SUPERSONIC STOVL PROPULSION TECHNOLOGY PROGRAM - AN OVERVIEW

Bernard J. Blaha
and
Peter G. Batterton

ABSTRACT

Planning activities are continuing between NASA, DOD, and two foreign governments to develop the technology and to demonstrate the design capability for advanced, supersonic, short-takeoff and vertical-landing (STOVL) aircraft by the mid-1990's. As a result, a Memorandum of Understanding (MOU) has been established with the United Kingdom to jointly pursue the required technology; and an MOU with Canada is expected to be signed shortly. NASA Lewis Research Center will play a lead role in the development of the required propulsion technologies which have been identified as being "critical" to achieve viable STOVL aircraft. These 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 present an overview of the Lewis Research Center's role in the overall program plan and recent results in the development of the required propulsion technologies.

SUPERSONIC STOVL PROPULSION TECHNOLOGY PROGRAM OVERVIEW

This figure shows silhouettes of the five propulsion system concepts being considered for an advanced, supersonic, short-takeoff and vertical-landing (STOVL) aircraft which could be developed in the post-ATF time frame (late 1990's). These include a remote augmenter lift system (RALS), vectored thrust, ejector augmenter, tandem fan, and lift plus lift/cruise systems, respectively. Interest in the development of the technology required for such an aircraft has increased in recent years and 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 technology, and an MOU with Canada is expected to be signed shortly. 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. NASA and the DOD have recently added the lift plus lift/cruise concept to their investigations.

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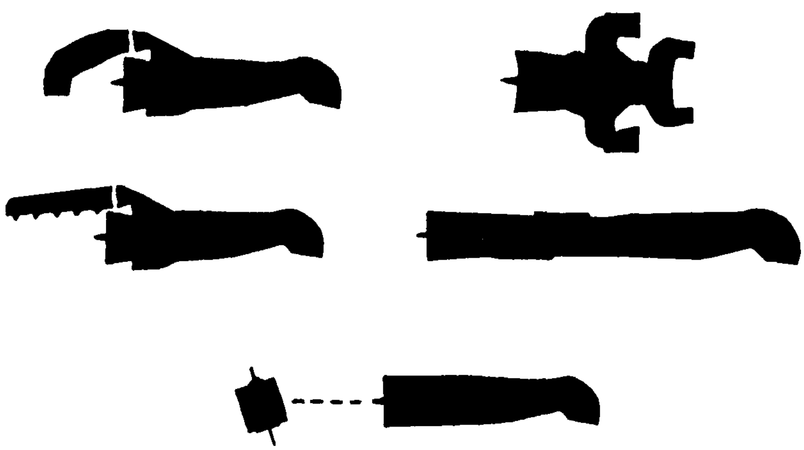
SUPERSONIC STOVL PROPULSION TECHNOLOGY PROGRAM

OVERVIEW



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PROGRAM GOAL

The supersonic short-takeoff and vertical-landing (STOVL) technology program is focused on having the technologies by the early 1990's, so that a decision to start a research aircraft program can be made with relatively low risk. The key technologies to be developed are primarily propulsion related. We know how to design fighter/attack aircraft which can dash and cruise supersonically (e.g., F-14, F-15, and F-16). We also know how to design a subsonic aircraft for vertical takeoff and landing (e.g., Harrier and AV-8B). 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 require the development of unique engine system components with multifunction capabilities (e.g., vectoring and deflecting nozzles and, in particular, new control systems).

PROGRAM GOAL

TO HAVE THE TECHNOLOGIES IN PLACE TO PERMIT THE LOW RISK INITIATION OF A RESEARCH STOVL SUPERSONIC FIGHTER/ATTACK AIRCRAFT IN THE EARLY TO MID-1990's

PROPULSION TECHNOLOGIES ARE THE KEY CRITICAL TECHNOLOGIES REQUIRED TO ACHIEVE THE GOAL. THIS IS A PROPULSION DRIVEN PROGRAM.

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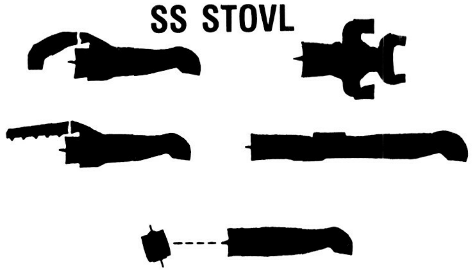
PROPULSION TECHNOLOGIES

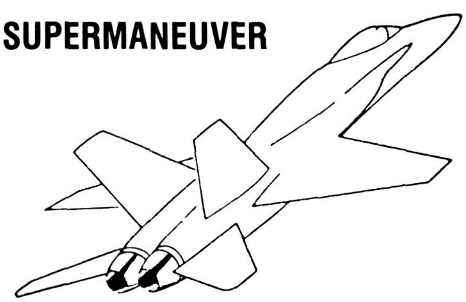
The propulsion technologies, identified as key to the supersonic STOVL program, cover a broad spectrum and are listed in the figure. Some of these are related to and will be developed in other on-going NASA and Air Force base technology programs combined with the STOVL program. The new higher T/W (15 to 20) engine core technology required will come from programs such as IHPTET and NASA's base technology efforts. Much high-alpha inlet and vectoring nozzle information will come from the NASA supermaneuver program with an F-18 aircraft at Dryden (HATP/HARV). The rest of the needed developments will be made in the supersonic STOVL program. The first issues to be resolved are the propulsive lift concepts themselves and which is the best propulsion system concept to pursue for a research aircraft. Each of the propulsive lift concepts has technical problems with performance, volume, weight, etc. We are 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. The impact of compressor bleed (for reaction control) will have to be evaluated for the higher T/W engines. New short diffuser inlets with high-alpha capability and vectoring nozzles with full 90° deflecting capability will have to be developed. Two of the more notable issues to be resolved 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.

STOVL SUPERSONIC AND SUPERMANEUVER PROPULSION TECHNOLOGY

SS STOVL



SUPERMANEUVER



TECHNOLOGY ISSUES:

- PROPULSIVE LIFT CONCEPTS
- HIGH T/W ENGINES AND IMPACT OF ATTITUDE CONTROL SYSTEMS (BLEED)
- SUPERSONIC INLETS WITH HIGH ALPHA LOW SPEED CAPABILITY
- LIGHTWEIGHT MODULATING, DEFLECTING, AND VECTORING NOZZLES
- EFFICIENT LOW LOSS DUCTS, VALVES, AND COLLECTORS
- HOT GAS INGESTION AVOIDANCE/ACCOMMODATION
- INTEGRATED FLIGHT/PROPULSION CONTROLS

