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A PERFORMANCE INVESTIGATION OF AN EIGHT-INCH HUBLESS PUMP INDUCER IN WATER AND LIQUID NITROGEN

by Charles D. Miller and Loren A. Gross

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DEFINITION OF SYMBOLS

N	pump speed, rpm
Q	pump flow rate, gpm
ΔH	pump head rise, ft
ϕ	pump flow coefficient $\left(K_1 \frac{Q}{N}\right)$
Ψ	pump head coefficient $\left(K_2 \frac{\Delta H}{N^2}\right)$
N_{ss}	suction specific speed, $\left(N \frac{Q^{\frac{1}{2}}}{NPSH^{\frac{3}{4}}}\right)$
NPSH	net positive suction head at pump inlet
τ	specific suction head, $\left(K_3 \frac{NPSH}{N^2}\right)$
η	pump efficiency

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INTRODUCTION

A pump inducer concept in which the blades are attached to a rotating shroud was introduced by Worthington Corporation in 1958. Initial testing of a small inducer by Worthington was sufficiently encouraging to warrant awarding a contract for further investigation under the NASA propulsion technology program. The results of the effort are reported in Jekat [1]. This contract called for the delivery of a large-diameter inducer to NASA for evaluation. The results of the evaluation of the 8-in. inducer are reported herein.

During the period from September 1964 to June 1965 a series of tests was conducted at Marshall Space Flight Center on this hubless inducer. The inducer was tested in conjunction with a shrouded centrifugal impeller, a configuration approximating that commonly found in rocket engine propellant pumps. Tests were conducted in water and liquid nitrogen. The objectives of the program were to evaluate the cavitation performance and general characteristics of the inducer.

INDUCER DESIGN AND CONFIGURATION

The concept of the hubless inducer (Fig. 1) as cited in Jekat [1] is that vane friction may be used to generate head and that friction alone does not promote cavitation. Hence, the blade surface was purposely made large, resulting in a large inducer inlet diameter.

The purported advantages of the hubless design are

1. the elimination of tip vortices, (This is possible because of the effective seal that can be made between the blade shroud and casing.),

2. the centrifuging effect upon cavitation bubbles, which, due to their light mass, causes them to be forced to the center of the inducer where they collapse harmlessly,

3. extreme sweepback of the vanes can be employed. (This type of vane is purported to be advantageous in a high-suction specific speed machine.)

Pertinent data relating to the inducer are shown in Figure 2.

FACILITY DESCRIPTION

The hubless inducer was tested with an impeller in a facility pump fixture (Fig 3). The pump was driven through step-up gearing by a 2500- hp dc motor capable of operating up to a speed of 15 000 rpm.

The impeller assembly (Fig. 4) consisted of the hubless, axial flow inducer attached at its periphery to a sweep-back, shrouded impeller. The pump volute assembly was composed of a vane entrance diffuser and a constant velocity scroll. The pump normally developed a head rise of 1630 ft and 3220 gpm flowrate at 6440 rpm.

Figures 5 and 6 show a schematic and photo, respectively, of the test cell. Fluid was supplied to the pump from an overhead 20 000-gal supply tank. The fluid flowed vertically through an 8-in. diameter line in which a turbine type flowmeter and fast acting butterfly valve were installed. The fluid was then turned to flow horizontally for about 15 ft before entering the pump. An anti-vortex device was located in the tank at the entrance of the suction line. A viewing section was also installed in the suction line immediately adjacent to the pump inlet so that inducer operation could be photographed during test runs. A 4-in. valve was located just downstream of the pump volute, followed by a pressure reducing flow control orifice which could be changed to accommodate various flowrates. The pump discharge fluid was routed to a 28 000-gal remotely located catch tank.

