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## NOMENCLATURE

D Effective jet diameter, 10.39 cm (4.09 in.)

EVV Extended vertical vane deflections, $20° \leq \delta_{VV} \leq 70°$

H Height above deck measured to bottom of fuselage in the plane of the jet centerline

HV Horizontal vanes

$\Delta pm$ Change in pitching moment coefficient due to horizontal vane deflection, $\Delta pm = pm_{HV=-10°} - pm_{HV=+10°}$

OEI One engine inoperative

TPS Turbofan propulsion simulator

VV Vertical vanes

$\phi$ Roll angle between model and deck, positive right wing down

$\theta$ Pitch angle between model and deck, positive model nose up

## SUMMARY

Characteristics in hover of an 11.36%-scale, powered, twin-tilt nacelle model were measured in the NASA Ames Research Center's 40- by 80-Foot Wind Tunnel. The model was powered by two high-pressure air-driven turbofan propulsion simulators. The position of the sting-mounted model was fixed and a movable ground plane was used to vary ground height and orientation. Hover characteristics were investigated in and out of ground effect for roll angles of -2° to +14° and pitch angles of -15° to +10°. Results for the basic configurations are compared with data from hover tests of the full-scale tilt nacelle model. Two methods were investigated to increase vertical vane effectiveness: (1) extending the maximum vane deflection from 20° to 70°, and (2) adding a third vertical vane. The goal was to increase the roll-control capability to significantly reduce or balance the strong, unfavorable rolling moment created by the loss of one engine. Results indicate that the three-vertical-vane configuration is more effective than two vertical vanes and that extended vane deflections significantly reduce the engine-out roll in hover.


## INTRODUCTION

For several years, NASA, Grumman Aerospace Corporation, and the Navy have been involved in a joint program to develop the technology for a subsonic, tilt nacelle V/STOL aircraft. This concept is interesting because of its simplicity and unique control system. The aircraft is powered by two high-bypass turbofan engines which are mounted to a single carry-through structure, sometimes called the dumbbell assembly, which allows them to rotate from 5° to 100°. During nacelle rotation, the thrust centerline is kept close to the aircraft's center of gravity to minimize trim requirements. Aircraft control is provided by control vanes submerged in the fan exhaust during hover and transition. The control vane assemblies are rigidly attached to the nacelle structures so that the relative position between the vanes and the engine nozzles are maintained at all nacelle angles. As the aircraft transitions to conventional flight, the control vanes are phased out and aerodynamic controls are phased in.

Extensive research has been done on this design beginning with component testing and radio-controlled models (refs. 1-4). The characteristics of a full-scale model powered by two General Electric TF-34 turbofan engines were studied in the NASA Ames Research Center 40- by 80-Foot Wind Tunnel in 1980 and at the Ames Outdoor Aerodynamic Research Facility in 1980 and 1983 (refs. 5-7). In addition, several piloted simulations have been completed (refs. 8 and 9). Most of the research has concentrated on hover and transition characteristics.

As part of this ongoing joint research program, characteristics of a small-scale powered model in hover were studied in the Ames 40- by 80-Foot Wind Tunnel. The goals of the hover test were to

1. Determine scale effects by comparison of the basic configurations with results from the full-scale model.

2. Define the hover characteristics over a rolled or pitched surface.

3. Investigate two methods of increasing control vane effectiveness.

4. Expand the database for programming flight simulators.

## MODEL/TEST DESCRIPTION

The model was an 11.36%-scale model of Grumman Design 698-411. The scale was determined by the size of the two turbofan propulsion simulators which were used to power the model. Design and fabrication of the model was done by Grumman Aerospace Corporation under contract to NASA. The model geometry is shown in figure 1 and a photograph of the model in the wind tunnel is shown in figure 2. The underside of the fuselage was equipped with longitudinal strakes designed to improve the favorable fountain effects. The strakes were fixed at 15° for the entire test. The control vane geometry is shown in figure 3. The vertical vane assembly on the port side was modified to increase the maximum deflection from 20° to 70° and to add a third vertical vane midway between the original vanes. For a vertical-vane deflection of 50°, the inboard fence on the horizontal vane was removed and for a deflection of 70°, both fences on the horizontal vanes were removed.

Two high-pressure air-driven turbofan propulsion simulators (TPS) were used to power the model. Each TPS has a 13-cm-diam (5-in.) two-stage fan driven by a three-stage turbine. The nacelle geometry is shown in figure 4. During testing several operational limits were monitored to protect the simulators. For this purpose, each simulator was instrumented with two magnetic rpm pickups, two front bearing thermocouples, two rear bearing thermocouples, and one plenum-drive-pressure transducer. In addition, an air-supply-pressure transducer was located at the back of the sting support. A schematic of the simulator monitoring and safety system is shown in figure 5 and the operational limits are detailed in table 1. Although the manufacturer defines maximum rpm as 45,000, during the hover test the rpm was limited to 40,000 to prolong the bearing life and to increase the margin of safety. The one-engine-inoperative (OEI) configuration was achieved by inserting a plug in the air supply system to the starboard simulator.

Model forces and moments were measured by three internal-strain-gage balances. The first balance measured the loads on the nacelles and dumbbell assembly, the second measured the airframe loads, and the third measured the total loads. An aircoil-bellows assembly was used to reduce the air momentum forces on the balances to small interactions which were subtracted from the force and moment data. A detailed discussion of the air supply/balance crossover system is given in reference 10. The arrangement of the balances and the air supply system are shown in figure 6. In addition to the instrumentation for safety monitoring, the nacelles were heavily instrumented for simulator performance data. Table 2 details the nacelle instrumentation.

The sting-mounted model was suspended over a 4.6 × 4.6-m (15 × 15-ft) ground plane (fig. 7). The ground plane was supported by three legs, each equipped with an electromechanical actuator which permitted the ground-plane height and incidence to be remotely controlled. The ground-plane height was measured from the underside of the fuselage midway between the two simulators to the surface of the ground plane directly underneath. A height of 10.7 cm (4.2 in.) corresponded to gear height. The gear were on for the entire test, but the wheels were removed during testing. The ground-plane heights and angles that were tested are shown in figures 8-10. The pitch angles were limited by interference between the ground plane and model or model support.

## RESULTS AND DISCUSSION

### Increased Control-Vane Effectiveness

During hover and transition, attitude control is achieved by control vanes immersed in the fan exhaust (fig. 11). Differential horizontal-vane deflection is used for yaw control, symmetrical horizontal-vane deflection provides pitch control, and differential thrust combined with vertical-vane deflection is used for roll control. Two methods were investigated to increase vertical-vane effectiveness: (1) extending the maximum vane deflection to 70°, and (2) adding a third vertical vane. There were two potential applications which prompted this investigation. One was to increase the roll-control capability to significantly reduce or balance the strong, unfavorable rolling moment created by an OEI situation, and the other was to use asymmetrically deflected vertical vanes as a speed brake/glidepath controller. All of the three vertical vanes and extended-vane testing was done with one simulator inoperative since only one vane set was modified.

Vertical-vane deflections up through 20° were investigated in previous tests of this configuration and results indicated that only side forces and the associated lateral/directional moments were produced by vertical-vane deflections. For this discussion, vertical-vane deflections greater than 20° are defined as extended vertical-vane (EVV) deflections. In the EVV range, large forces were produced in the direction of the thrust line as a result of vertical-vane drag. If the vertical vanes are deflected asymmetrically, the side forces will cancel, leaving only the net force along the thrust line to provide an effective speed brake. Results of the two-vertical-vane configuration are compared to the three-vane configuration in figure 12. As might be expected, the three-vane configuration produced more drag for all deflections.

During hover, loss of power in one engine creates a large rolling moment caused by differential thrust. Extended vertical-vane deflections significantly reduce this rolling moment. Figure 13 shows the reduction in rolling moment caused by vertical-vane deflection for the three-vane configuration. At 70° vane deflection, the rolling moment caused by OEI was reduced by 75%.

Results of the EVV testing also indicated an interference between the horizontal vane and the vertical vanes. For vertical-vane deflections up to 20°, previous tests have shown that vertical-vane deflections have a negligible effect on normal force and pitching moment (ref. 5). Interactions between the horizontal and vertical vanes at higher vertical-vane deflections produced changes in both normal force and pitching moment. For a given horizontal vane deflection, the normal force and pitching moment diminished with increasing vertical-vane deflection. Figure 14 shows the results for horizontal-vane deflection of +10°. The longitudinal control was not only reduced but actually reversed. The reversal occurred at 68° for the two-vane configuration and at 54° for the three-vane configuration (fig. 15).

The maximum side force caused by vertical-vane deflection occurred at 50° for both the two-vane and three-vane configurations (fig. 16). Ground proximity only slightly decreased the side force produced by vertical-vane deflection (fig. 17).

## Ground Effects

The ground-effects characteristics of the twin-tilt nacelle concept hovering over a level surface were investigated in earlier tests (refs. 5-7). The prominent feature of the flow field was a positive fountain effect at low heights. One of the objectives of the subject hover test was to define how the ground-effects characteristics changed over a rolled or pitched surface.

