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THE EFFECT OF A COMPLETE SPIN TURBINE ON THE EXHAUST FLOW-FIELD FOR A TUBE-LAUNCHED ROCKET

Samuel J. Sutter

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Unbalanced forces on tube launched rockets during launch caused by exhaust fluid flow in the launcher-rocket annular gap is a problem confronting tube-launched rocket system designers. One alternative considered to alleviate the adverse effects is to rotate the rocket about its center of gravity during the launch phase to average out small deviations in the flight path. The spin turbine is a possible alternative with which to increase the rocket's angular momentum. Previous work considered a single vane's effect on the exhaust flow, a complete

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20. ABSTRACT Continued...

spin turbine effect on the exhaust flow, and a rocket nozzle equipped with a complete spin turbine exhausting into a cylindrical launch tube. The current program demonstrates a significant difference in the flow around an isolated single vane from that around a single vane of a complete spin turbine. Three vane heights are considered.

The Effect of a Complete Spin Turbine on the Exhaust Flow-field for a Tube-Launched Rocket*

by

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INTRODUCTION

At present, the problem of unbalanced forces on the rocket caused by fluid flow in the launcher-rocket annular gap confronts the designers of tube-launched rocket systems. One alternative under consideration to alleviate adverse flow effects is to rotate the rocket about its center of gravity during the initial launch phase in order to average out small deviations in the flight path. A spin turbine is a feasible alternative with which to increase the rocket's angular momentum. "The Effects of Spin Vanes on the Exhaust Flow-Field for a Tube-launched Rocket" (Ref. 1) reported on the spin turbine application. That program investigated the single vane's effect on the exhaust flow, the complete spin turbine's effect on the exhaust flow, and a rocket nozzle equipped with a complete spin turbine exhausting into a cylindrical launch tube. Continued interest in this area prompted additional experimentation; particularly concerning the shock/viscous interaction generated by flow around adjacent vanes and the effect of vane height, h_v, on the exhaust flow through the complete spin turbine. The current program demonstrates a significant difference in the flow around an isolated single vane from that around a single vane of a complete spin turbine. This interaction is shown for three vane heights in the following sections.

EXPERIMENTAL PROGRAM TEST FACILITY

Similar experimental procedures as detailed in Reference 1 were used in this follow-on program. The blow-down type facility, Figure 1 was used to generate and record the data. Figure 2 presents the flow exhausting from a reservoir where $P_{t1} = 6.74 \times 10^6$ N/m^2 (978 psia) through a 10° conical nozzle and into quiescent air. This same rocket nozzle was equipped with a complete spin turbine similar to that shown in Figure 3. In order to obtain appropriate data, the spin turbine was instrumented as shown in Figure 4. In addition, data were obtained utilizing supersonic pitot-tubes as portrayed in Figure 5. The three stagnation pressures investigated for each vane height are listed below:

P_{t1} N/m^2 (psia)

6.87×10^6 (987.9)

5.09×10^6 (738.4)

3.44×10^6 (499.2)

Complete Spin Turbine

The geometry of the large vanes, h_v = 0.521 cm (.205 in) used in the complete spin turbine were identical to that of the single vane used in Reference 1. The dimensions are reiterated in Figure 6, 7a, and 7b in this report. Note that the complete spin turbine used in tests of Reference 1 had vanes with a thickness of 0.076 cm

(.030 in). However, to facilitate instrumentation of the complete turbine the vane thickness was increased to 0.127 cm (.050 in) in the current program. Further the vane heights were not consistent from Reference 1 to this program. The table below presents the differences:

Reference 1		Present Report	
Vane	Height cm(in)	Vane	Height cm(in)
V1	0.521 (0.205)	V11	0.521 (0.205)
V2	0.347 (0.137)	V22	0.394 (0.155)
V3	0.174 (0.068)	V33	0.267 (0.105)

Test Program

The effects of the complete spin turbine on the free exhaust were investigated in this program. Use of the launch tube and the consequentially constrained plume flow field were not examined during this continued experimentation.

DISCUSSION OF RESULTS

The flow field of a complete spin turbine is very complex. The relatively "clean" plume in Figure 2 is radically changed by the addition of the turbine to the exit of the nozzle. The photographs on Figure 8 are repeated from Reference 1. They demonstrate the compound effects of the interaction flow of ten spin vanes comprising the turbine.

In order to obtain some measure of the decrease of total pressure within the exhaust plume, the pitot-pressure profiles were integrated over the control area A_{ne} at each $\tilde{x}$ station downstream of the nozzle. The integral

$$\overline{\frac{p_{pit}}{p_{t1}}} = \int_0^1 \left(\frac{p_{pit}}{p_{t1}}\right) d\left(\frac{A}{A_{ne}}\right),$$

$$\text{or} \int_0^1 \left(\frac{p_{pit}}{p_{t1}}\right) \left(\frac{r}{r_{ne}}\right) d\left(\frac{r}{r_{ne}}\right)$$

was evaluated with a trapezoidal approximation. The average pitot-pressures, nondimensionalized by dividing by $p_{t1} = 6.87 \times 10^6$ N/m^2 (978 psia), are presented in Figure 9. The triangular symbols have been added to Figure 27 of Reference 1 to demonstrate the effect of spin height, h_v, and thickness on the downstream flow field. The close agreement between the values for the V3 turbine and for "no spin turbine" indicate that the V3 turbine causes little net loss of total pressure. The average values for the pitot pressures measured downstream of the V11 turbine were significantly lower than those for the V3 turbine. Recall that the vane thickness for the spin turbine of the present test program is seventy percent greater than for the previous test program. Of importance to the spin turbine designer is the significant effect that the increased vane height and thickness had in decreasing the nondimensionalized pitot pressures. This total pressure loss due to a spin turbine in the exhaust should significantly alter the flow field in a launch tube, where the stagnation pressure of the exhaust is a critical factor in the generation of blow-by flow. Logically, then, a spin vane can be designed which does not significantly effect the plume local stagnation pressures but is adequate in imparting increased angular momentum to the rocket.

The flow field around a single isolated vane is thoroughly described in Reference 1. Figures 10 and 11 present idealized flow and the shock wave structure produced by a single vane for $M_{ne} = 2.34$.

The flow field around a single vane in the complete spin turbine shows signficant effect from the shock structure of the adjacent vanes. Figure 12 shows that the peak static pressures occur considerably further downstream of the leading edge as compared to those for the isolated vane.

Note the increase in the local surface pressure and the aft movement of the peak is attributed to the impingement of the shock generated by the adjacent vane. The static pressure distributions on the turbine surface between the vanes are presented in Figure 13. These data are repeated in Figure 14 of this report, which includes the data for the isolated vane (as taken from Figure 16 of Reference 1). From the data presented in Figure 14, it is clear that Figure 21 of Reference 1 does not clearly illustrate the degree of interaction of the coalesced shock structure. The theoretical flow angles from Fig. 11 are overlayed on the complete spin turbine in Figure 15. The result is Figure 16 which shows a greater degree of shock interaction between adjacent vanes than was presented in Reference 1.

The mutual effect of adjacent vanes presented in Figure 12 is again shown on Figure 17. However, the data presented in this figure illustrate the effect of vane height. Consistent with the results of Figure 9, the flow field of the complete turbine equipped with small vanes, h_v = 0.267 cm (0.105 in), demonstrates small adjacent vane shock interactions.

Concluding Remarks

The flow around a spin vane in a complete spin turbine is radically different from that of an isolated vane. Nevertheless, the disturbances can be minimized by decreasing the vane size consistent with that of maintaining minimum surface area needed to produce the desired rocket angular velocities.

REFERENCES

1. Cribbs, D.W. and Bertin, J.J." "The Effects of Spin Vanes on the Exhaust Flow-Field for a Tube-Launched Rocket," Aerospace Engineering Report 77006, December 1977, The University of Texas at Austin.