The pump bearings were lubricated by a pressure-fed lube oil system with oil heating capabilities. Thirty-six instrumentation channels were monitored during a test. Specific measurements were fed into a digital tape system which, when played back through a computer, produced a printout of various pump operating parameters. The test facility was equipped with fast-response pressure transducers located in the suction line, pump inlet and pump discharge line for evaluation of the dynamic characteristics of the pump. Three accelerometers were also installed on the suction line, pump inlet and pump bearing to measure vibration in the horizontal, vertical and axial direction. Pump flowrate was measured by the turbine flowmeter and redundantly calculated by measuring the ΔP across the flow control orifice. Thermocouples were located in the suction line and pump discharge line. Pump speed was recorded digitally to an accuracy of ± 1 rpm.

TEST PROCEDURE

Twenty-five tests were accomplished during the test program. Testing began using de-ionized water with a nominal flowrate of 2400 gpm at 6500 rpm and was increased in 200-gpm increments to 4000 gpm while holding the speed constant. One test was also run at 2650 gpm and 4500 rpm.

All tests were started with a minimum NPSH of 60 ft, which diminished with the decrease in liquid level and tank pressure. A 10 percent decrease in developed head of the pump constituted the end of the test.

DISCUSSION OF RESULTS OF WATER TESTS

A normalized curve of the developed head versus flowrate is illustrated in Figure 7. The pump developed about 13 percent less head than the design value and was 11 percent less efficient than the design value. Also plotted in Figure 7 is efficiency versus flow coefficient.

The developed head versus NPSH at 6500 rpm and 4500 rpm is shown in Figures 8 and 9, respectively. The hubless inducer exhibited good suction performance over the entire flow range tested. NPSH at 2 percent head loss varied from 9.8 ft at 2610 gpm to 24.6 ft at 3960 gpm (Fig. 10). Suction specific speed values varied from 50 800 to 37 200 over the range of flow coefficients tested and are shown in Figure 11.

High-amplitude, low-frequency inlet and discharge pressure oscillations. characteristic of cavitating pump inducer systems were observed at all lower than design flowrates. At design flowrates and higher, the low-frequency oscillations were observable, however, the amplitude was severely diminished. Oscillation frequency was apparently dependent upon NPSH and flowrate as is observed from the data plotted in Figure 12. Amplitude of the oscillations as a function of the same parameters is plotted in Figure 13. The amplitude of the oscillations at the low flowrates was great enough to depress the local pressure to the fluid vapor during low-pressure portion of the cycle. These oscillations were observed to have no effect on pump cavitation performance; it should be noted, however, that they are highly undesirable from the standpoint of the dynamics of space vehicle and rocket engine operation, and much effort is expended to eliminate them.

No damage caused by cavitation was found in the impeller or inducer upon disassembly. Only slight pitting on the forward section of the outer shroud of the inducer where metal was removed for dynamic balance was evident. In general the pump appeared to be in excellent condition after 3012 seconds of water testing.

An attempt at flow visualization through strobe-triggered motion pictures was only partially successful because of difficulties in focusing properly on the inducer. The less than excellent quality film did not, however, show any evidence of cavitation bubble centrifuging. The films showed a very clean flow into the inducer with little turbulence and only a small amount of backflow past the shroud. This backflow had only slight velocity and was swept immediately into the inducer.

MODIFICATIONS

Several modifications were made to the pump at the completion of the water test to improve the efficiency. A larger impeller hub was added, and the rear of the inducer blades was cut back 0.225 in. to improve the incidence angle on the impeller blade. Except for approximately 1 in. of length on the outer edge of the impeller, the back vanes were removed to decrease the turbulence and pumping action behind the impeller. A smooth back plate was added to the housing behind the impeller to aid in decreasing the turbulence.

DISCUSSION OF RESULTS OF LN_2 TESTS

Figure 14 is a plot of head coefficient and efficiency versus flow coefficient for the LN_2 test series. Overall pump efficiency was approximately 6 percent lower than the normal operating efficiency. The developed head was about 10 percent lower than the design value.