The key features of the ground-induced flow over a rolled surface are presented in figure 18. The maximum induced rolling moment occurred at 6° and then decreased with increasing ground-plane angle. The magnitude of the induced rolling moment decreased as H/D increased. In general, the normal forces were positive up to roll angles of 6° and negative at higher angles (fig. 18).

At low ground heights, the pitch range of the ground plane was limited by interference with the model or model support. The change in pitching moment caused by attitude change is shown in figure 19. In ground effect, the pitching moment increased with increasing theta. The maximum induced pitching moment occurred at the lowest ground height and decreased with increasing H/D. For the lower ground heights, the normal force changed initially and then remained almost constant as theta increased (fig. 19).

## Scale Effects

Comparisons were made with results from the hover tests of the full-scale twin-tilt nacelle model (fig. 20) to determine what effect, if any, model size had on the results. Usually, full-scale models are fabricated after testing small-scale models, and often design enhancements are included that make the full-scale model slightly different. In this case, the 11.36%-scale model was designed and fabricated after the full-scale model and was made geometrically similar to allow direct comparisons. During hover testing, the small model was configured to match the full-scale model; i.e., flaps set to 5° and gear on.

Previous studies have indicated that small-scale models tend to underpredict fountain effects (ref. 11). The ground-effects data for both models presented in figure 21 support those studies. The positive fountain effects which are the predominant feature of the flow at low ground heights are indicated by both models; however, the magnitude is less for the small-scale model. Data were unavailable for the full-scale model at the intermediate ground heights.

A comparison of control-vane effectiveness is presented in figures 22 and 23. The effect of ground proximity on longitudinal control is shown in figure 22. There is good agreement between the two models. Both indicate that there is little effect on longitudinal control owing to ground proximity. Results for vertical-vane control also indicate excellent agreement between the two models (figure 23).

# CONCLUSIONS

A hover test of a small-scale twin-tilt nacelle model has been successfully completed, fulfilling all of the principal research objectives. The following comments summarize the data presented:

1. Asymmetrically deflected vertical vanes provided an effective speed brake, with the three-vane configuration providing a greater reduction in net thrust for all vane deflections.

2. Engine-out rolling moment was significantly reduced with the EVV deflections; however, the control was inadequate to trim the airplane.

3. Interactions between the horizontal and vertical vanes caused a loss of longitudinal control at high vertical-vane deflections.

4. The change in ground-effects characteristics over a rolled or pitched surface were defined.

5. The small-scale model indicated the same trends in ground effect as the full-scale model, but the magnitude of the fountain effects were underpredicted by the small model.

6. Comparisons of the control-vane effectiveness showed excellent agreement between the small- and full-scale models.

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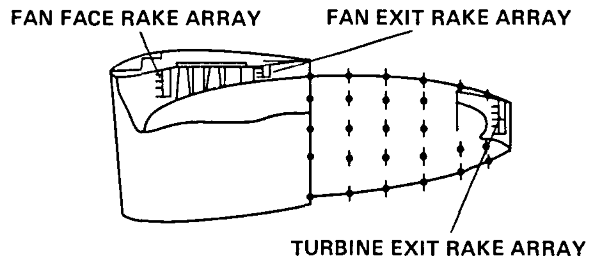
11. Christiansen, R. S.: A Large Scale Investigation of VSTOL Ground Effects. AIAA Paper 84-0336, Jan. 1984.

TABLE 1.- SIMULATOR OPERATIONAL LIMITS

| PARAMETER | LIMIT | RATE OF CHECKING | ACTION | NOTES |
|---|---|---|---|---|
| DRIVE GAS PRESSURE, psi | 260 | 1/sec | SHUTDOWN | RATE OF CHANGE OF PRESSURE MONITORED CONTINUOUSLY BY STALL DUMP UNIT |
| REVOLUTIONS PER MINUTE, krpm | 40 | 1/sec | SHUTDOWN | RPM MONITORED CONTINUOUSLY BY OVERSPEED RELAY |
| TOTAL REVOLUTIONS, krev | 225 | 1/sec | WARNING | PERFORM BEARING LUBRICATION |
| FRONT BEARING TEMPERATURE, °F | 160 | 2/sec | SHUTDOWN | BOTH THERMOCOUPLES ARE CHECKED |
| REAR BEARING TEMPERATURE, °F | 120 | 2/sec | SHUTDOWN | BOTH THERMOCOUPLES ARE CHECKED |
| DRIVE GAS TEMPERATURE, °F | 160 | 1/sec | SHUTDOWN | |
| RPM RATE OF CHANGE, krpm/sec | 5 | 1/sec | SHUTDOWN | |
| BEARING TEMPERATURE RATE OF CHANGE, °F/sec | 10 | 1/sec | SHUTDOWN | NO SHUTDOWN IF RATE CAN BE EXPLAINED BY RPM OR GAS TEMPERATURE INCREASE |
| ENGINE RUN TIME, min | 60 | 1/sec | WARNING | PERFORM BEARING LUBRICATION |

TABLE 2.- ENGINE SIMULATOR/POWERED NACELLE INSTRUMENTATION




| INSTRUMENTATION | TOTALS | STATICS (WALL) | TEMP |
|---|---|---|---|
| THRUST DATA - EACH NACELLE | | | |
| FAN FACE RAKE ARRAY<br>6 RAKES OF 6 $P_T$ EACH | 36 | | |
| FAN EXIT RAKE ARRAY<br>6 RAKES OF 6 $P_T$, 2 $P_{S_{WALL}}$ AND 1 $T_T$ EACH (6) | 36 | 12 | 6 |
| FAN NOZZLE EXIT STATIC PRESS.<br>8 EQUALLY SPACED TAPS IN NOZZLE TRAILING EDGE<br>8 MATCHING TAPS ON ENGINE COWL | | 8<br>8 | |
| TURBINE EXIT RAKE ARRAY<br>4 RAKES OF 5 $P_T$ AND 1 $T_T$ EA. (4) | 20 | | 4 |
| EXHAUST NOZZLE EXIT STATIC PRESS.<br>EQUALLY SPACED TAPS IN NOZZLE TRAILING EDGE | | 8 | |
| EXTERNAL AERODYNAMICS ONE NACELLE | | | |
| ENGINE COWLING LIFT, DRAG AND PITCH MOMENT<br>8 MERIDIANS OF 5 $P_S$ TAPS (ONE NACELLE ONLY) | | 40 | |
| SIMULATOR OPERATION - EACH NACELLE | | | |
| 2 BEARING TEMPERATURES (2 front, 2 rear) | | 2 | |
| OIL PRESSURE | 1 | | |
| RPM (2) | | | |
| TURBINE INLET TOTAL TEMP. | | | 1 |
| TURBINE INLET TOTAL PRESS. | 2 | | |

| 11.36% SCALE | WING | HORIZONTAL TAIL | VERTICAL TAIL |
|---|---|---|---|
| SPAN, m, (ft) | 1.27 (4.17) | 0.40 (1.33) | – |
| AREA, $m^2$, ($ft^2$) | .21 (2.29) | 0.04 (0.43) | 0.05 (0.49) |
| ASPECT RATIO | 7.6 | 4.1 | .95 |
| LEADING EDGE SWEEP | 2.5°/–7.5° | 25° | 40° |
| TAPER RATIO | 0.466 | 0.489 | .53 |
| DIHEDRAL | 0°/13°/–7° | 0° | – |
| AIRFOIL | – | NACA 64A012 | NACA 64A012 |

ALL DIMENSIONS IN m (ft)

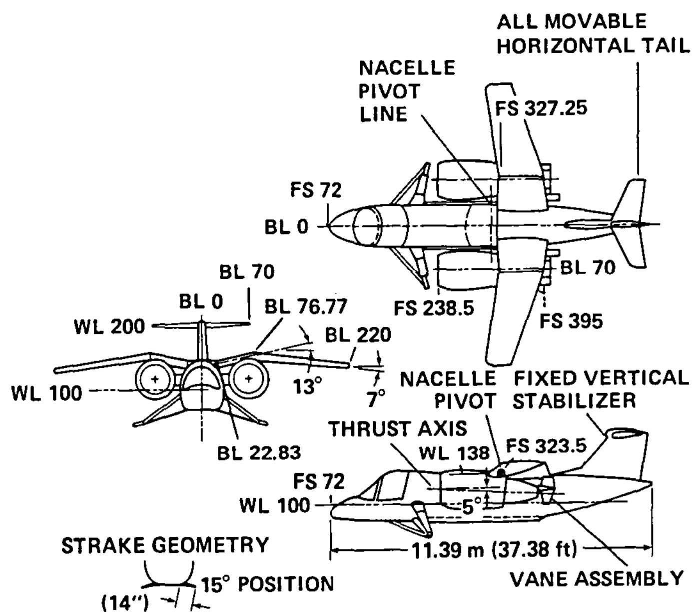



Figure 1.- Twin-tilt nacelle geometry, coordinates in inches (full scale).