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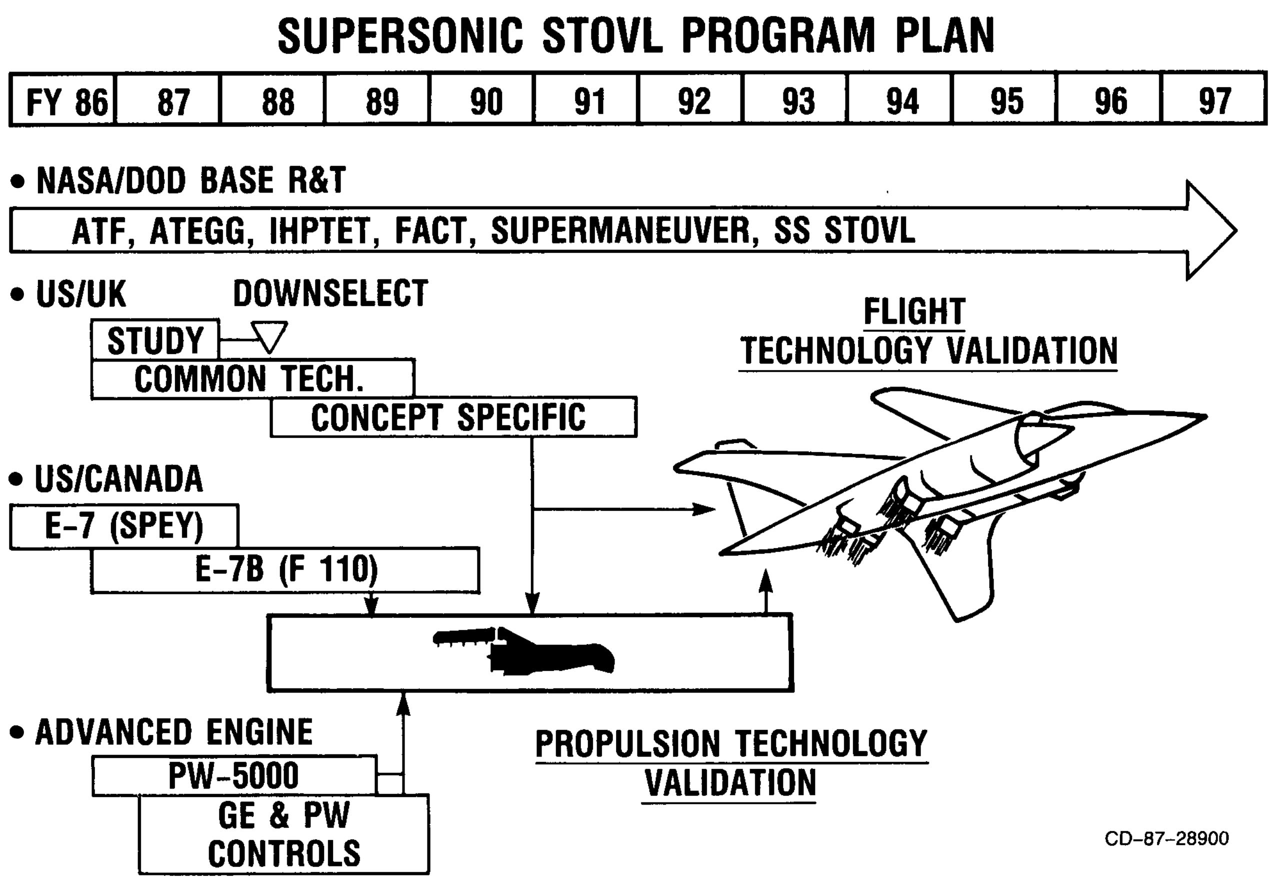
SUPERSONIC STOVL PLAN

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 STOVL capabilities in the post-ATF time frame (beyond the year 2000). As previously stated, propulsion is key to achieving this. With that in mind, an enabling plan was developed and is shown in the figure. 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 take place early in the 1990's. As shown, several of the research programs have already been initiated. These include the NASA and DOD on-going 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 detail) development efforts.



STOVL STUDY CONTRACTS

This figure presents a collage of the supersonic STOVL configuration study contracts currently in existence to generate the data necessary for the downselect process. This downselect process is now scheduled to begin early next year. Three propulsion system contracts, with General Electric (GE), Pratt and Whitney (PW), and Allison Gas Turbine (AGT) Division of General Motors, are being managed by Lewis. Also, four airframe contracts, with McAir, General Dynamics (GD), Grumman, and Lockheed, are being managed by Ames. 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 to 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.

STOVL STUDY CONTRACTS—FY87

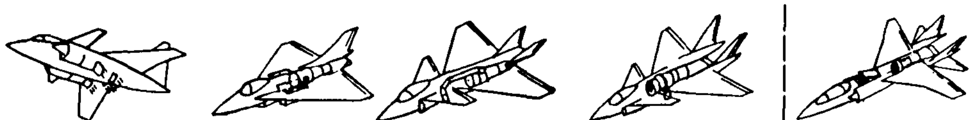
PROPULSION DATA BASE PREPARATION

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

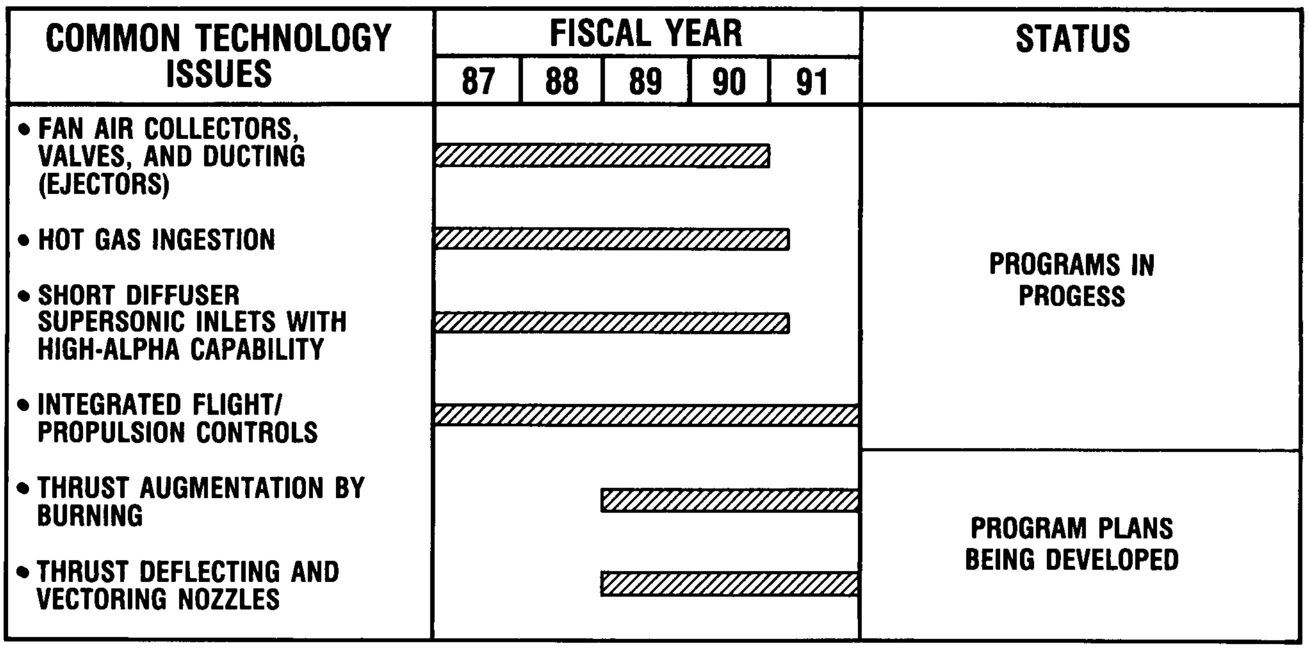
	McAIR	GD	GRUMMAN	LOCKHEED	McAIR
AMES AIRFRAMER CONTRACTS					
	VECT. THRUST	EJECTOR	RALS	TANDEM FAN	LIFT + LIFT/CRUISE
LEWIS/ENGINE CO.	P&W	GE	GE	ROLLS (P&W)	AGT
INTEGRATION TASKS	X	X	X	X	X



BASE PROGRAM

The current Lewis base R&T program elements for the supersonic STOVL are shown in the figure. As indicated, these elements are 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 are planned to begin shortly, as shown. Programs are already in progress for 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 systems. 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.

BASE PROGRAM



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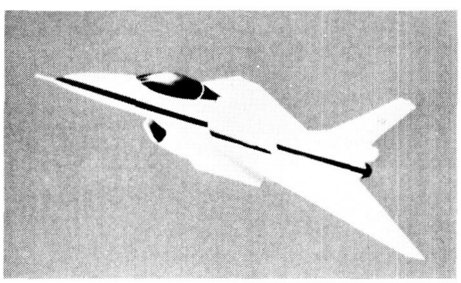
U.S./CANADA EJECTOR TECHNOLOGY

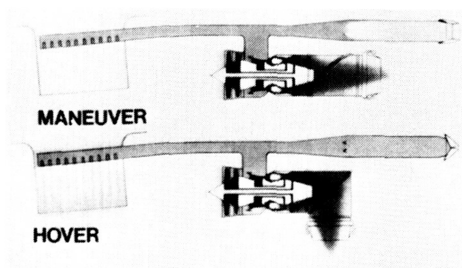
This figure is a collage of the various elements of the joint U.S./Canada ejector technology program. In this program, a full-scale model of the General Dynamics (GD) E-7 supersonic STOVL aircraft configuration will be tested in the Ames 40- by 80-foot wind tunnel. This aircraft incorporates the ejector augmenter propulsion concept to provide the required lift at takeoff and landing. The model will be tested with a complete engine system (first a Spey engine, then eventually with an F110). After the wind tunnel tests, the full-scale system components will be tested on the new Powered Lift Facility (PLF) at Lewis. Component performance tests can be run on this facility using high pressure (95 psig at 160 lb/sec) and high temperature (300 °F) combustion air for engine simulation. Both internal flow performance measurements and thrust performance can be determined on this facility. Eventually, testing with complete engine systems will be possible on the PLF. Results from the initial full-scale ejector tests on the PLF will be presented in the following figures.

