ADAM III V/STOL Concept

Byron R. Winborn Jr.*
Vought Aeronautics Division, LTV Aerospace Corporation, Dallas, Texas

ADAM III, the current evolution of a turbofan propulsive wing V/STOL concept, is described. Objectives used to guide concept formulation are listed and the potential problem areas, both technical and management type, are identified. Propulsion system features, component arrangement, operation, and control are discussed for application to the small subsonic strike-reconnaissance aircraft. Larger CTOL, STOL, and V/STOL transport designs are illustrated employing the same technology, and some of the same size components. Future prospects, including supersonic operation, are briefly discussed. The ADAM III concept appears to be adaptable to a wide range of airplane types. Full flexibility between VTOL and STOL operation is afforded with a high degree of safety because of redundancy of gas generators, hot gas ducts, fan-turbine power units, and flight control surfaces. Lift-to-drag ratios, cruise fuel consumption, and useful loads appear fully competitive.

1. Introduction

ADAM III is the current version of a turbofan propulsive wing V/STOL concept which has been evolving during the past 10 years as a consequence of studies, tests, and contacts with potential users. "ADAM," an acronym for Air Deflection and Modulation, had the following objectives from the start of concept formulation:

1) Center the effort on V/STOL airplane configurations which use high bypass ratio turbofans to supply vertical lift and alternatively cruise thrust.

2) Design a configuration which assures that the internal propulsion flows and external aerodynamic flows will interact in a compatible manner so as to afford smooth transitions, good inflight maneuverability, and efficient cruise.

3) Provide adequate control authority in the hover and transition modes to enable the pilot to handle the airplane safely without stability augmentation. Note that this does not rule out the possibility of employing stability augmentation to lighten the pilot's workload under normal circumstances.

4) Select a propulsion system which will continue to provide controllability and symmetrical vertical thrust following the failure of any one gas generator in the hover mode. If so required, as in the case of a transport, continued hover capability must be retained following the failure of any one gas generator.

5) Retain capability for continued safe flight in the cruise mode and for landing on a runway following the failure of any one gas generator, any one hot gas duct system, any one fan-turbine set, or any one flight control surface.

2. Principles

Remote Turbofan Arrangement

One objective of the ADAM program dictates that, in the interest of safety, the propulsion system must continue to exert thrust in a symmetrical manner following the failure of any one gas generator. This objective might be accomplished through offsetting the loss of thrust because of an engine failure by spoiling the thrust of one or more diametrically opposite lifting units. This particular approach would incur a double penalty in terms of the cost, size, and weight of the required propulsion system. The penalty may be reduced by using a large number of small engines, but the complexity of the multiengine system is unattractive for many applications. An alternate approach, used in the ADAM concept, is to transfer power in one manner or another from the gas generators which are still operative so as to compensate for the loss of the power of a gas generator which has become inoperative. A basic premise of this latter approach is that the probability of sudden failure of fans and power turbines is extremely remote. It is believed that current experience with turbofan engines substantiates this premise.

Extensive studies have shown that at the power levels of turbofan systems, which are high compared to those for propeller and rotor systems, hot gas power transmission systems are substantially lighter than mechanical power transmission systems. Other transmission means, such as electrical and hydraulic, have been found to be outside the realm of feasibility for turbofan propulsion systems based on today's technology. No acceptable design approach is known for hot gas equalization of a propulsion system in which a fan, its power turbine, and the gas generator are all components of an integral coaxial propulsion package. Satisfactory designs are, however, readily arrived at when the fan-turbine sets are located remotely from the gas generators. With this approach, it becomes possible and generally desirable to use more fan-turbine sets than gas generators.

Propulsion Technology

The technology of turbofan engines now in production is adequate for the ADAM concept insofar as the gas generator and the fan are concerned. Further development of the flexibility of operation of the power turbine will be needed.

Selection of Design Point Bypass Ratio

The augmentation ratio of the ADAM system is defined as the ratio of the thrust exerted by the turbofans to the thrust that would be exerted by the gas generators used as turbojets. The static augmentation ratio increases indefinitely with design point bypass ratio. The effect of bypass ratio on net thrust in the subsonic speed regime is indicated in Fig. 1. It may be noted that in the upper subsonic speed range, the design point bypass ratio has only a secondary effect on net thrust. Thus, it becomes possible to design a turbofan propulsion system which is just large enough to provide the thrust required for cruise with an allowance for climb and acceleration, and to use the same system to provide whatever static

Presented as Paper 69-201 at the AIAA/AHS VTOL Design, and Operations Meeting, Atlanta, Ga., February 7–9 1969; submitted March 5, 1969; revision received August 6, 1969.