Figure 15 is a graph of the developed head versus NPSH for five different flowrates. NPSH values at 2 percent head loss ranged from 1.1 ft at a nominal flowrate of 2200 gpm to 21.3 ft at 4000 gpm. A plot of these values can be seen in Figure 16.

Figure 17 shows the dimensionless parameter of suction specific speed versus flow coefficient. Suction specific speed values at 2 percent head loss ranged from 286 000 to 40 000 over the flowrange tested.

During the analysis of the water data, a discrepancy was noted between the volumetric flowrate recorded by the flowmeter and that calculated from the orifice ΔP. It appeared that the flowmeter reading was probably a good indication of the actual volumetric flowrate through the inducer since its value was higher than calculated for the orifice, thus showing the increased flowrate caused by air coming out of solution at low inlet pressures. The same discrepancy was noted in the nitrogen data, however, and the idea of air coming out of solution was discredited. The most logical explanation for this inconsistency was that the turbine flowmeter was cavitating at low inlet pressure. Therefore all flow data are based upon the calibrated curves of the various orifices.

A point which deserves some mention here is the increase in developed head as NPSH is reduced. This slope is unusual and no explanation can be offered at present except to say that there is an apparent improvement in the flow field through the pump at low NPSH values perhaps caused by some blade surface phenomenon which reduces the fluid friction.

Premature cavitation was encountered in the tests immediately following a pump overhaul. Final inspection of the pump after these tests revealed an oversized clearance between the inducer and wear ring. This clearance was machined when inspection revealed that the Kel-F wear ring had cold flowed and appeared to bind the inducer. Upon reassembly, the wear ring did not contract to the degree expected, leaving a large clearance between the inducer and the wear ring. This clearance allowed considerable back flow which disturbed the inducer inlet flow.

CONCLUSIONS

The cavitation performance of the hubless inducer has been evaluated, and parameters at cavitating and noncavitating conditions have been defined in de-ionized water and liquid nitrogen.

Analysis of the water data indicated the cavitation performance of the inducer was at least equal to the state-of-the art over a wide operating range. Pump efficiency and developed head was slightly lower than expected. The liquid nitrogen tests results were slightly lower than expected from the standpoint of lowering NPSH requirements, but were encouraging with respect to the objectives achieved through hardware modifications, namely the increased efficiency.

The critical NPSH, or NPSH at 2 percent head loss, appeared to be highly dependent upon the inducer to casing clearance. This was evidenced by the fact that the premature cavitation runs occurred when the large shroud-casing clearances were present.

