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STOL and STOVL Hot Gas Ingestion and Airframe Heating Tests in the NASA Lewis 9- by 15-Foot Low-Speed Wind Tunnel

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SUMMARY

Short takeoff and landing (STOL) and advanced short takeoff and vertical landing (STOVL) aircraft are being pursued for deployment near the end of this century. These concepts offer unique capabilities not seen in conventional aircraft: for example, shorter takeoff distances and the ability to operate from damaged runways and remote sites. However, special technology is critical to the development of this unique class of aircraft. Some of the real issues that are associated with these concepts are hot gas ingestion and airframe heating while in ground effects. Over the past nine years, NASA Lewis Research Center has been involved in several cooperative programs in the 9- by 15-Foot Low-Speed Wind Tunnel (LSWT) to establish a database for hot gas ingestion and airframe heating.

This report presents the modifications made in the 9- by 15-Foot LSWT - including the evolution of the ground plane, model support system, and tunnel sidewalls - and flow visualization techniques, instrumentation, test procedures, and test results. The 9- by 15-Foot LSWT tests were conducted with independent inlet and exhaust nozzle controls for the models. The tests were conducted at full-scale exhaust nozzle pressure ratios. The headwind velocities varied from 8 to 120 kn depending on the concept (STOL or STOVL). Typical compressor-face distortions (pressure and temperature), ground plane contours, and model surface temperature profiles are presented.

INTRODUCTION

Supersonic aircraft configurations capable of operating from remote sites and damaged runways, and of using thrust vectoring for short landing are being investigated for possible deployment around the turn of the century. To achieve these capabilities, the technology critical to this unique class of aircraft must be developed. One of the propulsion technologies that is critical to these concepts is the control of hot gas ingestion (HGI) and the resulting airframe heating (refs. 1 and 2).

Short takeoff and landing (STOL) and short takeoff and vertical landing (STOVL) aircraft operating near the ground can encounter large-pressure and/or high-temperature distortions due to HGI. These distortions can produce thrust loss and/or engine stall.

NASA Lewis Research Center has conducted several HGI and airframe heating programs over the past nine years. Over the past five years, Lewis has been improving the testing techniques, the instrumentation requirements, and the quality of the data obtained for HGI testing. Concurrently, a large database in HGI and airframe heating testing has been developed. Some of these data are being used with analytical codes to make a preliminary assessment of the applicability of these codes.

Thrust reversers, when deployed in ground effects, tend to send a thick ground jet ahead of the aircraft. This jet eventually separates from the ground, is blown into the inlet flow-field region, and is ingested by the engine inlet. The point of ground separation is a function of the nozzle pressure ratio, the thrust reverser deflection angle, the model height above the ground, and the free-stream velocity. Stewart and Kemmerley, and Kuhn (refs. 3 and 4) have found that the thickness and strength of the ground jets, and the position of the ground vortex are a function of the thrust reversal jet deflection for STOL concepts.

In general, the lift jets for the advanced STOVL concepts produce two sources of hot gas ingestion when in ground effects (refs. 1 and 2). The first is near-field ingestion. Near-field ingestion results when the exhaust jets impinge on the ground and are deflected outward and upward forming an upwash fountain that interacts with the undersurface of the fuselage. Some of this flow runs along the undersurface of the fuselage and is sucked into the engine inlet. The second source is far-field ingestion, which results when the exhaust nozzle ground jets run ahead of the aircraft and separate from the ground because of the thermal buoyancy and headwind. This flow mixes with the ambient air and returns to the inlet flow field at a temperature lower than that of the near-field hot gas ingestion.

Tunnel wall interference and premature heating of the model, ground plane, and test section can all influence the results.

FACILITY

The tests were conducted in the NASA Lewis 9- by 15-Foot Low-Speed Wind Tunnel (LSWT), which is located in the return leg of the 8- by 6-Foot Supersonic Wind Tunnel (fig. 1). The STOL tests were conducted over free-stream velocities ranging from 40 to 120 kn. The STOVL tests were conducted over two different free-stream velocity ranges: from 8 to 23 kn and from 30 to 90 kn. The lower velocities, 8 to 23 kn, were obtained by using the blowers located in the dryer building and by changing the amount of the opening of doors 4 and 5 (doors 1 and 2 were closed) shown in figure 1. The higher free-stream velocities (30 to 120 kn) were obtained by using the compressor and by sliding doors 1 and 2 from fully open to fully closed (fig. 1).

MODELS AND CONFIGURATIONS

Short Takeoff and Landing Configurations

The first STOL test consisted of a General Dynamic 12.5-percent-scaled model of the F-16XL followed by the F-16, both in the STOL demonstrator configuration (fig. 2). The models were equipped with thrust deflecting and reversing nozzles, which are needed to obtain the required short landing distance. The model nozzles were supplied with high-pressure heated air (500 °F (960 °R)), and the engine inlet flow was obtained by using the NASA suction system. Test variables included nozzle mass flow (nozzle pressure ratio), inlet mass flow, nozzle vector angle, aircraft angle-of-attack and sideslip angle, and forward velocity. The tests were conducted with wheels down.

The next STOL entry consisted of a McDonnell Douglas Aircraft 7.5-percent-scaled model of a modified F-15. The model was equipped with two-dimensional convergent-divergent nozzles with canards and 10 sets of nozzle reverser vanes ranging from 45° to 135° (fig. 3). These reverser vanes are needed to obtain the required short landing distance. The nozzles were supplied with high-pressure heated air (up to 500 °F (960 °R)), and the engine inlet air flow was controlled independently by the NASA Lewis suction system. The test variables included nozzle pressure ratio, engine inlet airflow to match a value appropriate to the existing nozzle condition, nozzle airflow temperature, sideslip angle, vane angle, rudder angle, and free-stream velocity. This test was also conducted in the wheels-down mode.

Short Takeoff and Vertical Landing Configuration

The STOVL configuration was a 9.2-percent-scaled model of the McDonnell Douglas Aircraft Company concept 279-3C (fig. 4). The model was equipped with four single expansion ramp nozzles (SERN) with vectoring capability ranging from 0° (full aft flowing) to 100° (nozzles are pointing slightly forward). The forward SERN nozzles could be rotated inboard or outboard to form a splay angle varying from -12° (inboard) to 18° (outboard). The aft SERN nozzles were always at a 0° splay angle. The nozzles were supplied with high-pressure heated air ranging from ambient to 500 °F (960 °R). The engine inlet mass flow was independently controlled by the NASA Lewis suction system. Test variables included nozzle pressure ratio (nozzle mass flow), engine inlet airflow (inlet Mach number), angle-of-attack, sideslip angle, main landing gear height above the ground plane, nozzle airflow temperature, canard angle, forward nozzle splay angle, lift improvement devices (LID's), and free-stream velocity. This test was also conducted in the wheels-down mode with the exception of a series of runs where the landing gears were removed to obtain touch-down data.

MODEL-SUPPORT SYSTEMS

Short Takeoff and Landing Support System

A schematic of the side and top view of the F-16XL/F-16 model installed in the wind tunnel is shown in figure 5. The model was sting mounted on the NASA Lewis standard suction support system. The model was located approximately 48 in. from the tunnel sidewall and had a pitch range from 0° to 20° and sideslip angle from 0° to 15°. As stated earlier, the inlet airflow was supplied by the NASA Lewis suction system and the model nozzle was supplied with high-pressure hot airflow. The nozzle supply system was located on the aft end of the suction-model support system, which is downstream of the model and aft of the test section.

A three-quarters front view of the modified F-15 is shown in figure 6. The model was supported by twin flow-through stings. These stings were mounted from the NASA Lewis standard suction support system to a core hardware yoke that supported the airframe. The yoke moved the model to the centerline of the test section, 90.50 in. from the tunnel sidewalls. The model had a pitch range up to 30° and a sideslip angle ranging from 0° to -30°. The flow-through sting contained mass flow plugs to set the engine inlet airflow. The nozzle high-pressure airflow system was mounted on the aft end of the support system downstream of the test section.

Short Takeoff and Vertical Landing Support System

Figure 7(a) contains a view of model 279-3C installed in the 9- by 15-Foot LSWT on the model support system. The model support system included the high-pressure hot (500 °F (960 °R)) air lines and a suction line that provided the engine inlet airflow. The model height was varied by changing the number of spacers between the upper and lower flanges and adjusting the jack screws.

The high-pressure air lines provided the airflow for the model SERN nozzles. The suction duct also provided support for the hot air and instrumentation lines. Pitch, roll, and yaw were adjusted by changing the position of the ball joint, located below the lower flange.

Water-Injection System

A water-injection system was used to conduct flow visualization testing. Water was injected into unheated nozzle airflow where it was atomized. Porous plates located in the nozzle air-supply lines helped to atomize the flow. White light illumination was used to allow the flow field to be visualized. A simplified schematic of the water injection system is shown in figure 7(b).

TEST SECTION MODIFICATIONS

The current test section configuration has evolved through a series of modifications to improve the handling of the ground-jet flow of hot gases from the nozzles. These modifications were made to the sidewall, the ground plane, and to the model installation system.

Sidewall Bleed System

The 9- by 15-Foot LSWT test section sidewalls are slotted. During the second STOL and the STOVL tests, a horizontal row of paneling was removed along each sidewall at approximately the height of the ground plane (fig. 8). The removal of these panels prevented the ground hot airflow from hitting the test section sidewalls and recirculating in the test section. The ground airflow exited the test section through the sidewalls and returned to the wind tunnel downstream of the model support system. The removal of the sidewalls also minimized the hot airflow heating of the test section.

Ground Plane

Figure 9 shows a schematic of the three ground planes used for STOL and STOVL model tests.

The minimum height of the ground plane with the F-16 models was 40.70 in. from the tunnel floor. When the angle-of-pitch increased, the height of the ground plane was also increased as shown in figure 5(a). For example, at a 20° pitch the ground plane height was increased to approximately 61.00 in. The ground plane was 180 in. wide by 96 in. long.

The ground plane used with the F-15 scaled model was a modification of the one used with the F-16 tests. The ground plane length was increased to 156 in., and the width remained the same (180 in.). The ground plane height was fixed at 40.70 in. above the wind tunnel floor.

The ground plane for the STOVL model was unchanged in width, but the length was increased to approximately 336 in. The ground plane also contained a sliding trap door with a scavenging system controlled by two ejectors located at the aft end of the duct under the sliding trap door. The trap door was open when the nozzle pressure ratio and temperature were being set and was closed after.

INSTRUMENTATION

The instrumentation used in the facility, on the STOL and STOVL models, and on the ground plane is presented next.

Facility Instrumentation

The STOL models used a total static-pressure rake located in the test section ahead of the model and on the tunnel centerline in the ceiling, (fig. 10(a)). The free-stream velocity was calculated from this total static-pressure rake.

The STOVL model used a propeller anemometer to determine the free-stream velocities up to 95 kn, (fig. 10(b)). Strips of thermocouple taps were located on the tunnel sidewalls and ceiling, and a strip of static-pressure taps was located in the test section ceiling.

Instrumentation for Models

Short takeoff and landing model. - The F-16XL and F-16 had steady-state instrumentation, both pressure and temperature measurements. A compressor-face rake consisted of eight legs with five rings each (fig. 11(a)). Each ring consisted of alternating total pressure and thermocouple probes. The steady-state pressures were measured by 20 total-pressure probes located in the compressor face rake. Eight wall static-pressure probes were located at the compressor face, and four static-pressures probes were located on the thrust reversers. The compressor face rake also contained 20 thermocouples. The vertical tail contained 16 thermocouples, and the thrust reversers had 4 thermocouples (fig. 11(b)).

