AN INVESTIGATION OF SCALE MODEL TESTING OF VTOL AIRCRAFT IN HOVER

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and
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Abstract

Utilizing the unique opportunity created by full scale hover testing of the twin-jet Grumman Design 698 VTOL aircraft in the NASA-Ames Hover Facility, a series of experiments was conducted to evaluate the effectiveness of scale model testing in predicting full scale behavior. Interference forces were found to be sensitive to aircraft lower surface geometry, but when the geometry was modeled accurately the small scale results matched full scale forces quite well. The interference forces were found to be insensitive to core nozzle temperature and fan nozzle pressure ratio. The results clearly demonstrate that small scale models can be reliably utilized for aircraft and technology development when the appropriate sensitivities are recognized.

Introduction

The propulsion induced forces acting on a VTOL aircraft when operating in ground effect during landing and takeoff generally prove to be the governing factor in propulsion system sizing. Since the thrust required for forward flight is much less than the aircraft weight, the hover requirement determines the engine thrust and weight. A downward interference force during takeoff results in an increased engine size and weight. As an example of this sensitivity parametric studies have shown that a downward directed interference force of five percent of the thrust results in a loss in mission radius or payload of approximately forty percent. Determination of these forces requires prediction methods during early design stages, and scale model testing for development. One of the prime problems in developing and evaluating the accuracy of both the analysis methods and model testing programs has been the unavailability of full scale data.

A significant improvement was made in this state of affairs by the recent NASA-Navy-Grumman full scale testing program of the Grumman Design 698 twin tilt nacelle fanjet aircraft in the NASA Ames Full Scale Hover Facility (Ref 1-3). Responding to the unique opportunity created by these full scale tests, a careful scale model testing program was conducted to determine the adequacy of scale model testing for predicting full scale behavior. These experiments were conducted at the Grumman Research and Development Center in the Low Speed Flow Research Laboratory and the Grumman Environmental Test Facility using geometrically accurate models of 1/24th scale (Ref 4). Further experiments were conducted in these facilities with a 1/48th scale model and are reported here.

Since scale model test facility capabilities often preclude matching all full scale conditions, the sensitivity of the results to basic parameters such as nozzle temperature and total pressure were also investigated. Results are presented as comparisons of measured interference forces obtained on the small scale and full scale models. In addition, the effects of the fan nozzle total pressure, the core nozzle total temperature, and the nozzle and aircraft geometry on interference forces are presented. Comparisons of full scale and model scale results for aircraft lower surface pressures, ground plane pressures, and ground plane wall jets are presented in succeeding sections.

Aircraft Configuration

The full scale aircraft tested in the NASA Ames Hover Facility was a twin fan jet, tilt nacelle subsonic aircraft designated Design 698-411B. A feasible aircraft design, utilizing real TF-34 fanjet engines, this demonstration model is constructed for ground interference and wind tunnel testing in an inexpensive but overweight fashion and can therefore not sustain actual vertical flight. A description of this vehicle and the hover test results can be found in Ref 1-4. A photograph of the aircraft is shown in Fig. 1.

Models of 1/24th and 1/48th scale were constructed for the investigations described; photos of these models are shown in Fig. 2. The models matched the full scale geometry with a few exceptions. The most significant differences involved the propulsion system simulation. The nozzle flow was accurately modeled by continous pipes scaled to equal the fan nozzle diameter, and the inlet suction flow was not simulated. The small scale fanjet nozzles were modeled with a circular cross section in contrast to the full scale TF34 engines which have fan nozzles with an "egg-shaped" cross section (see Fig. 3). The control vanes in the nozzle flow of the full scale engines were not present in either of the scale models. All of the full scale data examined in this paper are for conditions with no vane deflection, i.e., vanes are aligned with the flow. A more thorough description of the scale models and experimental facility used in this work is given in Ref 4.

