NASA Technical Memorandum 85938

V/STOL Concepts in the United States — Past, Present, and Future

W. P. Nelms
S. B. Anderson, Ames Research Center, Moffett Field, California

NASA

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field. California 94035

V/STOL CONCEPTS IN THE UNITED STATES
PAST, PRESENT, AND FUTURE

W. P. Nelms and S. B. Anderson
NASA Ames Research Center
Moffett Field, California 94035, U.S.A.

SUMMARY

This lecture summarizes V/STOL aircraft developed in the United States and describes concepts considered for future applications. The discussion is limited to non-helicopter types of vehicles. In particular, past V/STOL aircraft will be reviewed, and some lessons learned from a selected number of concepts will be high-lighted. The only current concept described is the AV-8B, which was developed by modifications to the British Harrier. Configurations recently proposed for the future subsonic, multimission aircraft and the future super-sonic fighter/attack aircraft will be described. Emphasis in the lecture will be on these supersonic concepts.

1. INTRODUCTION

In the history of aviation development, visions of vertical-takeoff and landing (VTOL) flight preceded visions of fixed-wing operation. Leonardo da Vinci proposed a lift fan VTOL version in 1483 — an idea that would have to wait some 475 years to become reality. Even as the conventional aircraft's appearance and successful development was paced by the requirement for a relatively lightweight power plant, the development of the VTOL concept obviously needed a major breakthrough in the ratio of engine power to weight. VTOL capa-bility has been achieved in the helicopter, but the additional desire for high-speed flight and maneuverability resulted in a continued search for other approaches. The surge to achieve VTOL operation occurred soon after World War II (WW II) when large thrust-to-weight jet and turboprop engines became available. Particularly in the United States, a vast proliferation of VTOL concepts were designed and tested in the period following WW II.

There were many reasons for the failure of some of these concepts to become operational, including a lack of a requirement for VTOL operation, in addition to a need for further technological development. Although a sharp cutback in VTOL flight articles occurred in the U.S. in the late '60s, studies have continued by the Department of Defense (DOD) to weigh the cost effectiveness of various VTOL designs and to consider the impact of the related aeronautical and propulsion disciplines that have improved over the years.

The intent of this lecture paper is to briefly review (in chronological order) some of the past VTOL con-cepts in the United States (non-rotorcraft) and to summarize the lessons learned, either good or bad. Hope-fully, some of these lessons learned will influence present and future concepts developed in the U.S. The prospect of accomplishing this will be left for the reader to ponder, as the paper continues with a description of the present (AV-8B) and proposed concepts.

2. PAST CONCEPTS

Although only a small measure of operational utility has resulted from the large number of VTOL concepts developed and tested in the post-WW II period, valuable information was obtained from these programs which can help guide the design of future vehicles. In contrast to the European approach, which used jet-lift exclu-sively for the vertical thrust mechanism, a wide variety of lifting principles were examined in the U.S. In part this was due to the differing mission requirements specified by the Air Force, Army, and Navy, and also due to a "flight research" attitude which prevailed on the DOD/NASA ad hoc advisory committees. For this paper, only those vehicles which achieved some form of flight evaluation are discussed; unfortunately, this results in the exclusion of some interesting concepts such as the XFV-12A. The material presented herein is taken from Refs. 1 and 2, which give additional details on the aircraft presented here as well as a description of additional concepts.

2.1 Tail Sitters

In the late 1940s, a U.S. Navy program to permit VTOL operation from small ship platforms spawned several tail-sitter designs; i.e., the vertical attitude takeoff and landing (VATOL) aircraft concepts. Two were turboprops, the Lockheed XFV-1 (Fig. 1) and the Convair XFY-1 (Fig. 2), and the other the jet-powered Ryan X-13. Of the turboprop types, the Convair XFY-1 achieved a more complete VTOL operational evaluation; the Lockheed XFV-1 highly tapered, straight-wing design made the transition to vertical flight only at altitude, using a jury-rigged, landing-gear cradle for conventional takeoff and landings.

The Convair XFY-1, which had a delta wing planform and was powered by an Allison YT40A-14 turboprop, made its first vertical flight in August 1954; six transitions to conventional flight were successfully completed before testing was curtailed because of engine and gear-box reliability problems.

In retrospect, the XFY-1 and the other VATOL concepts had some serious fundamental limitations which were not fully appreciated in the early years of VTOL aircraft testing. Foremost among the deficiencies was the lack of STOL operational capability which could improve the poor payload and range capabilities of these air-craft. The benefits to be gained from STOL capability were not recognized during the early development of these VTOL concepts. Although dispensing with a conventional landing gear improved the empty weight fraction for these VATOL aircraft, some form of gear was required on the vertical and horizontal tail surfaces. Not only were these landing gears limited to relatively low allowable sink rates, but as can be appreciated from the photograph of the Lockheed XFV-1 (Fig. 1), tip-over tendencies were a constant worry in gusty air and on uneven ground, particularly with the propellers turning. Another problem was the pilot skill required to operate these tail-sitter designs in landing approach and touchdown because of (1) the unusual spatial orien-tation where the pilot looked over his shoulder and down, (2) the sensitivity to atmospheric turbulence, and (3) reduced control power near touchdown. The precision of flightpath control offered by these concepts was,

needless to say, less than desired. In addition, hovering over a given spot and touching down precisely was extremely difficult.

Although vertical takeoff and transition to conventional flight was easily carried out, the transition from conventional flight to landing approach utilized by the Convair XFY-1 was somewhat unorthodox in that a zoom climb was made to achieve a vertical attitude for the descent and to reduce airspeed (altitude gain of about 3,000 ft).

The only jet VATOL, the Ryan X-13 Vertijet, which first flew in May 1956 (Fig. 3), was more successful, completing over 120 flights. It used a high-wing, delta planform and was powered by a Rolls-Royce Avon turbo-jet. In part because of the concern for operating the turbojet engine close to the ground, the X-13 was flown from an elevated position on a vertical platform. Although it had deficiencies similar to those of the Convair XFY-1 from the standpoint of the lack of STOL capability for increased payload and range, as well as some limitations in precise flightpath control in approach and hookup, the aircraft satisfactorily demon-strated the potential for VATOL operation from a portable landing pad. These tests were carried out in spite of an undesirably large positive dihedral effect (particularly at high angles of attack), and heavy buffet in transitioning from conventional to low-speed flight as the wing operated through the stall angle-of-attack range.

On the positive side, no hot-gas ingestion or aerodynamic suck-down were evident and the high-speed per-formance potential was not compromised by the VTOL features of these designs.

2.2 Bell Air Test Vehicle and X-14 Aircraft

The Bell Air Test Vehicle (ATV) (Fig. 4) was a proof-of-concept vehicle and the first jet VTOL aircraft to fly in the United States (1953). Using a high wing with a "T" tail layout, and powered by two Fairchild J-44 turbojet engines and a separate Poulouste compressor for reaction-control jets, the ATV was flown from a platform to reduce exhaust ingestion effects. Although it never made the transition to conventional flight, it effectively demonstrated that this VTOL design could indeed be flown at low airspeeds using a simple reaction control system with no stabilization augmentation system (SAS). As a result, work proceeded on the design and development of the Bell X-14 vehicle, which had a much broader flight envelope.

The X-14 (Fig. 5) used Beech Bonanza wings, engine bleed air nozzles at the aircraft extremities for hover control, and Bristol Siddeley Viper turbojet engines with cascade thrust diverters. It first hovered in February 1957 and transitioned in May 1958. This configuration clearly demonstrated the detrimental effects of engine gyroscopic cross-coupling, aerodynamic suck-down, and hot-gas ingestion in hover operations. No STOL performance potential (favorable lift-induced flow) was possible with the type of cascade thrust-deflection system used. Partially vectored thrust caused undesirable random flow which seriously affected precision of low-speed flightpath control. Because of this, the thrust could not be rapidly vectored from forward acceleration to a partial vectored position for STO operation, as is done for the Harrier.

It is of interest to note that in spite of a long, successful, trouble-free, flight operational history (over 25 yr), the cascade-vector principle used on the X-14 has not been used in any subsequent U.S. VTOL designs; however, the Russian experimental YAK-36 ("Free-hand") used a similar VTOL principle.

2.3 Bell XV-3 Tilt Rotor

The XV-3 tilt-rotor aircraft (Fig. 6) transitioned in December 1958, with a two-bladed rotor system. It was powered by a single piston engine in the fuselage. It had a positive aerodynamic ground effect, but could not hover out of ground effect. The XV-3, tested extensively at NASA Ames Research Center, disclosed that the design had good STOL performance capability by virtue of favorable induced flow effects, rapid tran-sition with only small trim changes, and a wide speed and angle-of-attack corridor.

Maximum speed was limited by a pitch and yaw dynamic instability associated with destabilizing side forces on the rotor blade which was forward of the center of gravity. This was aggravated as blade angle was increased for high-speed operation. This instability could have been reduced by stability augmentation or a larger tail volume or both.

In general, the performance and handling qualities of the XV-3 were favorable enough to warrant proceed-ing to a more advanced (higher-performance) tilt-rotor vehicle (the XV-15, discussed later).

2.4 Ryan VZ3-RY Deflected Slipstream

The VZ3-RY (Fig. 7) was one of the more successful fixed-wing designs employing the deflected slipstream principle for high lift. Powered by a Lycoming T-53-L-1 turboshaft engine, it first flew in December 1958, with large (40% chord) double-slotted flaps and a hot-exhaust nozzle for pitch and yaw control. The VZ3-RY clearly demonstrated good STOL performance; however, hover capability was limited by ineffective turning of the slipstream, recirculation, and random flow disturbances in ground effect (IGE). Improvements in low-speed capability were obtained during tests at NASA Ames Research Center by installing a full-span leading-edge slat. Although this lift improvement allowed hovering out-of-ground-effect (OGE), slipstream recirculation precluded making a true VTOL vehicle of this design. In addition, transition with this concept required precise pilot techniques because of static pitch instability at high C_L, very large pitch trim changes with flap deflection and engine power changes, and poor flightpath control in steep approaches as power was reduced to descend.

2.5 Boeing-Vertol VZ-2 Tilt Wing

The VZ-2 (Fig. 8) high-wing, "T" tail configuration first flew in August 1957, with the first transition in July 1958. It was powered by a Lycoming YT53-L-1 turboshaft engine with cross-shafting between the two propellers. The VZ-2 successfully demonstrated the good STOL performance potential of the tilt-wing concept. Because of low pitch-control power and no SAS to aid the low inherent pitch damping, hover operations had to be restricted to calm air conditions. Tests at NASA Langley Research Center disclosed the need to provide good wing leading-edge stall protection during deceleration or descent when power was reduced. Transition to

wing-supported flight imposed no limitations, lending confidence to proceed to high-performance tilt-wing designs.

2.6 Doak VZ-4 Ducted Fan

The VZ-4 (Fig. 9), a low-wing conventional planform, first flew in February 1958, powered by a Lycoming YT53 turboshaft engine with cross-shafting to tilting ducts at each wing tip. This configuration suffered from low inherent control power about all axes, sensitivity to ground-effect disturbances, large side forces associated with the large ducts, and a large (positive) dihedral effect which restricted operation to calm-air conditions and no crosswinds. No large STOL performance gain was evident with this design. Transition to conventional flight could be made rapidly (17 sec); however, large nose-up trim changes required careful speed and duct-angle programming. The deceleration and/or descent corridor was restricted by duct-lip stall as power was reduced. Although this aircraft was limited in low-speed and hover capability, it indicated the feasibility as well as the inherent problems of the tilt-duct concept which helped the X-22 design which followed and is described later.

2.7 Lockheed XV-4A Augmentor Concept

The XV-4A (Hummingbird) (Fig. 10) made its first conventional flight in July 1962 and first transition in November 1963. The XV-4A was a 7,200-lb, two-seat, twin-engine (JT-12 turbojet) vehicle which used the engine exhaust directed into an augmentor jet ejector system contained in the fuselage to provide increased vertical lift. Jet (bleed-air) reaction nozzles on three axes were used for hover control. Good low- and high-speed performance potential existed for this concept (estimated 530 mph), because the vertical lift capability was completely enclosed in the fuselage and full engine thrust was available for conventional flight. STOL performance was poor, however, because of the large ram drag associated with turning the airflow through the augmentation system and the lack of favorable flow over the wing induced by the augmentor exhaust to increase lift. Hover performance was compromised by inadequate augmentor efficiency, aerodynamic suck-down (approximately 5%), and hot-gas ingestion. The aircraft trim position in hover was nose-up, which increased the possibility of hot-gas ingestion as forward speed was increased. Flow mixing in the augmentor reduced gas temperature from 1,200°F at the engine exit to 300°F at the augmentor exit. An important lesson was learned during transition attempts in which a strong pitch-up was encountered at 60 knots. An unusual operational procedure was used to get through this critical speed range; engine power was reduced when the pitch-up occurred and then added as the aircraft was in the dynamic process of pitching down. This procedure was too difficult and the aircraft (and pilot) were lost during transition in June 1964.

2.8 Ryan XV-5A and XV-5B Fan-in-Wing

The Ryan XV-5 VTOL design (Fig. 11) was a 9,200-lb twin-engine, tri-fan, turbojet-powered research aircraft; it hovered in June 1964 and first transitioned in November 1964. Two fans in the wings and a third in the forward fuselage for pitch control provided vertical lift. This vehicle had many successful flights because of extensive ground and full-scale wind-tunnel test programs that pinpointed potential problem areas before flight. The lift-fan concept proved to be relatively free of mechanical problems. A moderate dihedral effect and low roll-control power limited crosswind operation to 12-15 knots. Although positive aerodynamic lift was inherent in this design (favorable fountain effect), hot-gas ingestion from the exhaust of the tip-turbine fan drive degraded lift-off thrust by as much as 15% until a wheel height of 10 ft was attained. Operational techniques to minimize ground effects included lifting off in a slightly nose-high attitude, keeping the tail to the wind, and gaining height as rapidly as possible. For several reasons STOL performance was extremely poor: (1) large ram drag of the three fans, (2) low horizontal acceleration because of limited turning of exhaust flow (maximum fan-thrust angle was 45°), and (3) low thrust-vector rotation rate. The transition corridor was marginally adequate because of limited forward thrust and the need to abruptly increase angle of attack (about 12°) to gain aerodynamic lift when the wing fan doors were closed. Because of a strong nose-up force with wing fan start-up, a large reduction in angle of attack was required by elevator input. This, together with fan overspeed tendencies, increased conversion difficulties. Low-speed stall characteristics included a potential deep-stall problem. NASA tests of the XV-5B disclosed flightpath control problems during steep (up to 20°) decelerating approaches including the following: (1) power management was compromised by dual height-control methods (lift spoilage or engine speed) (pilot prefers one lever for power management), and (2) there was a need to minimize aerodynamic lift because longitudinal static stability changed adversely as speed decreased.

This configuration has limited high-speed potential because of the relatively thick wing section needed to house the lift fans and vectoring hardware.

Several lessons were learned from operational demonstrations of the XV-5A. One demonstration involved a large pitch trim change in converting from conventional flight. The aircraft was observed to pitch down abruptly from level flight (about 45°) during transition to powered-lift flight. (The pilot ejected just before ground contact but was killed.) The accident was attributed to inadvertent selection of full nose-down stabilizer position at too high an airspeed. Another concern of this design was the susceptibility of the fans to foreign object damage when the vehicle hovered near the ground.

2.9 Ling-Tempco-Vought XC-142 Tilt Wing

The XC-142 tilt-wing (Fig. 12) used four T64-GE-1 engines with cross-shafting to four propellers and a tail propeller for pitch control. The first conventional flight was made in September 1964, the first hover in December 1964, and transition in January 1965. Hover of the XC-142 was satisfactory with no adverse flow upsets, and precise spot positioning was good. This configuration produced no adverse lateral-directional characteristics in sideward flight to 25 knots. In slow forward flight, a long-period (20-sec) oscillation was apparent which could lead to an uncontrollable pitch-up. On one occasion full-forward stick did not arrest the pitch-up, whereupon the pilot reduced engine power, the nose fell through, and the aircraft was extensively damaged in a hard landing. STOL performance was not as good as predicted, and low-speed controllability was compromised IGE by several factors, including (1) severe recirculation of propeller slipstream for wing-tilt angles in the range 40° to 80° (speed range 30 to 60 knots), producing large-amplitude lateral-directional upsets; (2) weak positive, neutral, and negative static longitudinal stability with speed

changes; and (3) low directional control power. The transition corridor was satisfactory, with ample acceleration/deceleration capabilities. Higher drag inherent in the configuration geometry resulted in poor cruise performance.

Many successful demonstration flights were made with the XC-142, some directed at commercial applications; however, the complexity of the design and the deficiencies noted would have made FAA certification difficult. A failure of the drive shaft to the tail propeller (pitch control) in low-speed flight caused a fatal crash which curtailed further development.

2.10 Curtiss Wright X-19A Tilt Prop

The six-passenger X-19A aircraft (Fig. 13) had twin intershafted engines, a tandem high wing, and four tilting, large-chord propellers. These were designed to develop large radial (lift) forces in conventional flight, thereby reducing wing-area requirements and subsequent drag. The first hover flight was made in November 1963. Transition tests progressed to about 120 knots, but the aircraft never completed transition. Poor mechanical control system characteristics, not peculiar to the concept, severely penalized low-speed operation and made precision hover impossible. Upsets caused by random-flow IGE further increased pilot workload in hover. A positive ground effect was observed up to wheel heights of 4 to 5 ft. Low downwash velocities and lack of hot-gas ingestion were favorable features of this design. Control and height coupling was a problem, in part because of sluggish height-control response (engine rpm was varied instead of collective prop pitch). A pilot induced oscillation (PIO) tendency in height control was encountered as a result of these characteristics which were not concept-inherent. A moderately favorable STOL performance could be expected with this configuration as well as good cruise performance because of the clean (low-drag) design. One prototype crashed because of a fatigue failure of a gearbox mounting. This caused the left rear propeller to separate from the aircraft during transition tests. This exemplified an inherent deficiency of this VTOL (lift) arrangement: to safely transmit power to the extremities of the planform, very strong (and fatigue-resistant) structures must be incorporated with an obvious weight penalty.

2.11 Bell X-22A Ducted Fan

This tandem-wing ducted-fan/propeller X-22A aircraft (Fig. 14) was powered by four GE T-58 turboshaft engines in the rear fuselage interconnected to the ducted fans such that in the event of an engine failure the remaining engines would drive all four fans. The first hover flight took place in March 1966, and transition was completed in June 1967. Hover operation OGE in no wind was rated excellent, with no perceptible hot-gas ingestion. A 12% positive thrust increase was generated IGE by the favorable fountain. Airframe shaking and buffeting occurred at wheel heights up to about 15 ft, and cross-wind effects were quite noticeable because of large side forces generated by the ducts. Vertical cross-wind landings required an excessive bank angle to avoid lateral drift. STOL performance was rated good by virtue of the increased duct-lifting forces. High-speed performance was limited by inherent high drag associated with the four large ducts. Transition to conventional flight could be made easily because of a wide transition corridor; however, inherent damping was low. Deceleration and descent at low engine powers caused undesirable duct "buzz" as a result of flow separation on the lower duct lips. Vortex generators appreciably improved this flow-separation problem.

2.12 Bell XV-15 Advanced Tilt Rotor

The Bell XV-15 research aircraft (Fig. 15), a modern version of the XV-3, is powered by two Lycoming LTC 1K-4K engines rated at 1800 shaft hp each. This aircraft first hovered in May 1977. Two interconnected 25-ft-diameter three-bladed rotors are used with a blade twist of 45° from root to tip. Hover characteristics are similar to those of other tandem-rotor helicopter configurations in that wind direction changes rotor span-loading, affecting hover precision. The concept has a large hover envelope (30 knots sideward and 30 knots rearward) with no handling-qualities limitations. There is an unsteadiness when hovering close to the ground which disappears above a wheel height of 6-12 ft. Transition to conventional flight is easily accomplished with this concept because of a wide speed corridor, a large reduction in power required for level flight, and good (0.4 g) acceleration capability. Trim changes are small, and stability and damping are adequate to minimize unwanted flightpath excursions.

In conventional flight, a unique aircraft longitudinal response (which has been called "chugging") occurs in gusty air; it is attributed to gust-induced angle-of-attack changes on the propeller blade. No undesirable limits in stability or damping (which restricted high-speed flight in the XV-3 aircraft) have appeared to speeds of 300 mph. Stalling behavior in conventional flight is mild, with ample warning and no roll-off. In the event of an engine failure, the aircraft can be either landed at low speeds with the propellers windmilling or brought to a hover-type landing in an autorotative mode. One-engine-out hover performance is not possible with the power currently available. Reconversion characteristics permit slow or fast decelerations with adequate descent rates and a wide speed corridor. A variable tilt rate for the rotors would appear to enhance operational flexibility.

This design shows the best potential for combining good hover performance with reasonable cruise efficiency. It remains to be seen if the relatively complex propulsive system can achieve a low-cost maintenance record and high reliability.

2.13 Lessons Learned

An overview of the development of a wide variety of V/STOL concepts has served to identify several problem areas which, when considered collectively, make it easier to understand why no fixed-wing commercial V/STOL design exists today, and why only one type has achieved military operational status.

Foremost among the reasons for lack of acceptance were poor handling qualities, some unexpected and some ignored in the design stage. Deficiencies in handling qualities were serious enough to cause the loss of several aircraft and pilots. The dominating factors were the inadequate control power to trim out the moments associated with power-induced effects, ground-effect disturbances, and changes in power, flap setting and speed. Flightpath control in landing approach was less than desired, particularly for the VATOLs and tilt-wing vehicles with power reduced for steep descents.

The need for some degree of SAS for all lift concepts in hover and low-speed flight was apparent for safely carrying out even simple operational tasks, particularly in turbulence. For many types, VFR operation was marginal and IFR capability impossible because of low inherent stability and damping.

Marginal performance restricted operational evaluations for many V/STOL concepts. Some vehicles exhibited marginal performance in transition to conventional flight. The need for good STOL performance, a virtue not shared by many of the vehicles, was not appreciated at the onset. V/STOL aircraft that effectively utilize propulsion-induced flow to augment aerodynamic lift have the best chance to be truly competitive. Several of the aircraft lacked good low- and high-speed compatibility in that the features that provided VTOL capability severely compromised high-speed performance.

Most of the aircraft suffered in several ways from ground effects. Reingestion of engine exhaust lowered takeoff thrust, and exhaust flow effects resulted in aerodynamic suck-down for most jet-powered concepts. Ground erosion was a major problem for all turbojet operations. Noise from the turbojet engines was a major deficiency for commercial operation. Recirculation of the propeller slipstream resulted in performance degradation and stability and control problems for tilt-wing types. The significance of these ground-effect problems was not appreciated at the aircraft design stage and there is a continued need for better prediction techniques.

3. PRESENT CONCEPT

The only V/STOL fighter aircraft currently in service in the United States (Marine Corps) is the AV-8A Harrier developed by British Aerospace. This aircraft is described in another lecture in this series, so it will not receive attention here. Rather, the higher-performance AV-8B Harrier II, developed by McDonnell Douglas and the major subcontractor, British Aerospace, will be reviewed. Since the concept is well known, the discussion will be brief, focusing primarily on the differences between the AV-8A and AV-8B. At present, four full-scale development AV-8B aircraft are flying, and production is under way for the first squadron of AV-8Bs, scheduled to be operational by 1985.

