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SUPERSONIC STOVL PROPULSION TECHNOLOGY PROGRAM - AN OVERVIEW

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SUMMARY

Planning activities are continuing between NASA, the Department of Defense (DOD), and two foreign governments to develop the technology and to demonstrate the design capability by the mid-1990's for advanced, supersonic, short-takeoff and vertical-landing (STOVL) aircraft. These planning activities have resulted in a Memorandum of Understanding (MOU) with the United Kingdom to jointly pursue the STOVL technology, and an MOU with Canada is expected to be signed shortly. Propulsion technology is key to achieving viable STOVL aircraft, and NASA Lewis Research Center will play a lead role in the development of these required propulsion technologies. The initial research programs are focused on technologies common to two or more of the possible STOVL propulsion system concepts. This paper will present an overview of the Lewis Research Center's role in the overall program plan and recent results of the research program. The future research program will be focused on one or possibly two of the propulsion concepts seen as most likely to be successful in the post-advanced-tactical-fighter (ATF) time frame.

INTRODUCTION

New interest has recently been generated in developing the capability for a supersonic short-takeoff and vertical-landing (STOVL) fighter/attack aircraft which could be developed in the post-ATF time frame. This interest has resulted in the initiation of several separate programs and separate Memorandums of Understanding (MOU's) between the U.S. and other governments. An MOU has recently been established with the United Kingdom (U.K.) to jointly pursue the required technologies, and an MOU with Canada is expected to be signed shortly. In these joint programs and others a minimum of five different propulsion concepts for a supersonic STOVL aircraft are being studied.

There have been few successful STOVL fighter/attack aircraft designs. The most notable success is the AV-8 Harrier. The reasons for the few successes are many, but the obvious ones are that the propulsion system becomes much more complex, and considerably more is asked of it. That is, it must provide levels of upward thrust capable of supporting the landing weight of the aircraft and controlling its attitude, yet be capable of switching to provide high levels of forward thrust for normal flight and possibly assisting the flight control. Required weight and volume of the resulting propulsion system has in the past been large and inefficient, forcing the weight of the total aircraft higher, and ultimately resulting in an undesirable aircraft design. Therefore one concludes that for supersonic-capable STOVL aircraft to be successful, advanced propulsion technology is the key to allowing it to happen (refs. 1 and 2).

It has always been a goal of NASA aeronautics research to address and resolve high-risk, long-lead technologies. An attempt to design a current advanced, supersonic-cruise-capable STOVL fighter aircraft would lead to the conclusion that the required propulsion technologies are not yet available. Further, demonstration of these technologies will be required before the DOD and industry will attempt even a prototype. NASA Lewis Research Center will play a leading role in the development of the required propulsion technologies, which have been identified as being critical to achieve viable STOVL aircraft. Planning activities have already resulted in initial research programs focused on technologies common to two or more of the proposed propulsion system concepts. This paper will identify these concepts, and will present an overview of the program goals and the Lewis Research Center's role in the overall program plan, and recent results in the development of the required propulsion technologies.

PROPOSED CONCEPTS AND PROGRAM GOAL

Currently, as shown in silhouette in figure 1, five propulsion concepts are being considered for an advanced, supersonic STOVL aircraft which could be developed in the post-ATF time frame (late 1990's). These concepts are shown here in silhouette because they have been identified in the past and have been discussed in detail in many previous references (e.g., refs. 1 and 2), but studies have failed to prove one as being better than the other. In the order shown in the figure, these include

(1) Remote augmenter lift system (RALS), a concept with burners and nozzles located remotely from the engine and forward of the center of gravity (CG) and which use air provided by the engine fan bypass

(2) Vectored thrust (e.g., the AV-8 Harrier), which uses a separate flow bypass engine supplying nozzles forward and aft of the aircraft CG

(3) Ejector augmenter, a concept with an airflow augmenting ejector located forward of the CG with primary air provided by the engine fan bypass

(4) Tandem fan, a variable-cycle engine concept in which the fan stages can be separated so that the front stage provides air for nozzles forward of the CG for vertical mode. The front stage supercharges the aft fan stage for normal flight.

(5) Lift plus lift/cruise (e.g., the YAK-36), a concept that uses a separate lift engine forward of the CG during vertical thrust of operation. This engine is used at this time only.

The current supersonic STOVL Program will study these systems in greater depth than before in the hope of generating data to identify which one or two may be better than the others. The joint U.S./U.K. program is studying the first four concepts shown. The U.S./Canada program is focused on the ejector concept alone. General Dynamics and deHavilland have been working on this concept for some time and are convinced that it is a viable concept. NASA and the DOD have recently added the lift plus lift/cruise concept to their investigations. This concept has always proved favorable in past studies, so it has been added for completeness. There are many other propulsion concepts as well, but these can be considered as hybrids of the five just described.

The goal of the supersonic STOVL technology program is to have the required technologies in place by the early 1990's, so that a decision to start a research aircraft program can be made with relatively low risk. As stated before, the key technologies to be developed are primarily propulsion related. The design of fighter/attack aircraft which can dash and cruise supersonic (e.g., F-14, F-15, and F-16) is a standard practice. A subsonic aircraft for vertical takeoff and landing (e.g., the AV-8B Harrier) has been successfully designed. The challenge therefore is to combine these capabilities into a new, efficient, high-performance supersonic fighter/attack aircraft for the post-advanced-tactical-fighter (ATF) time frame. This will involve developing those unique engine system components with multifunction capabilities (e.g., vectoring and deflecting nozzles and, in particular, new control systems).

REQUIRED PROPULSION TECHNOLOGIES

The propulsion technologies, identified as key to the supersonic STOVL program, cover a broad spectrum and are listed in figure 2. Some of these are related to and will be developed in other ongoing NASA and U.S. Air Force (AF) base research and technology (R&T) programs combined with the STOVL program. As indicated in the figure, the supersonic STOVL program will benefit from related research programs going on during the same time frame. Examples are the Supermaneuver programs which currently exist in DOD and NASA. These include the AF F-15 STOL/Maneuver Technology Demonstrator (S/MTD) program; the joint Defense Advanced Research Projects Agency (DARPA)/U.S Navy/West Germany Enhanced Fighter Maneuverability (EFM) program; a Navy F-14 program including a nozzle with deflecting paddles, at Pax River Naval Air Station; and the NASA F-18 High-Alpha Research Vehicle (HARV) program at the Dryden Flight Research Facility. In these programs high-angle-of-attack inlets, propulsive controls, and multiplane vectoring nozzle technology will be developed which will be directly applicable to STOVL. Most of these programs will be completed before the STOVL program achieves its goal. Likewise the new higher thrust-to-weight ratio (15 to 20) engine core technology required for supersonic STOVL will come from programs such as IHPTET and NASA's base technology efforts. The rest of the needed developments will be made in the supersonic STOVL program.

The first technology issue to be resolved in the supersonic STOVL program is the propulsive lift concept, which may be the best to pursue for a research aircraft. Each of the propulsive lift concepts being studied, including RALS, vectored thrust, ejector augmenter, tandem fan, and lift plus lift/cruise, has technical problems with performance, volume, weight, etc. The supersonic STOVL program is actively addressing some of the key issues which will be shown shortly. A downselect will have to be made early in the program to manage the scope of this effort to appropriate levels.

As mentioned earlier in this section, the new higher thrust-to-weight ratio (T/W) engines required will come from other existing programs such as

Integrated High Performance Turbine Engine Technology (IHPTET). However the impact of those things which will be unique to STOVL on these new higher energy and smaller core engines, for example, compressor bleed (for reaction control), will be evaluated in this program.

New short diffuser inlets with high alpha capability will be required for the supersonic application. The Harrier (AV-8) has a inlet which works well even at the extreme angles of attack associated with takeoff and transition. This inlet, however, has a thick lip and auxiliary inlets well suited to the local flow conditions. Similar capabilities will have to be developed for the thin lip supersonic inlet, which may also have the added complication of a shorter diffuser. The shorter diffuser will result from the STOVL requirement of locating the engine closer to the aircraft center of gravity (CG) for better balance and better location of the lift vectors.

New lightweight modulating, deflecting, and vectoring nozzles will have to be developed for the supersonic STOVL. The issue here is not a small scale one. Much work has been done at small scale over the last few years, demonstrating that high internal nozzle efficiency can be obtained with deflected thrusts exceeding 90° (refs. 3 and 4). What has to be researched is how to make these nozzles at large scale with real actuators, seals, materials, and cooling. These will be supersonic nozzles with normal CD area variations as well as the capability of 90° or more deflection for takeoff and landing. Some of these nozzles will also have to be able to perform with afterburning. All of these capabilities will have to be included at reasonable weights. A new type of nozzle may also have to be researched, namely, ventral nozzles located on the side of the engine nacelle with a variable blocker downstream.

Efficient low-loss ducts, valves, and fan air collectors will also have to be developed, particularly for the RALS and ejector systems. Past attempts at designing ejector systems were unsuccessful due in large part to high internal pressure losses (ref. 5).

Two of the more notable issues to be resolved for a supersonic STOVL include hot gas ingestion (HGI) and integrated flight/propulsion controls. The higher T/W engines will enhance the HGI problem already seen with the Harrier. Likewise the propulsion controls will become more critical at takeoff, transition, and landing, where the traditional aerodynamic controls are relatively ineffective. This last issue may be the most difficult to solve, and as a result was one of the first programs initiated. The work load seen with the Harrier is particularly high at takeoff and landing. With the higher performance aircraft a new control system will be required which does a more efficient job of allowing the pilot to manage the aircraft.

SUPERSONIC STOVL PROGRAM PLAN

As stated in the program goal there is interest in being able to develop and fly a research aircraft in the mid-1990's. The need for such an effort was clarified in the recent AF Forecast II study results, which identified requirements for an aircraft with VSTOL capabilities in the post-ATF time frame (beyond the year 2000). As previously stated, propulsion is key to achieving these capabilities. With that in mind an enabling plan was developed (fig. 3). To meet the technology demonstration schedule the required technologies have to be developed now, and a ground demonstration of the complete propulsion system (for the research aircraft) will have to be completed early in the 1990's. As shown, several of the research programs have already been initiated. These include the NASA and DOD ongoing base technology programs, the joint U.S./U.K. program, the U.S./Canada ejector program, and a series of contracted efforts with the major engine companies to investigate advanced engine concepts and, in particular, integrated flight/propulsion controls. These efforts include studies, experimental test programs, and some design (conceptual and detailed) development activities.