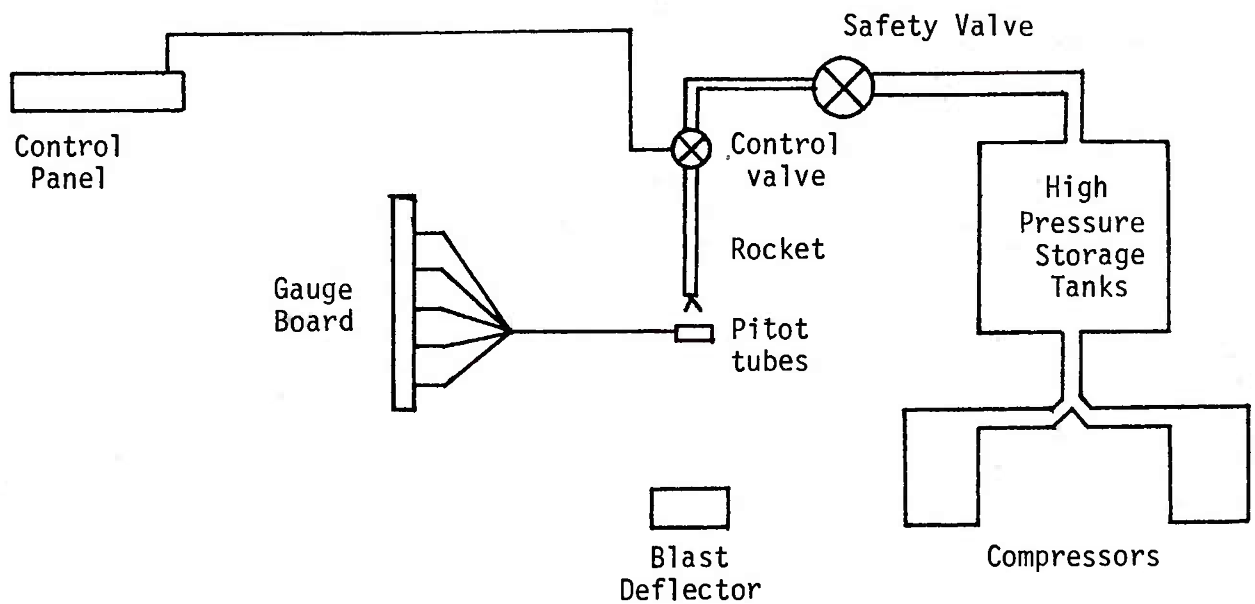


Figure 1. - Schematic of the University of Texas Rocket Exhaust Effects Facility

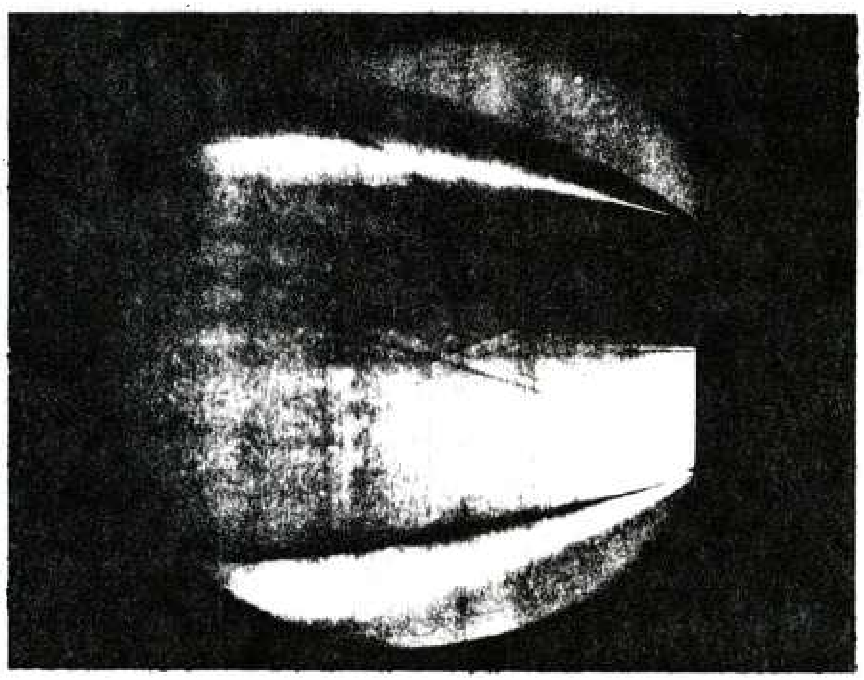


Figure 2. - Schlieren photograph of the flow exhausting from the rocket nozzle with no spin turbine. $P_{t1} = 6.74 \times 10^6$ N/m^2 (978 psia)

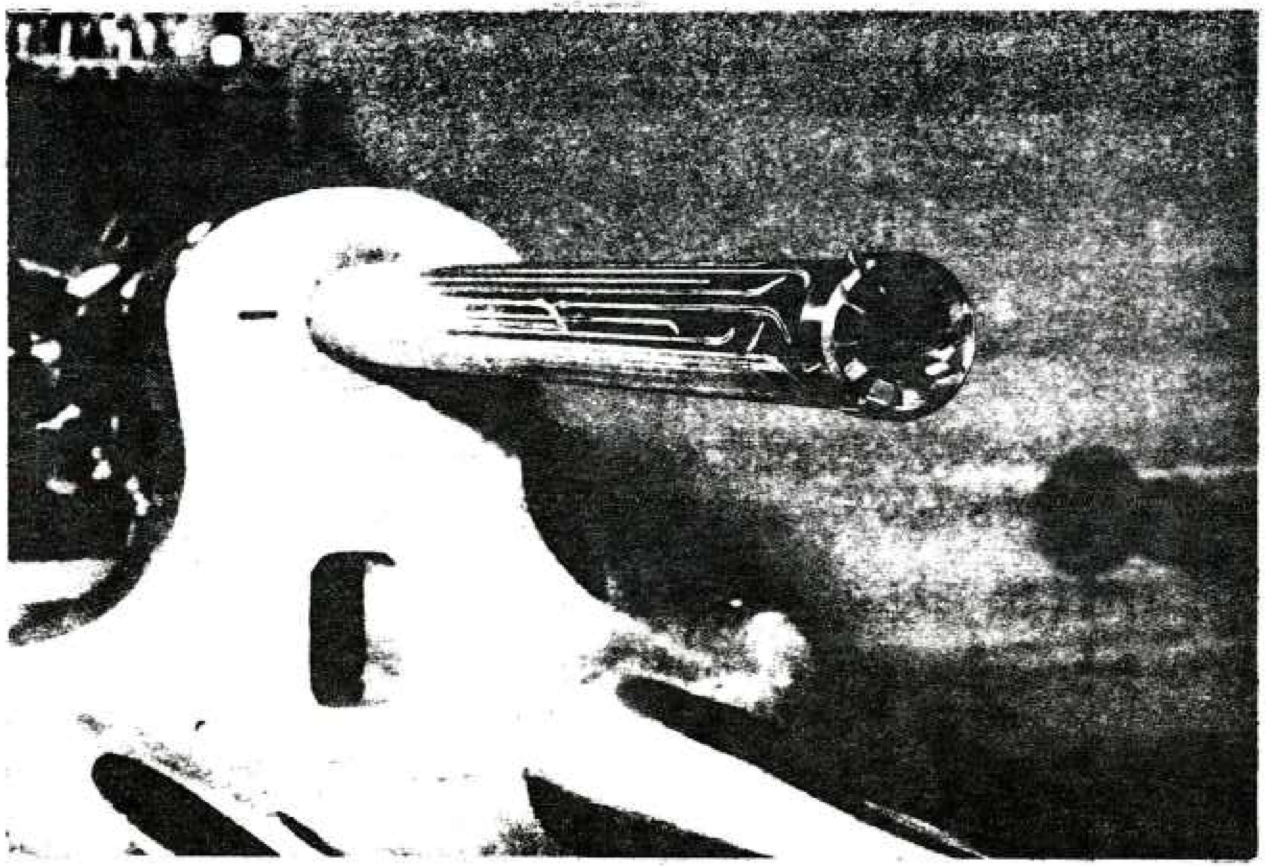


Figure 3. - Photograph of the spin turbine in position on the rocket nozzle.