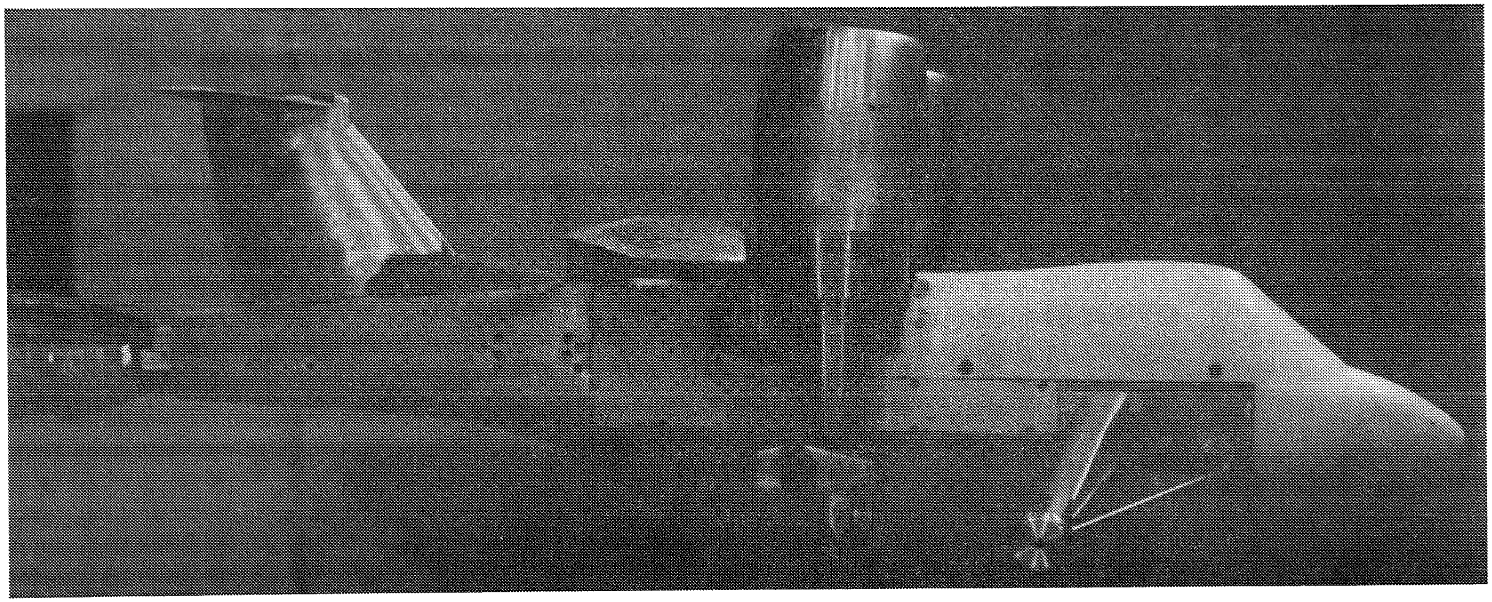


Figure 2.- 11.36% scale twin-tilt nacelle model.

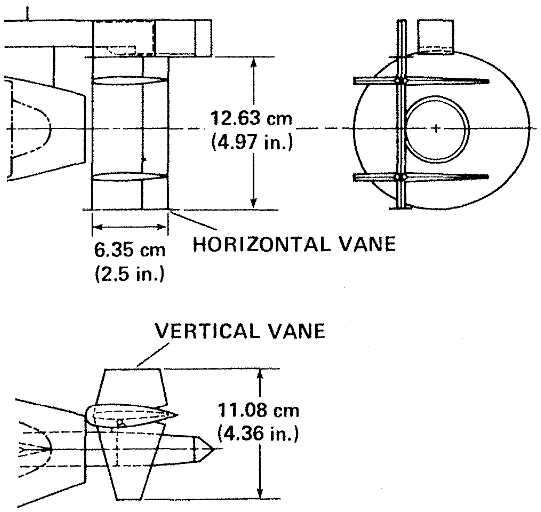



Figure 3.- Control vane geometry.

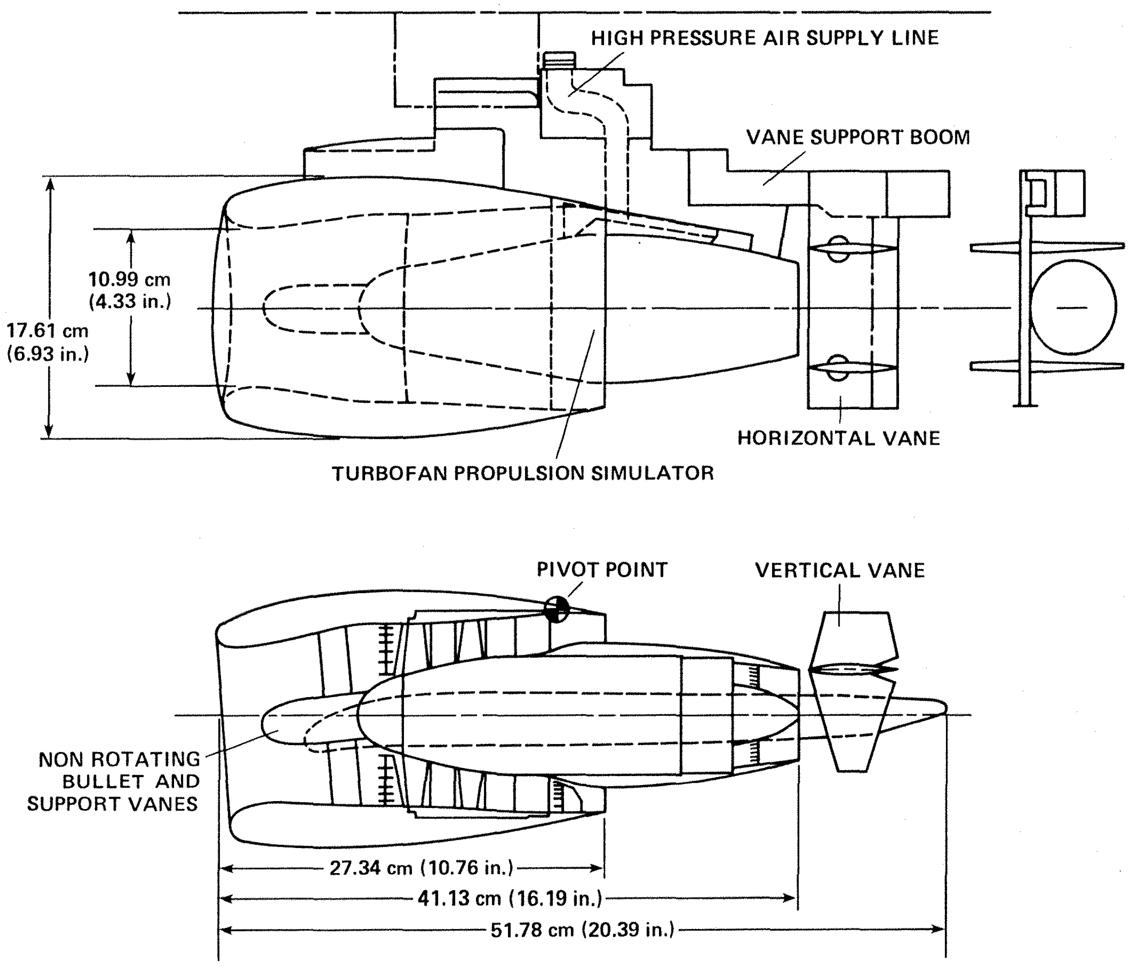



Figure 4.- Nacelle geometry.

