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Recent Progress In V/STOL Aircraft Technology

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RECENT PROGRESS IN V/STOL AIRCRAFT TECHNOLOGY

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SUMMARY

Recent results from wind-tunnel and flight-tests investigations for V/STOL aircraft are reviewed. Primary emphasis is given to technical results relating to three types of subsonic aircraft: a quiet STOL aircraft; a tilt rotor aircraft, and a turbofan V/STOL aircraft. Comparison and correlation between theoretical and experimental results, and between wind-tunnel and flight-test results, is made. The quiet STOL aircraft technology results are primarily those derived from the NASA/Boeing Quiet Short Haul Aircraft (QSRA) program. The QSRA aircraft uses an upper surface blown flap and develops a usable engine-out landing approach lift coefficient of 5.5 and landing distances less than 1,000 ft. The tilt rotor aircraft technology results are those obtained from the NASA/Army/Navy/Bell (XV-15-TRRA) aircraft flight investigations. The TRRA is a twin rotor research aircraft capable of vertical takeoff and landing and cruise speeds of 300 knots. The turbofan V/STOL aircraft technology results are from static ground facility and wind-tunnel investigations of a NASA/Navy/Grumman full-scale lift/cruise fan aircraft model, which features two tilting nacelles with TF-34 engines.

1. INTRODUCTION

The past several years have seen steady progress in the research and technology development of short takeoff and landing (STOL) and vertical takeoff and landing (VTOL) aircraft configurations. There now appears to be emerging a growing recognition that this technology can play an important role in providing a military logistics capability that will offset the growing vulnerability of large forward air bases and of large ships at sea. When the technology and the mission needs are made compatible with each other, we can expect to see a new generation of military logistics aircraft that will include long-range and short-range aircraft designed to operate with great versatility from a variety of bases.

This paper reviews some of the recent STOL and VTOL technology advances in the United States that have derived from collaborative programs between NASA, the Army, the Navy, and the aircraft industry. The primary emphasis here is on three kinds of aircraft that can potentially fill the current "versatility gap" between conventional military transport aircraft and conventional helicopters. The results from several representative investigations are discussed to demonstrate the improvements that have been made through wind-tunnel, simulator, and flight programs. In addition, an attempt is made to summarize applicable technology with respect to the readiness of these types of aircraft for future military applications.

2. MISSIONS AND VEHICLES

Currently, only two means of air-logistics are available to support military and naval operations:

1. Large conventional takeoff and landing (CTOL) aircraft capable of long-range missions but limited to arrival points that have long runways

2. Helicopters capable of taking off and landing at a wide variety of locations, including unprepared sites, but with limited payload and range capabilities.

As the need for greater basing flexibility and faster response continues to grow – in Europe, in the Middle East, and elsewhere – the limitations of large aircraft serving fixed, concentrated supply bases that are subject to runway denial by enemy attack, are now recognized. Similarly, the concentration of naval resources in a relatively few large ships places severe limitations on the flexibility of the deployment of naval forces; as a result, greater attention is being directed to the use of a distributed seagoing force having appropriate air logistics. Although the helicopter has played a vital role in very-short-range logistics its inherently limited range and speed prevent it from fulfilling many missions in which material must be rapidly transported over intermediate distances.

The full exploitation of air logistics requires additional kinds of aircraft – vehicles capable of bridging the gap between conventional aircraft and helicopters; that is, aircraft that can operate efficiently over intermediate ranges and also be capable of operating into short-to-intermediate runways, including ships at sea. Figure 1 is a simple representation of the air logistics gap described in terms of two parameters: aircraft range and field length. The helicopter is at one extreme and the CTOL transport is at the other; between the two there has been no other successfully developed form of air transportation.

The design of a single aircraft, capable of efficient cruise over long range and of efficient hover for short range, must be considered too difficult a task for the near term. It is not surprising, therefore, that a number of concepts have been proposed that partially fill the void suggested in Fig. 1. Three of these concepts – the fixed wing STOL transport, the tilt-rotor V/STOL transport, and the lift-cruise fan transport – attempt to perform in the region between the CTOL and the helicopter. Because of recent technical progress, it is worthwhile to review the status of these concepts, and to assess the degree to which each may be ready for development.

When these three concepts are characterized in terms of range and field length (Fig. 2), it is clear that the fixed-wing STOL transport, which derived from the CTOL, sacrifices some range capability in order to achieve short-field operation capability. Similarly, the tilt-rotor transport, which derives from the helicopter, sacrifices some hover performance to achieve greater range. Because of the derivative nature of these two concepts, their technical development has progressed more rapidly than that of the third

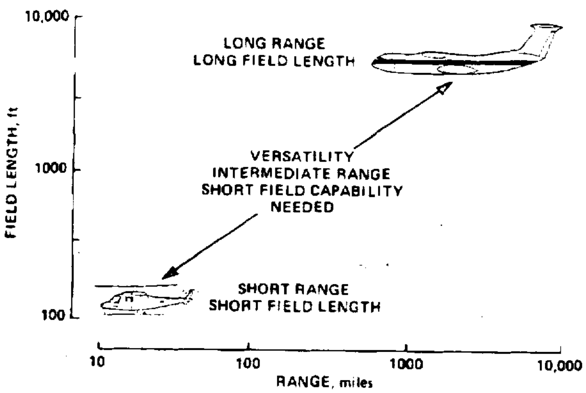


Figure 1. Aircraft range and field length capabilities.

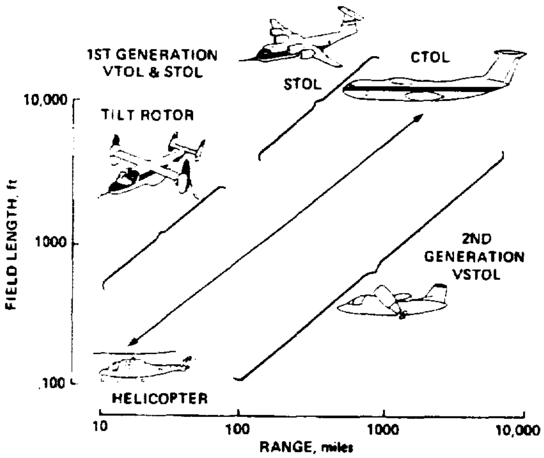


Figure 2. New technology aircraft: powered-lift STOL, tilt-rotor, turbofan VTOL.

concept, the lift-cruise fan aircraft, which is a more radical departure from current aircraft design. However, this third concept is potentially capable of vertical takeoff, high cruise speed, and long range. In the remainder of this paper the technical progress recently made with each of these three V/STOL aircraft concepts is described.