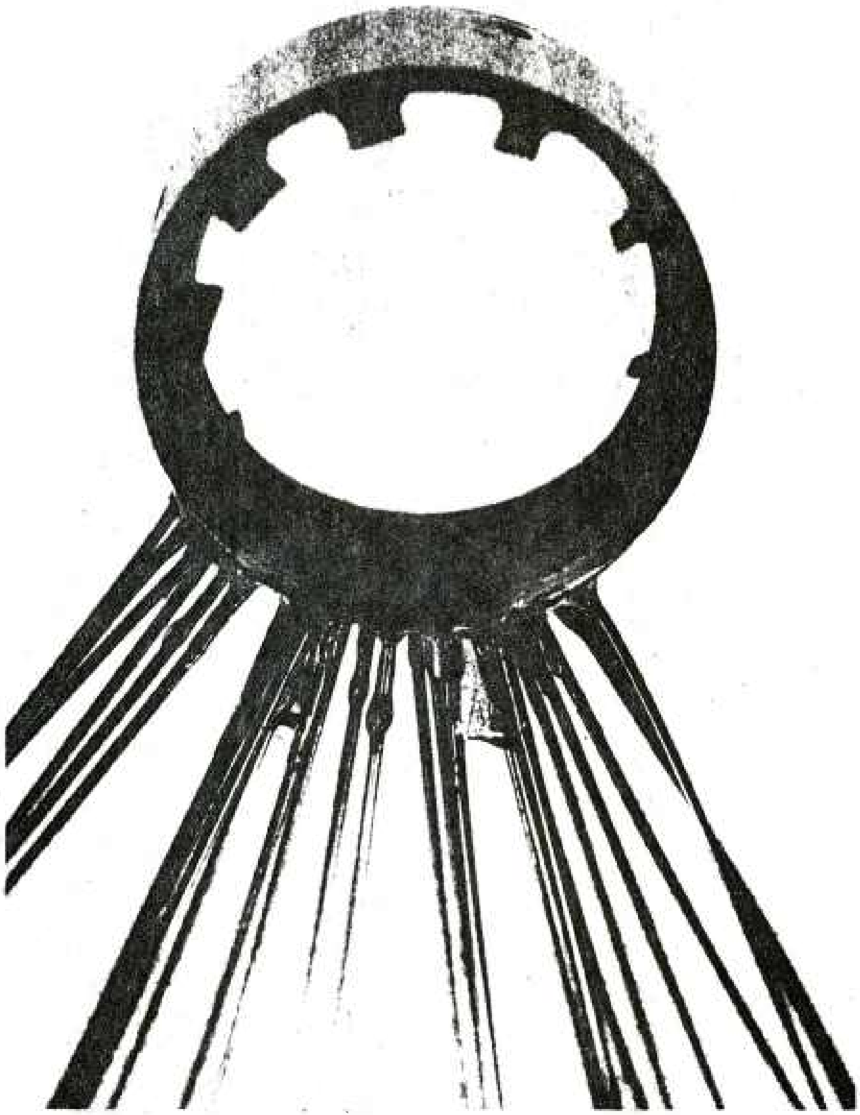


Figure 4. - The instrumented complete spin tubine

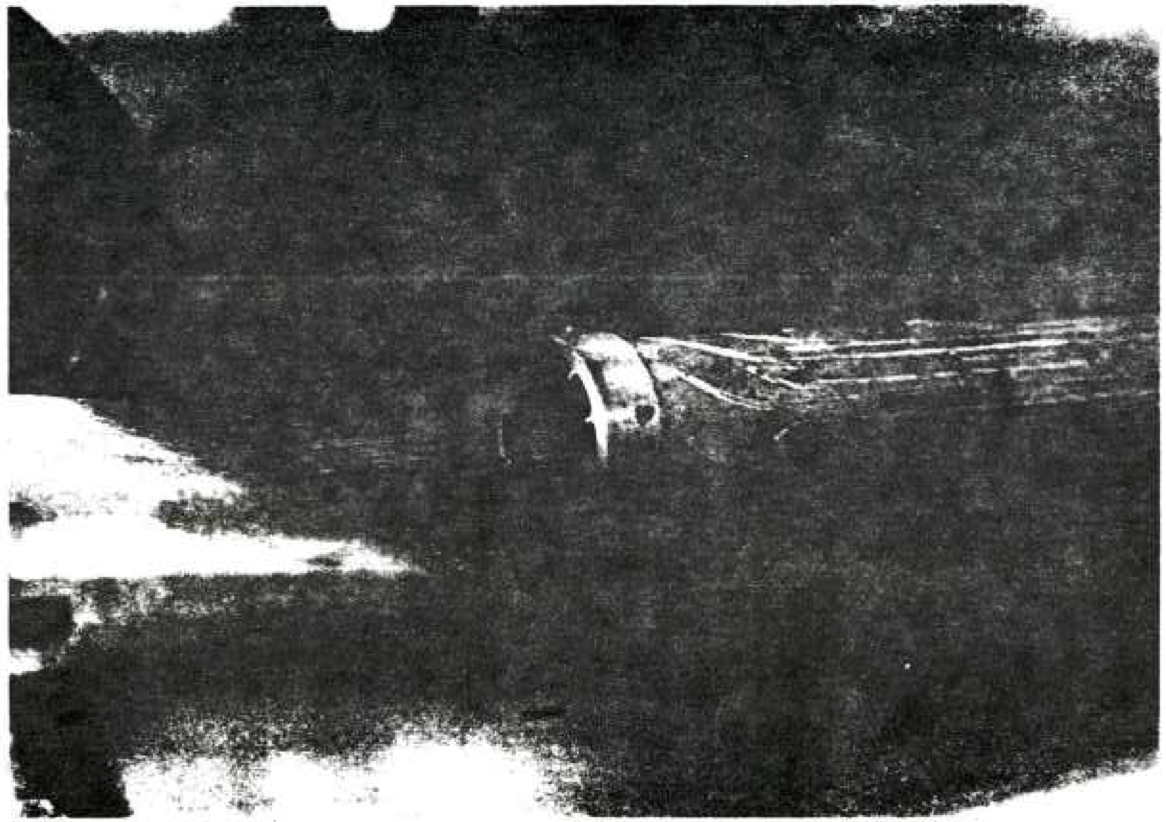
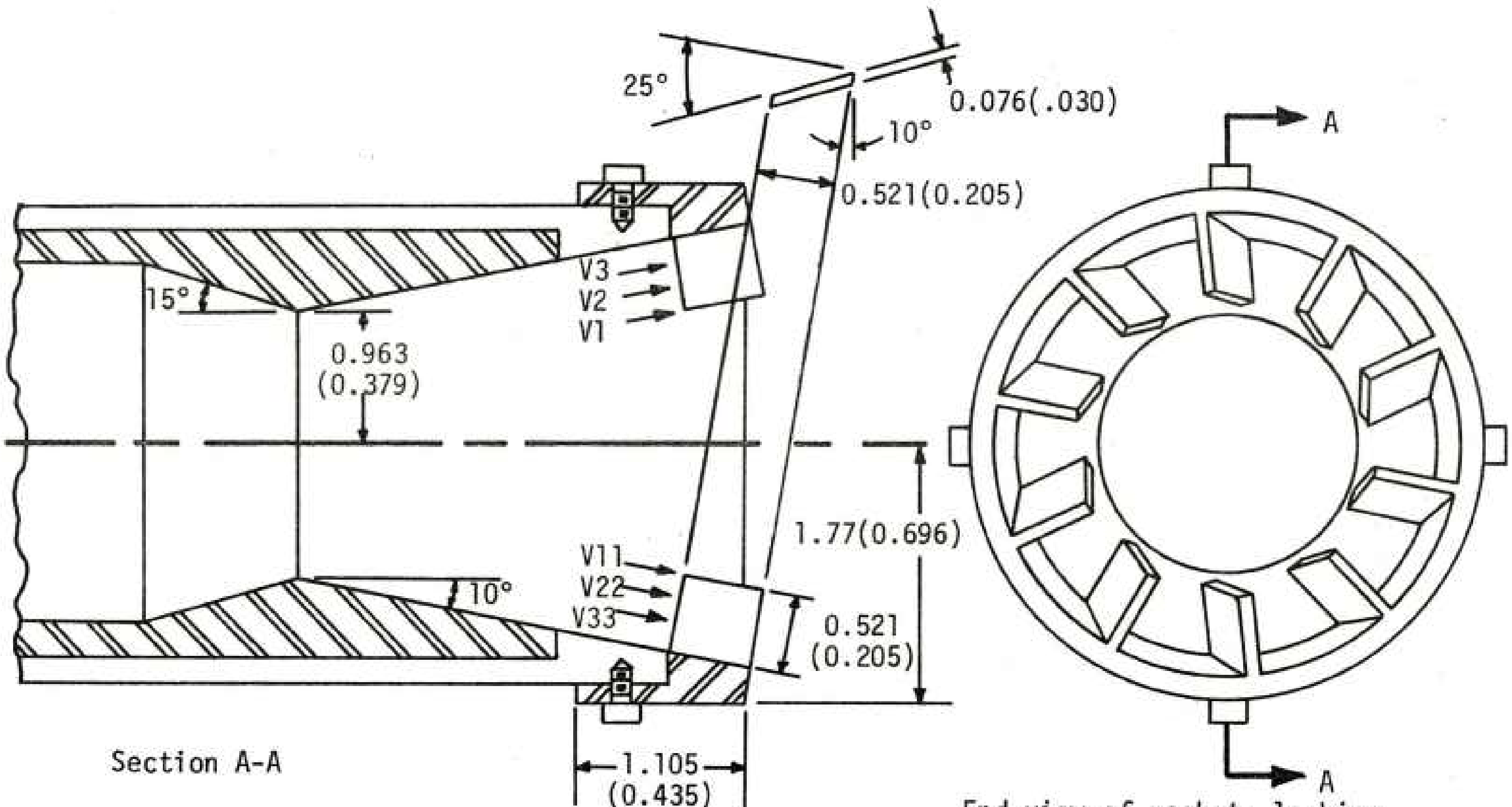


Figure 5. - Closeup of pitot rake in position - Photograph of the Rocket Exhaust Effects Facility

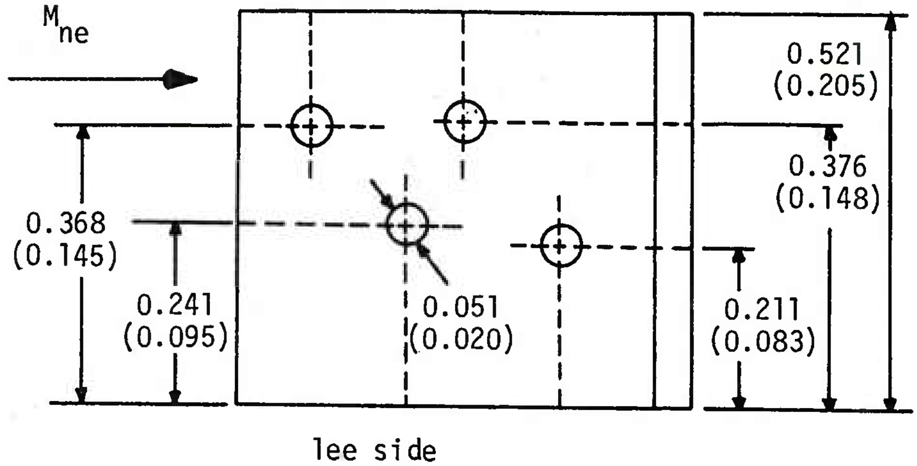
Note: dimensions in centimeters (inches).



Section A-A

End view of rocket, looking upstream

Figure 6. - Detailed sketch of rocket nozzle with spin vane attached.
Scale: twice actual size.



Note: dimensions in centimeters (inches)

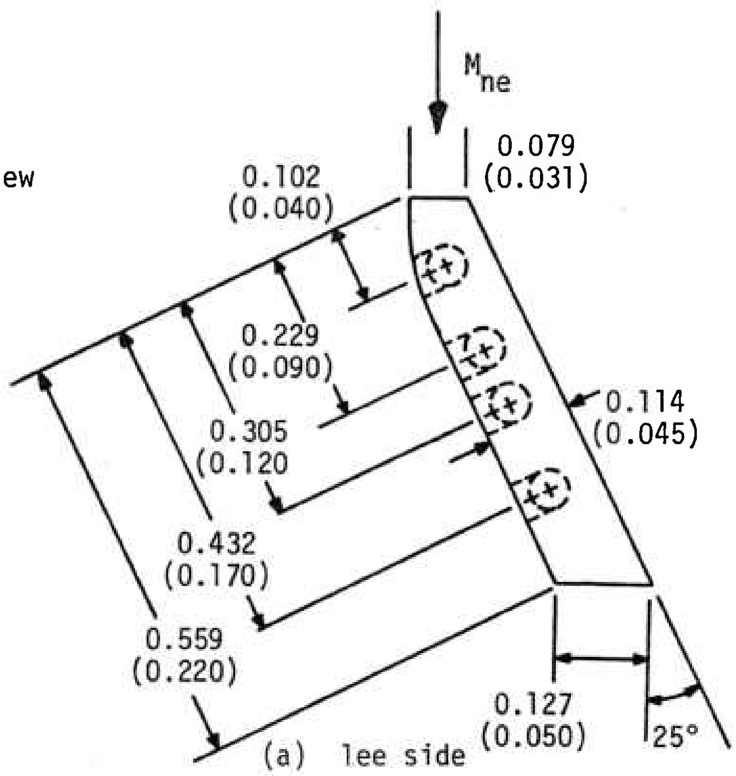
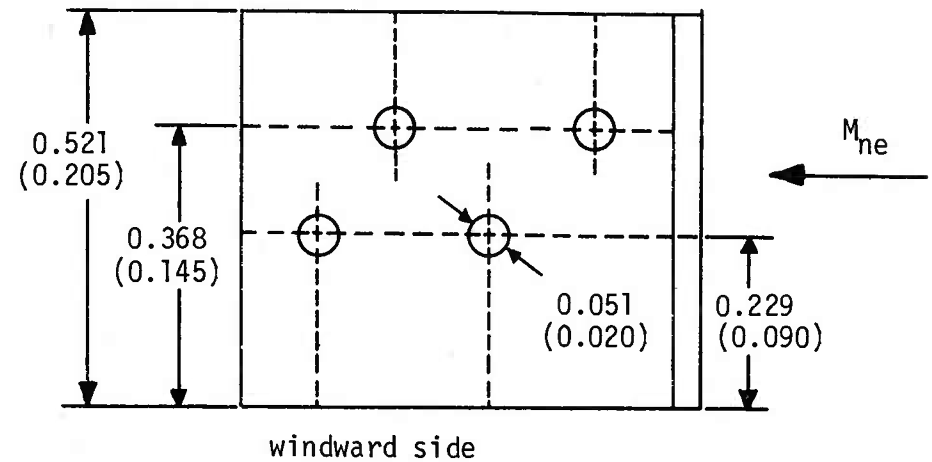
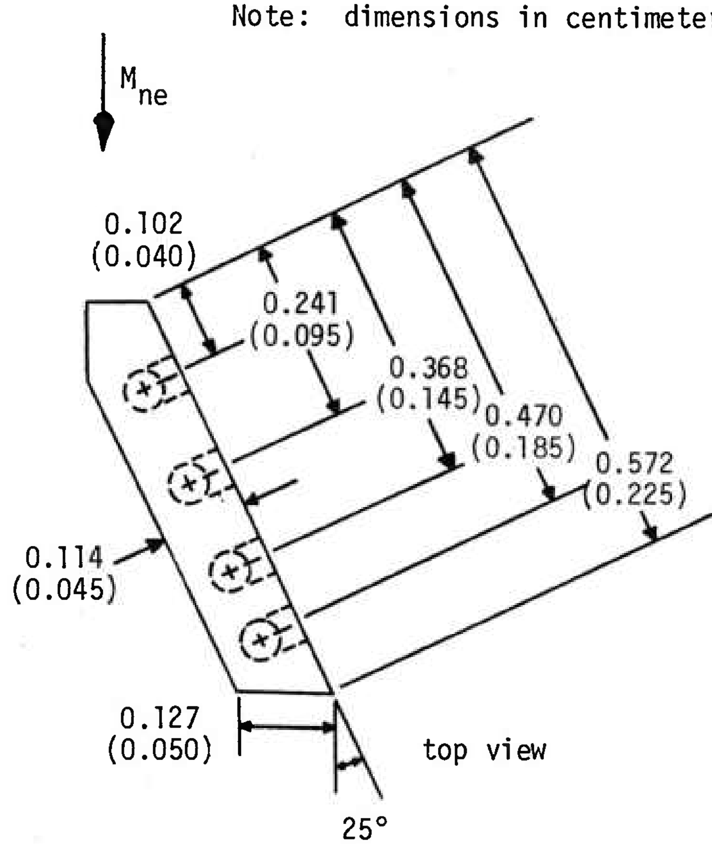