The F-15 contained both steady-state pressure and temperature instrumentations (fig. 12). Figure 12(a) shows a summary of the instrumentation on the model. The instrumentation on the vertical tails is shown in figure 12(b). The inlet contained eight total-pressure probes and eight thermocouples (four sets per inlet). Each compressor-face rake contained 24 total-pressure, and 24 total-temperature probes: There were eight rake legs per compressor-face, with each leg containing three total pressure probes and three thermocouples. The upper fuselage contained 10 thermocouples, and the lower fuselage had 16. The vertical tails had a total of 30 thermocouples (15 each), and the horizontal tails had 16 thermocouples. The nozzle exits had a total of four thermocouples and four total-pressure probes, plus the jet airflow supply contained eight thermocouples and eight total pressure probes. A grand total of 68 total pressures, 60 total temperatures, and 80 surface temperatures were measured on the model. The mass flow plugs for each inlet had 48 total-pressure probes, 4 total-temperature probes, and 1 static-pressure probe.

Short takeoff and vertical landing model. - Model 279-3C contained both steady-state pressure and temperature probes. The model was made up of three fuselage sections. The forward fuselage (fig. 13(a)) consisted of the nose cone assembly, nose gear, inlet centerbody, canopy, main and auxiliary inlets, and midinlet section. The instrumentation consisted of three rakes:

(1) The nose cone measured the local free-stream conditions.

(2) The inlet plane undersurface measured the temperature profile under the model approaching the inlet region.

(3) The compressor face rake measured the inlet temperature distortion and rise. This rake was also used to determine the compressor face pressure distortion and recovery.

Static-pressure taps were located along the undersurface centerline and also in the vicinity of the inlet.

The center fuselage section (fig. 13(b)) contained the nozzle plenums, nozzles, air supply lines, wings, main landing gear, nozzle ramps, and LID's. The instrumentation in this section consisted of two total-pressure probes, two total-temperature probes, and eight exit-plane static-pressure taps in each of the four nozzles. Static-pressure taps located along the undersurface centerline are shown in figure 13(c).

The aft fuselage (fig. 13(d)) consisted of a cover and a lower body section. During the hot gas ingestion and airframe heating test, the aft fuselage did not contain instrumentation. However, during the structural acoustic test, the center and aft fuselage sections had high-response pressure instrumentations located along the undersurface centerline (fig. 13(d)).

Test variables included nozzle pressure ratio (nozzle mass flow), inlet airflow (inlet Mach number), angle-of-attack, sideslip angle, main landing gear height above the ground plane, nozzle airflow temperature, canard angle, forward nozzle splay angle, LID's, and free-stream velocity. This test was also conducted in the wheels-down mode, with the exception of a series of runs where the landing gears were removed to obtain touch-down data. The relationship of the instrumentation to the model is shown in figure 14(a). The three instrumented sections represent the model at 0°, 15°, and 30° yaw angles. There were a total of 14 temperature and 48 pressure taps per panel. Total pressure rakes were also located on the ground plane (figs. 6 and 14).

Ground Plane Instrumentation

The ground plane was instrumented for the modified F-15 and 279-3C models. The ground plane for the STOVL model (279-3C) was extensively instrumented with pressure and temperature rakes, static-pressure taps, and temperature taps. The thermocouples were insulated from the ground plane to prevent conduction effects. Figure 15 shows the layout of the ground plane instrumentation and rakes.

TEST PROCEDURE

Short Takeoff and Landing Tests

In general, all of the STOL testing in the 9- by 15-Foot LSWT used the same test procedure. All test data were taken at steady-state conditions with the model attitude fixed. The planned test configuration was set-up manually. The variable parameters for a test sequence included nozzle pressure ratio, nozzle temperature, compressor-face Mach number, pitch angle, yaw angle, and free-stream velocity.

In general, STOL tests proceeded as follows:

(1) A pretest data point was taken to verify instrumentation operation.

(2) The facility natural gas air-supply heater was started and brought up to the desired (test) temperature. Usually (at the beginning of the test only), the high-pressure air line was vented external to the wind tunnel until a temperature close to the test temperature was reached. The high-pressure air was then routed into the test section and vented into the diffuser section of the wind tunnel until the test temperature was reached. Meanwhile, just before venting in the diffuser, the inlet suction flow was set to obtain nearly the desired compressor-face Mach number. Also, the model control person would cycle through the nozzle pressure ratio settings to obtain a rough valve pot setting. This allowed the nozzle pressure ratios to be set more quickly once the high-pressure air was up to temperature.

(3) The control valve(s) were closed and the high-pressure air flowed through the nozzles. A nozzle pressure ratio was quickly set, and the inlet Mach number was adjusted along with the free-stream velocity.

(4) The inlet temperature rise was monitored for the steady-state condition. When the inlet temperature rise leveled off, the steady-state condition was reached, and data readings were taken.

(5) After the data were taken, the nozzle airflow was vented aft into diffuser, and the next test condition was set up. The remainder of the testing repeated steps (3) through (4) above.

Short Takeoff and Vertical Landing Tests

The STOVL test program in the 9- by 15-Foot LSWT used an elaborate ground plane with a sliding trap door under the model. The trap door alternated the predata and data recording conditions. All test data were taken at steady-state conditions with model attitude fixed. The planned test configuration was set up manually. The model attitude, the main landing gear height above the ground plane, and the yaw, roll, and pitch angles were preset before the test. The variable parameters for a test sequence included the nozzle pressure ratio, the nozzle temperature, the compressor-face Mach number, and the free-stream velocity.

In general, advanced STOVL tests proceeded as follows:

(1) A pretest data point was taken to verify instrumentation operation.

(2) The trap door was open, and the ejectors that ventilated the trap door scavenging system were activated.

(3) The inlet suction flow was set to obtain the desired compressor-face Mach number.

(4) The nozzle high-pressure air supply system was activated, and each nozzle pressure ratio was set to approximately 4.0 for model heat up.

(5) The facility natural gas air-supply heater was started and brought up to its maximum temperature of 810 °F (1270 °R). This temperature level provided approximately 630 °F (1090 °R) at the control station (located in the forward section of the diffuser) and 500 °F (960 °R) at the model.

(6) The inlet suction airflow, nozzle pressure ratios, and nozzle temperatures were adjusted according to the test plan. The free-stream velocity was set at the desired condition.

(7) A reference data point was taken (recorded), and then the trap door was closed.

(8) The average inlet temperature rise was monitored on a scrolling video plot (inlet temperature rise versus time) to establish steady-state conditions. The steady-state condition occurred when the inlet temperature rise leveled-off with time.

(9) The trap door was opened, and steps (6) through (9) were repeated until the test plan was completed.

TEST RESULTS

The data presented in this section (figs. 16 to 22) show the typical results that were obtained throughout the STOL and STOVL programs, with the exception of the F-16. The F-16 data were not available for distribution.

The inlet distortion parameter is the ratio of the difference between the maximum and minimum compressor-face temperatures or pressures (depending on the parameter) divided by the average compressor-face total temperature or pressure. The inlet temperature rise is the difference between the average inlet temperature and the reference ambient temperature. The pressure recovery is the compressor-face average total pressure divided by the free-stream total pressure.

Short Takeoff and Landing Results

Compressor face contours. - The hot gas ingestion characteristics are shown in figure 16 for the modified F-15 STOL configuration. Data are shown for 100 kn, a reverser angle of 135°, and a nozzle pressure ratio of 2.70. Contour plots are shown for the inlet temperature rise (fig. 16(a)) and pressure recovery (fig. 16(b)) at the compressor face. These results are typical for both the left and right compressor faces. The presence of hot gas ingestion was determined by the inlet temperature across the compressor face for the test conditions. In general, hot gas ingestion occurred at a full reverse vane angle of 135° and at high nozzle pressure ratios over the free-stream velocity range. Reducing the reverse vane angle and the corresponding nozzle pressure ratio reduced the hot gas ingestion.

Vertical tail temperature contour at zero yaw. - The first part of the test was conducted with only the upper reverser ports operating. This provided data on the temperature effects on the vertical tails. A typical temperature contour plot is shown in figure 17(a). In general, the maximum temperature on the vertical tails was approximately 380 °F (840 °R). This would correspond to an engine intermediate power setting. This maximum temperature is within the design limits for the vertical tails.

Lower surface centerline temperature distribution. - The second part of the test was conducted with only the lower reverser ports operating. This provided data on the hot gas ingestion, if any, of the reverser port vane (angle) configuration. A typical temperature distribution is shown in figure 17(b) along the model undersurface centerline. At the maximum nozzle pressure ratio corresponding to the engine intermediate power, the lower surface temperature distribution showed that certain regions may see full-scale temperatures as high as 7140 °F (7600 °R).

Ground plane temperature and pressure contours. - The ground plane was instrumented around the model with both pressure and temperature taps. Typical pressure and temperature plots are shown in figure 18. Since there were a limited number of thermocouple channels available, only two rows of temperature taps were installed between the nozzles and the inlet regions. A typical temperature profile is shown in figure 18(a). The temperature ratio varied from 4 at the nozzle exit to about 1.8 at the inlet plane. The ground plane pressure contour plot (fig. 18(b)) is less than ambient, hence indicating a suckdown region under the model. This low-pressure region indicates that there is little velocity decay in the reversers flow.

Short Takeoff and Vertical Landing Results

Compressor-face contours. - The data for the STOVL configuration (model 279-3C) is shown at 23 kn free-stream velocity and for a nozzle pressure ratio of 3.05 for the front nozzles and of 3.15 for the aft nozzles. The inlet temperature rise contour at the compressor face is shown in figure 19(a). In general, the higher temperatures occur at the lower region of the inlet. This is an indication that the near field (fountain) is the big contributor. The temperature distortion at this condition was 10.3 percent, and the inlet temperature rise was 44 °F (604 °R). The pressure recovery contour at the compressor face is presented in figure 19(b). The low-pressure recovery occurs in the top of the compressor face. The average pressure recovery for this condition was 0.983, and the pressure distortion was 5.2 percent.

Undersurface centerline temperature distribution. - A typical undersurface air temperature distribution is shown in figure 20. The data represent a clean configuration (that is, without LID's) when the model was in ground effects. The air temperature on the undersurface of the model varied from 440 to 240 °F (900 to 700 °R) near the lower inlet section. The air temperature in the region of the inlet can be reduced by using LID's to deflect the hot air away from the model surface (ref. 2).

Ground plane temperature and pressure contours. - Both air temperature and static-pressure ground plane contour maps are shown in figure 21(a) and (b), respectively. The results are typical when the model was within ground effects. The temperature contour plot indicates that the hotter regions were near the model centerline and at the jet impingement points on the ground plane. Consequently, the hotter regions were also the areas of high-pressure as shown in figure 21(b).

Flow visualization. - Characteristics typical of the near-field hot gas ingestion are shown in figure 22(a). This is a three-quarters view of the clean configuration with a -6° splay angle. When the ground airflow from the two jets meet, a fountain is formed. If there are more than two jets, a fountain is formed between each pair and a central fountain is formed when the flow from all four jets meet. Figure 22(b) shows a typical far-field separation zone. The tufts on the ground plane pointing toward the model are upstream of the separation zone, under the influence of the headwind velocity. The tufts pointing away from the model are under the influence of the exhaust nozzle airflow, downstream of the separation zone. In general, the influence of the ground jet was confined laterally by the headwind velocity. This can be observed in figure 22(b) at the top region where the tufts are parallel to the separation zone but point aft.

THE NEXT STEP

The next normal evolution to the 9- by 15-Foot Low-Speed Wind Tunnel would be to alter the model support system and improve the high-pressure air temperature level. Figure 23 shows a schematic of the proposed model integrated support system (MISS) and of the different configurations that it could accommodate. MISS would have four degrees of freedom (pitch, roll, yaw, and vertical height adjustment) remotely operated from the control room. MISS would also have high-pressure air up to 1000 °F (1460 °R) using the existing suction system (used to simulate inlet airflow). The upgrade to the 9- by 15-Foot LSWT would include a laser Doppler velocimeter, a laser sheet system, and the NASA Lewis thermovision system. With these improvements, a test in the NASA Lewis 9- by 15-Foot LSWT should yield data that will give the complete physics of the test in both measurements and visualization.