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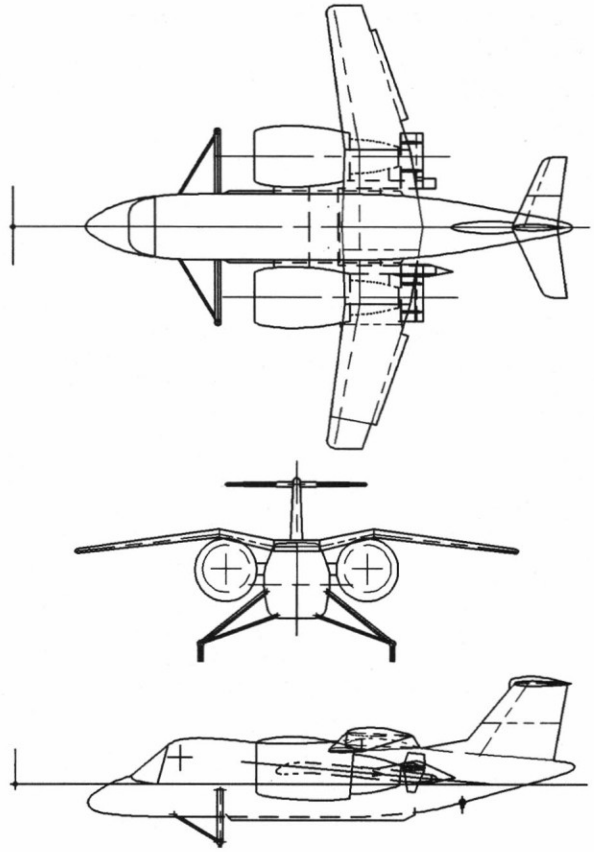
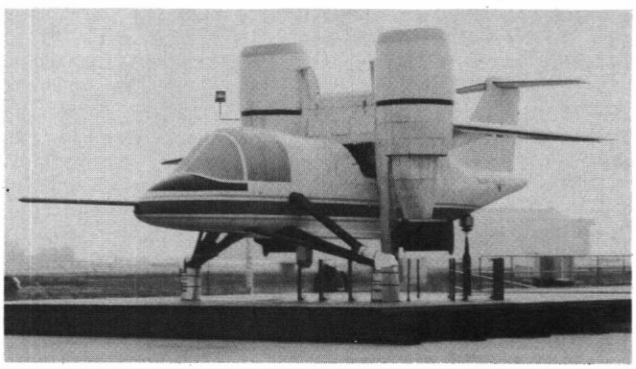
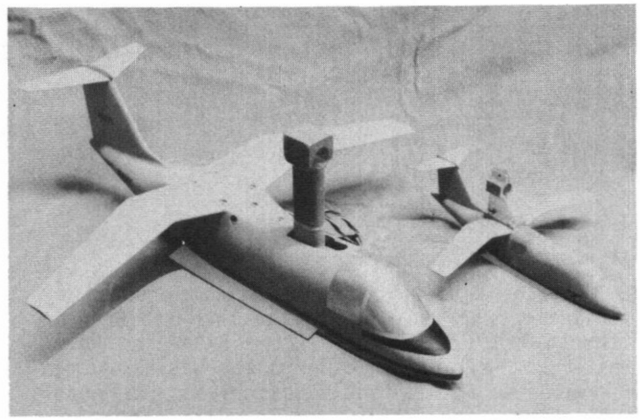


a) AIRCRAFT GEOMETRY

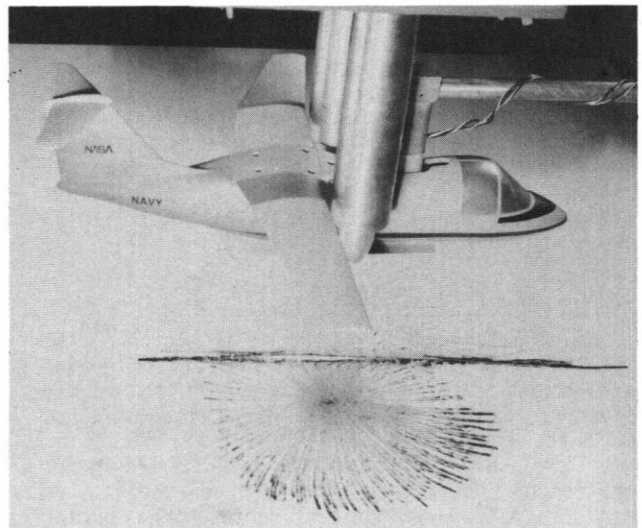


b) FULL SCALE MODEL ON TEST STAND

FIGURE 1 Grumman Design 698-411B, Twin-Jet Tilt Nacelle Aircraft



a) 1/24th AND 1/48th SCALE MODELS USED IN THIS STUDY



b) 1/24th SCALE MODEL INSTALLED IN FACILITY NOTE NOZZLE FLOW APPROACH TUBES AND BALANCE ATTACHMENTS STRUCTURE.

