ASTOVL

NASA Lewis Research Center

HOT GAS INGESTION: FROM MODEL RESULTS TO FULL SCALE ENGINE TESTING

BY

ALBERT L. JOHNS AND THOMAS J. BIESIADNY
NASA LEWIS RESEARCH CENTER

AND

L. L. PAGEL
MCDONNELL AIRCRAFT COMPANY

GROUND EFFECTS WORKSHOP
NASA AMES RESEARCH CENTER

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This presentation is an overview of a joint NASA Lewis-McDonnell Aircraft Company Hot Gas Ingestion (HGI) test program in NASA Lewis' 9'x15' Low Speed Wind Tunnel (LSWT). This initial program is scheduled for testing in late 1986.

Advanced short takeoff/vertical landing (ASTOVL) aircraft capable of operating from remote sites, damaged runways, figure 1, aircraft carriers (figure 2) and small air capable ships are being pursued for deployment around the turn of the century. To achieve this goal, it is important that technologies critical to this unique class of aircraft be developed, ref. 1. One of the ASTOVL concepts, the vectored thrust, has as its critical technology item, the potential of hot gas ingestion (which occurs during vertical flight operation while in ground effect) as a key development issue. Recognizing this need, NASA Lewis Powered Lift Section and McAir have defined a cooperative program for testing in the Lewis' 9'x15' LSWT.

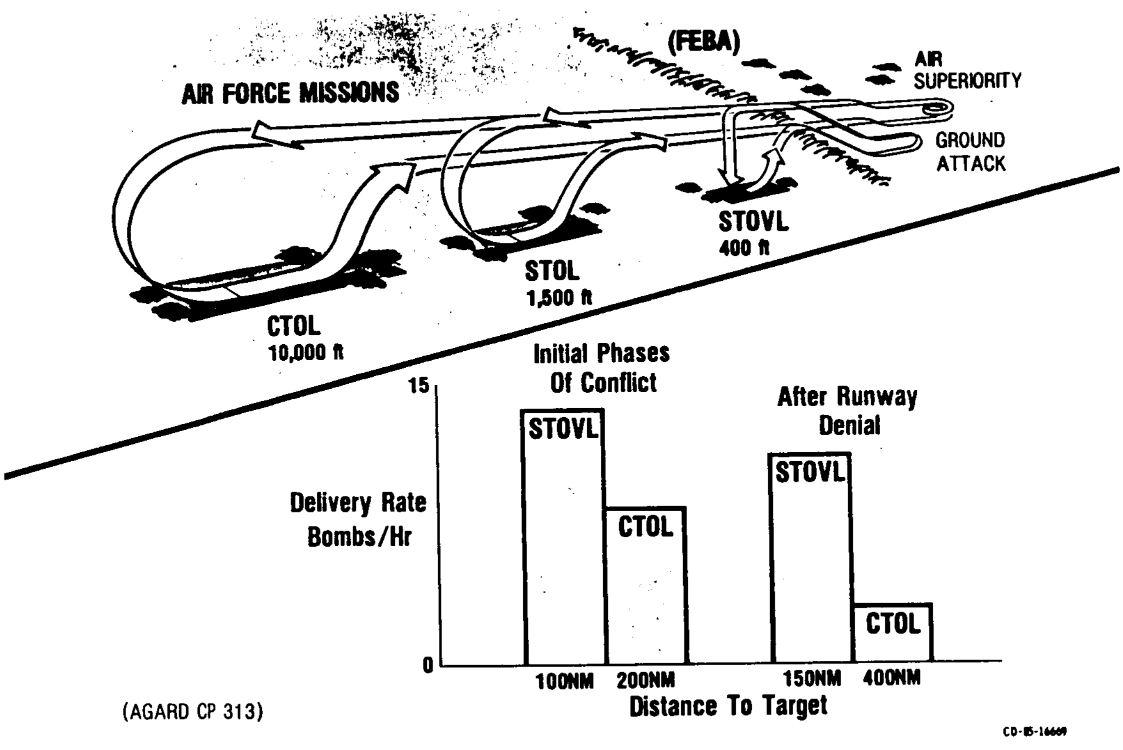

Figure 1.-STOVL improves Air Force operational effectiveness.

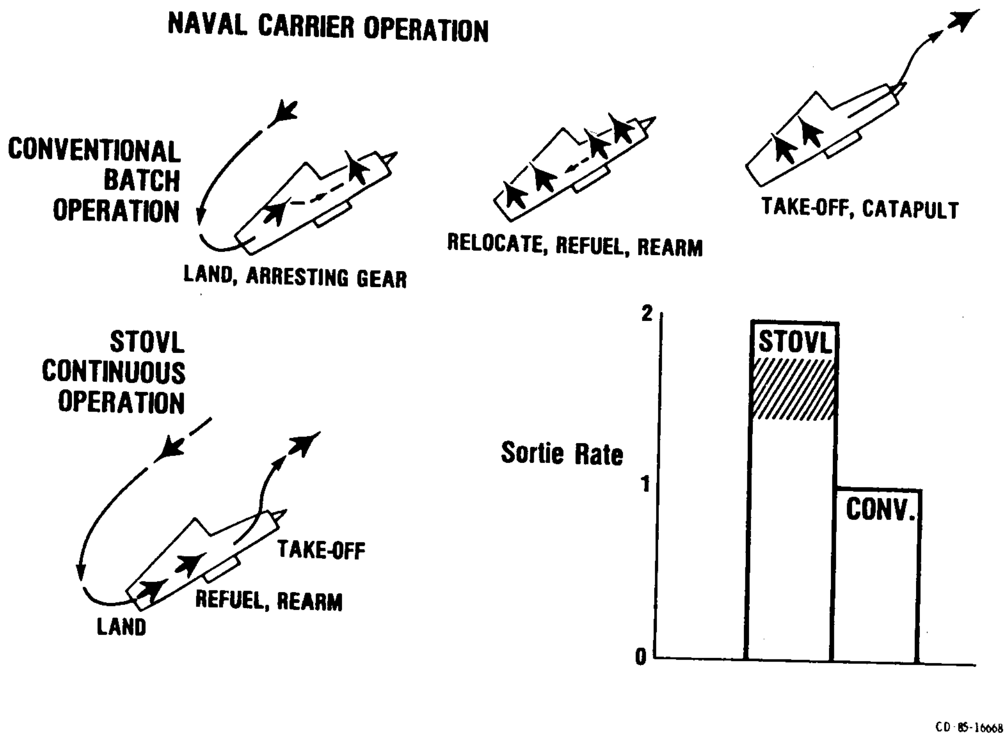

Figure 2. - STOVL improves Naval carrier operational effectiveness.