As shown, the base NASA and DOD R&T efforts include many different programs. However each will develop new technology that will be useful to future STOVL vehicles. The U.S./U.K. STOVL aircraft conceptual design study efforts have been ongoing and are scheduled to be finished shortly. They will then be followed by an approximate 6-month downselect phase. In this phase the study data will be analyzed in an attempt to be able to identify one or two configurations on which to focus further research. During the configuration study phase, a parallel common technology program was initiated to research those technologies which are common to two or more of the proposed configurations (e.g., fan air collectors, ducts, and valves; hot gas ingestion; and integrated flight/propulsion controls). Once the downselect process is complete, a concept-specific phase of the program will be initiated to study in greater detail the chosen concept(s).

The U.S./Canada program is dedicated totally to the ejector concept. General Dynamics and deHavilland have been researching ejector aircraft for some time, and as a result the program has evolved to the point of developing and testing large-scale hardware. A large-scale model of the E-7 aircraft configuration is being fabricated for testing in the 40- by 80-ft wind tunnel at NASA Ames early next year. This model will incorporate a Spey engine initially. As indicated in figure 3, the Spey engine will eventually be replaced by an F110 engine. The F110 will be more representative of the weight flows and fan pressure ratios required for an advanced supersonic STOVL application. Lastly, as indicated in the figure, a series of contracts has been established to study the capabilities of current advanced engine cores (e.g., the PW5000) to meet the supersonic STOVL mission. Future engine requirements for the mid- to late-1990's are also being investigated in these studies. These contracts are also being used to support NASA's and the DOD's efforts in addressing integrated flight/propulsion controls. The contractors will develop hardware for testing advanced control systems and will develop control algorithms.

All of the technology efforts shown in figure 3 will culminate in a full ground propulsion technology validation program to take place in the late 1980's and early 1990's. This program plans to include a complete STOVL engine system. This system is currently planned to be a nearly full-scale ejector system with all components in place, including inlet, engine, fan air collector, ducting and valving, nozzle(s), and integrated flight/propulsion control system. The ejector system is currently being planned for this phase because, as a matter of convenience, it is already being tested at large size in the joint U.S./Canada program. None of the other proposed STOVL concepts are at this stage of testing and consequently would not be ready in the planned time frame. The intent of the ground validation program will be to validate a complete STOVL engine system, including real-time comparisons with the computer simulations. A pilot in-the-loop capability may also be employed. At the completion of this program enough of the required technologies will have been developed and validated such that a reasonable, low-risk decision can be made to initiate a flight technology validation program in the time frame shown in the figure.

STOVL STUDY CONTRACTS

In figure 4 is presented a collage of the supersonic STOVL configuration study contracts currently in existence to generate the data necessary for detailed comparisons of the identified possible engine concepts. Three propulsion system contracts, with General Electric (GE), Pratt & Whitney (P&W), and Allison Gas Turbine (AGT) Division of General Motors are being managed at Lewis. Also, four airframe contracts, with McAir, General Dynamics (GD), Grumman, and Lockheed are being managed at Ames. As mentioned in the section Proposed Concepts and Program Goal, four of the engine concepts are being studied under the joint U.S./U.K. ASTOVL program, and the fifth concept was added for consideration by NASA and the DOD to generate an appropriate data base with this configuration for comparison with the others. Three of the propulsion concepts were assigned to multiple contractors in order to generate comparisons. Each airframer was teamed with an engine company for each concept so that consideration of the joint requirements of each could be factored into the studies of each. These contract efforts, which have been completed, will be followed by a phase whereby the data from these studies will be compared, and an attempt will be made to identify one or two of these configurations to pursue in the following technology programs.

BASE PROGRAM

The current Lewis base R&T program elements for the supersonic STOVL are shown in figure 5. Because the favored propulsion concept has not yet been identified, if it can ever be, the current technology research activities tend to be focused on common technology issues. These are issues which would be applicable to two or more of the propulsion system concepts currently being studied in the supersonic STOVL technology program. The individual thrusts are either in existence today or, as shown, are planned to begin shortly. The programs already in existence include fan air collectors, valves, and ducting (for ejector and RALS systems); hot gas ingestion (HGI); short diffuser supersonic inlets with high alpha capability; and integrated flight/propulsion controls. Each of these is important for all the proposed engine concepts. Information from each of the existing programs will be presented in the following figures. Plans are being developed to initiate in the near future corresponding programs in thrust augmentation by burning, and thrust deflecting and vectoring nozzles. In general, each of these program elements has both analytical and experimental phases. The program and results to date are now described for the four active program elements.

FAN AIR COLLECTORS, VALVES, DUCTING, AND EJECTORS

U.S./Canada Ejector Technology

The research activities associated with fan air collectors, valves, ducting, and ejectors are being accomplished in the joint U.S./Canada Ejector Program. NASA, the Canadian Government, deHavilland, and General Dynamics (GD) have for a number of years been highly interested in demonstrating the ejector lift concept. More recently, DARPA has also provided support to the concept. NASA Lewis is not only addressing the ejector performance, but also the performance of the engine to the ejector air delivery system. Shown in figure 6 is a collage of the various elements of the joint U.S./Canada ejector technology program. In this program, a large-scale model of the General Dynamics E-7 supersonic STOVL aircraft configuration will be tested in the Ames 40- by 80-ft wind tunnel. This aircraft incorporates the ejector augmentor propulsion concept to provide the required lift at takeoff and landing. As shown in the upper left corner of the figure, the ejectors are located in the wing root on each side of the fuselage. The model will be tested with a complete engine system (first with a Spey engine, then eventually with an F110). A schematic of the engine system is shown in the upper right corner. In anticipation of the complete aircraft test, a series of large-scale component tests have recently been made. An example of a fan air collector design is shown in the figure. These large-component tests were conducted on the new Lewis Powered Lift Facility (PLF). This program provided the strong impetus to develop this new facility, which uses a research air supply system to evaluate full-scale STOVL components and systems in a static, ground environment. After the wind tunnel tests, the complete large-scale aircraft system will also be tested on the PLF at Lewis. Results from the initial large-scale ejector tests on the PLF will be presented in the following figures.

Powered Lift Facility

The new Lewis Powered Lift Facility (PLF), shown in figure 7, was initially designed and built to support testing for the U.S./Canada program. The system includes a large triangular (30-ft on a side) frame supported 15 ft above the ground. This frame is supported by load cells, which provide a six-component force measuring system. Vertical (20 000 lb), axial (30 000 lb), and lateral (5000 lb) forces as well as pitch, roll, and yaw moments can be measured in plus and minus directions. High-pressure (95 psig) and heated air (to 300 °F) with flows greater than 160 lb/sec can be supplied to the stand to simulate fan bypass air. The high-pressure air is brought onto the system through a series of bellows, oriented 90° to the force system, to minimize delivery system momentum tare forces. The facility was completed, and flow tests were initiated in September 1986. Initial force calibrations were made in April 1987, and performance tests began in June 1987.

As stated in the preceding paragraph, the PLF was initially designed to support ejector component and system testing. However, because of its unique capabilities, it is completely suitable for evaluation of components and systems for all of the supersonic STOVL propulsion concepts. It also could be used as a static test facility for multi-axis nozzle tests for supermaneuverable aircraft.

Ejector Performance

The first test on the new Lewis Powered Lift Facility (PLF) mentioned in the preceding section included the full-scale internal fan flow ducting and valving scheduled to be installed in the large-scale GD E-7 aircraft model. A schematic of the installation on the aircraft model is shown in figure 8. The fan flow will be collected and fed through a plenum to either a forward or aft duct. The forward duct will direct the flow to the ejector augmentor in the aircraft wing. The aft duct will lead to a thrust nozzle in the back. Flow direction will be controlled by butterfly valves. This arrangement is unique to the E-7 configuration. A photograph of the duct and valve hardware installed on the PLF is also shown. The purpose of these tests was to evaluate the pressure loss performance of the system before the ejector was installed. Typical pressure loss data are shown and compared with previous predictions (lined curves). As seen in the figure the data for the rear duct show less loss (than predicted) and slightly higher loss for the ejector duct. These results were considered as being favorable and are expected to have minimal impact on the overall system performance.

After the internal duct and valve pressure loss tests were completed, the PLF force system was calibrated, and the first force test was initiated. As shown in figure 9, one-half (side) of the large-scale ejector was attached to the system ducting and tested on the PLF. These initial tests were completed in June 1987. This figure includes photographs of the model installed on the PLF and some of the more significant results. The upper photo is a view looking at the downstream end of the ejector. The lower photo is a closeup view looking at the inlet of the ejector secondary with the primary nozzles (12) clearly visible. For these tests the ejector was positioned on its side to avoid possible, and not currently understood, facility support interference effects. The test ejector measures approximately 10 by 2 ft and is supplied by 42-lb/sec primary airflow at the design point. The ejector achieved 3300 lb of thrust at that condition.

Preliminary thrust augmentation data are shown in the figure as a function of primary nozzle pressure ratio. The system design was for a thrust augmentation ratio of about 1.6 at a nozzle pressure ratio of 2.5 (corresponding to a Spey engine test condition). Previous deHavilland test results with another smaller scale model and lower flow facility are also shown for comparison. The Lewis data show excellent agreement with the previous data, and both exceeded the design by a considerable amount. The augmentation data shown are based on nozzle exit conditions. Correcting for the valve and duct pressure loss reduces this performance by only 3 percent. The resulting augmentation performance would still exceed the design requirement. It should be noted here that this test is somewhat analogous to a typical isolated nozzle test. Further, it can be expected that some of this performance may be lost upon installation in the aircraft model. This good agreement and sizable performance margin raises the confidence level for both the capabilities of the PLF and feasibility of an ejector system as one of the viable concepts for a future supersonic STOVL.

The next step in the U.S./Canada Ejector Program will be to install this same hardware in the complete E7 model and to test it in the Ames 40- by 80-ft wind tunnel. On the basis of the results discussed in the preceding paragraph, confidence in the success of this program is high. Follow-on work for the PLF will include a static evaluation of the E-7 model with the ejectors, evaluation of alternate ejectors, and an integrated flight/propulsion control system, which will be discussed later.

