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Rensselaer

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Richard T. Lahey, Jr.
Edward E. Hood, Jr. Professor of Engineering

Dr. Edwin P. Rood
Office of Naval Research
Scientific Office Code-1132F
800 North Quincy Street
Arlington, VA 22217-5000

Dear Dr. Rood:

The purpose of this letter is to transmit the Second Quarterly Progress Report for ONR grant N00014-91-J-1271 ("An Experimental Study of Plunging Liquid Jet Induced Air Carryunder and Dispersion", Lahey & Drew - CoPI).

The second quarter of this research project has been devoted to completion of both the axisymmetric and the planar nozzle designs, to qualifying the DANTEC 3-D LDA/PDA system for underwater operation, and to a preliminary analysis of two-phase jet spreading.

EXPERIMENT

As discussed in the last quarterly report, an axisymmetric nozzle will be used to benchmark our experimental results against prior data. Subsequently, a planar nozzle will be used to obtain data which should be more representative of the air carryunder process induced by a ship's bow wave.

During this report period the preliminary nozzle designs, reported on last quarter, were reviewed by wind tunnel design experts at RPI. In particular, Professors Nagamatsu and Hirsa reviewed our nozzle design and based on their comments, modifications were made. The final nozzle designs are shown in Figures 1-2 (axisymmetric nozzle) and Figures 3-4 (planar nozzle). These designs have now been turned into the RPI machine shop and will be fabricated during the third quarter of this research project.

A great deal of experimental qualification work was also done during the second quarter. In particular, the DANTEC 3-D LDA/PDA fiber flow system was designed and tested underwater. Unfortunately, it was found that the sealing of the lens was not adequate (ie, leakage occurred). All sets of lenses (301 mm, 600 mm and 1200 mm) have been returned to DANTEC and they are currently being redesigned and manufactured (in Denmark) to obtain a leak-tight seal. Delivery of these new lenses is expected during the third quarter.

The Benjamin System 3-D traversing mechanism was delivered during the report period and was installed and operated. This traversing mechanism has the capability of giving one micron positioning accuracy in each orthogonal direction (ie: x, y and z). It is not clear at this point whether our measurements must be made in the forward or backward scattering direction. If forward scattering is required then a special mirror system will be needed to allow for accurate PDA pickup. Such determinations can only be made when the entire system is in place and operated. In accordance with our original Work Scope, this is scheduled for next year.

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ANALYSIS

During the Second Quarter of this research project preliminary analysis was performed on two-phase jet spreading phenomena.

Appropriate equations of motion have been derived by assembling the relevant equations from Arnold's (1988) PhD. Thesis (G. Arnold, "Entropy and Objectivity as Constraints Upon Constitutive Equations for Two-Fluid Modeling of Multiphase Flows"), and adding the appropriate term representing the action of surface tension, which was not included in Arnold's thesis. These equations were non-dimensionalized for a long, narrow jet. The resulting equations are parabolic, so that numerical solution should be straightforward.

In addition, we have approximated the equations of motion by assuming that the gas volume fraction is small. This allows us to use the known solution for the velocity field in a planar jet for the liquid. If we further approximate the momentum equation for the bubbles by neglecting all effects except drag, virtual mass, and liquid pressure gradient, we are able to solve the resulting equations for bubble trajectories in the known liquid velocity field. It was assumed that the bubbles do not affect the liquid velocity field and that the gas density is negligible. The resulting equation in Lagrangian form is

$$\frac{d\vec{r}_g}{dt} = \vec{v}_g$$

$$\rho_g V_b \frac{d}{dt}\vec{v}_g = \rho_\ell V_b \frac{d}{dt}\vec{v}_\ell\left(\vec{r}_g(t)\right) + C_{vm}\rho_\ell V_b \frac{d}{dt}(\vec{v}_\ell - \vec{v}_g) + \frac{1}{2}\rho_\ell A_b C_D \left|\underline{\vec{v}_\ell} - \underline{\vec{v}_g}\right| \left(\underline{\vec{v}_\ell} - \underline{\vec{v}_g}\right)$$
$$+ (\rho_\ell - \rho_g) V_b \vec{g} \qquad (1)$$

The Tollmein solution for a planar jet was used for the liquid velocity.