An artist's conceptual view of the vectored thrust concept (Model 279-3) is shown in figure 3. The aircraft concept consists of:

1. single engine;
2. bi-furicated inlet;
3. VTOGW 30,000 lbs;
4. M Max. = 2.0;
5. Four nozzles - two forward and two aft

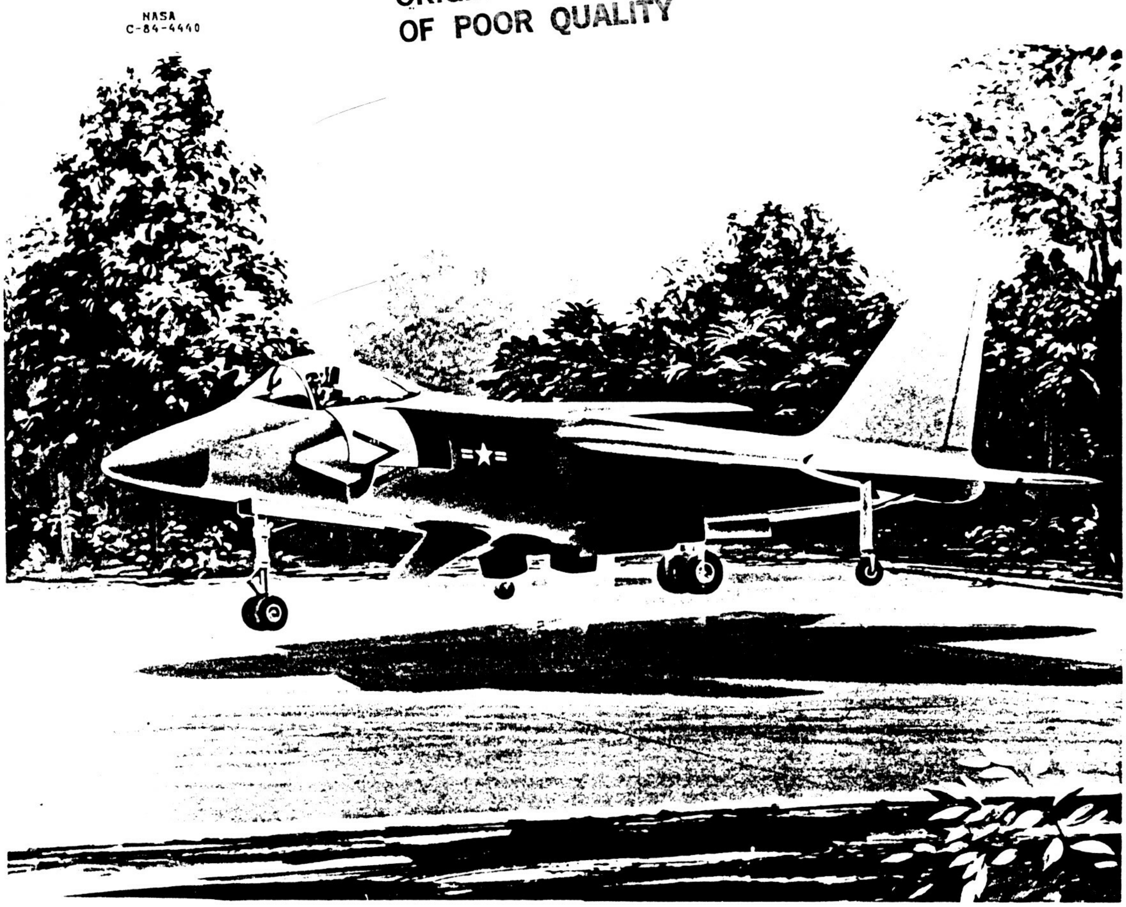

Figure 3. - Model 279-3 with improved LIDs and deflector.

The two front deflector nozzles will be required to accommodate burning of the fan airflow. The two aft deflector nozzles will control the core airflow. The concept may also have the following:

1. front flow deflector;
2. sidewall deflectors (streaks)

The testing of this vectored thrust concept requires a unique model support system and modification to the 9'x15' LSWT test section.

The next figure (4) shows a schematic of the 9.2% scaled Model 279-3 installed in the 9'x15' LSWT with the unique model support system. The model support system provides four degrees of freedom: Vertical movement, yaw, pitch, and roll capabilities. The vertical movement range is four feet above the ground plane; yaw angle range is $\pm$ 180°; pitch angle range is $\pm$ 30°, and the roll angle is $\pm$ 20° range. Another feature shown in figure 4 is the: Ground plane which has a sliding trap door.

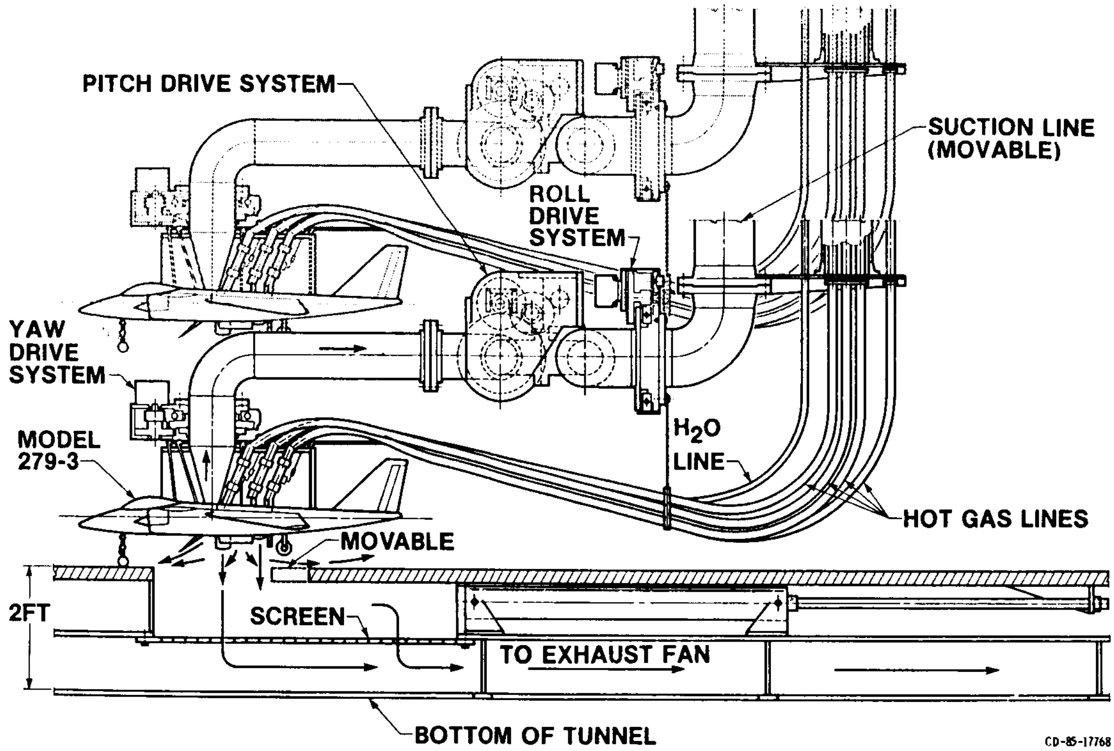

Figure 4.-Schematic of model 279-3 and support system installed in the 9'X15' LSWT.

We have built in flexibility in this program. The aircraft inlet airflow is controlled independently of the nozzle airflow. The inlet airflow is controlled by a vacuum system and the nozzle airflow is supplied by a high pres sure-hot air system, with temperature ranging from ambient to 1000°F at the nozzles. The freestream velocity will vary from static to 65 kts.

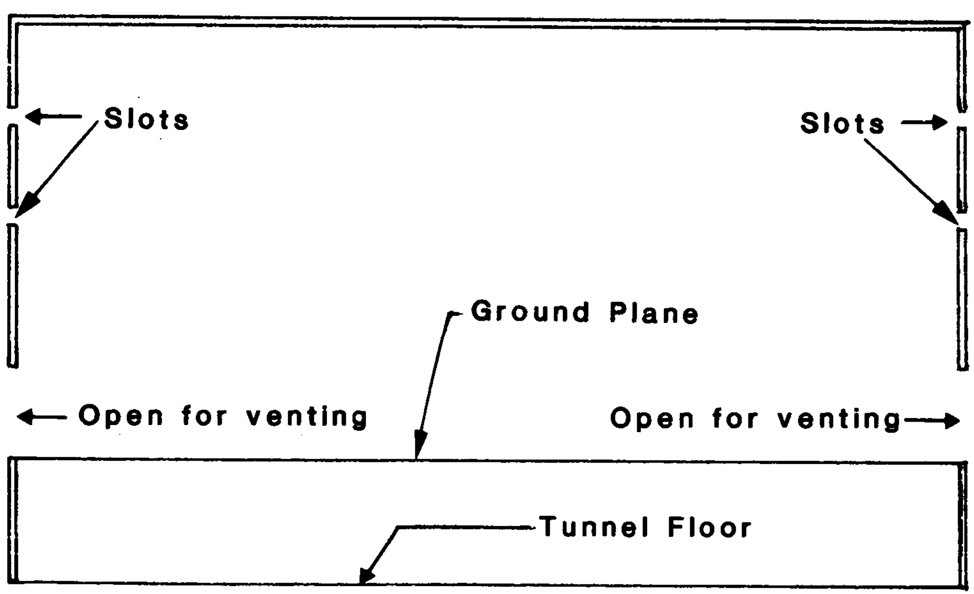

Figure 5. - Modified 9'X15' Low Speed Wind Tunnel.