3. RECENT DEVELOPMENTS IN V/STOL TECHNOLOGY

A number of V/STOL concepts are being actively pursued, including the ABC rotorcraft, the X-wing (stoppable rotor) concept, and various approaches to powered-lift STOL and VTOL aircraft. This paper, however, is restricted to a discussion of some recent work on three aircraft: (1) a STOL powered-lift aircraft (the QSRA), (2) a compound rotorcraft (the TRRA), and (3) a turbofan V/STOL aircraft. These three programs are thought to represent the forefront of technology-readiness for logistics/utility vehicles designed to fill the capabilities gap between helicopters and CTOL aircraft.

3.1 STOL Transport Technology

There has been significant progress in powered-lift technology for STOL transport aircraft during the last 10 years. The primary effort within NASA, undertaken in conjunction with the Boeing Company, has been the flight demonstration of an advanced upper-surface-blowing (USB) powered-lift concept. The aircraft used in this program, the Quiet Short-Haul Research Aircraft (QSRA), has provided proof-of-concept verification of the USB approach and has been used extensively to investigate terminal-area operations for STOL aircraft.

The QSRA (Fig. 3) utilizes a deHavilland C-8 Buffalo fuselage and empennage, and a new swept wing with four Lycoming YF-102 turbofan engines mounted above the wing. As illustrated in Fig. 4, the USB concept is used for propulsive-lift. The wing, nacelles, and propulsion system were designed to be representative of a configuration capable of efficient cruising flight at Mach 0.74. To pursue the flight research objectives at minimum cost, the configuration uses fixed landing gear, fixed leading-edge flaps, and other configurational compromises that limit maximum airspeed to 190 knots. Some of the QSRA characteristics are presented in Table 1.

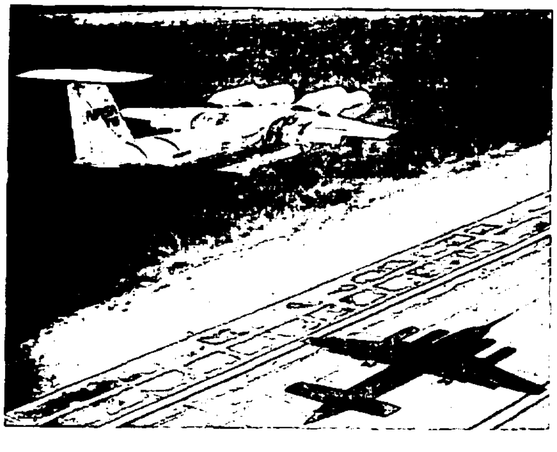


Figure 3. QSRA in landing configuration.

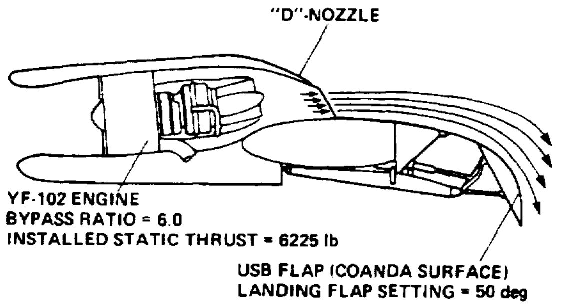


Figure 4. Upper-surface-blowing wing-engine schematic.

The airframe modification program was completed by the Boeing Commercial Airplane Company in July 1978. In 1979-1980, QSRA research activities included the areas of configurational aerodynamics and acoustics, as well as flight control systems research to expand the research flight envelope; a cooperative program with the U.S. Navy that featured unarrested landings and unassisted takeoffs aboard the U.S.S. Kitty Hawk; and a guest evaluation program in which pilots from other NASA centers, the military services, airline organizations, the FAA, and industry participated. Presently the QSRA is being flown at reduced engine settings to determine the low-speed characteristics applicable to the class of propulsive-lift aircraft that feature low to medium thrust-to-weight ratios. As of February 1981, the QSRA had accumulated 280 research flight hours.

The QSRA flight research envelope is shown in Fig. 5. The upper boundary is limited by the usable approach lift-coefficient when one engine is inoperative and while meeting the usual commercial safety margins, such as speed, angle of attack, and normal acceleration. This approach lift-coefficient is 5.5 with USB flaps and double-slotted flaps (located outboard of the USB region) deflected 50° and 59°, respectively. By design choice, the left-hand boundary is for a wing loading of 65 lb/ft^2 and the right-hand boundary is for a wing loading of 100 lb/ft^2. As shown in Fig. 5, at lower wing loadings the upper part of the research envelope is bounded by aircraft control and safety margin limits at an approach airspeed of 65 knots. Other powered-lift aircraft have also experienced limitations in approach-lift coefficient because of inadequate control (rather than because of inadequate propulsive-lift performance), particularly for the required engine-out case.

The lower boundary for the QSRA flight-research envelope is somewhat arbitrarily defined as the CTOL configuration that features no deflection of the USB flaps (with double-slotted flap deflection of 59°). With an engine out and operating in compliance with commercial margins, the QSRA has a minimum turn radius of 380 ft, a typical flightpath approach angle of 7.5°, and a required field length of 1,530 ft. With a 30-knot wind over the deck of the U.S.S. Kitty Hawk, the QSRA landing ground-roll was 200 ft (approximately twice its fuselage length), without using arresting gear and without reverse thrust.