The system (1) was solved numerically using a 4^{th} order Runge-Kutta subroutine. The computed trajectories are shown in Figure 5 for different initial conditions. $\vec{v}_g(t=0) = 0$ and $p \in [-1, 1]$ is a parameter that specifies $\vec{r}_g(t=0)$. See Figure 6.

One result of this calculation is the point s where the trajectory comes to the surface. Figure 7 depicts s as a function of the parameter p. It can be easily seen that for p near -1 there are trajectories that cross each other.

If P(p) is the distribution of bubbles at the inlet and S(s) is the distribution at the free surface, then

$$S(s) = \left|\frac{dp_1}{ds}\right| P[p_1(s)] + \left|\frac{dp_2}{ds}\right| P[p_2(s)]$$

where $p_1(s)$ and $p_2(s)$ are monotone.

Improvements to this model are contemplated, including evaluation of the effects of the neglected terms, and using this model with a realistic bubble density distribution at the beginning of the jet, in order to obtain the bubble density field.

This last concept points to a research direction that we shall pursue; namely, the development of the air being dragged along the liquid jet into bubbles under the surface. We have been developing a model for bubble coalescence and breakup for predicting flow regime transition for bubbly flow. We propose to use this model to see if it is capable of predicting bubble formation for the plunging jet.

If you have any questions concerning the material presented in this letter please do not hesitate to contact us [Lahey: 518-276-8579; Drew: 518-276-6903].

Sincerely yours,

Donald A. Drew

Dr. D.A. Drew
Professor of Mathematical Sciences

DAD/ev

cc:
- Administrative Grants Officer - ONR
- Director - Naval Research Laboratory
- Defense Technical Information Center
- R.T. Lahey, Jr. (RPI)
- F. Bonetto (RPI)