FIGURE 2 Small Scale Models

Forces

The forces on the aircraft induced by the propulsion system while operating in hover in ground effect are probably the most important aspect of V/STOL performance predictions. In the course of investigating the adequacy of scale model testing for predicting these forces, we varied model scale and nozzle flow conditions. Interference forces are sensitive to the geometry (cf Ref 5), so all experiments were conducted with as accurate a modelling of the fanjet nozzles, nozzle flow properties, and aircraft geometry we could provide, except for those cases where the parameters were deliberately varied for sensitivity investigations.

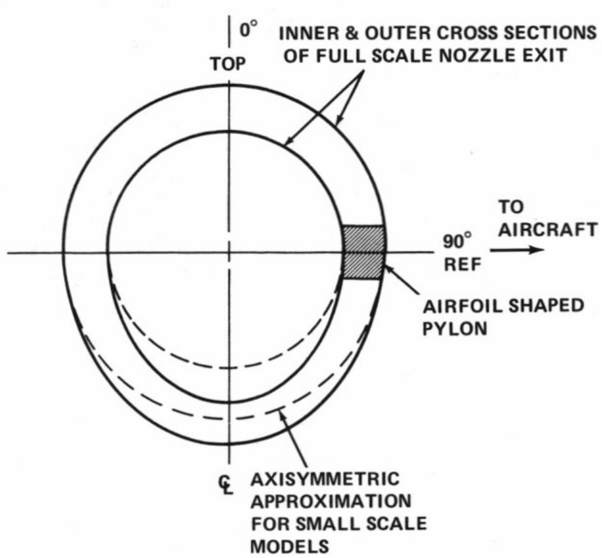


FIGURE 3 Fanjet Nozzle Exhaust Geometry

Figure 4 presents a comparison of full scale interference force measurements versus height above the ground (Ref 1,2,3) with 1/24th scale model results (Ref 4). In this figure and Fig. 5-8, the interference force is nondimensionalized by the total thrust and the height above ground by the outer diameter of the fanjet nozzle. The small scale results with a core nozzle total temperature of 415°C pass very close to the average values of the full scale results where the core nozzle total temperature was approximately 460°C. The full scale tests were conducted at the three values of height above ground indicated on the figure, while the scale model tests were run with a continuous traverse, as shown. The full scale results showed a very large variation in force from run to run (Ref 1 & 3). This range was reduced in Ref 2 by utilizing only the data from the highest thrust levels. More will be said about this variation later.

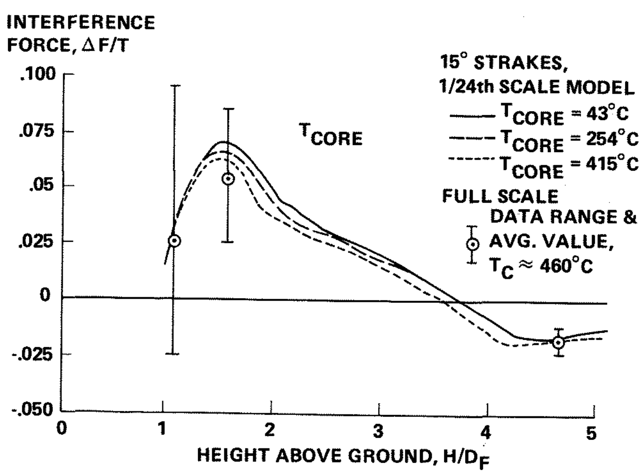


FIGURE 4 **Comparison of Full Scale and 1/24th Scale Propulsion Induced Forces. Effect of Core Nozzle Temperature is Also Shown.**

Since many small scale test facilities cannot duplicate all aspects of engine flow, the sensitivity of the forces to the fundamental parameters was investigated in a series of experiments. The scale model test results in Fig. 4 show that changing the core temperature from 415°C to ambient resulted in a small change in the interference forces. The qualitative behavior is the same, and the temperature effects appear to be amenable to correlation.