Figures 16 and 17 show the AV-8B aircraft in hover. Three views are given in Fig. 18. The propulsion system is a single 21,500-lb-thrust, Rolls-Royce Pegasus 11 turbofan engine with four rotating exhaust nozzles. These rotating nozzles direct thrust vertically for VTOL or at intermediate angles for STOL operation. In cruise flight, thrust is directed to the rear, and thrust vectoring can be used to improve maneuverability throughout the flight envelope. Aircraft attitude control during V/STOL and hover is accomplished by reaction controls located at the wing tips, the nose, and the tail. A cannon is available for air-to-ground or air-to-air attack. Seven store stations are available for a variety of bombs, flare launchers, rocket pods, AIM-9 missiles, guided weapons, and/or external fuel.

A number of changes were made to the AV-8A design to develop the AV-8B Harrier II. These are summarized in Fig. 19 together with a drawing showing the interior arrangement of the aircraft. A number of advanced technologies have been incorporated into the AV-8B, and these are summarized in Fig. 20. Of note is the new wing having a supercritical airfoil for improved lift and cruise characteristics, plus greater fuel capacity. Graphite-epoxy/composite materials are used for the wing, ailerons, flaps, horizontal stabilator, rudder, and outrigger fairings. Redesigned inlets and fuselage-mounted lift-improvement devices enable greater lift for vertical and short takeoff and for more efficient cruise. A raised cockpit has been incorporated to improve visibility. A positive-circulation, inboard flap is used to increase STOL capability and a wing root leading-edge extension to improve maneuverability.

4. FUTURE CONCEPTS

The past and present V/STOL aircraft which have been described are characterized by actual hardware. As for the future concepts, the descriptions will be based on extensive studies conducted by the U.S. Government and industry. In some cases, the concepts described are several years old and many not necessarily represent the current thinking of the organization involved. However, the concepts represent the possible applications of various propulsive lift systems and are therefore appropriate to include in this paper.

Two classes of future vehicles will be considered. The first is the subsonic, multimission aircraft, sometimes referred to as "Type A," but herein referred to as the medium-speed concept. The second is the supersonic fighter/attack aircraft with twin or single cruise engines. The fighter aircraft will be given the major attention in the paper.

4.1 Medium-Speed Concepts

During the past several years, the subsonic, multimission V/STOL aircraft has received considerable attention in the United States, primarily as a result of the Navy's desire to develop a versatile aircraft to perform a number of critical missions from either large or small surface vessels. These missions include ASW, AEW, COD, Tanker, SAR, Marine Assault, and Missileer. More recently, a V/STOL aircraft of this type is of interest to perform other specialized missions, such as rapid deployment of forces and heavy lift logistic transport.

Numerous V/STOL aircraft concepts to fulfill these roles have been studied by the U.S. Government and industry. These concepts have included a number of approaches to the propulsive lift system. The concepts described are not all-inclusive, but are intended to serve as examples of the application of the various propulsive lift approaches. It should be noted that the concepts described represent the thinking of the contractor involved at the time of the study and may not, in all cases, be the currently preferred concept.

4.1.1 Boeing

In the recent past, Boeing studied several approaches to the medium-speed concept. Two of these are briefly described here.

One concept features two tilting nacelles and a forward lift fan. An artist's rendering of this concept is shown in Fig. 21. The two tilt-fan engines, with a pressure ratio of approximately 1.3, are used for both hover and cruise flight. The nose-mounted lift fan is used for hover and transition only. The tilt engines and nose fan are interconnected by a mechanical system. Pitch and roll control in hover are provided by differential collective fan blade pitch, and yaw control is provided by movable vanes in the fan efflux.

Another concept studied by Boeing features a blown flap system, (Fig. 22). Two fixed-fan engines (pressure ratio of about 1.15) are mounted on the wings. The exhaust is directed below the wing, and in hover is directed downward by triple slotted trailing edge flaps. Also in hover half of the fan exhaust is directed downward in front of the wing through "chin" nozzle ports (Fig. 22). In hover, roll control is achieved by differential fan blade pitch, pitch control by angular change in the trailing-edge flaps and the chin exhaust vanes, and yaw control by differential motion of the flaps and vanes.

4.1.2 General Dynamics

A medium-speed concept studied by General Dynamics, Fort Worth Division, features a powered lift system referred to as ABLE (Advanced Blown Lift Enhancement). The heart of this system is a "lifting nacelle" integrated into the wing that vectors the thrust of turbofan engines by using a series of movable flaps to make up the nozzle as illustrated in Fig. 23. One flap forms the upper surface of the two-dimensional nozzle, and two flaps form the lower surface. The upper flap has two slots. The upper forward slot forms the high-aspect-ratio nozzle for the turbine engine exhaust, and the upper aft slot is a boundary layer control slot. The intent is to energize the external boundary layer and thus maintain attached airflow over the "lifting nacelles" to produce significant gains in STOL and transition performance and in aircraft controllability in these modes of flight. In forward flight, the flaps are arranged as shown on the left in Fig. 23, and in transition flight the flaps are deflected into intermediate positions as in the center of the figure. In hover flight (right in Fig. 23) the lower aft flap becomes a part of the aft wall of a vertical-thrust nozzle. The lower forward flap becomes the forward wall of the nozzle and provides a generous radius of the inside of the turn to reduce separation.

This propulsive lift system has been used in a configuration (A-311) illustrated by the model in Fig. 24. A three-view sketch is shown in Fig. 25, and the means of providing folding capability for a Navy configuration is illustrated in Fig. 26. Reference 3 gives a more complete description of this concept.

Four turbofan engines are used in the lifting nacelles of configuration A-311. The fans are cross-shafted together using bevel gears in the fan nose bullets for engine-out considerations. Two load compressors are mounted between the inboard engines and the fuselage and are driven directly from the cross shaft. These compressors provide compressed air to the pitch trim/control system in the aft fuselage. This compressed air drives two air turbines which in turn drive two fans. The fan exhaust passes through dual nozzles which can be aimed up or down using a movable deflection system. Roll control in hover is achieved by biasing the thrust of the main engines either left or right through the cross shaft. Yaw control in hover is achieved by differentially deflecting the main engine nozzle flaps fore and aft on opposite sides of the aircraft.

4.1.3 Grumman

A medium-speed concept studied extensively by Grumman features a tilt-nacelle arrangement for propulsive lift. This concept (Design 698) is shown in Fig. 27, which depicts the various modes of flight from hover, to transition, to cruise. In this concept, all V/STOL related equipment have been located within the engine nacelles. Some of the features of the concept are noted in Fig. 28. Grumman has been working on the 698 concept since about 1976, and they have accumulated over 6000 hr in wind tunnels and on simulators. References 4-15 describe these study and test activities.

Design 698 is a twin tilt-nacelle configuration controlled in vertical flight through horizontal and vertical vanes located in the turbofan exhaust flow, supported by booms attached to each nacelle. In conventional flight, control is provided by spoilers, an all-movable horizontal stabilizer, and a rudder. The large-scale model of the 698 undergoing tests at NASA Ames uses two General Electric TF34-100 turbofan engines, which are proposed also for the demonstrator aircraft.

As shown in Fig. 29, the control vane assembly behind each engine rotates with the nacelle and thereby maintains its position in the engine's exhaust flow. Each vane assembly consists of one horizontal vane crossed by a pair of vertical vanes. The horizontal vane of each assembly is outfitted with a 30% chord antibalancing flap that is geared to move in opposition to the vane's deflection with a 1:1 ratio. The vertical vanes are positioned to remain clear of the hottest region of the engine exhaust flow.

During vertical flight, the pitch of Design 698 is controlled by symmetrical deflection of the horizontal vanes on the two control vane assemblies. Yaw is controlled by differential deflection of the two horizontal vanes as depicted in Fig. 30. Deflection of the vertical vanes and differential operation of variable inlet guide vanes in front of the two engines work together to provide roll control (Fig. 31). Differential operation of the variable inlet guide vanes amounts to differential thrust control of the two engines. Collective variation of thrust is used to control height during vertical flight.

4.1.4 Lockheed

Lockheed has conducted studies of medium-speed V/STOL concepts for the past several years (Refs. 16-20). In their current approach, a split-fan, fixed-nacelle concept is employed for propulsive lift and aircraft control/trim during vertical/transition operation. This propulsion concept is shown schematically in Figs. 32 and 33, and is described in detail in Ref. 17. The nacelle internal arrangement is shown in Fig. 32, and an example of the control concept is illustrated in Fig. 33. A cross duct and associated nacelle plenums provide cross-flow capability from one nacelle to the other. Figure 32 shows twin engines installed in nacelles below and integral with the wing. Each nacelle has two exhaust nozzles, a thrust-vectoring nozzle located aft of the aircraft center of gravity and a fixed-position nozzle located forward of the aircraft center of gravity, each having variable exit area. Airflow to the forward nozzles is supplied from a plenum located circumferentially around the fan duct aft of the fan exit.

During ground acceleration and cruise operation, the entire engine fan and core flows are mixed and exhausted horizontally through the aft nozzle. During vertical operation the engine core air and a portion of the fan air exhausts vertically through the aft nozzle. The remainder of the fan air is exhausted through the forward nozzle. The modulated split of fan air between the fore and aft nozzles is that required to maintain pitch trim.

During vertical flight, pitch control can be provided by the nacelle fore and aft nozzles or by using fan bleed air from the cross duct to an aft fuselage-mounted nozzle (Fig. 33). Yaw control is provided by differential vectoring of the nacelle aft thrust deflectors. In addition to these examples, Lockheed has studied a number of options for control of the split-fan concept during vertical flight (Ref. 17). These options include nacelle fan air transfer, fan bleed reaction control, compressor bleed reaction control, and combinations of these. The system selected will depend to a large degree on the range/payload mix for the mission under consideration.

Lockheed has developed a number of configurations featuring the split-fan propulsive-lift concept. These configurations are either twin- or four-engine designs. On a four-engine configuration, sufficient crossflow can be provided during an engine failure to maintain adequate lift, trim, and control for a safe vertical landing at reduced gross weight. On a twin-engine design, the crossflow should allow a wings-level attitude for crew ejection during a single-engine failure. Figure 34 shows three views of a twin-engine design using F101 engines with cross-duct coupling. A similar but somewhat smaller aircraft has been configured using two TF34 engines. Three views of a four-engine design using TF34 engines is shown in Fig. 35. In their studies, Lockheed conducted an assessment of cross-shafting versus cross-ducting as a means of coupling multiengine concepts. The cross-ducting approach resulted in an appreciably higher useful load capability (Ref. 16).

4.1.5 McDonnell Douglas

Over the past 10 yr or so, the McDonnell Aircraft Company (MCAIR) has conducted studies of medium-speed V/STOL utility aircraft. Candidate concepts included gas and mechanically coupled lift-fan aircraft. A number of these concepts were wind-tunnel-tested. Parallel to this lift-fan activity, MCAIR conducted the AV-8B program and gained valuable experience in the design of vectored thrust concepts. This experience was recently (1980) applied to the design of another medium-speed concept featuring a "two-poster" propulsive lift system. All of these concepts are briefly described in the following paragraphs.

The first concept, proposed in 1973 for Navy consideration, was a gas-driven aircraft (Model 260) utilizing a three-fan, lift plus lift/cruise propulsion system. Figure 36 is an artist's rendering of the MCAIR gas-driven version of the 260 design. The propulsion and vertical-flight-control system are illustrated in Fig. 37. In this system, pitch and roll control are accomplished via energy transfer between the fan assemblies, and yaw control is achieved through differential thrust vectoring. Thrust vectoring of the lift/cruise engines is provided by means of a MCAIR-developed vented "D" nozzle (Ref. 21). Figure 38 illustrates the characteristics of this nozzle in both the cruise and VTOL modes. The nozzle consists of movable deflector hoods and a split yaw vane/closure door assembly attached to a single support beam centrally located on the bottom of the nozzle structure. In the cruise mode, the yaw vane doors are closed to form a flat bottom duct and a "D" shaped exit area (Fig. 38). For transition to vertical flight, the closure doors are each rotated 90° to form a single split-yaw vane. Longitudinal thrust vectoring is then accomplished by rotation of the deflector hood elements. Lateral vectoring is obtained by deflection of the split-yaw vane.

The "D" nozzle utilizes a concept referred to as "venting." This is accomplished by removing the inside wall of the elbow turn of a conventional deflector nozzle design, which has been shown to improve the 90° vectoring performance (Ref. 22). The performance characteristics of the "D" vented nozzle was demonstrated in a NASA Ames/MCAIR test program (1981) using a TF34 engine. The results are discussed in Refs. 22 and 23.

In 1977 MCAIR proposed a mechanically driven version of the Model 260 to the Navy. This concept is shown in Fig. 39. The baseline aircraft featured a low wing, three engines, and a mechanically driven three-fan arrangement. This propulsion and vertical-flight-control concept is illustrated in Fig. 40. The third engine, mounted forward of the vertical fin, is used only during V/STOL operation. All jet-borne aircraft control is provided by differential operation and deflection of the propulsion system, eliminating the need for a separate reaction-control system. All three fans and turboshaft engines are identical, minimizing development and maintenance costs. Lift/cruise thrust from each of the direct-drive, wing-mounted fan/engine assemblies is provided via the "D" vented nozzle.

In 1980 MCAIR initiated definition of a twin-engine vectored-thrust concept with a simpler propulsion system than the three-fan Model 260 concept. This concept is designated Model 276 and is depicted by the artist's rendering in Fig. 41 and discussed in Ref. 24. The Model 276 is a high wing design with two shoulder mounted high by-pass turbofan engines. As shown in Fig. 42, attitude control in powered-lift flight is provided by an engine-bleed reaction-control system in pitch, differential thrust modulation in roll, and differential thrust vectoring in yaw. Power transfer between engines by means of cross shafting permits a wide range of thrust modulation for roll control, including engine-out balance capability. A technology demonstrator of this concept using two "D" vented nozzles and TF34 engines has been defined. Mission performance characteristics of the Model 276 aircraft are discussed in Ref. 24.

4.1.6 Rockwell

During the studies of "Type A" aircraft, one of the concepts developed by Rockwell is a design that employs lift-augmenting ejectors for the propulsive lift system. The ejectors are located spanwise in the wing as shown in the artist's concept in Fig. 43. This figure shows the full-span ejectors open in the hover operating mode. The ejectors are powered during vertical flight by the flow from the two turbofan propulsion systems at the wing roots. Integrating the ejectors into the wing as Rockwell has done in this concept provides good transition and STOL performance, since the exhaust flows from the ejectors act as a jet flap to increase the circulation lift of the wing.

Rockwell has considered two variations in the propulsion system for this concept. Depending on the design requirements, each nacelle contains either a single core with a fan or two core engines driving a single fan.

The latter propulsion arrangement allows the loss of a core engine without loss of the aircraft. This is based on the philosophy that the major portion of engine failures are core related rather than associated with the fan.

Figure 44 gives three views of the Rockwell ejector-in-wing concept. An interesting feature of the design is the twin booms which support the vertical tails, the horizontal tail, and the aft reaction control system (RCS) pitch pipes. Also visible in the figure are the twin ducts for the two core engines in each nacelle located below the fan inlet.

For pitch control during hover, Rockwell uses forward and aft pitch pipes. Roll control can be provided by wing-tip RCS or by differential lift from the ejectors. Yaw control is achieved by directing the flow from one ejector aft and the other forward. During up-and-away flight, aileron-type controls are used, as are rudders on the vertical tails and an elevator on the horizontal tail.

4.1.7 Vought

For the past several years, Vought has studied a medium-speed concept (V-530) that features a tandem-fan propulsion system (Refs. 25 and 26). Figure 45 is an artist's rendering of an early V-530 configuration which emerged from studies in support of the Navy's "Type A" subsonic multimission V/STOL notional requirements. The aircraft is a high wing monoplane with moderate-aspect-ratio wing and winglets, and with two shoulder-mounted engine nacelles. The V/STOL propulsion system is essentially self-contained in the two nacelles. Each nacelle contains a core engine, two fixed-pitch fans with variable-inlet guide vanes, and associated inlets and nozzles.

Figure 46 illustrates the tandem-fan propulsion concept. Two fans on a common shaft are located ahead of, and are directly driven by, a turboshaft engine. Small fan diameters resulting from the use of two fans in each nacelle permit direct drive by the core engine with no reduction gear between engine and fans. Also, the tandem placement of these relatively small fans results in a smaller nacelle diameter and therefore reduced drag. Each fan has its own inlet and nozzle, and flow through the two fans is maintained separately at all times. The forward inlet supplies air to the front fan, which has a nozzle that can be vectored from a vertical position for hover, to an intermediate position for transition, and to an aft position for cruise (Fig. 46). The upper inlet feeds both the aft fan and the core engine (which is supercharged by the aft fan). The core and aft fan flows are mixed and discharged through the aft nozzle. This nozzle is also vectorable for VTOL and up-and-away flight.

Figure 47 illustrates the propulsion system arrangement in the two nacelles and the cross shafting between the two nacelles. A common fan size is used in all four fan applications. Power is transferred from the gas turbine in one nacelle through the cross shaft to the fans in the opposite nacelle to maintain thrust symmetry during single-engine operation or to provide asymmetric thrust for lateral control during hover. Variable-inlet guide vanes on each fan provide thrust modulation for pitch and roll control (Fig. 48). Differential deflection of the left and right nacelle nozzles provides yaw control.

The forward two-dimensional nozzle uses a two-piece deflector for vectoring thrust (Fig. 46). Variation of nozzle area in cruise is achieved with a small flap mounted on the nacelle surface. The aft two-dimensional nozzle vectors mixed flow from the core engine and aft fan. The nozzle deflector is hinged along the lower portion of the nacelle and rotates downward for vertical flight. A rotating lower flap is used to achieve the nozzle areas required for cruise.

Vought has conducted a number of tests of the tandem-fan configuration and propulsion system components over the past several years. These have included a series of inlet tests with NASA Lewis Research Center, front and rear nozzle tests, powered model tests to evaluate ground effects, and low-speed wind-tunnel tests. References 25-33 describe some of these activities.

4.2 Supersonic Fighter Concepts

The V/STOL and short takeoff and vertical landing (STOVL) fighter concepts described in this section were developed in two research programs jointly sponsored by NASA Ames Research Center, the Navy, and the industry. The Navy organizations that participated were the David Taylor Naval Ship Research and Development Center and the Naval Air Systems Command. The first research program considered twin-cruise-engine concepts and the second considered single-cruise-engine designs. Although many concepts have been proposed over the years, it is felt that those considered in these two programs represent a reasonable cross section of the current thinking in the United States.

The key ingredient in the research programs was a contracted effort with the following objectives:

1. Identify and analyze a wide variety of high-performance V/STOL concepts that have potential utility to fulfill the Navy fighter/attack role.

2. Estimate the aerodynamic characteristics of the configurations and assess the aerodynamic uncertainties requiring additional research.

3. Define a wind-tunnel program, including model design and construction, to explore these uncertainties and provide an initial high-quality aerodynamic data base for Navy, NASA, and industry use.

The information obtained in the first of these objectives will be emphasized in this paper.

The statement of work for this contractor study was jointly prepared by the Navy and NASA Ames to emphasize aerodynamic technology development of V/STOL fighter/attack aircraft. These guidelines were not intended necessarily to reflect specific future naval aircraft performance or operational requirements. Rather, the intent was to provide a limited set of guidelines sufficient to allow the contractors to perform a conceptual aircraft analysis based upon their definition of a mission and payload. The following is a brief description of the guidelines furnished in the statement of work:

1. The conceptual aircraft analysis is for a high-performance V/STOL concept with potential to fulfill the Navy's fighter/attack role after 1995.

2. The aircraft shall have supersonic dash capability with a sustained Mach number capability of at least 1.6.

3. The aircraft shall be operational from land and from ships smaller than CVs without catapults and arresting gear. Good short takeoff (STO) capability is a requirement.

4. To assure high maneuver performance, the aircraft shall have a sustained load factor (N_{Z_S}) of at least 6.2 at Mach number 0.6, at an altitude of 3048 m (10,000 ft) and at 88% VTOL gross weight.

5. The aircraft shall have a specific excess power at 1 G $(P_{S_{1G}})$ of 274 m/sec (900 ft/sec) at Mach number 0.9, at an altitude of 3048 m (10,000 ft) and at 88% VTOL gross weight.

6. The following aircraft weights are to be used as a guide:

   Twin engine: VTOL gross weight = 9072 to 15,876 kg (20,000 to 35,000 lb); STO sea-based gross
        weight = VTOL gross weight plus approximately 5,436 kg (10,000 lb).

   Single engine: VTOL gross weight = 6,800 to 13,000 kg (15,000 to 30,000 lb); STO sea-based gross
        weight = VTOL gross weight plus approximately 3,630 to 4,540 kg (8,000 to 10,000 lb).

The following sections describe the twin- and single-engine fighter concepts studied in the contract efforts. The concepts will be described under headings relating to the contractor involved.

4.2.1 Twin-Engine Concepts

Four contractors proposed twin-engine designs that are described in this section. The contractors were: General Dynamics, Fort Worth Division, Fort Worth, Texas; Grumman Aerospace Corporation, Bethpage, New York; Northrop Corporation, Aircraft Group, Hawthorne, California; and Vought Corporation, Dallas, Texas.

Three horizontal-attitude takeoff and landing (HATOL) and two VATOL concepts are described. Northrop proposed two concepts, a HATOL and a VATOL design.

Typical mission profiles used by the contractors for aircraft sizing are outlined in Fig. 49. These are only examples as the contractors had some variations in such things as payload, combat time, and best cruise altitude and velocity (BCAV). All concepts are single-place aircraft with two cruise engines. Each configuration is briefly described in the following sections, and a complete description of the concepts and the wind-tunnel test activities is given in Refs. 34-50.

4.2.1.1 General Dynamics

The configuration proposed by General Dynamics (Refs. 34 and 35) is a wing-canard HATOL concept that has Alperin jet-diffuser ejectors as its vertical lift system. The design also features a vectored-engine-over (VEO) wing-integrated airframe/propulsion system to achieve good transonic maneuvering and STOL performance. In this design, the full engine flow is directed over the wing aft surface to augment the aerodynamic lift through a jet flap effect. At low speeds, this is combined with spanwise blowing, which utilizes a portion of the engine exhaust at high angles of attack to produce leading-edge vortex augmentation. Figure 50 shows three views of the concept, and Fig. 51 presents isometric sketches of the configuration, showing the four ejector-diffuser bays closed for up-and-away forward flight and open for vertical flight.

Two Pratt and Whitney augmented-turbofan study engines are used. The ejector diffusers are located between the fuselage and nacelles in the thick root section of the wings (Fig. 51). For vertical takeoff and landing, the engine flow is diverted to the four ejector bays, where it is injected in both primary and diffuser nozzles. Pitch control during vertical flight is accomplished by thrust modulation of the forward and aft ejectors; yaw control is achieved by vectoring the ejector flow. Wing-tip reaction controls are used for roll control. The ejector-diffuser nozzles and doors fold into the wing, nacelle, and fuselage to form a smooth configuration for up-and-away flight (Fig. 51). An augmentation ratio of 1.70 (defined as the ratio of total lift to isentropic thrust of the engines) is predicted for this concept at liftoff. A major advantage of the ejector-diffuser lift system, of course, is its relatively cool footprint, which could be an important factor for shipboard operation.

The VEO-wing feature has been studied by General Dynamics both in-house and under several Air Force contracts. The engine flow exits above the wing surface (Fig. 50) through a two-dimensional convergent-divergent exhaust nozzle operating in conjunction with the wing flap to provide vectored thrust for pitch control during transition, improved STOL performance, and maneuver enhancement.