* Project Engineer. Associate Fellow AIAA.

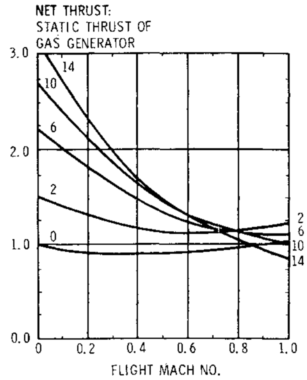

Fig. 1 Effect of bypass ratio on net thrust sea level 100% N.

thrust may be required for vertical flight. In practice, it is found advantageous to deviate from the above idealistic approach in the direction of using larger gas generators and smaller fans to provide the required static thrust. The resultant airplane becomes smaller and its empty weight is decreased. With the same gross weight and less empty weight, the smaller airplane will carry more useful load. Being more highly powered, it will have improved climb, acceleration, and maneuverability characteristics. Some degradation in cruise specific fuel consumption (SFC) may be expected because the larger gas generators will be operated at lower power settings. This degradation is offset by the reduction in thrust required to propel the smaller airplane. To arrive at a near-optimum configuration for any given set of mission requirements, it is necessary to design a family of airplanes having a systematic variation in fan diameter, and to design each member of the family in considerable detail.

Continuing advancement in gas generator technology is serving to minimize the penalty incurred in cruising at lower power settings. The same advancement is leading to a gradual increase in the fan pressure ratio of carefully designed V/STOL propulsion systems, with either no change or a slight decrease in design point bypass ratio.

Wing Fan Installation

The wing fans in the ADAM concept are installed in a forward-facing attitude. This provides high inlet recoveries and low distortion indices during both the cruise and the hover modes. Each fan is shift-driven by a power turbine located directly to its rear. The power turbines are supplied with hot compressed gas delivered by centrally located gas generators.

High bypass ratio turbofans are bulky components. If fans large enough for vertical flight capability are installed in conventional pods, the external wetted surface of the airplane will be increased to an extent precluding the attainment of good $(L/D)_{max}$. In the ADAM concept, the fans are packaged into the wings, so that the external surfaces of the fan nacelles become the lifting surfaces or wings of the airplane. The resultant package is commonly referred to as a "propulsive wing." The minimization of wetted surface resulting from this method of packaging is one of the principal merits of the ADAM concept, and is the reason why the $(L/D)_{max}$ of ADAM designs compares well with that of conventional airplanes.

It will be remembered that

$$\left(\frac{L}{D}\right)_{max} = \left[\frac{\text{Span Efficiency}}{\text{Eff. Frict. Coeff.}} \times \frac{\pi}{4} \times \frac{\text{Span}^2}{\text{Wetted Surface}}\right]^{1/2}$$

The span efficiency and effective friction coefficient based on wetted surface for ADAM designs appear to be about the same as for other designs, hence the ratio (Span^2/Wetted Surface) becomes a meaningful index of aerodynamic efficiency. With gas generators located in the wing roots, the (Span^2/Wetted Surface) ratio for a small, four-wing-fan ADAM III strike-reconnaissance airplane is 1.0, which is thought to be equal to or better than this ratio for any modern swept-wing strike or fighter type airplane which does not employ variable sweep.

Vectoring

With forward-facing fans, fan efflux is vectored downward for the hover mode, as shown diagrammatically in Fig. 2. In this arrangement, considered to be the heart of the ADAM concept, fan flow is vectored by a system of doors and flaps, and turbine exhaust flow is vectored over the large-radius trailing edge flap by Coanda effect. Vectoring is continuously variable from one end point to the other.

Early tests of open duct vectoring arrangements showed that total pressure losses could be minimized by performing most of the turning at reduced velocities upstream of the jet nozzle. It was found, however, that centrifugal force acted upon the flow in the bend, setting up a velocity vs static pressure distortion tending to have a vortex velocity distribution (local velocity is inversely proportional to the radius of curvature of the stream path), as indicated diagrammatically in Fig. 3a. This distortion was transmitted upstream through subsonic flow to the station of the fan, establishing an adverse environment for the fan.

