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Advanced Two-Phase Instrumentation Program Quarterly Progress Report for January–March 1978

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ADVANCED TWO-PHASE INSTRUMENTATION PROGRAM QUARTERLY PROGRESS REPORT FOR JANUARY–MARCH 1978

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ABSTRACT

Preliminary testing of advanced spool piece I in the ORNL two-phase air-water loop is described. Single-phase air and water calibration data and analyses are presented for several experimental drag target configurations.

INTRODUCTION

The objective of the Advanced Two-Phase Instrumentation Program is to improve the accuracy and precision of transient two-phase measurements required in reactor safety research. Both instrumented piping spool pieces and in-bundle measurement devices are being considered.

Testing of advanced spool piece I in the ORNL two-phase air-water loop is in progress. In addition to evaluation of the design of the spool piece itself, the behavior of various drag body configurations to be used for measurement of fluid momentum is being studied. Single-phase air and water calibration runs have been performed in the facility with ten experimental drag targets. These data have been used to determine drag coefficients of the targets to be studied in two-phase flow.

EXPERIMENT DESCRIPTION

The ORNL two-phase air-water loop (Fig. 1) has been modified for horizontal testing of advanced spool piece I. The facility is capable of supplying air at flow rates up to 512 scfm and water flow rates to 500 gpm. (When elements of large hydraulic resistance are present in the loop, the highest two-phase flow rates are often not obtainable.) For this study, ∿15 ft of straight 4-in. PVC piping was located upstream of the test section and ∿4 ft downstream. The single-phase air and water flows were at ambient temperature and near atmospheric pressure.

Advanced spool piece I (Fig. 2) consists of a 3-ft length of stainless steel pipe with fittings for a full-flow turbine meter, two drag

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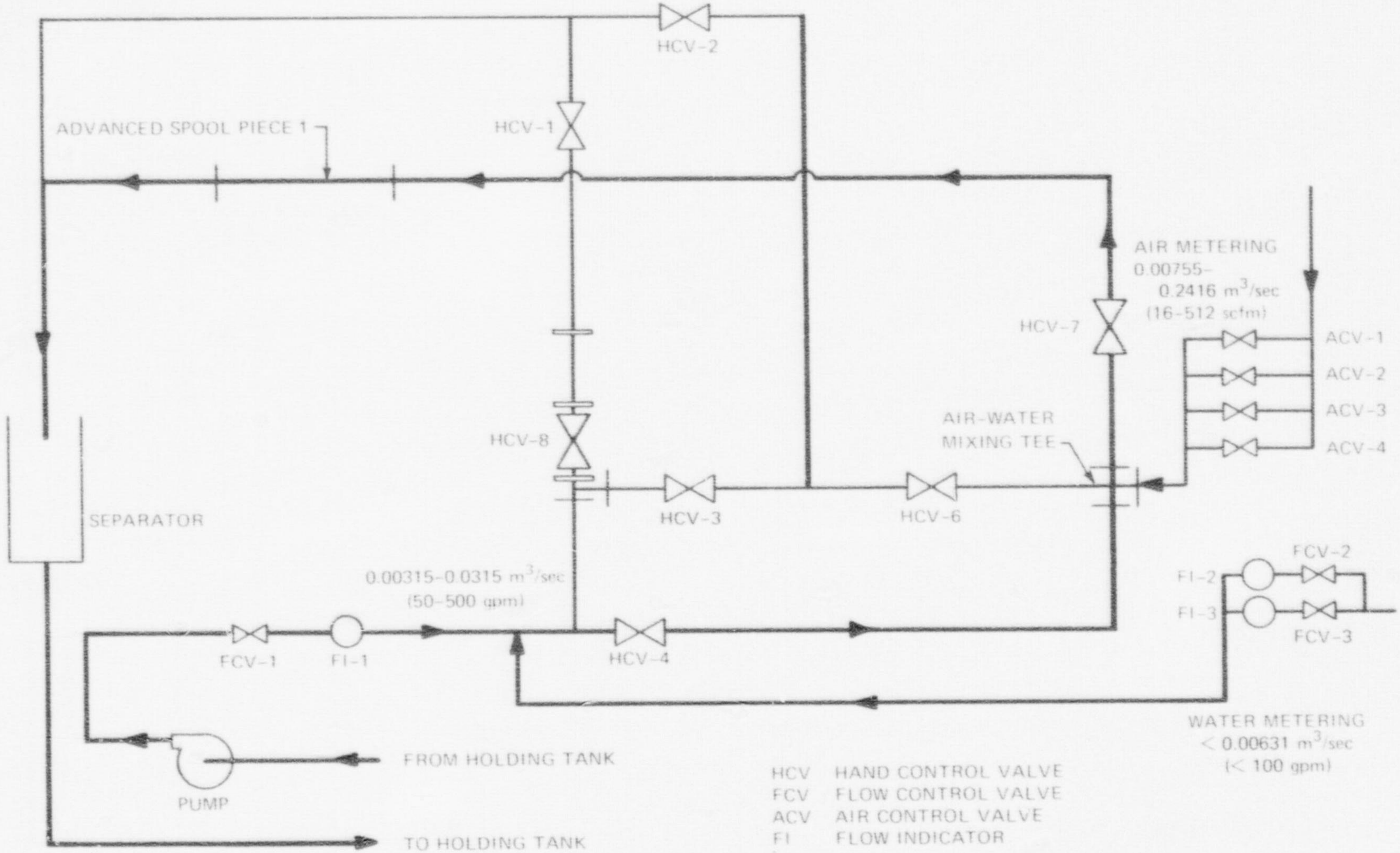