CONCLUDING REMARKS

The modifications made in the NASA Lewis 9- by 15-Foot LSWT - including the evolution of the ground plane, model support system, and tunnel sidewalls; and flow visualization techniques, instrumentation test procedures, and test results have been presented. Results show the increased quantity and improved quality of the STOL and STOVL testing in this facility. Future testing with planned improvements could produce even more complete data acquisition capabilities such that both research and analytical verification data can be obtained simultaneously.

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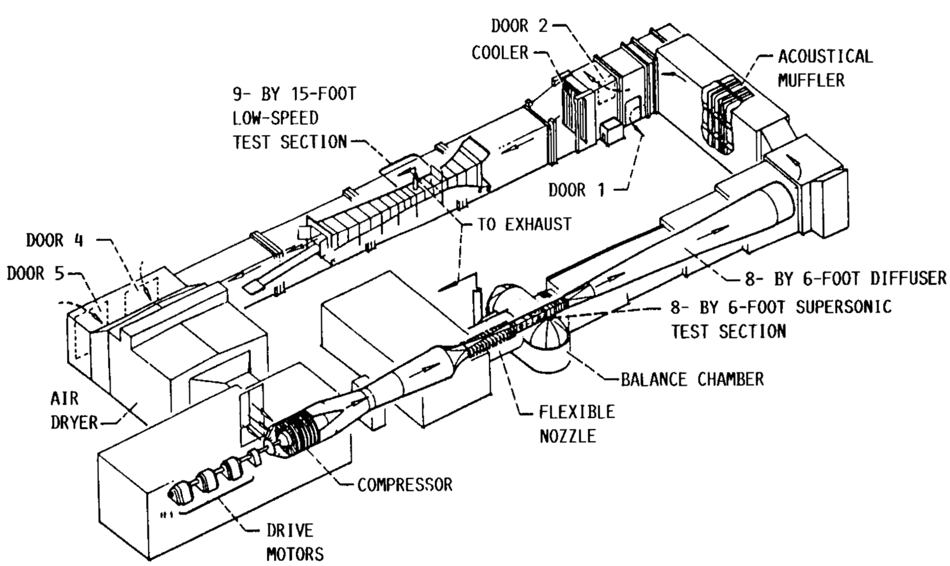

FIGURE 1. - 9- BY 15-FOOT LOW-SPEED WIND TUNNEL AND 8- BY 6-FOOT SUPERSONIC WIND TUNNEL.

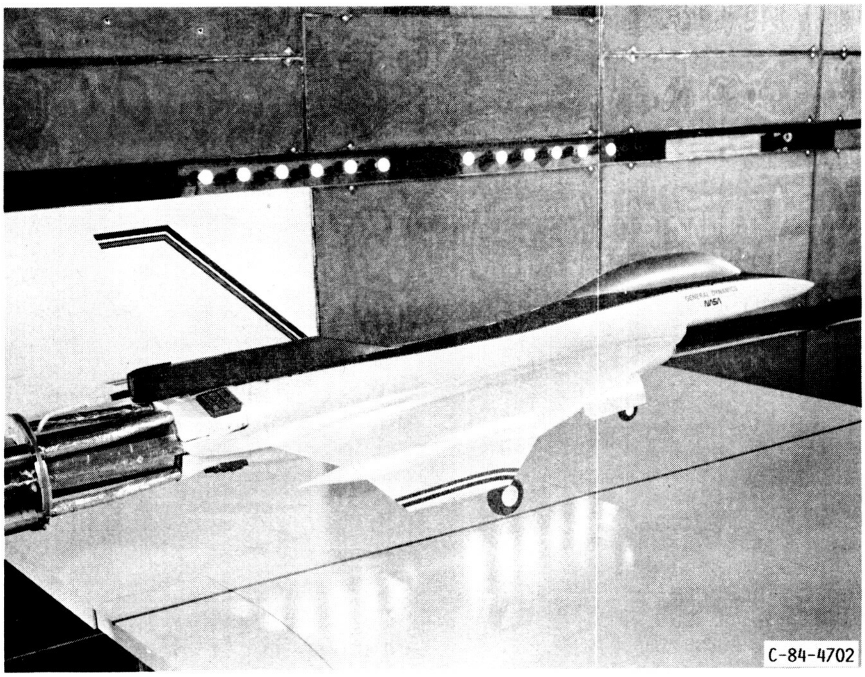

FIGURE 2. - THREE-QUARTER AFT VIEW OF A 12.5-PERCENT F-16XL SHORT TAKEOFF AND LANDING (STOL) DEMONSTRATOR MODEL IN THE 9- BY 15-FOOT LOW-SPEED WIND TUNNEL (LSWT).

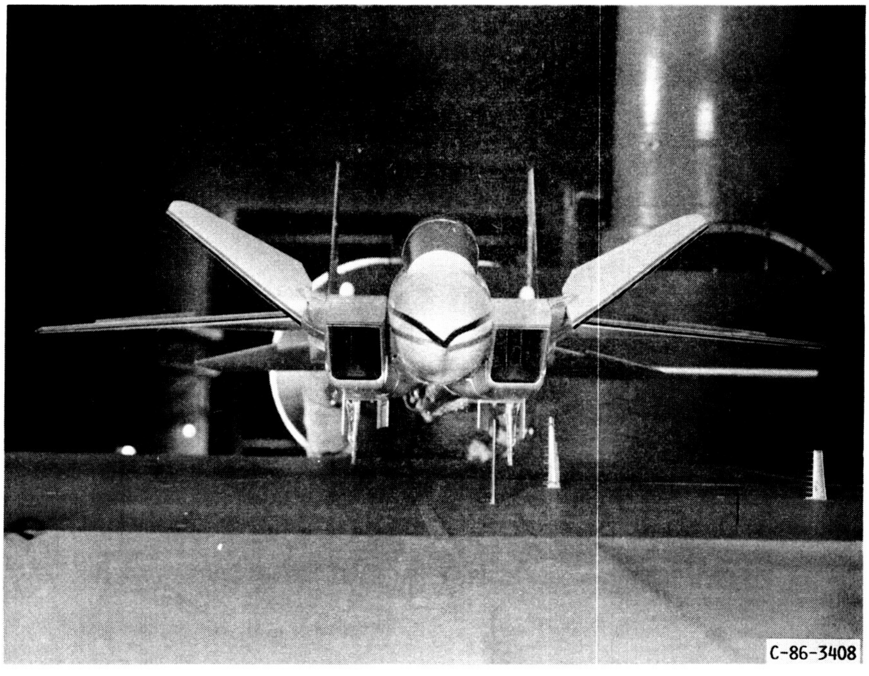

FIGURE 3. - FRONT VIEW OF A 7.5-PERCENT-SCALED, MODIFIED F-15 SHORT TAKEOFF AND LANDING (STOL) DEMONSTRATOR MODEL IN THE 9- BY 15-FOOT LOW-SPEED WIND TUNNEL (LSWT).

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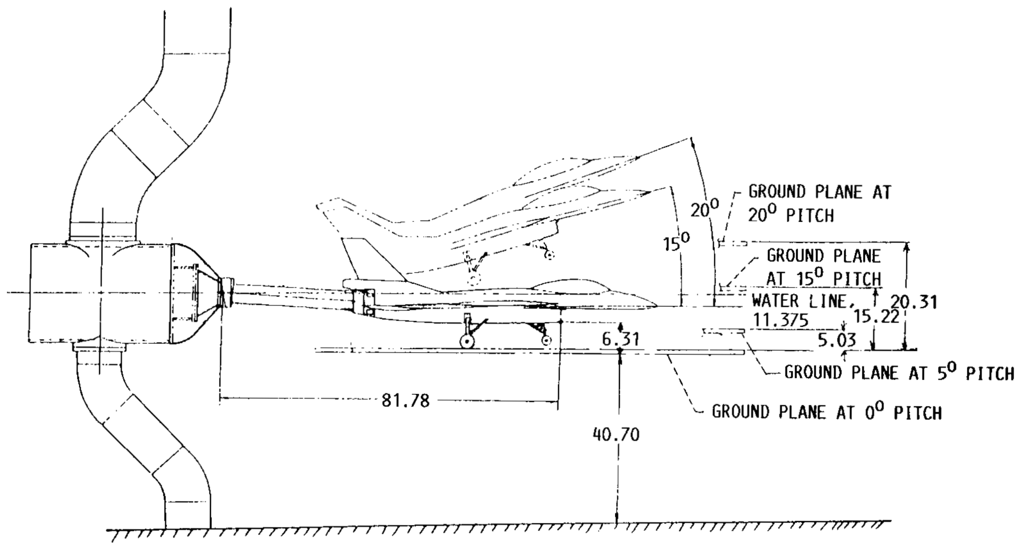
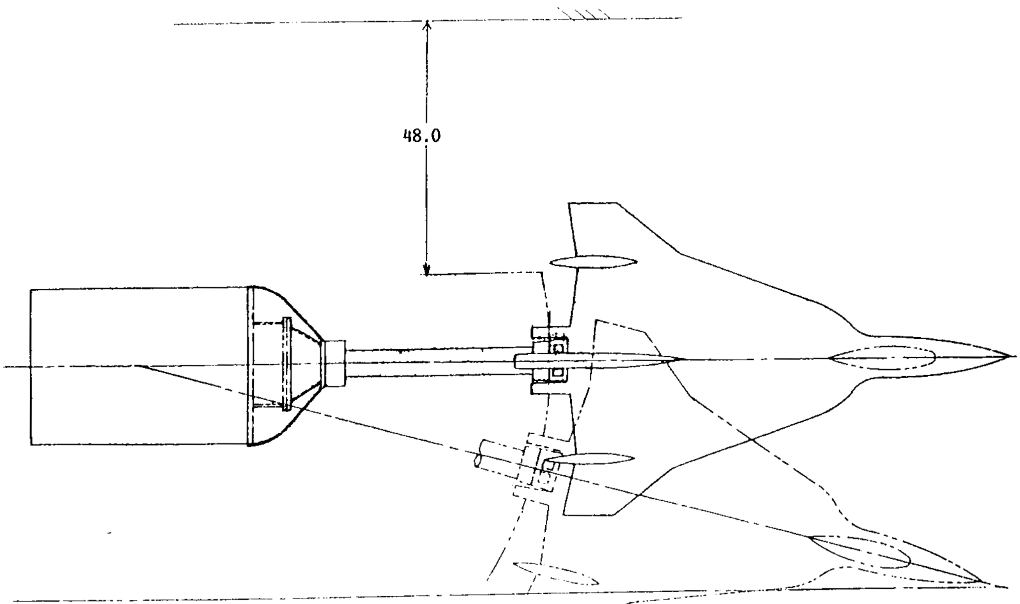
FIGURE 4. - THREE-QUARTER FRONT VIEW OF A 9.2-PERCENT-SCALED SHORT TAKEOFF AND VERTICAL LANDING (STOVL) MODEL IN THE 9- BY 15-FOOT LOW-SPEED WIND TUNNEL (LSWT).



(a) SIDE VIEW.



(b) TOP VIEW.

FIGURE 5. - SCHEMATIC OF THE F-16XL/F-16 INSTALLED IN THE WIND TUNNEL. (ALL DIMENSIONS ARE GIVEN IN INCHES UNLESS INDICATED OTHERWISE.)