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama, October 14, 1966

FIGURE 1. HUBLESS INDUCER - FRONT VIEW

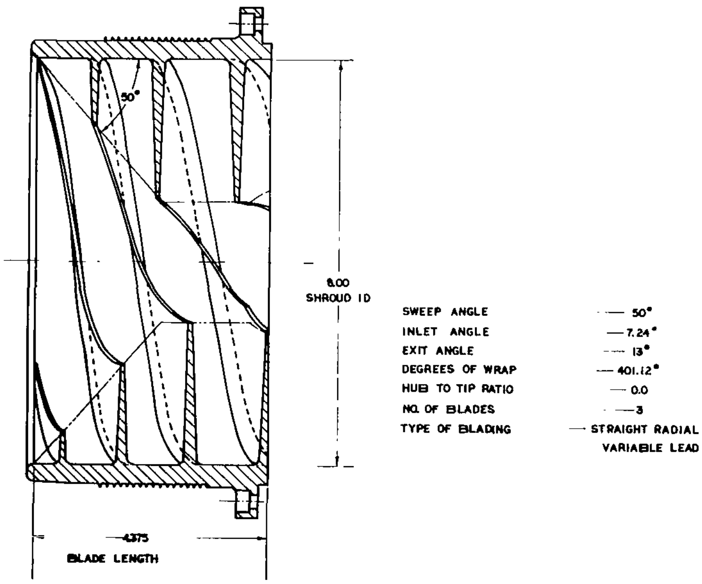