US/CANADA EJECTOR TECHNOLOGY

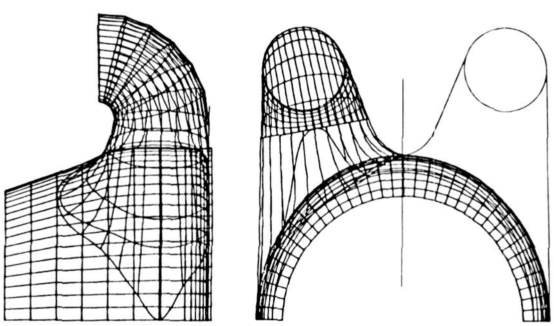
EJECTOR AIRCRAFT CONFIGURATION



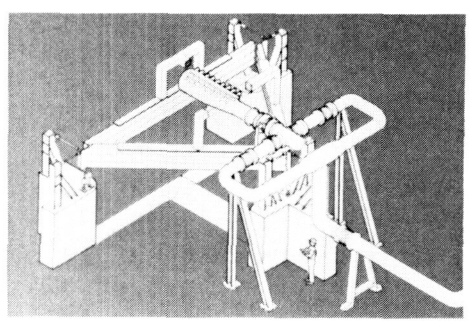
EJECTOR AUGMENTED LIFT SYSTEMS



FAN AIR COLLECTORS



POWERED LIFT FACILITY (PLF)



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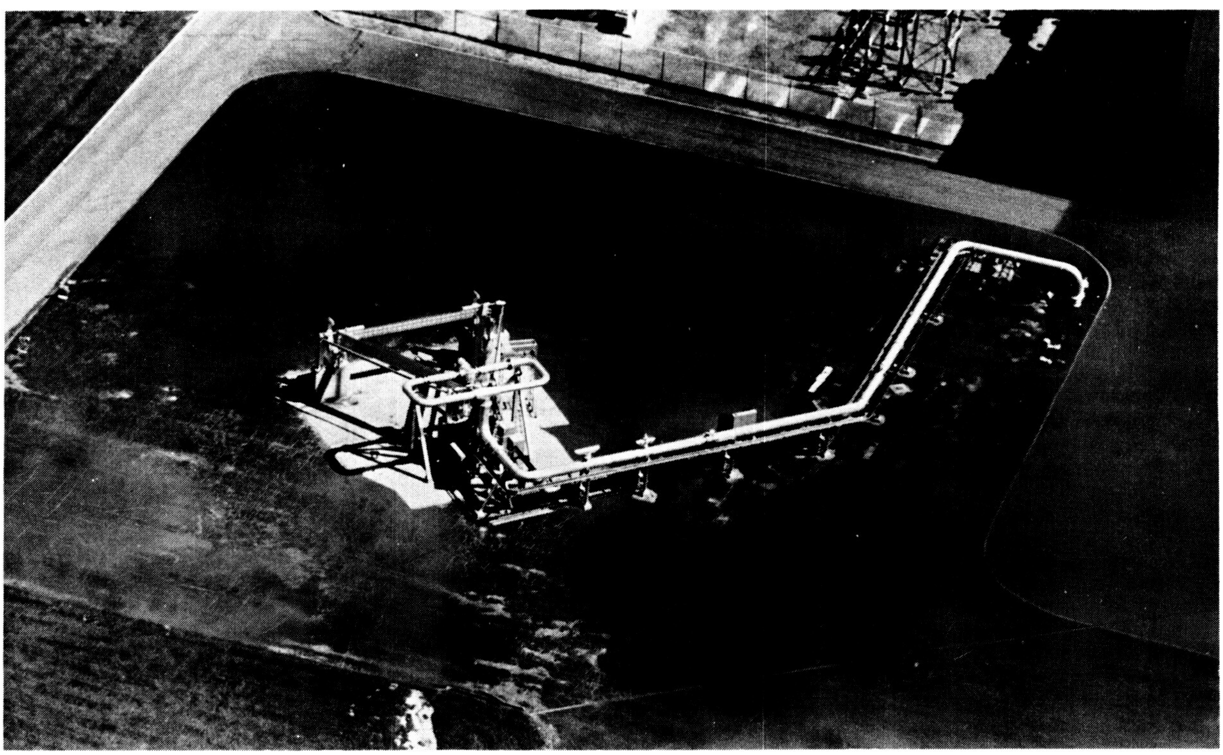
POWERED LIFT FACILITY

The Lewis Research Center's new Powered Lift Facility (PLF), shown in the figure, was designed and built to support testing of all the concepts being proposed. The system includes a large (30 ft on a side) triangular frame supported 15 feet off the ground. This frame is supported by load cells, thereby providing a six-component force measuring system. Vertical (20,000 lb), axial (30,000 lb), and lateral (5,000 lb) forces can be measured in plus and minus directions. High pressure (95 psig) and heated (to 300 °F) air, at flow rates up to about 160 pounds per second, can be supplied to the stand to simulate fan exit conditions. The high pressure air is brought onto the system through a series of bellows, oriented 90° to the force system, to minimize 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. Plans are now being developed to modify the PLF for complete engine system testing.

POWERED LIFT FACILITY



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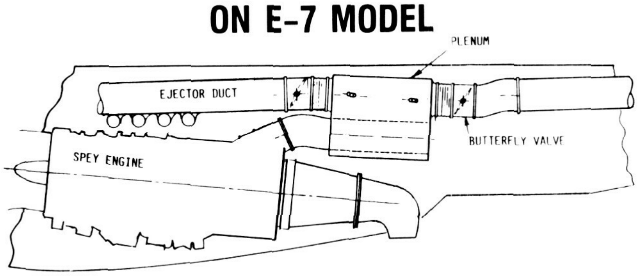
deHAVILLAND FULL-SCALE DUCT AND VALVE TEST

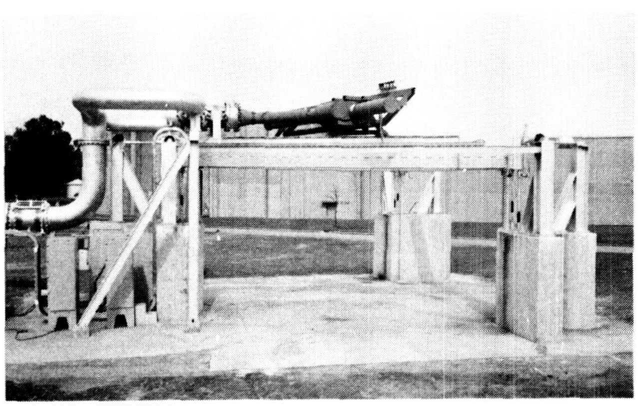
The first test on the new Powered Lift Facility (PLF) at Lewis was performed in September 1986. It included the full-scale internal fan flow ducting and valving scheduled to be installed in the full-scale GD E-7 aircraft model. A schematic of the installation on the aircraft model is shown in the figure. 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 to previous predictions (dashed curves). The test data show that the pressure losses were higher than predicted for the forward duct and lower than predicted for the rear duct. These results are expected to have minimal impact on the overall system performance.