Fig. 1. Location of advanced spool piece I in ORNL two-phase air-water loop during horizontal flow tests. Heavy line indicates flow path for current tests.

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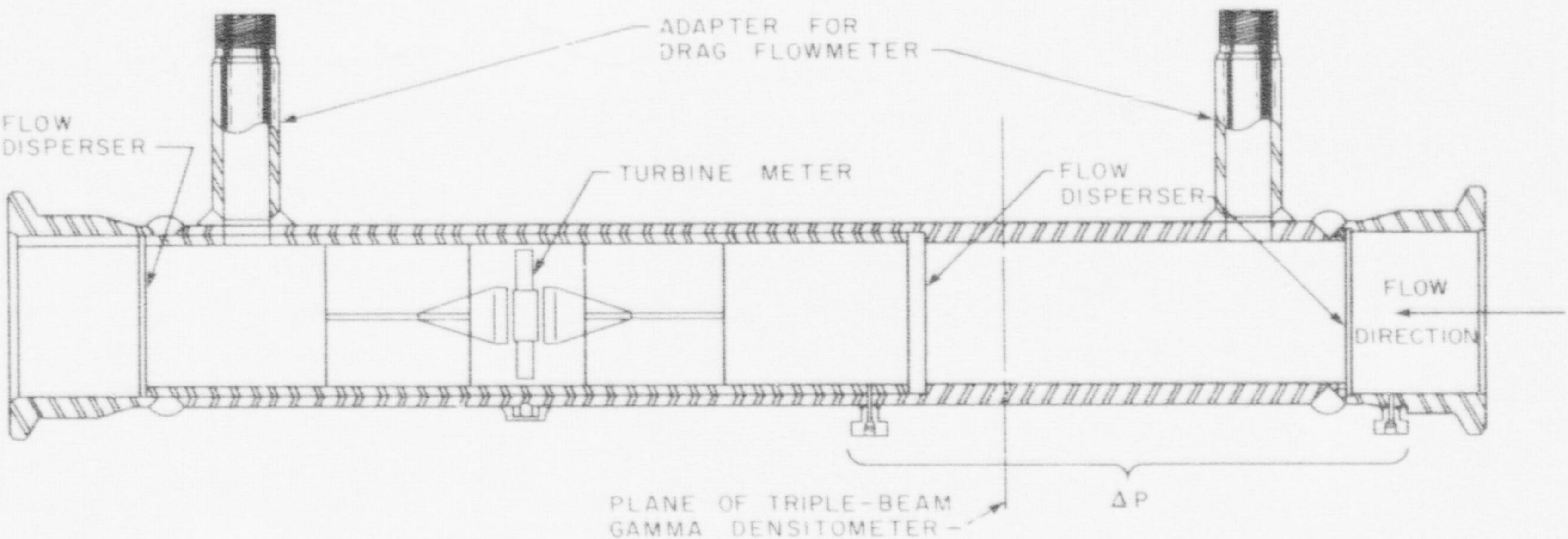

Fig. 2. Advanced spool piece 1.

flowmeters, pressure sensor lines, and three flow dispersing screens.[1] A three-beam gamma densitometer is located approximately 1 ft from the upstream end of the spool piece.