HOT GAS INGESTION

Hot gas ingestion (HGI) will be a problem for all of the currently proposed supersonic STOVL engine concepts. The problem, as demonstrated in figure 10, is extremely complex and results from, in the case of a vectored thrust configuration, the jet flow impinging upon the ground and creating either of two conditions: (1) a fountain upwash is formed, which flows up to the fuselage and then forward to the inlet (near field) or (2) the ground flow, feeding forward, either interacts with the oncoming flow and gets recirculated or lifts off the ground because of buoyancy (far field). The fountain upwash essentially is the desired reflection of the jet exhaust off the ground upon the underside of the aircraft, which increases lift by offsetting jet-induced suckdown effects. However, this hot gas can run along the underside of the fuselage and enter the engine inlet system, producing a temperature distortion to the engine, loss of thrust, and at worst an engine compressor stall. The far-field phenomena can have the same result. These phenomena have already been a problem for the Harrier (ref. 6) and have been addressed in earlier V/STOL programs. With the higher T/W engines required for the supersonic STOVL it will be a worse problem. Therefore either control devices or operational procedures will have to be developed to reduce or eliminate the problem. The following figures will describe the Lewis program in place to work on the problem.

Analytical Results

An integral part of each Lewis supersonic STOVL program includes analytical development. An example of where significant progress has been made is illustrated in figure 11 for the case of hot gas ingestion (HGI). Shown in the figure are preliminary results from calculations made by using a three-dimensional Navier-Stokes code based on the TEACH code of Imperial College. This code assumes incompressible gas, but allows temperature differences between gases and their corresponding different densities, so results at this stage are purely qualitative (ref. 7). As shown calculations were made around a simplified forebody/inlet configuration, which included two subsonic jets close to a ground plane. A reflection plane down the middle of the fuselage thereby resulted in an equivalent four-jet (vectored thrust), two-inlet configuration. For the model, the inlet mass flow rate was matched to the exhaust nozzle flow rate.

The results shown are temperature profiles on planes at various heights from the ground to the aircraft inlets. As seen on the ground (plane 4) the jets show strong interactions, and the fountain upwash, typically seen with these configurations, is predicted together with the corresponding outflows and interactions with the free stream. The calculation for a location about midway between the ground and the fuselage (plane 3) indicates the strong development of the fountain between the nozzles and some spreading of the flow in the forward direction. Near the underside of the fuselage a stronger forward flow is observed (plane 2), and then hot flow is actually seen entering the inlet (plane 1). Qualitatively, these results are just about what one would expect to see. At present more analytical studies of these phenomena are being made with more complicated three-dimensional codes. Advanced studies will include compressible effects and more realistic forebody/inlet shapes and wing flows.

Scale-Model Results

A 1/10 scale model of a McDonnell Aircraft Company (McAir) 279-3 supersonic STOVL aircraft configuration, seen in figure 12, was tested in the Lewis 9- by 15-ft low-speed wind tunnel. The objective of these tests is to assess at scale-model sizes HGI and the distortion which must be accommodated by an engine, and to investigate possible approaches for either avoiding HGI and/or controlling it. Data from this model will also be valuable in validating the analytical codes used to assess the problem. This is a joint program between DARPA, NASA, and McAir. The model is a four-nozzle (post) vectored thrust configuration and includes high-pressure heated air (500 °F). Exhaust air provides inlet flow. A heater external to the tunnel was used to heat the nozzle flow, and flow to each nozzle could be individually controlled. Temperature and pressure rakes are included at the compressor face station to evaluate ingestion and to determine distortion profiles. As seen in the left photograph, the model was mounted from a fairly rigid support, which did provide some (but limited) model attitude and height variation. The tunnel installation included a ground plane which, as seen in the closeup view (right photo), included a trap door beneath the model. This allowed the hot gas to be ducted out of the tunnel while test conditions were being established. This door closed in about 0.5 sec, and then data were taken.

Preliminary results of the effect of model height on inlet temperature are shown in figure 13. In this figure the average temperature increase at the compressor face is presented as a function of free-stream velocity. Conditions were for a nozzle pressure ratio of 3.0 and exhaust gas temperature of 500 °F. The model height is expressed in feet for a full-scale aircraft rather than model scale to give a better understanding of the test results. As shown, hot gas began to be ingested with the landing gear, scaled up to full scale, about 4 ft above the ground for these simulated model and tunnel flow conditions. Hot gas ingestion is shown to increase as the model height was reduced. Basically, the data indicate that free-stream velocity had little effect. To use the model temperature on a full-scale basis it has to be scaled up, in this case, by a factor of about four since the nozzle supply was only at 500 °F. Investigation of temperature scaling was a part of these studies. Preliminary results indicate that the predicted scaling factors were validated for some conditions but not for others. Basically the trends observed in the data were as predicted. This test provided extremely valuable information to enhance the basic test technique for future tunnel entries and to develop possible solutions.

An example of this is shown in figure 14. In this figure the data shown indicate that model geometry seems to have a more significant impact on HGI than either tunnel or model flow conditions. As shown, hot gas ingestion can be significantly reduced if the proper flow diverter were added to the model. A series of supposed lift improvement devices (LID's) were also tested. These devices were extremely effective in reducing the HGI. A change in nozzle splay angle could result in further reductions in HGI. It became apparent in this testing that each aircraft concept will probably be subject to HGI in some degree. There are many possible solutions indicated, but the effectiveness of each will vary with the individual geometry.

As shown in figure 12, the 1/10 scale model was mounted in the test section from a relatively rigid support system. For future HGI tunnel entries a new model integrated support system (MISS), shown in figure 15, is currently being fabricated. This support will allow testing at increased temperatures (1000 °F) and have remotely variable height, angle of attack, pitch, roll, and yaw. This support will again include exhaust for inlet flows and be capable of being used in other types of model testing. Thrust reverser, isolated inlet, and forebody inlet models could be tested over wide ranges of model and test conditions. The current model also will be modified to accept different nozzle configurations and locations. Both the model and MISS should be ready for a new series of tests in about a year.

SUPERSONIC INLET WITH SHORT DIFFUSER

Conventional supersonic dash or cruise inlets have long diffusers which maintain well behaved attached flows over wide ranges of aircraft angle of attack and attitude. The engine location in a typical supersonic STOVL may have to be moved forward for better weight and balance and to better locate the thrust vectors. This will then result in a problem for the diffuser design, particularly for operation at angle of attack. A two-dimensional supersonic inlet model, shown in the upper right corner of figure 16 with a conventional length diffuser, was built and tested in the Lewis 9- by 15-ft wind tunnel at angles of attack exceeding 100°. In these tests, variations in lip geometry and auxiliary inlets were investigated to improve alpha performance. Results of these tests show that good performance can be obtained even at the high alpha's. A modification to this model has been designed and fabricated which includes a short diffuser, as shown in the lower left corner, more appropriate to STOVL configurations. As indicated in the lower right corner of the figure, analysis has shown that this short diffuser will separate and have poor performance unless something is done to affect the boundary layer.

Short Diffuser Analysis

An analytical methodology was applied to the design of this diffuser, which incorporates techniques of boundary-layer control successfully studied and validated with subsonic V/STOL inlets at high angles of attack (ref. 8). In these previous studies both boundary-layer bleed and jet blowing were effective in maintaining attached diffuser flows in subsonic inlets at angles of attack approaching 100°. An example of these same methodologies applied to the design of the new short diffuser is shown in figure 17. As shown in the figure, the methodology was applied by McAir to the short diffuser including natural bleed. The short diffuser (L/D = 1.25) was designed without bleed (using typical techniques, including potential flow codes) and then with viscous corrections. Shown in the figure is the Mach number distribution along the top of the diffuser just outside the boundary layer. The analysis of this case indicated that the flow was separated at about halfway back even without any angle-of-attack considerations. This result is reflected also in the calculated skin friction, indicating that it approaches zero near this station. Varying distributions of boundary-layer bleed were then analytically applied until this separation was eliminated (also reflected in the skin friction calculation). As shown in the figure, this result was achieved with reasonable amounts of bleed required. Analyses including jet blowing were also made, again with favorable results.

Model Hardware

As a result of this work a new short diffuser section was then designed for the existing NASA Lewis/McAir two-dimensional inlet model shown previously. This model will permit experimental incorporation of several different methods of boundary-layer control including suction, blowing (discrete and distributed), and other devices (e.g., vortex generators). The short diffuser model has been fabricated and is being readied for test in the Lewis 9- by 15-ft low-speed tunnel. A photograph of this model is shown in figure 18. The model can use any of the systems indicated either individually or in combination. Data from these tests will be used to validate these analyses. This hardware is currently being instrumented and is planned for evaluation at low speed and angle of attack in late 1988.

INTEGRATED FLIGHT/PROPULSION CONTROLS

One of the most difficult technology issues relative to supersonic STOVL will be integrated flight/propulsion controls. The supersonic STOVL aircraft goals require integration of supersonic flight, highly maneuverable flight, short takeoff, and vertical landing technologies. These modes of flight all are different and require different control strategies to implement. A pilot in combat cannot be expected to deal with all of these modes, some occurring simultaneously; hence the interest in developing integrated flight/propulsion control (IF/PC) systems has become paramount. In the joint U.S./U.K. program this was identified as being critical enough to be started immediately. As a result a joint effort was organized between NASA Ames and NASA Lewis to develop IF/PC technology. The collage shown in figure 19 represents that joint effort. Ames will work the flight aspects and Lewis the propulsion. Aircraft and engine simulations will be developed, and various control architectures will be pursued. A new real-time simulation computer has been installed at Lewis to model the propulsion and airframe dynamics. The future goal will be to eventually develop a pilot in the loop simulation capability, test these systems on the Ames Vertical Motion Simulator, and eventually verify the technology in a flight research program.

The initial effort in this joint program is an extension of the U.S./Canada Ejector Program because the characteristics of this system are currently the most clearly known. In this initial effort contracted support will provide the required hardware and develop initial control law algorithms. Participants in these efforts include GE, GD, Systems Control Technology, and deHavilland. The initial objectives will be to apply and evaluate the new Design Methodology for Integrated Control Systems (DMICS) technologies (refs. 9 and 10) as extended to STOVL. The goal of the program is the successful closed-loop demonstration of an operational engine with the ejector augmenter and simulated aircraft.

