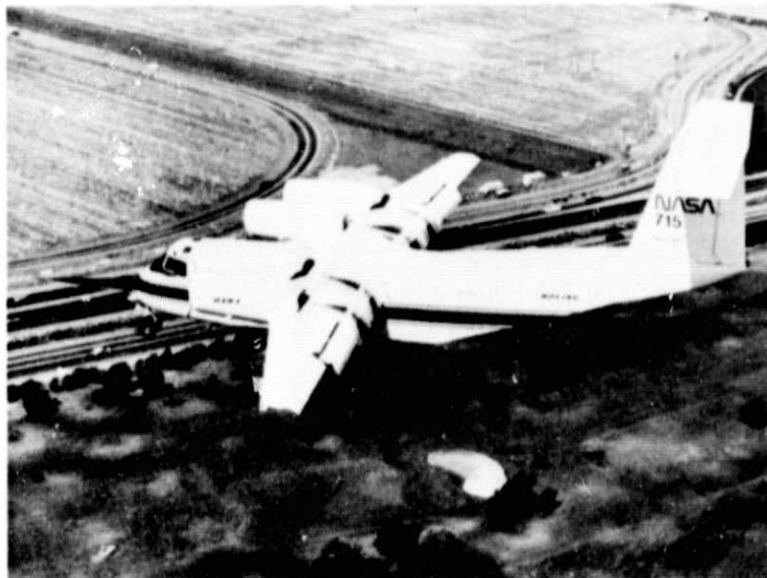


Figure 2. QSRA on Landing Approach

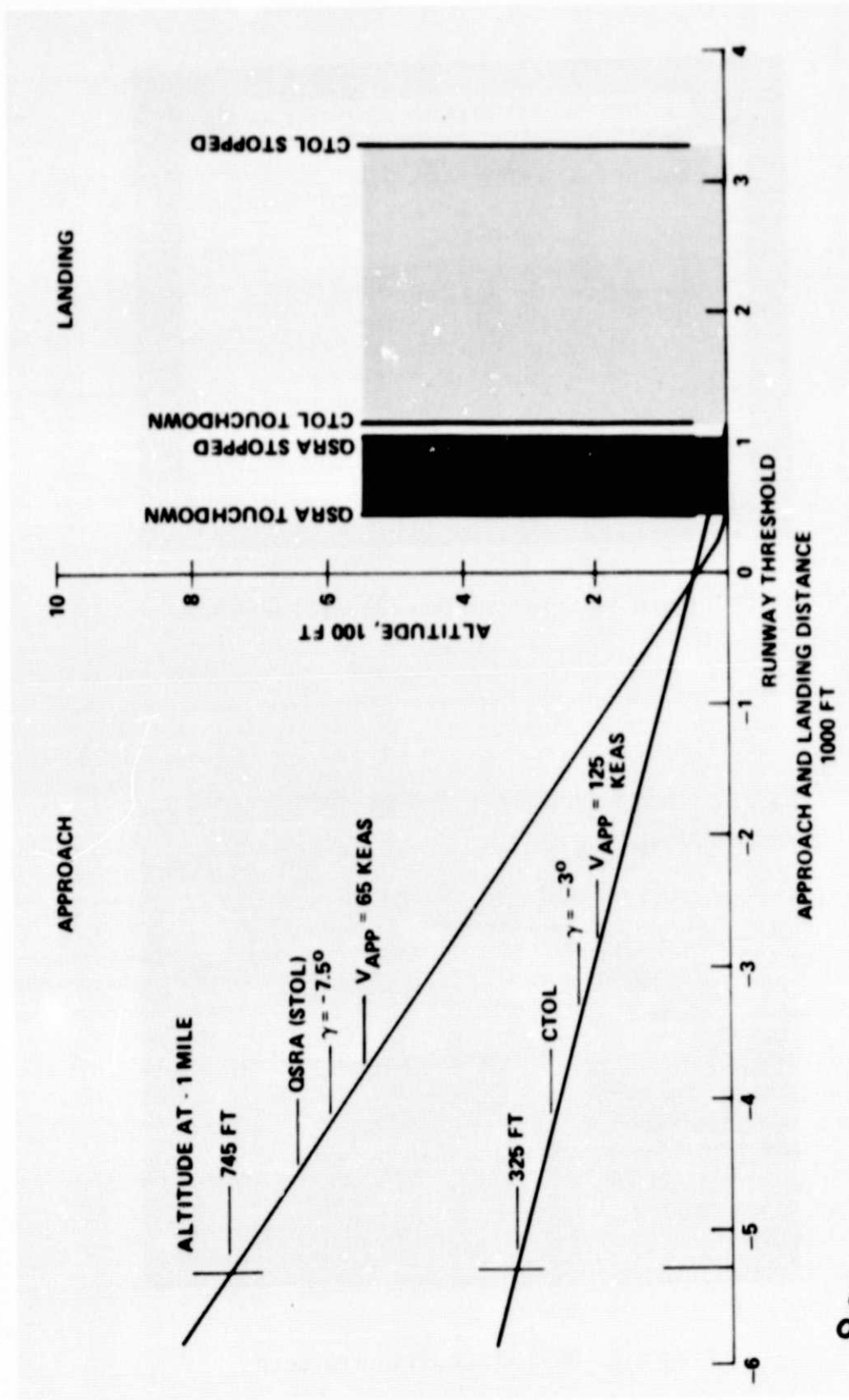