Figure 5 illustrates negligible sensitivity of the normalized interference forces to the fan nozzle total pressure (Ref 4), indicating that the matching of pressure levels is not necessary.

To further increase our knowledge of the effect of model scale and geometry on interference force, additional experiments were conducted with a similar 1/48th scale model. Figure 6 compares results for two scale models for the cases of both 15° and 45° strakes. The agreement is good, and the scale model results fall close to the average of the full scale

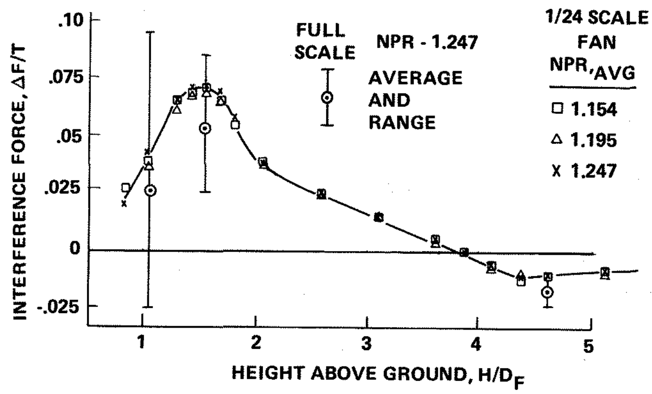


FIGURE 5 **Forces Effect of Fan Nozzle Pressure on Interference**

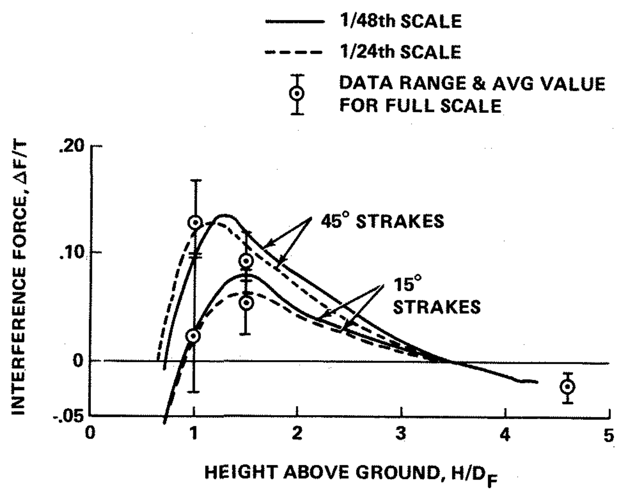


FIGURE 6 **Comparison of Measured Interference Forces on the 1/24 & 1/48th Scale Models.** *Full scale data was available for these conditions and is also shown for comparison.*

results. Further experiments were run with these two scale models for conditions not included in full scale testing to extend the range of geometries examined (Fig. 7). Agreement is good for 90° strakes and for a flat, sharp cornered lower surface, but a rounded fuselage corner without strakes produces larger differences. This sensitivity is probably due to Reynolds number dependent phenomenon, similar to the effect of corner radius observed in Ref 5.

The differences in these results for different fuselage shapes indicate the sensitivity of forces to geometry. Another example of this sensitivity (Ref 4) can be found in the effects of the nozzle flow geometry, as shown in Fig. 8. This figure illustrates the differences in interference forces when uniform circular nozzle flow is used instead of the fanjet simulation. Note that total temperature variations produced only small changes in forces for these open nozzles also.