The target flowmeters used with advanced spool piece I are Mark V-4PBRDX made by Ramapo Instrument Company. The meters can measure bidirectional flow and have a range of 2500 to 250,000 $lb_m/ft\text{-}sec^2$ with the standard 0.5-in.-diam target disk. Previous studies at ORNL have shown that larger disks and screen-type targets may be used successfully to obtain greater signal output from the same transducer with nearly linear behavior in a single-phase calibration.[2] For blowdown studies, the ideal drag flowmeter output would be large enough to minimize the importance of temperature effects on the transducer but small enough that the instrument is overranged very briefly or not at all.

The present study is exploring the use of larger, "full-flow" drag targets with the Ramapo Mark V transducer in advanced spool piece I. Designs under consideration are shown in Fig. 3 and described in Table 1; the 1/2-in. target is included for comparison. The full-flow targets (types 1, 2a, 2b, 3, 4, 5, and 7) reach within 0.125 in. of the pipe wall in the 3.5-in.-ID spool piece. To investigate the effect of target thickness, a target similar to the type 2a (intermediate-sized holes), except with a thickness of 0.375 in. instead of 0.125 in., has been tested. The thin targets are held to the transducer lever arm by means of a tube which is welded to the target back and a screw which is coaxial with the pipe centerline. The 0.375-in.-thick target, like the 1/2- and 1-in. disk targets, has a 0.228-in. hole drilled radially through it for passage of the lever arm.

Single-phase calibration tests using each of the targets described above have been completed in the air-water two-phase flow loop. Flow was horizontal and in the direction indicated by the arrow in Fig. 1. For calibration with air only, the turbine meter was not put in the spool piece, since high air flow rates can destroy the turbine meter bearings. The turbine was used for the water tests, however, as a check on the magnetic flowmeter used to supply water to the loop. A pressure-difference reading was taken across the location of the upstream drag target, and

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Fig. 3. Ramapo Mark V drag flowmeter and experimental drag targets (see Table 1).

Table 1. Experimental drag targets

Target No.	Thickness (in.)	Frontal area[a] (in.^{2})	Description
1	0.125	2.32	Perforated plate, 1.375-in.-diam holes on 1.56-in. triangular pitch
2a	0.125	2.75	Perforated plate, 0.938-in.-diam holes on 1.040-in. triangular pitch
2b	0.375	2.624	Same as target 2b, except for thickness and method of attachment to lever rod
3	0.125	2.851	Perforated plate, 0.4375-in.-diam holes drilled on 0.500-in. triangular pitch
4	0.125	1.44	Four-bladed target, blades 90° apart, each subtends 15°; some additional metal for support near pipe axis
5	0.125	1.44	Three-bladed target, blades 120° apart; each subtends 20°
6	0.025 (screen) 0.125 (rim)	2.099	Five-mesh screen held in 2.25-in.-diam circular rim; Y-shaped tubing used for support
7	0.025 (screen) 0.125 (rim)	3.642	Five-mesh screen held in 3.28-in.-diam circular rim; Y-shaped tubing used for support
8	0.375	1.067	1-in.-diam disk
9	0.375	0.5339	0.50-in.-diam disk

[a]Includes frontal area of mounting tubes or support rod directly exposed to flow.

readings for absolute pressure were taken in the spool piece during the air calibrations.

In the air-water loop, air flow rate is determined using a pressure gauge upstream of the critical flow orifices. Air flow rates of 16, 32, 64, 96, 128, 160, 192, 224, 256, 320, 384, 448, and 512 scfm were used. Water is metered into the loop by means of rotometers (flow rates less than 100 gpm) or by a magnetic flowmeter. Calibration data were also taken with water-only f' rates of 10, 20, 30, 40, 60, 100, 150, 200, 250, 300, 350, 400, 450, and 500 gpm. Voltage output for each point was recorded from an integrating digital voltmeter.