Trimmed lift coefficients as functions of angle of attack for the QSRA and for a typical CTOL short-haul turbofan transport are presented in Fig. 6; data in the figure are for all engines operating. The approach coefficients of the QSRA are several times that of the CTOL transport. With the QSRA, the percentage of lift-loss with one engine inoperative is low, which permits an operational lift-coefficient close to maximum lift coefficient. Note from the previous discussion and from Fig. 5 that the QSRA approach lift-coefficient is a maximum of 5.5 with all engines operating or with one engine out. Using a typical flightpath approach angle of 7.5°, the QSRA fuselage attitude is essentially horizontal during approach. This characteristic simplifies landing flare requirements and implies passenger comfort. At maximum engine thrust levels (not shown on Fig. 6) the QSRA has flown at maximum lift-coefficients above 10.

TABLE 1 QSRA CHARACTERISTICS

Design takeoff gross weight	50,000 lb
Maximum takeoff gross weight	60,000 lb
Demonstrated maximum takeoff gross weight	57,000 lb
Wing loading at design gross weight	83 lb/ft^2
Thrust-to-weight at design gross weight, measured	0.50
Maximum sink rate at design gross weight	12 ft/sec
Wing fuel capacity	10,670 lb
Fuselage fuel capacity	5,409 lb
Range with 45-min reserve (2,800 lb)	387 n.mi.
Typical test mission duration	2-1/4 hr
Long-range cruise speed at 10,000 ft	170 KTAS
Design ceiling	15,000 ft

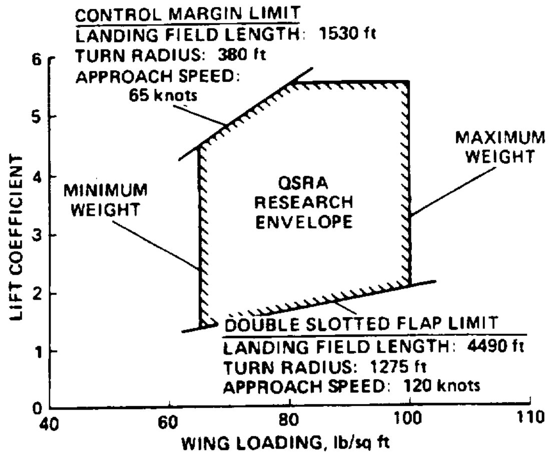


Figure 5. QSRA flight envelope: lift coefficient vs wing loading.

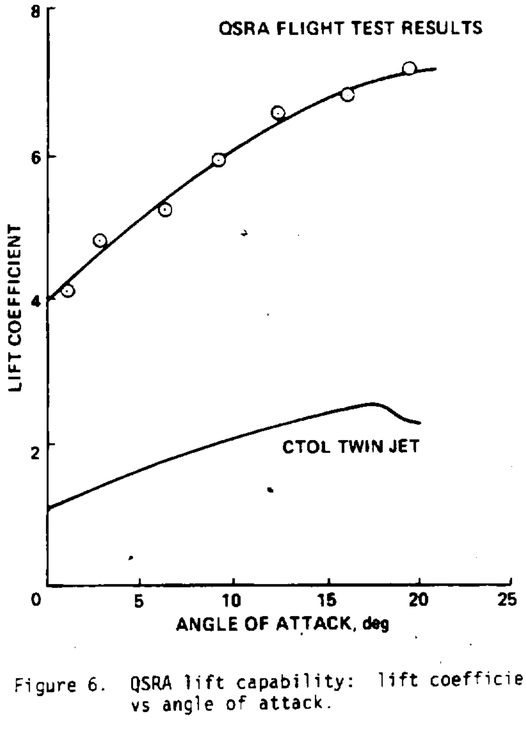


Figure 6. QSRA lift capability: lift coefficient vs angle of attack.

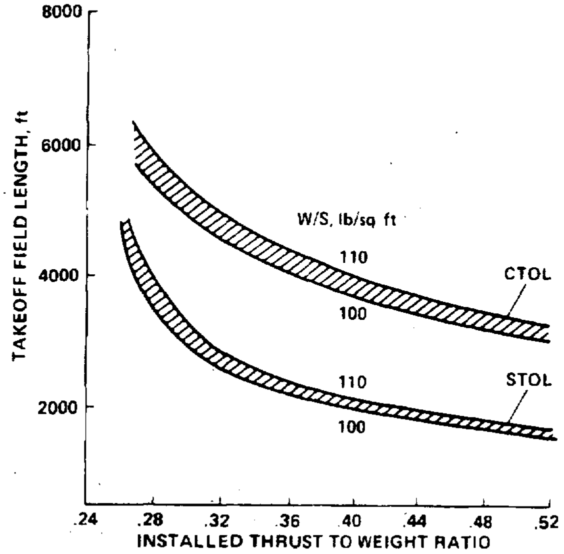


Figure 7. STOL and CTOL field length vs thrust/weight.

Figure 7 is a plot of Federal Air Regulation (FAR) takeoff field length (based on FAR rules for transport aircraft) as a function of installed thrust-to-weight ratio for a STOL transport based on QSRA technology and for a CTOL short-haul turbofan aircraft with comparable wing loadings. At high thrust-to-weight ratios the takeoff field length for the STOL transport is about one-half that of the CTOL aircraft. For example, for a wing loading of 110 lb/ft^2 and a thrust-to-weight ratio of 0.50, the STOL field length is 1,750 ft; that of the CTOL is 3,350 ft. Note that at low thrust-to-weight ratios, typical of values used on CTOL transports, field length differences remain significant. For example, for a wing loading of 110 lb/ft^2 and a thrust-to-weight ratio of 0.30, the STOL and CTOL field lengths are 3,200 and 5,300 ft, respectively.

Also notice the implications of Fig. 7 if STOL and CTOL designs are compared at a fixed field length. For example, for a wing loading of 110 lb/ft^2 and a takeoff distance of 4,000 ft, the STOL and CTOL required thrust-to-weight ratios are about 0.28 and 0.40, respectively. These differences in required thrust-to-weight ratios at equal field distances have significant implications in aircraft design. Using the same engines, whether existing engines or advanced engines, the STOL gross weight could be higher than that of the CTOL, with an accompanying larger useful load or payload for the STOL aircraft. At equal field lengths, the STOL aircraft would feature a much larger useful load, relatively small penalties in cruise airspeed and empty weight, and therefore a higher productivity. It should be noted that the state of the art of STOL technology makes this an opportune time for in-depth aircraft design studies in which powered lift would be viewed from many aspects, not just as an approach to short field lengths.