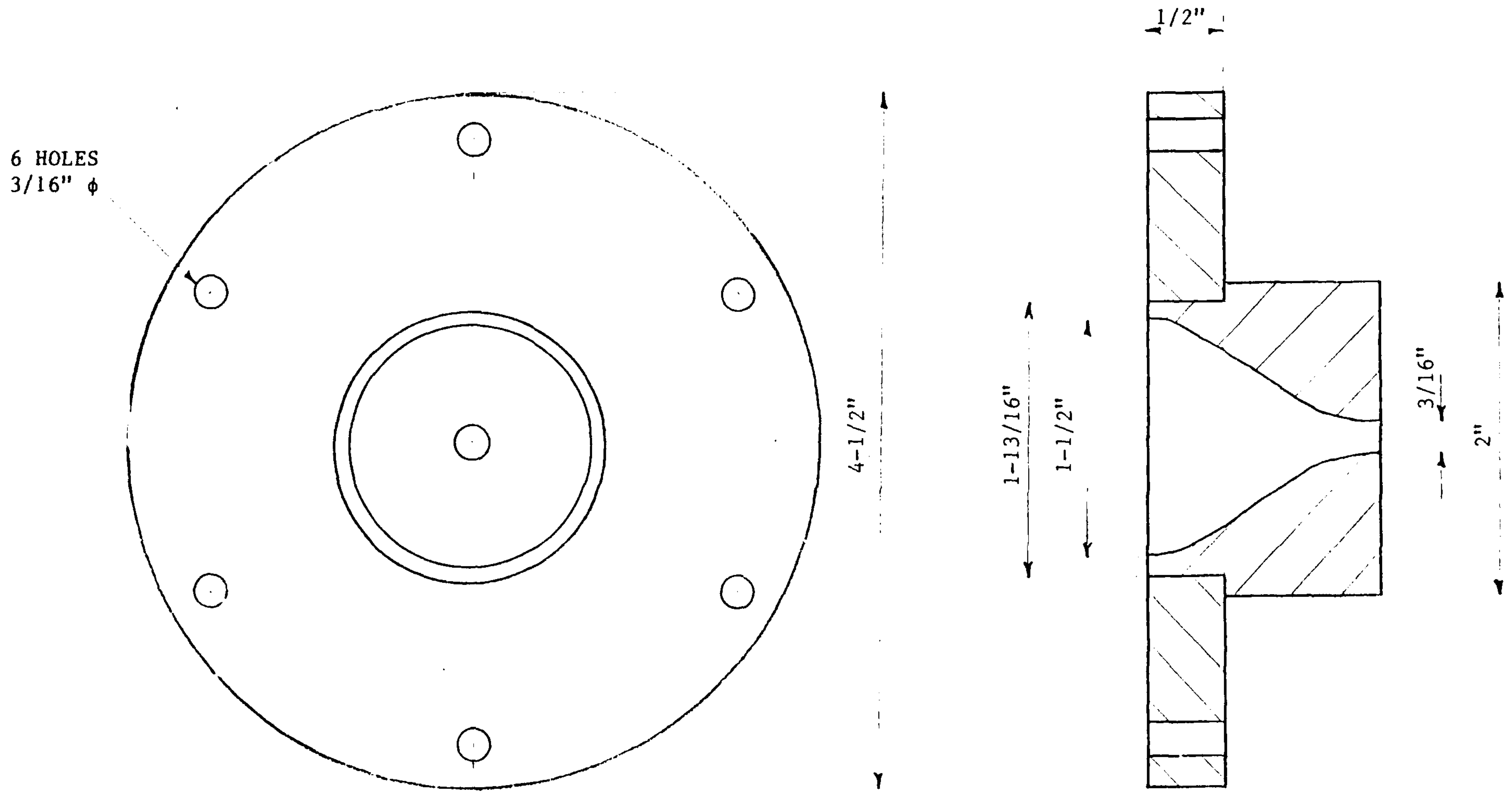


FIGURE-1 AXISYMMETRIC NOZZLE