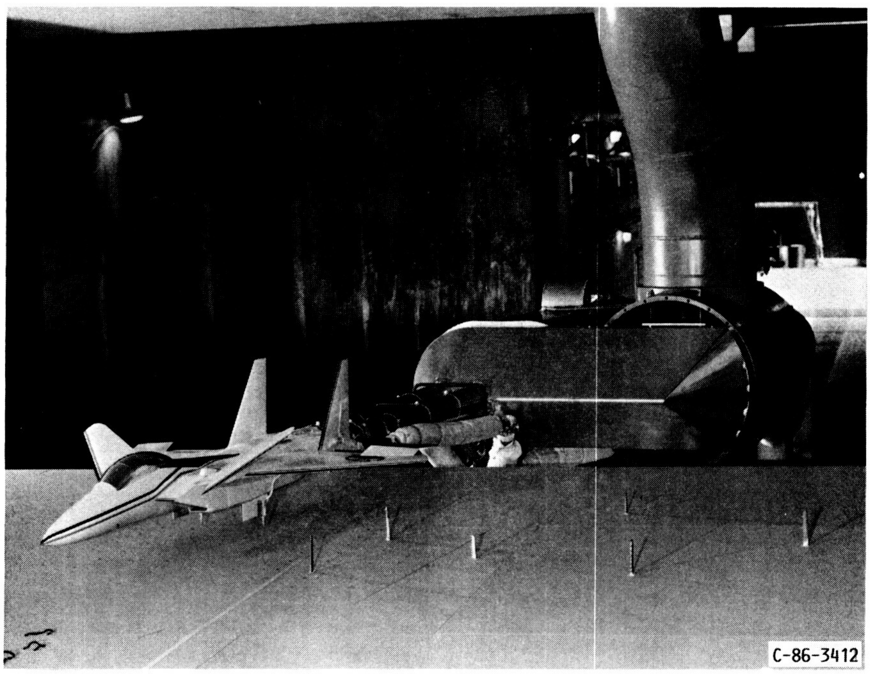
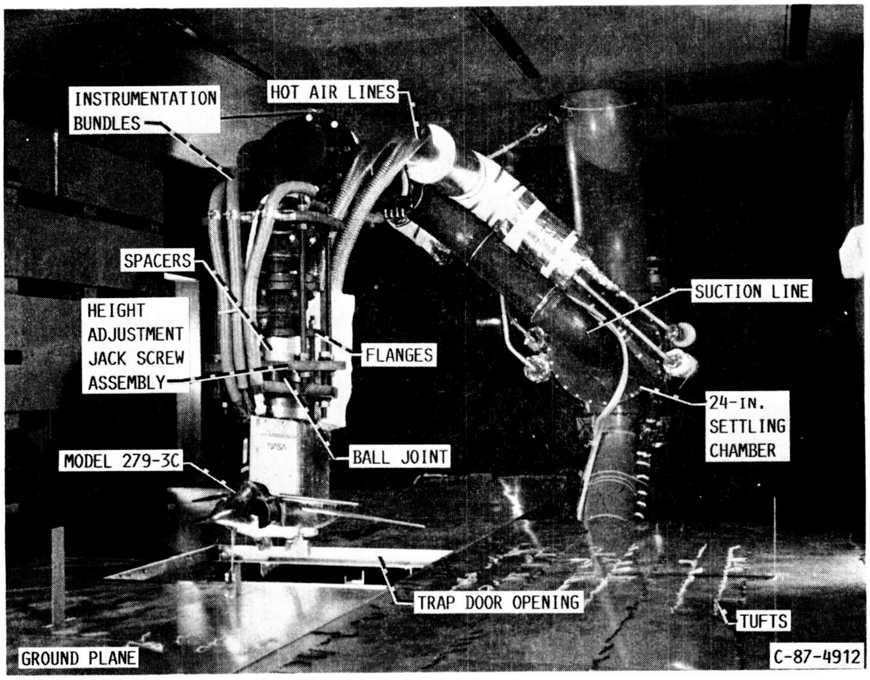
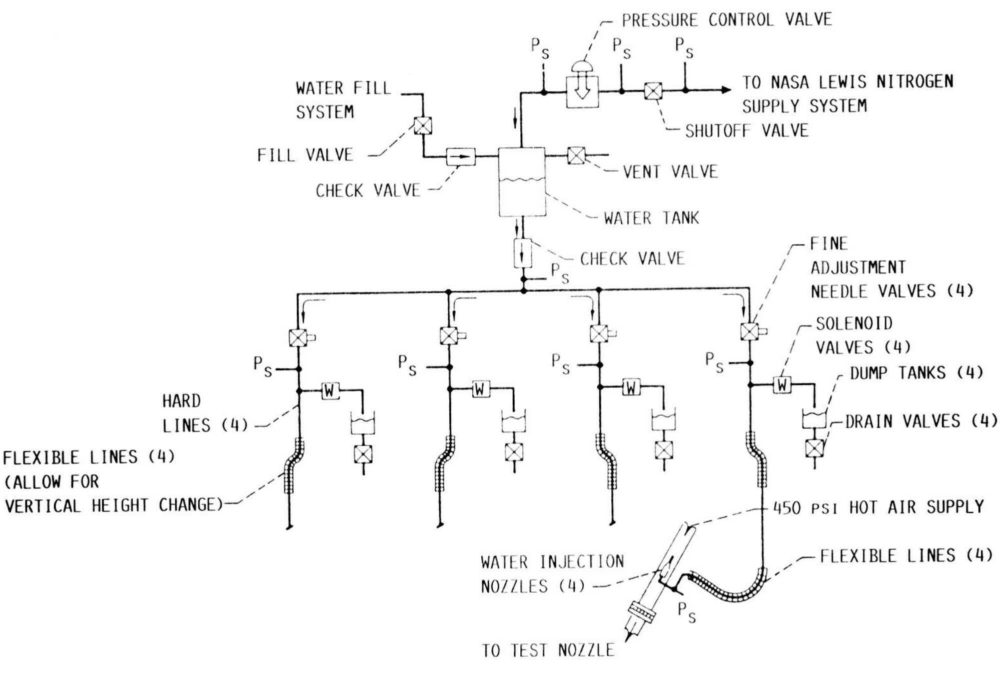


FIGURE 6. - MODIFIED F-15 INSTALLED ON LEWIS STANDARD SUCTION SUPPORT SYSTEM.



(a) HOT GAS INGESTION STOVL MODEL AND SUPPORTING SYSTEM INSTALLED IN THE 9- BY 15-FOOT LOW-SPEED WIND TUNNEL.



(b) SCHEMATIC OF THE MODEL FLOW VISUALIZATION WATER INJECTION SYSTEM SHOWING VALVES AND STATIC PRESSURE, P_S, PROBES.

FIGURE 7. - SHORT TAKEOFF AND VERTICAL LANDING (STOVL) MODEL INSTALLATION.

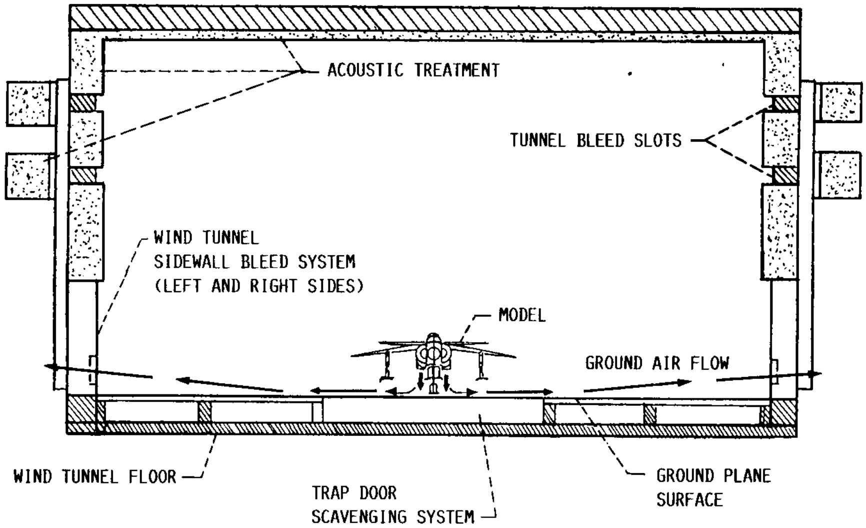


FIGURE 8. - CROSS SECTION OF TEST SECTION SHOWING THE SIDEWALLS BLEED AND TRAP DOOR SCAVENGING SYSTEMS.

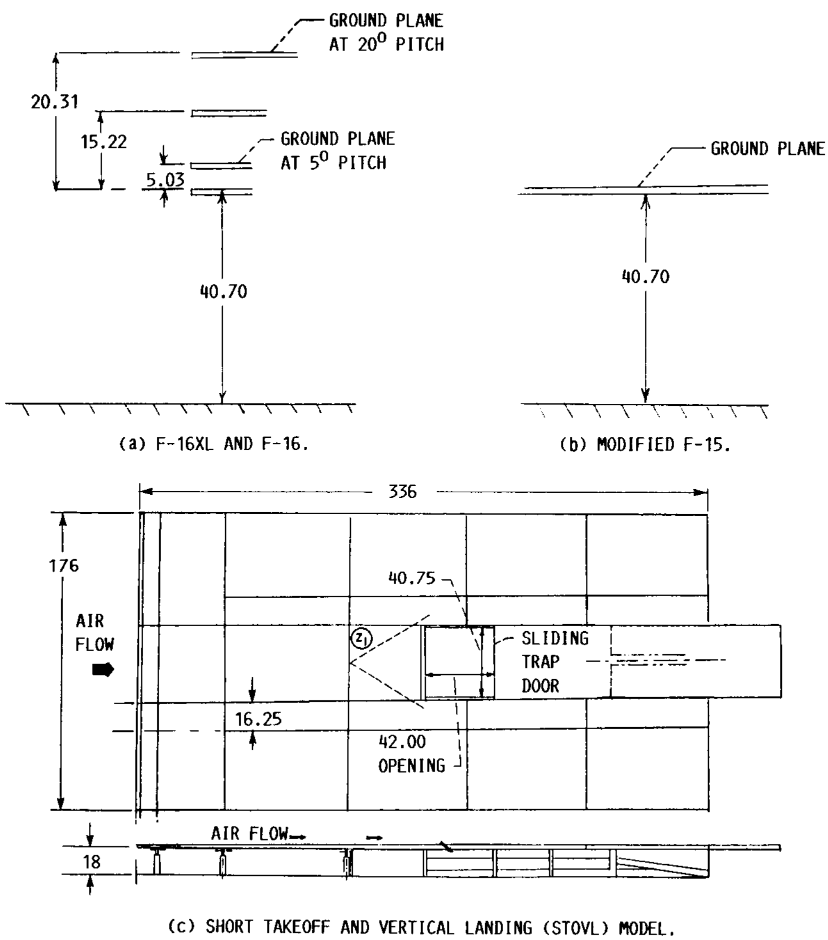
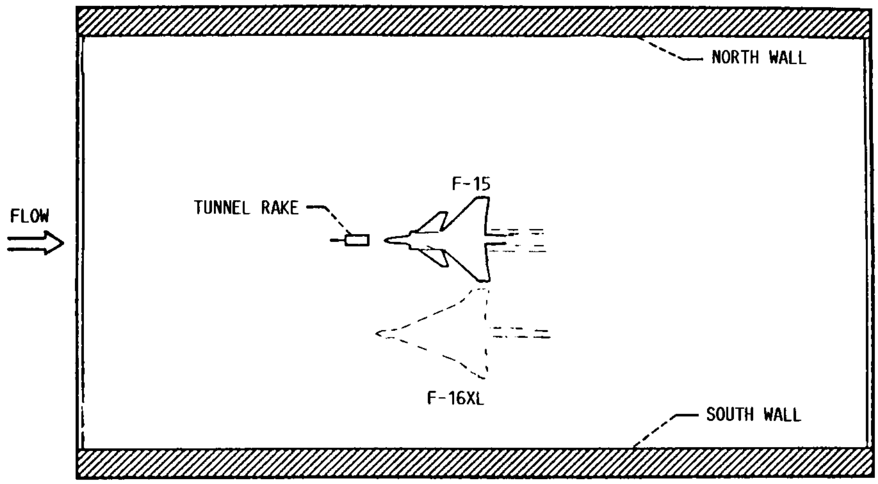
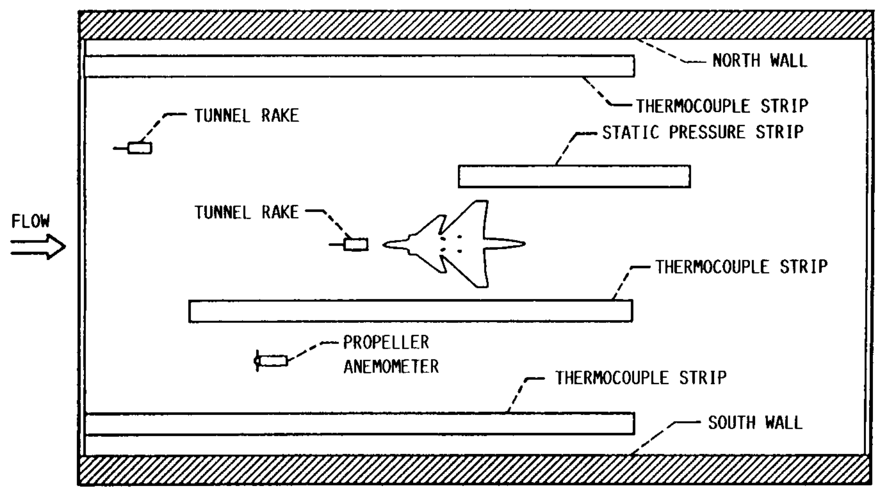


FIGURE 9. - GROUND PLANE SCHEMATIC FOR SHORT TAKEOFF AND LANDING (STOL) AND SHORT TAKEOFF AND VERTICAL LANDING (STOVL) TESTING. (ALL DIMENSIONS ARE GIVEN IN INCHES.)