deHAVILLAND FULL-SCALE DUCT AND VALVE TEST ON PLF

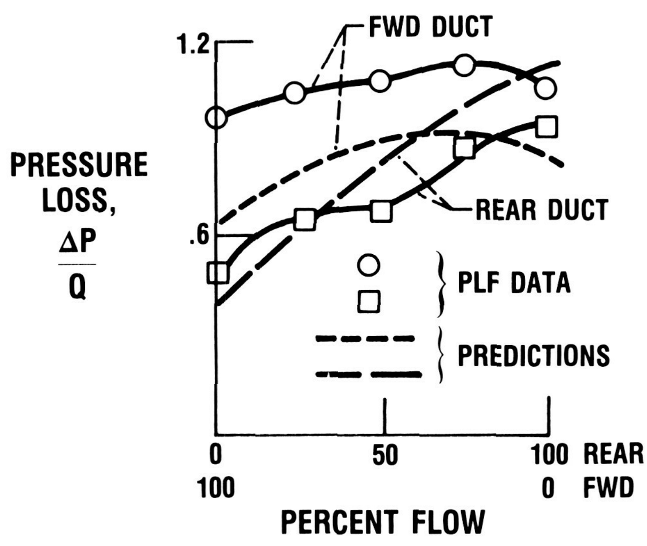
SCHEMATIC OF INSTALLATION ON E-7 MODEL



INSTALLED ON PLF



PRESSURE LOSS PERFORMANCE (SIM. FPR = 2.5)



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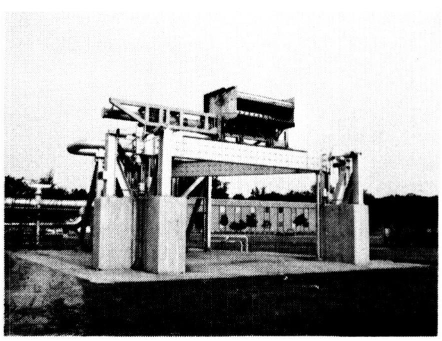
deHAVILLAND FULL-SCALE EJECTOR TEST ON PLF

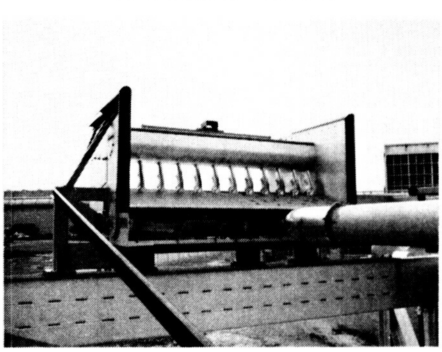
One half (side) of the full-scale ejector was attached to the system ducting and tested on the PLF in June 1987 for thrust performance. This figure includes an overall view of the model installed on the PLF and a closeup view. Preliminary thrust augmentation data are shown as a function of primary nozzle pressure ratio. The system design was for a thrust augmentation ratio of about 1.6 at a nozzle pressure ratio of 2.5. Previous deHavilland test results with another 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. This good agreement raises the confidence level for both the capabilities of the PLF and the feasibility of an ejector system as one of the viable concepts for a future supersonic STOVL.

deHAVILLAND FULL-SCALE EJECTOR TEST ON PLF

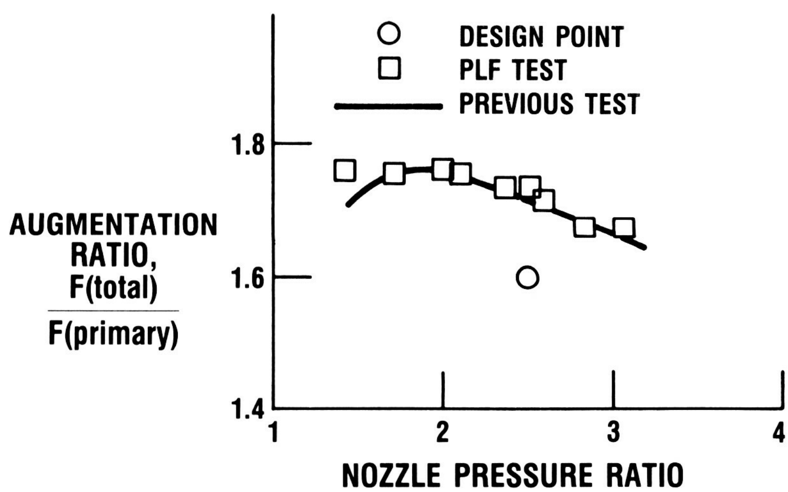
INSTALLED ON PLF



CLOSEUP VIEW



LIFT/THRUST PERFORMANCE



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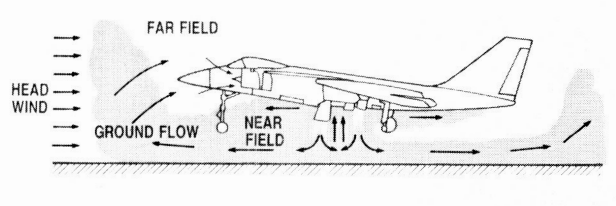
HOT GAS INGESTION (HGI)

Hot gas ingestion (HGI) will be a problem with all the proposed engine concepts. With the vectored thrust configuration, the problem results from the jet flow impinging upon the ground and (1) forming a fountain upwash 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 bouyancy (far field). This has already been a problem for the Harrier. 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 the problem.

HOT GAS INGESTION (HGI)

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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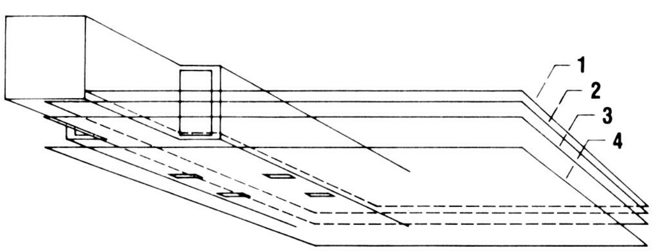
HGI ANALYTICAL RESULTS

An integral part of each of Lewis's programs includes analytical development. An example of where significant progress has been made is the program dealing with hot gas ingestion (HGI). Shown in the figure are preliminary results from calculations made using a 3-D 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. 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 provided an equivalent four-jet (vectored thrust), two-inlet configuration. 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 along with the corresponding outflows and interactions with the free stream. 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). Data from recent wind tunnel tests are being used to validate these results.

HOT GAS INGESTION

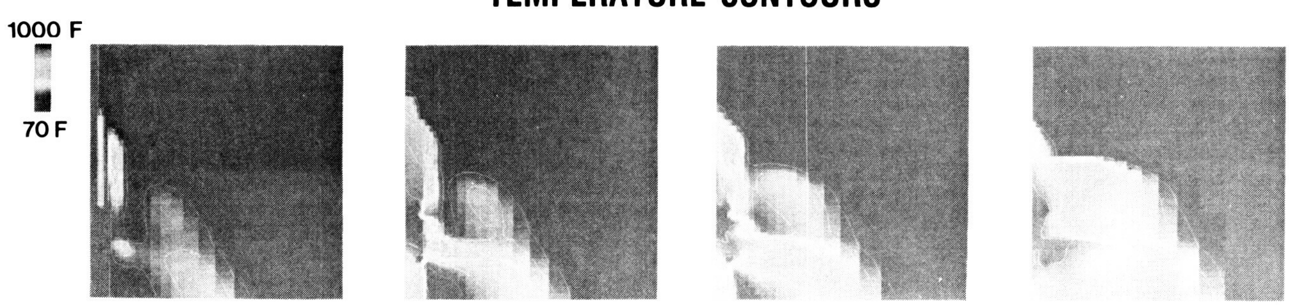


OBJECTIVE

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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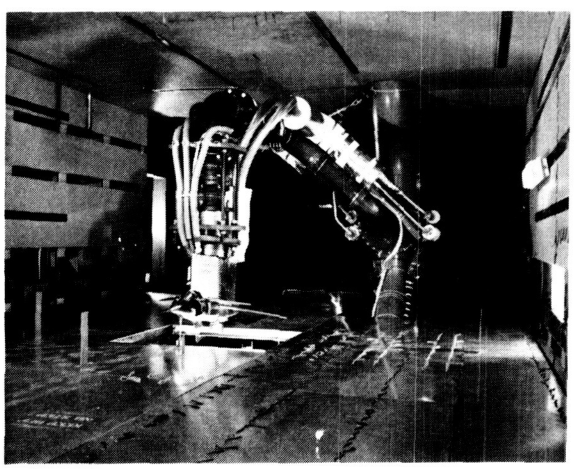
ONE-TENTH SCALE HGI MODEL