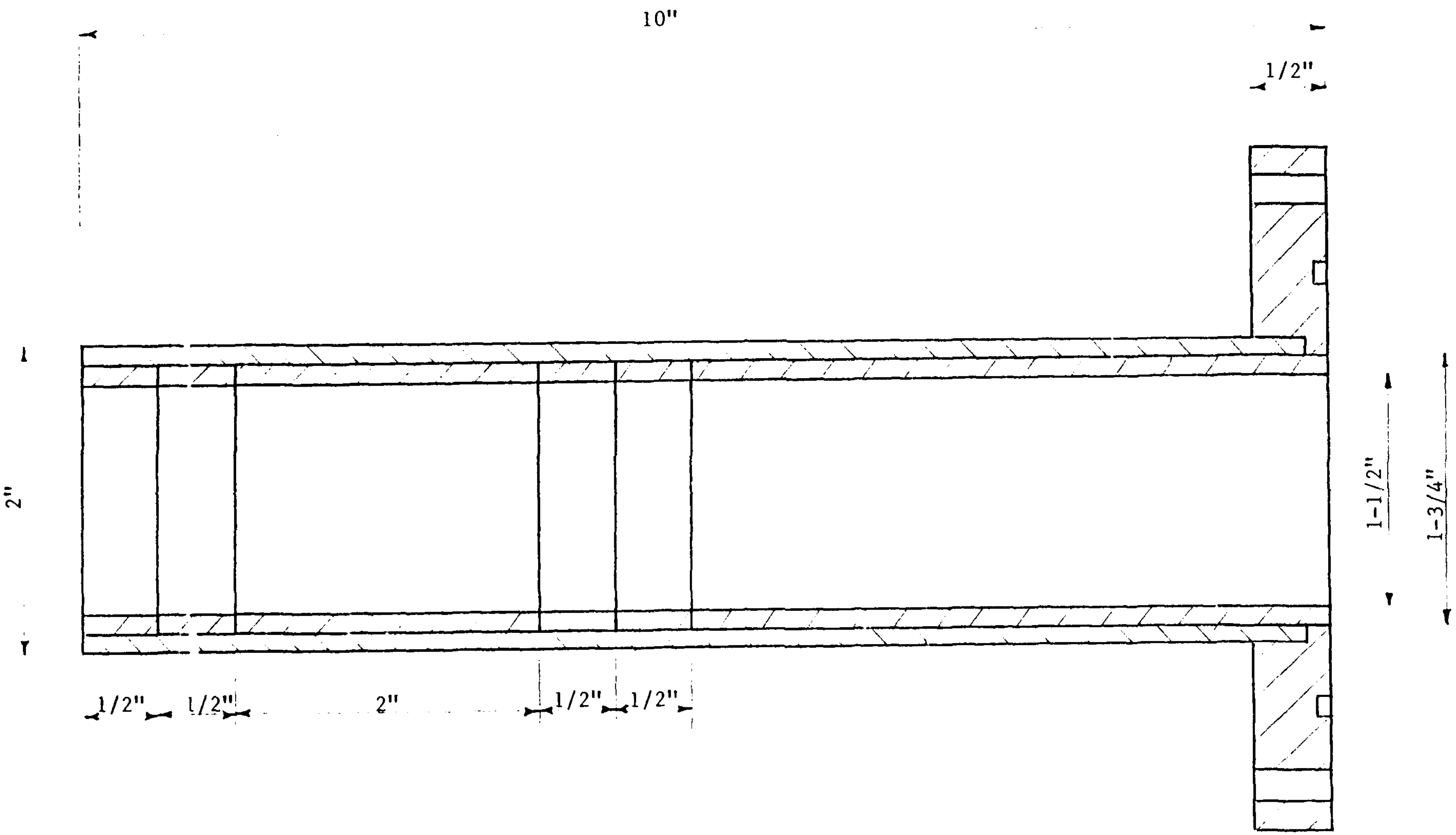


FIGURE-2 INLET (CALMING) SECTION FOR AXISYMMETRIC NOZZLE