It was apparent that the distortion problem could be alleviated by using a cascade or series of turning vanes to vector the flow without setting up a gross distortion extending from the inner wall to the outer wall of the bend. Such an arrangement is shown diagrammatically in Fig. 3b. To satisfy the variable vectoring requirement of the bend in the propulsive wing, the cascade had to be provided with some sort of variable geometry. Design studies led to the conclusion that this approach was feasible but too complex to be attractive.

Continuing theoretical and experimental effort led to the development of duct contours having a bulge on the inner surface of the bend whose effect is to counter the distortion set up by centrifugal force on the flow in the bend. This approach is illustrated in Fig. 3c. Tests of this type of bend in a representative, scaled fan-and-duct model have shown acceptably low distortion indices.

Wind-tunnel tests to date have indicated that in making transitions between the hover and cruise modes, deflection angles of the fan and turbine vectoring devices will have a programmed relationship to each other, in general with the fan flow vectoring leading the turbine flow vectoring for both takeoff and landing transitions.

Pitch Fan

The best forward flight characteristics are obtained when the airplane center of gravity is located some 25–35% of the mean aerodynamic chord behind the leading edge of the propulsive wing. In converting the airplane to the hover

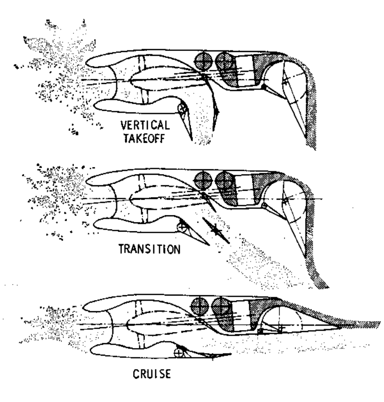

Fig. 2 Thrust vectoring.

configuration, only a small shift in center of gravity location results from extension of the landing gear and actuation of the vectoring flaps and doors.

With normal proportioning of the wing section, the resultant of the wing fan and wing turbine vertical lifts will be substantially behind the desired center of gravity location. A balance of forces in the hover mode is obtained by incorporating a pitch control fan into the front portion of the fuselage. Depending upon particulars of the application for which the airplane is intended, the pitch fan may be forward-facing, designed for continuous operation in all modes of flight, or alternatively the pitch fan may have an approximately vertical axis. The latter type of pitch fan is inactivated for high-speed flight. The pitch fan contributes a significant portion of the total fan disk area required for producing vertical lift. Means are provided for vectoring the pitch fan efflux to the rear so that it may contribute a net propulsive thrust to the airplane when used during forward flight.

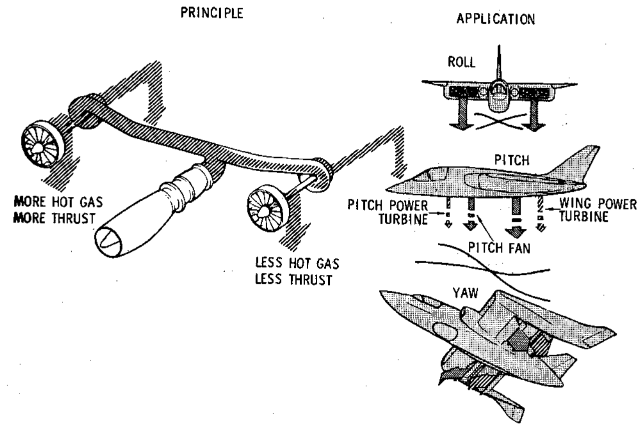

Fig. 4 Gas power exchange hover control.

Hover Control

After reviewing and analyzing many types of hover control systems, the ADAM project has grown to rely strongly upon a gas power exchange or power transfer system, which becomes possible when the remote turbofan approach is adopted. The principle, illustrated diagrammatically in Fig. 4, is as follows. One gas generator furnishes hot compressed gas to two (or more) power turbines. By varying the inlet geometry of the two power turbines differentially, opening one while closing down the other with no change in total turbine nozzle diaphragm (first stage stator) area, more hot gas will be taken by one turbine than the other. The turbine taking more hot gas will develop more shaft horsepower, and the fan it drives can exert more thrust. The other fan exerts less thrust. Thus, there is a transfer of thrust from one location in the airplane to another, setting up a control moment with very little change in total thrust exerted. Obtaining more thrust by expending more power involves one of the three following approaches.