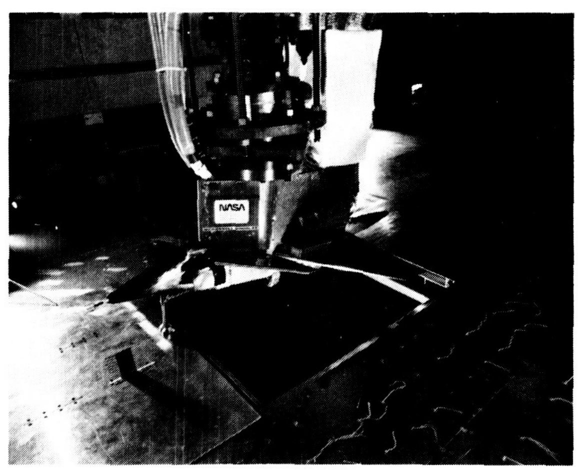
A 1/10 scale model of a McDonnell Aircraft Company (McAir) 279-3 supersonic STOVL aircraft configuration was tested in the 9- by 15-foot Low Speed Wind Tunnel (LSWT). This is a joint program between DARPA, NASA, and McAIR. The model is a four-nozzle, vectored-thrust configuration and includes high pressure, heated air (500 °F). Exhaust air provides inlet flow. Temperature and pressure rakes are included at the compressor face station to evaluate ingestion and determine distortion profiles. 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, 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 second and then data were taken.

ONE-TENTH SCALE McAIR 279-3 SUPERSONIC STOVL MODEL HOT GAS INGESTION (HGI) TEST IN LeRC 9- BY 15-FT WIND TUNNEL

MODEL INSTALLED IN TUNNEL



CLOSEUP VIEW



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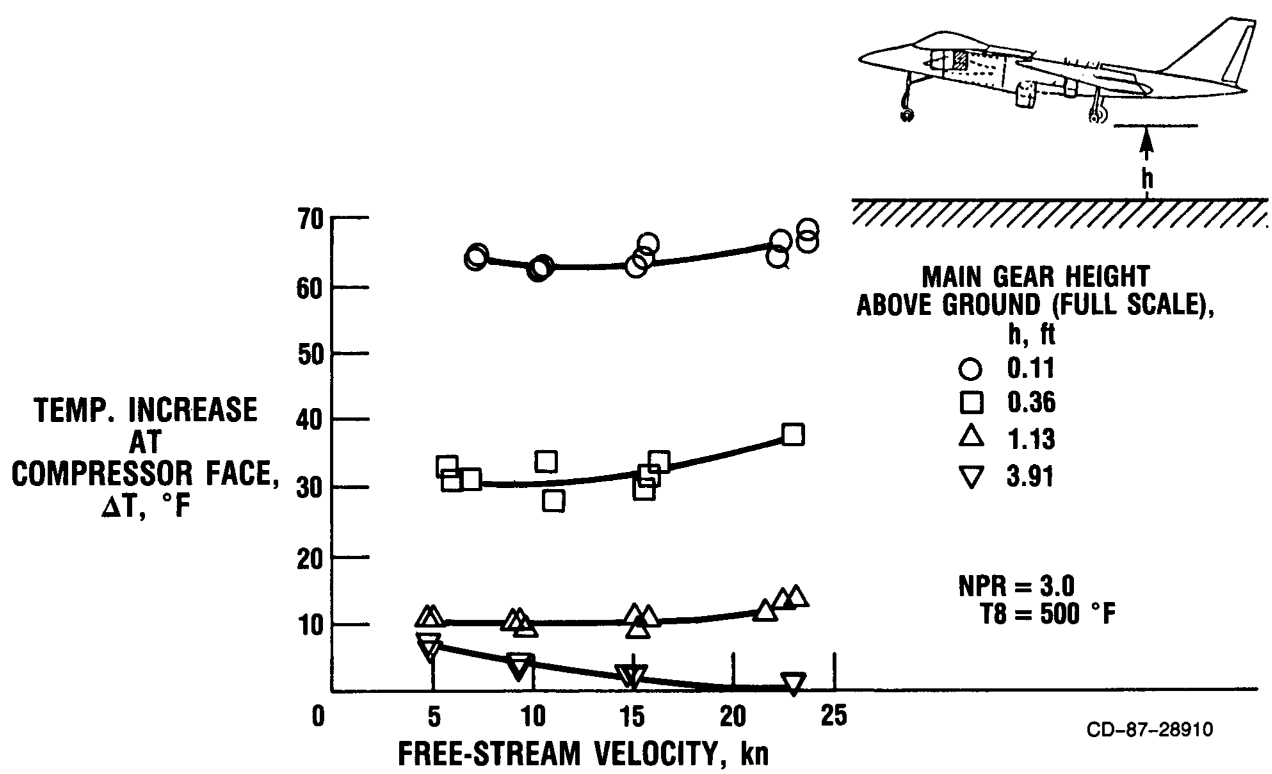
EFFECT OF GROUND PROXIMITY ON HGI

Preliminary results of the effect of model height on inlet temperature are shown. As seen, hot gas began to be ingested with the landing gear, scaled up to full scale, about 4 feet above the ground for these simulated model and tunnel flow conditions. To use the model temperature on a full-scale basis it has to be scaled up, in this case, by a factor of about 4, since the nozzle supply was only at 500 °F. Investigation of temperature scaling was a part of this investigation. Preliminary results indicate that for some conditions the predicted scaling factors were validated 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 develop possible solutions.