Figure 20 is a schematic of the currently proposed ground engine and integrated flight/propulsion controls demonstration test. Although the control logic is being evaluated here on an ejector-based system, the number of control loops, nonlinearities, etc., that must be dealt with are typical of the STOVL propulsion concepts. The configuration shown includes the GE F110 engine and ejector system that will be mounted on the Lewis Powered Lift Facility (PLF). The model will include a vectorable, two-dimensional convergent/divergent (CD) aft nozzle and a ventral nozzle for vertical thrust. Again these items are typical of many of the STOVL propulsion concepts. This system will be tested with a real-time aircraft simulation running in parallel. The control computers will be fitted with the integrated control algorithms, first based on the contractors design methodology for integrated control systems (DMICS), and then with some new NASA-developed methodologies. Testing on the PLF will focus on vertical and transition operation at static conditions. This program is currently scheduled to take place in late 1989 and early 1990, and will be followed by a further evaluation of the ejector concept powered by an F110 in the NASA Ames 40- by 80-ft wind tunnel.

CONCLUDING REMARKS

A comprehensive program has been put in place that will develop the required propulsion technology to allow the initiation of a research aircraft in the early- to mid-1990's. A supersonic STOVL technology program is important, as indicated by the interest and involvement of three separate governments. The DOD is involved. Specifically, the Air Force is already an active participant, and there is indication that the Navy will soon be involved. Successful studies which will lead to more certainty on a concept specific effort are nearing completion. And, test programs are already in place and generating promising results. New facilities and research capabilities have also been developed which will be useful not only to this effort but also to others such as highly maneuverable fighter aircraft.

With adequate resources, considerable progress can be expected over the next several years, thus allowing supersonic STOVL to be a promising candidate for future fighter/attack aircraft.

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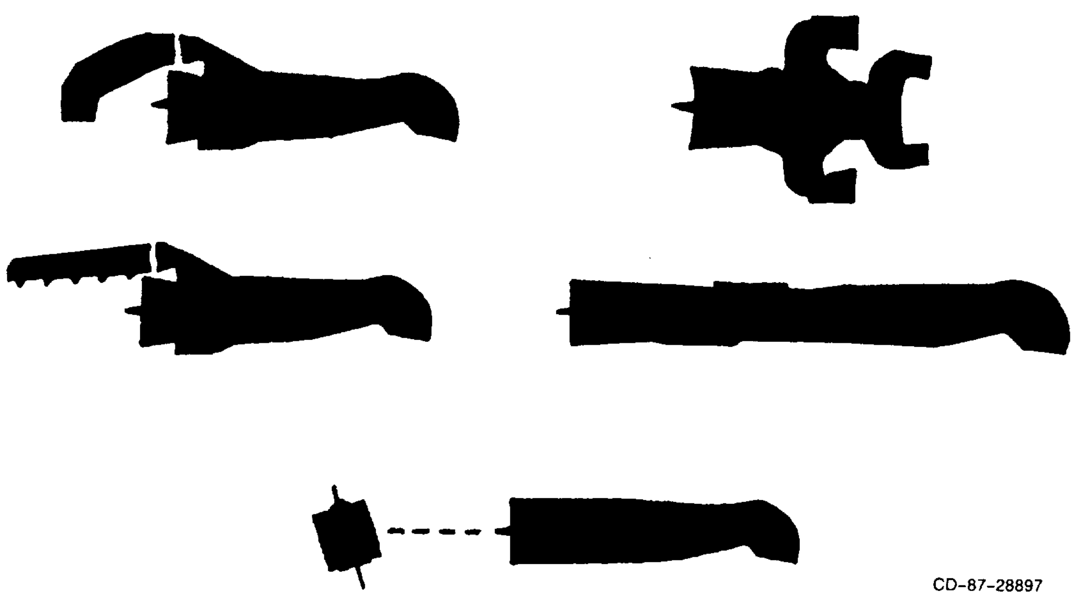

Figure 1. - Supersonic STOVL propulsion technology program.

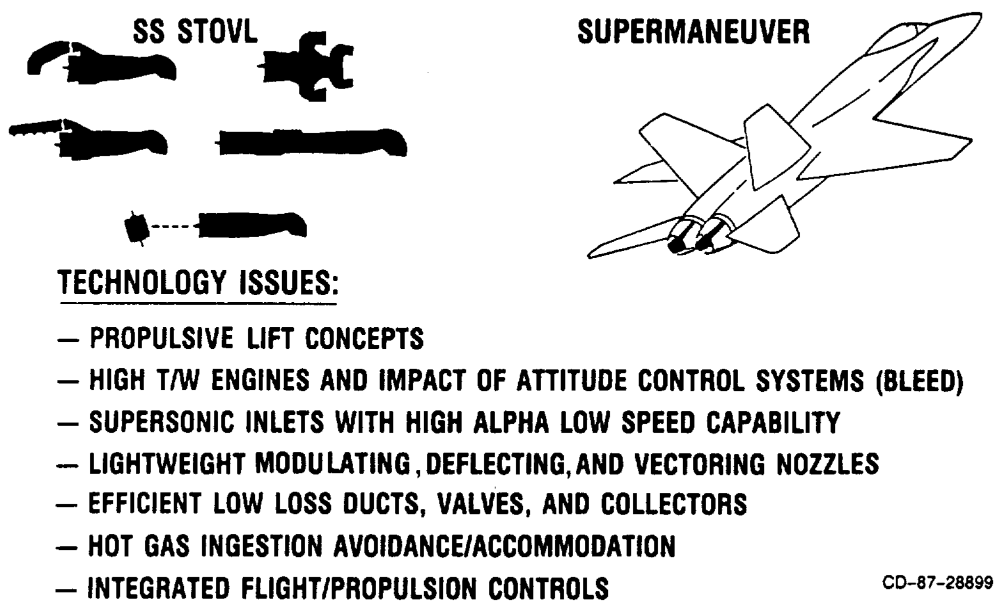

Figure 2. - STOVL supersonic and supermaneuver propulsion technology.

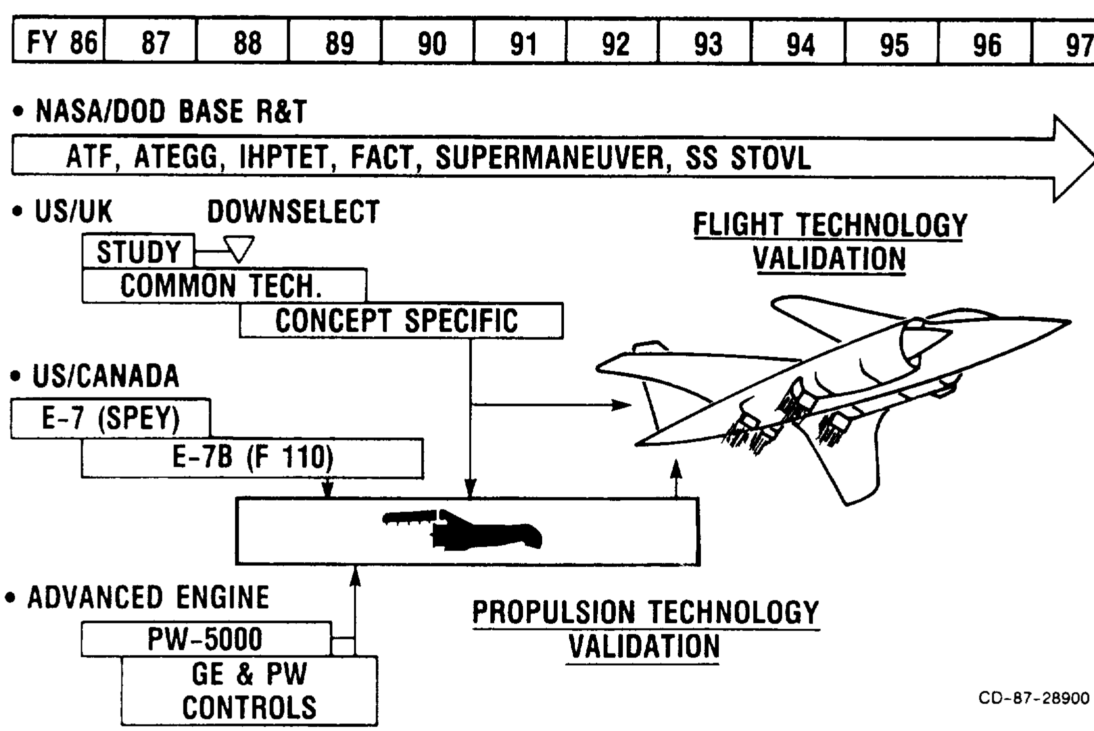

Figure 3. - Supersonic STOVL program plan.

PROPULSION DATA BASE PREPARATION

US/UK ←→ NASA/DOD

LEWIS/ENGINE CO. DATA BASE TASKS	VECT. THRUST	EJECTOR	RALS	TANDEM FAN	LIFT + LIFT/CRUISE
P&W ROLLS	X		X	X(ROLLS)	
GE	X	X	X		
AGT			X	X	X

AIRFRAME/PROPULSION INTEGRATION

AMES AIRFRAMER CONTRACTS	McAIR	GD	GRUMMAN	LOCKHEED	McAIR
	VECT. THRUST	EJECTOR	RALS	TANDEM FAN	LIFT + LIFT/CRUISE
LEWIS/ENGINE CO.	P&W	GE	GE	ROLLS (P&W)	AGT
INTEGRATION TASKS	X	X	X	X	X

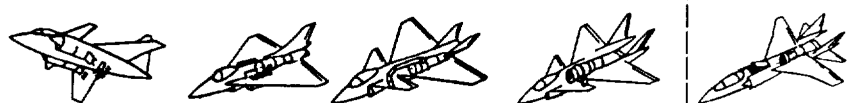

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Figure 4. - STOVL study contracts -- FY87.