ANALYSIS

The single-phase momentum flux for air or water may be calculated as

$$\dot{M} = \rho(Q/A)^2 , \qquad (1)$$

where Q is the volumetric flow rate, ρ is the density of air or water metered into the system, and A is the spool piece flow area. For these experiments, the temperature and absolute pressure of the air were used to determine air density at the location of the upstream drag flowmeter; the water density was 62.4 lb_m/ft^3. The spool piece has a flow area of 0.06681 ft^2.

The linearity of a fluid momentum meter may be checked by plotting instrument output vs the momentum flux obtained independently using Eq. (1). Figure 4 is such a graph for data from three of the drag targets: th 1/2- and 1-in. disks and target 2b. Output voltages are from the flowmeter located in the upstream end of the spool piece; no flow dispersers were used. Note that the air and water momentum fluxes encompass nearly three orders of magnitude and that there is overlap of the air and water data in the range below 1300 $lb_m/ft\text{-}sec^2$. The greatest momentum obtainable was approximately 17,000 $lb_m/ft\text{-}sec^2$ at a water flow rate of 500 gpm. The ordinate is plotted in terms of millivolts output per volt bridge excitation (5.00 V in this case). The nominal maximum output was 2.0 mV/V, but the maximum rod travel was limited in the spool piece tested such that maximum instrument output was approximately 1.4 mV/V. Zero-flow drag flowmeter readings were noted before and after taking calibration data for each target. Appropriate corrections based on assumption of linear drift of the transducer output with time have been made to the recorded data. The corrections for zero shift were insignificant for the full-flow targets, except at low flow rates. A significant proportion of the data shown is for an instrument output less than 1% of full scale (0.02 mV/V). Such a reading corresponds to fluid

