The nuclear engine was assumed to give a thrust of 10,000 lb. The graph is broken off at an initial weight of 20,000 lb because beyond that limit, gravity losses are no longer negligible in the determination of payload efficiency. For practical application, the graph should be redrawn, to a larger scale, on graph paper.

The equivalence condition has been discussed more elaborately in Refs. 1 and 3. Graphs similar to Fig. 1 can also be constructed for the comparison of more than two rocket drives as was dealt with in Ref. 3.

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Cylindrical Diffuser Performance using a Truncated Plug Nozzle

Fred L. Galanga* and Thomas J. Mueller†
University of Notre Dame, Notre Dame, Ind.

Nomenclature

A = area
D = diameter
L = length
P = pressure
r = radius
x = axial distance from T-P nozzle exit

Subscripts

at = atmospheric conditions
b = plug base
cell = cell region
d = diffuser duct
ne = nozzle exit
nt = nozzle throat
p = plug
sh = nozzle shroud
01 = stagnation conditions

Introduction

CONVENTIONAL altitude facilities used to evaluate nozzle performance are generally equipped with simple exhaust diffusers that supplement facility exhausters.[1] Although flow models have been developed which are able to accurately predict diffuser performance characteristics using conventional bell nozzles, the performance of such systems using the altitude compensating truncated plug (T-P) nozzles has not been fully developed at present due to its complicated flowfield. This Note reviews some aspects of diffuser performance for a T-P nozzle without external flow.

General Features of Diffuser Operation

The process of achieving a reduced nozzle ambient or cell pressure with a supersonic nozzle and a cylindrical diffuser is relatively simple. The free-jet boundary emanating from the exit of a bell nozzle or the T-P nozzle, acts as a pump. Viscous shear along the jet boundary tends to pull the dead air from the cell region (Fig. 1) causing the plume to expand farther until it impinges on the diffuser wall. Here a quasi-steady-state condition is achieved; the cell pressure remains relatively constant while the impingement shock forms a complex shock system downstream, along with a static pressure rise in the diffuser. The condition of a very nearly constant cell pressure to upstream stagnation pressure ratio (P_{cell}/P_{01}) with changing overall (i.e., atmospheric to stagnation) pressure ratio (P_{at}/P_{01}) constitutes the "started" condition of the nozzle-diffuser system,[1] as opposed to the "unstarted" condition where cell pressure ratio varies with overall pressure ratio.

Equipment and Procedure

Tests were conducted using the Notre Dame blowdown Nozzle Thrust Facility (NTF). The T-P nozzle used (Fig. 1) was designed for an exit Mach number of 1.9 based on the overall nozzle exit to the throat area ratio. The nozzle shroud contour from the throat to the exit was cylindrical which fixed the nozzle exit angle at zero degrees. The plug was conical in shape from the throat and converged to the axis of symmetry at an angle of 10°. The base of the plug contained a central pressure tap to monitor the base pressure during all tests. A mating section was constructed to allow the diffuser to be bolted directly to the nozzle. The actual diffuser section was fashioned into two 13.97 cm lengths to facilitate boring of the duct diameter and to allow for testing of two different duct lengths. Six different duct diameters were evaluated during the tests. The diffuser was fitted with 39 sidewall taps to record pressure conditions from the cell region to the exit. A slotted hypotube was installed in its base to measure pressure distribution down the centerline of the diffuser. Twenty 150 cm mercury-filled manometers were used to record pressures.

Standard operating procedure for the NTF consisted of presetting the desired nozzle total pressure and then starting the flow. After allowing oscillations to damp, pressure conditions indicated by the manometers were photographically recorded. Shadowgraphs and total pressure measurements of the diffuser exit flow were also taken at this time.