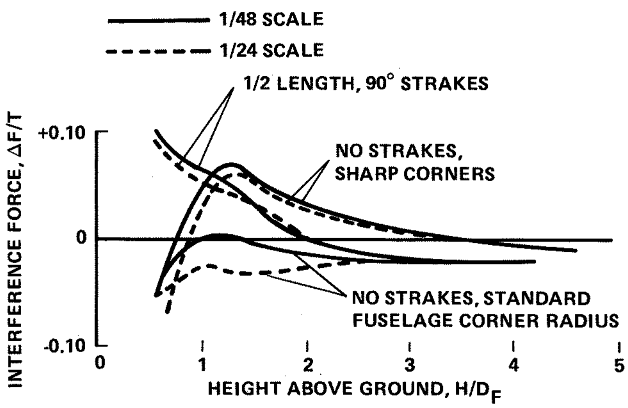


FIGURE 7 Sensitivity of Interference Force to the Geometric Detail of the Fuselage Bottom Surface

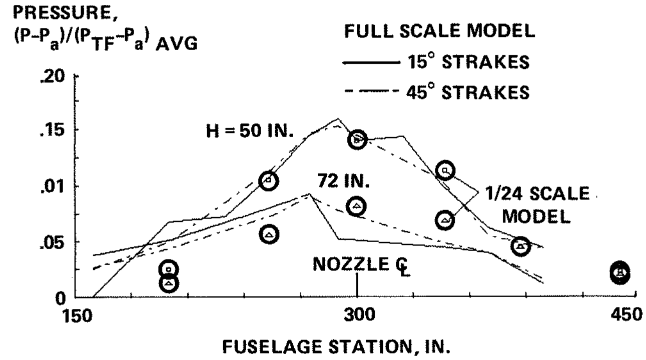


FIGURE 9 Comparison of the Measured Centerline Pressure Profiles, on the Bottom of the Fuselage, for the Full Scale and 1/24th Scale Models

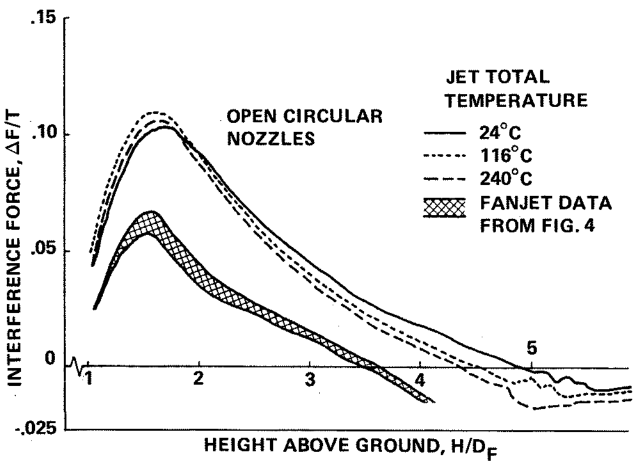


FIGURE 8 Sensitivity of Interference Force Results to Nozzle Simulation: Open Circular Nozzles Produce Much Larger Forces Than Fanjet Nozzles

Fuselage Surface Pressures

Pressures on the undersurface of the fuselage are the key driving factor for the induced forces acting on a high wing aircraft such as Design 698. The pressures measured along the centerline of the fuselage bottom for full scale (Ref 3) and 1/24th scale (Ref 4) tests are compared in Fig. 9. Pressures measured on the fuselage are normalized by the fanjet average total pressure. The results show good agreement at the 50 in. height above ground and fair agreement at 72 in. It should be noted that several pressure taps on the full scale model were inoperative at the time these data were taken, particularly during the 72 in. runs. The full scale data are drawn as straight lines between valid data points, and this could be responsible for some of the disagreement between model and full scale results.

In search of a clue to the cause of the wide variation in interference forces observed during the full scale tests, the centerline fuselage pressures were examined for a number of data points at the 50 in. height, including runs which yielded the wide range of interference forces shown in Fig. 4. As seen in Fig. 10 the large range of forces cannot be accounted for by the centerline pressure variation. Further investigations will be needed to determine the pressure distributions and time history of the pressures in detail.