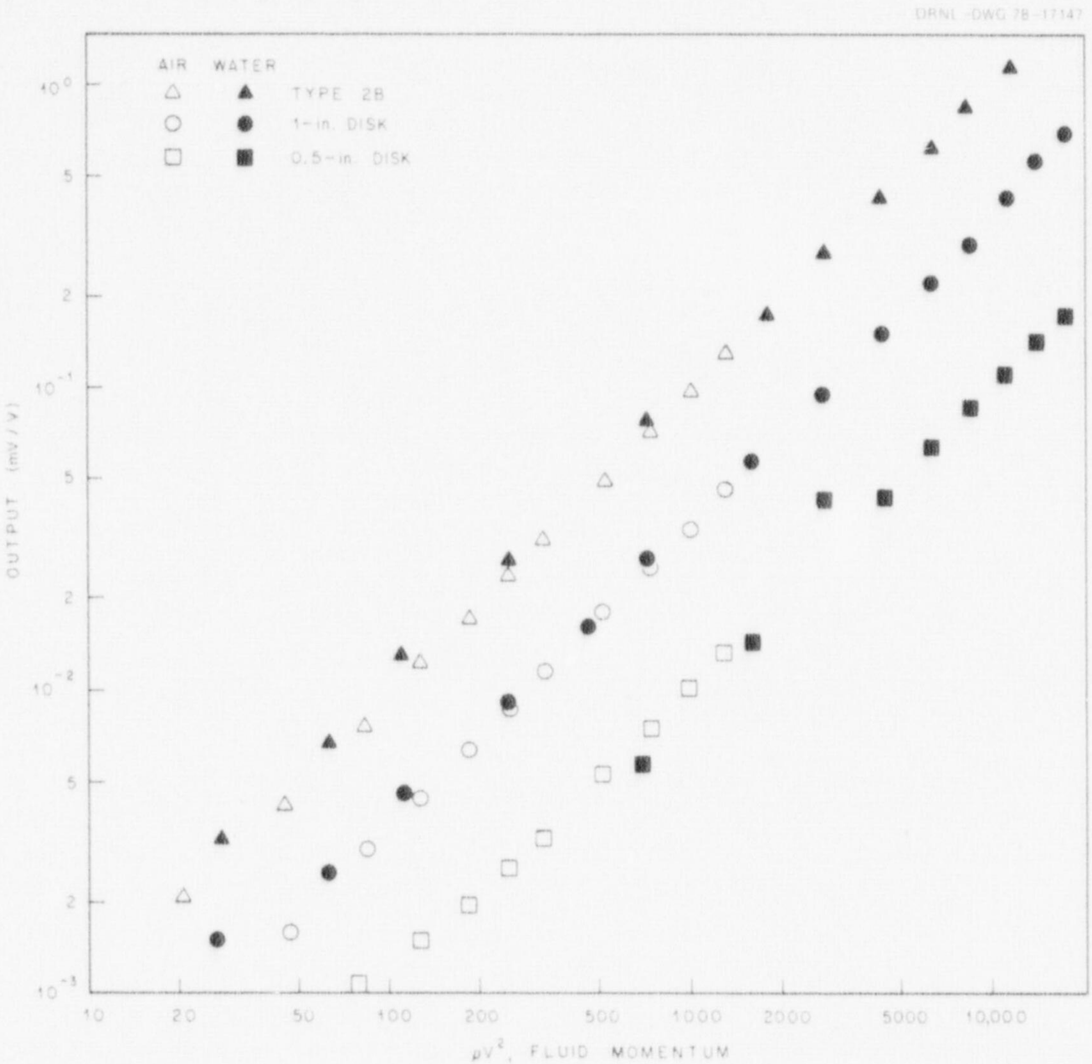

Fig. 4. Drag transducer millivolt output per volt bridge excitation vs air and water single-phase fluid momentum for three drag targets.

momenta of 2000 for the 1/2-in. disk, 600 for the 1-in. disk, and 200 for the full-flow target.

In order to calculate the drag coefficients C_d for the various targets, the force exerted by the fluid on the drag target was obtained from the instrument output using the weight calibration supplied by Ramapo. In general, the drag coefficient is defined as

$$C_d = \frac{F/A_t}{\dot{M}} .$$

From the weight calibration, the force F on the lever arm is related to the instrument output signal V by a constant factor

$$k = \frac{V_{output}}{V_{excitation}} \frac{1}{F} .$$

Thus, expressing the momentum flux in psi and the target area (A_t) in in.^{2}, as in Table 1, we have

$$C_d = \frac{2g_c\ 144\ V_{output}}{V_{exc}\ k\dot{M}A_t} . \qquad (2)$$

For the drag transducer in the upstream position in the spool piece, k was 0.167 mV/V/lb_f.

Graphs of the drag coefficients obtained using Eq. (2) for several targets appear in Figs. 5 through 8. Since a choice of a characteristic diameter D for some of the targets is rather arbitrary, the independent variable used is the Reynolds number per unit length, dependent only on the air and water fluid properties,

$$\frac{Re}{D} = \frac{\rho V}{\mu} = \frac{V}{\nu} ,$$

where V is the fluid velocity and μ is the fluid viscosity.

Drag coefficients for the three- and four-bladed targets appear in Fig. 5. Although the targets block equal proportions of the pipe area (Table 1), the four-bladed target has a significantly higher C_D than does the three-bladed target. It is likely that the influence on the fluid momentum of such a blade extends relatively far from its edges, as evidenced by the C_D well over unity for both targets. Comparing the four-blade to three-blade targets, it appears that the addition of a fourth blade has a much greater effect than the reduction of each blade's area by 25%. Both targets, however, have nearly constant C_D for Re/D greater than ~100. (For these targets and those discussed below, data for smaller Re/D have much larger error bars because of the very small instrument output signal for those air flow rates and because the spool piece may not have been full of water for the low water flow rates.) In