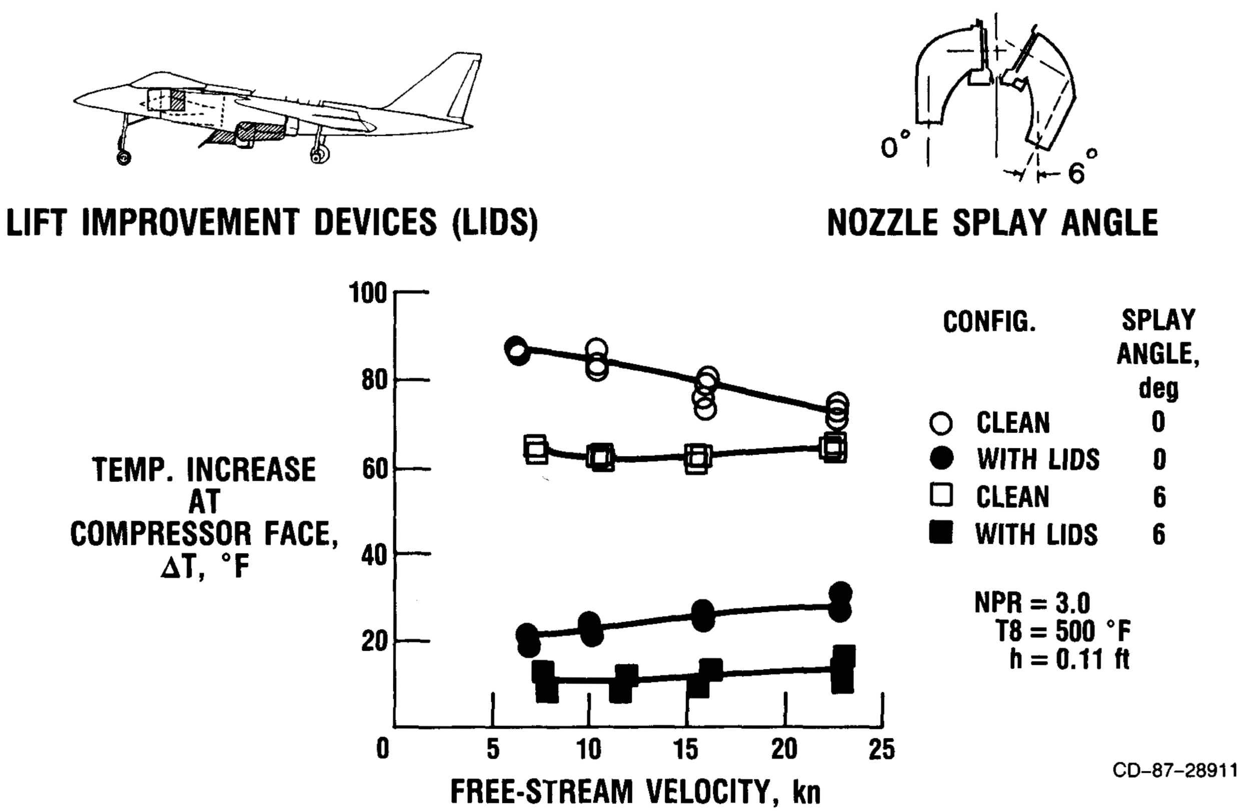
EFFECT OF GROUND PROXIMITY ON HOT GAS INGESTION (HGI) WITH BASIC 279-3 MODEL



EFFECT OF MODEL GEOMETRY ON HGI

The data shown indicate that model geometry seems to have a more significant impact on HGI then either tunnel or model flow conditions. As seen, hot gas ingestion can be significantly reduced if the proper flow diverter were added to the model. In the testing, a series of supposed lift improvement devices (LIDS) were used. 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. However, there are many possible solutions, but the effectiveness of each will vary with the individual geometry.

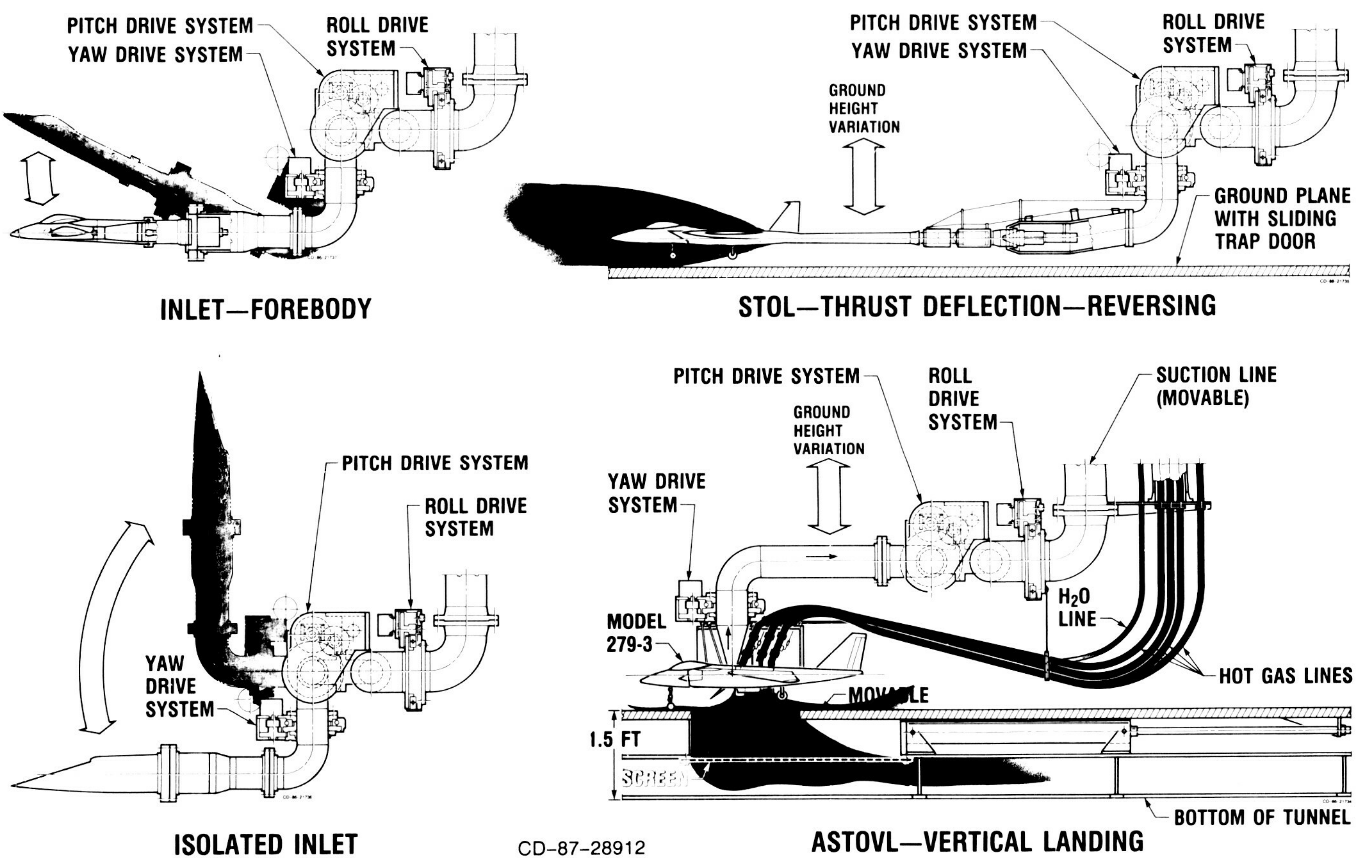
EFFECT OF GEOMETRY ON HOT GAS INGESTION (HGI)



MODEL INTEGRATED SUPPORT SYSTEM (MISS)

As shown previously, the 1/10 scale model was mounted in the test section from a relatively rigid support system. For future tunnel entries, a new model integrated support system (MISS) is currently being fabricated. This support will allow testing at increased temperatures (1000°F) and have 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.

MODEL INTEGRATED SUPPORT SYSTEM (MISS) FOR VERSATILE AND EFFICIENT RESEARCH TESTING

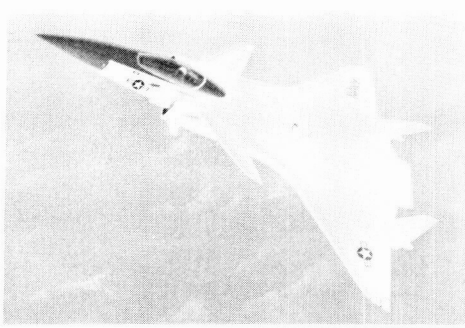


SUPERSONIC INLET WITH SHORT DIFFUSER

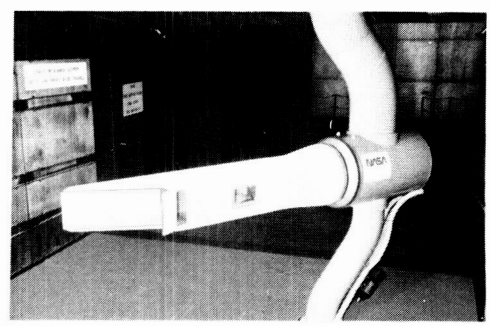
Conventional supersonic dash or cruise inlets have long diffusers which maintain well behaved, attached flows over wide ranges of aircraft angle of attack and attitude. The engine location in a typical supersonic STOVL may have to be moved forward for better weight and balance and to better locate the thrust vectors. This will then result in a problem for the diffuser design, particularly for operation at high angles of attack. A 2-D supersonic inlet model with a conventional-length diffuser was built and tested in the Lewis 9- by 15-foot Low Speed Wind Tunnel at angles of attack exceeding 100°. In these tests, variations in lip geometry and auxiliary inlets were investigated to improve angle-of-attack performance. Results of these tests show that good performance can be obtained even at the high angles of attack. A modification to this model has been designed and fabricated which includes a short diffuser more appropriate to STOVL configurations. Analysis has shown that this short diffuser will separate and have poor performance unless something is done to affect the boundary layer.