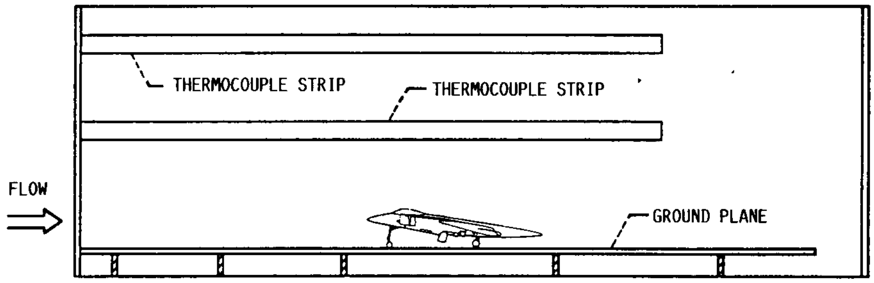
(a) SHORT TAKEOFF AND LANDING (STOL) MODELS.



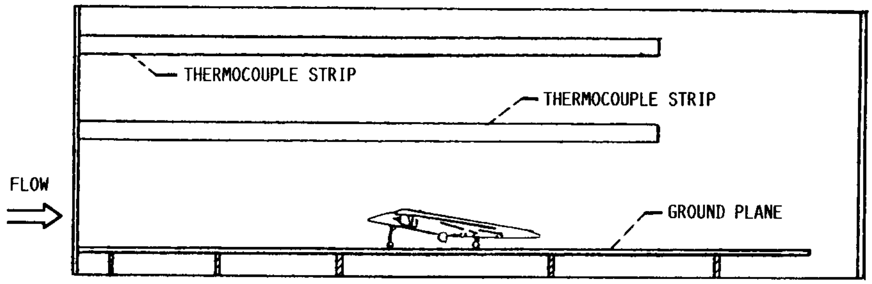
CEILING (LOOKING DOWN)

(b) SHORT TAKEOFF AND VERTICAL LANDING (STOVL) MODEL.

FIGURE 10. - TEST SECTION INSTRUMENTATIONS.



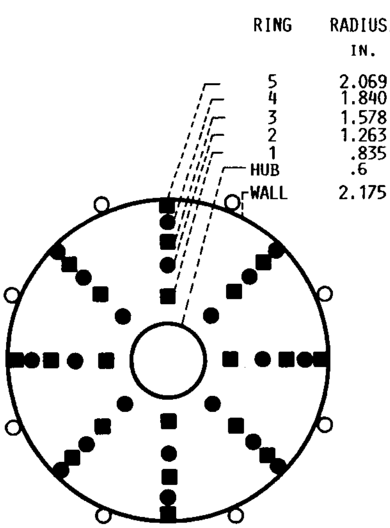
NORTH WALL



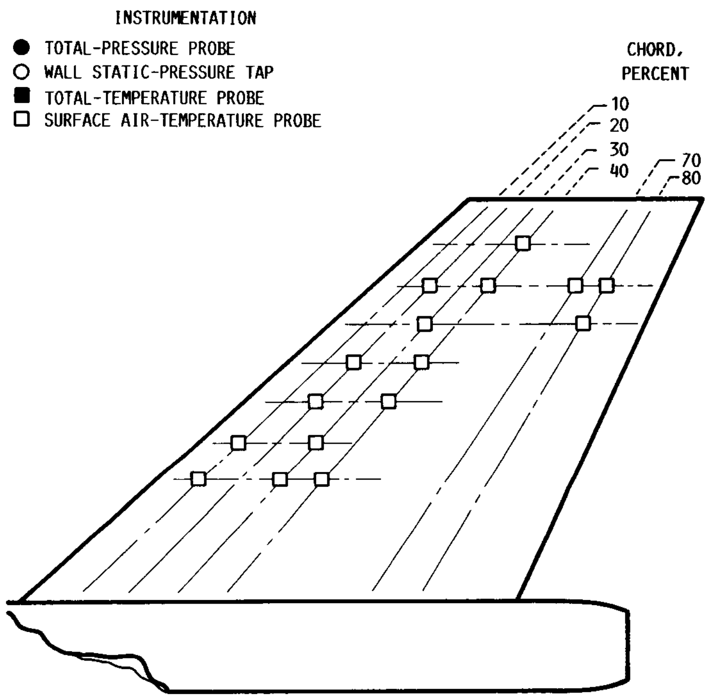
SOUTH WALL

(b) CONCLUDED.

FIGURE 10. - CONCLUDED.

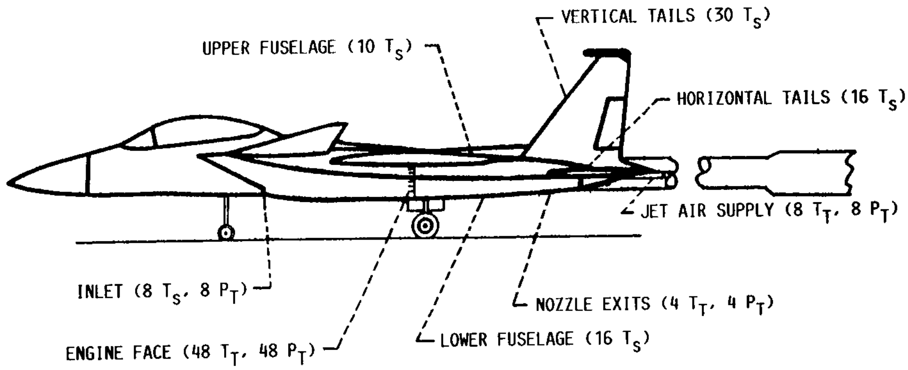


(a) COMPRESSOR-FACE RAKE. (VIEW LOOKING AFT.)

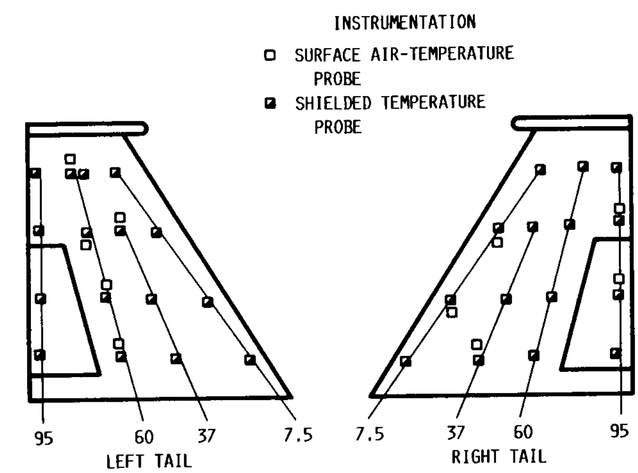


(b) MODEL OF VERTICAL TAIL.

FIGURE 11. - F-16XL AND F-16 MODEL INSTRUMENTATION. (ALL RADII, ARE GIVEN IN INCHES.)



(a) SUMMARY.



(b) VERTICAL TAILS. (ALL MEASUREMENTS ARE EXPRESSED AS PERCENT OF CHORD.)

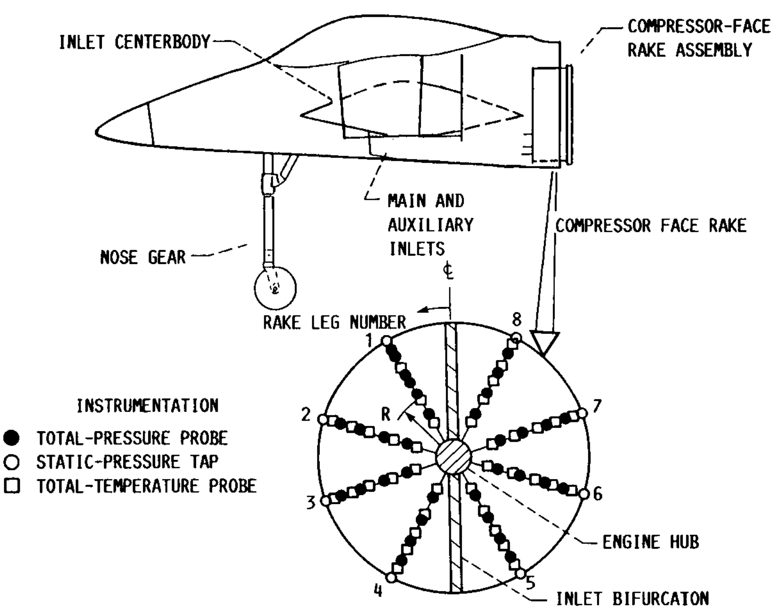
FIGURE 12. - MODIFIED F-15 MODEL INSTRUMENTATION. TOTAL INSTRUMENTATION: TOTAL-PRESSURE PROBES, P_T, 68; TOTAL-TEMPERATURE PROBES, T_T, 60; SURFACE TEMPERATURE PROBES, P_S, 80.