The configuration has a high-mounted variable-incidence canard, a low-mounted wing with trailing-edge elevons/flaperons, and a single all-movable vertical tail. The air-induction system features two axisymmetric inlets with aerodynamically operated blow-in doors for adequate flow during takeoff/landing and low-speed flight.

For this study, General Dynamics sized the aircraft to a deck launch intercept (DLI) mission similar to that in Fig. 49. The weapons consist of two advanced short-range air-to-air missiles, two advanced medium-range air-to-air missiles, and one 30-mm gun with 300 rounds of ammunition. To perform this mission and meet the statement-of-work maneuver guidelines, the aircraft has a VTO gross weight of 15,870 kg (34,987 lb), a length of 16.3 m (53.3 ft), and a wing-span of 11.4 m (37.3 ft). Some of the more important vehicle characteristics are summarized in Table 1.

To serve as a comparative design, General Dynamics conducted a parallel in-house design study of the present concept with a General Electric remote augmented lift system (RALS) instead of the ejector-diffuser vertical lift system. In the RALS propulsion system, the fan air is collected and routed forward to a burner/nozzle arrangement to provide propulsive lift. Figure 52 is a schematic of the RALS propulsion concept. The General Dynamic RALS concept, shown in Fig. 53, uses the same wing/canard arrangement, the same spanwise blowing feature, and the same podded engines, except that the nacelles are more closely spaced than on the ejector-diffuser configuration. The VEO-wing nozzle in this case has provision for full 90° thrust deflection for vertical flight. A vectorable, two-burner, forward lift system is employed which uses fan air from the variable-cycle engines. Sized to the same mission and payload, the RALS concept has a VTO gross weight of 14,810 kg (32,650 lb), or approximately 1,043 kg (2,300 lb) less than the ejector configuration.

4.2.1.2 Grumman

The second HATOL configuration is a lift plus lift/cruise concept proposed by Grumman (Refs. 34 and 36). The configuration, shown in Figs. 54 and 55, is a wing-canard design that employs a General Electric RALS. Grumman modified an earlier V/STOL fighter design (Model 623) by incorporating a canard and a new wing to meet the maneuver requirements in the present statement of work. Two General Electric variable-cycle augmented-turbofan study engines are used with General Electric augmented deflector exhaust nozzles (ADEN) (Fig. 56). The RALS forward lift element is a dual burner/nozzle design. To minimize the size of this forward lift system, the ADEN nozzles are mounted at the wing trailing edge as far forward on the configuration as possible. The ADEN nozzles not only provide vertical lift for takeoff and landing, but also have in-flight thrust vectoring to enhance maneuvering (Fig. 56).

As shown in Fig. 54, the configuration features a high-mounted, variable-incidence canard with leading and trailing edge flaps, an advanced variable-camber wing with leading and trailing edge devices, and twin vertical tails. The canard has 5° of dihedral, and the wing has 10° of anhedral. The air induction system consists of side-mounted, fixed-geometry inlets with top-mounted blow-in doors for increased airflow during takeoff/landing and low-speed operation.

In conventional flight, longitudinal control is provided by the incidence of the canard augmented at low speed and high angle of attack by the canard flaps; roll control is provided by asymmetric deflection of the wing trailing edge devices; and directional control is provided by the rudder surfaces. In hover flight, pitch control is provided by flow shifting between the forward and aft nozzles; wing tip reaction controls are used for roll control; and differential lift/cruise nozzle deflections are used for yaw control.

The configuration has been sized to a deck launched intercept (DLI) mission similar to that shown in Fig. 49. The weapons are two AIM-7 missiles, two AIM-9 missiles, and one internally mounted 20-mm gun and ammunition. To perform this mission with a vertical takeoff and to meet the statement-of-work maneuver guidelines, the configuration has a VTO gross weight of 17,112 kg (37,726 lb). The length is 17.3 m (56.5 ft) and the wingspan is 11.5 m (37.8 ft). Some of the other configuration characteristics are summarized in Table 2.

4.2.1.3 Northrop (HATOL)

The third HATOL concept is a lift plus lift/cruise design by Northrop (Refs. 34 and 37). This design is one of two proposed by Northrop. Three views of the concept are shown in Fig. 57; an artist rendering of the aircraft is given in Fig. 58. Northrop is using a General Electric RALS concept in this design with two variable-cycle turbofan engines, ADEN nozzles, and a single forward augmentor lift system with a gimbaled nozzle. The engine has a miniafterburner (1000°F temperature rise) to provide additional thrust during combat. This augmentation is not used for vertical takeoff or landing.

The configuration is a wing-canard design with two vertical tails mounted on twin afterbodies, as shown in Fig. 57. The clipped delta wing has variable camber, using automatically phased leading and trailing edge flaps. The canard is high mounted and all-movable. Side-mounted, two-dimensional inlets are used with topside auxiliary inlet doors for takeoff. The two ADEN nozzles are mounted side by side on the aft fuselage centerline between two wing-mounted afterbodies. These bodies have been shaped and located to provide: (1) a favorable area distribution, (2) twin surfaces for additional lift augmentation from flow entrained by the deflected ADEN nozzles during takeoff, (3) favorable flow on the upper and lower wing surfaces, and (4) space for landing gear, avionics and fuel storage, which in turn provides a means to adjust the center of gravity.

During takeoff and hover, pitch control is provided by thrust modulation of the forward and aft nozzles; roll control by wing-tip reaction controls. Yaw control is derived from lateral deflection of the forward nozzle. For conventional flight, the wing trailing edge elevons are used for pitch and roll control and pitch stabilization. The all-movable vertical tails provide directional control and stabilization. The leading edge flaps and canard surface are scheduled as a function of angle of attack and speed for optimum aerodynamic performance. Thrust vectoring and combined canard/thrust deflection are used for maneuver enhancement.

For this study, a VTO gross weight of 13,608 kg (30,000 lb) has been selected by Northrop as representative of a 1995 VSTOL aircraft designed to perform the Navy fighter/attack mission similar to that of the F-18. To assist in configuration development during the study, an arbitrary fighter escort mission has been used. To meet the statement of work maneuver requirements with a VTOL gross weight of 13,608 kg (30,000 lb), the aircraft (Fig. 57) has a wingspan of 9.9 m (32.6 ft) and a length of 16.0 m (52.5 ft). Some of the configuration characteristics are summarized in Table 3.

When resized to perform a 926-km (500-n. mi.) fighter escort mission, the configuration has a VTO gross weight of 14,424 kg (31,800 lb) and a VTO wing loading of 2.87 kN/m² (60 lb/ft²).

4.2.1.4 Northrop (VATOL)

The second concept studied by Northrop (Refs. 34 and 38) in the present effort is a VATOL concept shown in Fig. 59 and as an artist's rendering in Fig. 60. The configuration is a tailless design that features a wing leading edge extension (LEX) to maintain lift to high angles of attack. Top-mounted inlets are used to provide

a low radar cross section as well as to free the lower surface for efficient weapon/landing gear integration and to ease mating with the alighting gantry.

Both Northrop concepts have a common wing with leading and trailing edge flaps automatically programmed to provide variable camber for optimum aerodynamic performance.

In this VATOL concept, twin Pratt and Whitney variable-geometry, nonafterburning turbojet engines are used with gimbaled axisymmetric nozzles located aft close to the aircraft centerline. The top-mounted air induction system has fixed geometry, two-dimensional inlets with topside auxiliary inlet doors for low-speed operation.

Control in the vertical takeoff and landing mode is provided by the gimbaled nozzles, which can be deflected ±30° in pitch and ±15° in yaw. Wing-tip-mounted reaction controls provide primary roll control; antisymmetric pitch deflection of the nozzles can be used for auxiliary roll control. In conventional flight, pitch and roll control is provided by the trailing edge elevons, and directional control and stabilization are provided by the all-movable vertical tail. Thrust vectoring in combination with the trailing edge flaps is used for maneuver enhancement.

The configuration has conventional landing gear for overload takeoff and landing in the horizontal attitude. A capturing hook mechanism is integrated with the nose gear to engage the launch-and-retrieval platform for VATOL operations.

Several means have been explored to provide a more favorable pilot orientation during takeoff and landing. These means have included a rotating seat similar to the X-13 concept, an articulating capsule, and a system for hinging the entire aircraft nose. The present design employs a tilting cockpit module.

For this study, a VTO gross weight of 13,608 kg (30,000 lb) has been selected by Northrop as representative of a 1995 VSTOL aircraft designed to perform the Navy fighter/attack mission similar to that of the F-18. To assist in configuration development during the study, an arbitrary fighter escort mission has been used. To meet the statement-of-work maneuver requirements with a VTO gross weight of 13,608 kg (30,000 lb), the aircraft has a wingspan of 9.9 m (32.6 ft) and a length of 15.8 m (51.7 ft). Some of the configuration characteristics are summarized in Table 4.

When resized to perform a 926-km (500-n. mi.) fighter escort mission, the configuration has a VTO gross weight of 10,523 kg (23,200 lb) and a VTO wing loading of 2.73 kN/m² (57 lb/ft²).

4.2.1.5 Vought

The final configuration is a VATOL concept proposed by Vought (Refs. 34 and 39). As shown in Figure 61, the design features a fixed, close-coupled, high-mounted canard with trailing edge flaps, a midwing of low aspect ratio, and a single vertical tail with a rudder. The wing has trailing edge flaps that are optimally phased to operate throughout the flight envelope in unison with the canard flap to implement longitudinal and lateral commands. Full-span leading edge flaps are automatically phased to maintain optimal camber for high maneuver performance. Split-flap speedbrakes are located at the inboard wing trailing edge.

Side-mounted, two-dimensional, fixed geometry inlets (Fig. 61) supply air to two Pratt and Whitney advanced technology, mixed flow, augmented turbofan engines. Blow-in doors are provided for low-speed operation. Axisymmetric convergent-divergent nozzles are mounted side by side in the aft fuselage. These nozzles can be gimbaled ±15° in pitch and yaw to provide control during takeoff/landing, hover, transition, and in-flight maneuvering. A reaction-control system in the wing tips provides roll control for vertical takeoff and landing.

Conventional tricycle landing gear is used for short takeoff (STO) and conventional takeoff and landing (CTOL) operation as well as to facilitate deck handling. A capture mechanism is integrated with the nose landing gear to engage the landing platform grate for vertical attitude takeoff and landing. A tilting-seat arrangement is employed to provide the pilot with a comfortable position in the VATOL mode of flight as well as with a conventional seat position for cruise.

The aircraft has been sized to a DLI mission similar to that of Figure 49. The armament consists of two AIM-7 missiles, two AIM-9 missiles, and one 20-mm gun with 400 rounds of ammunition. To perform this mission with a vertical takeoff and to meet the statement-of-work maneuver requirements, the configuration weighs 10,603 kg (23,375 lb) and has a wing span of 8.7 m (28.5 ft) and a length of 13.8 m (45.3 ft). Some of the configuration characteristics are summarized in Table 5. Figure 62 shows the Vought VATOL concept operating in the STO overload condition of 15,139 kg (33,375 lb).

4.2.2 Single-Engine Concepts

Four contractors proposed designs that are described in this section. The contractors are: General Dynamics, Fort Worth Division, Fort Worth, Texas; McDonnell Douglas Corporation, St. Louis, Missouri; Rockwell International, Columbus, Ohio; and Vought Corporation, Dallas, Texas. The concepts are all single-place aircraft with a single cruise engine. Each concept is briefly described in the following sections, and a complete description is given in Refs. 51-60.

4.2.2.1 General Dynamics

The General Dynamics (GD) single-engine fighter concept (Refs. 51-53) combines both vectored thrust and a thrust-augmenting ejector for vertical flight. This propulsive lift system is combined with a delta wing and a tailless design (Configuration E7). The E7 hover configuration is shown in Fig. 63, and the cruise flight mode is depicted in Fig. 64.

The guidelines for the development of this configuration were, first, that it be based on an existing engine or, at most, on a near-term derivative. Second, the aircraft must be capable of STOVL, rather than pure VTOL flight. Observations of AV-8A operations indicate that the Harrier rarely takes off vertically for a

military mission; the overload capability provided by a short deck or ground run is used most often. For naval use, however, the vertical landing provides such significant advantages in deck cycle times that its retention is highly desirable. Finally, the aircraft must be capable of a meaningful naval mission. The latter sets the maximum hover gross weight requirement: (1) 5% reserve fuel, (2) fuel for 20 min of sea level loiter, and (3) retention of expensive weapons (e.g., AIM-7, AIM-9).

An ejector concept was selected as the propulsive lift system for the GD configuration. The ejector system has advantages beyond providing thrust augmentation; for example, it is significant that the ejector exhaust is relatively cool and that its velocity is low. Although burner systems such as the RALS are capable of equally good augmentation, and although lift engines are probably the most compact systems available, the environmental and inlet ingestion problems associated with the hot and high-velocity exhausts of these systems are significant. An ejector system partially avoids these problems.

The propulsive lift system that appeared attractive was the ejector system developed by de Havilland of Canada working with Ames Research Center (Refs. 54-57). This ejector system has more volume than a short-diffuser type, such as the Alperin ejector, but it has a substantial and dependable augmentation ratio that has been measured on a large-scale, engine-driven model at Ames.

However, all ejector systems present some difficulties, one being the ram drag of the entrained air at forward speeds. The data from the original ejector model tested in the Ames 40- by 80-Foot Wind Tunnel suggested that an aircraft using the ejector would be marginal in transitioning from ejector-borne to wing-borne flight. Although it was demonstrated that this could be overcome by vectoring the ejector nozzles aft, an operational aircraft would require controllable vector angles that in turn would require complex actuation systems. One way to avoid this problem is to duct only part of the engine flow to the ejector and to exhaust the remainder to a single, vectorable nozzle. By using fan air to power the ejector, the duct weights are lowered, because of the cooler flow, and the inlet thermal reingestion becomes modest.

In the GD study, three aircraft were considered, a flight demonstrator and two operational aircraft (a threshold and a goal aircraft). The flight demonstrator would be built around an existing engine or a very near-term derivative. The primary purpose of the demonstrator would be to investigate the VL and STO ends of the flight regimes, and therefore afterburners would not be included. However, the demonstrator has been constrained to possess the same airframe as the operational aircraft so that only extrapolations required from the flight demonstrator are propulsional. In the demonstrator, reaction-control-system power is provided by an auxiliary power unit (APU). The threshold operational aircraft is defined as one whose engine thrust may be assumed to be developed in the normal course of engine growth during the next 15 yr or so, but which will require technological advances primarily in the area of reaction control power provided by the engine. The goal operational aircraft requires a more advanced engine in order to provide significantly enhanced hover thrust. Again it is emphasized that all three airframes are identical.

Configuration. In the GD design, fan air is collected in an annular plenum aft of the engine fan stages and is released into a duct that runs along the top of the fuselage (Fig. 65). This air can flow either into an aft nozzle or into the forward ejector nozzles. The ducts are provided with valving to regulate the flow rate of fan air to the ejectors and to an aft nozzle. An afterburner is placed in the duct forward of the aft nozzle. The engine core flow exhausts through a separate, two-dimensional vectorable nozzle (Fig. 65). An afterburner can be located in the core flow duct also. For vertical flight, the core flow is vectored downward, and all fan flow is ducted to the ejectors. For up-and-away flight, the core flow is vectored aft, the ejector doors are closed, and the fan flow exhausts through its aft nozzle. The afterburners are used as required for acceleration and supersonic flight. For STO operations, the core flow is partially vectored and the fan flow is split between the ejector and its aft nozzle as required for balance and acceleration. The three modes of operation of the propulsion system are illustrated in Fig. 66.

Three views of the E7 configuration are shown in Fig. 67, and a dimensional summary is given in Table 6. The forward fuselage, cockpit and canopy, and vertical tail are geometrically identical to those of the F-16A. The wing has an aspect ratio of 1.67 and a leading edge sweep of 60°. The main landing gear is located in the wing; the nose wheel is located in the forward, underside of the inlet. The aircraft is designed to a limit load factor of 7 5 (11.35 ultimate), and approximately a 35% composite material usage is assumed. The avionics weights are estimated on the basis of functional equivalence to that of the F-18.

Propulsion System. Although the demonstrator aircraft in the study uses a General Electric F101/DFE engine, GD has evaluated other engines, including F100 and Pegasus derivatives as part of another study for NASA Ames Research Center. A two-dimensional vectorable nozzle is used for the core flow and an axisymmetric nozzle is used for the fan flow during up-and-away flight. The inlet system has a modified F-16 conformal shape with a normal shock at supersonic speeds. Both the fan stream and core stream are equipped with afterburning capability in the operational aircraft.

The ejectors are of the Ames/de Havilland type, with a diffuser area ratio of 1.6 and throat-area-to-primary-nozzle-area ratio of 25.0. The ejector bays are located longitudinally in the wing root area. In static tests at Ames Research Center, the de Havilland ejector system demonstrated an augmentation ratio of 1.725 (Refs. 54-57). This was degraded to 1.63 for the present studies because of design compromises likely in an actual aircraft. Figure 63 shows the ejector in the open position for hover.

Mission Performance. The primary mission for which the E7 is sized is the naval escort mission (Type Spec. 169) shown in Fig. 68, with the interdiction mission secondary. These missions have been modified to specify a 122-m (400-ft), zero-wind, zero-sink takeoff with vertical landing. The payload consists of two AMRAAM plus two AIM-9L missiles. No gun is used. A summary weight statement of the operational aircraft is given in Table 7.

Point performance parameters are shown in the first column of Table 8 for the goal operational aircraft. The second column shows the performance calculated at 60% of full fuel weight in accordance with TS 169. The E7 configuration meets or exceeds all performance thresholds. The radius for the escort mission is 402 km (217 n. mi.) greater than that required by the specification, and is a direct result of sizing to meet the interdiction mission with internal fuel. The performance values given in the third column are calculated at

88% VTOL gross weight. They have no meaning in a military sense, but are included to provide a measure of performance for comparison with NASA guidelines shown in the last column.

4.2.2.2 McDonnell Douglas

The concept studied by McDonnell Douglas (MCAIR) is a canard/wing design with swiveling nozzles forward and aft of the aircraft center of gravity. The four-poster configuration, MCAIR Model 279-3, is shown in Figs. 69 and 70; Fig. 69 depicts the vertical flight configuration, and the cruise flight mode is shown in Fig. 70. References 51 and 58 give details of this concept.

Configuration. Model 279-3 features a close-coupled canard and side-mounted half-axisymmetric inlets to provide air to a single engine with modulated fan-stream augmentation. Four swiveling nozzles provide thrust vectoring capability for vertical flight as well as for in-flight maneuvering. Fan air flows through the forward nozzles and the engine core flow exits through the aft nozzles. Modulation of the fan stream and engine speed provides the capability of trimming center of gravity travel associated with fuel burnoff and store loading. This modulation can also provide a portion of the pitch maneuvering control or can be used as a backup system. The location of the aft nozzles near the wing trailing edge offers the potential of enhanced circulation, translating into increased maneuverability and STOL performance. Thrust vectoring can increase the sustained load factor of Model 279-3 by 0.2 g and the instantaneous load factor by 2.0 g's at 0.6 Mach number at an altitude of 3,048 m (10,000 ft).

As shown in Fig. 69, the main landing gear of Model 279-3 are located fore and aft on the fuselage in a bicycle fashion with outriggers in pods on the wing.

Three views of the MCAIR concept are shown in Fig. 71, and a dimensional summary is given in Table 9. The wing has an aspect ratio of 3.0, a leading-edge sweep of 45°, and 9° of anhedral. The close-coupled canard is mounted high on the inlet sides and has 0° of dihedral, a leading-edge sweep of 50°, and an aspect ratio of 3.0. The exposed area of the canard is 20% of the wing reference area. The single vertical tail is mounted on the aft fuselage.

The configuration has a vertical takeoff wing loading of 3.34 kN/m^2 (69.7 lb/ft^2) and a tropical-day, vertical-takeoff, thrust-to-weight ratio of 1.15 with full fan-stream burning.

Aerodynamic Surfaces. Pitch control is provided by the all-movable, close-coupled horizontal canard; roll control by the differential ailerons; and directional control by the rudder. The wing leading and trailing edge flaps and also the canard are deflected as a function of angle of attack and Mach number to maximize maneuvering capability. The leading edge flaps also are used supersonically as decamber flaps to reduce drag. The trailing edge flaps, which are plain flaps at small deflections, become single slotted flaps at large deflections, for high-lift operation. These flaps, which are close to the aft nozzle, increase the STOL lift. The location of the forward nozzle under the wing, rather than at the leading edge, also improves lift during STOL.

The wing planform selection is based on a compromise between subsonic and supersonic performance. Subsonic emphasis is on high sustained maneuverability requiring low drag due to lift. Supersonic emphasis is on lower-lift-coefficient maneuvering conditions during which the minimum drag coefficient C_{D_0} is equally important. The wing airfoil camber increases outboard on the wing. There is no twist at the wing-fuselage juncture, but there is leading-edge-down twist at the wing tip.

Control System. The Model 279-3 has a digital fly-by-wire control system, which is necessary to augment the subsonic longitudinal instability. This active control system also makes possible (1) engine/fan-stream augmentation/reaction-control-system integration, (2) augmented thrust-vectoring control, and (3) coupled flight/propulsion control.

A three-axis reaction control system (RCS), operating on engine bleed air, provides control moments independent of dynamic pressure. During VTOL operation it provides the complete maneuvering control. The pitch RCS is located in the aft fuselage and the forward lower mold line of the inlet, just forward of the nose gear. The lateral RCS thrusts both up and down in opposite wing tips. The directional RCS, thrusting laterally in either direction, is located in the aft tip of the fuselage.

During VTOL operation the thrust center is positioned by varying the engine speed and the fan-stream augmentation, using the flight controller. Decreasing the forward nozzle thrust moves the thrust center aft, with the level of thrust maintained by increasing the engine speed. This provides the static trim during VTOL; transient control is provided by the pitch RCS.

Additional control is provided by the engine nozzle thrust-vectoring control (TVC). The fore and aft nozzles are symmetrically deflected a small amount for rapid load-factor changes, with rapid turns plus deceleration followed by acceleration. Differential deflection of the fore and aft nozzles is used for STOL control to augment the canard deflection in controlling the high-lift flap pitching moment.

Propulsion System. A single, advanced Pratt and Whitney thrust-vectoring engine (STF 561-C2) with fan-stream augmentation serves as the propulsion system. It has a twin-spool turbofan gas generator utilizing a two-stage fan and a five-stage low-aspect-ratio high-through-flow axial compressor with a single-stage, high-pressure turbine and a two-stage, low-pressure turbine. The bypass ratio is 1.16, the overall pressure ratio is 25.0, and the fan pressure ratio is 3.50. Table 10 gives additional propulsion system characteristics.

The forward, side-mounted nozzles incorporate fan-stream burning augmentors. There is no engine-core augmentation associated with the aft nozzles. The half-axisymmetric, side-mounted inlets have fixed 16.5° half-conical spikes.

Structure. Composites are used extensively in the Model 279-3. The structural weight consists of 41% graphite epoxy, 21% aluminum, 13% titanium, 8% steel, and 17% other materials. Graphite epoxy is distributed as follows: wing 50%, canard 52%, vertical tail 65%, fuselage 46%, and the engine section 55%.