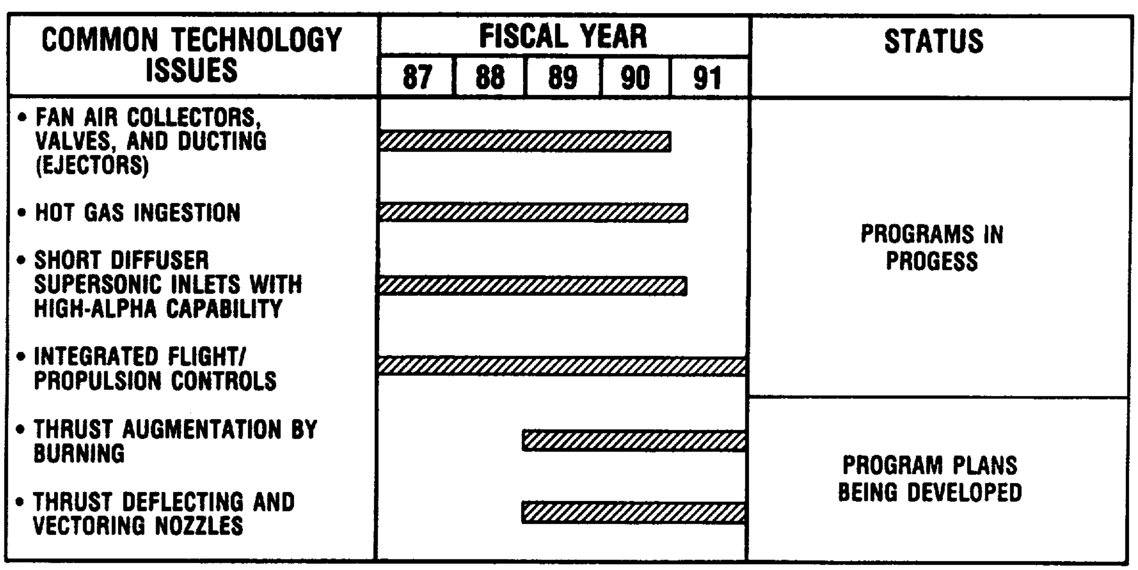

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Figure 5. - Base program.

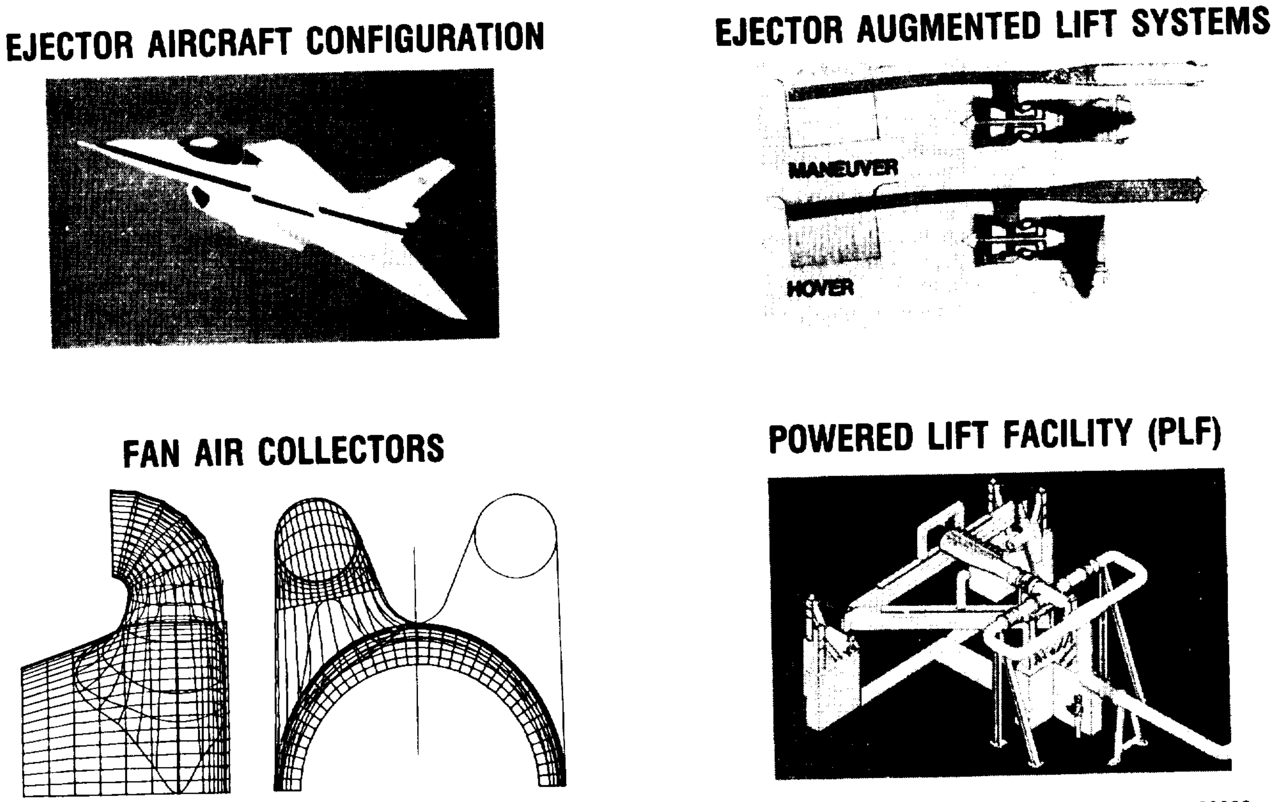


Figure 6. - U.S./Canada ejector technology.

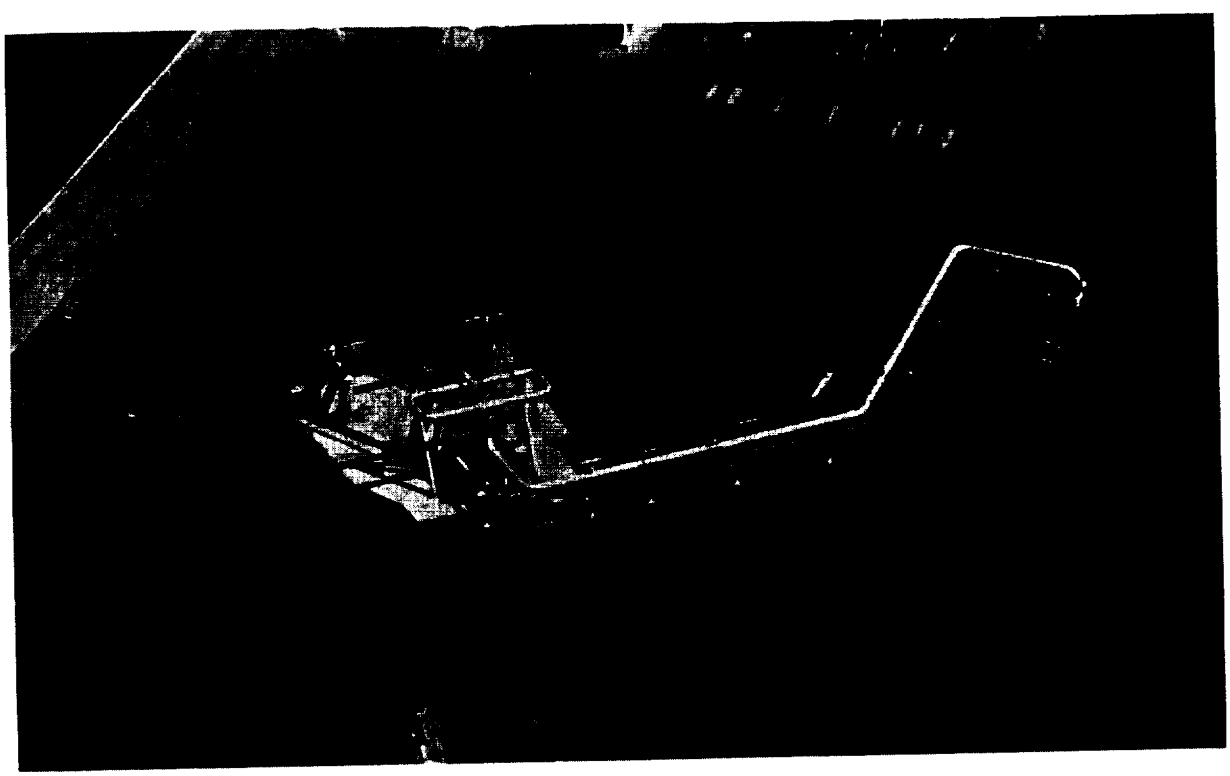


Figure 7. - Powered Lift Facility.

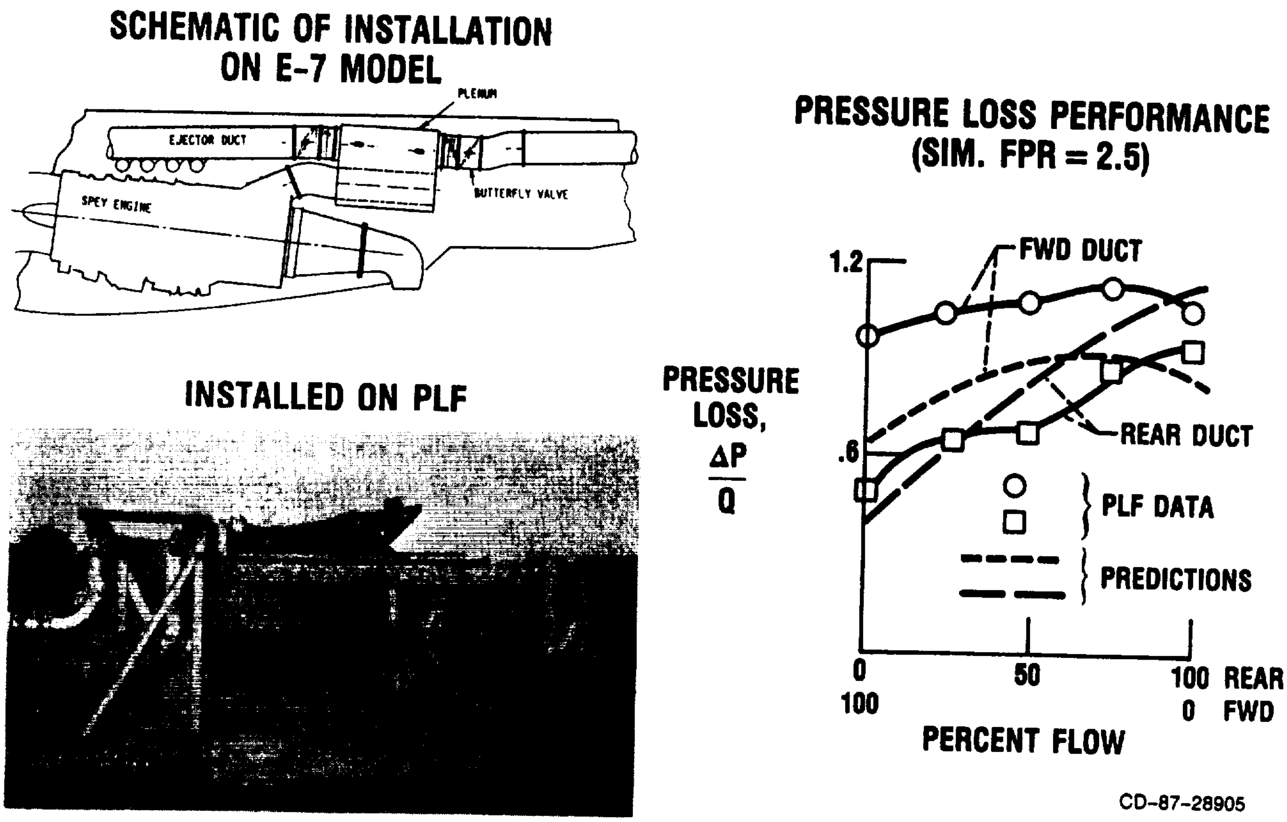


Figure 8. - DeHavilland full-scale duct and valve test on PLF.