Summary conclusions from the results of the QSRA flight research to date include the following:

1. A four-engine USB configuration can have very high performance and at low speeds can be a relatively easy aircraft to fly.

2. At any design thrust-to-weight ratio, including the low ratios typical of CTOL transports, a propulsive-lift design can operate from significantly smaller fields than its CTOL counterpart.

3. Even when short field length is not a mission constraint, a propulsive-lift aircraft may compare favorably with its CTOL counterpart in terms of commonly used figures of merit, such as useful load and overall productivity.

Propulsive-lift aircraft are often discussed only in the context of high thrust-to-weight ratios and very short field lengths; consequently, other potential attributes of propulsive-lift aircraft, such as conclusions (2) and (3) above, are less well understood.

3.2 Tilt-Rotor Aircraft Technology

The technology associated with tilting prop-rotor aircraft has been focused in recent years on the development of a research aircraft, the XV-15 Tilt Rotor Research Aircraft (TRRA), following extensive ground-based technical programs. The TRRA has been developed by a team comprising Bell Helicopter, NASA, and the U.S. Army and Navy; this team has successfully brought two aircraft to flight status. Additional advanced technology on advanced tilt rotors and control systems is currently being undertaken by NASA, Boeing-Vertol, and Bell. It is anticipated that the ongoing flight programs will provide the technological confidence necessary to the construction of larger aircraft and to the definition of the various operating modes that fall within the broad flight envelope of this type of aircraft.

The XV-15-TRRA (Fig. 8) is powered by two Lycoming T-53 turboshaft engines that drive three-bladed metal rotors that are 25 ft in diameter, have a blade twist of 45°, and are gimbal-mounted to the hub with

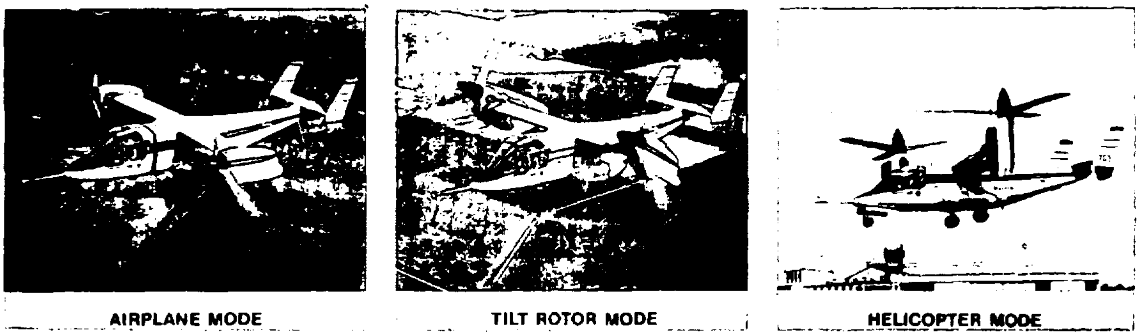

AIRPLANE MODE
TILT ROTOR MODE
HELICOPTER MODE

Figure 8. XV-15 tilt-rotor aircraft in airplane, tilt-rotor, and helicopter configurations.

an elastomeric spring for flapping restraint. At the VTOL design gross weight of 13,000 lb, wing loading is 77 lb/ft^2 and disk loading is 13 lb/ft^2. The two aircraft have accumulated approximately 100 flight hours. Following proof-of-concept, the program will move into research directed toward establishing the suitability of this kind of aircraft to various applications.

The XV-15 research flight envelope is presented in Fig. 9. The envelope, presented in terms of density-altitude as a function of true airspeed, is for level flight, with the predicted envelope as shown and with flight conditions superimposed on the predicted envelope. Based on flight results to date, the demonstrated flight envelope is expected to coincide with the predicted envelope. Flight hovering performance agrees well with predicted performance, and sideward flights and rearward flights to 25 knots have been conducted with favorable results. As originally expected, one-engine-out hovering flight is possible at lower gross weights while in ground effect. As shown in Fig. 9, a maximum cruise airspeed of 300 knots has been demonstrated at about 15,500 ft density-altitude. The XV-15 flight envelope is large; for example, it encompasses the combined envelopes of the UH-1H Iriquois helicopter and the OV-1D Mohawk fixed-wing aircraft.

Historically there has been a concern regarding the tilt-rotor aircraft concept with respect to aeroelastic rotor stability during high-speed cruise flight. Figure 9 shows the location of the predicted limiting rotor stability boundary for the XV-15. Flight results up to the maximum level-flight airspeed show that damping ratios are equal to or higher than predicted levels. Stability measurements have been made in windmilling descents and over the cruise rpm range at normal power. No significant changes in stability levels have been observed. Further exploration and documentation of aeroelastic characteristics, putting the aircraft into a shallow dive to attain higher airspeeds, are planned. The cruise airspeed of the tilt-rotor aircraft concept is not limited by the stability boundary shown in Fig. 9. That boundary is for the XV-15 specifically with its disk loading of 13 lb/ft^2 in its particular configuration (i.e., wing stiffness, rotor type, etc.). Higher disk loading or improved rotor technology or both will move the stability boundary to higher airspeeds.

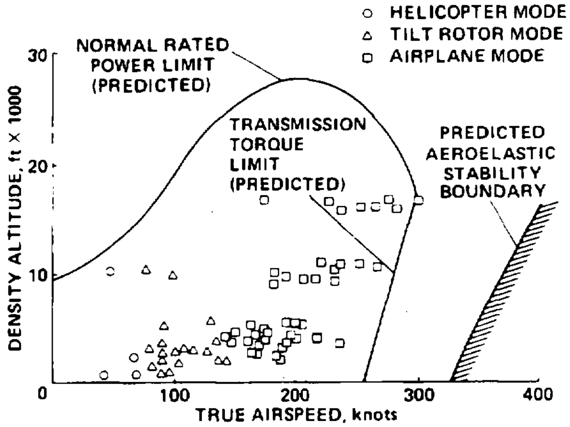


Figure 9. XV-15 flight envelope: altitude vs airspeed.