Figure 7. - Detailed sketch of vane illustrating static pressure orifices
Scale: ten times actual size.



Note: dimensions in centimeters (inches)



(b) Windward Side

Figure 7. - Concluded.

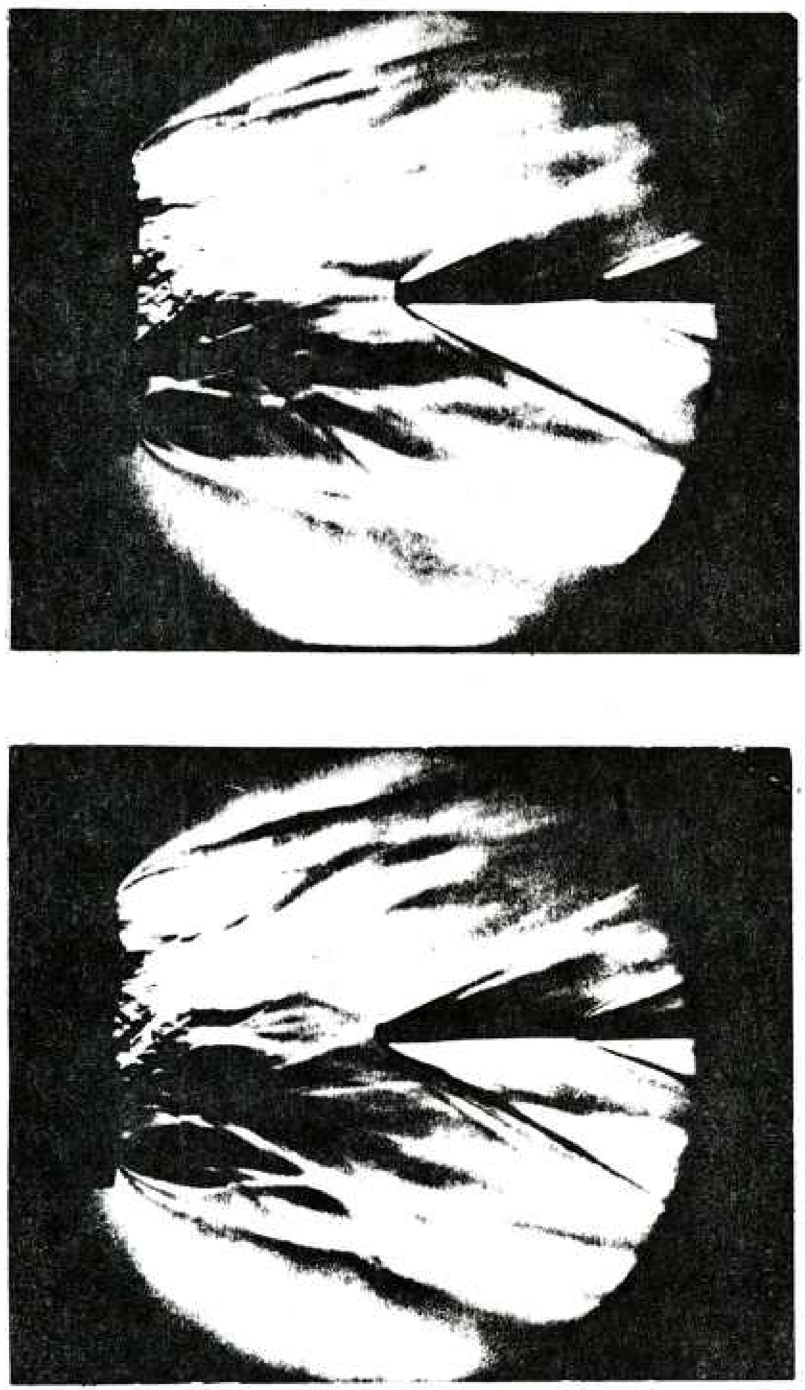


Figure 8. - Schlieren photographs of the flow exhausting through the V1 turbine, h_v = 0.521 cm (0.205 in), for two different orientations of the spin turbine (90° apart). $P_{t1} = 6.74 \times 10^6$ N/m^2 (978 psia)

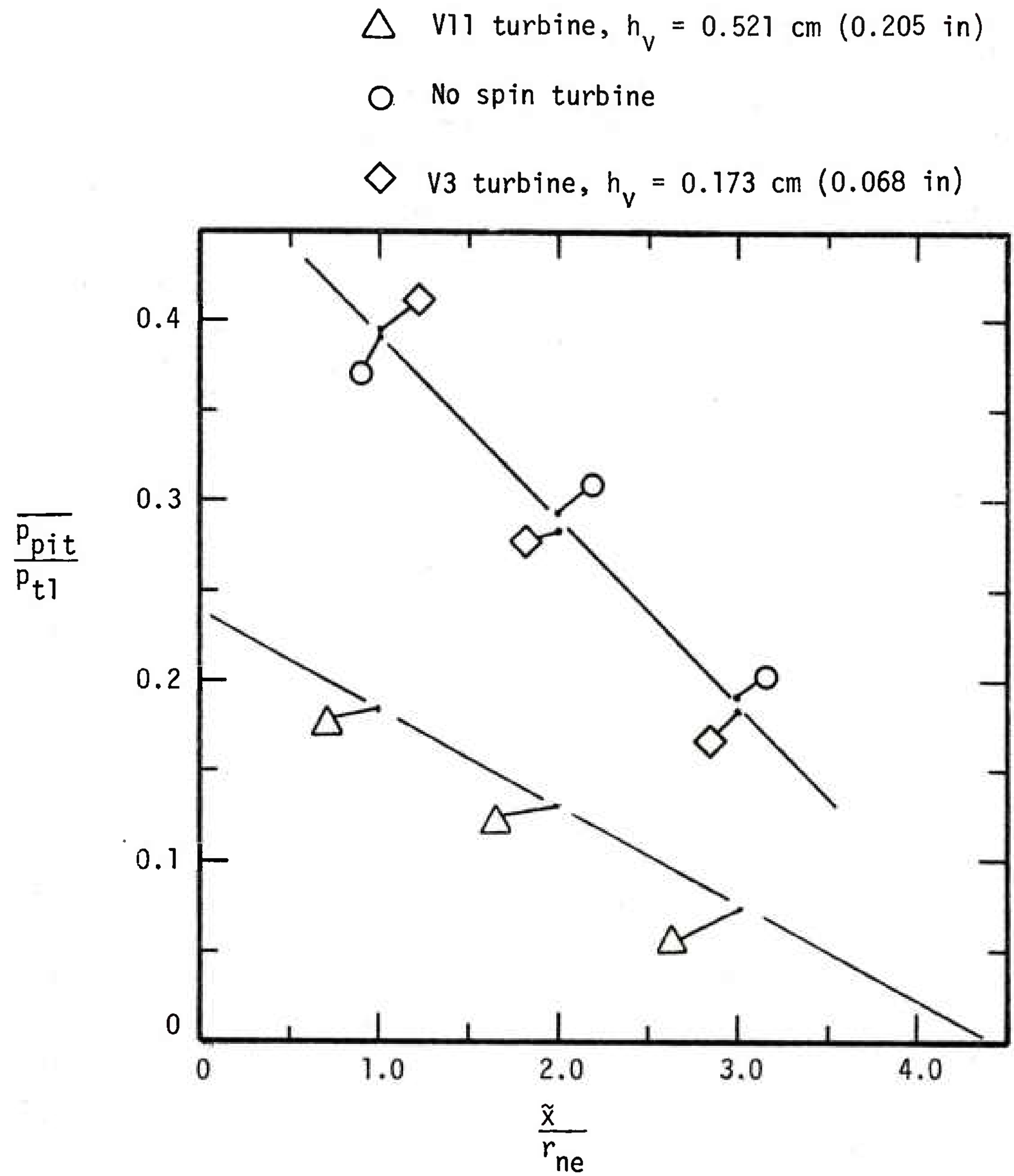


Figure 9 . - Average values of the pitot pressure as a function of distance downstream of the nozzle.
p_{t1} = 6.74 × 10^6 N/m^2 (978 psia)