Mission Performance. MCAIR sized the configuration to the vertical-takeoff, supersonic, DLI mission defined in Fig. 72. Weapons and ammunition are retained throughout the mission. To accomplish this mission and remain within the guideline vertical takeoff gross weight of 13,606 kg (30,000 lb), the aircraft has a mission radius of 191 km (103 n. mi.) and a vertical takeoff gross weight of 13,535 kg (29,840 lb). With full internal fuel [gross weight = 14,161 kg (31,220 lb)] and a rolling takeoff of less than 15 m (50 ft), the radius of the DLI mission is increased to 296 km (160 n. mi.) A weight summary for the vertical takeoff supersonic DLI mission is given in Table 11.

Performance of the Model 279-3 and NASA guideline performance are shown in Table 12. As indicated, all performance requirements are met or exceeded.

The STO characteristics of the Model 279-3 with full internal fuel have been determined by MCAIR for both a flat deck and a 12° ski jump. For a 122-m (400-ft) flat-deck run with zero wind over the deck, the Model 279-3 has an STO gross weight of 18,960 kg (41,800 lb) as shown in Table 12. With this same takeoff run, the STO weight is increased 17%, to 22,135 kg (48,800 lb) using the ski jump.

4.2.2.3 Rockwell International

The single-engine V/STOL fighter concept studied by Rockwell (Refs. 51 and 59), employs thrust-augmenting ejectors for the vertical lift system. This propulsive lift concept is used in two tailless designs by Rockwell. The baseline configuration has a double-delta wing planform. The alternative configuration has a straight leading edge, clipped delta wing. The baseline design will be described first.

Baseline Configuration. The baseline configuration is a tailless design with a double-delta clipped wing, a top-mounted inlet system, fore and aft thrust-augmenting ejectors, and twin vertical tails mounted on the aft fuselage (Fig. 73).

Rockwell selected the ejector concept for the propulsive lift system because of its low velocity and low-temperature footprint compared with that of a direct-lift, deflected-thrust, or RALS concept. In the Rockwell system, all of the mixed gas efflux (intermediate power) is diverted to the lifting system for vertical flight. The lifting system is composed of fore and aft rectangular thrust-augmenting ejectors with end plates arranged in a spanwise direction in each wing panel (Fig. 73). Each ejector unit consists of a pair of opposing Coanda flaps with end plates and a fully deflectable centerbody (0° to 90°). Engine air is injected along the shoulder of each flap and through the centerbody. The centerbody stows to form the upper mold line of the wing and the forward Coanda flap retracts to form the lower mold line. For cruise flight, the thrust diverter (upstream of the afterburner) is opened, allowing the engine efflux to flow through the conventional nozzle. The sketches in Fig. 74 show the operation of the ejector system in various flight modes.

The long-chord, low-aspect-ratio wing contains the fore and aft ejectors in an aerodynamically thin surface. Together with the highly swept leading edges, this delta shape should provide low wave drag. The highly swept leading edges should also allow moderate leading edge radii to provide leading edge suction at subsonic and supersonic speeds. Wing-trailing-edge elevons combined with moderate airframe instability provide increasing camber to trim increasing lift. The long wing chord also shields the top inlet from body crossflow.

Three views of the baseline configuration are shown in Fig. 75, and lifting surface dimensional parameters are given in Table 13. The wing has an aspect ratio of 1.83 and the leading edge sweeps are 48.1° inboard and 64.1° outboard. The wing thickness-to-chord ratio varies from about 0.037 inboard to 0.034 outboard. Twin vertical tails with a leading edge sweep of 53.1° are mounted on the aft fuselage.

As shown in Fig. 75, the landing gear is a bicycle arrangement with the main fore and aft gear in the fuselage. Outrigger gear are stowed in the end plates for the aft ejector.

The baseline configuration has a wing loading of about 2.11 kN/m² (44 lb/ft²) at vertical takeoff gross weight. For this same weight, the maximum afterburning thrust-to-weight ratio is 1.41 (uninstalled, sea-level-static, standard day).

Control. Control in the vertical flight mode is provided by differentially varying the fore and aft and left and right ejector lift magnitude and direction. The ejector lift magnitude is reduced by moving the trailing edges of the Coanda flaps closer together. This system is supplemented by a pitch-reaction-control system for rapid pitch-control inputs.

Control and stability augmentation in conventional flight are provided by wing-trailing-edge elevons and rudders. The control power and airframe instability are designed to permit operation at angles of attack from 0 to 90°. Additional control power and further reduced trim drag can be provided by an all-movable canard on the lower shoulder of the forward fuselage.

Forward flight is achieved by retracting all flaps in a conventional manner. Control during the transition from vertical to conventional flight is accomplished by gradually changing from thrust-magnitude and direction control to elevon-type control (i.e., both Coanda flaps in an augmentor segment move in the same direction) as the augmentor flaps are retracted through 60° deflection. The yaw control reverts from a differential aft augmentor thrust-vector control to differential thrust-magnitude control, and finally to rudder control.

Propulsion System. A single, advanced Pratt and Whitney augmented turbofan parametric engine serves as the propulsion system. The bypass ratio is 0.54, the overall pressure ratio is 30.0, and the fan pressure ratio is 3.60. Table 14 gives additional engine characteristics.

The intermediate-power-to-vertical-takeoff gross weight ratio is 0.86. The ejector system augments the engine intermediate-power gross isentropic thrust about 50% for vertical takeoff and landing.

The top-mounted inlet system has a simple fixed-ramp and is designed for operation to a maximum speed of Mach 2.0. An auxiliary inlet is provided to supply additional air to the engine for vertical takeoff and landing and for conversion flight operations.

Structure. The wing structure features a large central torque box plus a "back porch." The back porch is the surface between the aft augmentor and the flap (Fig. 75). The central torque box and back porch act in differential bending to provide a strong, stiff support for the wing outer panel. Composites are used throughout to minimize weight. The augmentor ducts utilize titanium aluminides, or fiber- or filament-reinforced titanium composites to accommodate the 642°C (1188°F) mixed gas temperature.

Mission Performance. The baseline aircraft was sized for a 278-km (150-n. mi.) radius vertical-takeoff, DLI mission and for 556-km (300-n. mi.) radius short-takeoff DLI mission. The DLI mission is defined in Fig. 76. Two AIAAM missiles are carried on the VTO mission and four are carried on the STO mission. No gun is carried, and the missiles are excluded from the performance calculations. In order to meet these missions and the guideline performance, the VTO gross weight is 10,866 kg (24,000 lb), and the STO gross weight is 13,336 kg (29,400 lb). Short takeoff distance is less than 122 m (400 ft). At 88% of the VTO gross weight, the aircraft has a sustained load factor of 6.9 g at Mach 0.6 at an altitude of 3,048 m (10,000 ft). At Mach 0.9 at an altitude of 3,048 m (10,000 ft) the $P_{S_{1G}}$ is 357 m/sec (1,170 ft/sec). The maximum speed capability is in excess of $M = 2.0$. These performance characteristics are compared with the study guidelines in Table 15. A summary of the baseline configuration weights is given in Table 16.

Alternative Configuration. The alternative configuration has a straight leading edge, clipped delta wing, with the same top-mounted inlet, but with the forward augmentor oriented in a chordwise, rather than spanwise, direction (Fig. 77). This configuration provides the same conventional flight benefits as the baseline configuration and possesses the same key features. The major differences are the flexibility available for wing planform design, the larger central wing structural torque box, and the increased capability for overload external-store stations on the wing.

The aft spanwise augmentor is identical in concept and is very similar in size and shape to the baseline configuration. The forward chordwise augmentor uses the side of the fuselage for its inboard Coanda flap and a movable outboard Coanda flap to provide thrust-magnitude control and to fair out the wing root lower mold line in conventional flight. A series of spanwise-oriented centerbodies swivel from 90° in vertical flight to 0° (stowed) in conventional flight as the aircraft transitions. In conventional flight the stowed centerbodies form the upper mold line of the wing root.

Three views of the aircraft are shown in Fig. 78. Key lifting-surface dimensional parameters are presented in Table 17. The alternative wing has a straight leading edge of 60° sweep and a constant thickness-to-chord ratio of 0.038. The aspect ratio and wing reference area are essentially equal to those of the baseline configuration; the vertical tails are identical in both configurations.

The alternative configuration engine, avionics, weapons, and performance characteristics are essentially the same as those of the baseline configuration. A weight summary of the alternative configuration is given in Table 18.

4.2.2.4 Vought

The Vought single-engine V/STOL fighter, TF120, is a wing/canard design featuring Vought's series-flow, tandem-fan propulsion concept. The tandem fan is a dual-mode, variable-cycle engine which will be described later. Figure 79 shows an early version of the configuration and Fig. 80 is a later version in which the canard has been mounted on the wing strakes. References 51 and 60 give details of this concept.

Configuration. Figure 81 shows three views of the Vought TF120 concept. The TF120 is a canard/delta-wing configuration featuring extensive wing-body blending in both planform and cross section. Canard control surfaces are located on the wing strakes. Small booms extend aft from the wing to support twin outboard vertical fins and ventrals. Both the fins and ventrals are canted inboard and both are all-movable surfaces. Two small, variable-incidence control fins mounted on the lower corners of the inlets pivot from vertical to horizontal depending on the flight regime.

The side-mounted inlets provide airflow to a single turbofan engine. A nozzle similar to the General Electric ADEN is mounted aft and vectors the thrust from 0° to greater than 90°. The landing gear is a conventional tricycle design. The main wheels fold inboard and slightly forward into the blended-body section at approximately the intersection of the strake and wing leading edge. The nose wheel retracts forward into the nose just ahead of the cockpit.

Four AMRAAM missiles are mounted on the lower blended fuselage inboard of the wing root. A 20-mm Gatling gun and 400-round ammunition drum are also located in the blended wing root area on the left side of the aircraft.

Table 19 gives a summary of the geometry of the various aircraft surfaces. The wing has an aspect ratio of 2.24, a leading-edge sweep of 50°, and a thickness-to-chord ratio of 0.06 at the root and 0.05 at the tip. The canard has a leading-edge sweep of 55° and a dihedral of 10°. The total canard exposed area is about 12% of the theoretical wing area. The twin vertical tails have a leading edge sweep of 45°. Ventral fins on the forward, lower inlet surface have a total exposed area that is about 2% that of the wing theoretical area.

Based on the maximum vertical takeoff gross weight, the TF120 has a vertical takeoff wing loading of 3.47 kN/m² (72.4 lb/ft²) and a vertical thrust-to-weight ratio of 1.16. For this same gross weight and the maximum augmented thrust for the high-speed flight mode (series flow), the thrust-to-weight ratio is 1.73.

Control. The TF120 is a control-configured vehicle with movable surfaces that can be optimally phased throughout the operating envelope. In addition to providing direct lift and direct side force, this system can cope with battle damage or random failures with fewer channels of redundancy than usually postulated for fly-by-wire systems because of the multiplicity of controls.

The ventral fins below the inlets are unit control surfaces with two axes of travel. In addition to pivoting to generate normal forces, these surfaces can be adjusted to any dihedral angle between -15° to -75°. In the down position they help generate direct side forces and aid in directional control. At supersonic speeds they fold out to reduce the rearward shift in aerodynamic center and augment longitudinal and lateral control. At a -45° setting the fins can be used as two-axis controls for gust alleviation and precision target tracking. The aft vertical fins and ventral fins are mechanically independent, all-moving controls. Therefore, a total of six control surfaces are available to generate side forces. The four ventrals provide control effectiveness into the post-stall regime to enhance combat agility.

Force controls available for longitudinal and lateral control are wing-trailing-edge flaps (elevons), canards, and the inlet ventral fins. A trailing edge flap attached to the ADEN provides longitudinal trim and high-speed, thrust-vectoring capability.

With the control surface group under integrated software control, it is possible to compensate for wide-ranging flight conditions, control nonlinearities, and component failures to achieve a high level of system performance. However, a high-quality aerodynamic database will be required to realize this potential.

During vertical takeoff and landing and during hover flight, the series-flow tandem-fan concept achieves longitudinal control by differential modulation of the fore and aft thrust. This is accomplished using variable inlet guide vanes (VIGV) for both the forward and aft fans. VIGV thrust modulation delivers rapid pitch-attitude response. Vanes in both exhaust streams provide yaw control in hover. Roll control is accomplished by a demand bleed-reaction jet system. A roll-control valve and an upward and a downward ejector are located in each wing tip. The flow to the reaction-control jets is ducted through piping in the wing leading edges.

Propulsion System. The propulsion system for the TF120 is the series-flow, tandem-fan, variable-cycle engine. The system is composed of shaft-coupled forward and aft fan units driven by a turbofan engine, as shown in Fig. 82. Both fans have VIGV for thrust modulation in the parallel-flow mode (vertical operation) and for fan-matching in the series-flow mode (high-speed operation). The flow-diverter valve, a moderate temperature burner for the forward fan, the forward fan ventral nozzle, and the rear fan inlet are located between the two fan units.

In high-speed flight, the propulsion cycle is a conventional afterburning turbofan. For vertical operation, the front fan flow is separated from the aft-fan/core-engine flow by simultaneously closing the duct splitter valve and opening the front fan exhaust nozzle and aft fan inlet. A unique "venetian blind" splitter valve acts as a variable-porosity wall to minimize flow distortion during mode transition.

The forward fan uses low-temperature duct burning during vertical operation. The VIGVs provide the rapid and precise thrust modulation needed for hover control.

The side inlets are fixed-geometry, vertical-ramp, bifurcated duct design with blow-in doors for improved VTO performance. The aft vertical mode inlet is a flush design located on the upper fuselage.

The forward nozzle is a parallel-flow, tandem-fan V/STOL nozzle; it has a low-temperature burner incorporated into the system to augment thrust during VTO. An ADEN-type nozzle is used to vector the aft flow stream. Full afterburning of the aft flow stream is possible anywhere in the flight envelope, but is not required in the hover mode. The exhaust footprint is comparable to that of the Harrier.

Table 20 gives the tandem-fan baseline cycle characteristics for both the parallel-flow mode (vertical operation) and the series-flow mode (high-speed operation). In the vertical-flight mode, the thrust split is 67% fore and 33% aft. The fan pressure ratios in the VTOL mode are 2.2 fore and 1.75 aft, and in the series-flow (high-speed) mode the ratio is 3.44. The overall pressure ratio is 17.5 in the VTOL mode and 25.2 in the high-speed mode.

Mission Performance. Vought determined the performance of the TF120 on three hypothetical design missions: A supersonic intercept (SI), a fighter escort (FE), and an interdiction (INX) (Fig. 83). The first two are vertical takeoff missions and the third requires a short takeoff. The payload for the SI mission is four AMRAAMs and a 20-mm gun. The payload for the FE mission (which requires the two 370-gal fuel tanks) is four AMRAAMs, two short-range missiles, and a gun. On the INX mission, which requires two 370-gal fuel tanks, the payload is two short-range missiles and four bombs. On all three missions, all missiles and ammunition are retained. The results of the mission studies are summarized in Table 21. The SI radius is 370 km (200 n. mi.) for a Mach 1.6 dash. Increasing the dash speed to Mach 2.0 reduces the radius to 258 km (139 n. mi.). With external fuel and an STO weight of 15,720 kg (34,664 lb), the interdiction mission radius is 960 km (519 n. mi.). Table 22 gives a weight summary for the SI mission.

A summary comparing the TF120 performance to the NASA guidelines is given in Table 23, which shows performance for maximum afterburning power setting as well as the maximum Mach number and altitude for intermediate power setting. At Mach 0.6 at an altitude of 3,048 m (10,000 ft), the TF120 has a sustained load factor of 6.62. The aircraft has a Ps_{1G} of 526 m/sec (1725 ft/sec) at Mach 0.9 and an altitude of 3,048 m (10,000 ft). The TF120 has a maximum Mach number of 2.4 at maximum power and also has supersonic capability (M = 1.42) at intermediate power.

5. CONCLUDING REMARKS

This lecture has summarized V/STOL concepts in the United States, including some from the past and some that may come in the future. Of the multitude of concepts that were studied in the past, only about 15 or so that reached some form of flight evaluation have been described. Nearly all of these concepts suffered from some weaknesses or problems. These problems included such things as (1) poor handling qualities, (2) the lack of a SAS for hover and low-speed flight, (3) marginal aircraft performance envelopes which restricted operational evaluations, (4) little or no STO capability, (5) low payload/range performance, (6) compromised high-speed performance due to features that provide VTOL capability, and (7) reingestion of hot gases. The lessons

learned from these past concepts need not be repeated, as the past efforts have provided a valuable database for present and future designs.

Design changes to a successful V/STOL aircraft, the British AV-8A Harrier, have resulted in an improved concept, the AV-8B Harrier II. This is the only current concept considered in the paper. A number of subsonic, multimission concepts proposed by U.S. industry indicate that there are still many approaches to V/STOL that have not been flight-demonstrated. A major portion of the paper has been devoted to the future V/STOL fighter, which also has not been flight-tested in the U.S. A number of different propulsive lift concepts proposed for these fighter designs have been described along with the configuration geometry, control concepts, and the mission performance. Many of these concepts appear to have benefited from the lessons of earlier efforts and have reasonable range/payload, control power, and STOL overload capability. In one case, a third generation of a successful concept, the Harrier, is under consideration as a supersonic V/STOL fighter. From this chronology we might say that the concept of V/STOL aircraft has survived its "birth pains" and is about to enter the growth stage.

6. REFERENCES

1. Anderson, S. B., "Historical Overview of S/TOL Aircraft Technology," NASA TM-81280, March 1981.

2. Anderson, S. B., "An Overview of V/STOL Aircraft Development," AIAA Paper 83-2491, Presented at AIAA Aircraft Design, Systems and Technology Meeting, Fort Worth, Texas, October 17-19, 1983.

3. Bradfield, G. W., "Design Features of a Sea Based Multipurpose V/STOL, STOVL and STOL Aircraft in a Support Role for the U.S. Navy." AIAA Paper 81-2650, AIAA/NASA Ames VSTOL Conference, Palo Alto, California, December 7-9, 1981.

4. Kalemaris, S., and Buchmann, W. G., "Aero-Propulsion Development of a Twin-Fan V/STOL Aircraft." AIAA Paper 77-595, June 1977.

5. Potonides, H. C., "Development of an Inlet for a Tilt Nacelle Subsonic V/STOL Aircraft." ASME-Gr-121, April 1979.

6. Potonides, H. C., Cea, R. A., and Nelson, T. F., "Design and Experimental Studies of a Type A V/STOL Inlet." AIAA Paper 78-956R, July 1978.

7. Burley, R. R., "Effect of Lip and Centerbody Geometry on Aerodynamic Performance of Inlets for Tilt Nacelle VTOL Aircraft." AIAA Paper 79-0381, 1979.

8. Johns, A. L., Williams, R. C., and Potonides, H. C., "Performance of a V/STOL Tilt Nacelle Inlet with Blowing Boundary Layer Control." AIAA Paper 79-1163, June 1979.

9. Kress, R. W., "An Affordable Means of Increasing Sea-Based Air Power." SAE Paper 801241, October 1980.

10. Falarski, M. D., Dudley, M. R., Buchmann, W. G., and Pisano, A., "Aerodynamic Characteristics of a Large-Scale Twin Tilt-Nacelle V/STOL Model." AIAA Paper 81-0150, January 1981.

11. Perera, M., "Hover and Transition Flight Performance of a Twin Tilt-Nacelle V/STOL Configuration." AIAA Paper 83-1824, July 1983.

12. Lehman, C. L., and Crafa, V. J., "Nacelle Design for Grumman Design 698." SAE Paper 831492, October 1983.

13. Wilson, S. B. III, Donley, S., Valckenaere, W., Buchmann, W. G., and Blake M., "Handling Characteristics of a Simulated Twin-Tilt Nacelle V/STOL Aircraft." SAE Paper 831549, October 1983.

14. Kalemaris, S. G., "V/STOL for Sea Control." AIAA Paper 83-2436, October 1983.

15. Kohn, J. S., "Aerodynamics, Propulsion and Longitudinal Control Requirements for a Tilt-Nacelle V/STOL with Control Vanes Submerged in the Nacelle Slipstream." AIAA Paper 83-2513, October 1983.

16. Waller, J. D., and Yackle, A. R., "A Split Fan Concept for a Medium Speed V/STOL." SAE Technical Paper 831548, October 1983.

17. Glasgow, E. R., Beck, W. E., and Carlson, J. G., "Cross-Ducted Propulsion Systems for Medium-Speed V/STOL Applications." SAE Technical Paper 831493, October 1983.

18. Glasgow, E. R., and Skarshaug, R. E., "Type A V/STOL Propulsion System Development." AIAA Paper 79-1287R, October 1980.

19. Glasgow, E. R., Beck, W. E., and Woollett, R. R., "Zero-Length Slotted-Lip Inlet for Subsonic Military Aircraft." AIAA Paper 80-1245R, February 1982.

20. Priestley, R. T., Sr., and Yackle, A. R., "V/STOL, STOL, CTOL Comparisons." SAWE Paper 1499, May 1982.

21. Rosenberg, E. W., and Esker, D. W., "Development of the "D" Vented Thrust Deflecting Nozzle." AIAA Paper 80-1856, August 1980.

22. Rosenberg, E. W., and Christiansen, R. S., "Ground Test of a Large Scale "D" Vented Thrust Deflecting Nozzle." AIAA Paper 81-2630, December 1981.

23. Rosenberg, E. W., "Test and Analysis of a Vented "D" Thrust Deflecting Nozzle on a Turbofan Engine," NASA CR 166279, March 1982.

18

24. Adelt, W. H., "Type A V/STOL: One Aircraft for All Support Missions?" AIAA Paper 81-2661R, J. of Aircraft, Vol. 20, No. 6, June 1983.

25. Beatty, T. D., and Riccius', M. V., "Vought Ground Effects and Transition Tests of a Tandem Fan Medium Speed V/STOL Configuration." SAE Paper 831547, October 1983.

26. Clingingsmith, T. W., "Medium Speed V/STOL Propulsion Installation Losses — Comparison of Prediction and Model Test Data." SAE Paper 831494, October 1983.

27. Rhoades, W. W., and Ybarra, A. H., "Low Speed Test of the Aft Inlet Designed for a Tandem Fan V/STOL Nacelle." NASA CR-159752, February 1980.

28. Ybarra, A. H., "Additional Testing of the Inlets Designed for Tandem Fan V/STOL Nacelles." NASA CR-165310, June 1981.

29. Williams, R. C., and Ybarra, A. H., "Low Speed Testing of the Inlets Designed for Tandem Fan V/STOL Nacelles." NASA TM 82728 (AIAA 81-2627), December 1981.

30. Limage, C. R., "Development of Low Pressure Ratio Vectoring Nozzles for V/STOL Aircraft." SAE Paper 770988, November 1977.

31. Burstadt, P. L., and Johns, A. L., "Experimental Results of a Deflected Thrust V/STOL Nozzle Research Program." AIAA Paper 83-0170, January 1983.

32. Pennington, D. F., "Tandem Fan Model — Front Fan Nozzle Test Applicable to a Type A V/STOL Aircraft." NASA CR-168024, July 1983.

33. Louthan, J. D., "The Impact of Propulsion Performance Parameters on V/STOL Design and Sizing." AIAA Paper 80-1875, August 1980.

34. Nelms, W. P., "Studies of Aerodynamic Technology for VSTOL Fighter/Attack Aircraft." AIAA Paper 78-1511, August 1978.

35. Lummus, J. R., "Study of Aerodynamic Technology for VSTOL Fighter/Attack Aircraft." NASA CR-152128, 1978.

36. Burhans, W. R., Crafa, V. J., Dannenhoffer, N. F., Dellamura, F. A., and Krepski, R. E., "Study of Aerodynamic Technology for VSTOL Fighter/Attack Aircraft." NASA CR-152129, 1978.