Rotor shaft horsepower as a function of calibrated airspeed is presented in Fig. 10 for (1) the helicopter mode (nacelle angle of 90°), (2) two tilt-rotor modes (nacelle angles of 30° and 60°), and (3) the airplane mode (nacelle angle of 0°). Also shown is the single-engine-maximum power line for this research aircraft. The speed-power curve for the helicopter mode is typical of helicopters, and the curve for the airplane mode is typical for fixed-wing turboprop aircraft. The buckets of the helicopter mode speed-power curve and the airplane-mode curve (and all tilt-rotor mode curves) occur at about the same power, that is, at about 920 rotor shaft horsepower per rotor. This phenomenom leads to an XV-15 total configurational minimum power envelope that is essentially flat from 50 to 170 knots calibrated airspeed. Thus there exists about a 120-knot range in airspeed that can be flown at minimum power by using the nacelle angle appropriate for a desired airspeed.

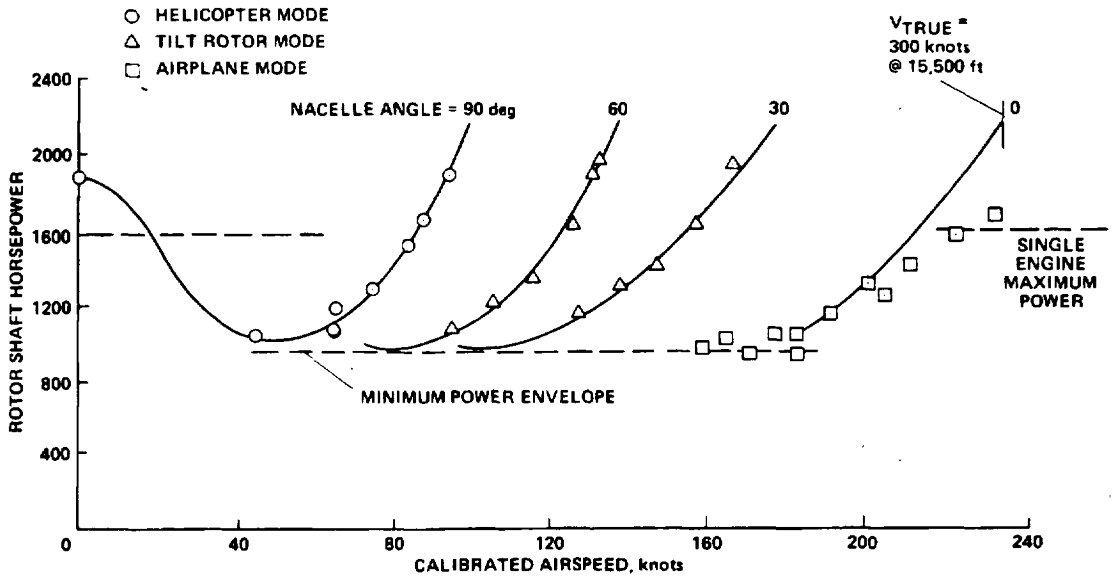


Figure 10. XV-15 power envelope: rotor shaft horsepower vs airspeed.

Figure 10 has several implications. Flight at minimum fuel flow (about 800 lb/hr for the XV-15 research aircraft) occurs anywhere within the 120-knot-wide minimum power envelope. This characteristic is of interest for a wide variety of flight conditions; for example, it would provide flexibility and endurance for search and rescue missions and efficient near-terminal operations. Other favorable implications pertain to such characteristics as noise levels, STOL performance, life of component parts, and single-engine conversion and reconversion in level flight. It may be of interest for some military missions to note that the cruise speed of the tilt-rotor aircraft with one-engine inoperative is much higher than that of the typical helicopter under full power.

A closer look at the XV-15 flight modes is presented in Fig. 11. Nacelle angle may be varied from 95° (used for autorotation) to 0°. For research purposes two rates of conversion can be used – either 7.5° or 1.7° of nacelle angle per second. Flight within the conversion corridor (tilt-rotor mode) is straightforward. Because the aircraft accelerates and decelerates well within the corridor, the pilot does not have to concern himself with a precise conversion schedule. At present, the conversion corridor has a width of from 50 to 70 knots, and further expansion is possible.

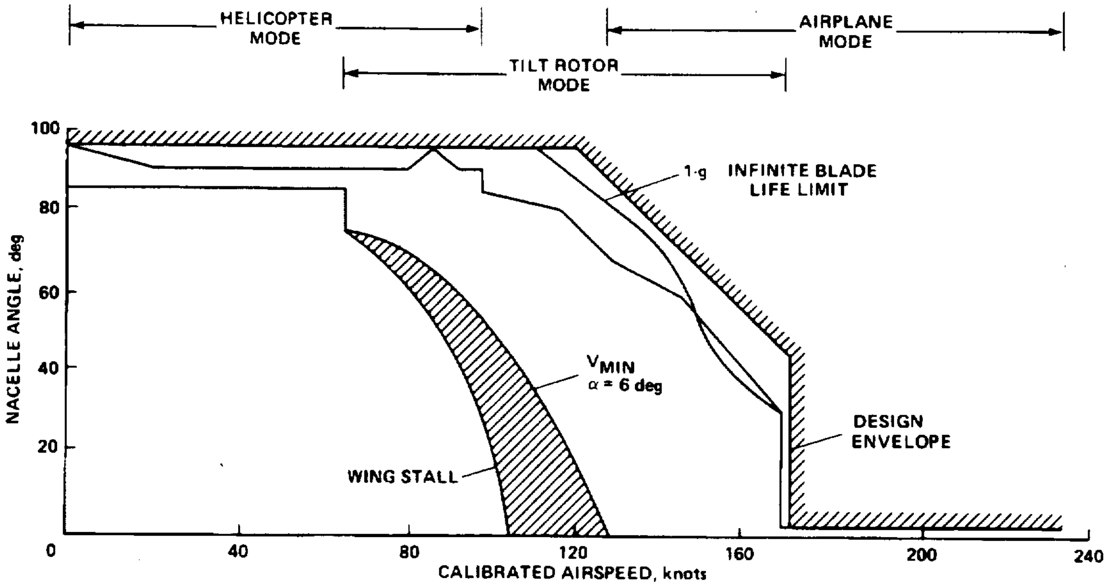


Figure 11. XV-15 conversion corridor: nacelle angle vs airspeed.