Results

Figure 2 shows a typical centerline and sidewall pressure variation along the length of the duct. For this case the duct area to nozzle exit area ratio is 1.384. The approximate jet impingement point corresponding to the highest recorded wall pressure is 0.34 nozzle diam downstream of the nozzle exit. The pressure distribution down the duct indicates a shock wave system of diminishing strength occurring for about 5-6 nozzle exit diam downstream of the nozzle exit. This is borne out by the fact that where the centerline pressure ratio is a maximum, the sidewall pressure ratio corresponds to a minimum and vice versa. Beyond 6 nozzle exit diam, both the sidewall and the centerline static pressures show a gradual rise. Here the flow is still supersonic but decelerating. At the duct exit the sidewall pressure suddenly jumps indicating a shock wave (verified by shadowgraph pictures). Plug base pressures obtained with the hypotube installed were within 2% of the base pressures obtained[2] without the tube which suggests that tube interference effects were small.

Figures 3 and 4 show the variation of cell pressure ratio with overall pressure ratio for the long and short diffusers, respectively. With the longer diffuser (Fig. 3) it is evident that as the duct area ratio increases the cell pressure ratio decreases, remaining relatively constant until an overall pressure ratio of approximately 0.27-0.30 is achieved where

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Index categories: Rocket Engine Testing; Airbreathing Engine Testing; Nozzle and Channel Flow.

*Research Assistant. Member AIAA.

†Professor. Associate Fellow AIAA.

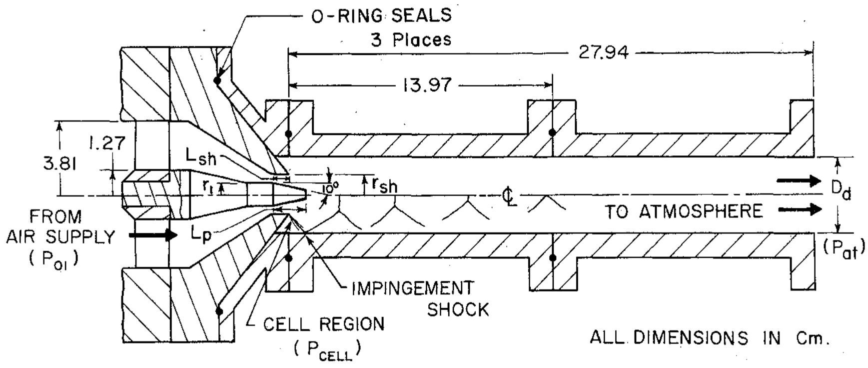

Fig. 1 Schematic of axisymmetric nozzle-diffuser system. $r_t = 0.615$, $r_{sh} = 1.026$, $L_{sh} = 0.762$, $L_p = 1.320$. $A_{ne} = 3.30$ cm^2, $A_{nt} = 2.12$ cm^2. $D_d = 2.26, 2.37, 2.42, 2.54, 2.79, 3.05$.

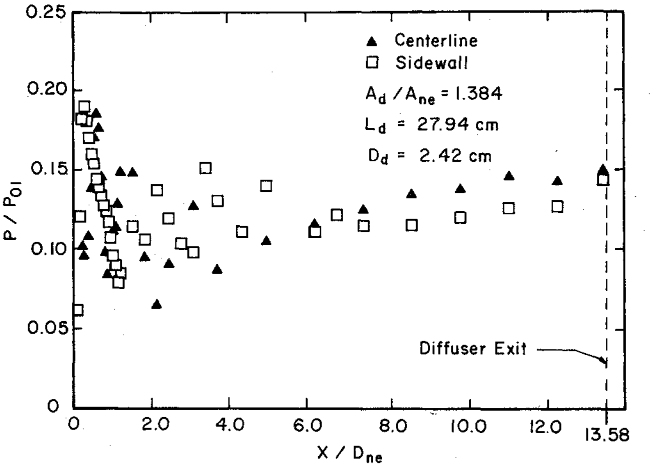

Fig. 2 Typical centerline and sidewall pressure ratio variation along diffuser, $P_{0l} = 482.65$ **kN/M^2 gage.**