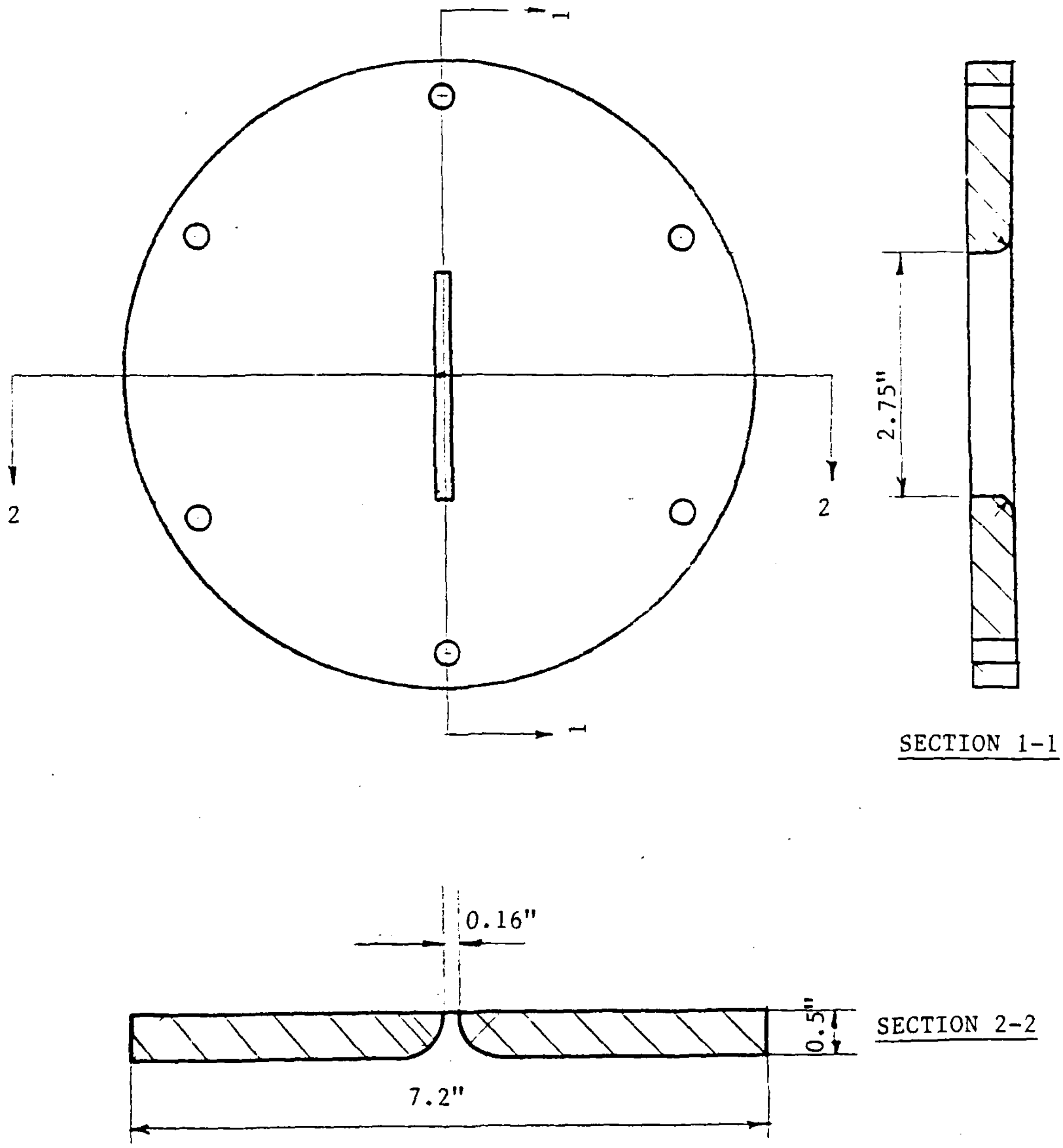


FIGURE-3 PLANAR NOZZLE