FIGURE 2. HUBLESS INDUCER DATA

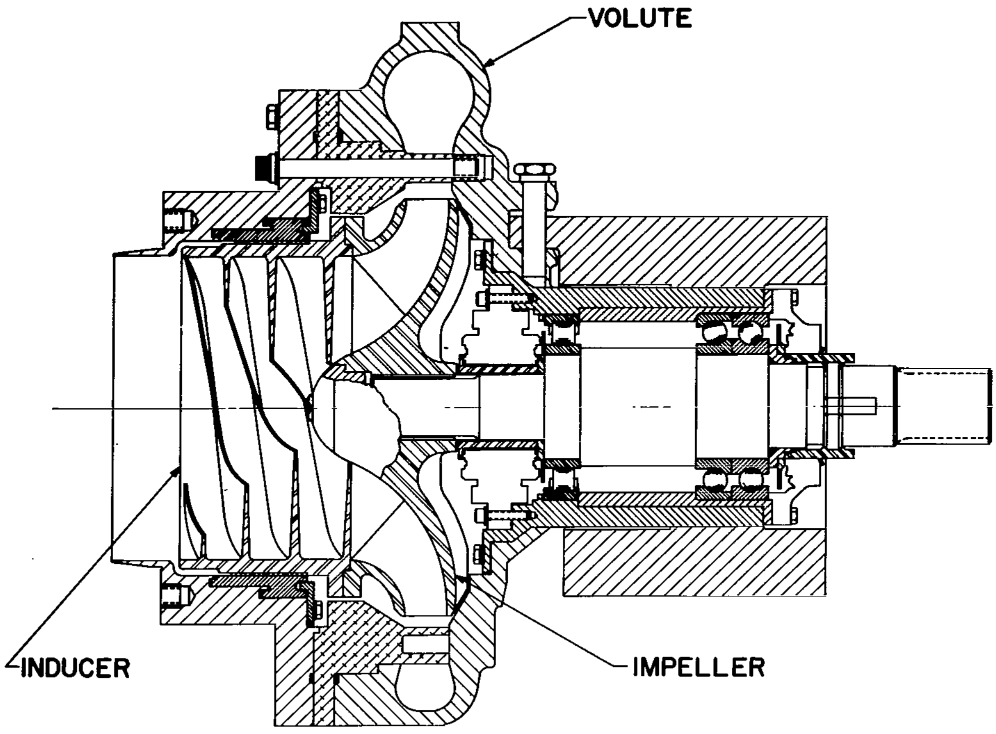

FIGURE 3. PUMP TEST FIXTURE

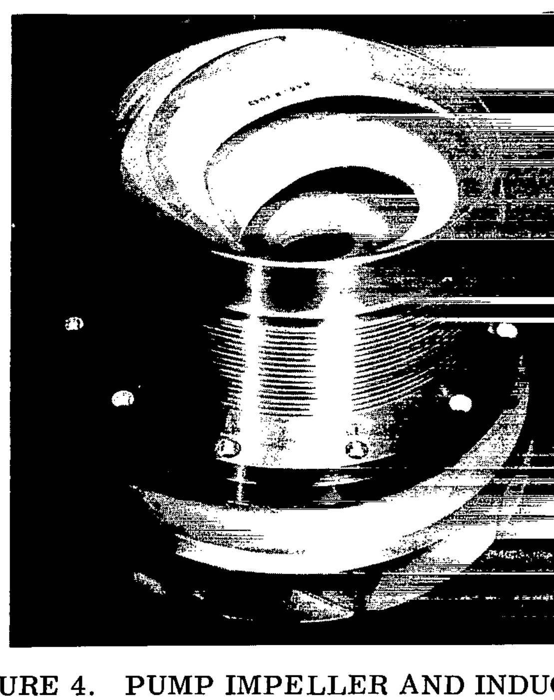

FIGURE 4. PUMP IMPELLER AND INDUCER