Figure 3. OSRA and CTOL Approach and Landing Distance Comparison

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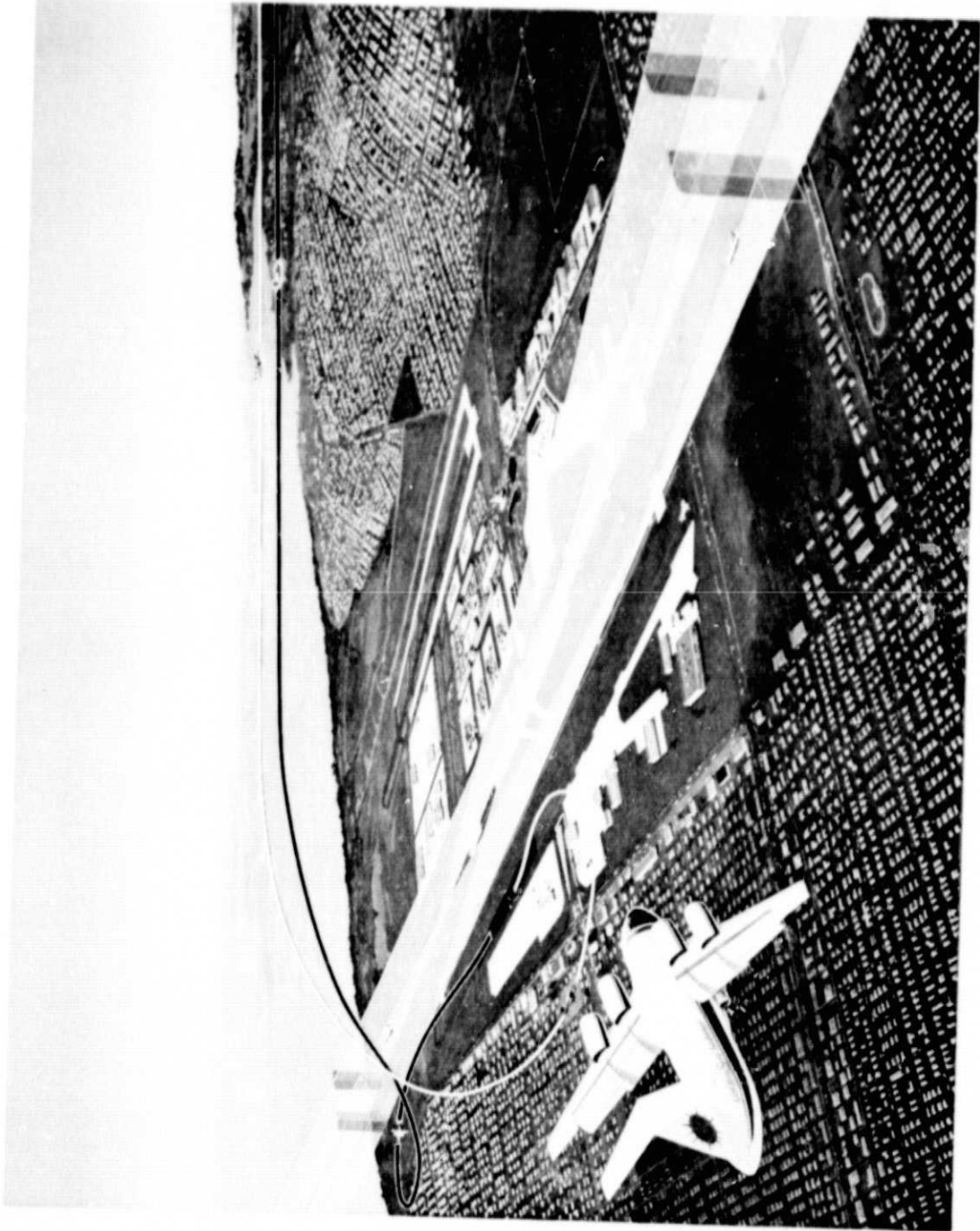