A cross-section of the 9'x15' LSWT is shown in figure 5. The 9'x15' LSWT has slotted sidewalls test section. The tunnel sidewalls will have an opening near the ground plane to allow the laterally-flowing hot gas from the exhaust nozzles to exit the test section.

THE PRIMARY OBJECTIVES OF THIS COOPERATIVE PROGRAM ARE TO INVESTIGATE TECHNIQUES WHICH WILL:

- o MINIMIZE/ELIMINATE HOT GAS REINGESTION DURING VERTICAL FLIGHT OPERATIONS WHILE IN GROUND EFFECTS.
- o PERMIT PREDICTION OF OPERATING CHARACTERISTICS OF VECTORED THRUST CONCEPTS WITH FORWARD VELOCITY.

IN ADDITION, THE TEST PROGRAM WILL ESTABLISH A WIND TUNNEL HOT GAS INGESTION DATA BASE FOR:

- o BOTH NEAR/FAR FIELD INGESTION
- o FOUNTAIN FLOW EFFECTS, AND
- o GROUND VORTEX FLOW FIELD.

THE DATA BASE DEVELOPED SHALL BE APPLICABLE TO THE DEVELOPMENT OF UNIQUE ANALYTICAL CODES.

Figure 6.–Primary objectives.

The program objectives are shown in figure 6. In addition to the primary objectives, we shall establish a database in several needed areas, one of which is the ground-vortex-flow-field-jet interaction. The objective is to answer the question of what effect, if any, the boundary layer thickness has on the ground-vortex-flow-field-jet interaction.

The figures which follow are used to indicate the type of data parameters we will investigate. The trends shown on the figures are considered typical.

The results of the boundary-layer study, figure 7, will indicate the forward extent of the ground vortex flow field-jet interaction due to the boundary-layer thickness.

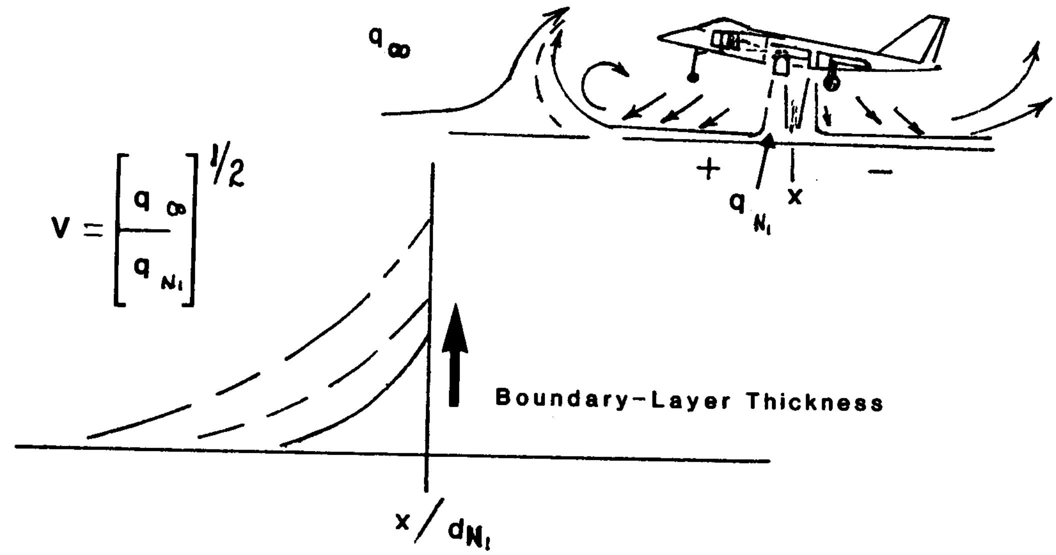

Figure 7.-Boundary-Layer thickness effect on the ground vortex flow.

Shown in figure 8 is a means of thickening the boundary-layer. Shown is a boundary-layer thickness configuration which consists of 1/4" dia. rods in four rows. The rods would extend the width of the ground plane. Several configurations could be utilized; for example, 3" height rods or 6" height rods, to obtain several different boundary-layer heights.

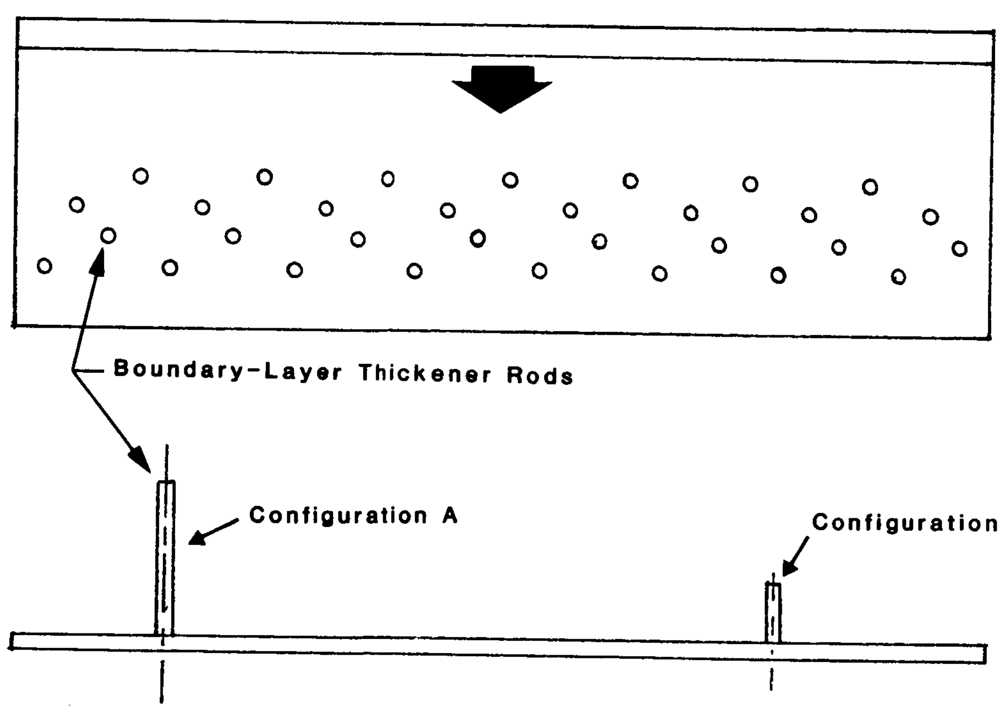

Figure 8.-Boundary-Layer Thickeners.

In addition to controlled thickening the boundary-layer, we also need to minimize the boundary-layer height due to axial distance. Figure 9 showns two methods of reducing the boundary-layer height. We have considered three techniques; a rotating belt was considered but was eliminated due to complexity and the temperature environment involved (1000°F). As shown, another concept involves using a suction pump(s), which is located outside of the test section. The suction pump(s) would remove part or all of the boundary-layer. The least concept involves lowering the front section of the ground plane. This technique would relocate the initial boundary-layer growth point. Prior to the use of either of these concepts, we shall have established the extent of the ground vortex flow field on the ground plane.