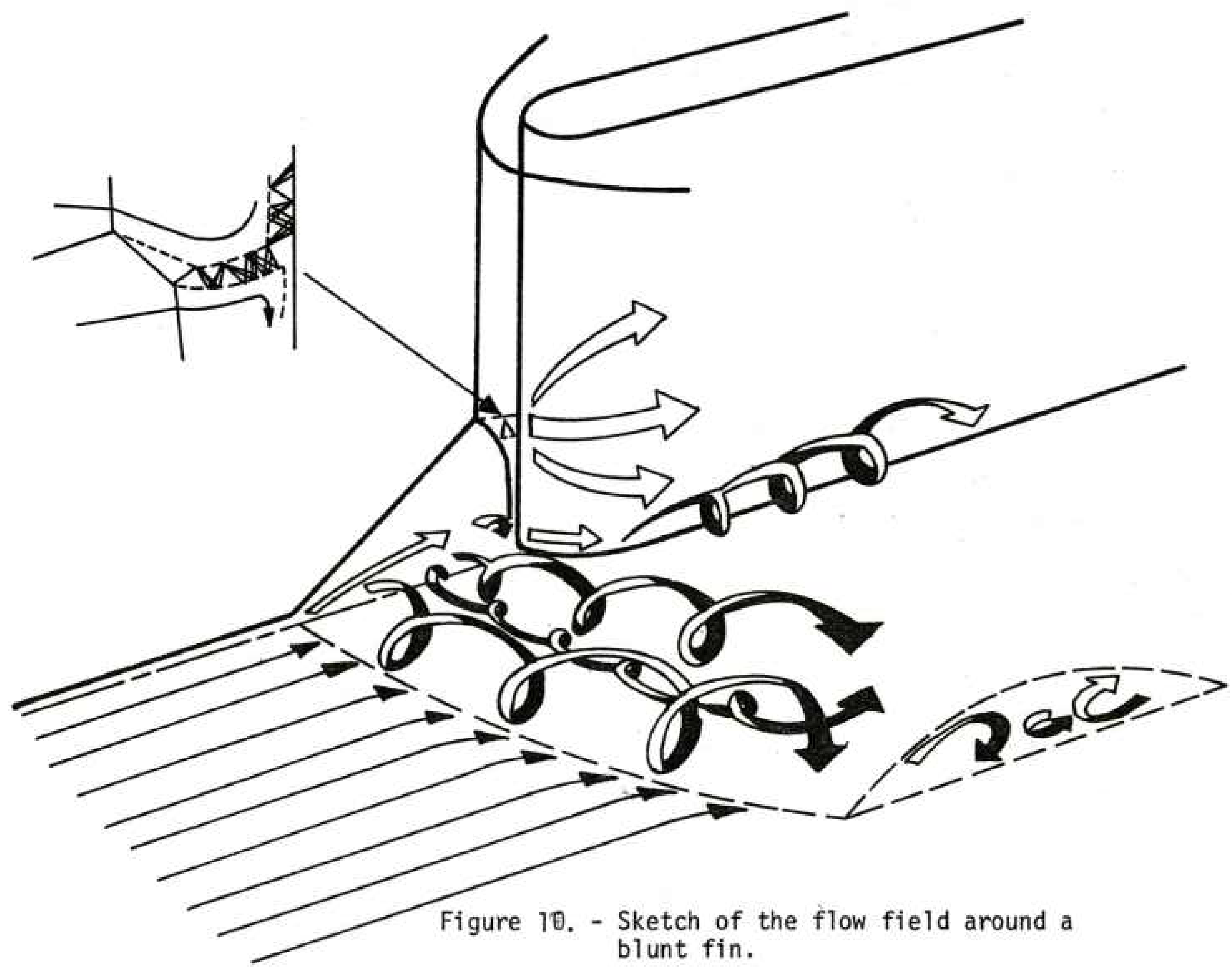
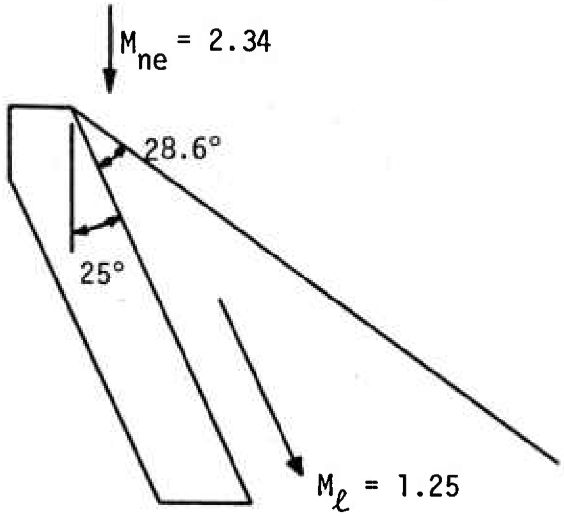
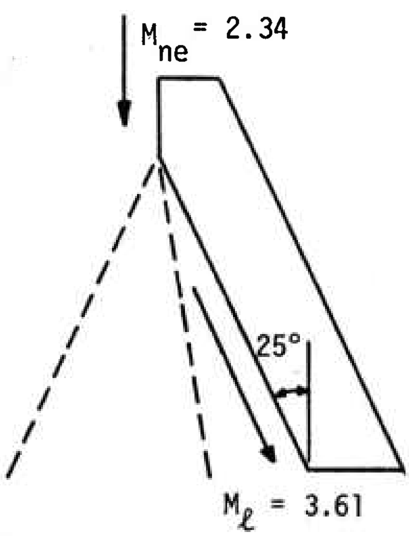


Figure 10. - Sketch of the flow field around a blunt fin.

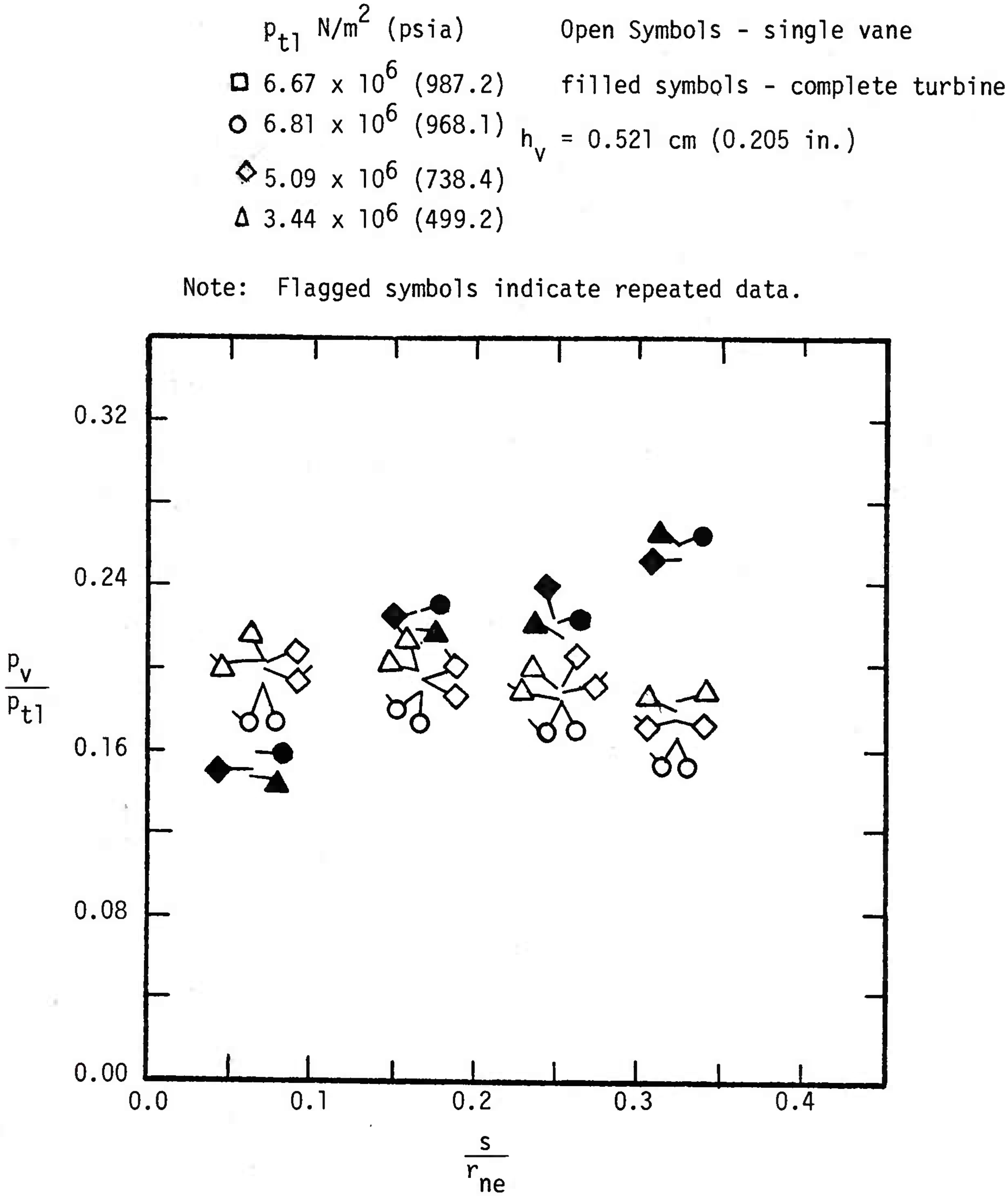


(a) weak oblique shock, windward surface.