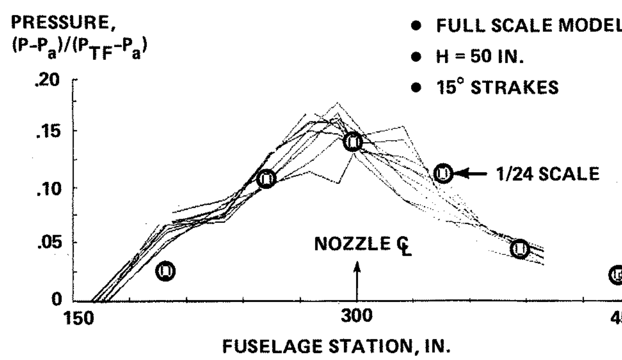


FIGURE 10 **Full Scale Fuselage Pressure For a Number of Runs.** *ΔF/T varied from 0.8% to 7.5% for these runs. For comparison, the 1/24th scale result with 15° strakes are shown*

Ground Plane Pressures

Pressures were measured at a range of locations on the ground plane beneath the aircraft. The most representative view of these pressures is the distribution along the line connecting the centerline of the jet impingement points. This gives a measure of both the jet impingement process and the fountain upwash formation process. Results from the full scale tests do not show as good an agreement with the small scale results for the ground plane pressures as they did for properties measured on the vehicle, but they do exhibit a qualitative similarity.

Figure 11 shows the ground pressure variation along the line drawn between (and past) the two jet impingement centers, for three body heights above the ground at 1/24th scale. Distance along the ground plane (y) has been nondimensionalized by the fanjet outer diameter and the pressure by the average value of the fan total pressure. The core nozzle flow is at room temperature for these runs. Note that close to the ground the profiles under the two nozzles are not identical, and that some unevenness occurs in the level of the distributions. We have found this to be common for impingement of fanjet plumes with a core total pressure lower than the fan total pressure (cf Ref 6). Figure 12 shows a comparison of these data with full scale data. The full scale data show higher ground pressures in the jet impingement region, with a narrower peak that is shifted away from the jet centerline. This may be due to the presence of the control vanes in the full scale exhaust,which were not present in the model flow. Ground pressures in the stagnation line region shows better agreement than in the impingement region, with the full scale pressures lower than those for the small scale model.

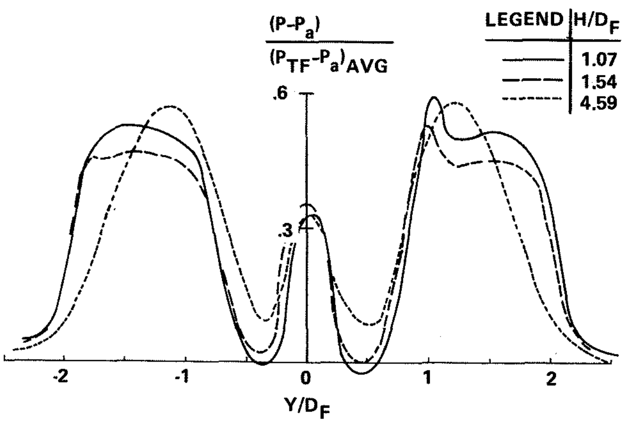


FIGURE 11 Ground Pressure Profiles for the 1/24th Scale Model with Fan Jet Impingement (Ref 4)