Constant fan geometry

The fan which is delivered more power accelerates and balances out at a higher rpm at which it exerts more thrust. The time constant for this acceleration must be very small (0.2 sec), or an alert pilot will overcontrol and set up a pilot-induced oscillation. As the technology of turbomachinery advances, the components become lighter and more highly powered, and this approach becomes more attractive. With present technology, it is probably marginally acceptable. Some improvement may be obtained by employing a technique known as "jazzing," in which a small change in control setting leads initially to a full change in power turbine geometry, which is then rapidly "washed out" as the turbomachinery responds.

Constant fan RPM

Fan rpm is held constant, and very rapid changes in thrust are obtained by variation of fan geometry, such as varying fan nozzle area, varying the setting of inlet guide vanes, or as a last resort, varying the pitch of the fan rotor blades.

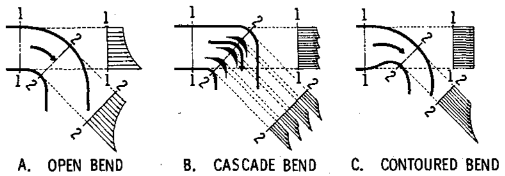

Fig. 3 Flow distortions in bends.

Composite approach

The composite approach employs variable fan geometry and also permits the fan shaft rpm to vary. This approach is favored over the other two.

For purposes of concept formulation, the following typical minimum requirements for hover control authority have been adopted, in terms of the maximum angular accelerations which must be made available: pitch axis, 0.6 radian per sec^2, roll axis, 1.0 radian per sec^2, yaw axis, 0.5 radian per sec^2.

When maximum control authority, needed only momentarily, is applied about one axis, capability of providing 50% of the maximum control authorities about the other axes is considered adequate.

The gas power exchange principle is applied differentially between the wing fans on opposite sides of the airplane to obtain hover roll control, and between the wing fans and the pitch fan located in the forward part of the airplane to obtain hover pitch control and trim. The maximum required hover pitch and roll control moments are obtained with a loss of about 4% in vertical lift. Hover yaw control is obtained through differential deflection of the vectoring systems on opposite sides of the airplane. The loss in lifting potential incurred in providing the yaw control moment is a matter of simple trigonometry. For deflections of $\pm 10°$ from the vertical, generally adequate to provide the maximum required yaw control moment, 17% (sine of 10°) horizontal components are obtained while retaining 98.5% (cosine of 10°) of the vertical component. With a gas power exchange system of this type, it becomes possible to provide adequate hover control about each of the three principal axes plus vertical height control with an installed thrust-to-weight ratio of 1.08.

A hover control system which does not employ power transfer must be capable of generating excess power at all extremities of the lifting system in order to set up control moments while still sustaining the weight of the airplane. Some 25–35% more static thrust must be installed with such a system to obtain controllability comparable to that of the ADAM system.

Pilot Controls

The pilot is provided with a stick and a rudder whose displacements act to impose the usual control moments upon the airplane in all modes of flight. The vectoring control of the ADAM airplane replaces the flap control of the conventional airplane, with similar although augmented effectiveness, particularly at low speeds.

Tail Configuration

The flow behind a propulsive wing is so positively deflected by the propulsion system that any horizontal tail located in

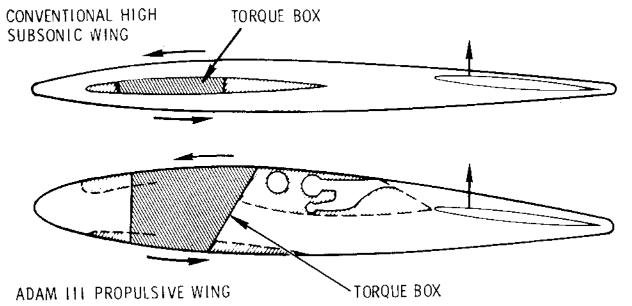

Fig. 5 Wing torque box area.

this flowfield experiences very little change in its effective angle of attack as the airplane is pitched. Thus, centerline horizontal tails located behind a propulsive wing are relatively ineffective ($1\text{-}d\epsilon/d\alpha = 0.35$), even at high T-tail locations. This problem has been overcome by adopting outboard horizontal tails located in the upwash portions of the wing tip vortex patterns. Now if the airplane is pitched up, the outboard tails will experience in full the increase in angle of attack resulting from the change in airplane attitude plus an increase in angle of attack resulting from the increase in upwash angle attributable to the increased wing lift. Thus, the outboard horizontal tails become highly effective at providing static longitudinal stability. Any tendency for the highly effective (and therefore highly loaded) tails to stall may be circumvented by employing an adequate leading edge sweep angle.