Figure 4. QSR Interface - Los Angeles International Airport

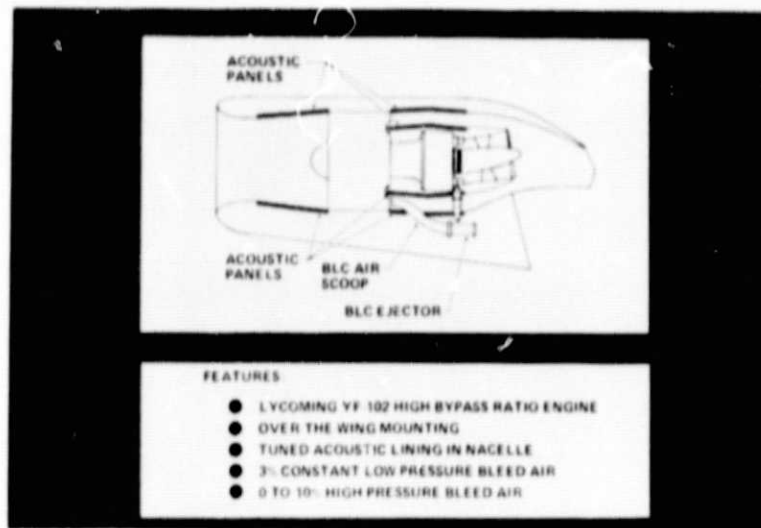


Figure 5. QSRA Engine Installation and Acoustic Panels

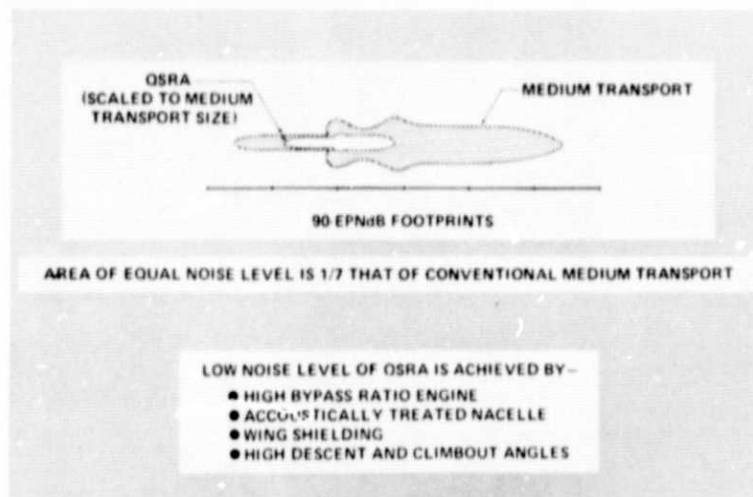


Figure 6. 90 EPNdB Footprint of Scaled QSRA vs. Commercial Medium Transport

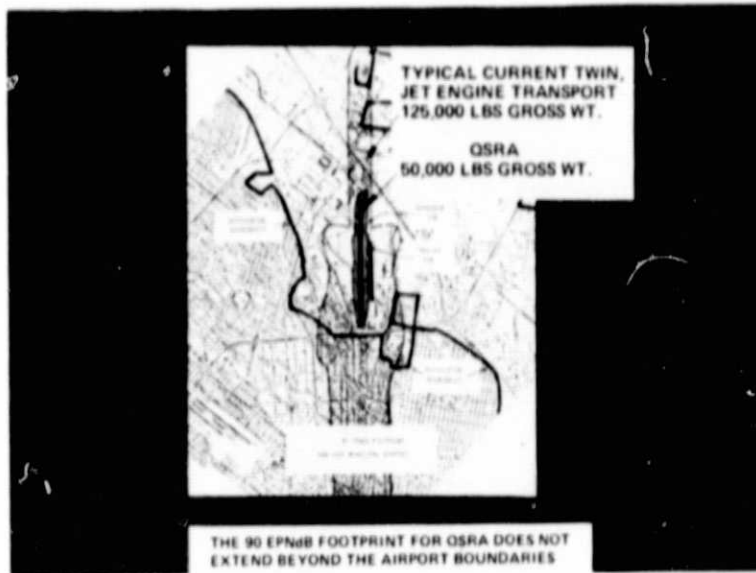