SUPERSONIC INLET WITH SHORT DIFFUSER

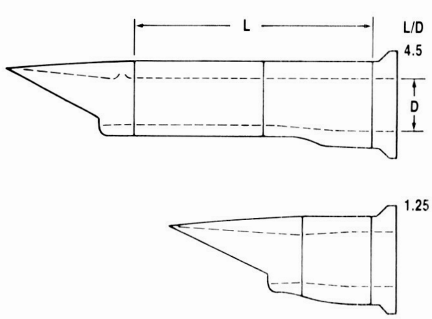
AIRCRAFT CONFIGURATION



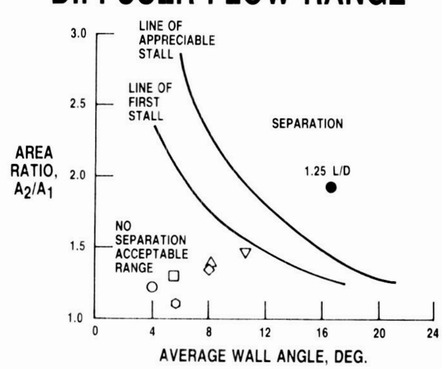
2-D SUPERSONIC INLET



DIFFUSER VARIATIONS



DIFFUSER FLOW RANGE



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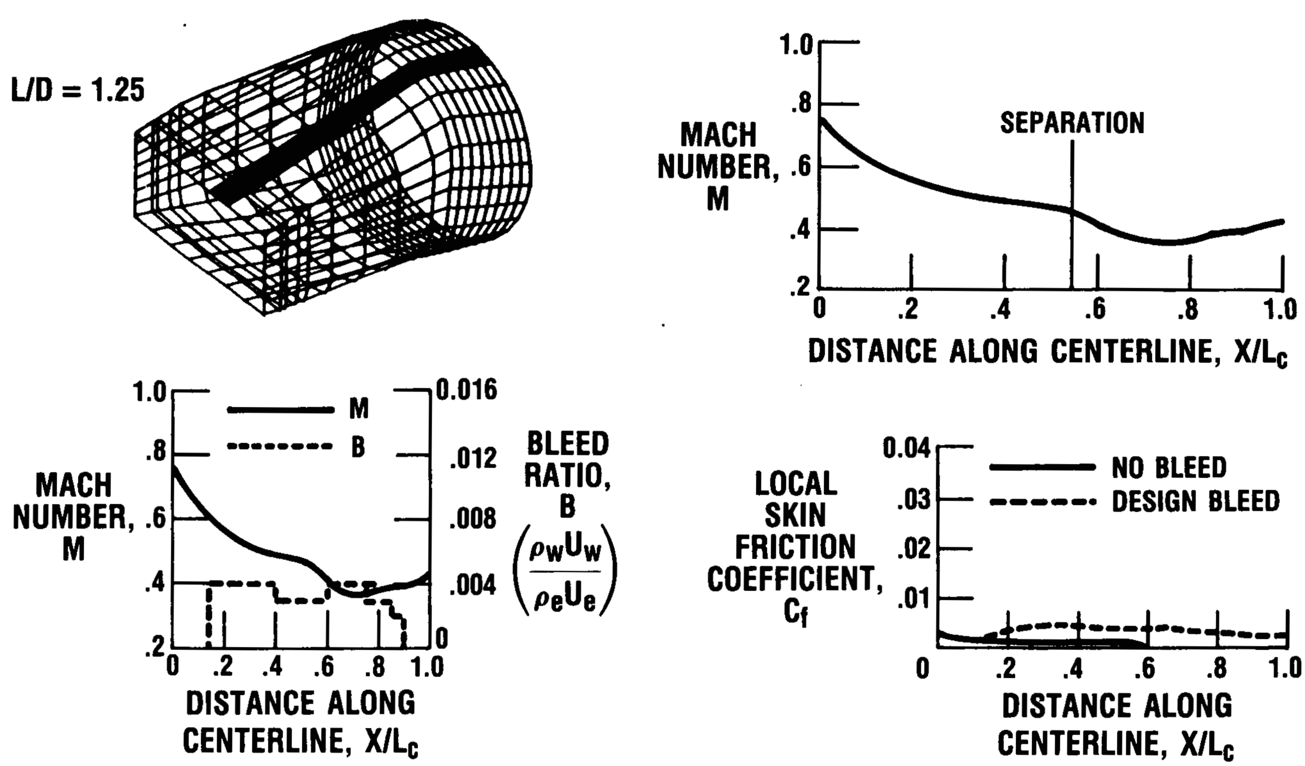
SHORT DIFFUSER ANALYSIS

An example of the analysis used in the design of the new short diffuser is shown in the figure. This analysis used a methodology, developed at Lewis, which incorporates blowing for separated boundary layer control in subsonic V/STOL inlets at high angles of attack. The methodology was adapted by McAir to include natural bleed. The short diffuser (L/D = 1.25) was designed without bleed using typical techniques including potential flow codes and 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 about halfway back. This is reflected also in the skin friction, which approaches zero near this station. Varying distributions of boundary layer bleed were then analyically applied until this separation was eliminated (also reflected in the skin friction calculation). This result was achieved with reasonable amounts of bleed. Analyses were also made with jet blowing, again with favorable results. As a result of this work, a short diffuser model was designed which permits 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-foot Low Speed Wind Tunnel. Data from these tests will be used to validate these analyses.

SHORT DIFFUSER ANALYSIS—EFFECT OF BLEED



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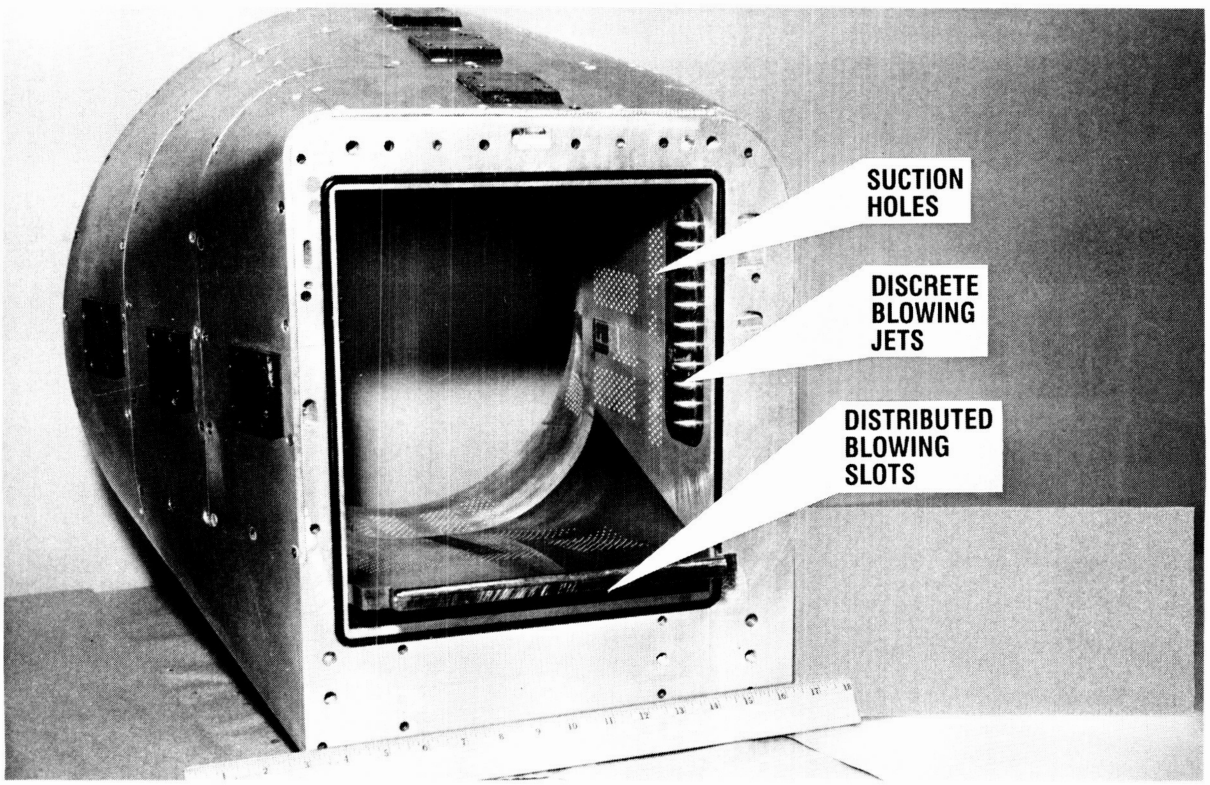
SHORT DIFFUSER MODEL

This is a photograph of the short supersonic diffuser model. The model includes suction holes of varying porosity and distribution, discrete blowing jets for energizing the boundary layer, and distributed slots for blowing. The model can use any of these systems individually or in combination. Additional devices can also be used (e.g., vortex generators). This diffuser will fit into the previously tested inlet model and will be tested in the Lewis 9- by 15-foot Low Speed Wind Tunnel. Data will again be obtained up to angles of attack exceeding 100°.