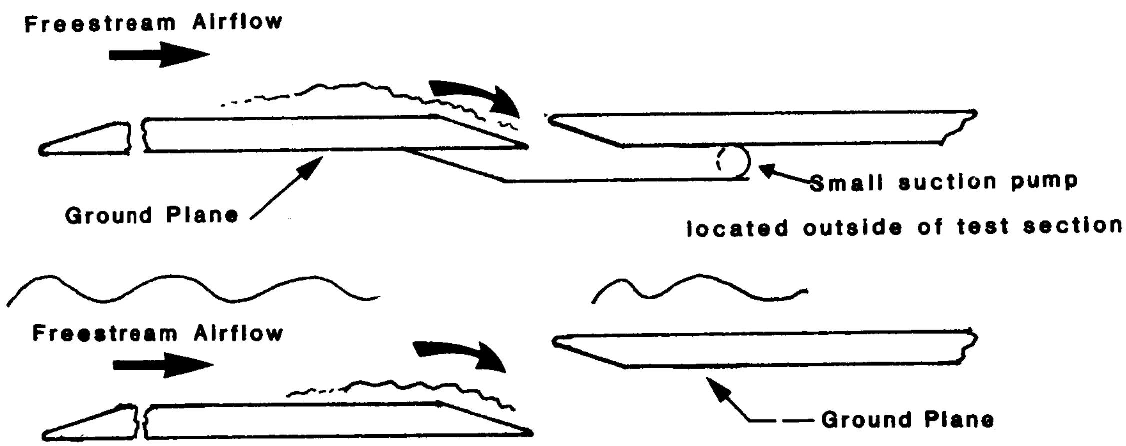

Figure 9.-Boundary-layer removal configurations.

One mechanism for near field ingestion is the jet fountain. If the velocity of the fountain or turbulence intensity is reduced, the effects of the near field ingestion will also be reduced. A means of reducing the fountain velocity and turbulence is to vary the front nozzles splay (laterally movement of the front nozzle) angle. It is anticipated that results will show a reduction in both fountain jet velocity and turbulence intensity with increasing splay angle, as shown in figure 10.

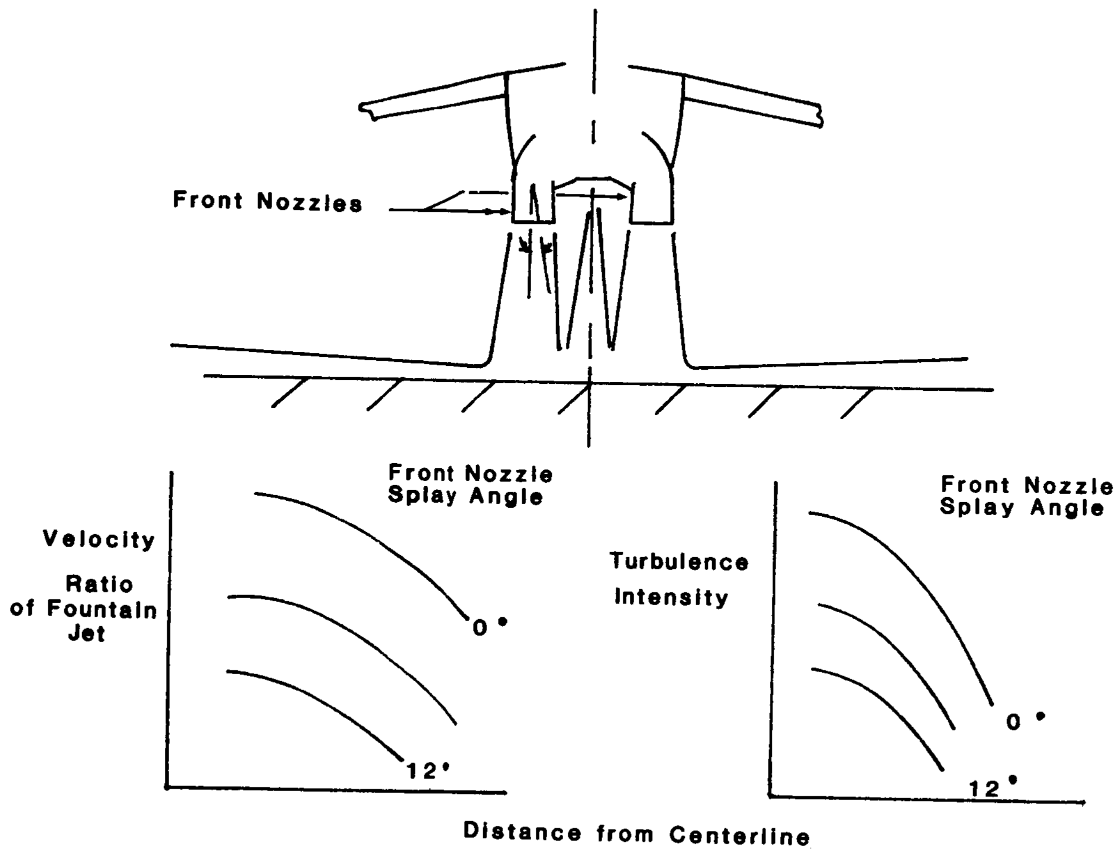

Figure 10.–Fountain turbulence and velocity.

Figure 11 illustrates the various configurations we will test to obtain the fountain flow characteristics. Shown is a schematic of four nozzle arrangements and the auxiliary inlets. The first configuration is Model 279-3 concept with both sets of nozzles flowing. The second configuration consists of only the front nozzles flowing. The third configuration consists of only the aft nozzles flowing. And the fourth configuration simulates a twin engine aircraft with one engine out. The jet temperature range is interchangable between the front and aft nozzles. These configurations will produce considerable information on the ground-vortex-boundary-layer-interaction.

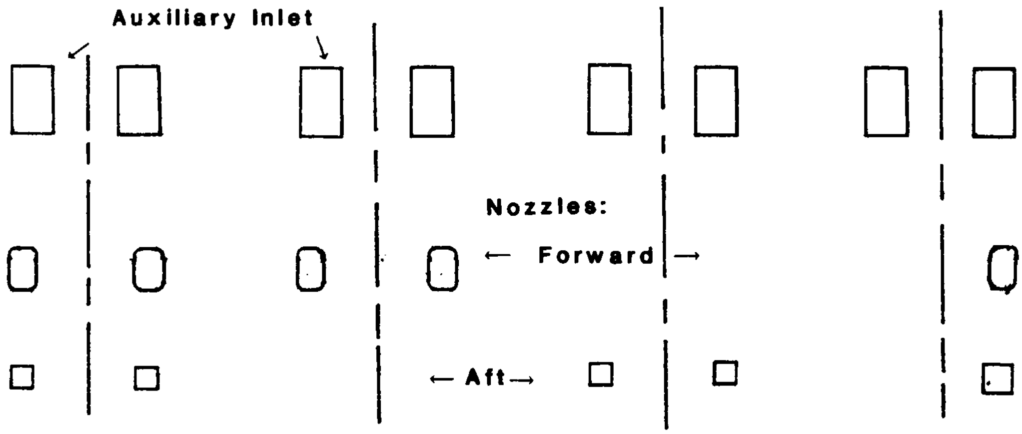

Figure 11.-Model deflected jet configurations.

Addressing the primary objectives of this joint NASA Lewis-McAir program, the major concern is hot gas ingestion in both the near and far field. In determining the effectiveness of the ingestion avoidance devices (IADs) for near field ingestion, the inlet temperature rise v.s. nozzle exhaust temperature will be plotted as shown in figure 12. Results from the configuration without IADs will be compared to a configuration with IADs. In general, a reduction should occur with ingestion avoidance devices.