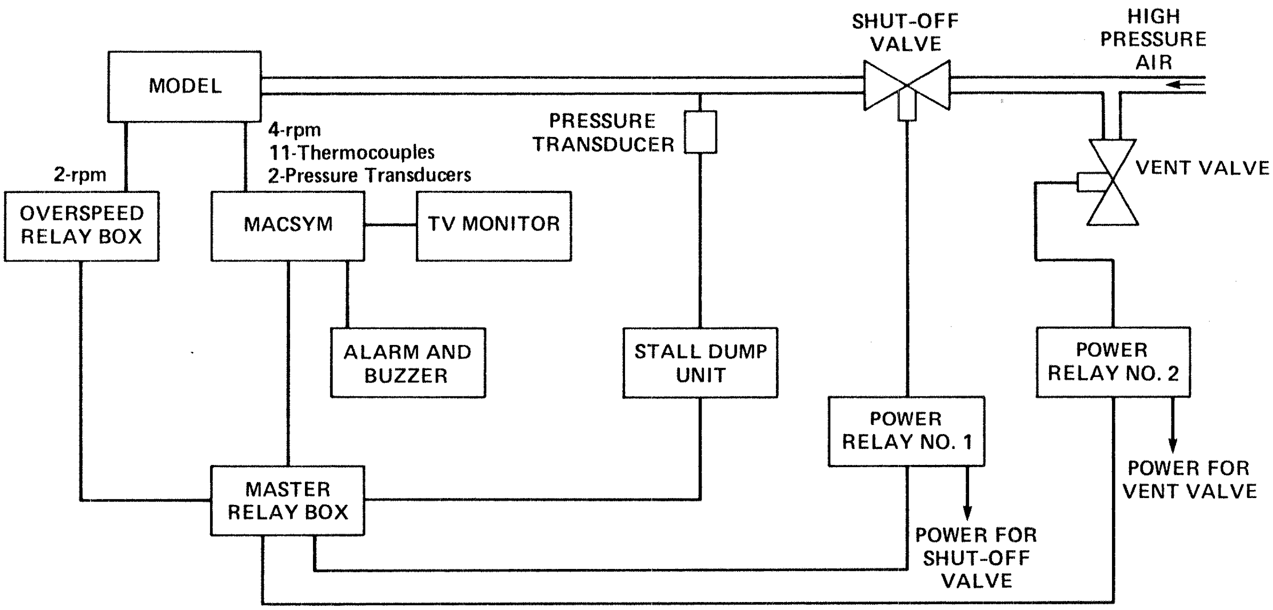



Figure 5.- Simulator health monitoring and safety system.

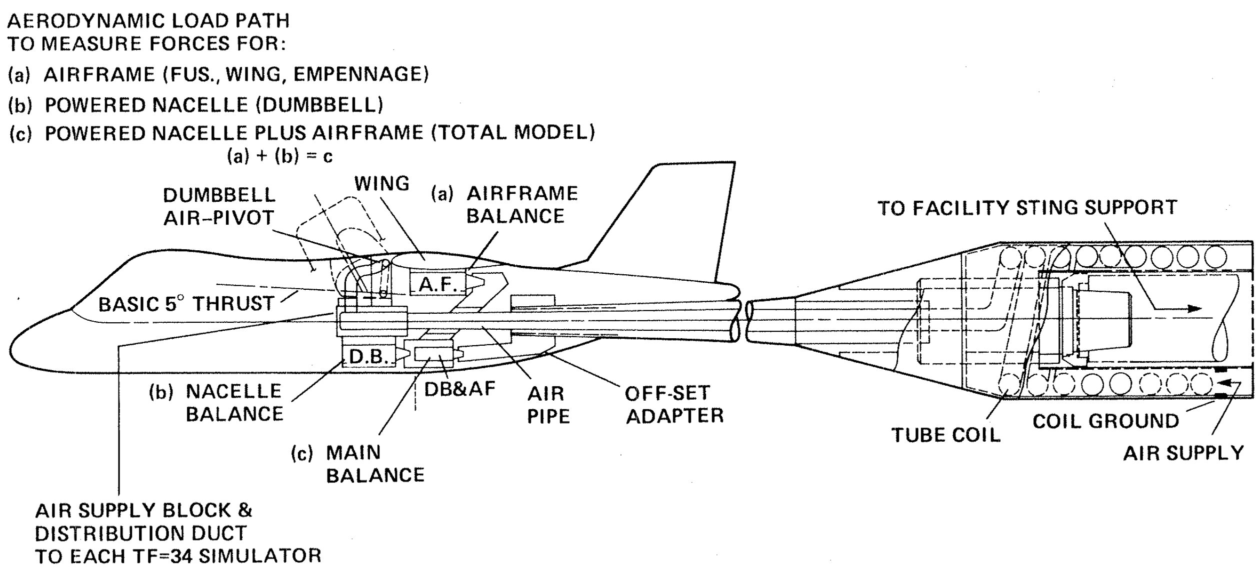



Figure 6.- Balances and air-supply system.

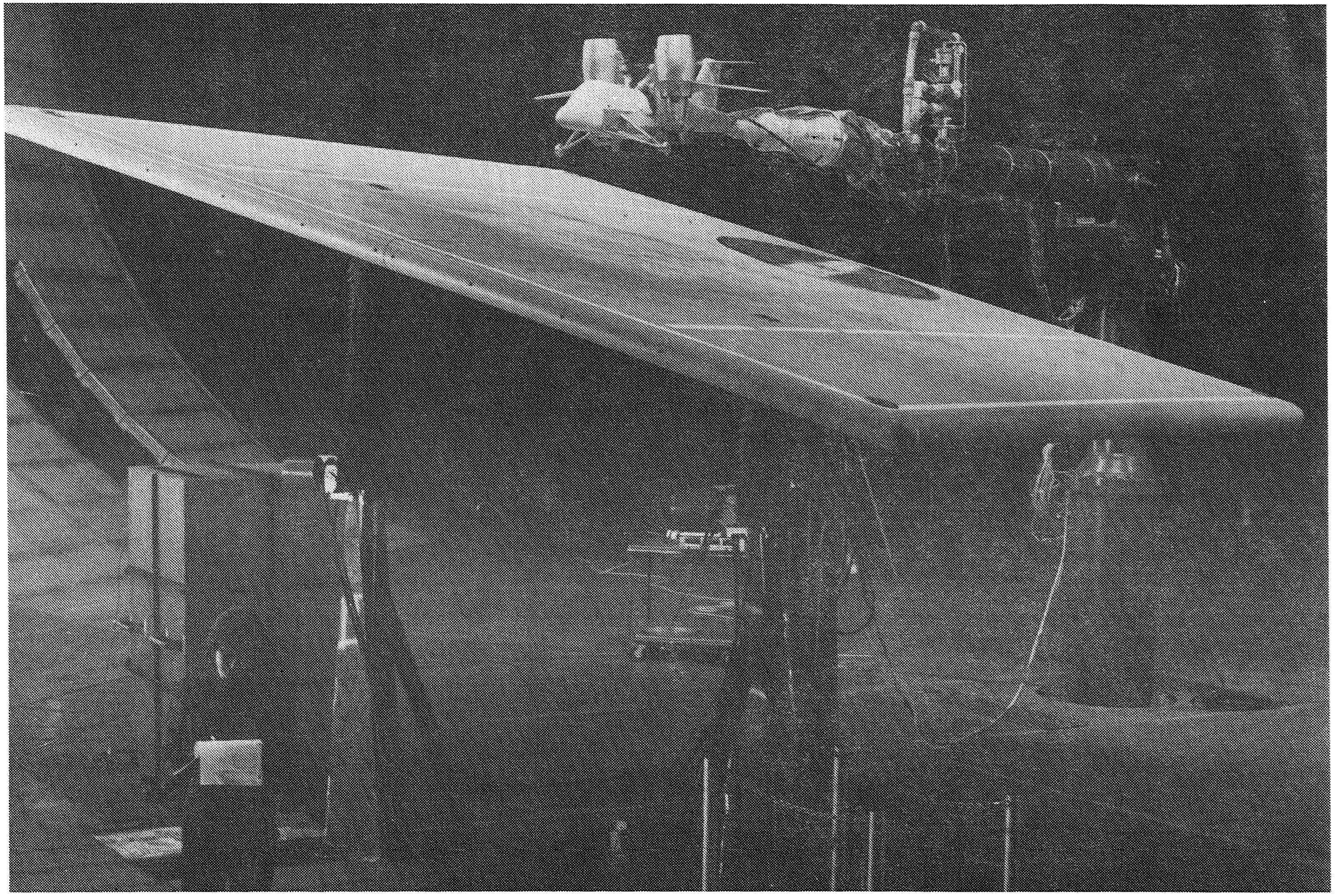


Figure 7.- Test installation in the NASA Ames Research Center's 40- by 80-Foot Wind Tunnel.

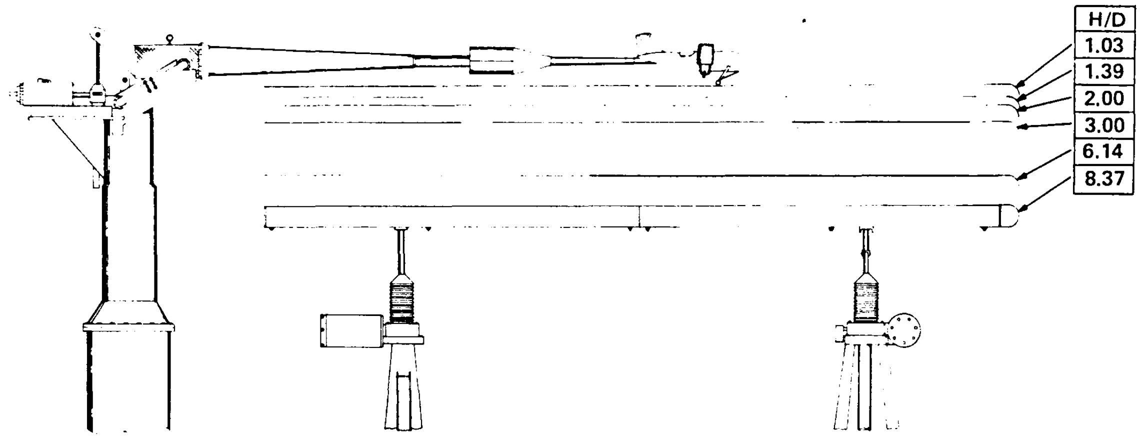



Figure 8.- Ground effects.