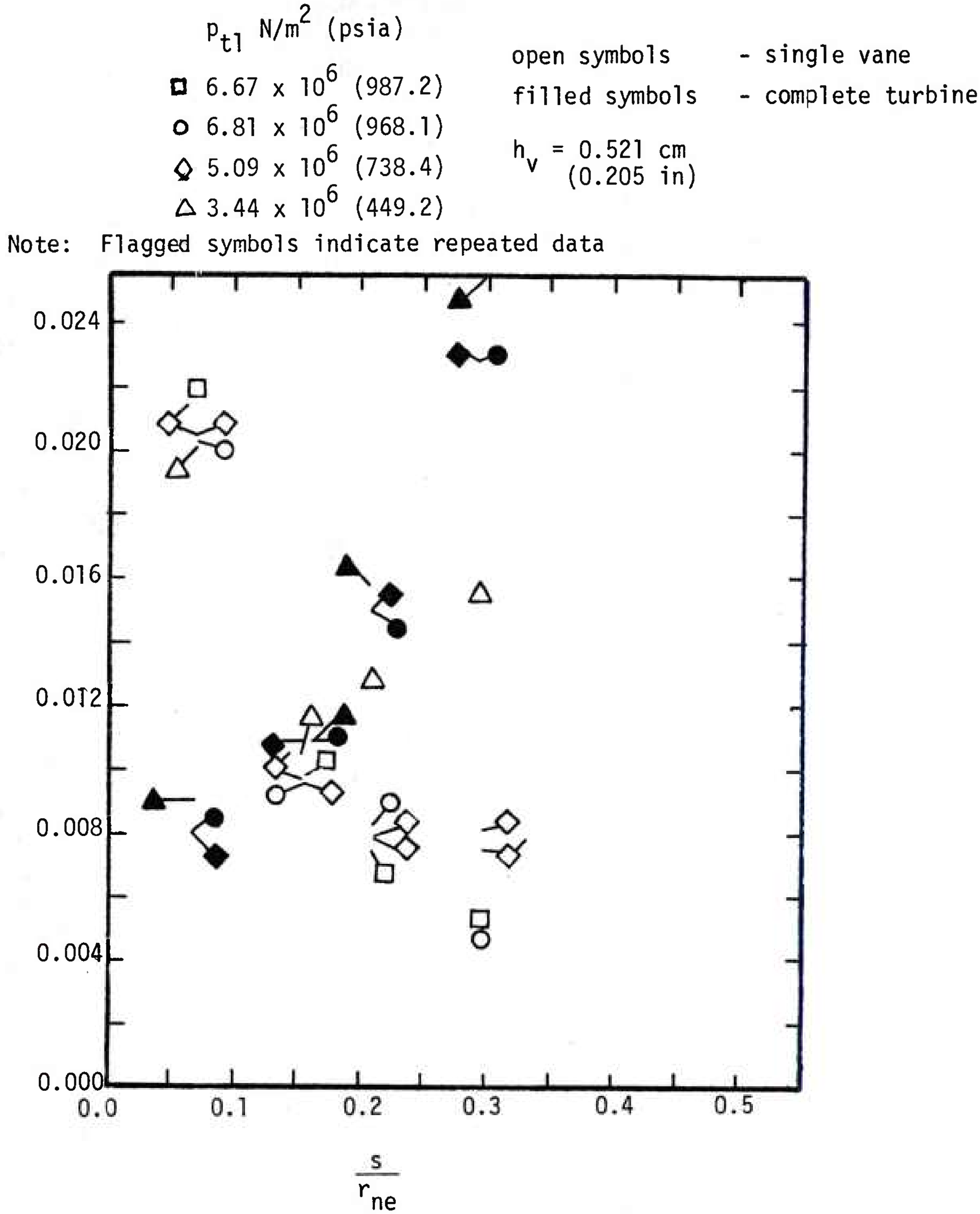
(b) Prandtl-Meyer expansion, leeward surface.

Figure 11. - Simplified model of the flow field around an isolated vane.



(a) windward surface

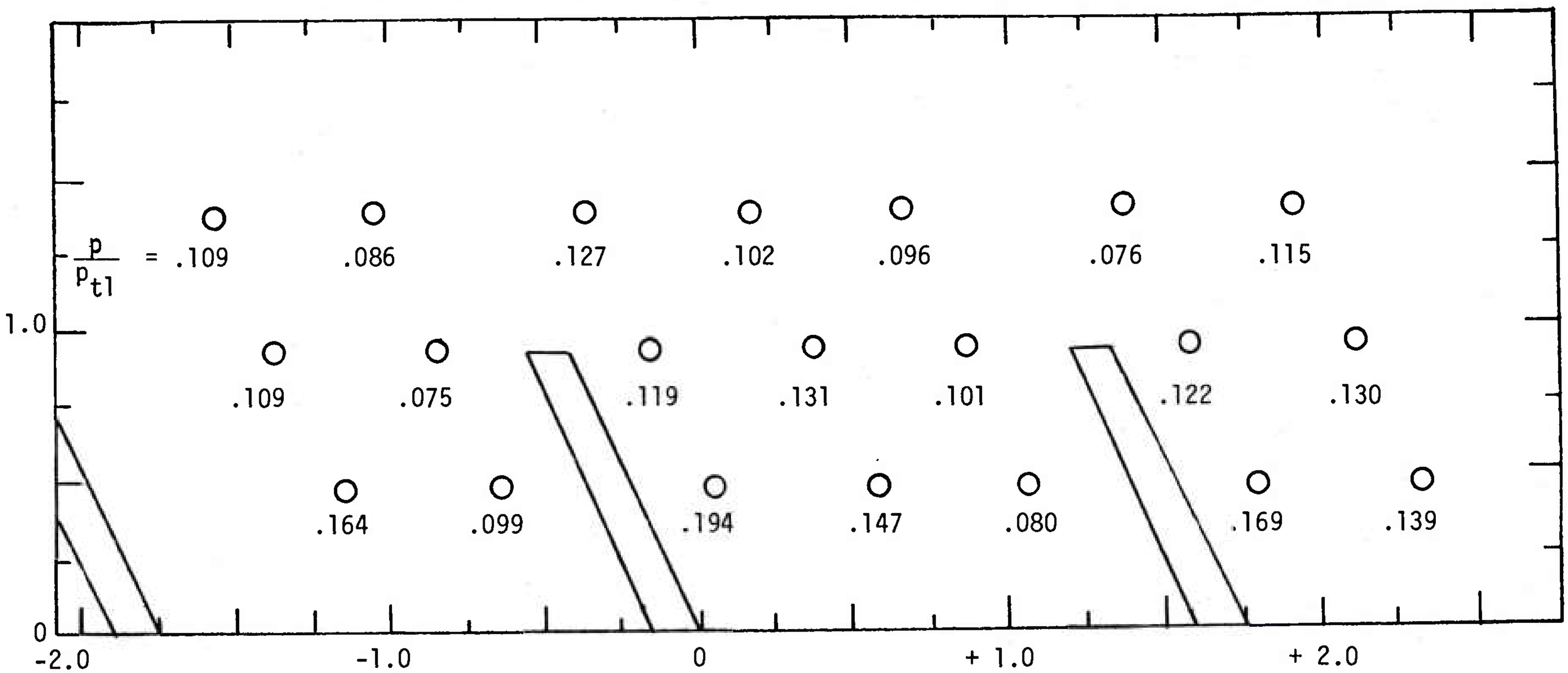
Figure 12. - Static pressure measurements on the surface of the spin vane as a function of the chordwise distance from the leading edge.



(b) Leeward surface

Figure 12. - Concluded

Note: Surface coordinates in units of vane chord length, 0.575 cm (0.226 in).



$p_{t1} = 6.74 \times 10^6$ N/m^2 (978 psia)

Figure 13. - Nondimensionalized static pressures, p/p_{t1} on the nozzle surface in the complete spin tubine. (a) h_v = 0.521 cm (0.205 in). Scale: 7.95 times actual size.

Note: Surface coordinates in units of vane chord length, 0.575 cm (0.226 in).

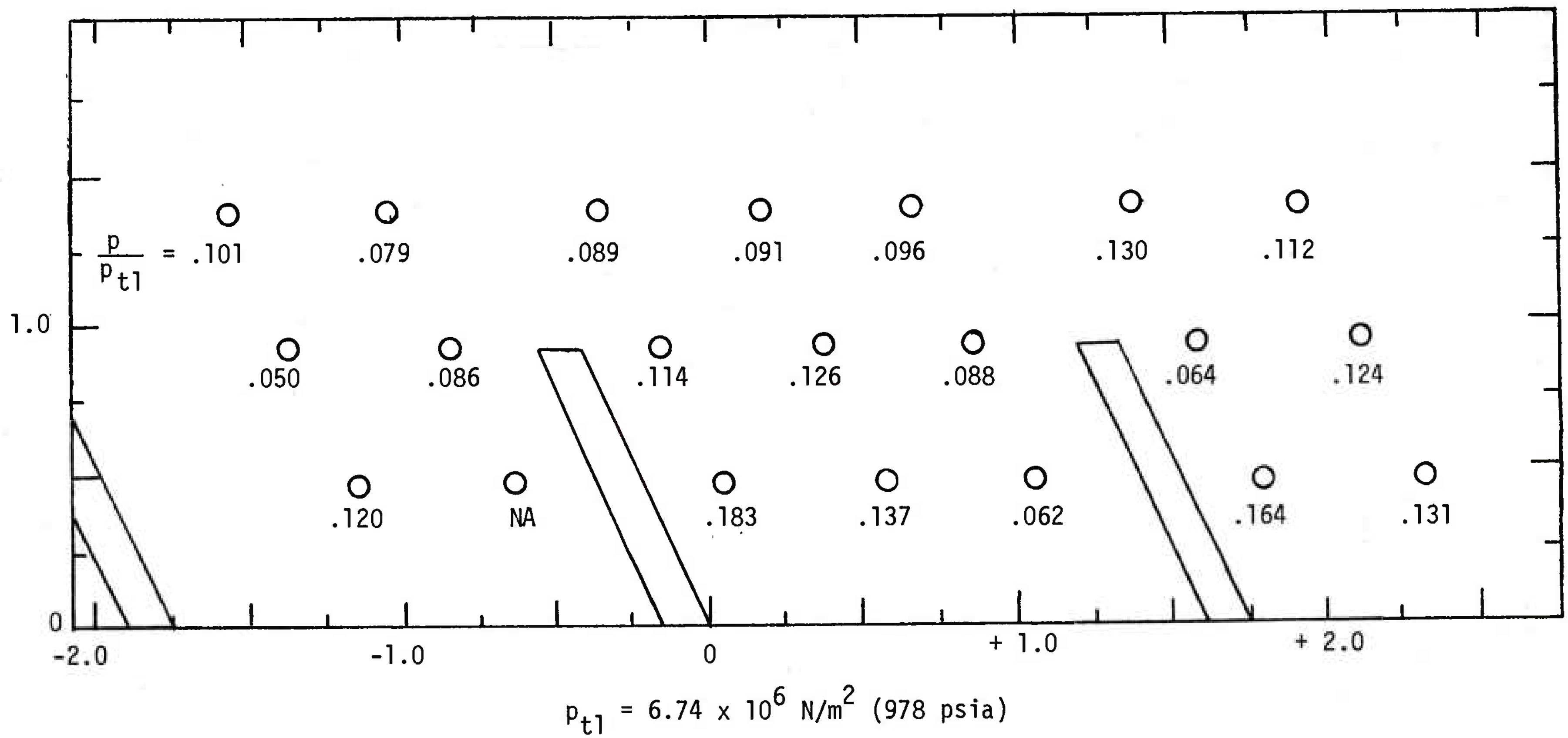
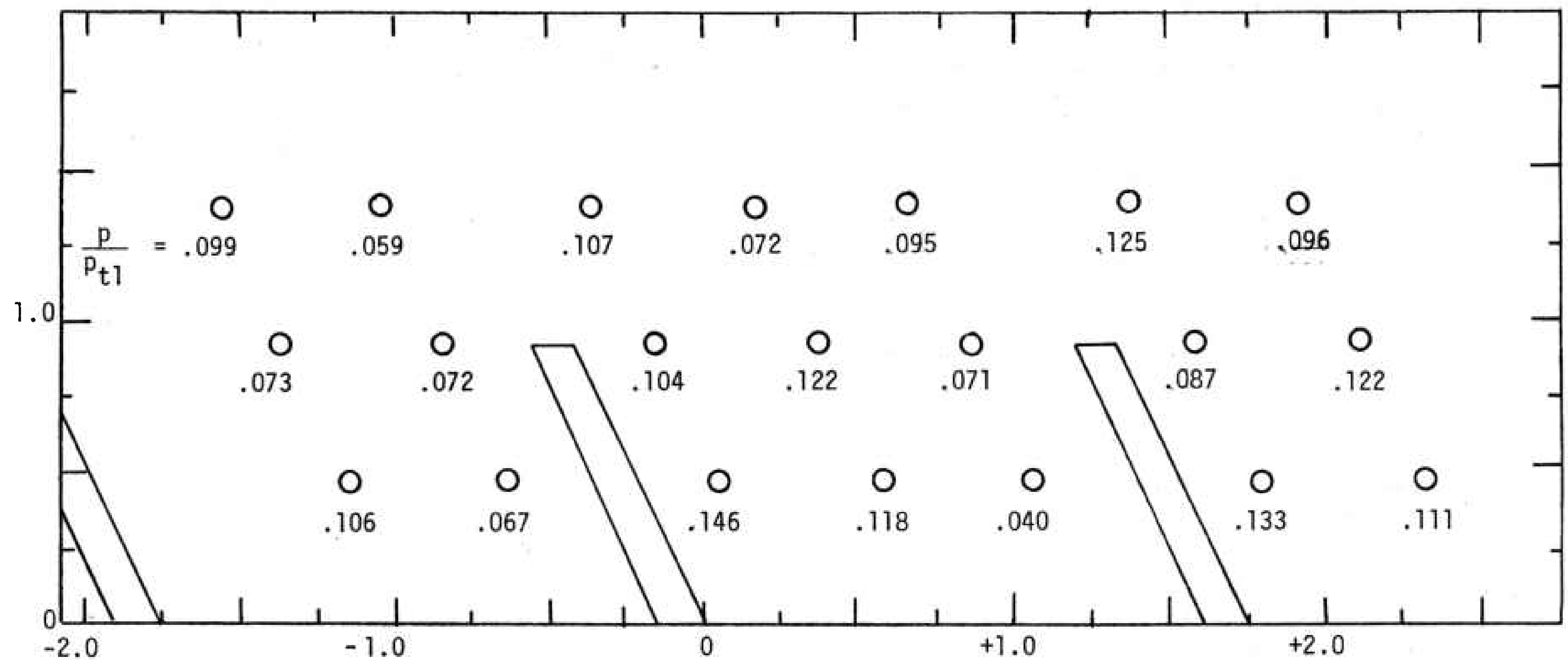