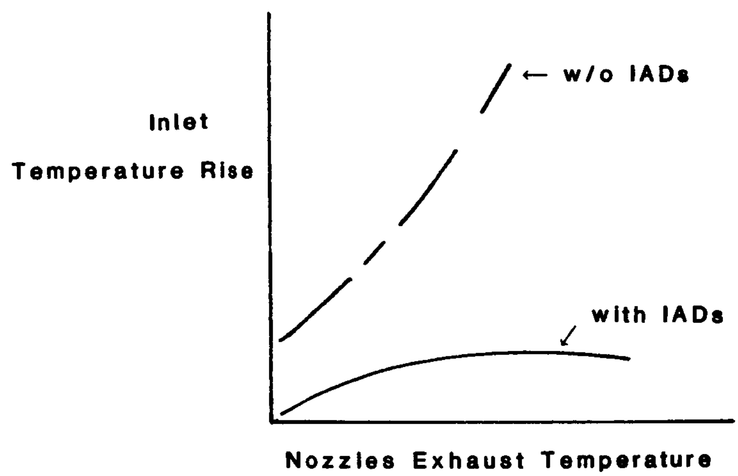

Figure 12.-Effectiveness of ingestion avoidance devices in reducing inlet hot gas ingestion.

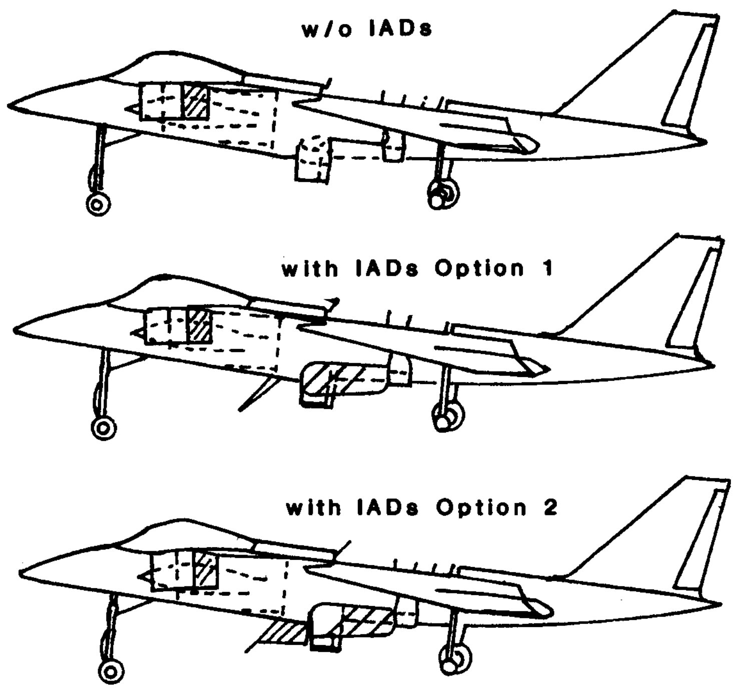

Figure 13. – Near field ingestion avoidance devices (IADs).

Figure 13 shows the three primary configurations:

1. without IADs,
2. with IADs, option 1: flow deflector and congitudinal streaks (2) installed,
3. with IADs, option 2: flow deflector and congitudinal streaks (2), aft fence and flow deflection sidewall (2) installed.

These configurations will be tested with the auxiliary inlets in the open and closed positions.

In addition to the near field, data applicable for determining the far field ingestion effect will also be obtained.

Pressure/temperature rakes are located on the ground plane (forward and aft of the model), figure 14. Also tufts will be located on the ground plane to give an indication of the far field airflow movement. The ground plane will contain static pressure and temperature taps. A thermo-vision system will be utilized to detect the most forward point of the hot gas at the various freestream speeds.

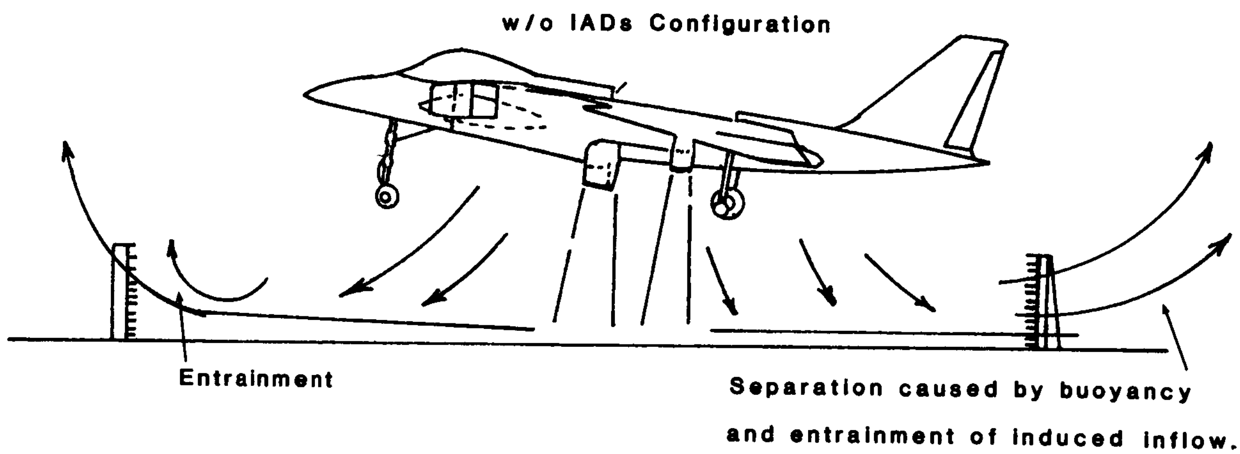

Figure 14. - Far field ingestion.

In the next several figures we shall briefly review some of the instrumentation to be utilized during the test.

Figure 15 illustrates several of the rakes installed on the model. They are as follows:

1. Nose boom rake which is used to measure the local freestream conditions.
2. Inlet plane undersurface rake which is used to measure the quality of air entering the inlet region.
3. Fountain upwash rake will measure the upwash flow characteristics.

The rakes contain both total pressure and temperature measurements.

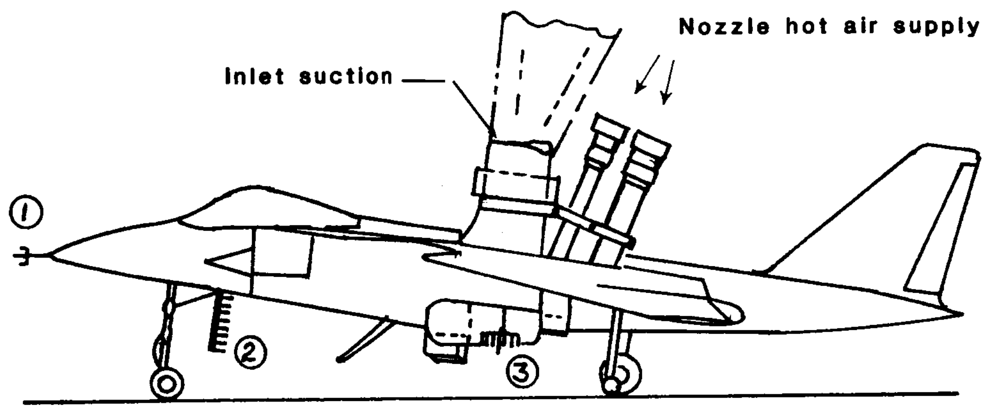

Figure 15. - Model 279-3 external instrumentation rakes.

In addition to rake instrumentation, static pressure taps and high response thermocouples are located along the bottom and sides of the fuselage, as can be seen in figure 16. Using the fuselage instrumentations, we should have a good indication of the thermo-profiles along the fuselage.