Wind-tunnel tests have shown that vertical tails mounted outboard of the wings have unsatisfactory characteristics because of the side wash induced by the propulsion flows and the wing tip vortex patterns associated with wing lift. Single vertical tails mounted on the fuselage centerline have performed well at all angles of attack tested.

Span

Wind-tunnel tests have shown that reasonably sized outboard horizontal tails become fully functional components of a lifting system whose effective span is the span over the tips of the outboard tails. With a total of four to six wing fans, depending upon the type of airplane concerned, it is generally possible to design a propulsive wing airplane with an adequate span for making short takeoffs and landings and for attaining good climb, loiter, and low-speed cruise performance. Proposals to use a larger number of fans have usually raised objections concerning complexity. Placing the gas generators in the wing roots affords some increase in span with generally favorable consequences to the over-all design.

The slope of the lift curve, the span efficiency, and the induced drag of the outboard tail airplane are comparable to the respective terms for a conventional airplane having the same over-all span.

Propulsive Wing Proportions

The thickness of a propulsive wing is determined as the diameter of the wing fan plus allowances for structure over and under the fan. The physical or structural thickness of the resultant propulsive wing is several times that of a comparable conventional wing.

The chord of a propulsive wing is determined as the minimum dimension required to house the following: the fan inlet, the fan, a reasonably contoured fan duct, the transverse hot gas ducts, the power turbine with its exhaust collector and nozzle, and the trailing edge flap. The turbine occupies the space provided over the fan duct in the region where the vertical dimension of the fan duct is reduced to form the fan jet nozzle. With careful design, the thickness ratio of the wing section will be found to be approximately $t/C = 0.25$.

Drag Divergence

In evaluating the high-speed aerodynamic characteristics of the propulsive wing, it is apparent that much of the approaching flow will pass through the wing rather than over and under it. This leads to the concept of an equivalent thickness ratio obtained through collapsing the wing profile by removing the thickness in undisturbed flow of the stream tube passing through the wing, as indicated in Fig. 5. The equivalent thickness ratio so determined for one high-speed cruise condition was $t/C = 0.16$. This was still large enough to occasion much concern over the ability of a propulsive wing airplane to fly into the upper subsonic speed range without encountering drag divergence. It has been found by model tests, however, that very little drag divergence is encountered at flight speeds below Mach 0.9. This is attributed to the fact that most of the rearward-facing area of the wing is immersed in propulsion flows. The usual mechanism in which a normal shock interacts with the boundary layer on the wing, inducing a separation which exposes the rearward-facing area of the wing to base drag, appears to be inapplicable to the case of the propulsive wing.

Wing Structure

Outboard tail lift loads are carried into the airplane through wing torsion. If these loads had to be carried through the torque box of a conventional wing having the same high-speed capability as the ADAM propulsive wing, the aeroelastic problem would appear to be insurmountable. This is perhaps the reason that outboard tails have not been more widely used. The full thickness of the propulsive wing is used to form the main beam and torque box of the propulsive wing, as shown in Fig. 6. The wing structure resembles that of the biplane. Conventional skin and multiple spar construction is used for the upper and lower members. Streamlined diagonals passing through the fan flow at stations, where the velocity is moderate, complete the front and rear members of the trusslike beam and torque box. Only moderately sized structural elements are needed to provide adequate stiffness with this large torque box.

Inflight Maneuverability

When the trailing edge flap is deflected in cruise flight, the increase in lift is augmented by the jet flap effect of the deflected propulsion flow. Outstanding low-speed maneuverability is attainable. The high lift is, of course, accompanied by the usual drag due to lift. With the highly augmented thrust afforded by high bypass ratio turbofans at low flight speeds, the high drag may be countered by the high thrust available. The high lift is accompanied by a large negative (nose-down) pitching moment. This moment is offset by