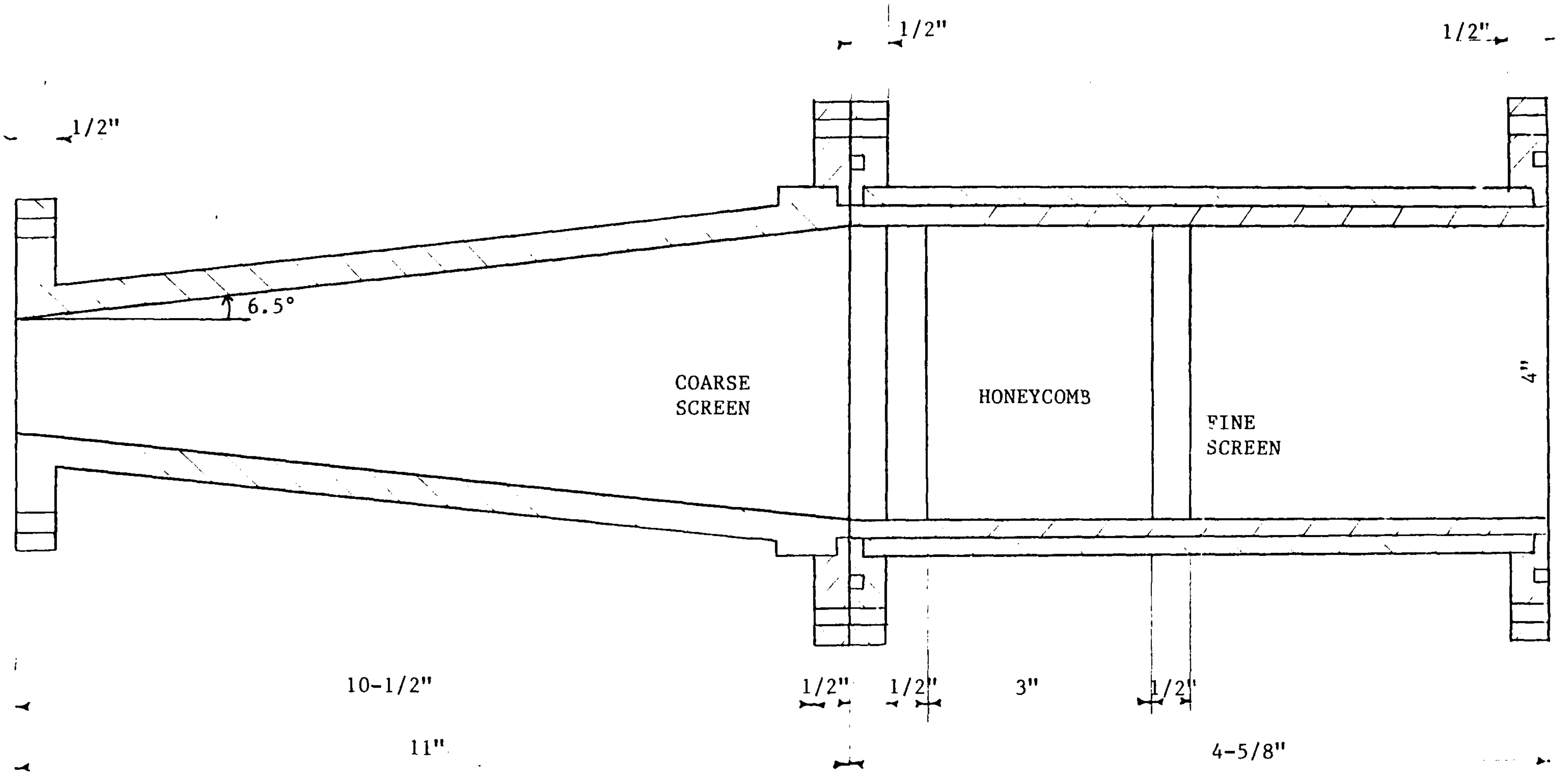
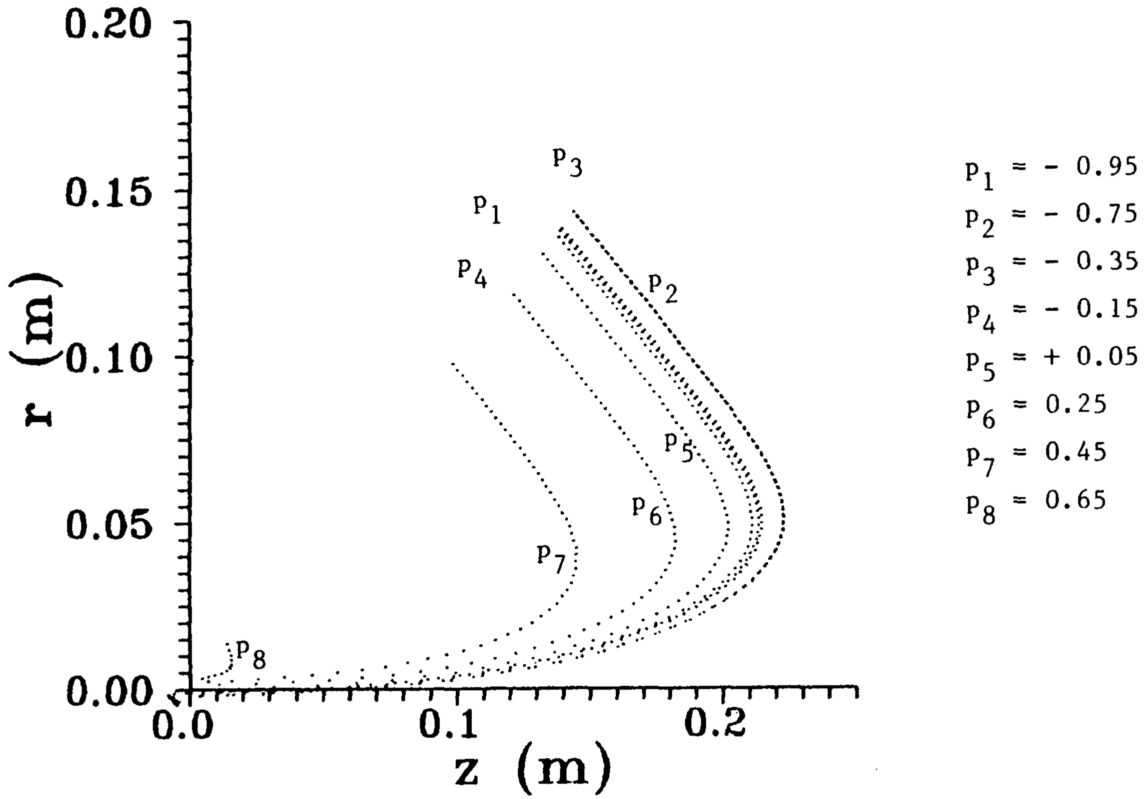