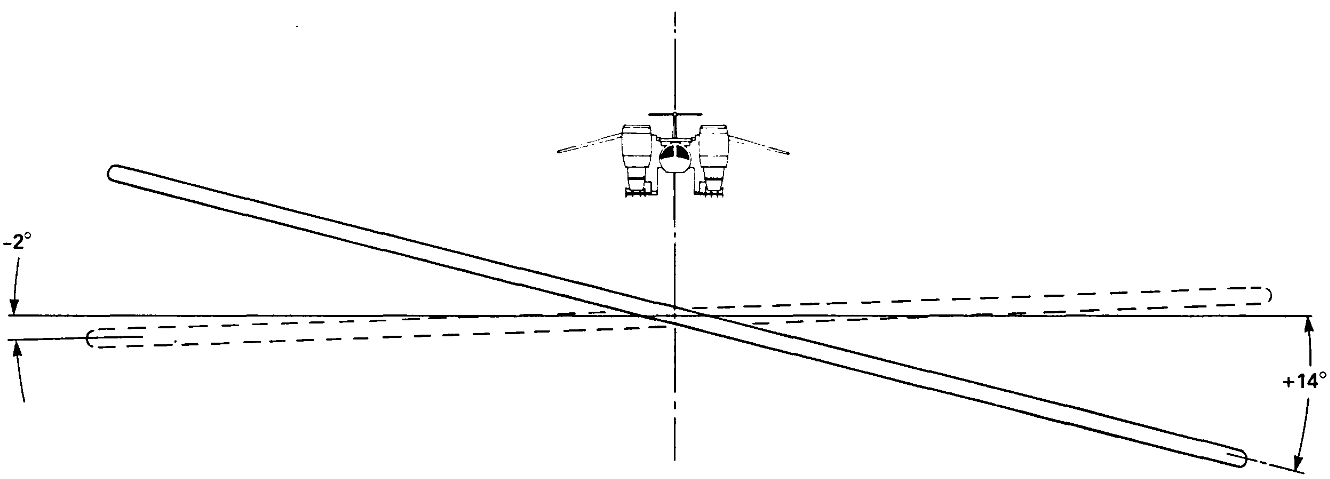



Figure 9.- Roll effects.

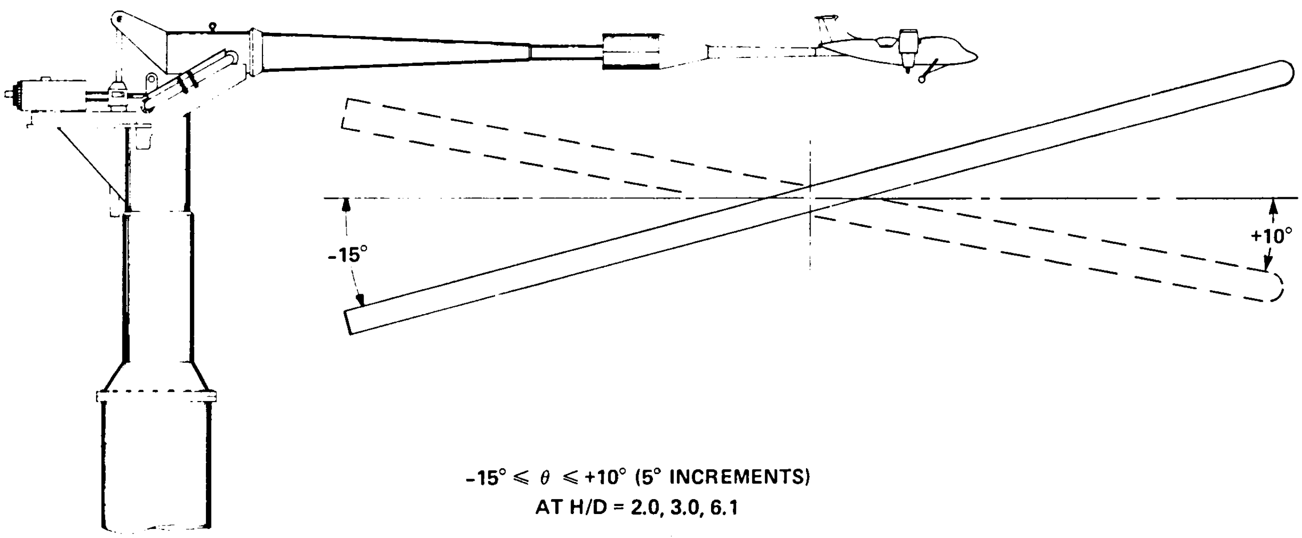



Figure 10.- Pitch effects.

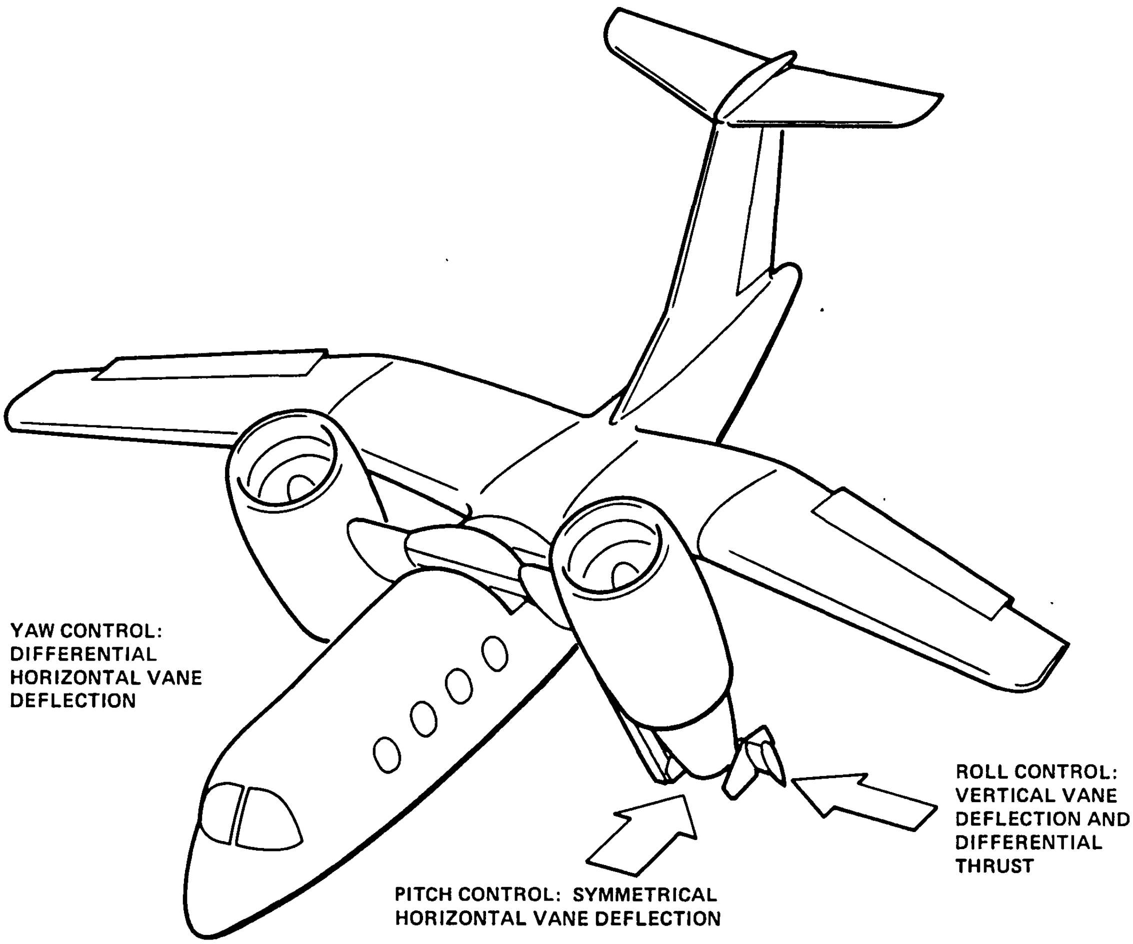



Figure 11.- Hover and transition control.