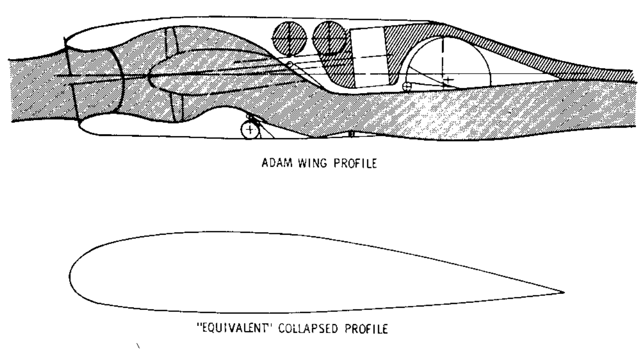

Fig. 6 Collapsing wing profile by removing tube of propulsion flow.

using the vertical thrust of the pitch fan in the forward portion of the airplane. Deflection of the flaps during forward flight permits flying at a more level or even nose-down attitude.

The propulsive wing does not appear to stall like a conventional wing. Wind-tunnel tests have shown lift continuing to increase with angle of attack up through $\alpha = 28°$.

Deceleration

Powered inflight deceleration or reverse thrust is obtained by using the propulsion system as follows. The wing fan and turbine flows are vectored downward. The pitch fan is activated, with its flow discharged downward. The gas generators are advanced to high-power settings. The airplane is flown at reduced or negative angles of attack so that a major portion of its weight is borne by propulsive thrusts. When deceleration is no longer desired, the control surfaces may be returned to the cruise position very rapidly, and high-reacceleration thrust is available almost instantaneously.

3. Problem Areas

Technological Problem Areas

The continuing advancement in gas generator technology over the years has been accompanied by a gradual but steady increase in the temperature of the hot gas output. With today's gas generators, this temperature is high enough to dictate the use of the best available materials in the hot gas ducting. Tomorrow's gas generators will operate at higher turbine inlet temperatures and deliver hotter gas. The VTOL airplane designer will want to use the higher ratings, because increasing turbine inlet temperature is perhaps the most effective way of increasing the VTO load-carrying capability and hence mission performance of his airplane. If no breakthroughs are made in materials for hot gas ducting, attention will have to be directed toward the development of cooled ducts, or ducts having part of the insulation inside the pressure-carrying shell.

The gas power exchange hover control principle is considered entirely feasible, but it must be recognized that extensive development is needed in this area. Any reference to control today must include consideration of stability augmentation and "fly-by-wire" approaches. Despite the objections of many veteran pilots, there is a definite trend toward full reliance upon stability augmentation. In making plans for exploitation of the ADAM concept, adequate hover control authority is being provided to enable a qualified pilot to handle the airplane without artificial assistance. The airplane will, of course, be easier to fly with stability augmentation. Acceptance of the philosophy of placing full reliance upon stability augmentation would almost surely yield weight savings as well as other benefits.

Methods for predicting the dynamic longitudinal stability characteristics, derived for conventional airplane configurations, indicate that the longitudinal dynamic stability of outboard tail configurations is marginal. Flight tests of outboard tail airplanes, conducted by Blohm und Voss in Germany and by Chance Vought Aircraft in the United States in the 1940's, revealed no unsatisfactory dynamic longitudinal stability characteristics. This introduces doubt whether the usual theoretical derivation involved is applicable to the outboard tail configuration. Dynamic stability testing of an ADAM model is in order. If, indeed a deficiency is encountered, it can be corrected by installing a fairly small, fixed horizontal surface at the top of the fin.

Project Management Problem Areas

A review of the principles of the ADAM concept will show that several of the most distinctive features are in the interdisciplinary zones. The propulsive flows have pronounced effects on the external aerodynamic flowfields. The converse is equally true. Significant problem areas exist in zones between the technical disciplines of structures and propulsion, structures and aerodynamics, and aerodynamics and propulsion. There appears to be no prospect of adequately treating the phenomena encountered in the propulsive wing by applying the various classical technical disciplines individually, with each discipline claiming sovereignty within a province having its own well-recognized boundaries. Instead it appears that new procedures for collaborating in the interdisciplinary zones must be devised and accepted. This presents a management problem of the first order. This problem is, of course, by no means peculiar to the ADAM concept.

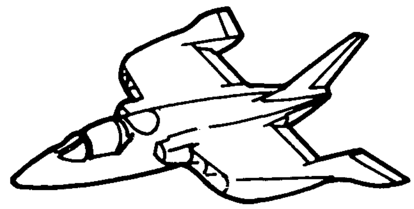

Fig. 7 Small V/STOL Strik-Recce airplane.