ANGULAR LOCATIONS OF COMPRESSOR FACE LEGS

LEG	ANGLE, DEG
1	66.499
4	293.501
5	246.499
8	113.501
2	21.533
3	338.467
6	201.533
7	158.467

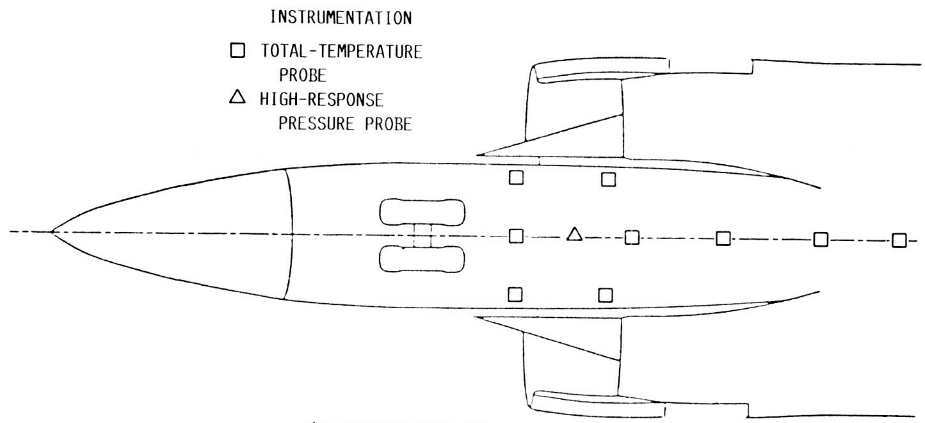
COMPRESSOR FACE RAKE INSTRUMENTATION LOCATIONS

INSTRUMENTATION	RADIAL DISTANCE FROM HUB, IN.	
	LEGS 1,4,5,8	LEGS 2,3,6,7
TOTAL TEMPERATURE	0.624	0.646
TOTAL PRESSURE	.698	.722
TOTAL TEMPERATURE	1.081	1.119
TOTAL PRESSURE	1.209	1.251
TOTAL TEMPERATURE	1.396	1.444
TOTAL PRESSURE	1.56	1.615
TOTAL TEMPERATURE	1.651	1.709
TOTAL PRESSURE	1.81	1.875
TOTAL TEMPERATURE	1.872	1.938
STATIC PRESSURE	2.038	2.038

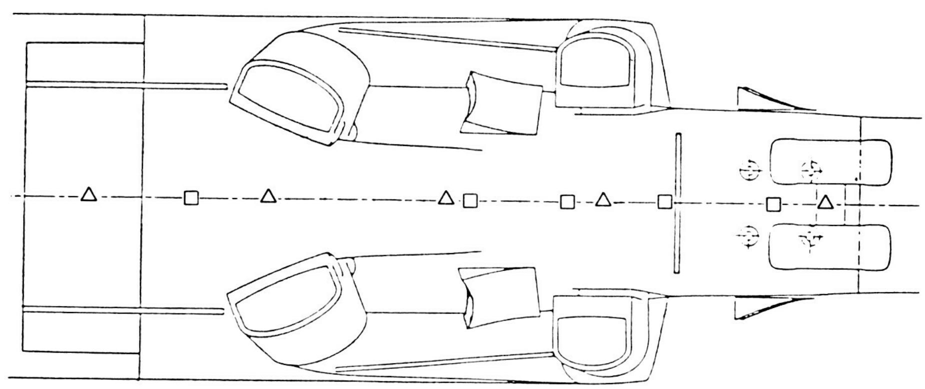


(a) COMPRESSOR FACE RAKE. (VIEW LOOKING DOWNSTREAM.)

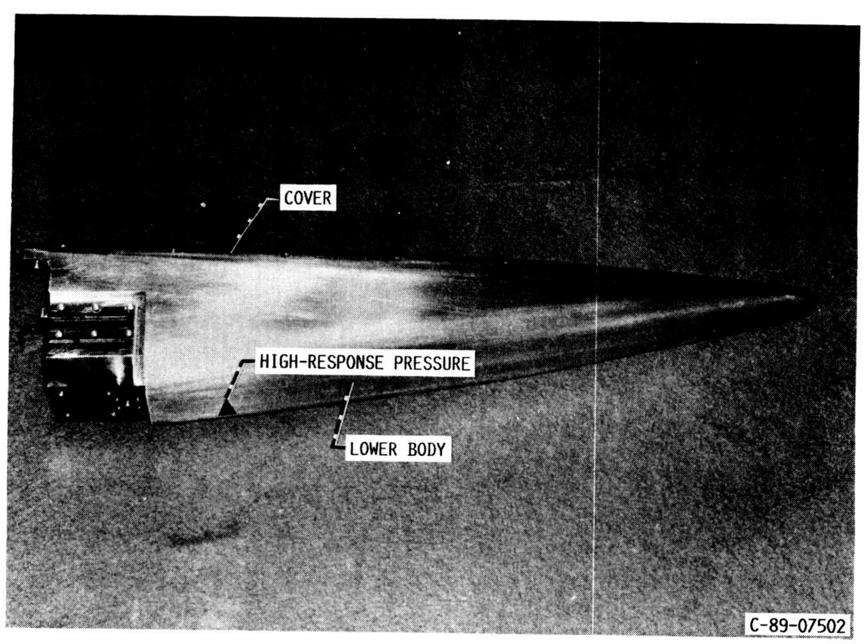
FIGURE 13. - SHORT TAKEOFF AND VERTICAL LANDING (STOVL) MODEL INSTRUMENTATION.



(b) FORWARD FUSELAGE UNDERSURFACE.



(c) CENTER FUSELAGE UNDERSURFACE.



(d) AFT FUSELAGE SECTION.
FIGURE 13. - CONCLUDED.

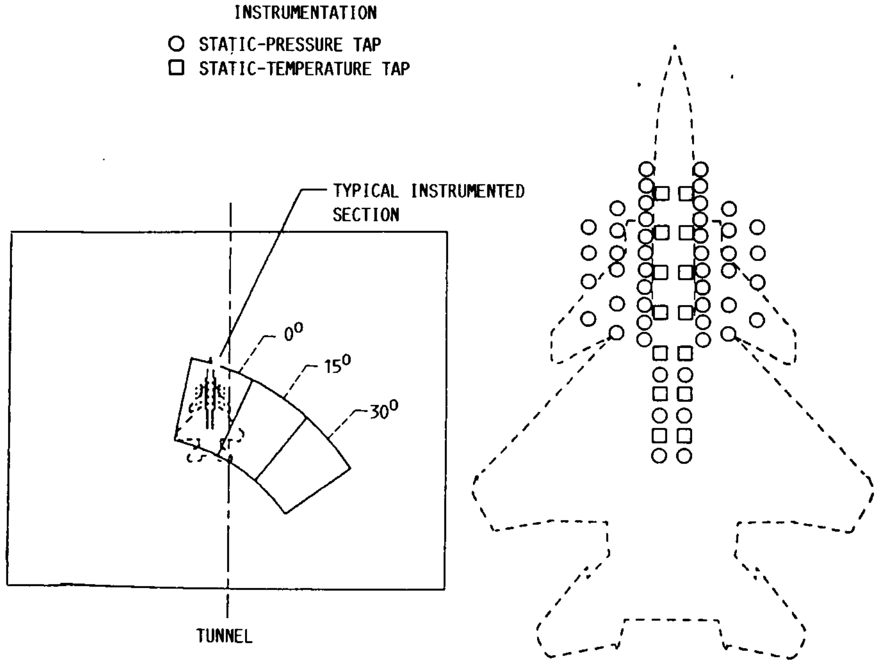
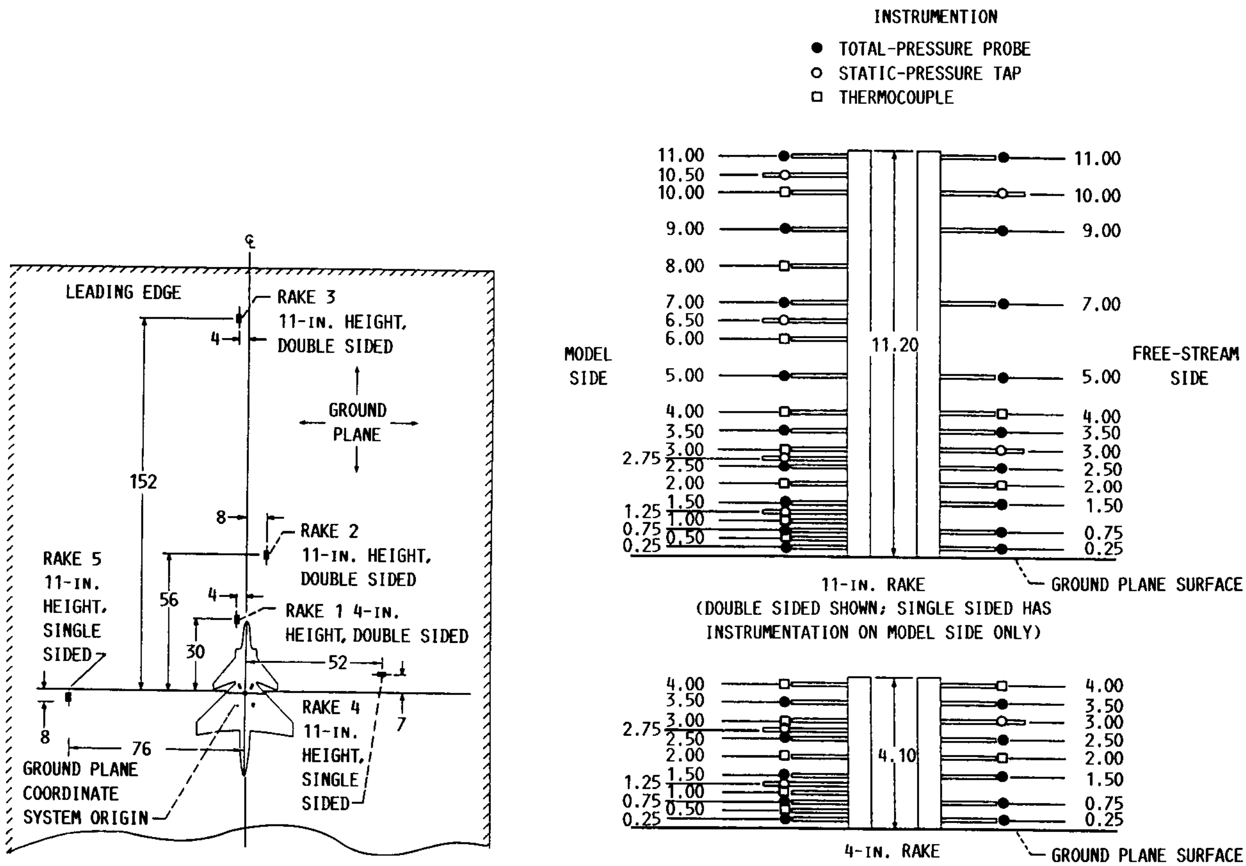


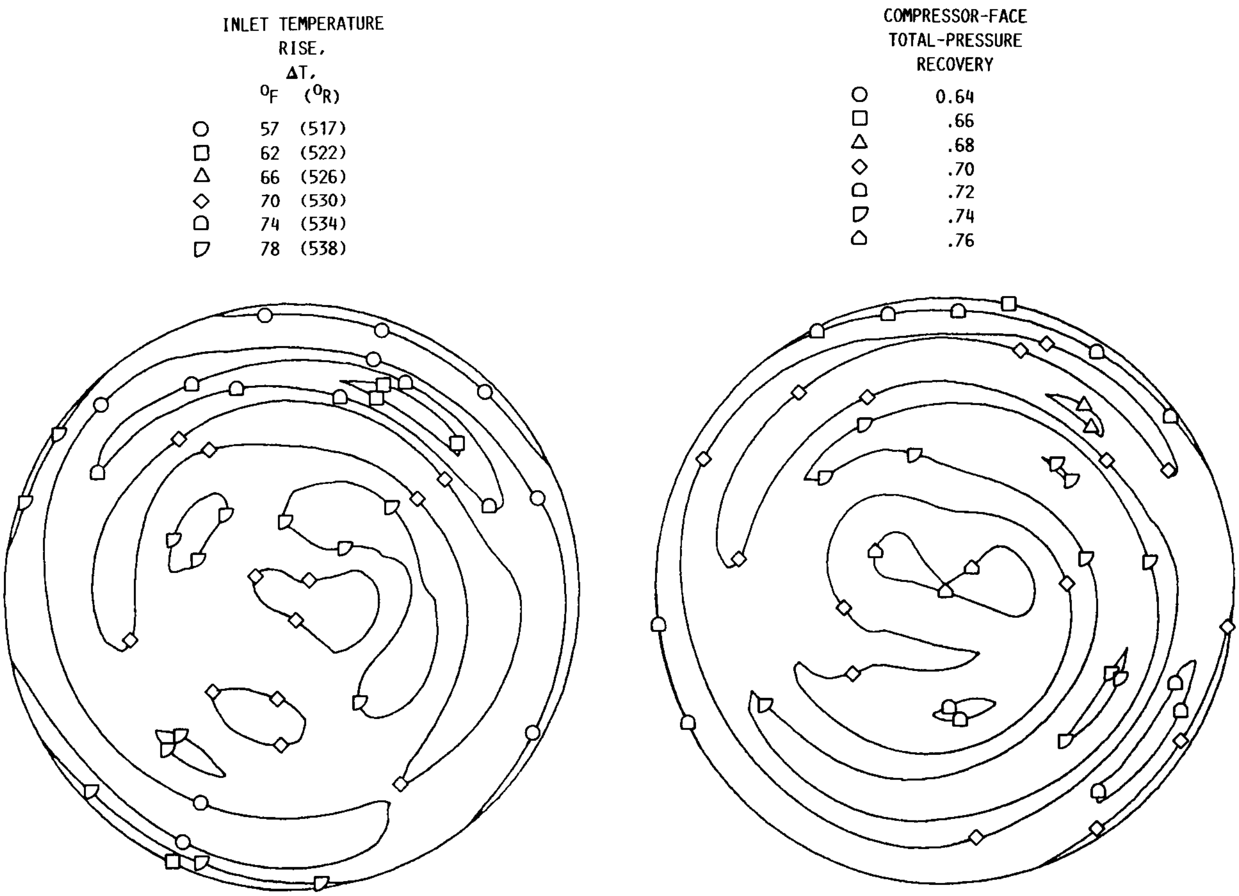
FIGURE 14. - MODIFIED F-15 MODEL GROUND PLANE INSTRUMENTATION (INSTRUMENTATION AND MODEL RELATIONSHIP MAINTAINED AT 0°, 15°, AND 30°).