Figure 13. - Nondimensionalized static pressures, p/p_{t1} on the nozzle surface in the complete spin turbine
(b) h_v = 0.394 cm (0.155 in). Scale: 7.95 times actual size.

Note: Surface coordinates in units of vane chord length, 0.575 cm (0.226 in).



$p_{t1} = 6.74 \times 10^6$ N/m^2 (978 psia)

Figure 13. - Nondimensionalized static pressures, p/p_{t1} on the nozzle surface in the complete spin turbine. (c) h_v = 0.267 cm (0.105 in)
Scale: 7.95 times actual size.

Note: Surface coordinates in units of vane chord length, 0.575 cm (0.226 in).

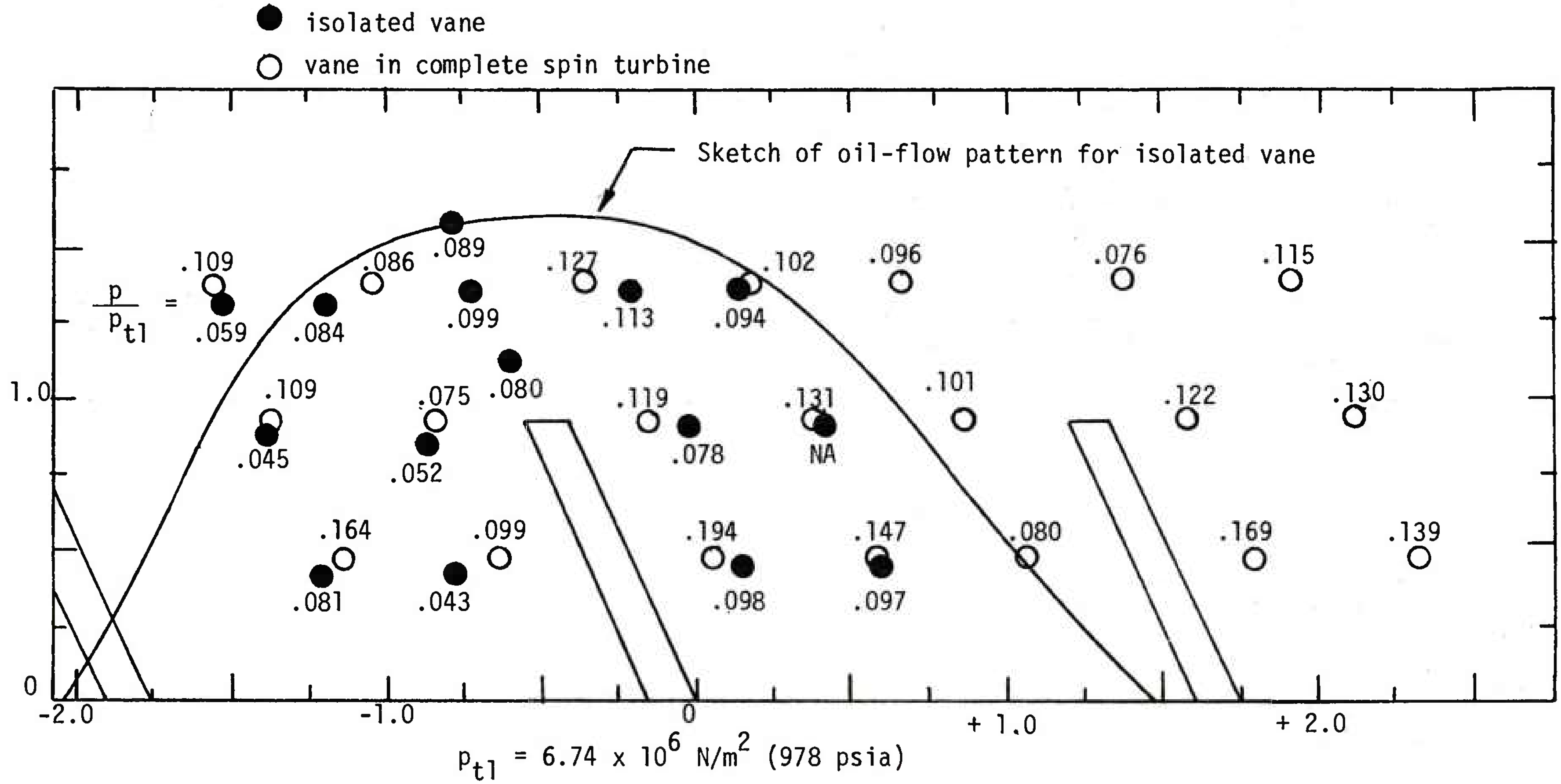


Figure 14. - Nondimensionalized static pressures, p/p_{t1} on the nozzle surface in the complete spin turbine and for isolated vane h_v = 0.521 cm (0.205 in).

Scale: 7.95 times actual size.

Note: Surface coordinates in units of vane chord length, 0.575 cm (0.226 in).

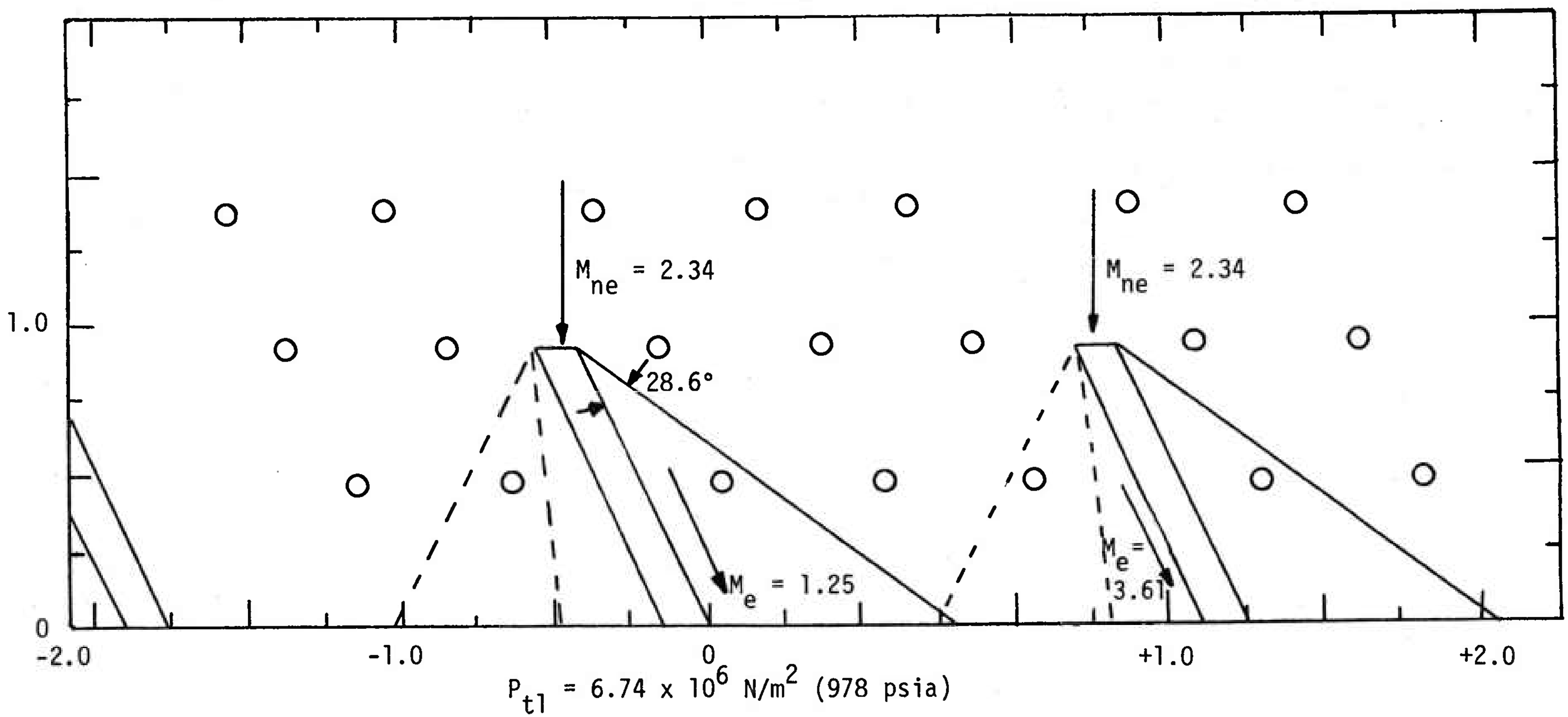


Figure 15. - Nondimensionalized static pressures, p/p_{t1} on the nozzle surface in the complete spin turbine and for isolated vane h_v = 0.521 cm (0.205 in).