It is probable that both airframe companies and engine companies would be most happy if propulsion were to be a unitary package that could be bolted to the airframe, and if guaranteed propulsion performance were to be evaluated by mounting strain gages on the attachment fittings. This idealistic approach is far from reality in the ADAM concept with its jet flap lift augmentation, propulsive inflight reverse thrust, and propulsion-controlled delay of drag divergence. New and closer working relationships between the engine company and the airframe company will be needed to develop the full potential of the propulsive wing.

4. Description of a Representative Airplane Design

General

A substantial amount of preliminary design effort has been devoted to small subsonic strike reconnaissance airplane designs. Studies indicate that the technology, and in some cases the acual propulsion components used in the small airplane, would be well-suited to propel larger STOL and CTOL transports. Rather extensive studies have been made of military and commercial V/STOL transports.

Small V/STOL Strike-Recce Airplane

A small ADAM III high-subsonic strike-recce airplane is shown in Fig. 7. The two gas generators are mounted in the wing roots with nearly straight inlets. Two forward-facing fans are installed in each wing. A large vertical axis pitch fan is located in the fuselage immediately behind the pilot. The efflux of the pitch fan is discharged through two rectangular nozzles in the underside of the fuselage. The major axes of these nozzles are in the longitudinal direction in order to minimize suck-down effects.

The hot gas ducting system which conveys the hot gas from the gas generators to the power turbines is shown in Fig. 8. Actually, two independent hot gas duct systems are used, with each gas generator supplying hot compressed gas to part of the periphery of each power turbine.

Each boom and outboard tail comprise an integral structure. A trailing-edge elevon is used for flight control. Directional stability and control are provided by a conventional vertical tail mounted on the centerline of the fuselage. The main

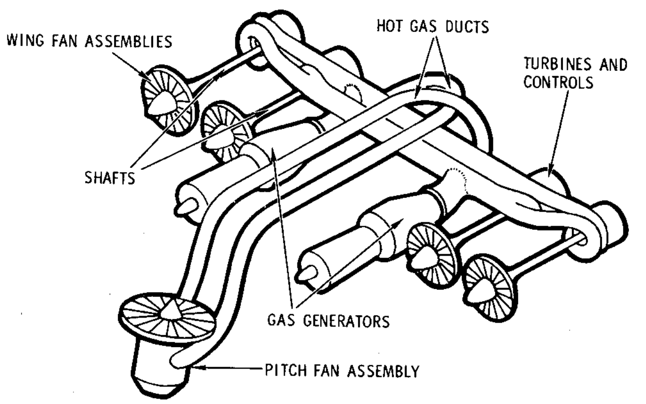

Fig. 8 Hot gas duct system.

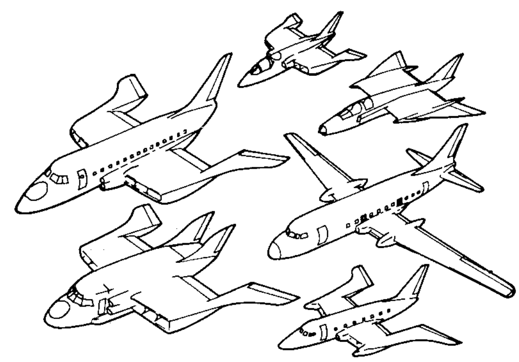

Fig. 9 Range of applicability.

landing gear is mounted under the wing, retracting into the fairings behind the gas generators. The nose gear is conventional, retracting aft into the space between the two pitch fan nozzles.

No fans, ducts, shafts, or landing gear are located forward of the pilot's seat bulkhead. The front end of the airplane can be configured so as to best meet user requirements. A large amount of space is available in the fuselage forward and aft of the center of gravity for fuel and other useful load. Large external tanks may be carried under the outboard boom tails. Most of the underside of the fuselage is available for user purposes.

The VTOL downwash velocity is high enough to require moderate site preparation. The various nozzles are arranged, however, so that there is virtually no chance of heating the ground appreciably. Likewise, there is no danger that hot propulsive flows will be reingested unless the airplane is hovered in a tail wind.

With the dual hot gas duct system, either gas generator may be started or shut down at any time on the ground or in flight, intentionally or otherwise, without requiring readjustment of the other gas generator. The airplane will fly in the cruise mode and make conventional landings with either gas generator or either hot gas duct completely inoperative. With loss of a gas generator or hot gas duct in the hover mode, thrust will remain symmetrical, and the airplane will remain controllable in a retarded descent.