SHORT SUPERSONIC DIFFUSER MODEL



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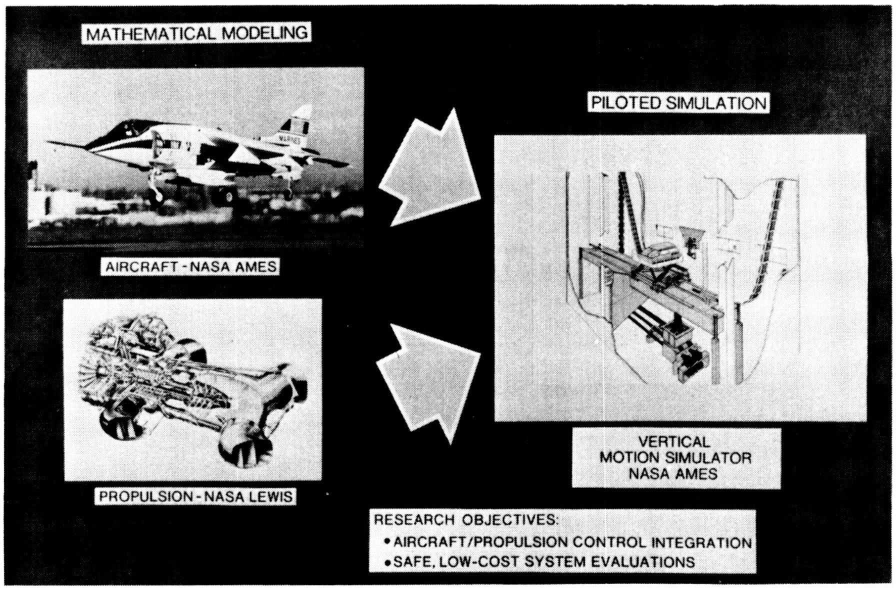
INTEGRATED FLIGHT/PROPULSION CONTROLS

One of the most difficult technology issues relative to supersonic STOVL will be integrated flight/propulsion controls. In the joint U.S./U.K. program, this was identified as being critical enough to be started immediately. A joint effort was immediately organized between NASA Ames and Lewis to develop the required technology. This collage 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 hybrid computer has been installed at Lewis to pursue the propulsion simulations. The goals 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.

STOVL SUPERSONIC AND SUPERMANEUVER PROPULSION TECHNOLOGY

INTEGRATED FLIGHT/PROPULSION SIMULATION AND CONTROLS



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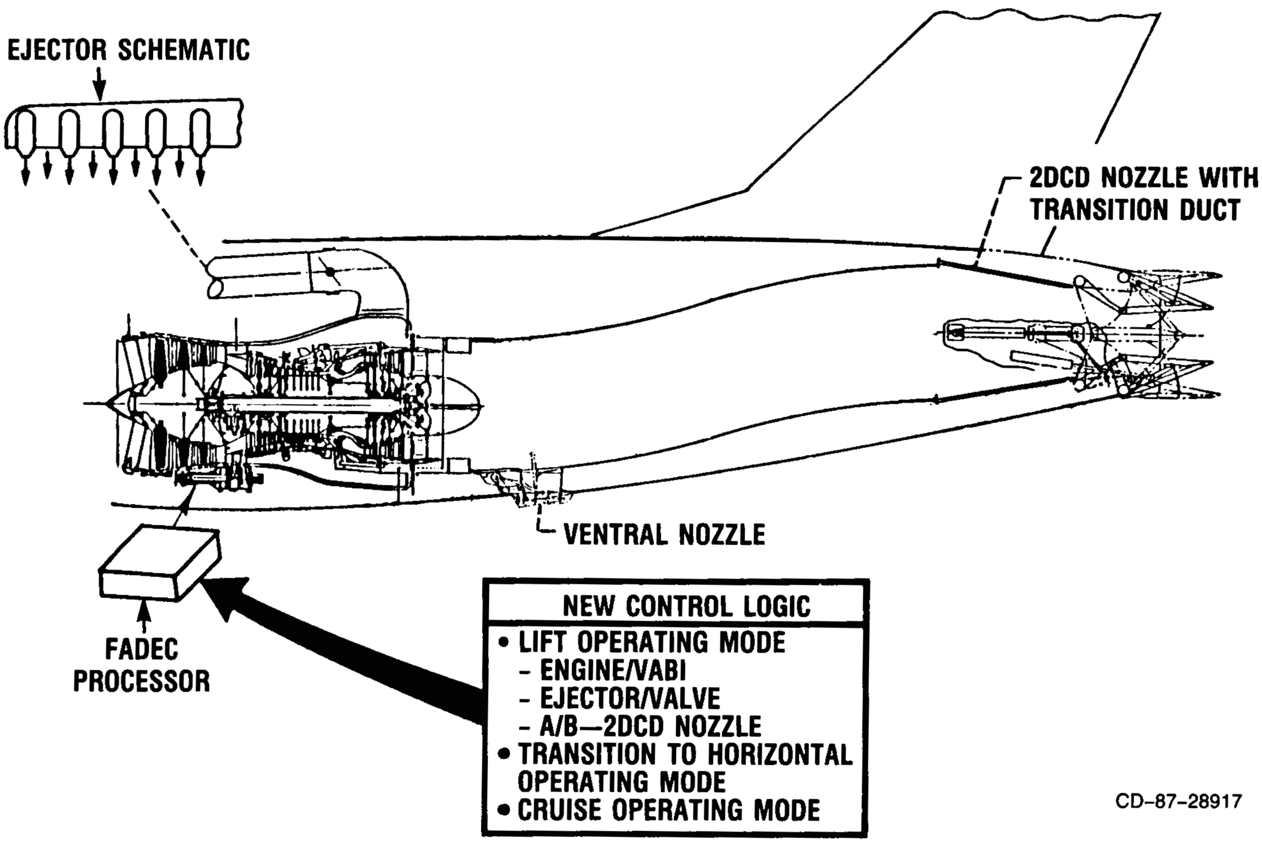
EJECTOR/CONTROLS CONFIGURATION

This figure is a schematic of the currently proposed ground engine and integrated flight/propulsion controls demonstration test. The configuration shown includes the GE F110 engine and ejector system which will be mounted on the Lewis Powered Lift Facility (PLF). The model will include a deflecting aft nozzle and a ventral nozzle for vertical thrust. The control computers will be fitted with the integrated control algorithms and a pilot station.

NASA/DARPA EJECTOR/CONTROLS CONFIGURATION



SUPERSONIC STOVL PLAN SUMMARY

In summary, a plan exists which will develop the required technology to allow the initiation of a research aircraft in the early- to mid-1990's. The interest seems to be there, as indicated by the involvement of three governments. The DOD is involved. The Air Force is already an active participant, and there is indication that the Navy will soon be involved. Successful studies and test programs are already in place and generating promising results.