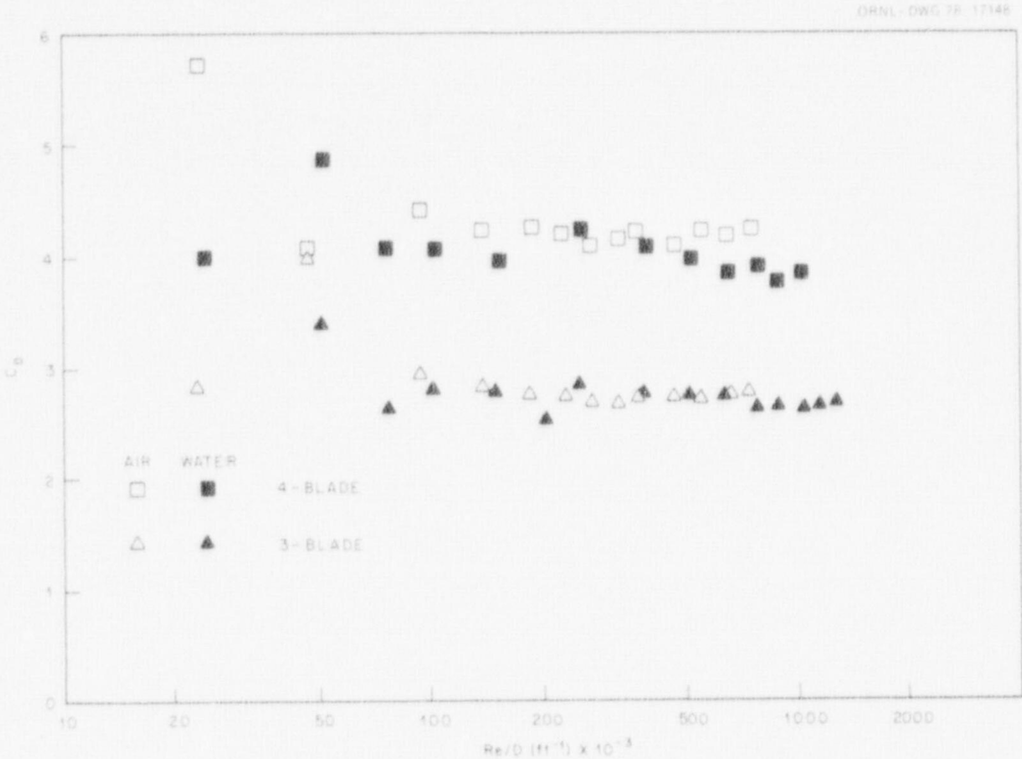

Fig. 5. Single-phase air and water drag coefficient vs Re/D for four-bladed and three-bladed targets.

addition, the air and water drag data agree well for each of the two targets. This characteristic is an important one for targets to be used in two-phase air-water studies.

Comparison of the behavior of thick and thin perforated plate drag targets may be made by studying C_D for target types 2a and 2b (Fig. 6), both of which have intermediate-sized holes. Again, data for Re/D less than 100 are not useful. For flow rates above this value, the drag coefficients obtained are between 2.0 and 2.3 for the thick target and between 2.25 and 2.6 for the thin target.

Figure 7 shows data for C_D vs Re/D for the three thin perforated plate targets. A comparison of air and water C_D values indicates that the data for each target are fairly consistent for Re/D above 100. There is more scatter in the data for the large-hole target than in the data for intermediate- and small-hole targets, and the average C_D for the large-hole target is higher than that of the others.

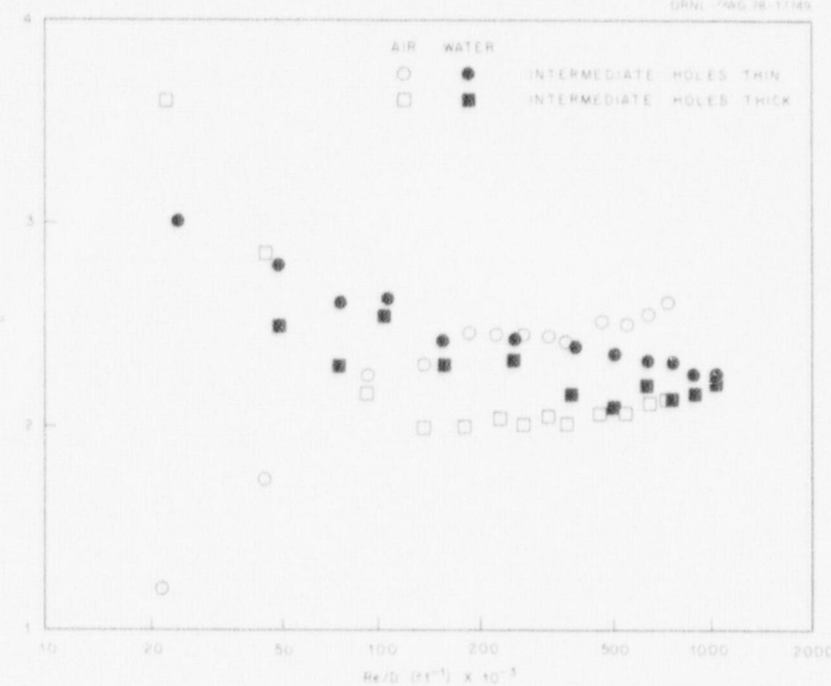

Fig. 6. Single-phase air and water drag coefficient vs Re/D for thick and thin targets with intermediate-sized holes.