37. Brown, S. H., "Study of Aerodynamic Technology for VSTOL Fighter/Attack Aircraft — Horizontal Attitude Concept." NASA CR-152130, 1978.

38. Gerhardt, H. A., and Chen, W. S., "Study of Aerodynamic Technology for VSTOL Fighter/Attack Aircraft — Vertical Attitude Concept." NASA CR-152131, 1978.

39. Driggers, H. H., "Study of Aerodynamic Technology for VSTOL Fighter/Attack Aircraft." NASA CR-152132, 1978.

40. Nelms, W. P., and Durston, D. A., "Preliminary Aerodynamic Characteristics of Several Advanced VSTOL Fighter/Attack Aircraft Concepts." SAE Paper 801178, October 1980.

41. Nelms, W. P., Durston, D. A., and Lummus, J. R., "Experimental Aerodynamics Characteristics of Two VSTOL Fighter/Attack Aircraft Configurations at Mach Numbers from 0.4 to 1.4." NASA TM-81234, December 1980.

42. Lummus, J. R., Joyce, G. T., and O'Malley, C. D., "Analysis of Wind Tunnel Tests Results for a 9.39-Percent Scale Model of a VSTOL Fighter/Attack Aircraft." NASA CR-152391, Vols. 1-4, January 1981.

43. Lummus, J. R., "Aerodynamic Characteristics of a VSTOL Fighter Configuration." AIAA Paper 81-1292, 1981.

44. Nelms, W. P., Durston, D. A., and Lummus, J. R., "Experimental Aerodynamic Characteristics of Two VSTOL Fighter/Attack Aircraft Configurations at Mach Numbers from 1.6 to 2.0." NASA TM-81286, May 1981.

45. Durston, D. A., and Smith, S. C., "Lift Enhancing Surfaces on Several Advanced VSTOL Fighter/Attack Concepts." AIAA Paper 81-1675, August 1981.

46. Moore, W. A., "Wind Tunnel Data Analysis of the Northrop Horizontal Attitude VSTOL Fighter Configuration for Mach Numbers from 0.4 to 1.4." NASA CR-166277, 1982.

47. Moore, W. A., "Wind Tunnel Data Analysis of the Northrop Vertical Attitude VSTOL Fighter Configuration for Mach Numbers from 0.4 to 1.4." NASA CR-166278, 1982.

48. Durston, D. A., and Smeltzer, D. B., "Inlet and Airframe Compatibility for a VSTOL Fighter/Attack Aircraft With Top-Mounted Inlets." ICAS Paper 82-4.2.2, August 1982.

49. Durston, D. A., and Smeltzer, D. B., "Inlet and Airframe Compatibility for a V/STOL Fighter/Attack Aircraft With Top-Mounted Inlets." NASA TM-84252, June 1982.

50. Durston, D. A., and Schreiner, J. A., "High Angle of Attack Aerodynamics of a Strake-Canard-Wing V/STOL Fighter Configuration." AIAA Paper 83-2510, October 1983.

51. Nelms, W. P., and Durston, D. A., "Concept Definition and Aerodynamic Technology Studies for Single Engine VSTOL Fighter/Attack Aircraft." AIAA Paper 81-2647, December 1981.

52. Foley, W. H., Sheridan, A. E., and Smith, C. W., "Study of Aerodynamic Technology for Single-Cruise-Engine VSTOL Fighter/Attack Aircraft." NASA CR-166268, 1982.

53. Foley, W. H., "An Integrated Aerodynamic/Propulsive Design for a STOVL Fighter/Attack Aircraft." ICAS-82-1.6.2, 1982.

54. Garland, D. B., "Static Tests of the J-97 Powered, External Augmentor V/STOL Wind Tunnel Model." de Havilland Report DHC-DND 77-4, February 1978.

55. Garland, D. B., "Phase 1 Wind Tunnel Tests of the J-97 Powered, External Augmentor V/STOL Model." de Havilland Report DHC-DND 79-4, September 1979.

56. Garland, D. B., and Harris, J. L., "Phase 2 and 3 Wind Tunnel Tests of the J-97 Powered, External Augmentor V/STOL Model." de Havilland Report DHC-DND 80-1, March 1980.

57. Gilbertson, F. L., and Garland, D. B., "Static Tests of the J-97 Powered External Augmentor V/STOL Model at the Ames Research Center." de Havilland Report DHC-DND 80-2 (Draft Copy, 1980).

58. Hess, J. R., and Bear, R. L., "Study of Aerodynamic Technology for Single-Cruise-Engine VSTOL Fighter/Attack Aircraft." NASA CR-166269, 1982.

59. Mark, L., "Study of Aerodynamic Technology for Single-Cruise-Engine VSTOL Fighter/Attack Aircraft." NASA CR-166270, 1982.

60. Driggers, H. H., "Study of Aerodynamic Technology for Single-Cruise-Engine VSTOL Fighter/Attack Aircraft." NASA CR-166271, 1982.

7. ACKNOWLEDGEMENTS

TABLE 1. GENERAL DYNAMICS HATOL CONFIGURATION CHARACTERISTICS

Wing

Area	35.7 m (384 ft^2)	
Aspect ratio	3.62	
Taper ratio	0.19	
Root chord	5.28 m (17.31 ft)	
Tip chord	1.00 m (3.29 ft)	
t/c (root/tip)	0.04/0.04	
Leading-edge sweep	40°	

Canard

Area (exposed)	7.14 m (76.9 ft^2)
Aspect ratio	2.16
Taper ratio	0.37
Root chord	2.65 m (8.71 ft)
Tip chord	0.98 m (3.22 ft)
t/c (root/tip)	0.05/0.03
Leading-edge sweep	45°

Vertical tail

Area	4.41 m^2 (47.5 ft^2)
Aspect ratio	1.27
Taper ratio	0.43
Root chord	2.61 m (8.55 ft)
Tip chord	1.12 m (3.68 ft)
t/c (root/tip)	0.053/0.04
Leading-edge sweep	47.5°

Weight summary (DLI mission)

	kg	lb
Structure	5138	(11327)
Propulsion	3876	(8545)
Fixed equipment	1601	(3530)
Payload	865	(1907)
Fuel	4390	(9678)
VTO gross weight	15870	(34987)

General (DLI mission)

W/S (VTO gross weight

        4.36 kN/m^2 (91 lb/ft^2)

T/W (SLS, uninstalled, max A/B)

    1.30

TABLE 2. GRUMMAN HATOL CONFIGURATION CHARACTERISTICS

Wing

Area	35.3 m (380 ft^2)
Aspect ratio	3.75
Taper ratio	0.30
Root chord	4.72 m (15.5 ft)
Tip chord	1.41 m (4.64 ft)
t/c (root/tip)	0.06/0.06
Leading-edge sweep	35°

Canard

Area (exposed)	7.90 m^2 (85 ft^2)
Aspect ratio	1.56
Taper ratio	0.37
Root chord	2.32 m (7.61 ft)
Tip chord	0.86 m (2.82 ft)
t/c (root/tip)	0.06/0.06
Leading-edge sweep	37.5°

Vertical tail (per panel)

Area	3.90 m^2 (42 ft^2)
Aspect ratio	1.37
Taper ratio	0.37
Root chord	2.48 m (8.13 ft)
Tip chord	0.91 m (3.00 ft)
t/c (root/tip)	0.05/0.05
Leading-edge sweep	47.5°

Weight summary (DLI mission)

	kg	lb
Structure	5047	(11126)
Propulsion	3617	(7974)
Fixed equipment	2339	(5156)
Payload	1204	(2654)
Fuel	4906	(10816)
VTO gross weight	17113	(37726)

General (DLI mission)

W/S (VTO gross weight)

        4.74 kN/m^2 (99 lb/ft^2)

T/W (SLS, uninstalled, max A/B)

    1.47

TABLE 3. NORTHROP HATOL CONFIGURATION CHARACTERISTICS

Wing		Vertical tail (per panel)	
Area	46.5 m (500 ft²)	Area	2.42 m² (26.0 ft²)
Aspect ratio	2.12	Aspect ratio	1.31
Taper ratio	0.18	Taper ratio	0.31
Root chord	7.92 m (26.0 ft)	Root chord	2.08 m (6.83 ft)
Tip chord	1.43 m (4.68 ft)	Tip chord	0.63 m (2.08 ft)
t/c (root/tip)	0.04/0.04	t/c (root/tip)	0.04/0.04
Leading-edge sweep	50°	Leading-edge sweep	42.5°

Canard		General (DLI mission)	
Area (exposed)	4.23 m² (45.5 ft²)	VTO gross weight	13,608 kg (30,000 lb)
Aspect ratio	1.53		
Taper ratio	0.27	W/S (VTO gross weight)	2.87 kN/m² (60 lb/ft²)
Root chord	2.62 m (8.58 ft)		
Tip chord	0.71 m (2.33 ft)	T/W (SLS, installed, intermediate power)	
t/c (root/tip)	0.04/0.04	1.20	
Leading-edge sweep	60°		

TABLE 4. NORTHROP VATOL CONFIGURATION CHARACTERISTICS

Wing		General (DLI mission)	
Area	46.5 m² (500 ft²)	VTO gross weight	13,608 kg (30,000 lb)
Aspect ratio	2.12		
Taper ratio	0.18	W/S (VTO gross weight)	2.87 kN/m² (60 lb/ft²)
Root chord	7.92 m (26.0 ft)		
Tip chord	1.43 m (4.68 ft)	T/W (SLS, uninstalled, intermediate power)	
t/c (root/tip)	0.04/0.04	1.29	
Leading-edge sweep	50°		

Vertical tail	
Area	2.51 m² (27.0 ft²)
Aspect ratio	1.10
Taper ratio	0.34
Root chord	2.26 m (7.42 ft)
Tip chord	0.76 m (2.50 ft)
t/c (root/tip)	0.04/0.04
Leading-edge sweep	50°

TABLE 5. VOUGHT VATOL CONFIGURATION CHARACTERISTICS

Wing	
Area	32.9 m² (354 ft²)
Aspect ratio	2.30
Taper ratio	0.15
Root chord	6.61 m (21.7 ft)
Tip chord	0.99 m (3.25 ft)
t/c (root/tip)	0.05/0.05
Leading-edge sweep	50°

Weight summary (DLI mission)

	kg	lb
Structure	2328	(5133)
Propulsion	1985	(4375)
Fixed equipment	1461	(3221)
Payload	1101	(2427)
Fuel	3728	(8219)
VTO gross weight	10603	(23375)

Canard	
Area (exposed)	4.89 m² (52.6 ft²)
Aspect ratio	0.80
Taper ratio	0.25
Root chord	2.80 m (9.17 ft)
Tip chord	0.70 m (2.29 ft)
t/c (root/tip)	0.05/0.04
Leading-edge sweep	60°

General (DLI mission)

W/S (VTO gross weight)
3.16 kN/m² (66 lb/ft²)

T/W (SLS, uninstalled, max A/B)
1.45

Vertical tail	
Area	5.57 m² (60.0 ft²)
Aspect ratio	1.00
Taper ratio	0.30
Root chord	3.63 m (11.92 ft)
Tip chord	1.09 m (3.58 ft)
t/c (root/tip)	0.05/0.04
Leading-edge sweep	53°

TABLE 6. GENERAL DYNAMICS E7 CONFIGURATION DIMENSIONAL DATA

Parameter	Wing	Vertical tail
Reference area, m^2 (ft^2)	58.58 (630.6)	5.09 (54.8)
Aspect ratio	1.665	1.294
Taper ratio	0.115	0.437
Span, m (ft)	9.88 (32.40)	2.57 (8.42)
Root chord, m (ft)	10.64 (34.90)	2.77 (9.10)
Tip chord, m (ft)	1.22 (4.00)	1.21 (3.96)
MAC, m (ft)	7.18 (23.56)	
Leading-edge sweep, deg	60	47.5
Trailing-edge sweep, deg	-10	
t/c root	0.04	0.053
t/c tip	0.04	0.030
Airfoil	NACA 64A004	Biconvex

TABLE 7. GENERAL DYNAMICS E7
CONFIGURATION WEIGHT SUMMARY

Item	Weight, kg (lb)
Structure	3848 (8494)
Propulsion	2573 (5672)
Systems and Equipment	1813 (3996)
Weight empty	8239 (18162)
Operational weight	8612 (18986)
Payload*	449 (990)
Zero fuel weight	9061 (19976)
Fuel	5578 (12297)
Takeoff gross weight	14640 (32273)

*Two AIM-9L and two AMRAAM.

TABLE 8. GENERAL DYNAMICS CONFIGURATION E7 POINT PERFORMANCE

	Note 1	Note 2	Note 3
Point performance weight	11461 (25267)	12402 (27341)	8722 (19228)
Escort mission			
Fuel, kg (lb)	4380 (9657)	5568 (12275)	
TOGW, kg (lb)	13667 (30130)	14629 (32251)	
Radius, km (NM)	741 (400)	1143 (617)	
Interdiction mission			
Fuel, kg (lb)		5568 (12275)	
TOGW, kg (lb)		16112 (35522)	
Radius, km (NM)		1020 (551)	
Maximum Mach			
35 KFT, maximum thrust	1.73	1.73	1.73
10 KFT, int. thrust	1.02	1.02	1.02
Turn load factor			
M 0.60, 10 KFT			6.9
M 0.65, 10 KFT	5.5	5.3	7.6
P_s @ 1 g, M 0.9, 10 KFT, m/sec (ft/sec)	237 (777)	228 (747)	323 (1059)

Notes: (1) Pt. perf. @ 60% escort fuel weight.
        (2) Pt. perf. @ 60% full fuel weight.
        (3) Pt. perf. @ 88% VTOL weight.

TABLE 9. MCAIR CONFIGURATION DIMENSIONAL DATA

Parameter	Wing	Canard (exposed)	Vertical tail
Reference area, m² (ft²)	39.80 (428.4)	7.95 (85.6)	6.04 (65.0)
Aspect ratio	3.0	3.0	1.2
Taper ratio	0.25	0.25	0.35
Span, m (ft)	10.92 (35.84)	4.88 (16.02)	2.69 (8.83)
Semispan, m (in.)	5.46 (215.04)	2.44 (96.14)	2.69 (105.98)
Root chord, m (in.)	5.83 (229.44)	2.61 (102.59)	3.32 (130.84)
Tip chord, m (in.)	1.46 (57.36)	0.65 (25.64)	1.16 (45.80)
Mean aero. chord, m (in.)	4.08 (160.52)	1.82 (71.81)	2.42 (95.14)
Leading-edge sweep, deg	45	50	45
Incidence, deg	0 at fuselage	0	0
Dihedral, deg	-9	0	-
Twist, deg	-4 at tip	0	-
Airfoil, root	64AX06MOD	64A005	64A005
Airfoil, tip	64AX04MOD	64A003	64A003

TABLE 10. MCAIR CONFIGURATION PROPULSION SYSTEM CHARACTERISTICS

Engine: P&WA STF-561-C2

F_N total: 152,638 N (34,316 lb) installed (F_N VTO at 90°F, T/W = 1.15)

Thrust split: fwd 61%, aft 39%

Inlet: Fixed half conical spike, 16.5° cone

AC = 1.13 m² (12.17 ft²)

BPR = 1.16, FPR = 3.50, OPR = 25.0

Maximum air flow: 167 kg/sec (369 lb/sec)

CET_{MAX} = 1760°C (3200°F), $T_{PCB_{VTO}}$ = 1866°C (3390°F)

$T_{PCB_{MAX}}$ = 1949°C (3540°F) at M = 2.0 and 7,620 m (25,000 ft)

TABLE 11. MCAIR CONFIGURATION WEIGHT SUMMARY

Item	Weight, kg (lb)
Structure	4351 (9592)
Propulsion	2003 (4415)
Fixed equipment	2186 (4820)
Weight empty	8540 (18827)
Operating weight empty	8985 (19808)
Payload*	665 (1466)
VTO usable fuel	3885 (8566)
STO usable fuel	4513 (9950)
VTO gross weight*	13535 (29840)
STO gross weight*	14161 (31220)

*Includes two AMRAAM and two AIM-9 missiles and 25-mm gun with 400 rounds of ammunition.

TABLE 12. MCAIR CONFIGURATION PERFORMANCE SUMMARY

Item	NASA guideline	Model 279-3
Sustained load factor at Mach 0.6, 3,048 m (10,000 ft), 88% VTOGW	6.2	6.2
PS_{1G} at Mach 0.9, 3,048 m (10,000 ft), 88% VTOGW, m/sec (ft/sec)	274 (900)	317 (1,040)
DLI mission radius, VTOGW = 13,535 kg (29,840 lb), km (n. mi.)	---	191 (103)
Sustained Mach number	1.6	2.0
STO sea-based gross weight, kg (lb)	17,164-18,071 (37,840-39,840)	16,960* (41,800)*

Note: Two AMRAAM, two AIM-9, and 25-mm gun with 400 rounds of ammunition.
*Flat deck run of 122 m (400 ft) at 0-knot wind over deck (WOD) or 61 m (200 ft) at 20-knots WOD.

TABLE 13. ROCKWELL BASELINE CONFIGURATION DIMENSIONAL DATA

Wing (total)	
Area, m^2 (ft^2)	50.26 (541.0)
Aspect ratio	1.8
Span, m (ft)	9.60 (31.5)
Root chord, m (ft)	8.36 (27.43)
Tip chord, m (ft)	0.98 (3.2)
MAC, m (ft)	6.14 (20.13)
Leading-edge sweep, inboard, deg	48.0
Leading-edge sweep, outboard, deg	64.0
Airfoil	65-005 MOD
t/c, inboard	0.038
t/c, outboard	0.034
Vertical (per panel)	
Area, m^2 (ft^2)	3.40 (36.7)
Aspect ratio	1.41
Root chord, m (ft)	2.35 (7.68)
Tip chord, m (ft)	0.78 (2.55)
Taper ratio	0.33
Leading-edge sweep, deg	41.6
MAC, m (ft)	1.69 (5.54)
Span, m (ft)	2.20 (7.2)
Cant angle, deg	30
Airfoil	NASA 65-00

TABLE 14. ROCKWELL CONFIGURATION ENGINE CHARACTERISTICS

Thrust (sea level, standard day, uninstalled)	
Max A/B, N (lb)	150,699 (33,880)
Intermediate, N (lb)	91,629 (20,600)
Bypass ratio (BPR)	0.51
Fan pressure ratio (FPR)	3.6
Overall pressure ratio (OPR)	30.0
Combustor exit temperature, °C (°F)	1,538 (2,800)

TABLE 15.   ROCKWELL BASELINE CONFIGURATION PERFORMANCE SUMMARY

Item	NASA guideline	Rockwell baseline configuration
Sustained load factor at Mach 0.6, 3,048 m (10,000 ft), 88% VTOGW	6.2	6.3
$P_{S_{1G}}$ at Mach 0.9, 3,048 m (10,000 ft), 88% VTOGW, m/sec (ft/sec)	274 (900)	357 (1,170)
DLI mission radius, VTOGW = 10,886 kg (24,000 lb), km (n. mi.)	---	278 (150)
Sustained Mach number	1.6	1.9

TABLE 16.   ROCKWELL BASELINE
CONFIGURATION WEIGHT SUMMARY

Item	Weight, kg (lb)
Structure	4143 (9133)
Propulsion	2437 (5373)
Fixed equipment	1462 (3223)
Weight empty	8042 (17729)
Operating weight empty	8248 (18184)
Payload	544 (1200)
Fuel	2559 (5641)
VTO gross weight	11351 (25025)

TABLE 17.   ROCKWELL ALTERNATIVE
CONFIGURATION DIMENSIONAL DATA

Wing (total)
    Area, m^2 (ft^2)   50.96 (548.5)
    Aspect ratio   1.809
    Span, m (ft)   9.60 (31.5)
    Root chord, m (ft)   9.46 (31.03)
    Tip chord, m (ft)   1.16 (3.79)
    Taper ratio   0.122
    MAC, m (ft)   6.39 (20.96)
    Leading-edge sweep, deg   60
    Airfoil   65-005 MOD
    t/c, inboard   0.038
    t/c, outboard   0.034

Vertical (per panel)
    Area, m^2 (ft^2)   3.40 (36.7)
    Aspect ratio   1.41
    Root chord, m (ft)   2.35 (7.68)
    Tip chord, m (ft)   0.78 (2.55)
    Taper ratio   0.33
    Leading-edge sweep   41.6
    MAC, m (ft)   1.69 (5.54)
    Span, m (ft)   2.20 (7.2)
    Cant angle, deg   30
    Airfoil   NASA 65-00

TABLE 18. ROCKWELL ALTERNATIVE CONFIG-
URATION WEIGHT SUMMARY

Item	Weight, kg (lb)
Structure	3916 (8633)
Propulsion	2475 (5456)
Fixed equipment	1454 (3206)
Weight empty	7845 (17295)
Operating weight empty	8052 (17750)
Payload	544 (1200)
Fuel	2427 (5350)
VTO gross weight	11023 (24300)

TABLE 19. VOUGHT CONFIGURATION DIMENSIONAL DATA

	Wing (total)	Canard (each)	Vertical fin (each)	Aft ventral (each)	Forward ventral (each)
Area, m² (ft²)	32.52 (350.0)	1.93 (20.8)	2.43 (26.2)	0.79 (8.5)	0.33 (3.6)
Aspect ratio	2.24	1.20	1.30	0.58	1.12
Taper ratio	0.15	0.28	0.35	0.0	0.30
Span, m (ft)	8.53 (28.00)	1.52 (5.00)	1.77 (5.84)	0.67 (2.21)	0.61 (2.00)
Root chord, m (ft)	6.63 (21.74)	1.98 (6.51)	2.03 (6.65)	2.03 (6.67)	0.84 (2.75)
Tip chord, m (ft)	0.99 (3.26)	0.55 (1.82)	0.71 (2.33)	0.0 (0.0)	0.25 (0.83)
Mean geometric chord, m (ft)	4.50 (14.78)	1.40 (4.60)	1.47 (4.84)	1.55 (5.10)	0.59 (1.97)
Leading edge sweep, deg	50.0	55.0	45.0	45.0	45.0
t/c, root/tip	0.06/0.05	0.04	0.04	0.03	0.04
Airfoil, root/tip	65A006/65A005	65A004	65A004	65A003	65A004
Dihedral, deg	0	10	---	---	-15 to -75
Fin cant, deg	---	---	15	15	---
Definition	Idealized no strake or trailing-edge extension	Root chord at strake	From wing reference plane	From wing reference plane	Exposed area

TABLE 20. VOUGHT TANDEM-FAN BASELINE CYCLE CHARACTERISTICS

	Parallel flow (VTOL)	Series flow (high speed)
Fan pressure ratio	2.2/1.75	3.44
Bypass ratio	3.43	1.00
Compressor PR	10.0	7.33
Overall PR	17.5	25.2
Combustor temperature, °C (°F)	1,538 (2,800)	1,479 (2,695)
Exhaust temperature, °C (°F)	510/510 (950/950)	1,871 (3,400)
Thrust, augmented, N (lb)	130,264 (29,286)	195,023 (43,845)
SFC, augmented	0.977	2.024
Thrust, unaugmented, N (lb)	111,200 (25,000)	117,810 (26,486)
SFC	0.541	0.665
Corrected airflow, kg/sec (lb/sec)	196/115 (433/254)	196 (433)
Core corrected airflow, kg/sec (lb/sec)	44 (97)	35 (78)
Actual airflow, kg/sec (lb/sec)	181/106 (400/234)	187 (412)
Core actual airflow, kg/sec (lb/sec)	65 (143)	93 (206)

TABLE 21. VOUGHT TF120 MISSION CAPABILITY

Parameter	Internal fuel	Plus two 370-gal tanks
VTO weight, kg (lb)	11312 (24940)	
STO weight, kg (lb)		15723 (34664)
Fuel, kg (lb)	3846 (8480)	6129 (13512)
Supersonic intercept radius		
M = 1.6, 15240 m (50000 ft), km (n. mi.)	371 (200)	
M = 2.0, 18288 m (60000 ft), km (n. mi.)	258 (139)	
Fighter escort radius, n. mi.	1003 (541)	1553 (838)
Interdiction radius, n. mi.		962 (519)

TABLE 22. VOUGHT TF 120 WEIGHT SUMMARY

Item	Weight, kg (lb)
Structure	2442 (5384)
Propulsion	2553 (5629)
Fixed equipment	1469 (3240)
Weight empty	6464 (14253)
Operating weight empty	6711 (14798)
Payload*	754 (1662)
Usable fuel	3846 (8480)
VTO gross weight	11310 (24940)

*Four AMRAAM and 20-mm gun with
400 rounds of ammunition.