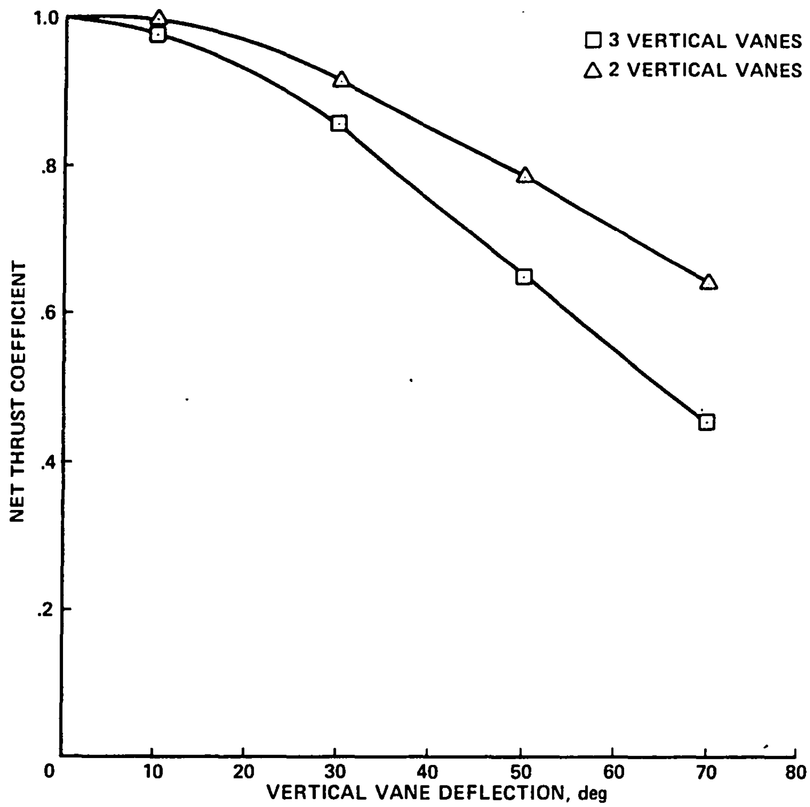



Figure 12.- Reduction in net thrust owing to EVV deflection.

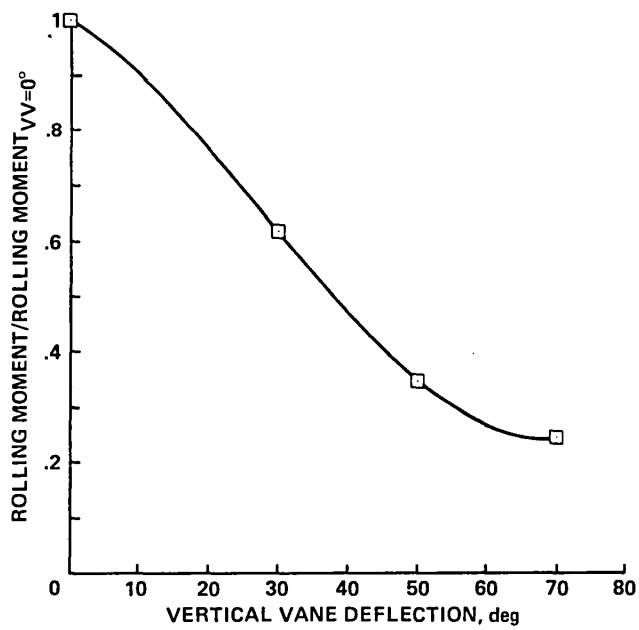
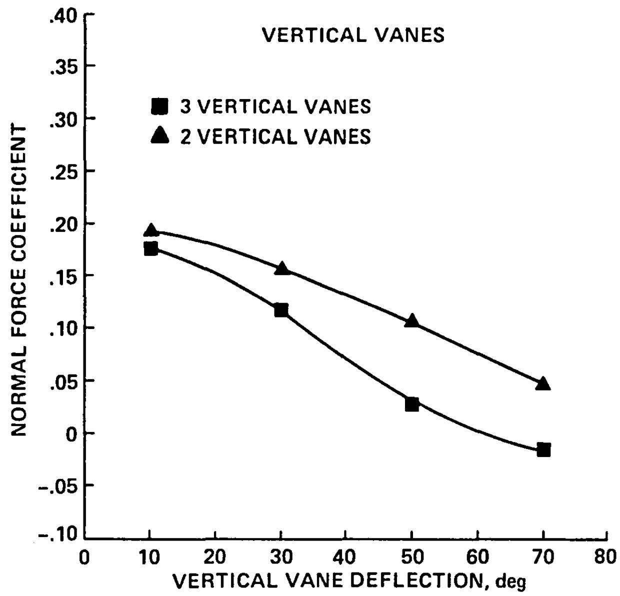
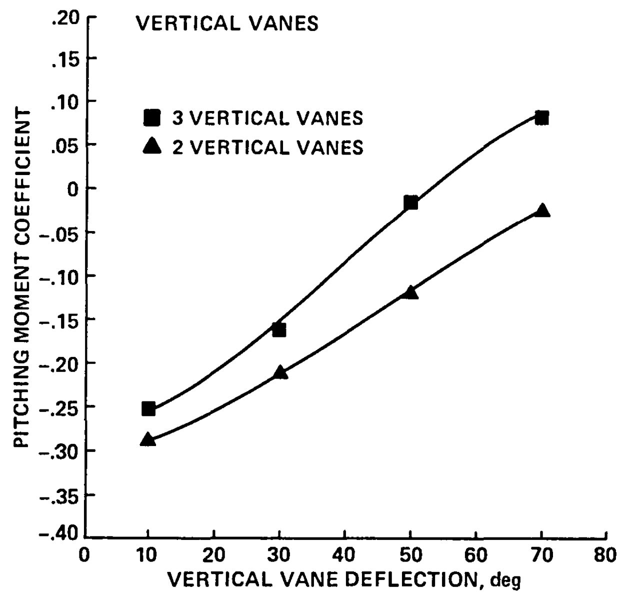



Figure 13.- OEI roll control.




(a) Normal force.




(b) Pitching moment.

Figure 14.- Interference between horizontal and vertical vanes (horizontal-vane deflection = +10°, nacelle deflection = 5°).

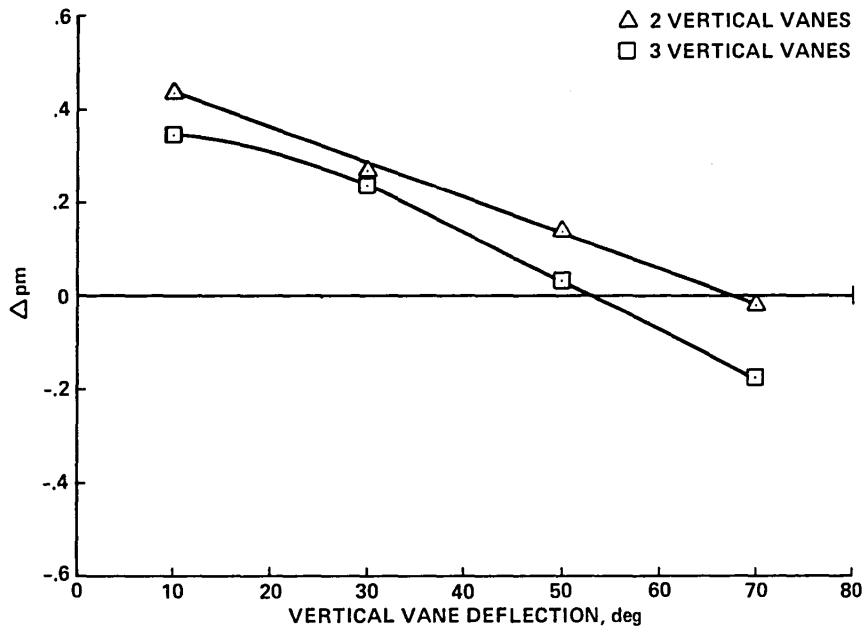



Figure 15.- Effect of vertical-vane deflection on longitudinal control (nacelle deflection = 5°).

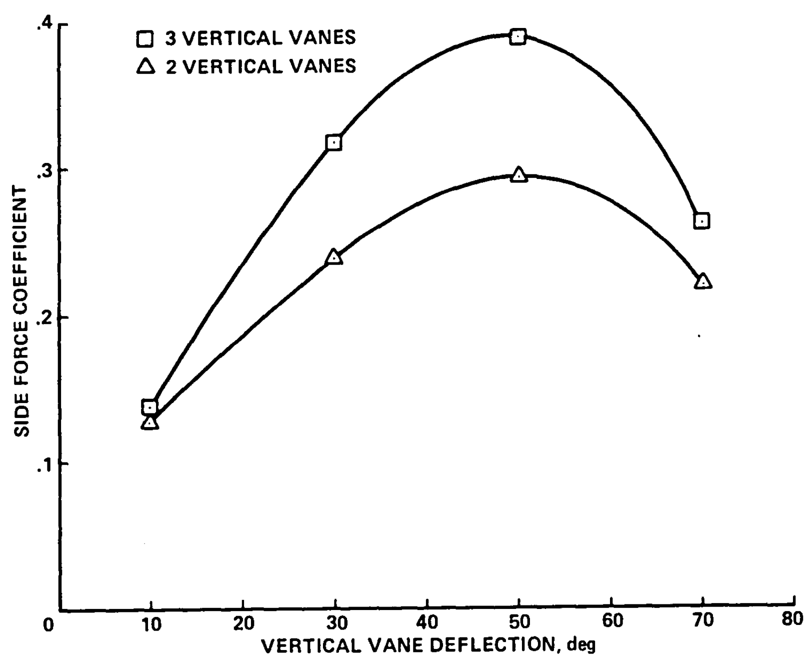



Figure 16.- Side force caused by vertical-vane deflection.