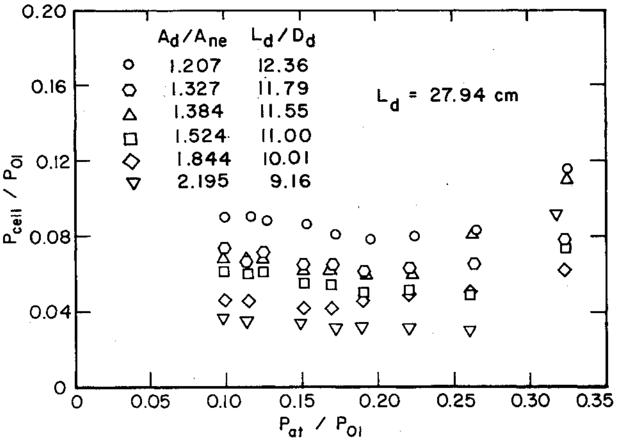

Fig. 3 Cell pressure ratio vs overall pressure ratio (long diffuser).

the system becomes unstarted. The cell pressure ratios obtained with the short diffuser (Fig. 4) tend to remain more constant than those for the longer duct. At the maximum overall pressure ratio investigated (0.32), the diffuser system is still started.

For all the the diffuser configurations and test conditions covered in this Note, base pressure ratio (P_b/P_{0l}) was equal to 0.102 within ±3%. The nominal base pressure ratio obtained with diffusers installed was within 2% of those recorded without the diffuser present.[3] This indicates that the impingement shock wave does not significantly affect the T-P nozzle near wake region, leaving the nozzle flowfield intact.

A comparison of diffuser performance obtained with the T-P nozzle and diffuser performance obtained with conventional bell nozzles having zero degree nozzle exit angles[1] is presented in Fig. 5. Interpolated minimum cell pressure ratios for a bell nozzle having an area ratio comparable to the T-P nozzle (1.555) are essentially identical to results obtained with the T-P nozzle. The most significant differences are evident with the smaller diameter diffusers ($A_d/A_{ne} \leq 1.8$) where T-P plug and plug base flow conditions apparently alter the shroud plume/diffuser interaction to some degree. Except for

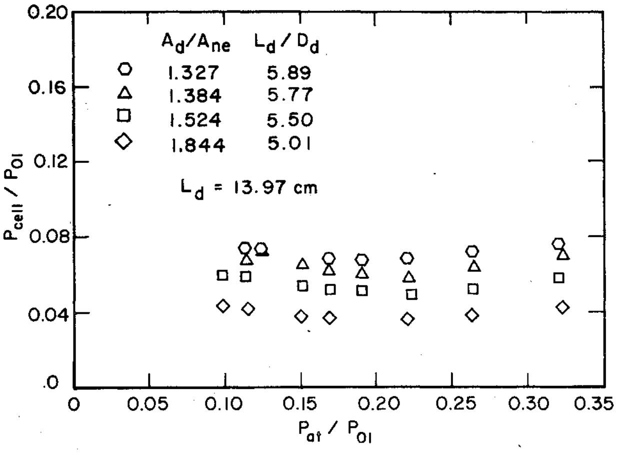

Fig. 4 Cell pressure ratio vs overall pressure ratio (short diffuser).

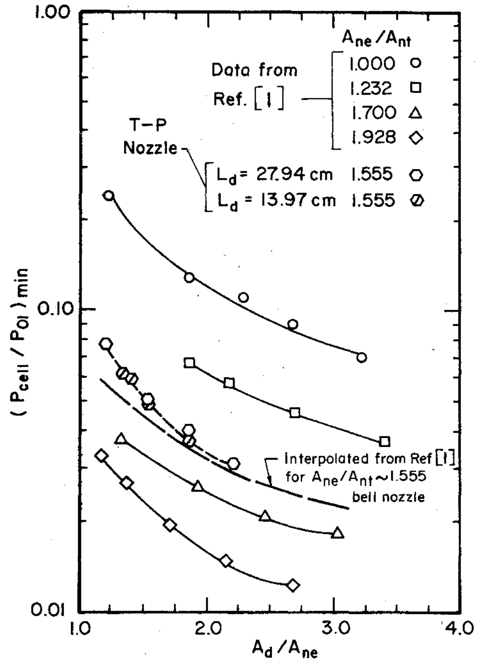

Fig. 5 Comparison of minimum experimental cell pressure ratio vs area ratio.

these modest differences, performance of cylindrical diffusers obtained with this particular T-P nozzle is essentially identical to diffuser performance obtained with bell nozzles.

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