Testing has been performed in steady level flight to a line approximating an angle of attack of 6°. Flights have been conducted beyond this line, as shown by the cross-hatched area in Fig. 11, to investigate the low-speed boundary of the conversion corridor. High power climbs have been performed at low speed, at nacelle angles between 50° and 65°. Wing stall boundaries have been investigated at nacelle angles of 0° and 30°; stall speeds were determined to be 104 knots at 0° and 100 knots at 30°. Stall characteristics were docile. It is expected that the corridor will be extended through the shaded region shown in Fig. 11. The anticipated high-speed boundary of the corridor is expected to be defined by power or infinite blade-life fatigue loads. The flap placard speed of 170 knots dictates the boundary at low nacelle angles.

Tilt-rotor aircraft technology is ready, at a reasonable risk, for application to a wide variety of potential military and civil aircraft. The technology is ready for application to aircraft design gross weights up to at least 30,000 lb (i.e., twice the XV-15 STOL gross weight of 15,000 lb) and possibly up to 40,000 lb.

It must be recognized, however, that the design of tilt-rotor aircraft requires close attention to vehicle dynamics. One fundamental potential problem is that as design gross weight increases, the frequencies of various pertinent rotor/nacelle/wing modes decrease and tend to merge together leaving less "design space" between modes. For a given low-disk loading, for example, there probably is a point at which increasing design gross weight will be difficult. Design studies, wind-tunnel experimental efforts, and piloted simulation investigations are needed to address the scaling of tilt-rotor aircraft to higher gross weights or to higher disk loadings or both.

3.3 Turbofan V/STOL Technology

The technology for turbofan V/STOL aircraft has also received considerable attention in recent years. Several multiengine configurations were considered in conceptual design studies and extensive large-scale wind-tunnel investigations were conducted in the 1960s and 1970s.

As a result of these efforts a more direct and simpler approach to turbofan V/STOL design is emerging. This approach attempts to minimize configuration complexity by reducing the numbers of engines and rotating machinery, and by integrating the propulsion and control system into a separate module that can be adapted to different mission-specific aircraft. One design that incorporates these features is shown in Fig. 12. It was developed by Grumman and tested extensively at large-scale by NASA. The design incorporates two tilting turbofan engines with controllable inlet guide vanes and a system of controllable vanes in the engine exhaust flow.

Although this approach to the design of a turbofan V/STOL aircraft looks promising, a number of technical questions must be addressed. One important concern with any design incorporating tilting nacelles is the possibility that premature inlet separation could impair performance during deceleration and descent. The induced aerodynamic effect of the large-diameter, high-velocity flow at various angles relative to the wing is also of concern. The effectiveness of the vanes in the exhaust in producing the necessary trim and maneuvering moments during transition and in hover also needs to be better understood. Finally (as is the case for all V/STOL aircraft) it is necessary that ground effects, the interaction between the airframe aerodynamics and the engine exhaust flow, and exhaust reingestion be properly understood.

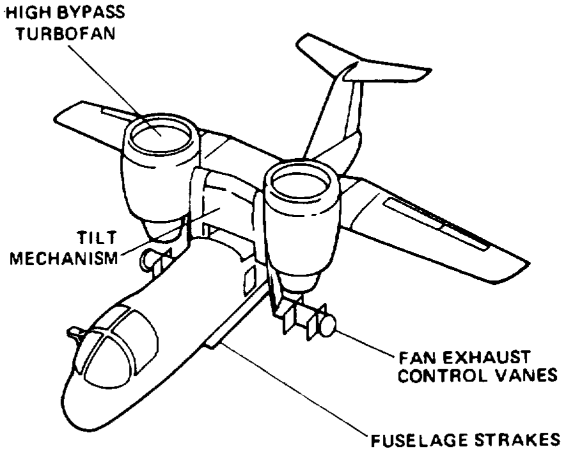
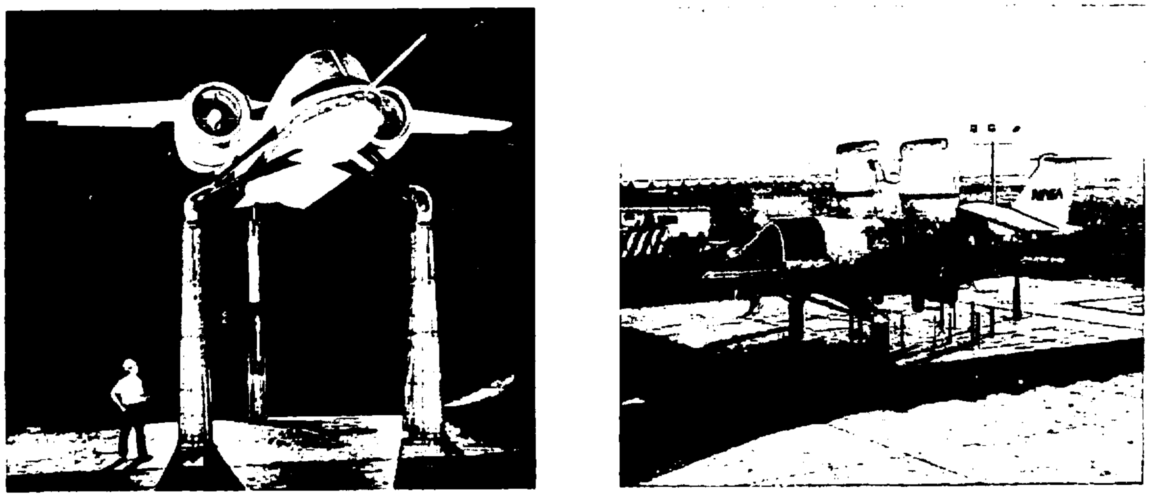


Figure 12. V/STOL turbofan aircraft schematic.

In view of the potential for this configuration to provide a simpler design for turbofan V/STOL aircraft of the future, a comprehensive investigation of its aerodynamic and propulsive characteristics has been undertaken as a joint effort between Grumman, NASA, and the U.S. Navy. The investigation utilized a full-scale model with TF-34 engines in NASA's static-test and wind-tunnel facilities, for the purpose of resolving the questions relating to possible aerodynamic and propulsive interactions. Figure 13 shows photographs of the model in the Ames 40- by 80-Foot Wind Tunnel and on the VTOL Aircraft Hover Research Facility.