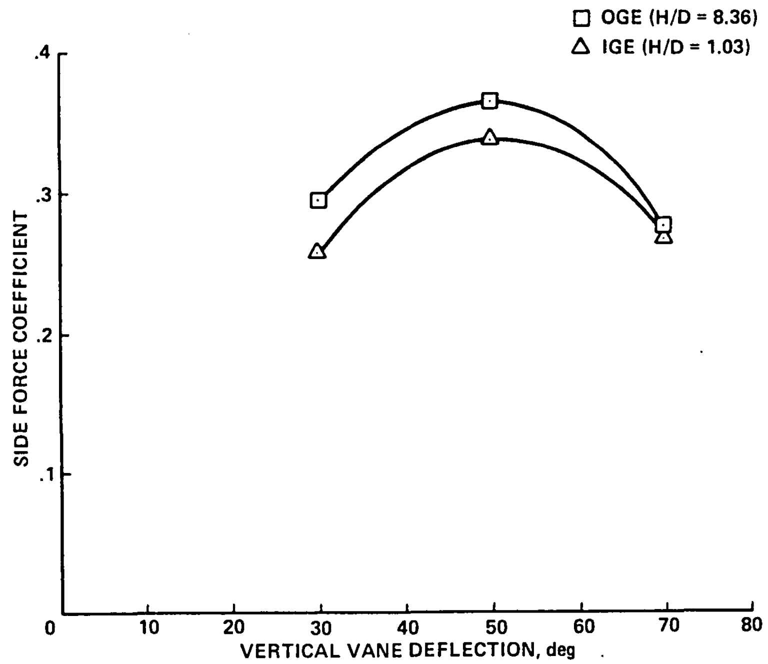
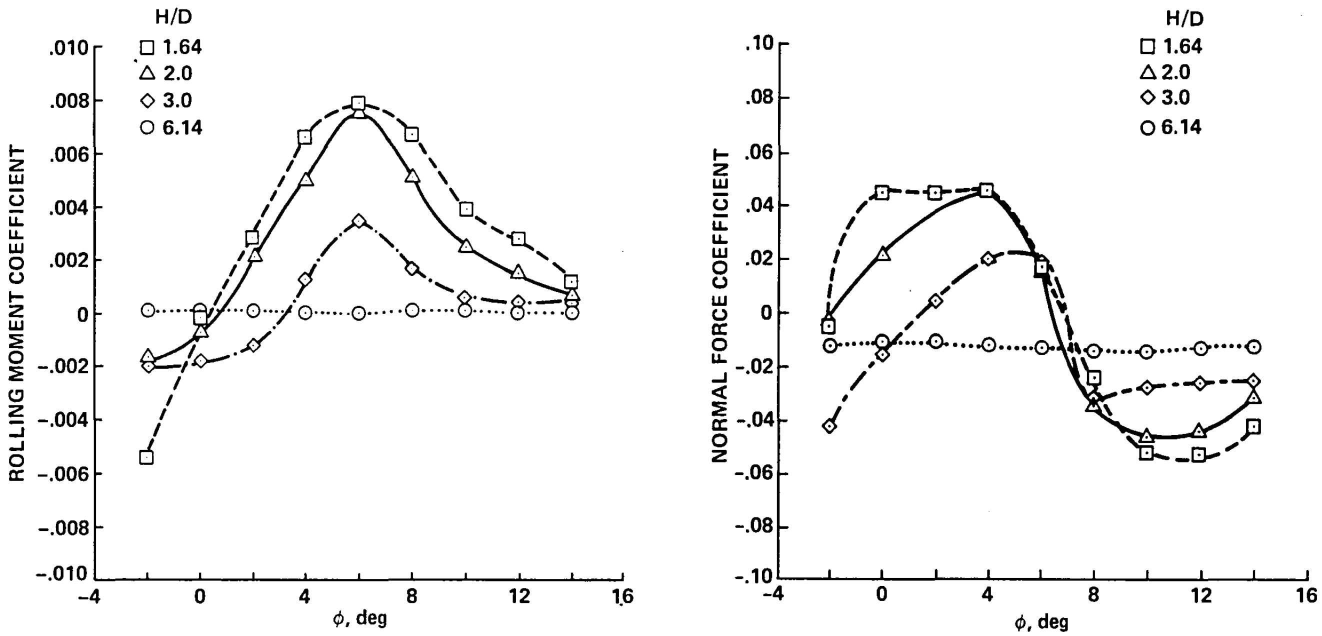


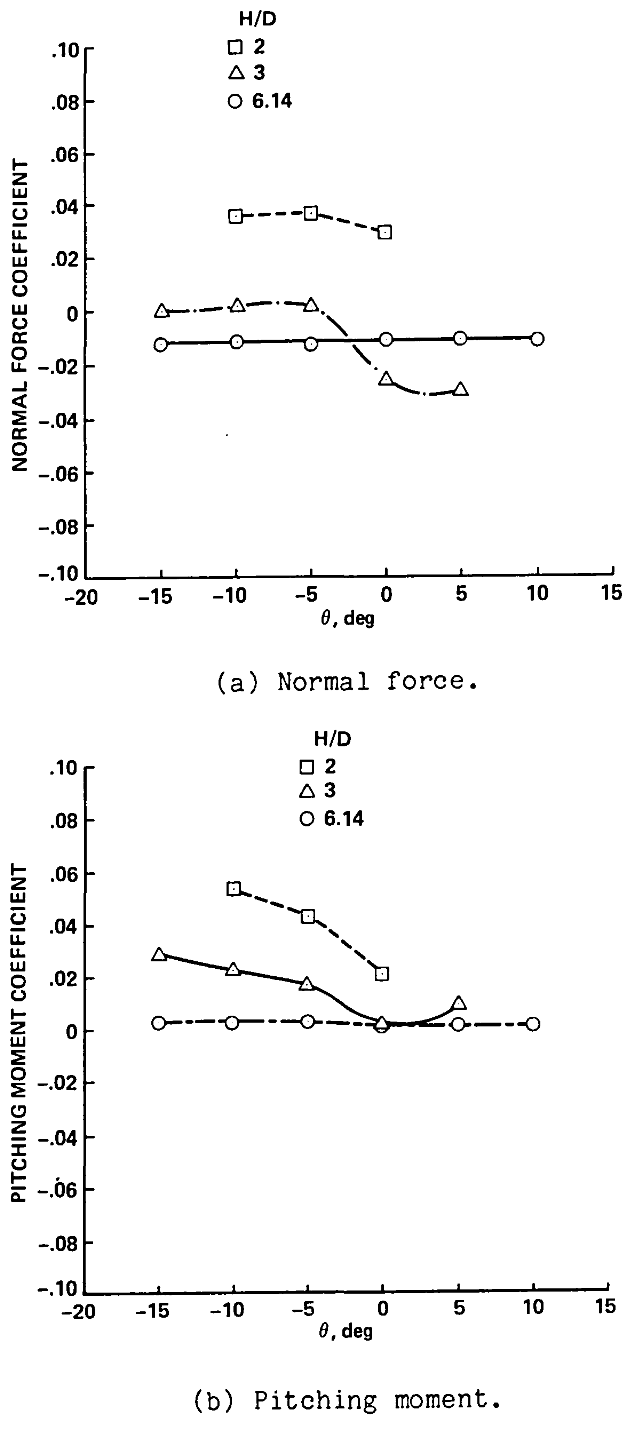

Figure 17.- Effect of ground proximity on vertical-vane control.




(a) Rolling moment.

(b) Normal force.

Figure 18.- Effects of rolled ground plane.




(a) Normal force.



(b) Pitching moment.

Figure 19.- Effects of pitched ground plane.