TABLE 23. VOUGHT TF120 PERFORMANCE SUMMARY

Item	NASA guideline	Vought TF120	
		Max A/B	Intermediate
Sustained load factor at Mach 0.6, 3,048 m (10,000 ft), 88% VTOGW	6.2	6.62	
$P_{S_{1G}}$ at Mach 0.9, 3,048 m (10,000 ft), 88% VTOGW, m/sec (ft/sec)	274 (900)	526 (1,725)	
Acceleration from M = 0.8 to M = 1.6 at 10,973 m (36,000 ft), sec	---	34	
Maximum Mach number at 10,973 m (36,000 ft)	1.6	2.40	1.42
Ceiling, m (ft)	---	20,379 (66,860)	16,331 (53,580)
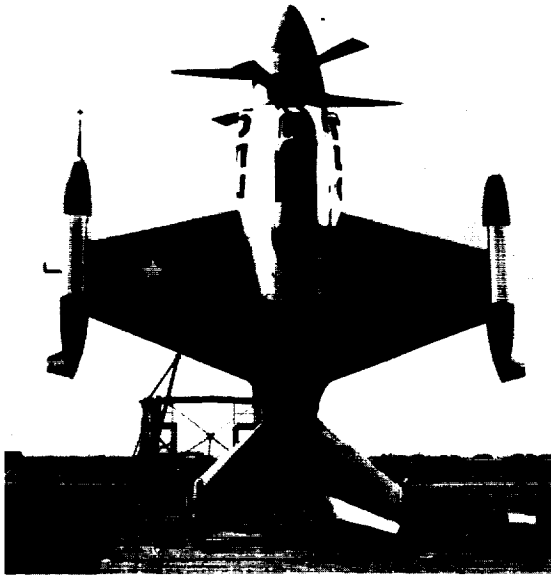
Figure 1.   Lockheed XFV-1.

Figure 2.   Convair XFY-1 Pogo.
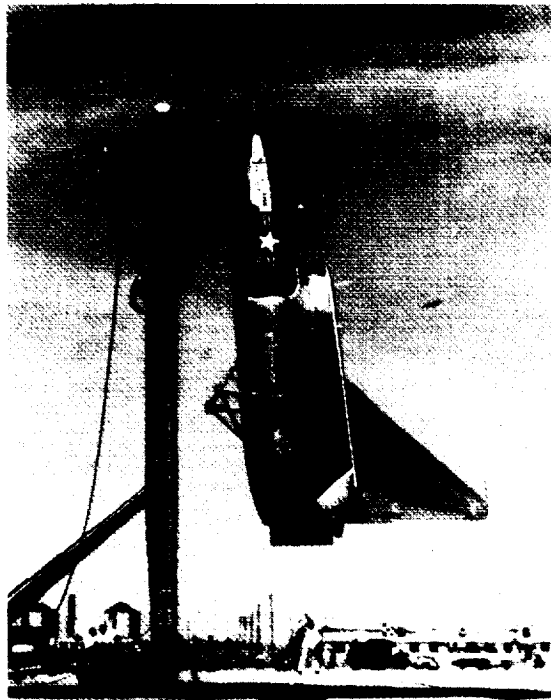
Figure 3.   Ryan X-13 Vertijet.
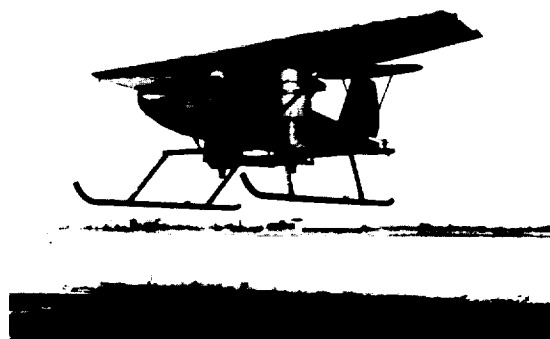
Figure 4.   Bell Air Test Vehicle (ATV).
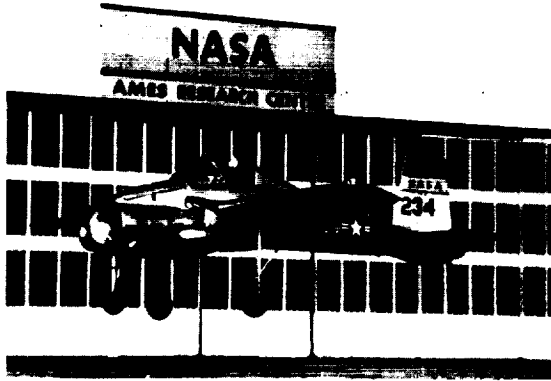
Figure 5.   Bell X-14.
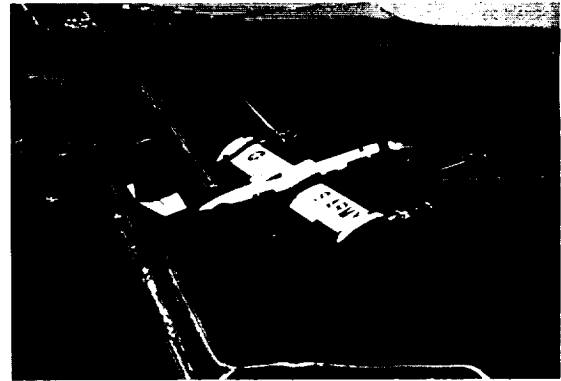
Figure 6.   Bell XV-3 Tilt Rotor.

Figure 7.   Ryan VZ3-RY.
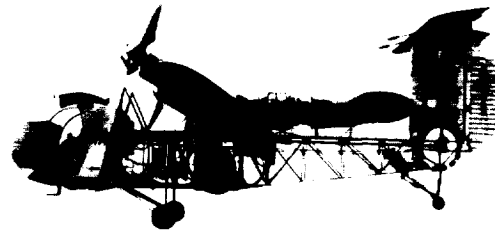
Figure 8.   Boeing-Vertol VZ-2.
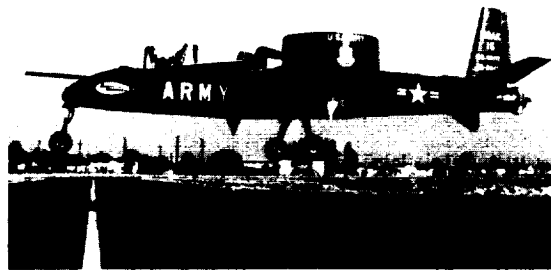
Figure 9.   Doak VZ-4 Ducted Fan.
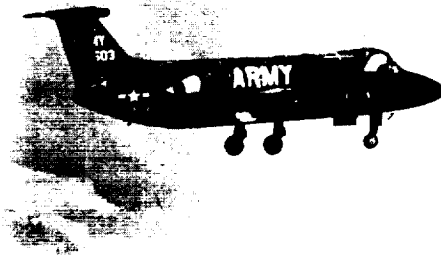
Figure 10.   Lockheed XV-4A Hummingbird.
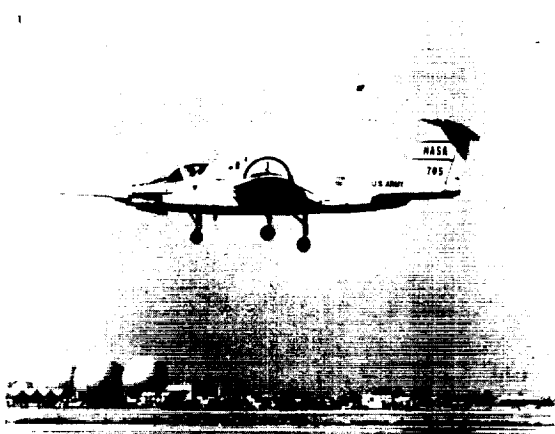
Figure 11. Ryan XV-5B.
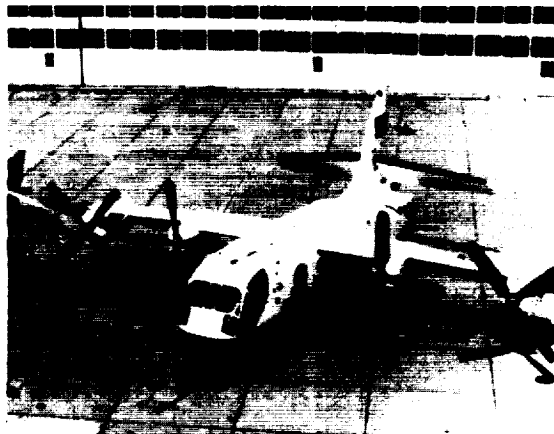
Figure 12. LTV XC-142 Tilt Wing.

Figure 13. Curtiss Wright X-19A Tilt Prop.
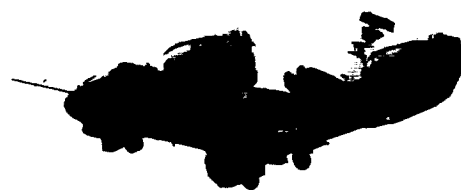
Figure 14. Bell X-22A Ducted Fan.
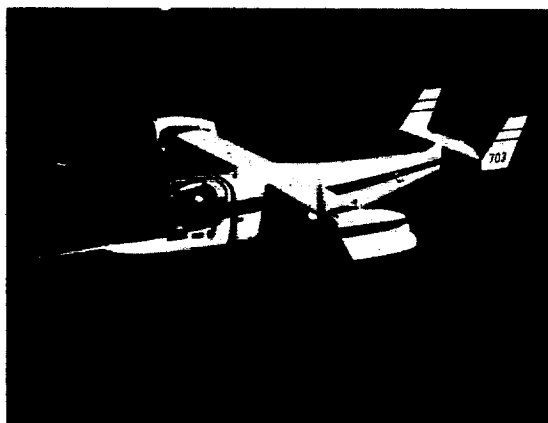
Figure 15. Bell XV-15 Tilt Rotor.

Figure 16. AV-8B Harrier II.
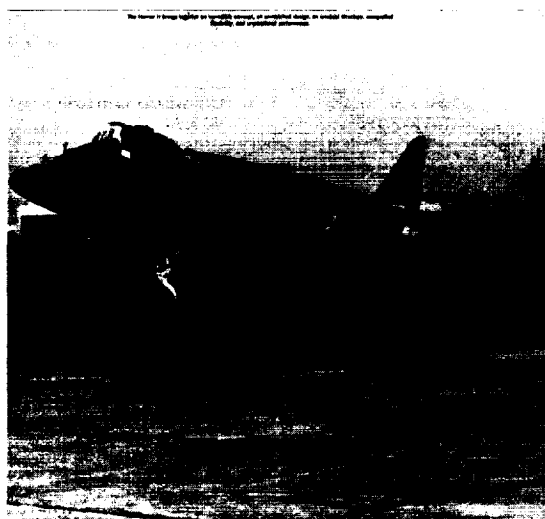
Figure 17. AV-8B Harrier II.

3.6 m
(11.6 ft)

9.2 m
(30.3 ft)

14.5 m
(46.3 ft)
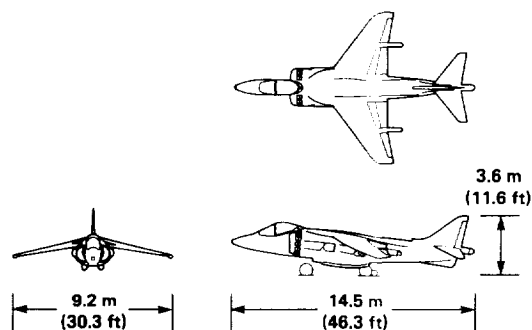
Figure 18. AV-8B Harrier II.
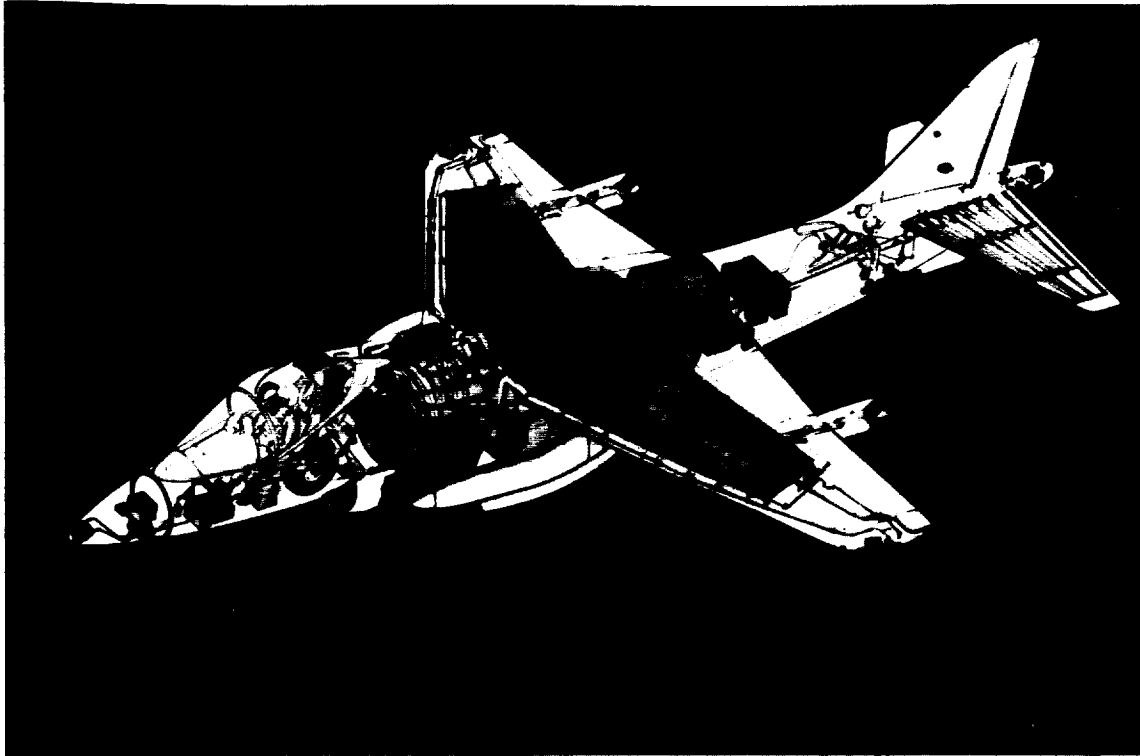
Figure 19. Changes to the AV-8A to develop the AV-8B Harrier II.

POSITIVE CIRCULATION FLAP
- **INCREASED STOL CAPABILITY (6,717 LB)**

SUPERCRITICAL AIRFOIL
- **REDUCED TRANSONIC DRAG**
- **IMPROVED MANEUVERING**

RAISED COCKPIT
- **IMPROVED VISIBILITY**
- **COMPOSITE STRUCTURE**
- **REDUCED WEIGHT (56 LB)**

COMPOSITE RUDDER AND HORIZONTAL TAIL
- **REDUCED WEIGHT (50 LB)**

LEADING EDGE ROOT EXTENSIONS (LERX)
- **INCREASED MANEUVER-ABILITY**

ANGLE RATE BOMBING SYSTEM

COMPOSITE WING
- **REDUCED WEIGHT (330 LB)**

ZERO SCARF NOZZLES
- **INCREASED THRUST (200 LB)**

INTAKE
- **INCREASED RECOVERY (1%)**
- **BETTER CRUISE EFFICIENCY**
- **MORE VTO THRUST (600 LB)**

LIFT IMPROVEMENT DEVICES
- **VTO LIFT INCREASED (1,200 LB)**

Figure 20. Advanced technologies incorporated into the AV-8B.

Figure 21. Boeing tilt-nacelle medium-speed concept.

Figure 22. Boeing blown-flap medium-speed concept.

HORIZONTAL FLIGHT
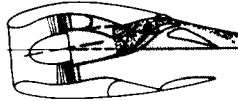
TRANSITION & STOL
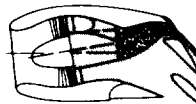
HOVER & VTOL
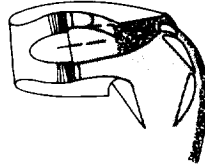
Figure 23. General Dynamics ABLE medium-speed propulsive-lift concept.
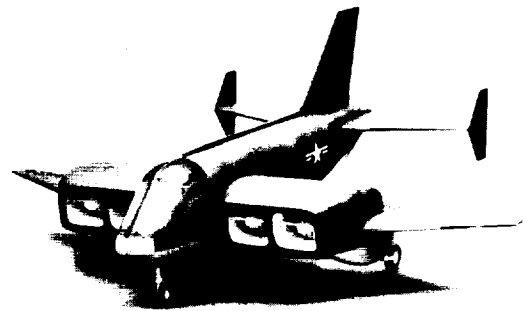
Figure 24. General Dynamics medium-speed concept.

6.6 m
(21.7 ft)

16.7 m
(54.8 ft)

14.3 m
(47.0 ft)
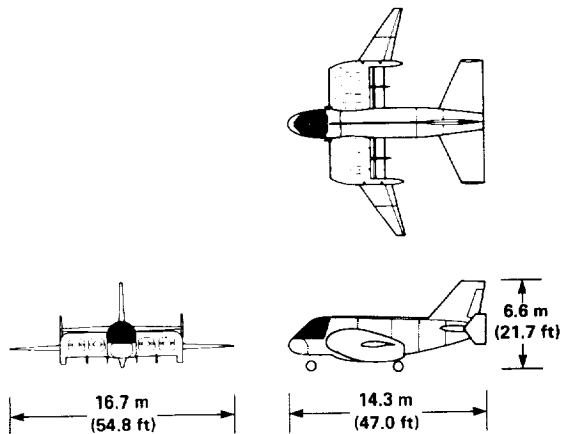
Figure 25. Three views of the General Dynamics medium-speed concept.
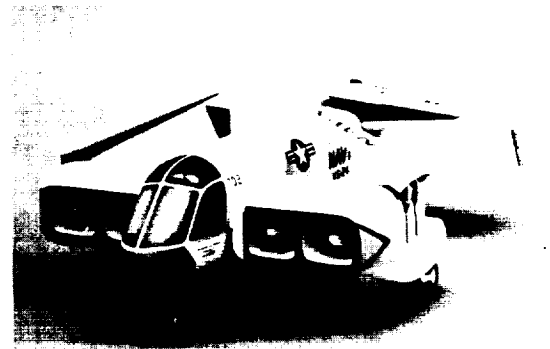
Figure 26. Folding capability of the General Dynamics medium-speed concept.
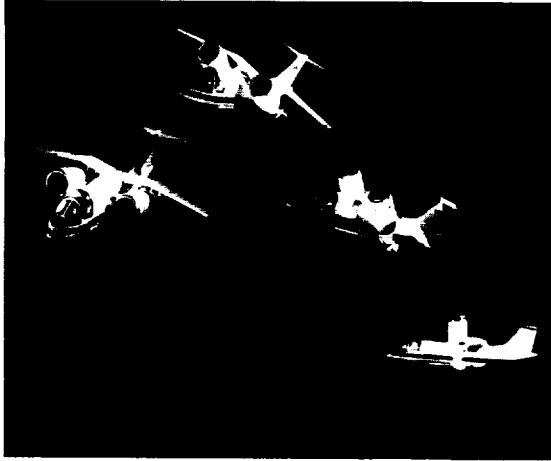
Figure 27. Grumman tilt-nacelle medium-speed concept (Design 698).

BACKUP CROSS-SHAFT FOR ENGINE-OUT

T-TAIL

NO DRAG ARRAYS IN WING

TF34 ENGINES

EXCELLENT VISIBILITY

16 ft FOLDED SPAN

STRAKES FOR POSITIVE GROUND EFFECT

TILTING NACELLES WITH CONTROL VANES

NO HI-LIFT DEVICES
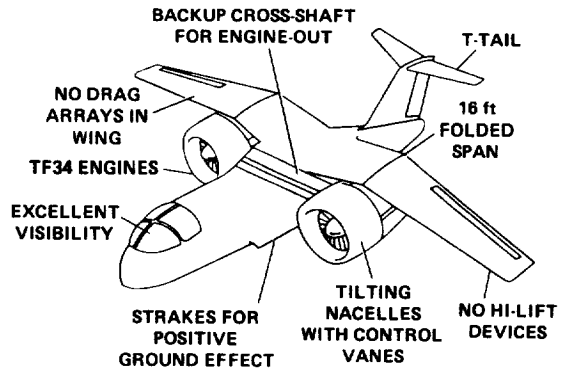
Figure 28. Features of Grumman Design 698.

NACELLE PIVOT LINE

BL 0

CARRY THROUGH STRUCTURE

VANE SUPPORT BOOM

TF-34-GE-100 TURBOFAN

HORIZONTAL VANE AND FLAP

TOP VIEW

NACELLE PIVOT

BULLET & SUPPORT VANES

VERTICAL VANE

SIDE VIEW
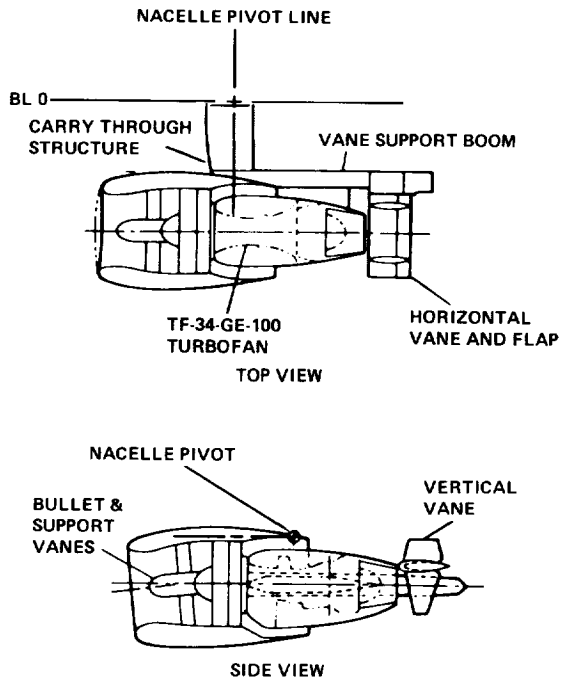
Figure 29. Design 698 tilting nacelle.