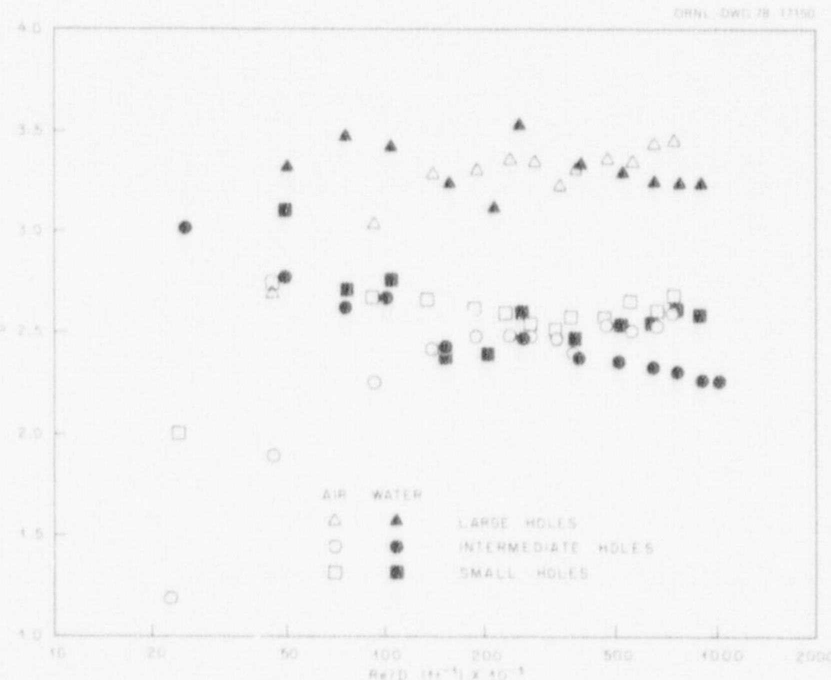

Fig. 7. Single-phase air and water drag coefficient vs Re/D for small-holed, intermediate-holed, and large-holed targets. Data are for 0.125-in.-thick targets.