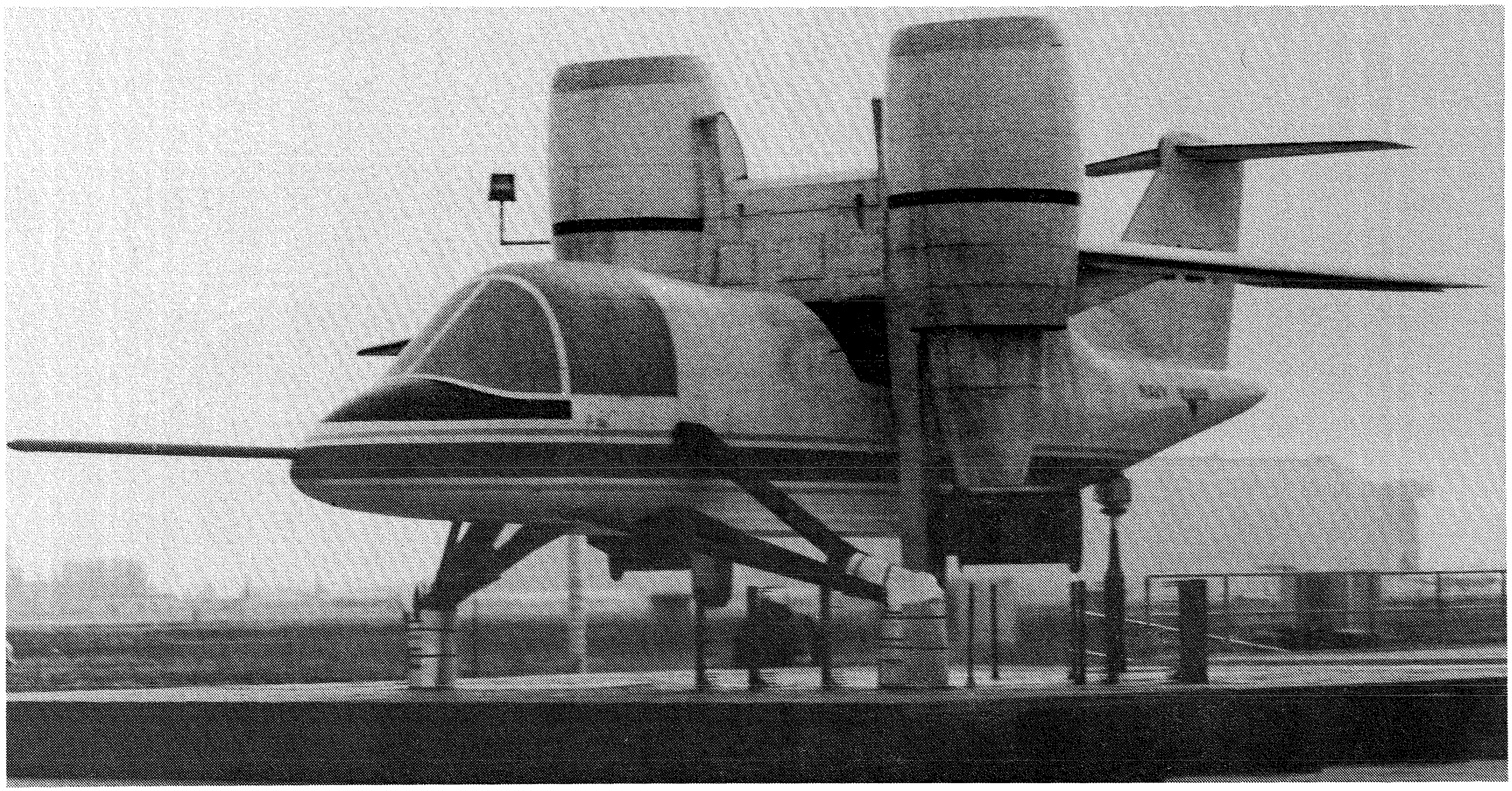


Figure 20.- Full-scale twin-tilt nacelle model at the Ames Outdoor Aerodynamic Research Facility.

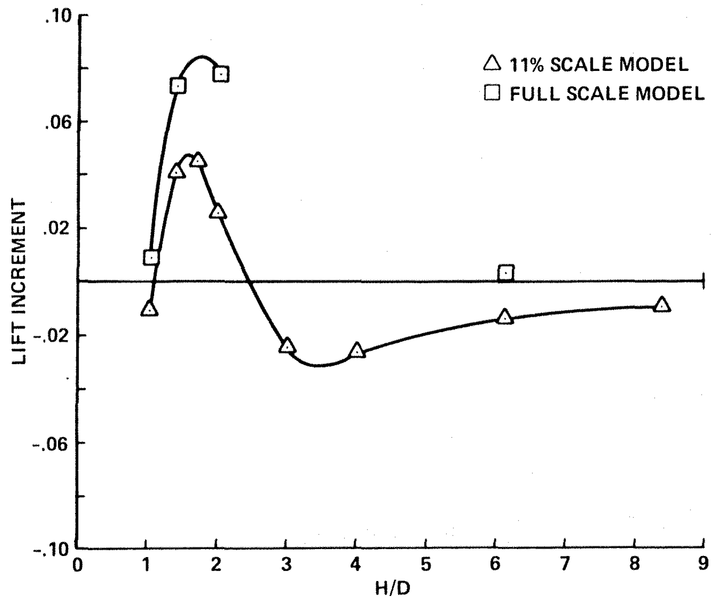



Figure 21.- Comparison of ground-effects characteristics.

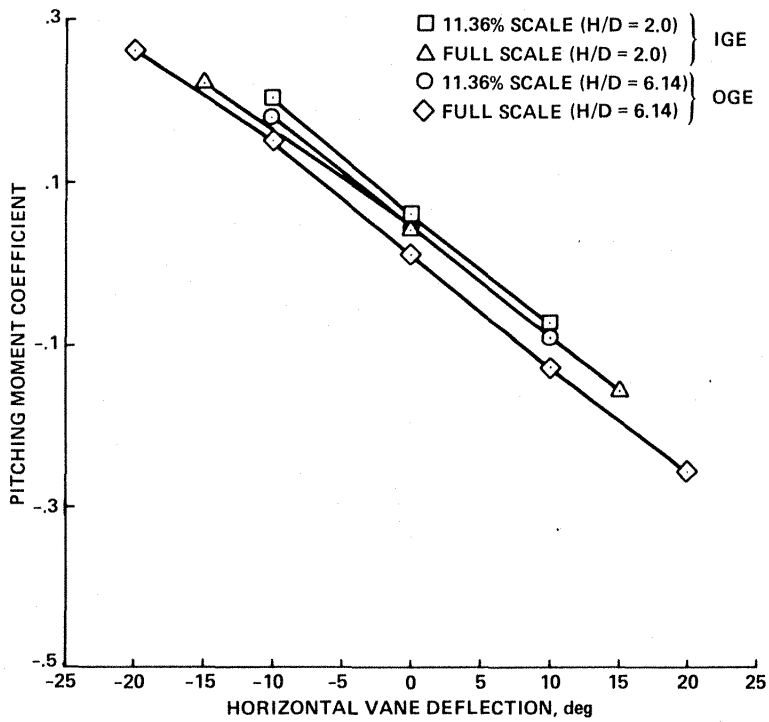



Figure 22.- Effect of ground proximity on longitudinal control.

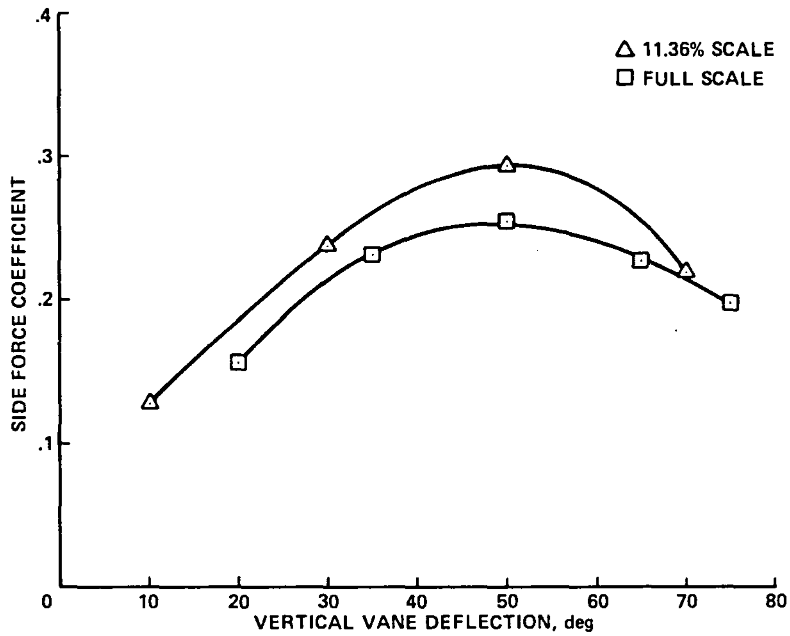



Figure 23.- Comparison of vertical-vane control.

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16. Abstract

Characteristics in hover of an 11.36%-scale, powered, twin-tilt nacelle model were measured in the NASA Ames Research Center's 40- by 80-Foot Wind Tunnel. The model was powered by two high-pressure air-driven turbofan propulsion simulators. The position of the sting-mounted model was fixed and a movable ground plane was used to vary ground height and orientation. Hover characteristics were investigated in and out of ground effect for roll angles of -2° to +14° and pitch angles of -15° to +10°. Results for the basic configurations are compared with data from hover tests of the full-scale tilt nacelle model. Two methods were investigated to increase vertical vane effectiveness: (1) extending the maximum vane deflection from 20° to 70°, and (2) adding a third vertical vane. The goal was to increase the roll-control capability to significantly reduce or balance the strong, unfavorable rolling moment created by the loss of one engine. Results indicate that the three-vertical-vane configuration is more effective than two vertical vanes and that extended vane deflections significantly reduce the engine-out roll in hover.

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