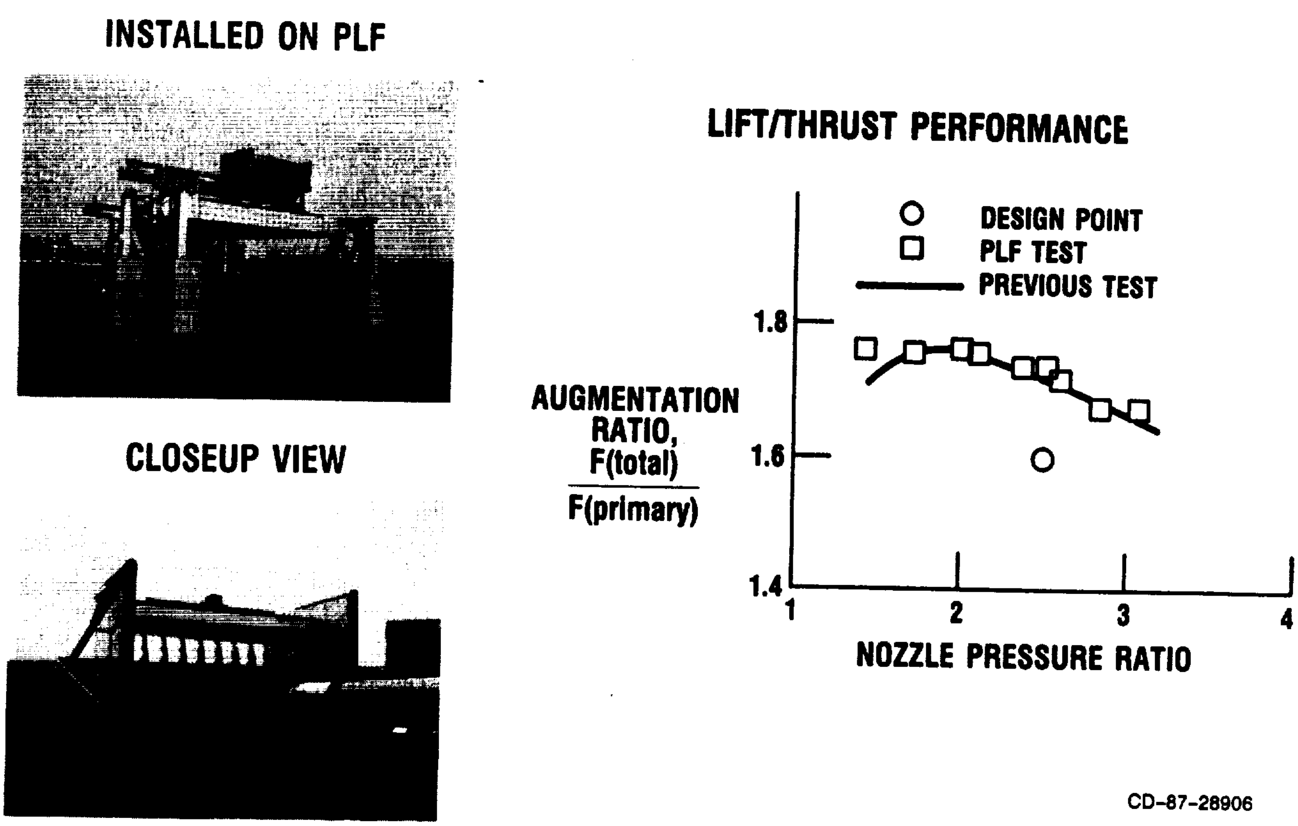
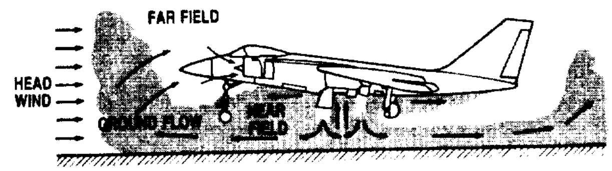


Figure 9. - DeHavilland full-scale ejector test on PLF.

STOVL DEFLECTED THRUST CONCEPT 279-3 AIRCRAFT

EXHAUST GAS INGESTION PHENOMENA



SOURCES

- NEAR FIELD
  - FOUNTAIN UPWASH
- FAR FIELD
  - SEPARATED GROUND FLOW

CONTROL

- LIFT IMPROVEMENT/FLOW DEFLECTOR
- INBOARD SPLAYING FRONT NOZZLES
- OPERATIONAL PROCEDURES
- ZONE BURNING FRONT NOZZLES
- INLET WATER INJECTION

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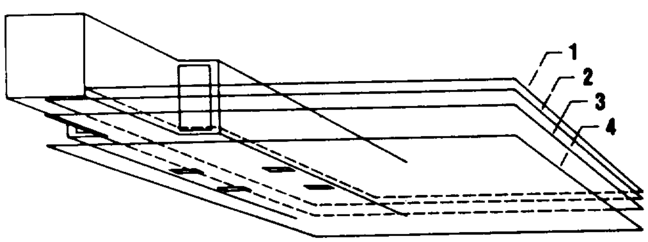
Figure 10. - Hot gas ingestion (HGI).

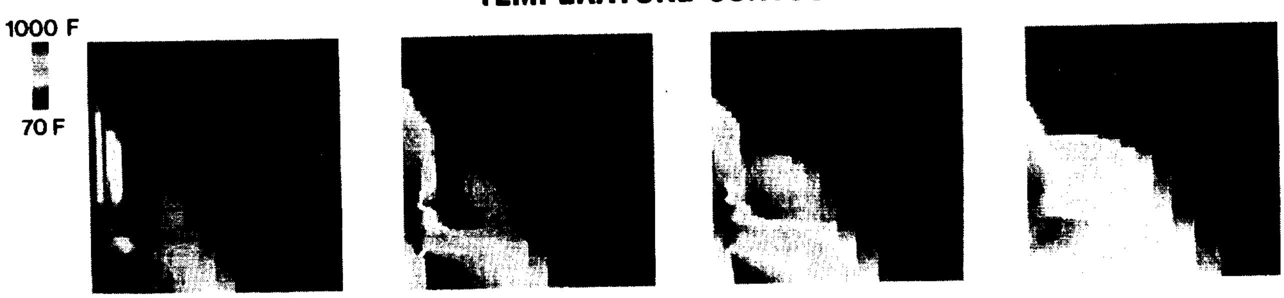


OBJECTIVE

ASSEMBLE AND VALIDATE 3-D COMPUTER CODES TO ANALYZE EFFECTS OF AIRCRAFT CONFIGURATION, FLIGHT SPEED, AND GROUND PROXIMITY ON HOT GAS ENVIRONMENT AROUND STOVL AIRCRAFT.

FORWARD VELOCITY = 28 m/s
EXHAUST VELOCITY = 300 m/s

TEMPERATURE CONTOURS



PLANE 1 PLANE 2 PLANE 3 PLANE 4

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Figure 11. - Hot gas ingestion analytical results.

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Figure 12. - One-tenth scale McAir 279-3 supersonic STOVL model hot gas ingestion (HGI) test in Lewis 9- by 15-ft wind tunnel.

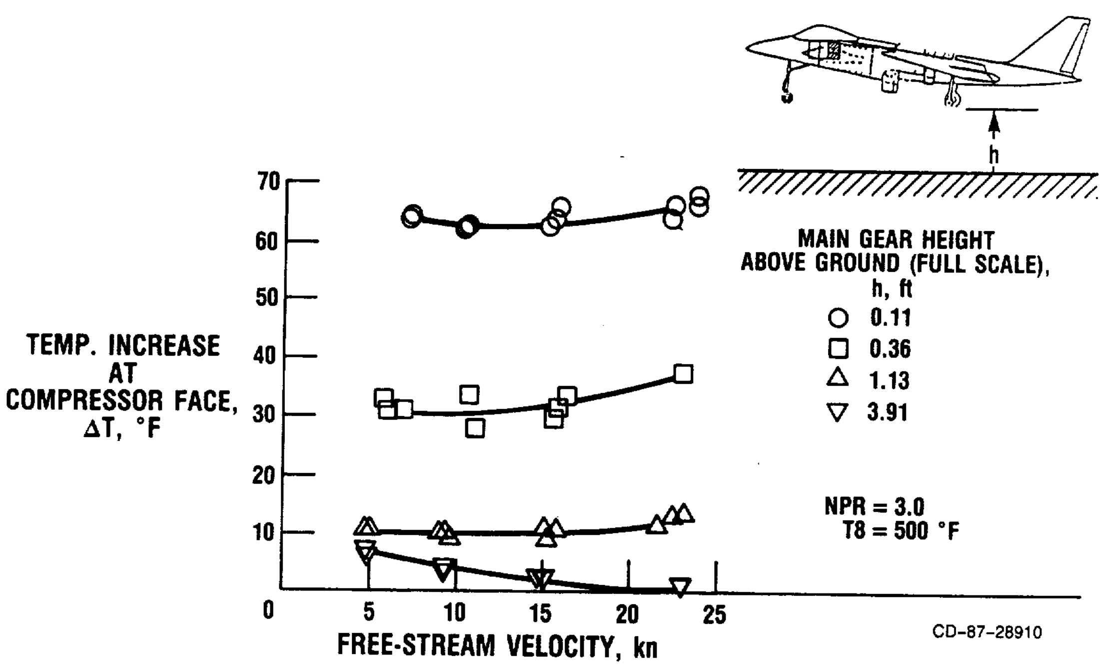

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Figure 13. - Effect of ground proximity on hot gas ingestion (HGI) with basic 279-3 model.