40- by 80-ft WIND TUNNEL **HOVER FACILITY**

Figure 13. V/STOL turbofan model in 40- by 80-Foot Wind Tunnel and hover facility.

Turning now to the specific technical concerns enumerated previously, the inlet airflow separation was first investigated and a flight boundary, in terms of nacelle angle versus airspeed, established from wind-tunnel data. Figure 14 shows the combination of nacelle angle and airspeed required to provide for a constant climb angle. Also shown is the inlet separation boundary giving an upper limit to the permitted nacelle angle as a function of airspeed; at 60 to 80 knots airspeed the maximum descent angle is $\gamma = -20°$. The inlet separation boundary is quite conservative because the engine could undoubtedly have withstood much greater flow separation.

Forces induced on the model by the engine airflow can be inferred from the data in Fig. 15. A comparison of the results for engine idling and a nacelle angle of 5°, with the results at high-thrust coefficient (C_μ - 3) and a nacelle angle of 40°, shows that engine operation increased aerodynamic lift, had little effect on drag, but altered pitching moment significantly. The lift on the nacelles when at large angles on the flow can be substantial. Apparently, the nacelle lift more than offsets any adverse effect of the jet on the flow over the wing, at least for nacelle angles up to 60°.

The effectiveness of a control vane immersed in a turbofan airstream has been investigated, using a full-scale independent nacelle. The results from this study, with a nacelle on a complete airframe, are summarized in Fig. 16, which shows control power of the vanes in pitch at a nacelle angle of 50°. The vane pitching moment contribution is linear until the vane is near maximum lift (at a deflection of 20°). For the particular condition shown ($\alpha = 4°$, $V_\infty = 80$ knots) approximately 5° of vane deflection was required for trim and ample control power remains for maneuvering. This was true of all transition flight conditions studied. Control power in hover out of ground effect ($L/D = 5.07$) and control power in ground effect ($L/D = 1.15$, almost wheel height) have been determined and show that no degradation of control power occurs due to ground effect.

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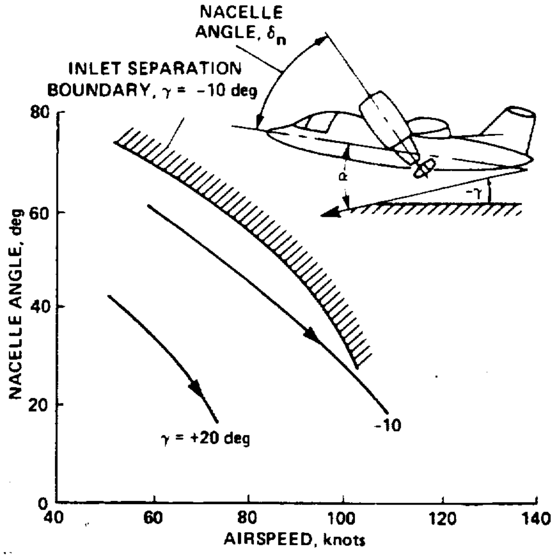

Figure 14. V/STOL transition corridor: nacelle angle vs airspeed.

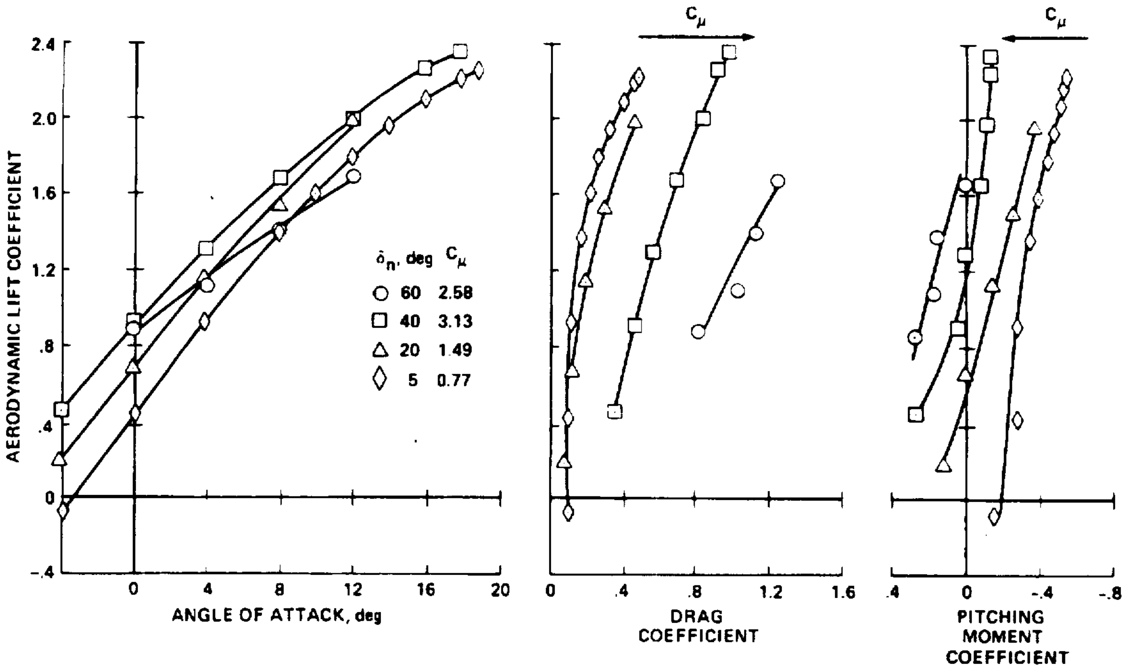

Figure 15. Lift, drag, and moment characteristics.

Ground effect does have an influence on lift during hover, however, and the magnitude of this effect will depend on the details of the configuration, and particularly on the placement of fuselage strakes. Figure 17 shows the lift-to-thrust ratio as a function of height above ground for two fuselage strake angles (15° and 45°). Ground effect is positive (lift/thrust > 1) for both strake angles and increases as the strake becomes more vertical. The spread in the data represents the variation in lift/thrust experienced over a 2-min test period (due to the meandering of the fountain formed by the exhaust flow). As the strakes become more vertical the data spread caused by the meandering flow diminishes. These data are representative of wind conditions up to 20 knots. Re-ingestion of high-temperature exhaust gas as a result of the short flow path to the inlet was minimal; this finding was confirmed by smoke-visualization studies.