⊕ CG

MOMENT ARM

L_{HV}

L_{HV} D_{HV}

D_{HV}

YAWING MOMENT

Z-AXIS
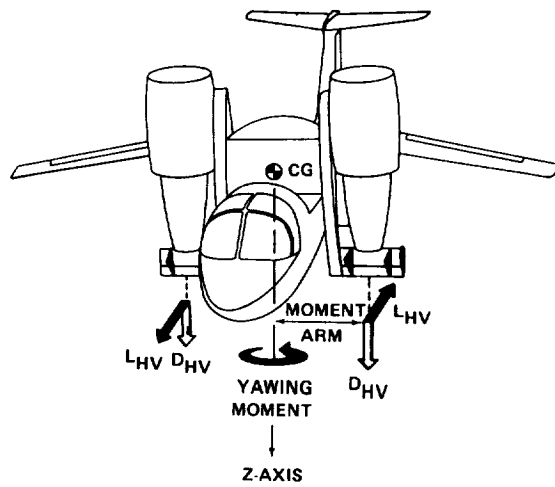
Figure 30. Differential horizontal vane deflection for yaw.

ROLLING MOMENT

Δ GTh

Δ GTh ≈ 10% GTh

MAX AVAILABLE

⊕ CG

L_{VV}

L_{VV}

D_{VV}

D_{VV}
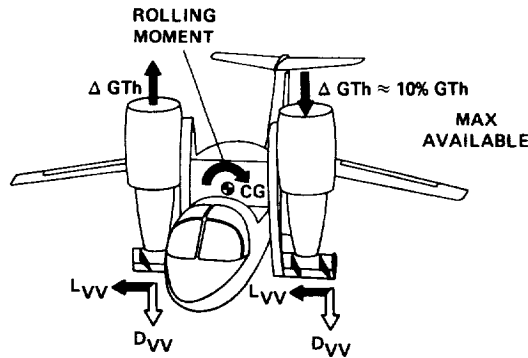
Figure 31. Vertical vane deflection and differential thrust for roll.
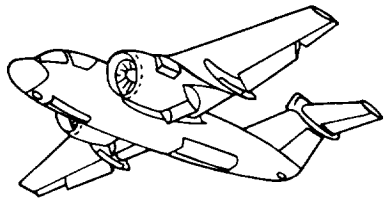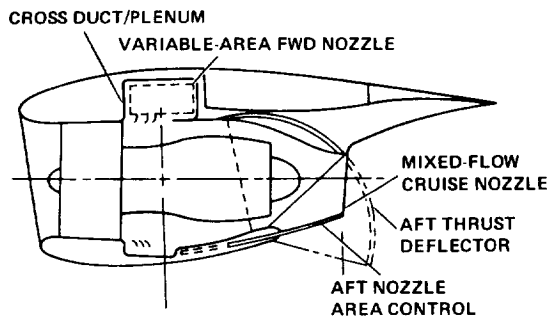
Figure 32. Lockheed split-fan propulsive-lift concept.
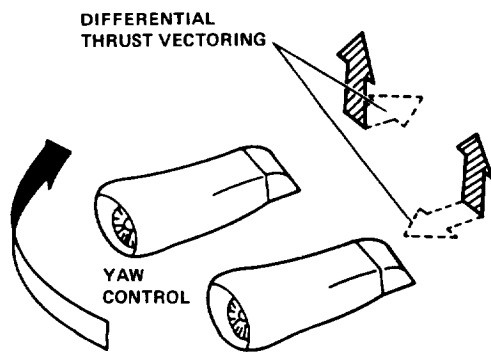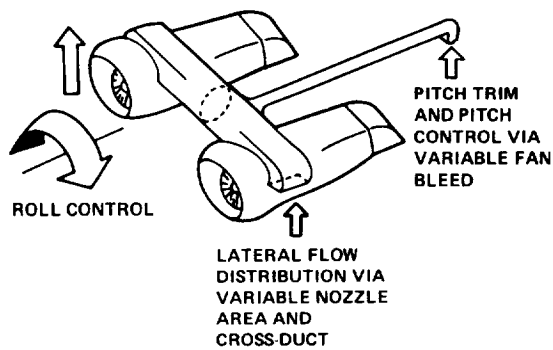
Figure 33. Lockheed split-fan hover-control concept.
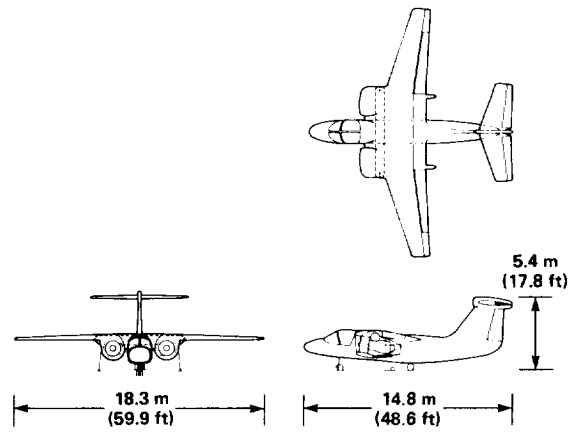
Figure 34. Lockheed twin engine, split-fan, medium-speed concept.
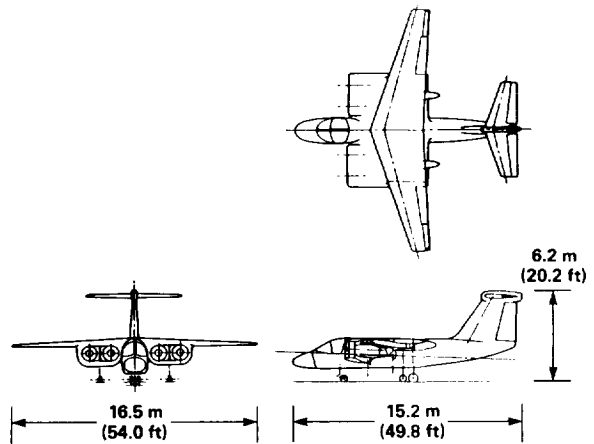
Figure 35. Lockheed four engine, split-fan, medium-speed concept.
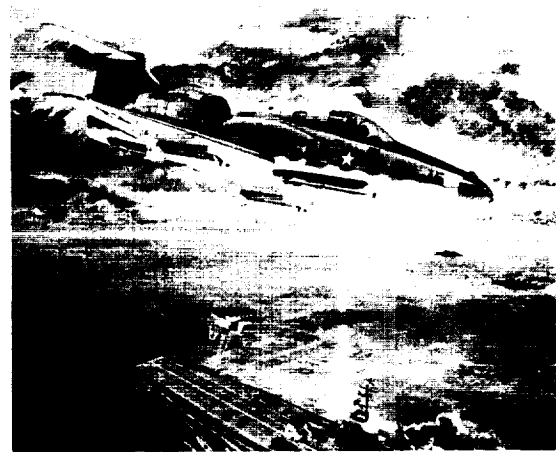
Figure 36. MCAIR gas-driven fan Model 260 medium-speed concept.

36
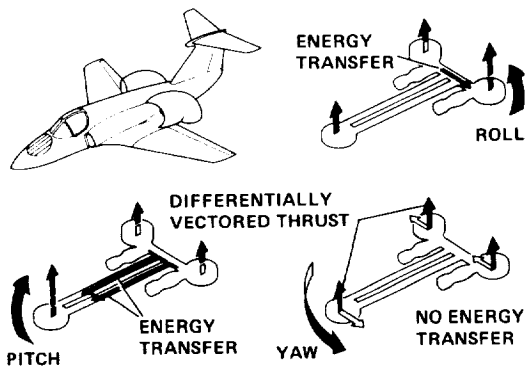
Figure 37. Gas-driven Model 260 propulsion/control system.
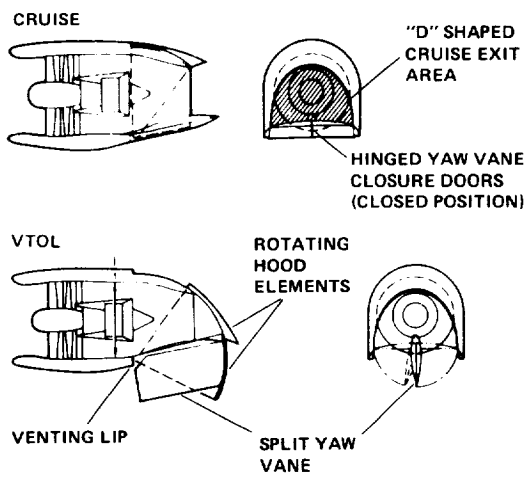
Figure 38. Vented "D" nozzle characteristics.
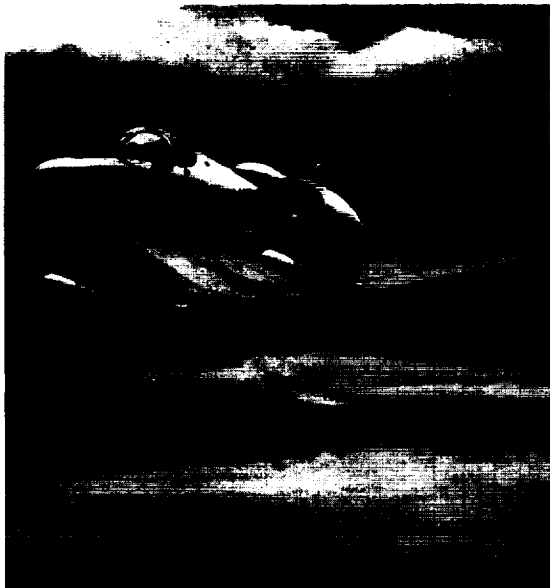
Figure 39. MCAIR mechanically driven three-fan Model 260 medium-speed concept.
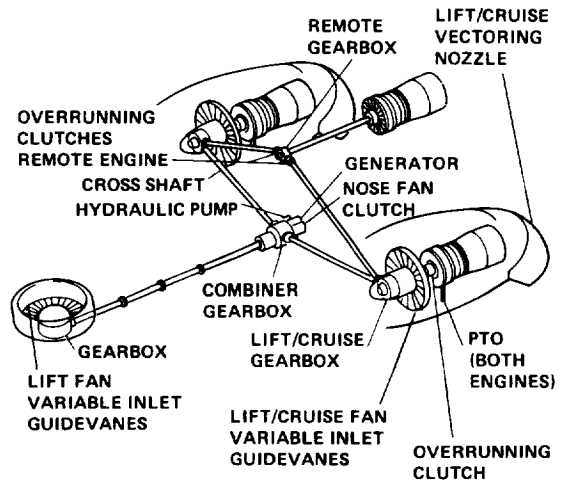
Figure 40. Mechanically driven Model 260 propulsion/control system.
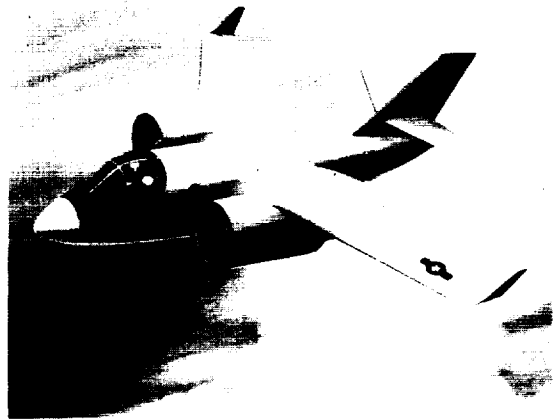
Figure 41. MCAIR vectored-thrust Model 276 medium-speed concept.
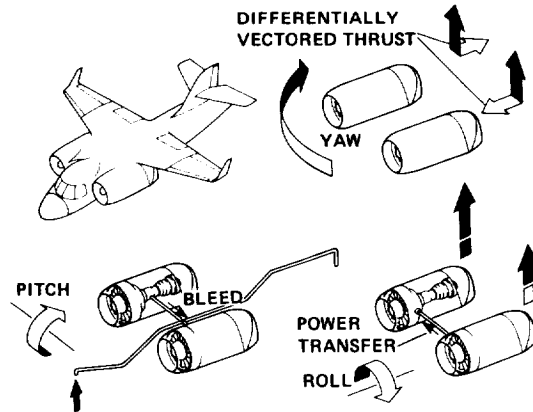
Figure 42. Vectored-thrust Model 276 propulsion/control system.
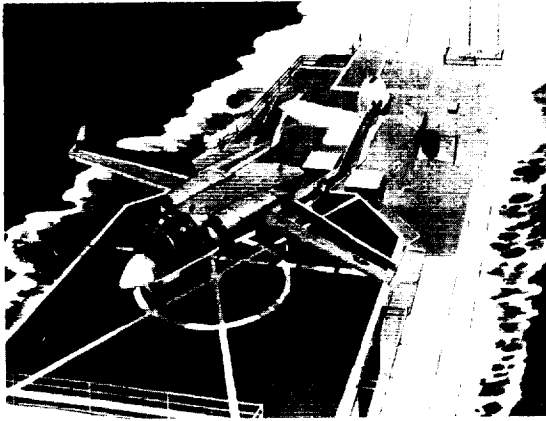
Figure 43. Rockwell ejector-in-wing medium-speed concept.

15.54 m
(51.00 ft)

14.71 m
(48.25 ft)
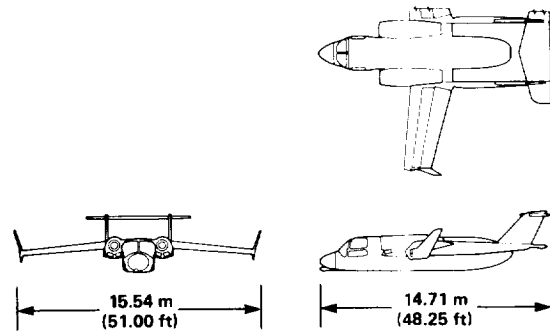
Figure 44. Three views of Rockwell ejector-in-wing medium-speed concept.
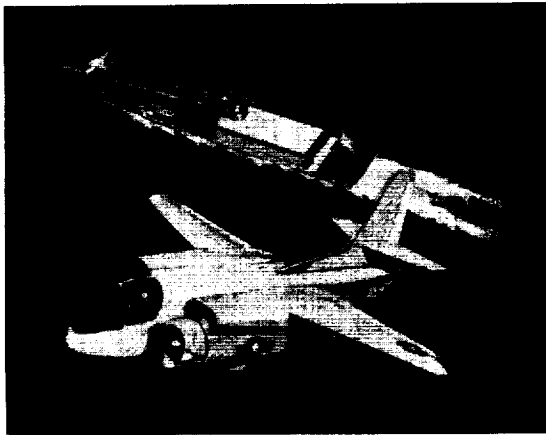
Figure 45. Vought tandem-fan medium-speed concept (V-530).

HOVER

4-POSTER
ARRANGEMENT

TRANSITION

CRUISE
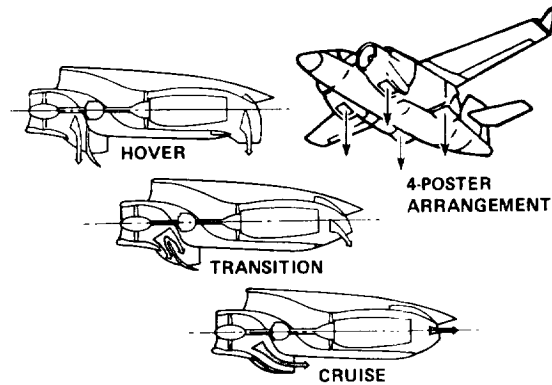
Figure 46. Vought tandem-fan propulsion concept.

VARIABLE INLET GUIDE VANES   OVERRUNNING CLUTCH

SHAFTING

AIRPLANE

FAN   GEAR BOX   FAN   ENGINE   NOZZLE
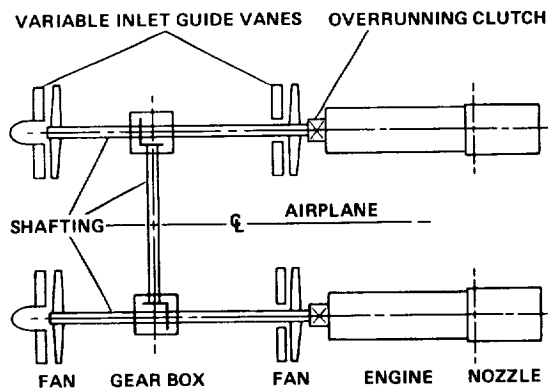
Figure 47. Vought tandem-fan drive system arrangement.

PITCH

FAN THRUST MODULATION
OF
FWD AND AFT FANS

ROLL

FAN THRUST MODULATION
OF
LEFT AND RIGHT FANS

YAW

DIFFERENTIAL DEFLECTION
OF
LEFT AND RIGHT NOZZLES
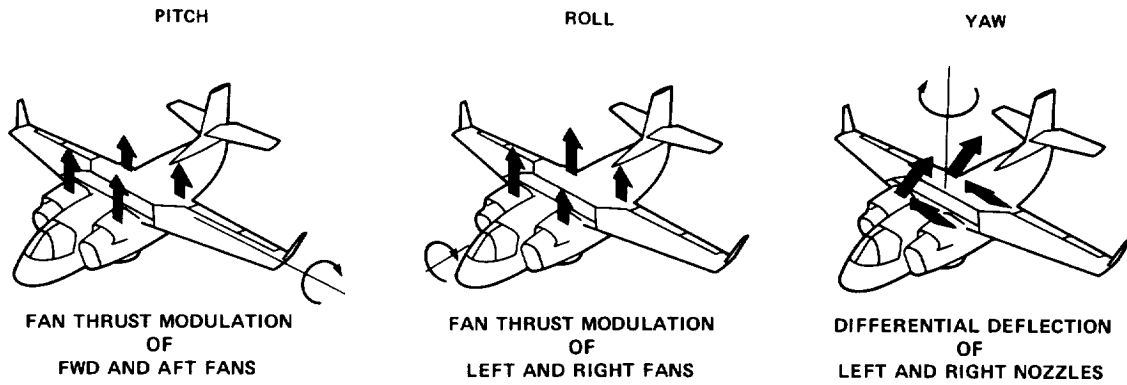
Figure 48. Vought tandem-fan hover-control concepts.

DECK LAUNCH
INTERCEPT
(DLI)

BCAV
M = 1.6
12192 m (40,000 ft)
VL
VTO   278 km
(150 n. mi.)

2 min A/B
M = 1.0
3048 m
(10,000 ft)

FIGHTER ESCORT

BCAV
BCAV
VL   VTO   RADIUS

2 min A/B
M = 1.6
12192 m
(40,000 ft)

SURFACE STRIKE

BCAV
BCAV
VL   556 km
STO   (300 n. mi.)   LOITER

5 min INT
M = 0.8
6096 m
(20,000 ft)

6096 m
(20,000 ft)
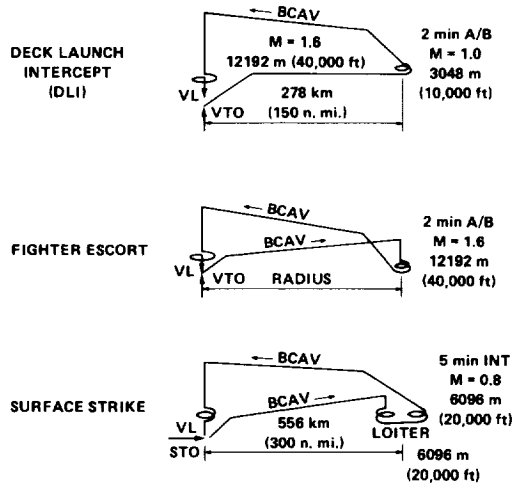
Figure 49. Example mission profiles for twin-engine VSTOL fighter/attack aircraft.

4.7 m
(15.4 ft)

11.4 m
(37.3 ft)

16.3 m
(53.3 ft)
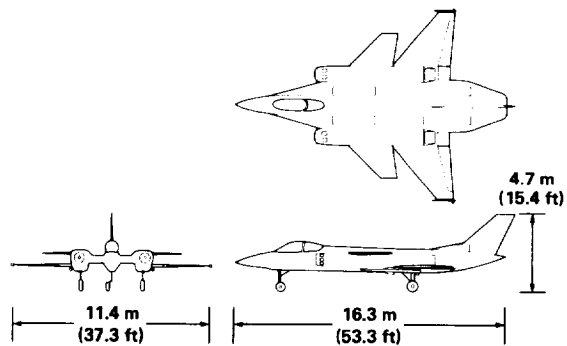
Figure 50. General Dynamics HATOL ejector-diffuser concept.
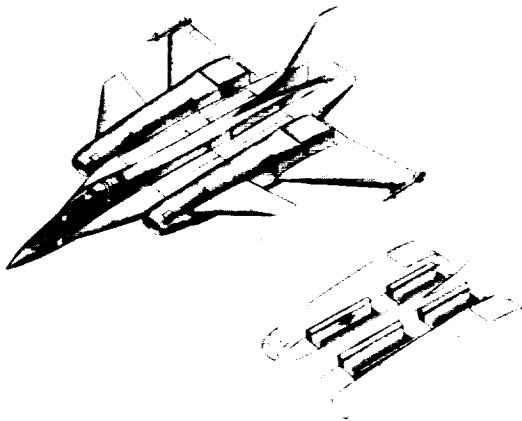
Figure 51. Ejector-diffuser bays open and closed on the General Dynamics concept.

REMOTE
AUGMENTOR

VTOL BUCKET
STOWED MODE

TRIM TAB
(±15°)

REMOTE
GIMBALLING
NOZZLE

VTOL BUCKET
DEFLECTED MODE
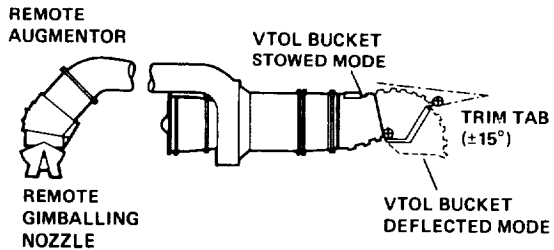
Figure 52. Remote Augmented Lift System (RALS).
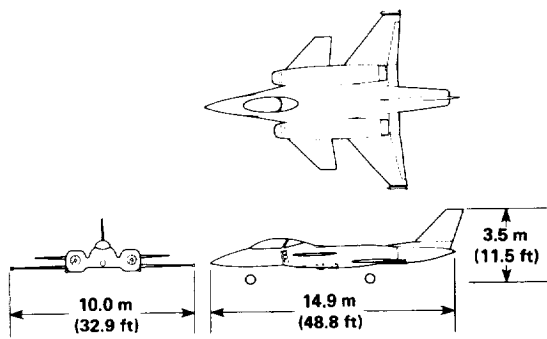
Figure 53. General Dynamics HATOL RALS concept.

10.0 m
(32.9 ft)

14.9 m
(48.8 ft)

3.5 m
(11.5 ft)
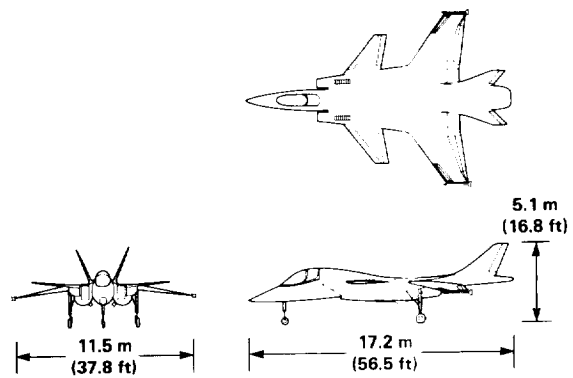
Figure 54. Grumman HATOL concept.