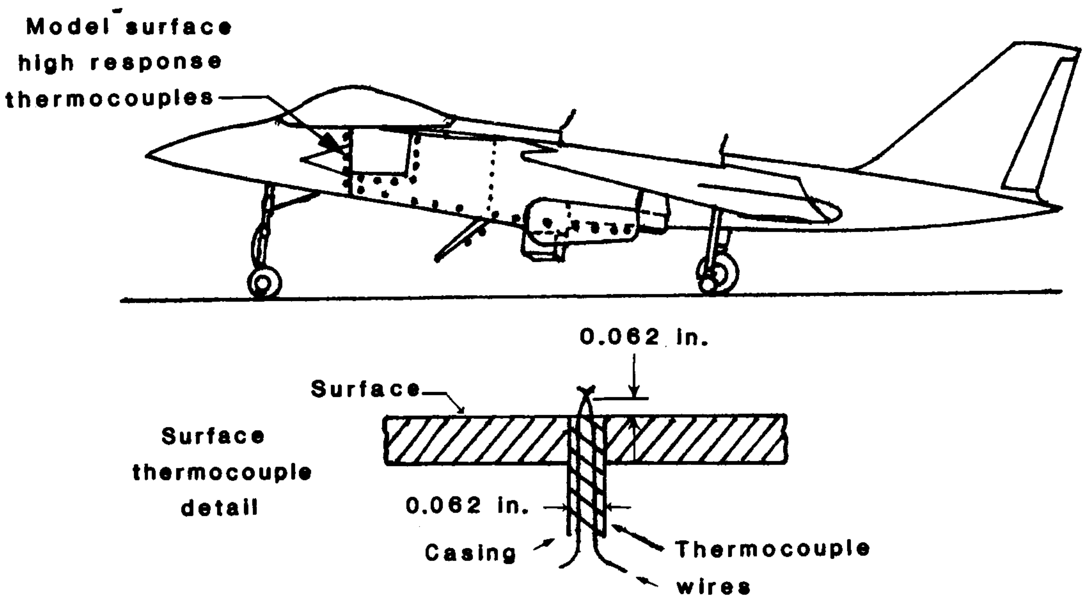

Figure 16. - Typical fuselage instrumentation.

Another major region of concern is the inlet. We need to know what effects inlet temperature rise has on the fan face Mach number rise. Figure 17 shows what might be a typical plot of inlet temperature rise vs inlet fan face Mach number. That is, the inlet temperature rise reaches a plateau at some fan face Mach number. This particular curve is a function of the model height above the ground plane.

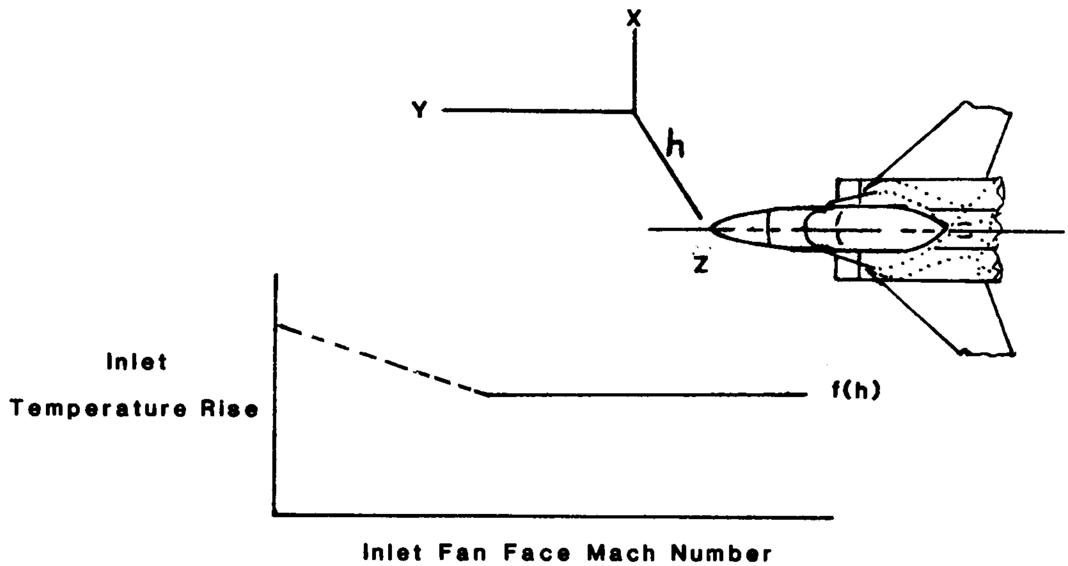

Figure 17. – Inlet fan face temperature rise.

Typical model inlet and nozzle instrumentations are shown in figure 18. The nozzles contain total pressure and temperatures probes. The engine fan face rake will also contain 32 total pressures and temperature measurements. To determine the severity of the hot gas ingestion, the inlet temperature rise and contour maps will be obtained utilizing the fan face rake. A typical contour map of a fan inlet instantaneous temperature profile is shown in figure 19.

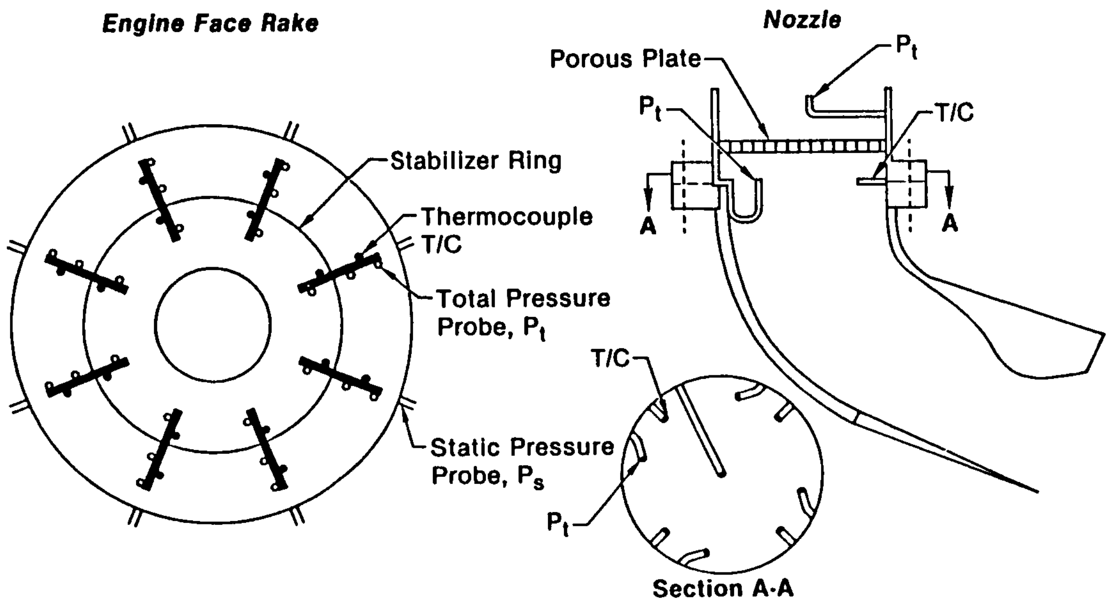

Figure 18. - Typical model inlet and nozzle instrumentations.

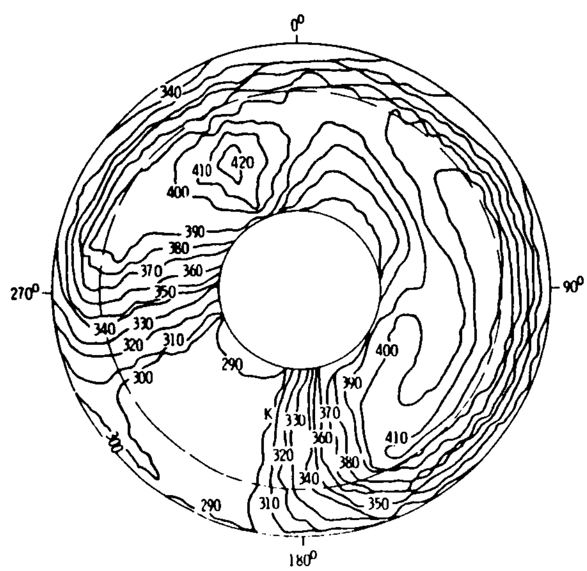

Figure 19. - Contour map of the fan inlet temperature profiles.