FIGURE-4 INLET (CALMING) SECTION FOR PLANAR NOZZLE



r (m)
0.20
0.15
0.10
0.05
0.00
0.0
0.1
0.2
z (m)
p1
p2
p3
p4
p5
p6
p7
p8
p1 = - 0.95
p2 = - 0.75
p3 = - 0.35
p4 = - 0.15
p5 = + 0.05
p6 = 0.25
p7 = 0.45
p8 = 0.65

FIGURE 5

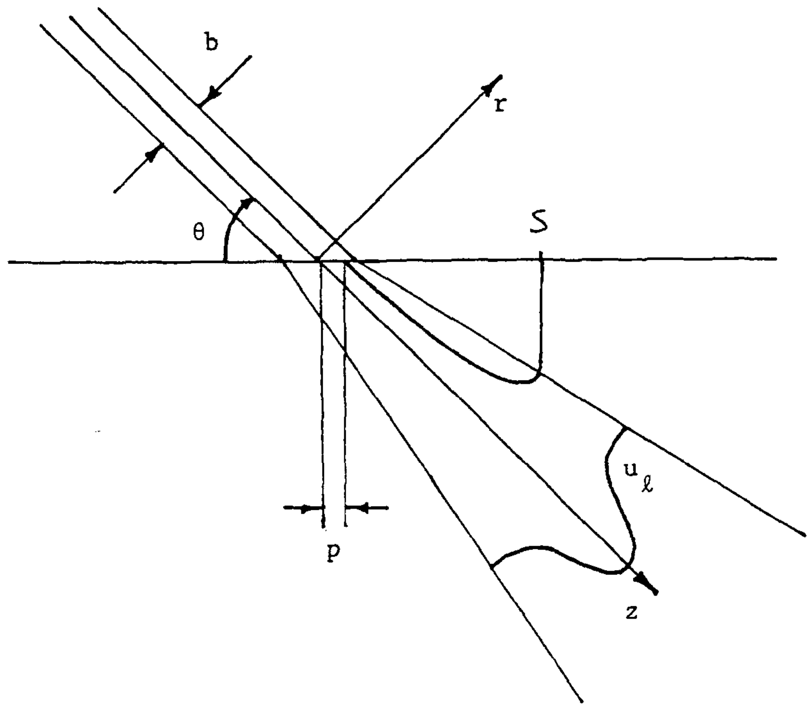


FIGURE 6

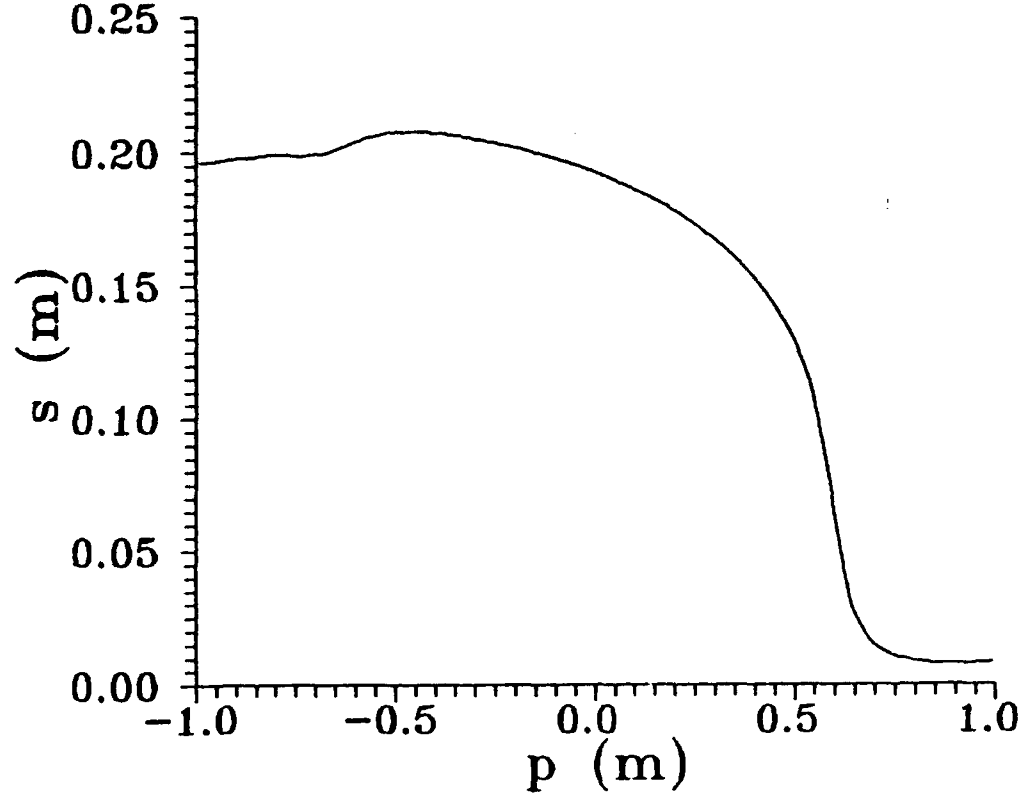


FIGURE 7