All hot gas components are located aft of all wing primary structure, so that it becomes possible to protect the primary structure from any hot gas leak.

The transition process is continuous, and is similar to gradually raising or deflecting the flaps in a conventional airplane. Activation of the pitch fan is not sensitive and may be accomplished over a wide range of flight conditions.

The useful load is approximately 43% of the VTO gross weight under tropical day, sea level conditions. For STO operation, the useful load may be increased to approximately 53% of the takeoff gross weight. These values are predicated upon the use of conventional rather than exotic structural materials.

5. Future Prospects

STOL-Only Derivatives

When the design objective is limited to the achievement of STOL capability, attractive performance may be obtained with externally blown-flap configurations. A simplified ADAM concept, in which both fan and turbine effluxes are vectored only by deflection of the trailing-edge flap, is also attractive and in many ways is similar to the externally blown-flap approach. The ADAM approach readily provides symmetrical thrust following a gas generator failure and reverse thrust for short landings. The inflight maneuverability, deceleration, and high subsonic speed capabilities of the ADAM V/STOL concept may be retained in the STOL-only configuration. Studies have indicated that when any blown-flap approach is used to attain the capability of taking off and landing in distances less than 1000 ft over 50 ft with a high performance airplane, a pitch control fan or rotor should be provided in the front part of the airplane.

Interburning

Interburning, or combustion of additional fuel in the hot gas between the gas generators and the power turbines, is a promising method of obtaining some 15% more static thrust with very little built-in performance penalty. Its use would, of course, aggravate the temperature problems of the hot gas duct system and would supposedly introduce the necessity for cooling the power turbines. The technology of the 1970's should suffice to resolve all problems posed by interburning.

Supersonic Derivatives

The prospect of attaining low supersonic speeds with a propulsive wing airplane is stimulating. For speeds up through Mach 1.25, the subsonic inlets, perhaps with minor modification, should provide nearly as high inlet recoveries as supersonic designs. A means of obtaining a moderate amount of thrust augmentation is needed. Interburning might well be the type of augmentation selected for this purpose.

At supersonic speeds, the pluming propulsive wakes will fill in most or all of the area behind the propulsive wing.

Mach 2.0 supersonic propulsive wing V/STOL configurations are believed to be feasible. For such speeds, supersonic inlets, as well as fan-flow burning, are considered mandatory. The inlets would remain in one position except for very low-speed flight, when they would have to be opened up.

Continuous Propulsive Wing

One trend in advanced gas generator technology is toward even more compactness. At some future date, gas generators should become compact enough so that space may be found for them between the fans and the turbines in the wing. This would appear to approach the end point of one branch of propulsive wing morphology in which all propulsion is distributed across the span in a continuous manner.

Range of Applicability

A rather wide range of applicability of the propulsive wing technology is illustrated in Fig. 9, which shows design concepts for a Strike-Recce airplane, small and medium STOL and V/STOL military and commercial transports, and a supersonic airplane.

6. Conclusions

The team working on the ADAM concept has borrowed extensively from the published technology of other V/STOL concepts. It would be idle, therefore, to assert that the ADAM concept is superior to all other concepts in all regards.

Any turbofan V/STOL must employ a powerful and expensive propulsion system. The ADAM concept endeavors to use this propulsion system to enhance many modes of flight. The propulsion system provides increased lift for short takeoffs and landings and inflight maneuverability through the jet-flap effect. It provides augmented thrust for short takeoffs, climb, acceleration, and inflight manuevers with its high bypass ratio turbofans. The fuel consumption during high- and low-altitude cruise compares well with that of other turbofan airplanes. The propulsion system can furnish reverse thrust during forward flight and landing runouts. It is used to delay drag divergence at transonic speeds by filling in the area behind the wing with propulsive wakes.

ADAM designs seek a high degree of safety through redundancy of gas generators, hot gas duct systems, fan turbine sets, and flight control surfaces.

The ADAM concept appears to be adaptable to a wide range of airplane types. Full flexibility between VTOL and STOL operation is afforded. Lift-to-drag ratios, cruise fuel consumptions, and useful load ratios appear to be fully competitive.

It is not thought that any of the other V/STOL concepts, which have contributed to the formulation of the ADAM concept, can offer all of the attributes itemized previously.