At the conclusion of the 9'x15' LSWT test, we will have pressure/temperature contour maps at the fan face for various freestream velocities and model attitudes. But what we would like to ascertain as an end item is the effect the hot gas ingestion has on the actual engine.

We anticipate, as a follow-on program, using both the pressure and temperature distortion profiles from the 9'x15' LSWT program and implement these into a full scale engine program. This full scale testing would establish the characteristics of the engine sentitivity due to the temperature, pressure and a combination of temperature-pressure distortion. At NASA Lewis Research Center, we have an altitude test chamber (PSL) in which we do full size engine testing. Figure 20 shows a view of the Altitude Test Chamber with a TF-34 engine installed. This facility's altitude simulation range from sea level to 100K feet.

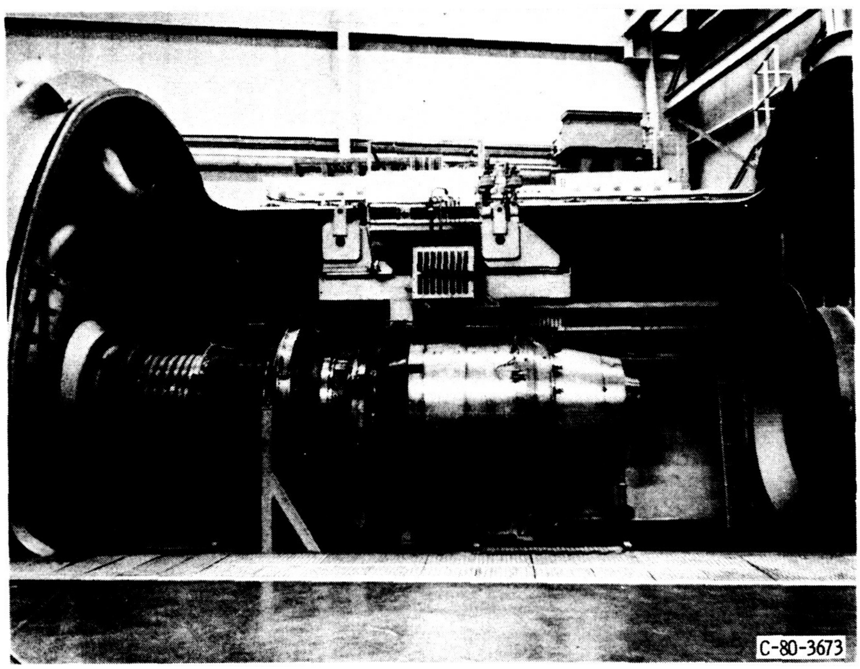

Figure 20. - TF-34 engine installed in the Altitude Test Chamber.

Figure 21 illustrates the extent of typical engine instrumentation. The instrumentation consisted of steady-state and dynamic total pressures, static pressures, and total temperature measurements. Transient total temperature and high-response pressure data are also recorded.

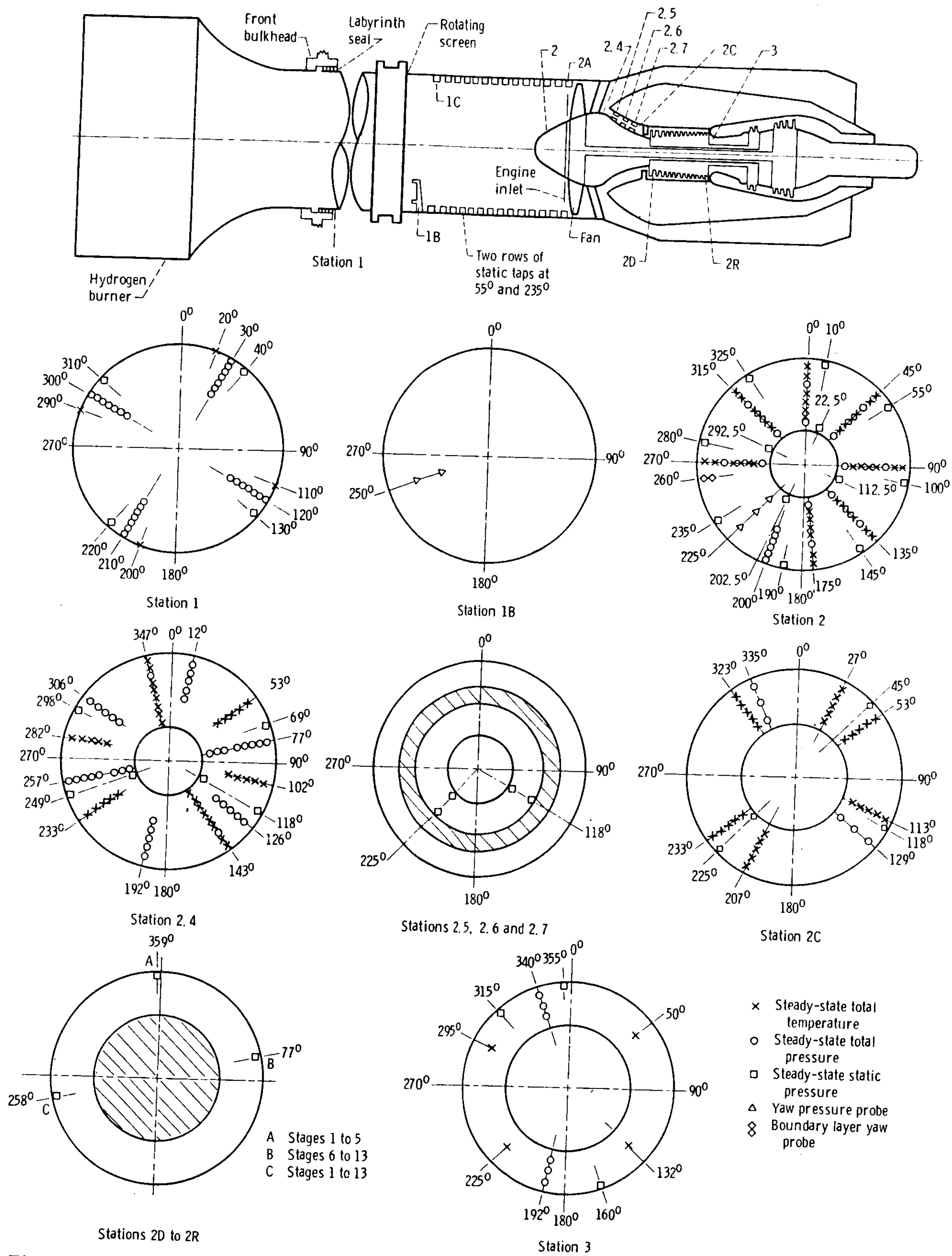

Figure 21. - Instrumentation layout for the TF-34 turbofan engine. (Stations viewed looking upstream. See symbols for description of station locations.)