5.1 m
(16.8 ft)

11.5 m
(37.8 ft)

17.2 m
(56.5 ft)
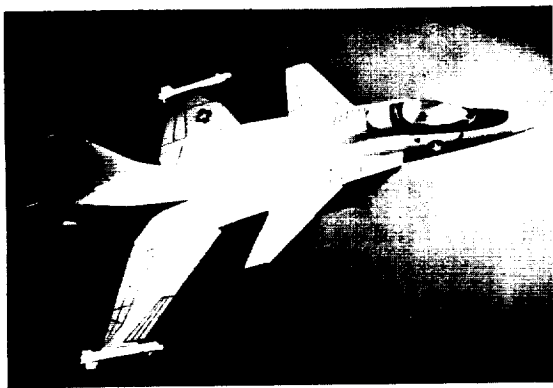
Figure 55. Grumman HATOL concept.

PRIMARY FLAP
SECONDARY FLAP
DEFLECTOR
(STOWED)
VEER
VENTRAL FLAP
TRANSITION
SECTION
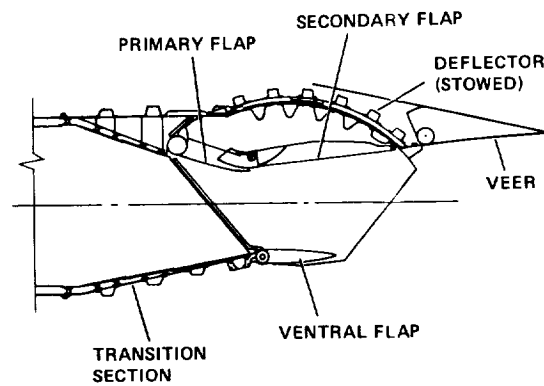
Figure 56. Schematic of ADEN.

9.9 m
(32.6 ft)

16.0 m
(52.5 ft)

4.1 m
(13.6 ft)
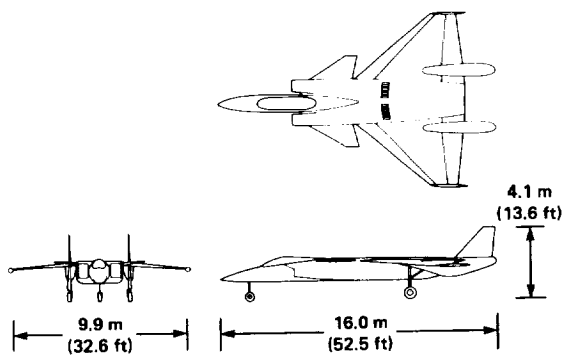
Figure 57. Northrop HATOL concept.
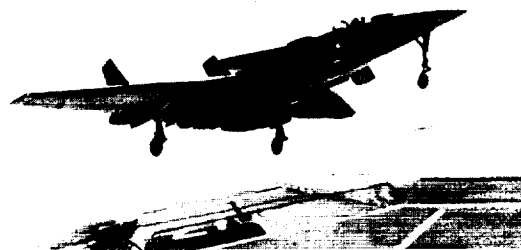
Figure 58. Artist rendering of the Northrop HATOL concept.

**4.0 m
(13.3 ft)**

**9.9 m
(32.6 ft)**

**15.8 m
(51.7 ft)**
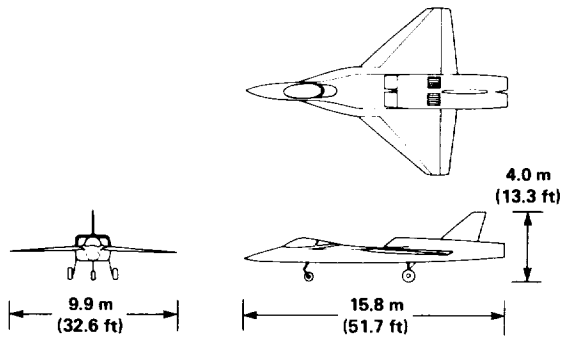
Figure 59. Northrop VATOL concept.
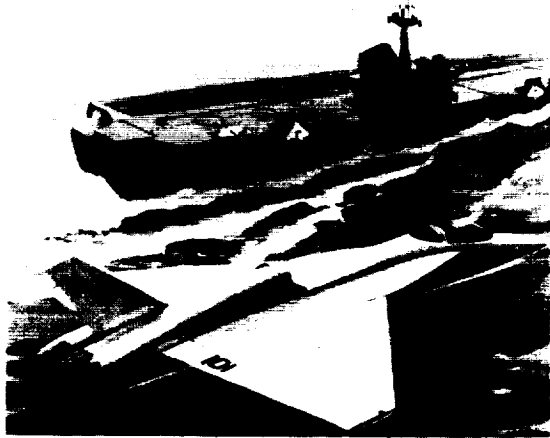
Figure 60. Artist rendering of the Northrop VATOL concept.

**4.3 m
(14.2 ft)**

**8.7 m
(28.5 ft)**

**13.8 m
(45.3 ft)**
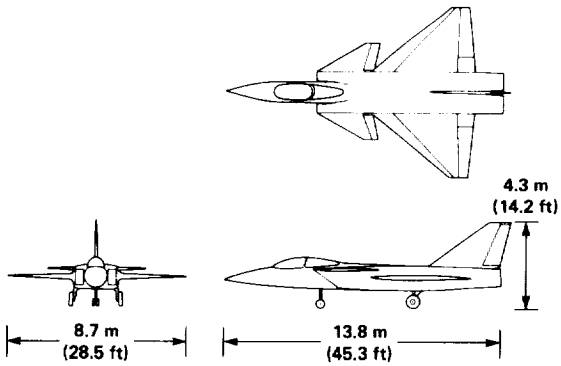
Figure 61. Vought VATOL concept.

Figure 62. Artist rendering of the Vought VATOL concept in a STOVL configuration.
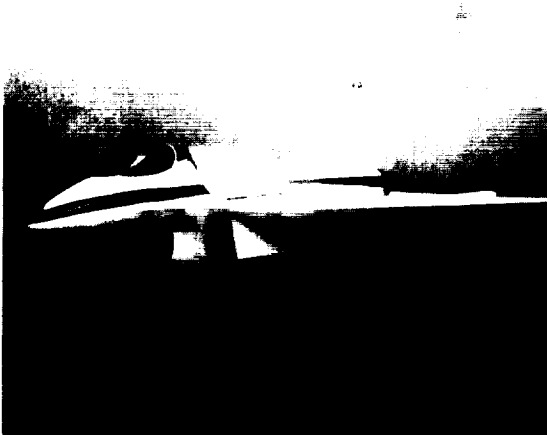
Figure 63. General Dynamics E7 configuration in hover flight.

Figure 64. General Dynamics E7 configuration in cruise flight
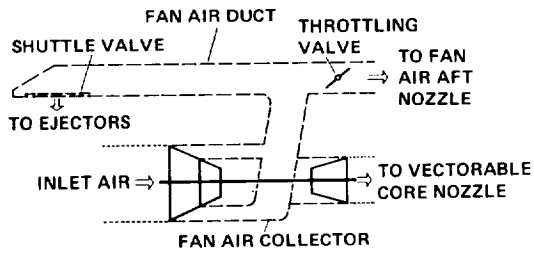
Figure 65. General Dynamics E7 configuration propulsive system schematic.

(a) Hover configuration.

FAN AIR TO EJECTORS   CORE AIR THROUGH ADEN NOZZLE
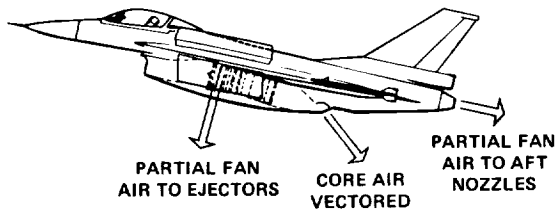
(b) STO and transition configuration.

PARTIAL FAN AIR TO EJECTORS   CORE AIR VECTORED   PARTIAL FAN AIR TO AFT NOZZLES
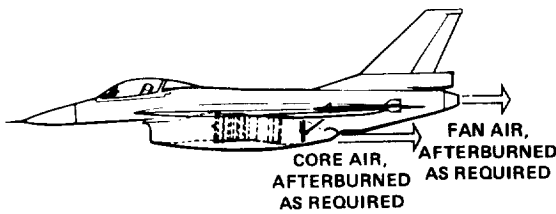
(c) Up-and-away configuration.

CORE AIR, AFTERBURNED AS REQUIRED   FAN AIR, AFTERBURNED AS REQUIRED

Figure 66. Three modes of operation of E7 propulsion system.

5.18 m (17.0 ft)

9.88 m (32.40 ft)   15.06 m (49.42 ft)

Figure 67. General Dynamics E7 configuration.
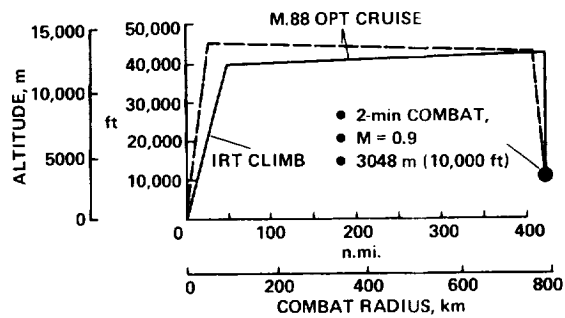
Figure 68. Naval escort mission used in the General Dynamics studies.
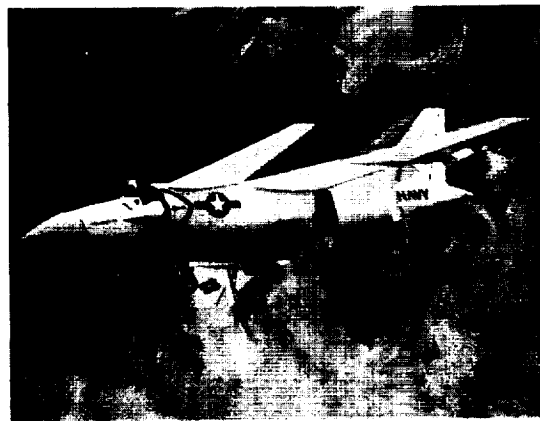
Figure 69. MCAIR configuration in hover flight.

42
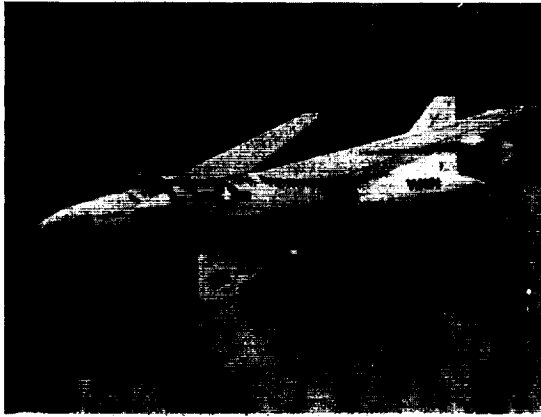
Figure 70. MCAIR configuration in cruise flight.

**5.29 m
(17.34 ft)**

**10.92 m
(35.84 ft)**

**17.07 m
(56.00 ft)**
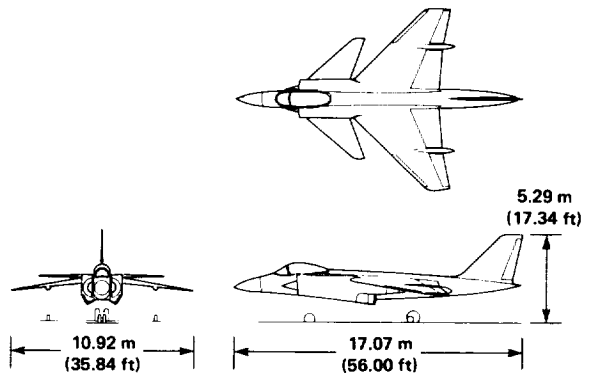
Figure 71. MCAIR 279-3 configuration.

RADIUS
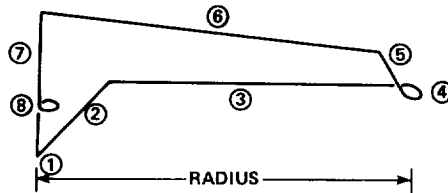
STORE LOADING: (2) SRM + (2) AMRAAM	
① WARM-UP, VTO, ACCELERATION	2 min, IRT; 0.5 min MAXIMUM POWER
② CLIMB	TO DASH CONDITION: MAXIMUM POWER
③ DASH	MACH 1.6 @ 12,192 m (40,000 ft)
④ COMBAT	2 min, MAXIMUM POWER AT DASH CONDITION
⑤ DECELERATE-CLIMB	TO BCAV
⑥ CRUISE	BCAV
⑦ DESCENT	TO SEA LEVEL NO FUEL OR DISTANCE CREDIT
⑧ LANDING ALLOWANCE LOITER LANDING RESERVE	 10 min, AT SEA LEVEL, MINIMUM FUEL 45 sec AT LANDING POWER 5% TOTAL FUEL

SERVICE TOLERANCE
5% FUEL FLOW

Figure 72. Vertical-takeoff supersonic deck-launched intercept (DLI) mission used in the MCAIR studies.

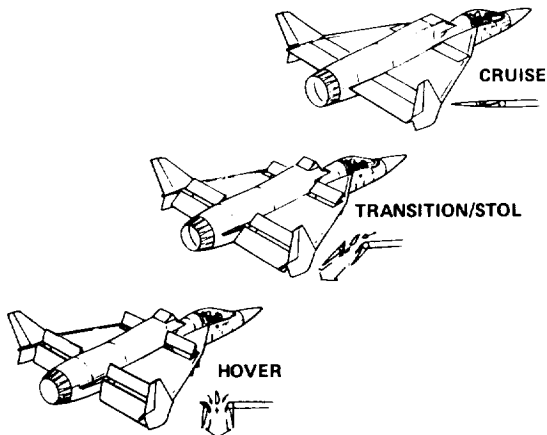Figure 73. Rockwell baseline configuration in cruise flight.

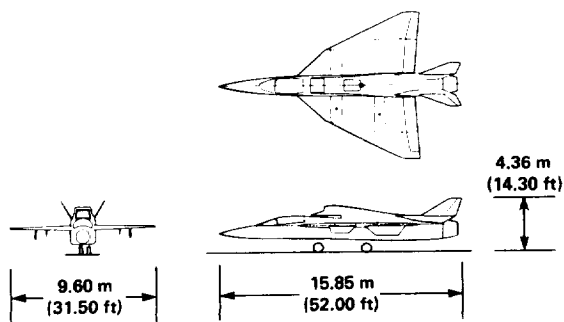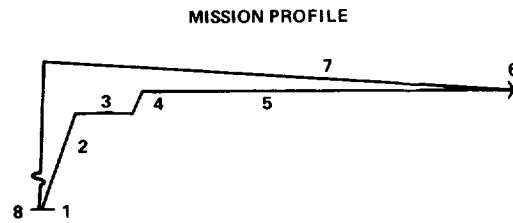Figure 74. Rockwell configuration in various flight modes.

MISSION PROFILE

1. WARMUP TAKEOFF AND ACCEL. TO CLIMB SPEED 4 min IDLE PLUS 1.25 min INTERMEDIATE
2. CLIMB TO 12,192 m (40,000 ft) MAX A/B
3. ACCEL. TO 1.6 MACH NUMBER @ 12,192 m (40,000 ft)
4. CLIMB @ 1.6 MACH TO 15,240 m (50,000 ft)
5. CRUISE @ 1.6 MACH @ 15,240 m (50,000 ft)
6. COMBAT 2 min @ 1.6 MACH @ MAX A/B
7. CRUISE BACK TO BASE @ BEST CRUISE ALTITUDE AND VELOCITY (BCAV)
8. LANDING RESERVE (5% INITIAL FUEL + 10 min LOITER AT SEA LEVEL)

Figure 76. Deck-launched intercept (DLI) mission used in the Rockwell studies.
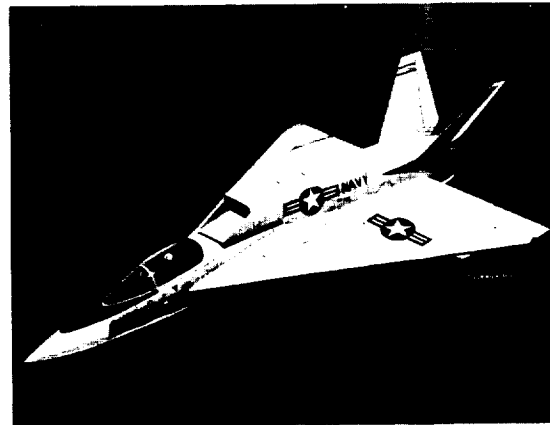

Figure 77. Rockwell alternative configuration in cruise flight.

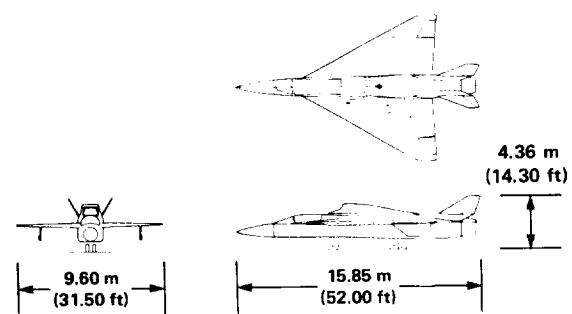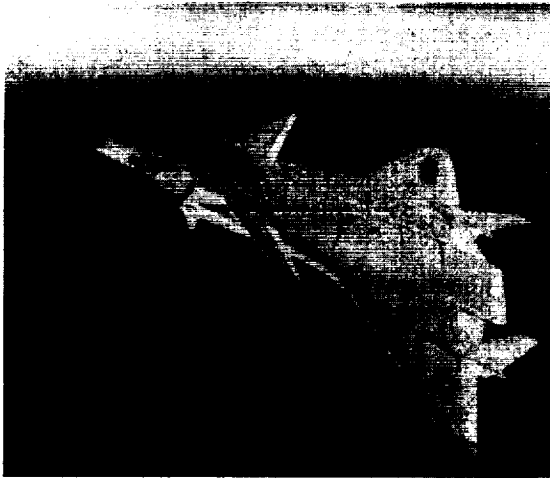Figure 75. Rockwell baseline configuration.

Figure 78. Rockwell alternative configuration.

Figure 79. Early Vought configuration in cruise flight.

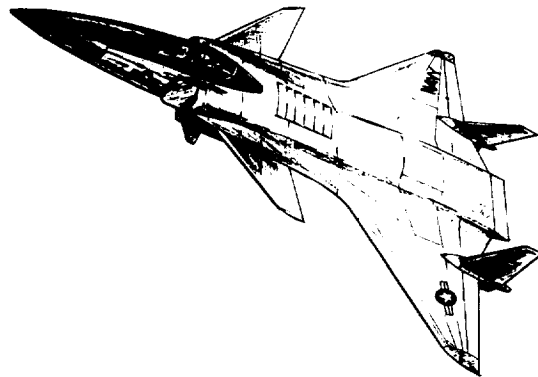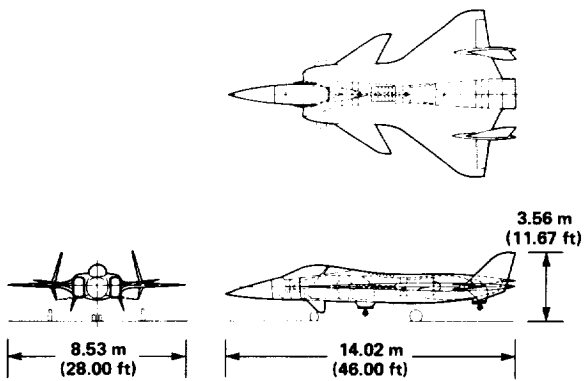Figure 80. Vought configuration in cruise flight.

3.56 m
(11.67 ft)

8.53 m
(28.00 ft)

14.02 m
(46.00 ft)

Figure 81. Vought configuration.

SERIES FLOW MODE - HIGH SPEED

PARALLEL FLOW MODE - V/STOL
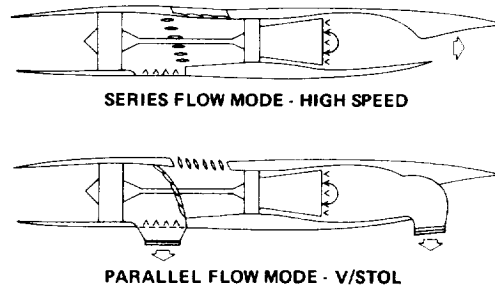
Figure 82. Schematic of Vought tandem-fan concept.

SUPERSONIC INTERCEPT (SI)
4 AMRAAM
LOITER 10 min, SL
BCAV
M = 1.6, 15,240 m (50,000 ft)
2 min A/B
M = 1.6, 12,192 m (40,000 ft)
VL
VTO
200 n. mi.

FIGHTER ESCORT (FE)
4 AMRAAM
+2 SRAAM
+2 TANKS
LOITER 10 min, SL
BCAV
BCAV
2 min A/B
M = 1.0, 9144 m (30,000 ft)
VL
VTO
RADIUS

INTERDICTION (INX)
4 LGB
+2 SRAAM
+2 TANKS
LOITER 10 min, SL
BCAV
BCAV
$M_{DASH, SL}$
5 min INT
$M_{DASH, SL}$
DROP BOMBS
VL
STO
RADIUS
DASH

M_{DASH} = 0.85 FOR DASH = 185 km (100 n. mi.)

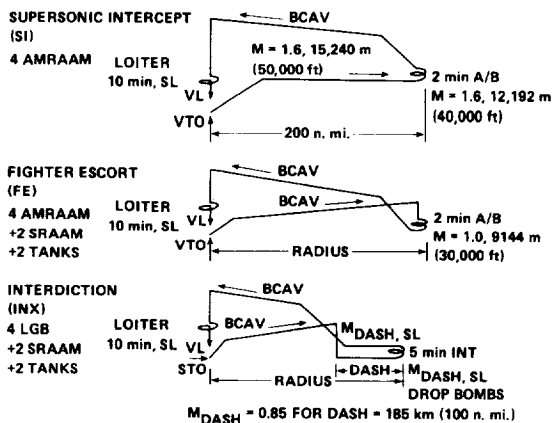Figure 83. Vought notional design missions.

1. Report No. NASA TM-85938	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle V/STOL CONCEPTS IN THE UNITED STATES — PAST, PRESENT, AND FUTURE		5. Report Date April 1984	
		6. Performing Organization Code	
7. Author(s) W. P. Nelms and S. B. Anderson		8. Performing Organization Report No. A-9695	
		10. Work Unit No. T3288Y	
9. Performing Organization Name and Address Ames Research Center Moffett Field, CA 94035		11. Contract or Grant No.	
		13. Type of Report and Period Covered Technical Memorandum	
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code 505-43-01	

15 Supplementary Notes
Point of contact: W. P. Nelms, Ames Research Center, MS 227-2, Moffett Field, CA 94035 (415) 965-5879 or FTS 448-5879

16. Abstract

This paper summarizes V/STOL aircraft developed in the United States and describes concepts considered for future applications. The discussion is limited to non-helicopter types of vehicles. In particular, past V/STOL aircraft are reviewed, and some lessons learned from a selected number of concepts are highlighted. The only current concept described is the AV-8B, which was developed by modifications to the British Harrier. Configurations recently proposed for the future subsonic, multimission aircraft and the future supersonic fighter/attack aircraft are described. Emphasis in the paper is on these supersonic concepts.

17. Key Words (Suggested by Author(s)) V/STOL aircraft, Powered lift, V/STOL aerodynamics, V/STOL propulsion systems, V/STOL fighters	18. Distribution Statement Unlimited Subject Category - 02		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 47	22. Price* A03