(a) STOVL MODEL.

(b) STOVL MODEL GROUND PLANE RAKES.

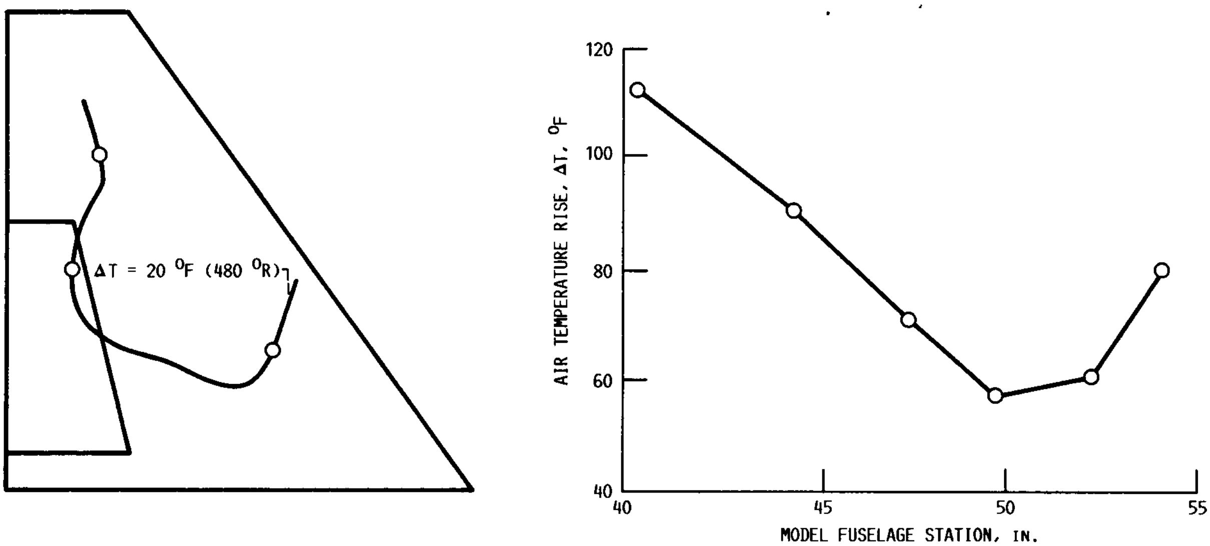
FIGURE 15. - SHORT TAKEOFF AND VERTICAL LANDING (STOVL) MODEL GROUND PLANE INSTRUMENTATION. (ALL DIMENSIONS ARE GIVEN IN INCHES.)



(a) INLET TEMPERATURE RISE.

(b) COMPRESSOR-FACE TOTAL-PRESSURE RECOVERY.

FIGURE 16. - TYPICAL COMPRESSOR FACE CONTOUR MAPS AT ZERO YAW FOR THE MODIFIED F-15. THRUST REVERSER ANGLE, 135°; NOZZLE PRESSURE RATIO, 2.70; INLET MACH NUMBER, 0.30; NOZZLE EXHAUST TEMPERATURE, 960 °R; FREE-STREAM VELOCITY, 100 KN.



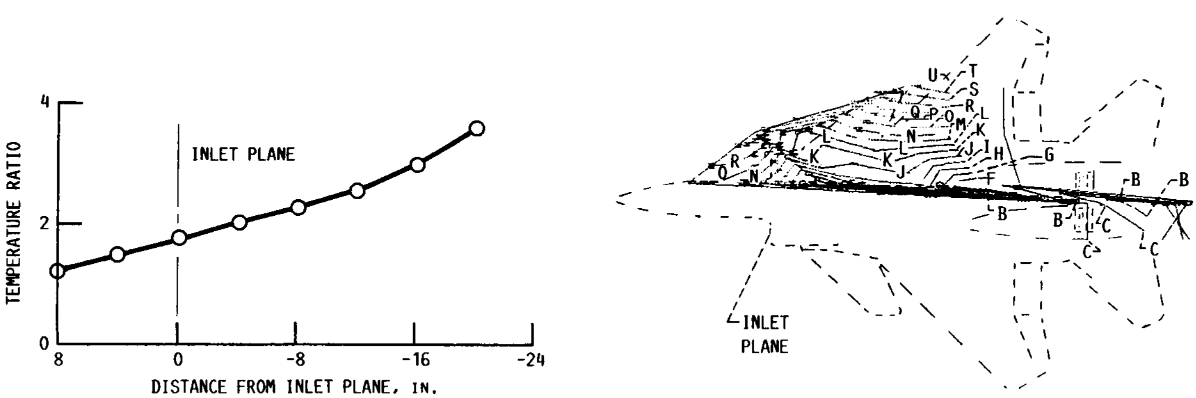
(a) VERTICAL TAIL TEMPERATURE CONTOUR.

(b) FUSELAGE UNDERSURFACE AIR TEMPERATURE DISTRIBUTION.

FIGURE 17. - TYPICAL AIRFRAME HEATING CHARACTERISTICS FOR THE MODIFIED F-15. THRUST REVERSER ANGLE, 135°; NOZZLE PRESSURE RATIO, 270; INLET MACH NUMBER, 0.30; NOZZLE EXHAUST TEMPERATURE, 960 °R; FREE-STREAM VELOCITY, 100 KN.

GROUND PLANE PRESSURE RATIO

A	0.9882	K	0.9941
B	.9888	L	.9947
C	.9894	M	.9953
D	.9899	N	.9959
E	.9906	O	.9965
F	.9911	P	.9970
G	.9917	Q	.9975
H	.9928	R	.9982
I	.9929	S	.9988
J	.9935	T	.9994
		U	1.0000



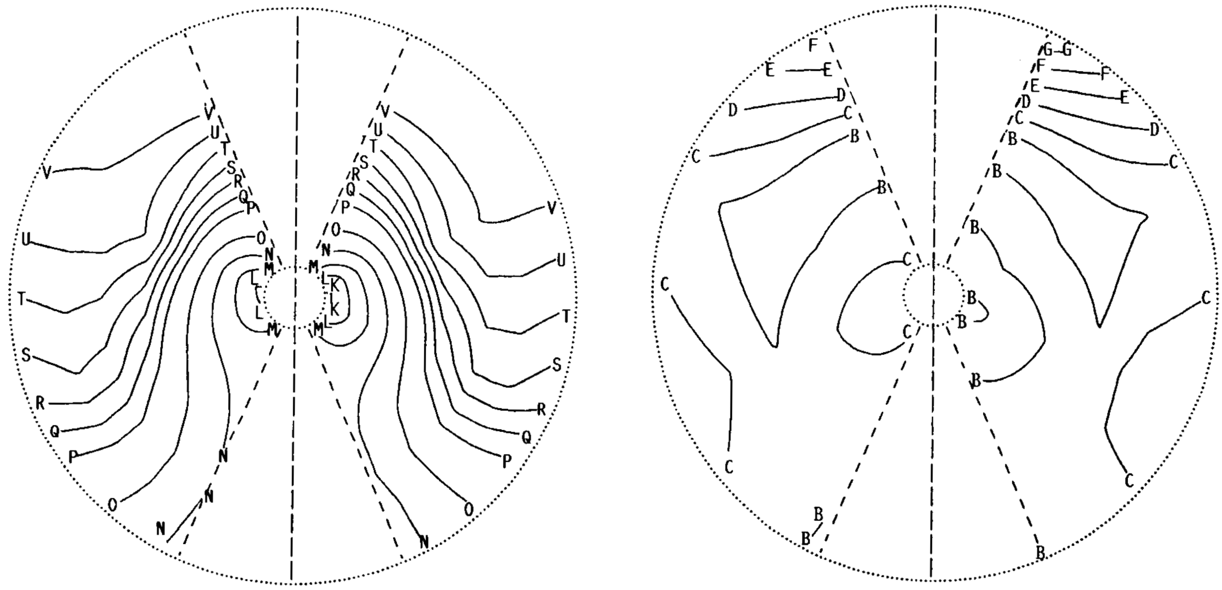
(a) TEMPERATURE PROFILE.

(b) STATIC PRESSURE CONTOUR.

FIGURE 18. - TYPICAL GROUND PLANE PROFILES FOR MODIFIED F-15 CONCEPT. THRUST REVERSER ANGLE, 135°; NOZZLE PRESSURE RATIO, 2.70; INLET MACH NUMBER, 0.30; NOZZLE EXHAUST TEMPERATURE, 960 °R; FREE-STREAM VELOCITY, 100 KN.

	TEMPERATURE RISE, ΔT, ^{0}F
K	100.0
L	90.0
M	80.0
N	70.0
O	60.0
P	50.0
Q	45.0
R	40.0
S	35.0
T	30.0
U	25.0
V	20.0

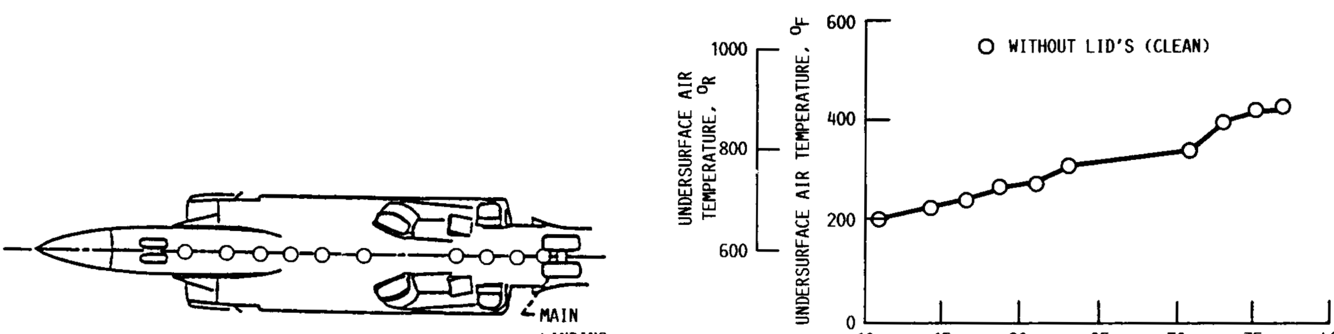
	PRESSURE RECOVERY
B	0.990
C	.980
D	.970
E	.960
F	.950
G	.940



(a) TEMPERATURE RISE. AVERAGE TEMPERATURE RISE, 44 ^{0}F; TEMPERATURE DISTORTION, 0.103.

(b) PRESSURE CONTOUR. AVERAGE PRESSURE RECOVERY, 0.9827; PRESSURE DISTORTION, 0.052.