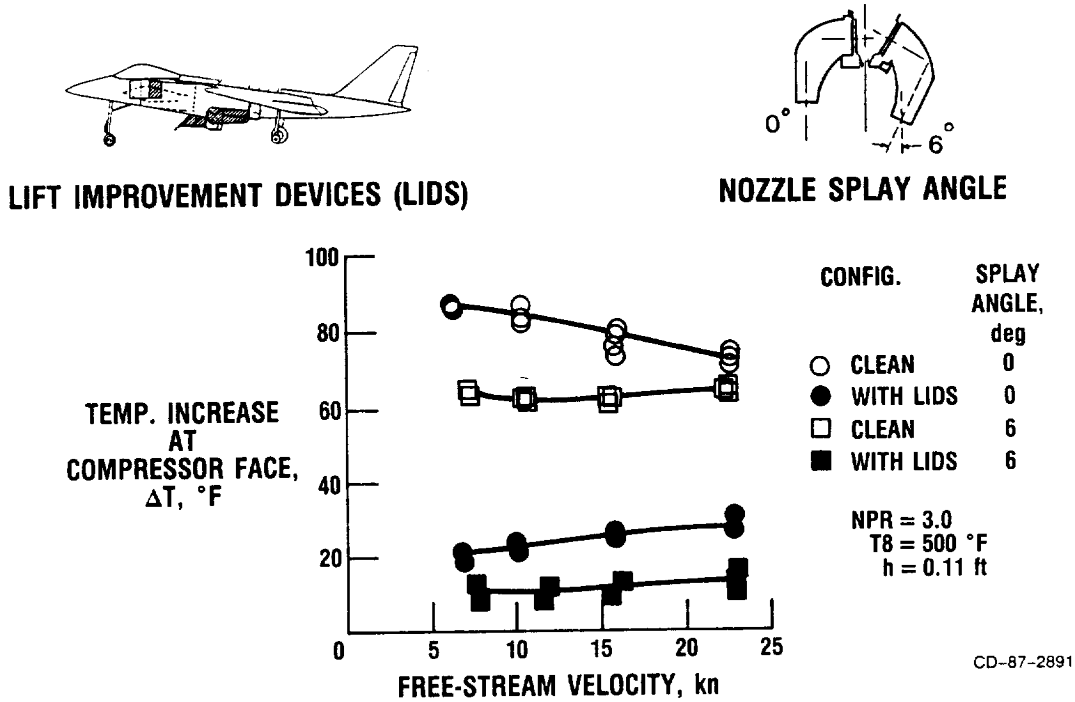

Figure 14. - Effect of geometry on hot gas ingestion (HGI).

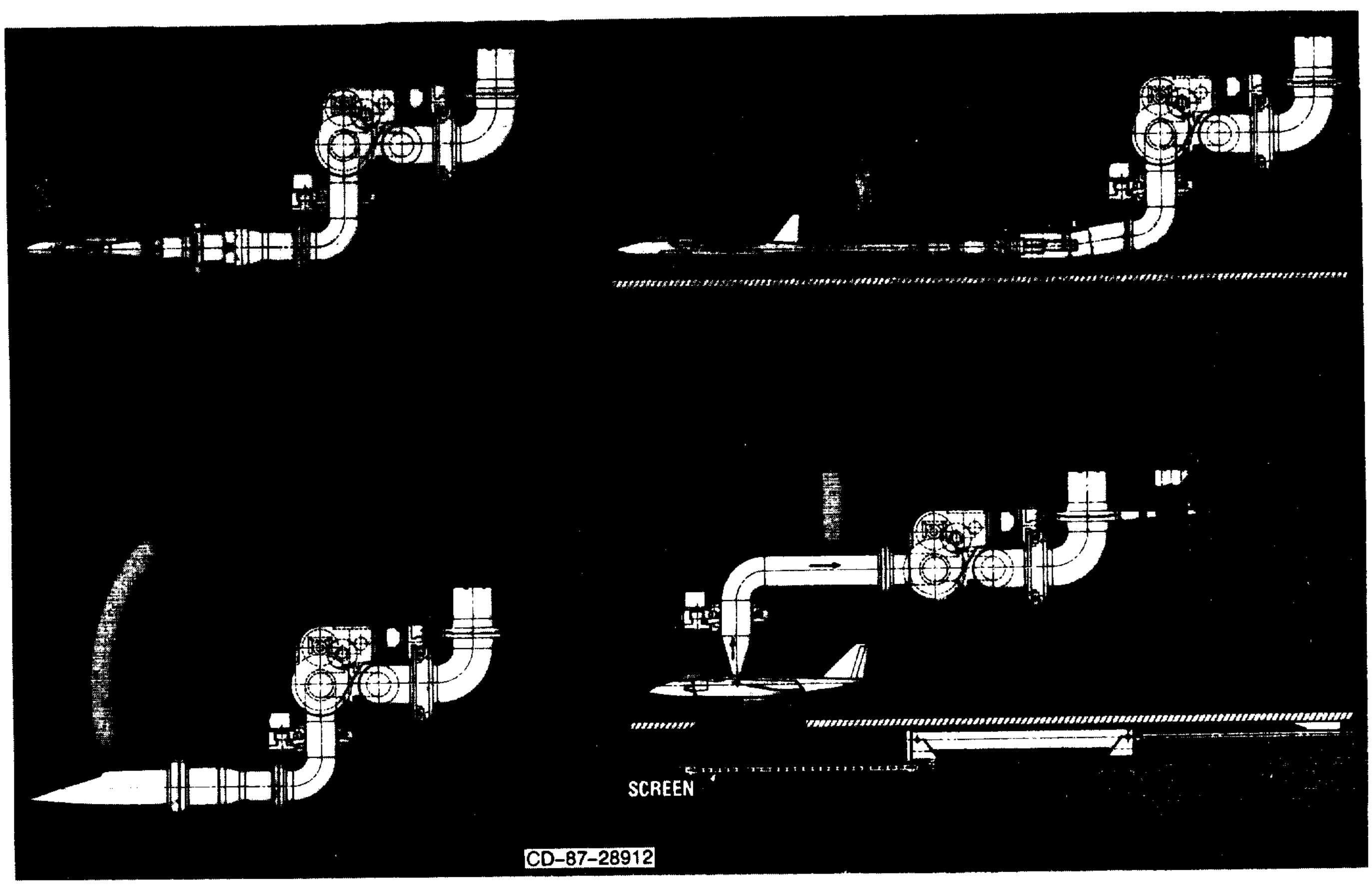

Figure 15. - Model integrated support system (MISS) for versatile and efficient research testing.

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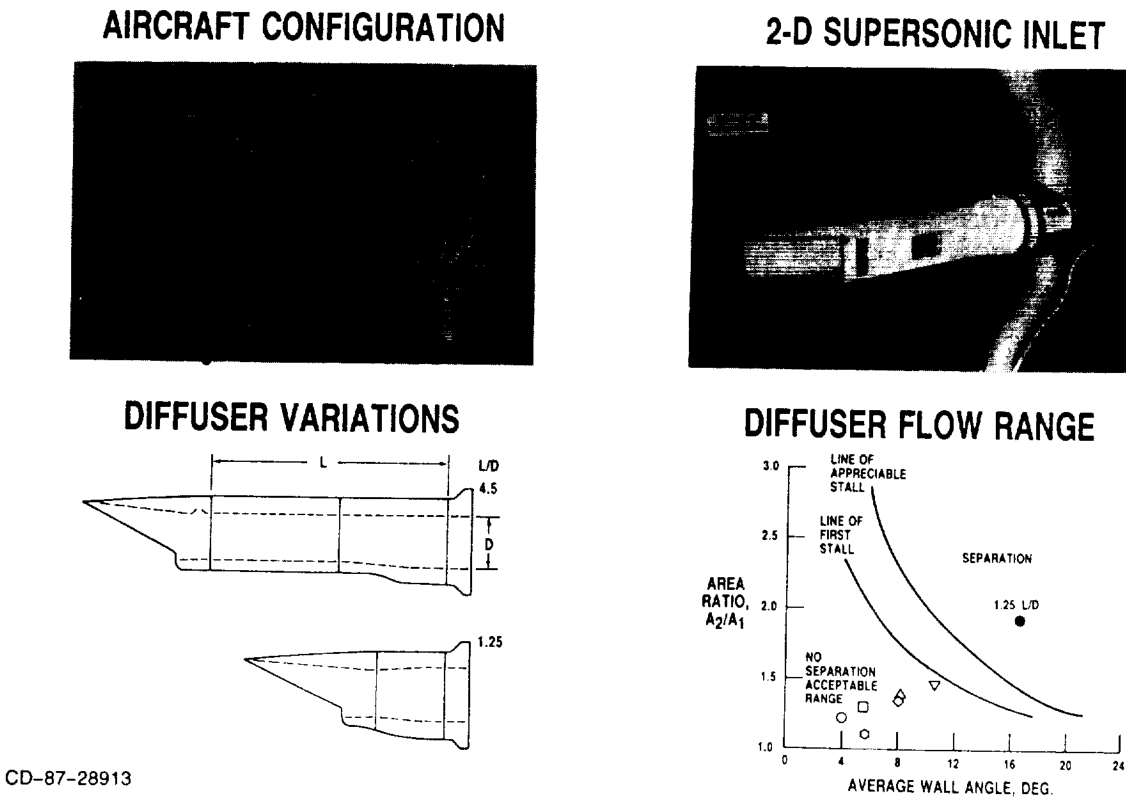

Figure 16. - Supersonic inlet with short diffuser.