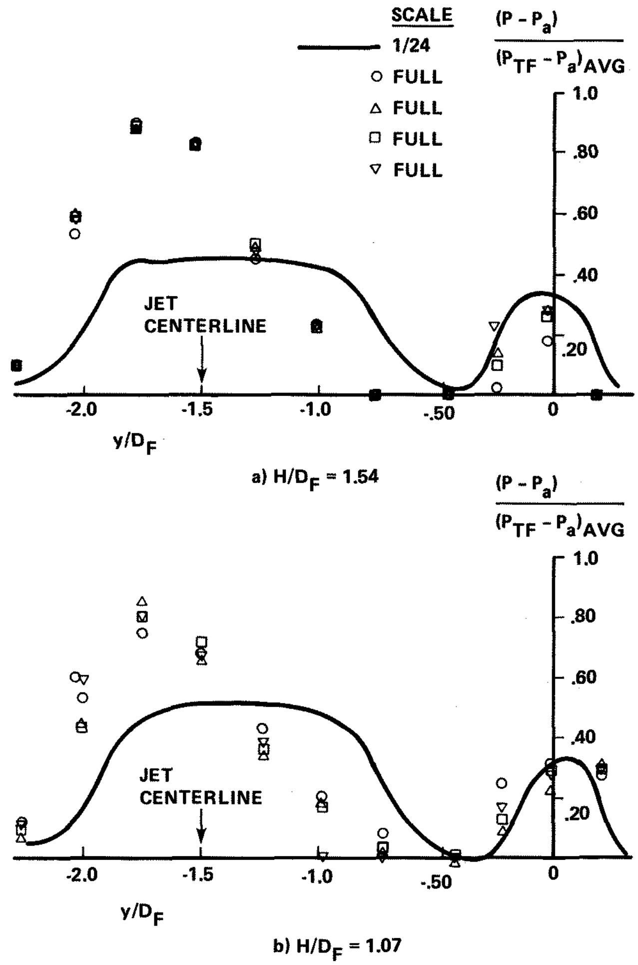


FIGURE 12 Comparison of Ground Plane Pressures, Full Scale vs 1/24 Scale

Wall Jet Measurement

In the full scale experiments total pressure profiles were measured in the wall jets spreading from the impingment center of one of the engine exhausts by a series of fixed location rakes. In the 1/24th scale flow the total pressure data were taken as continuous profiles by traversing a probe through the wall jet at points corresponding to some of the full scale rake locations. Figure 13 shows a comparison between full scale and 1/24th scale profiles at two corresponding probe locations with the probe data normalized by the average total pressure at the fan nozzle exit plane. Wall jet profiles have been characterized by the maximum Mach number and the thickness at the half-velocity point ($Z_{.5}$).

These properties are shown in Fig. 14 compared with full scale data from Ref 2. The data are plotted as a function of circumferential angle, θ, about the jet impingement point, where θ = 0° represents the forward direction parallel to the fuselage centerline. The full scale data show higher maximum pitot pressures and a more rapid decay with height above ground than the 1/24th scale data. This difference may be due to the presence of the control vanes in the full scale fan exhaust flow and is similar to the shift observed in the ground plane pressure distributions. The 1/24th scale experiments were run without these vanes in the exhaust. In a similar series of experiments with a different engine configuration (Ref 6) a closer agreement between small scale and full scale wall jet properties was obtained, Fig. 15. In Fig. 15, V_M is the maximum velocity in the wall jet, V_F is the fan nozzle velocity, $Z_{.5}$ is the height in the wall jet were the velocity is one half of its maximum value, and R is the radial distance from the nozzle impingement center.