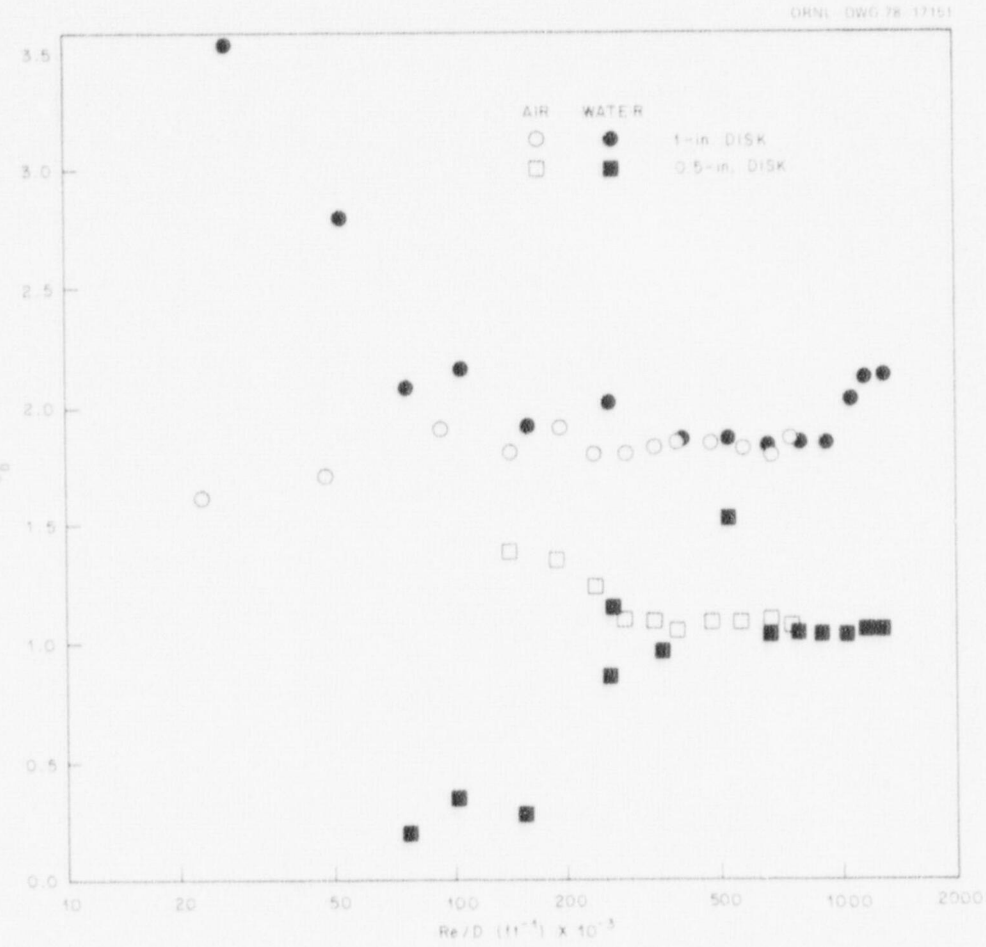

Fig. 8. Single-phase air and water drag coefficient vs Re/D for 1/2-in. and 1-in. disk targets.

Drag coefficients for the 1/2- and 1-in. disk targets appear in Fig. 8. The C_D value for the 1/2-in. disk is nearly constant at 1.05 for Re/D above ∿300; the transducer output is very low below that value. Data for the 1-in. disk are more nearly uniform in the lower range of Re/D but have a slight tailing upward at the highest Reynolds numbers.

Reduction of two-phase drag flowmeter data is to be performed using an equation of the form

$$\dot{M}_{2\phi} = aV^b \ , \qquad (3)$$

where $\dot{M}_{2\phi}$ is the two-phase momentum flux, V is the instrument output, and a and b are constants. A least-squares regression technique has been used to obtain a and b for each target, processing air and water data separately. The results appear in Table 2. The data for these fits include all the air and water flow points taken except some of the lowest flows, where instrument output was typically much less than 1% of full scale. Points where the transducer arm was pegged were also omitted. Because of the small drag it generates, the 1/2-in. disk is difficult to calibrate for low flow rates; the coefficients shown in Table 2 for that target are for air flow rates above 160 scfm and water flow rates above 200 gpm. The other targets perform reasonably well over the range of flow rates included in the data fit tested, as evidenced by the fact that the exponents b are nearly 1.000 for both air and water and the multipliers a are approximately equal for both phases.

Table 2. Experimental drag targets calibration factors[a]

Target No.	Description	Air		Water	
		a	b	a	b
1a	Thin perforated plate large holes	1,380	0.977	1,442	1.006
2a	Thin perforated plate intermediate holes	1,560	0.972	1,678	1.036
2b	Thick perforated plate intermediate holes	2,010	0.989	1,887	1.025
3	Thin perforated plate small holes	1,490	1.002	1,498	1.002
4	Four-bladed	1,840	1.000	1,950	1.007
5	Three-bladed	2,910	1.015	2,841	1.006
6	Small screen type	2,712	1.014	2,586	1.006
7	Large screen type	1,270	1.005	1,215	0.9956
8	1-in.-diam disk	5,620	0.996	5,348	1.006
9	1/2-in.-diam disk	19,400[b]	1.000[b]	19,900[b]	1.008[b]

[a]Factors a and b from equation $M = aV^b$, where M is fluid dynamic pressure ($lb_m/ft\text{-}sec^2$) and V is drag flowmeter output (V).

[b]Calculated using only air flow data above 160 scfm and water flow data above 200 gpm.

SUMMARY

Studies of the single-phase flow behavior of ten experimental drag targets in the ORNL two-phase air-water loop have been completed. For flow rates where transducer output was above 1%, drag coefficients for the 0.125-in.-thick full-flow targets had little variation with Reynolds number. As might be expected, perforated plate targets had no discernible advantage over blade-type targets for single-phase flow.

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