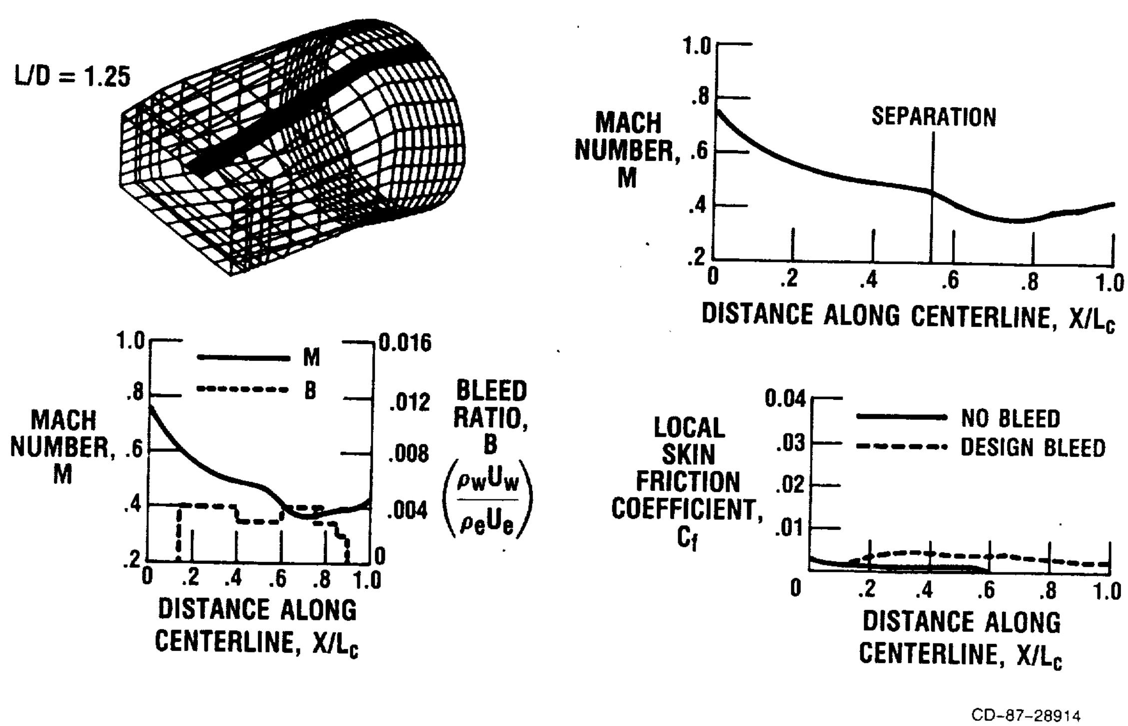

Figure 17. - Short diffuser analysis - effect of bleed.

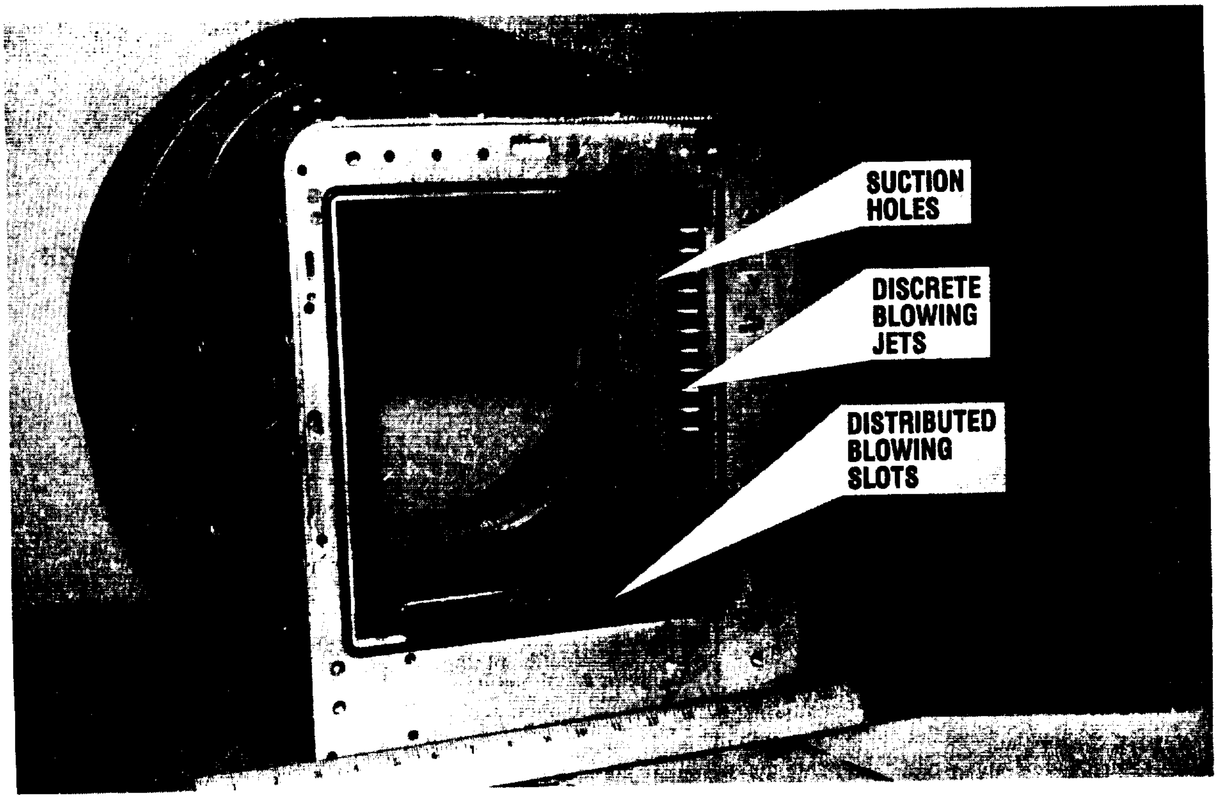

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Figure 18. - Short supersonic diffuser model.

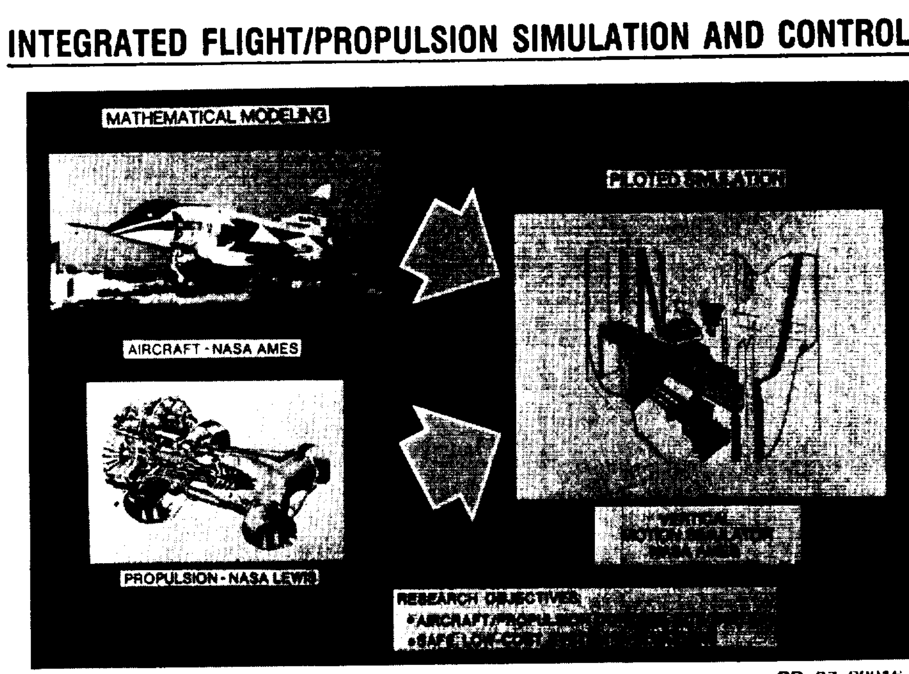

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Figure 19. - STOVL supersonic and supermaneuver propulsion technology.

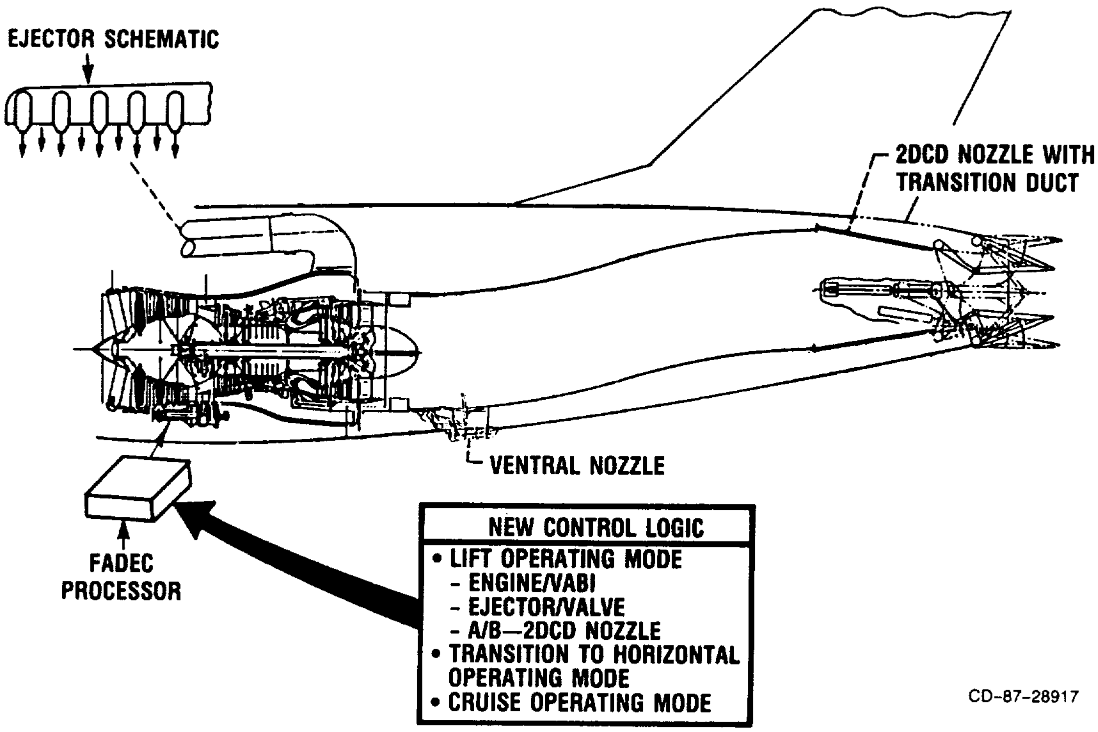

Figure 20. - NASA/DARPA ejector/controls configuration.