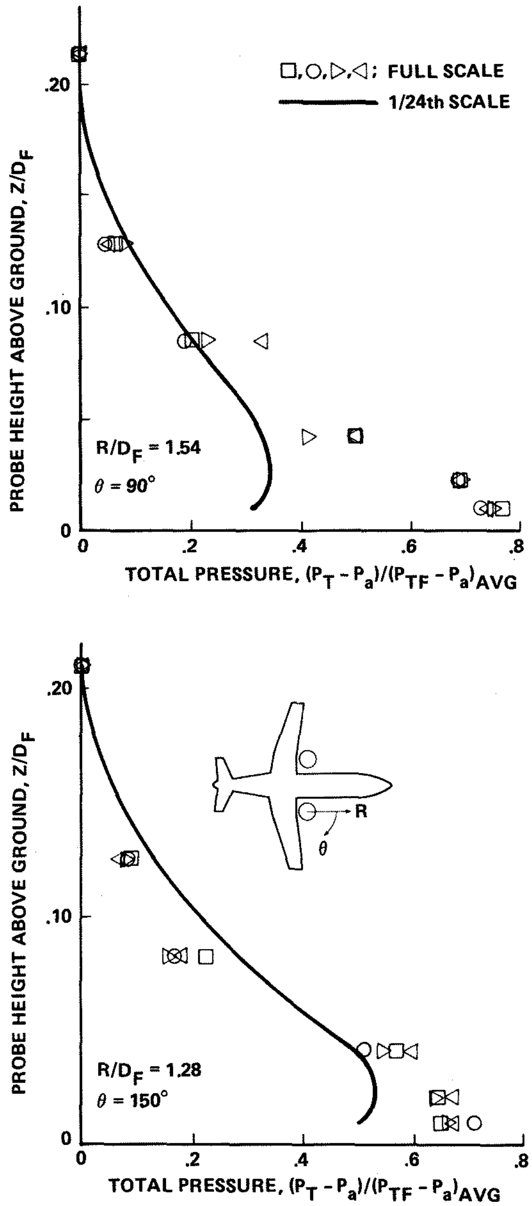


FIGURE 13 Comparison of Full Scale & 1/24th Scale Wall Jet Pressure Profiles

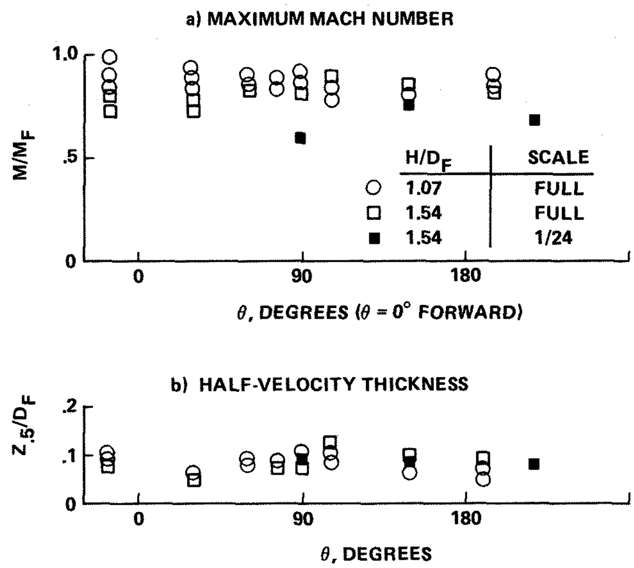


FIGURE 14 Comparison of Full Scale & 1/24th Scale Wall Jet Mach No. and Thickness

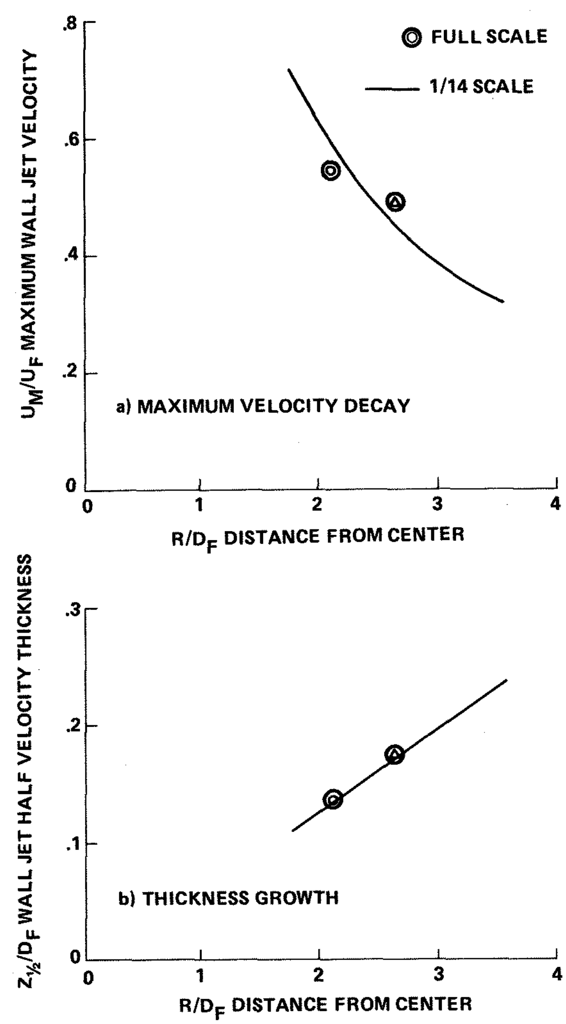


FIGURE 15 Radial Wall Jet Variation (Ref 6)

Conclusions

A comparison between measurements of interference forces and aircraft surface pressures in ground effect for full scale and small scale models of the Grumman V/STOL Design 698, showed good agreement. Model tests at 1/24th and 1/48th scale showed the normalized forces to be very sensitive to the lower surface and nozzle geometry, and relatively insensitive to the nozzle total pressure (0.7 to 3.6 psig) or total temperature (ambient to 420°C). Flow properties on the ground showed large differences between full scale and small scale results, a presently unexplained phenomena.

References

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