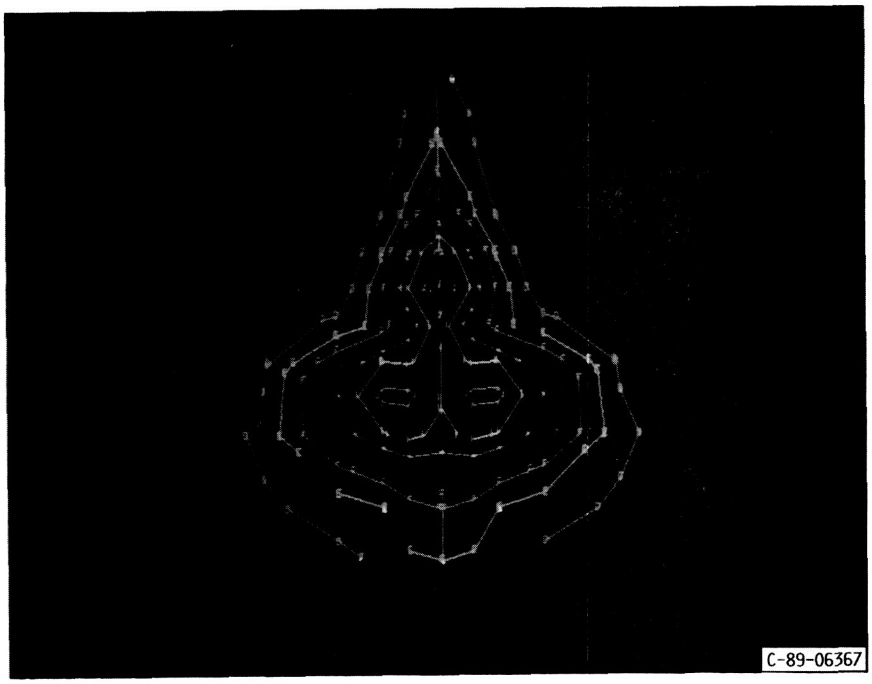
FIGURE 19. - TYPICAL CONTOUR MAPS AT THE COMPRESSOR FACE FOR MODEL 279-3C. (LOOKING UPSTREAM.)



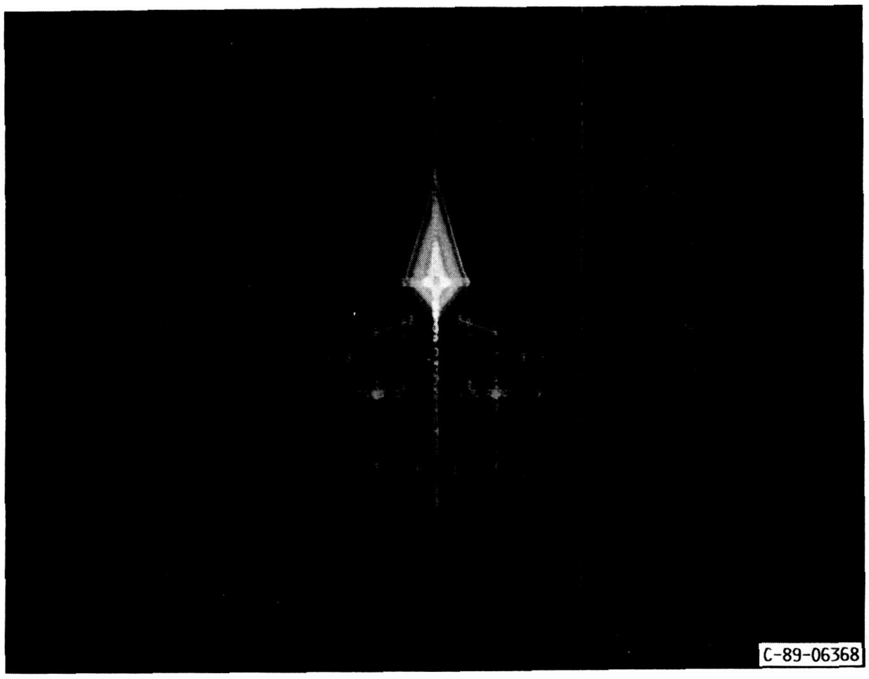
(a) UNDERSURFACE OF MODEL 279-3C.

(b) AIR TEMPERATURE DISTRIBUTION.

FIGURE 20. - MODEL 279-3C UNDERSURFACE AIR TEMPERATURE DISTRIBUTION. MAIN GEAR HEIGHT, 0.43 IN.; NOZZLE PRESSURE RATIO, 3.02; COMPRESSOR-FACE MACH NUMBER, 0.40; FORWARD NOZZLE SPLAY, -6^{0}; PITCH ANGLE, 6.5^{0}; NOZZLE EXHAUST TEMPERATURE, 960 ^{0}R; HEADWIND VELOCITY, 23 KN.

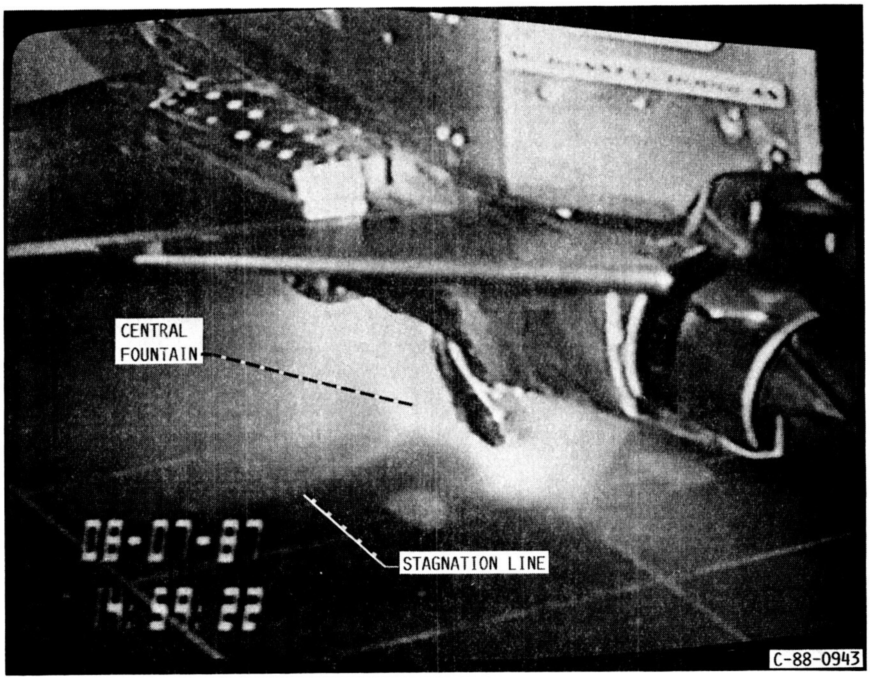


(a) TEMPERATURE CONTOUR.

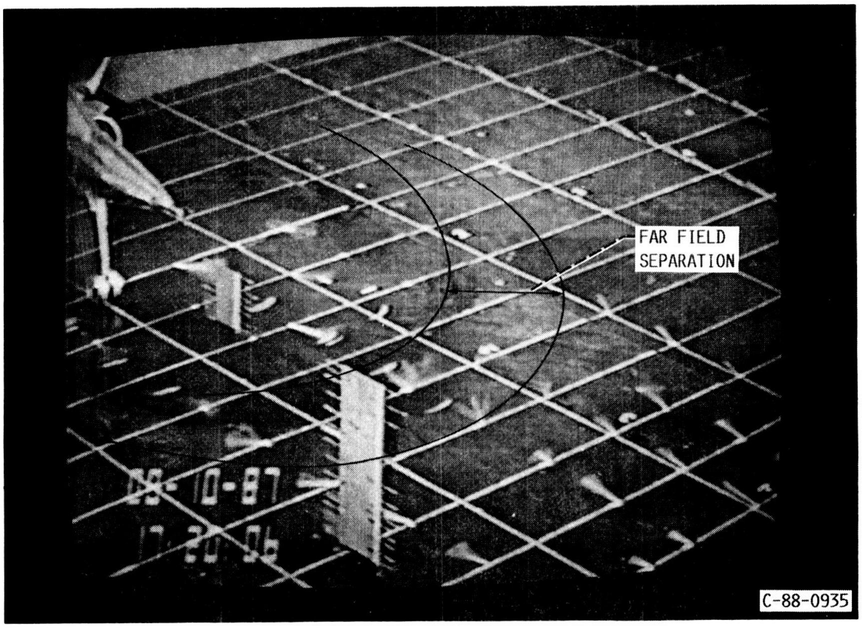


(b) PRESSURE CONTROL.

FIGURE 21. - TYPICAL GROUND PLANE CONTOURS FOR THE STOVL CONCEPT (MODEL 279-3C).



(a) NEAR-FIELD FLOW CHARACTERISTICS.



(b) FAR-FIELD SEPARATION CHARACTERISTICS.

FIGURE 22. - FLOW VISUALIZATION RESULTS.

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BLACK AND WHITE PHOTOGRAPH

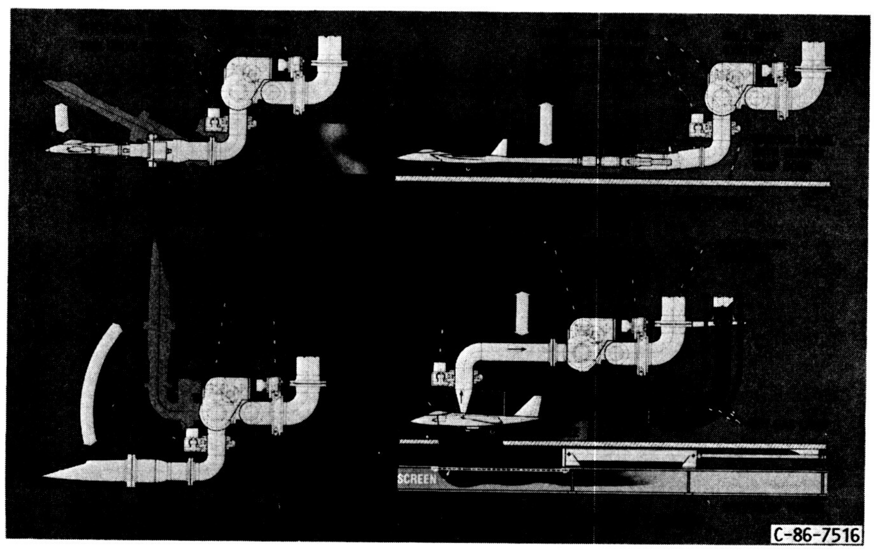

FIGURE 23. - PROPOSED MODEL INTEGRATED SUPPORT SYSTEM (MISS) FOR VERSATILE AND EFFICIENT RESEARCH TESTING.

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15. Supplementary Notes

16. Abstract

Short takeoff and landing (STOL) and advanced short takeoff and vertical landing (STOVL) aircraft are being pursued for deployment near the end of this century. These concepts offer unique capabilities not seen in conventional aircraft: for example, shorter takeoff distances and the ability to operate from damaged runways and remote sites. However, special technology is critical to the development of this unique class of aircraft. Some of the real issues that are associated with these concepts are hot gas ingestion and airframe heating while in ground effects. Over the past nine years, NASA Lewis Research Center has been involved in several cooperative programs in the 9- by 15-Foot Low-Speed Wind Tunnel (LSWT) to establish a database for hot gas ingestion and airframe heating. This report presents the modifications made in the 9- by 15-Foot LSWT—including the evolution of the ground plane, model support system, and tunnel sidewalls; and flow visualization techniques, instrumentation, test procedures, and test results. The 9- by 15-Foot LSWT tests were conducted with independent inlet and exhaust nozzle controls for the models. The tests were conducted at full-scale exhaust nozzle pressure ratios. The headwind velocities varied from 8 to 120 kn depending on the concept (STOL or STOVL). Typical compressor-face distortions (pressure and temperature), ground plane contours, and model surface temperature profiles are presented.

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