In summary, as the result of an experimental program using a full-scale model of a turbofan V/STOL aircraft, a number of concerns regarding aerodynamic performance and control have been alleviated. For example: (1) evidently there exists an adequate transition corridor within which inlet flow separation can be avoided; (2) aerodynamic lift due to flow around the nacelle tends to offset the loss of lift that the nacelle produces on the wing; (3) control power produced by the exhaust vanes appears to be quite linear with vane deflection and provides adequate control moment for maneuvering; (4) ground effect does produce a meandering fountain effect, but the lift/thrust ratio is not degraded in this condition; and (5) there is no evidence of high-temperature gas reingestion. All of the factors that influence the performance and

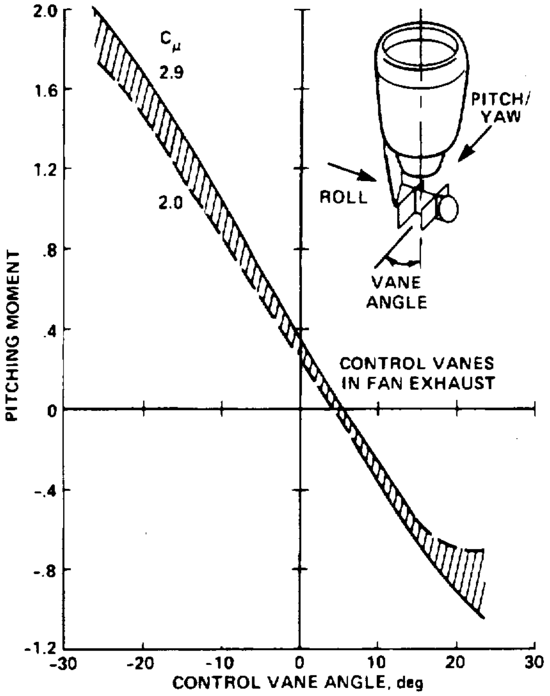

Figure 16. Longitudinal control effectiveness.

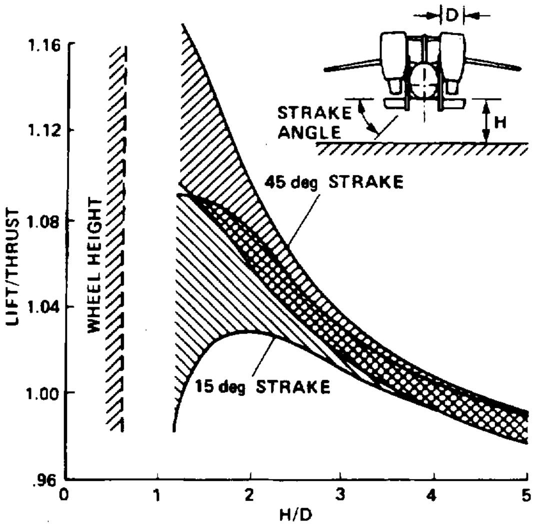

Figure 17. Ground effect: lift/thrust vs height above ground.

stability characteristics of this type of aircraft have not yet been analyzed and the work is continuing. Tests are planned for the 80- by 120-foot test section of the Ames Research Center's tunnel when that section becomes available in 1982.

4. CONCLUDING REMARKS

During the past 10 years several technology development programs have been undertaken to demonstrate that various alternatives are available to fill the "versatility gap" that exists between the capabilities of CTOL transport aircraft and helicopters. There is little doubt that the technology is sufficiently developed for at least two new aircraft configurations — the upper-surface-blown STOL aircraft and the tilt-rotor VTOL aircraft — to permit their introduction in a military logistics role during the 1980s. A third concept, the lift-cruise fan VTOL aircraft requires further technical development and demonstration; nevertheless, that development can probably be achieved by the early 1990s.

The logistics aircraft and missions that can become possible with new technology include the following:

1. Large powered-lift STOL transport aircraft capable of resupply over ranges in excess of 3,000 miles to landing zones having runways as short as 3,000 ft in length.

2. Medium cargo V/STOL rotorcraft capable of speeds of 350 mph and ranges up to 600 miles.

3. Small fixed-wing utility VTOL aircraft utilizing lift-cruise engines and capable of speeds of 500 mph and ranges up to 1,000 miles.

Perhaps the most significant step forward that must be made in the years ahead is the matching of new air-vehicle capabilities to the evolving mission needs. It will not be sufficient to argue that STOL and VTOL aircraft cannot compete because they have reduced the range/payload efficiency. A thorough reassessment of the air-logistics needs of land and sea forces, in light of the growing vulnerability of fixed military assets and in light of the growing confidence that the technology can provide a new generation of aircraft that will be both versatile and efficient, is necessary.

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15. Supplementary Notes

16. Abstract

Recent results from wind-tunnel and flight-tests investigations for V/STOL aircraft are reviewed. Primary emphasis is given to technical results relating to three types of subsonic aircraft: a quiet STOL aircraft; a tilt rotor aircraft, and a turbofan V/STOL aircraft. Comparison and correlation between theoretical and experimental results, and between wind-tunnel and flight-test results, is made. The quiet STOL aircraft technology results are primarily those derived from the NASA/Boeing Quiet Short Haul Technology (QSRA) program. The QSRA aircraft uses an upper surface blown flap and develops a usable engine-out landing approach lift coefficient of 5.5 and landing distances less than 1,000 ft. The tilt rotor aircraft technology results are those obtained from the NASA/Army/Navy/Bell (XV-15-TRRA) aircraft flight investigations. The TRRA is a twin rotor research aircraft capable of vertical takeoff and landing and cruise speeds of 300 knots. The turbofan V/STOL aircraft technology results are from static ground facility and wind-tunnel investigations of a NASA/NAVY/Grumman full-scale lift/cruise fan aircraft model, which features two tilting nacelles with TF-34 engines.

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