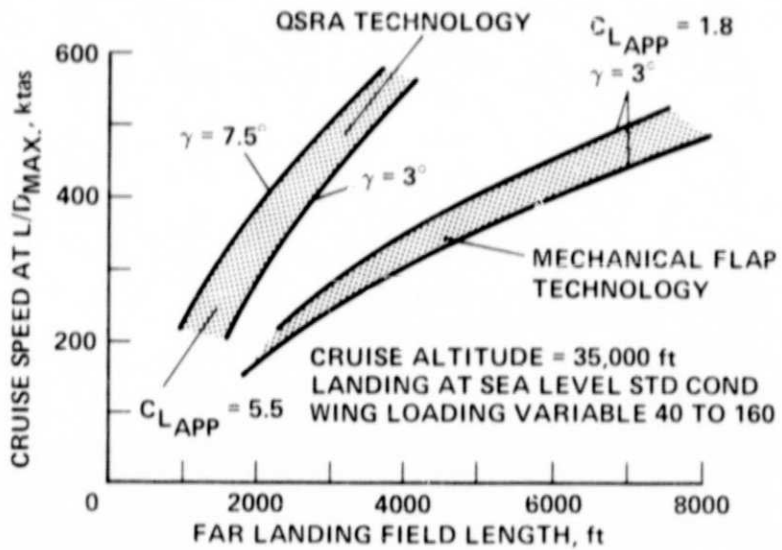


Figure 7. QSRA 90 EPNdB Footprint at San Jose Municipal Airport



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Figure 8. FAR Landing Field Length vs. Cruise Speed

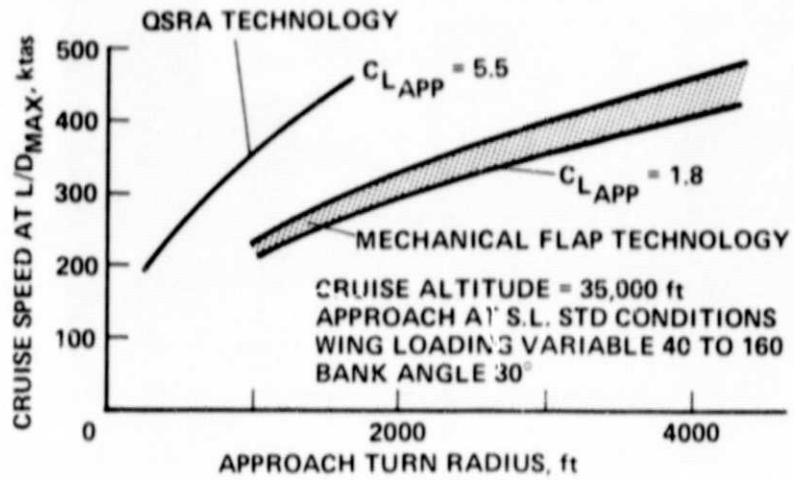


Figure 9. Turn Radius vs. Cruise Speed