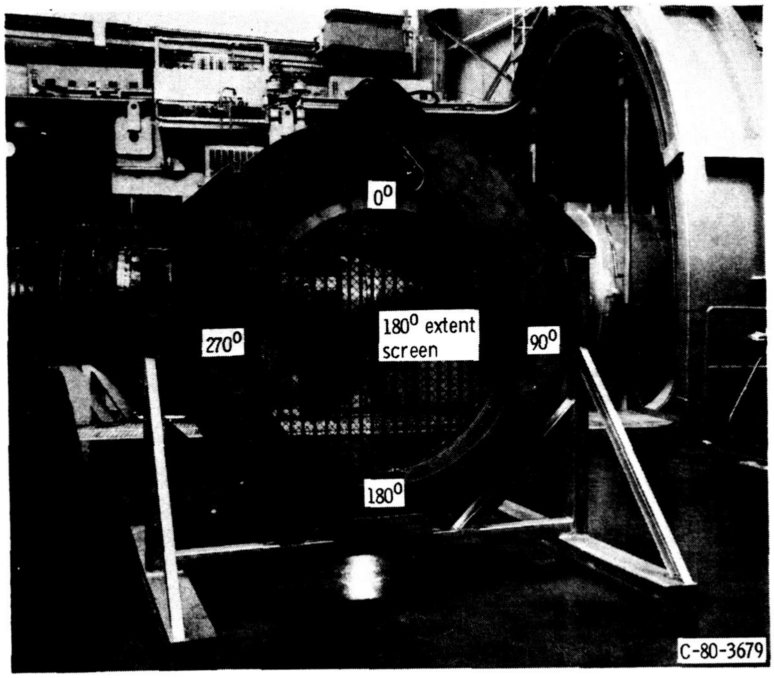

Figure 22. - Pressure distortion generator with rotatable screen assembly.

Pressure and temperature distortions can be imposed on the full size engine by using pressure and temperature distortion generators. Inlet pressure distortion (pressure lower than average) is generated using one of three screen configurations, figure 22. The pressure distortion circumferential extent of a 180° can be varied by a rotatable screen assembly which is mounted upstream of the engine inlet.

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The gaseous-hydrogen-fueled burner device, figure 23, is used to produce the time-dependent temperature distortion and is installed upstream of the engine inlet bellmouth. The burner has the capability of being rotated + 30° from the center position and is divided into four individually controlled quadrants. Air passing through the burner is heated in selected 90° sectors. Each sector has the following:

1. 6 swirl-can pilot burners, ignition source for hydrogen.
2. 6 annular gutters supported by 1 radial gutter.
3. 6 circular-tube manifolds (1 inside each annular gutter) with small holes for hydrogen injection.

High-response valves could be energized in any desired combination to produce the temperature distortion.

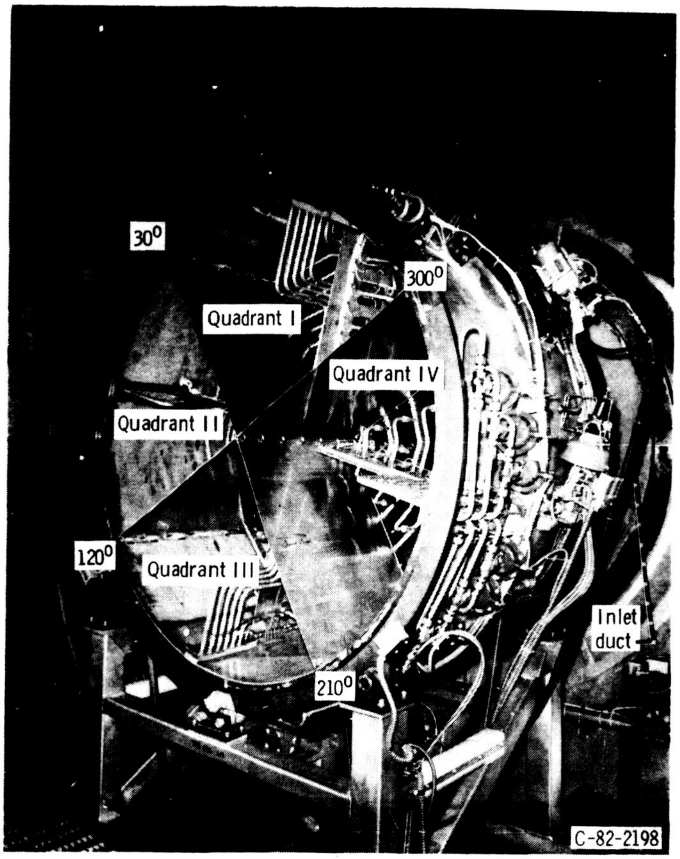

Figure 23. - Total temperature distortion generator with a gaseous-hydrogen-fueled burner.

By using the above distortion devices, we can arrive at the distortion sensitivity parameters for the engine inlet as shown in figure 24. The engine stall line is temperature and/or pressure distortion sensitive. This is ultimately the type of information you need to know about the model-inlet-engine characteristics.

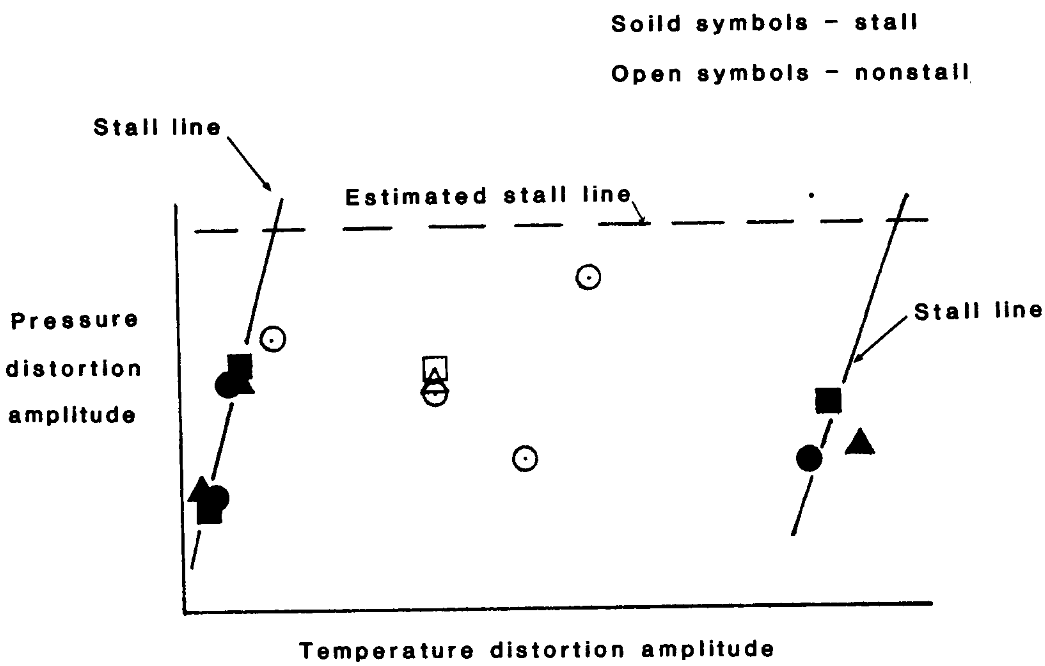

Figure 24. - Distortion sensitivity at the engine inlet.

In conclusion:

1. We shall obtain data which will permit prediction of operating characteristics of vectored thrust concepts with forward velocity.

2. We shall minimize/eliminate hot gas ingestion during vertical flight operations while in ground effects.

3. We shall establish a data base for near and far field ingestion, fountain flow effects, and ground vortex flow field - jet interaction.

4. We shall also obtain distortion results which can be utilized for full size engine testing in the altitude test chamber facility.

5. We shall obtain the extent of ground effects on the vectored thrust ASTOVL concept.

6. It is important to develop analytical codes which will predict the overall effects of hot gas ingestion.

REFERENCE

1. Kuhn, R. E. and Eshleman, J., "Ground Effects on V/STOL and STOL Aircraft - A Survey," NASA TM 86825, Nov. 1985.