Scale: 7.95 times actual size.

End view of rocket nozzle looking upstream.

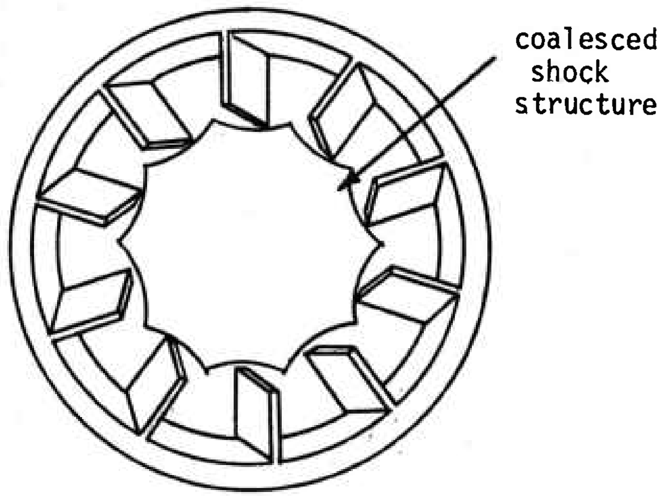
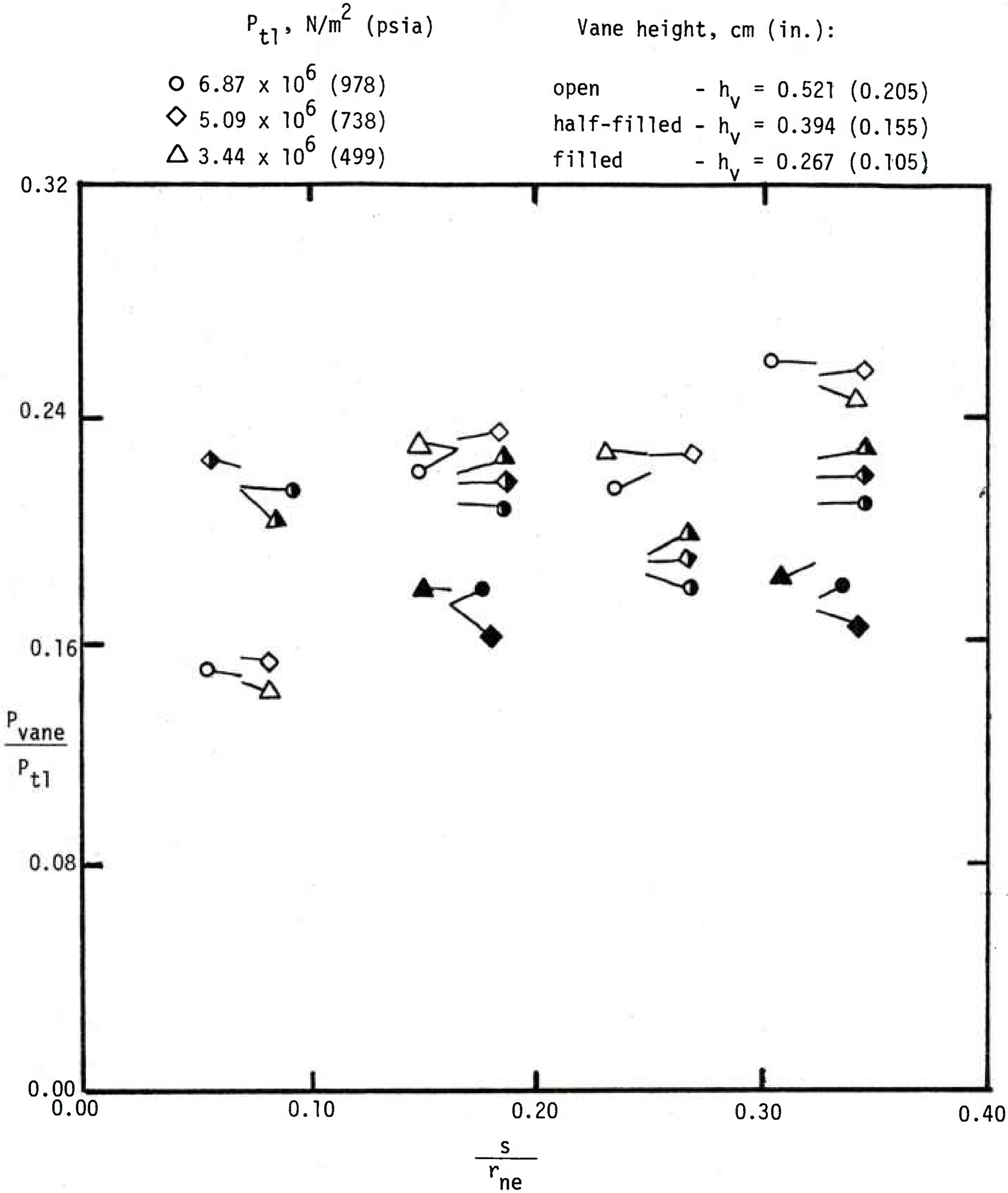
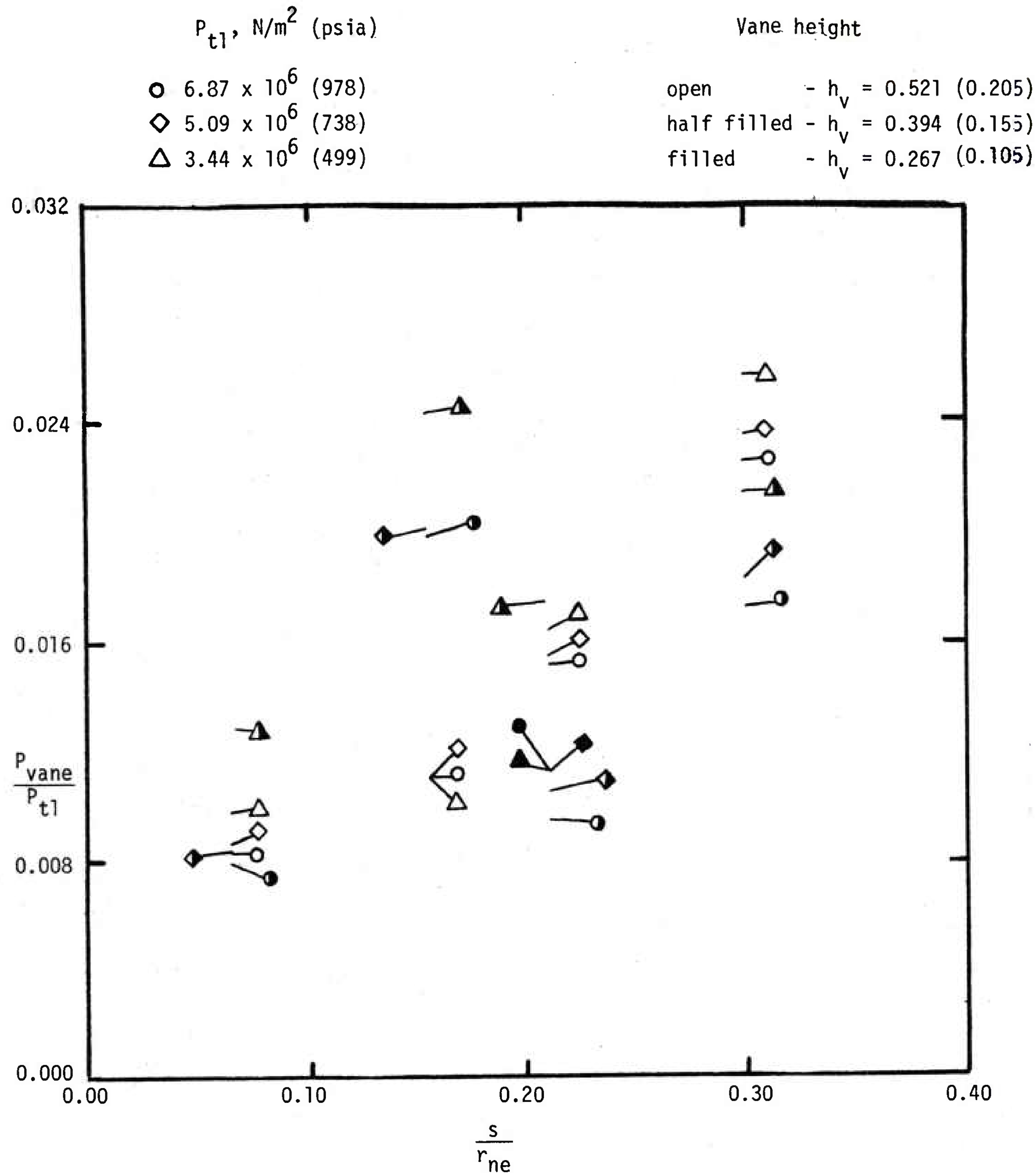


Figure 16. - Cross-sectional sketch of the coalesced shock structure at the nozzle exit.



(a) Windward side

Figure 17. - Static pressure distribution on the surface of the spin vane as a function of chordwise distance from leading edge.



(b) Leeward side

Figure 17. - Concluded