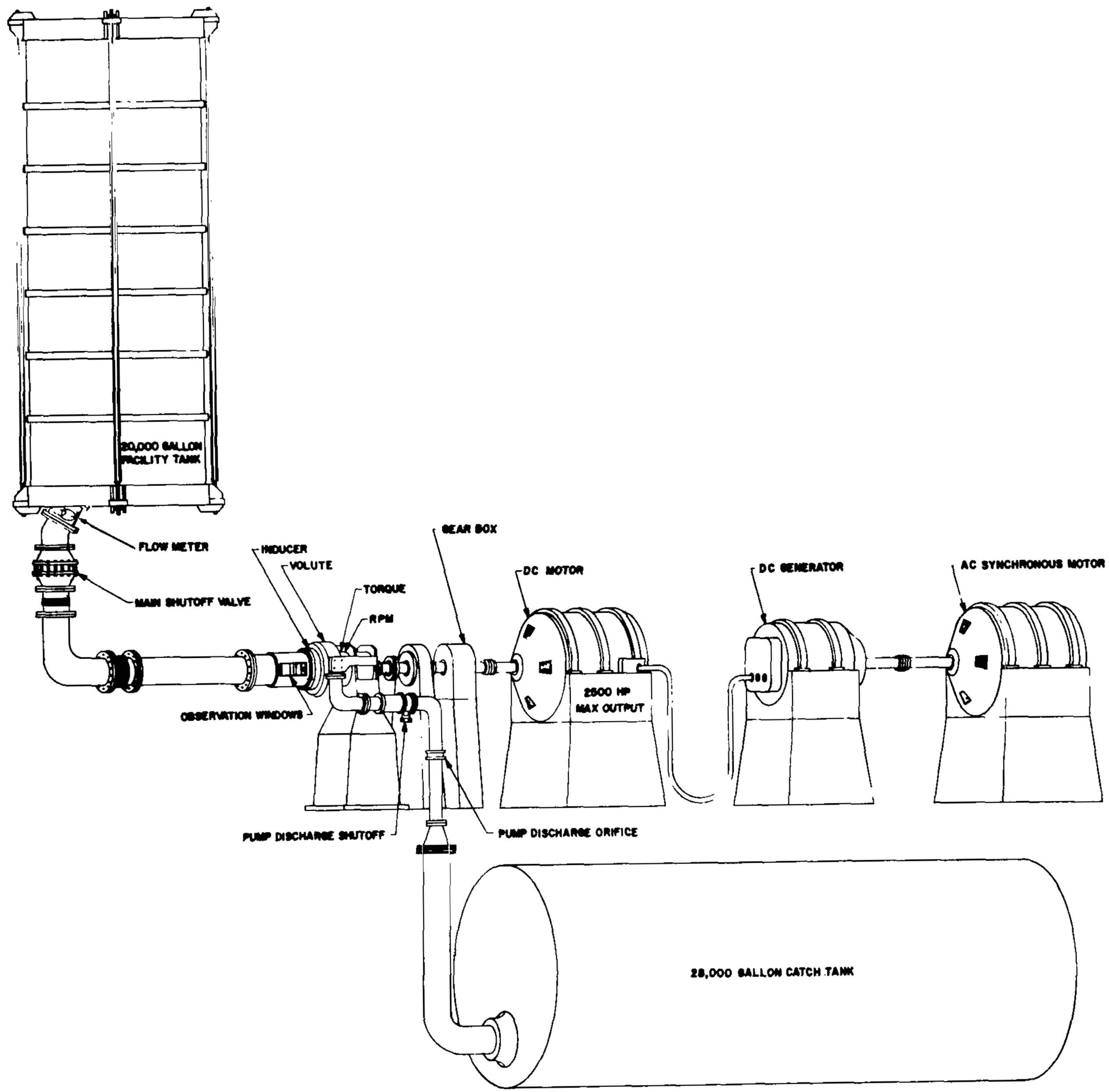

FIGURE 5. PUMP TEST FACILITY SCHEMATIC

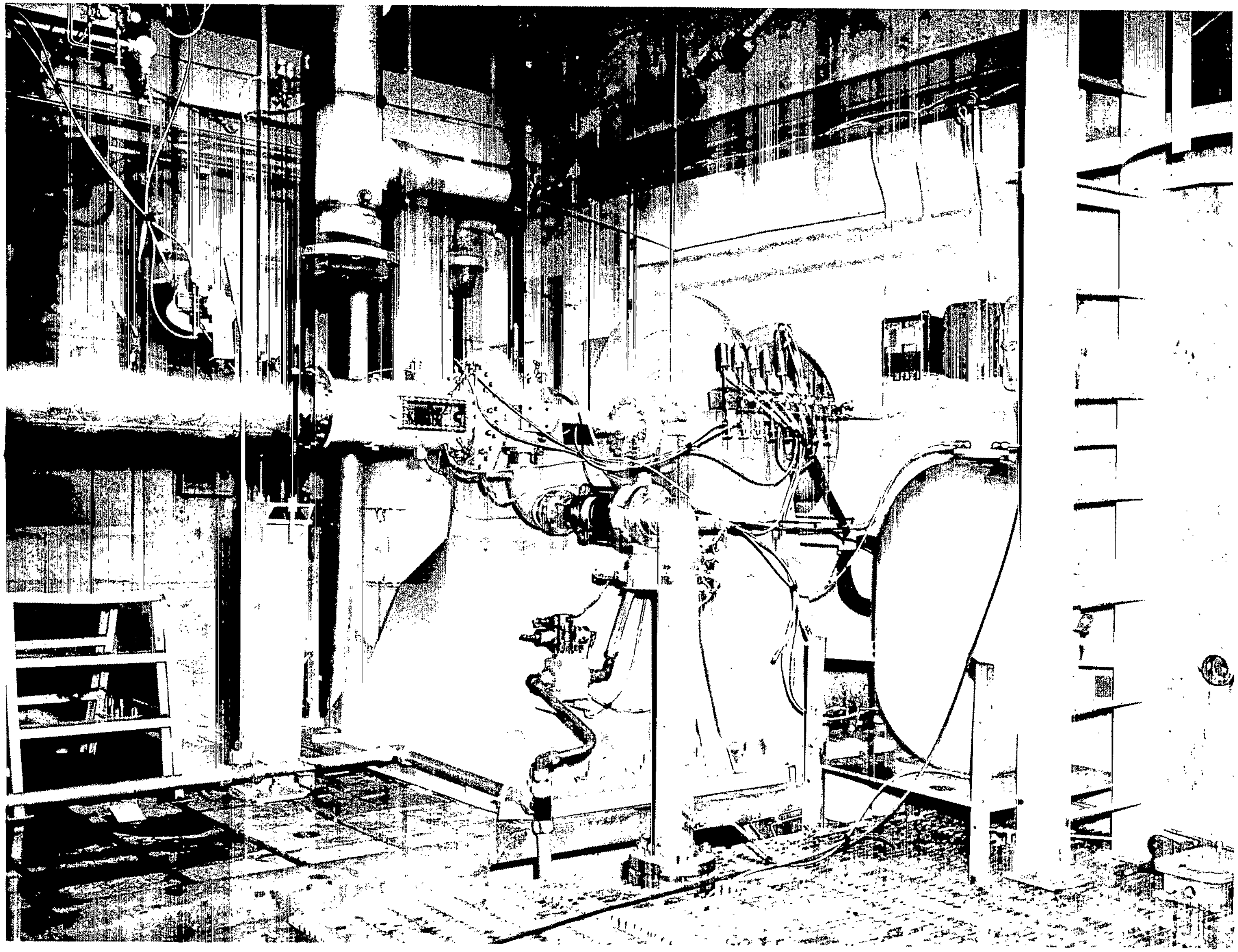

FIGURE 6. PUMP TEST FACILITY

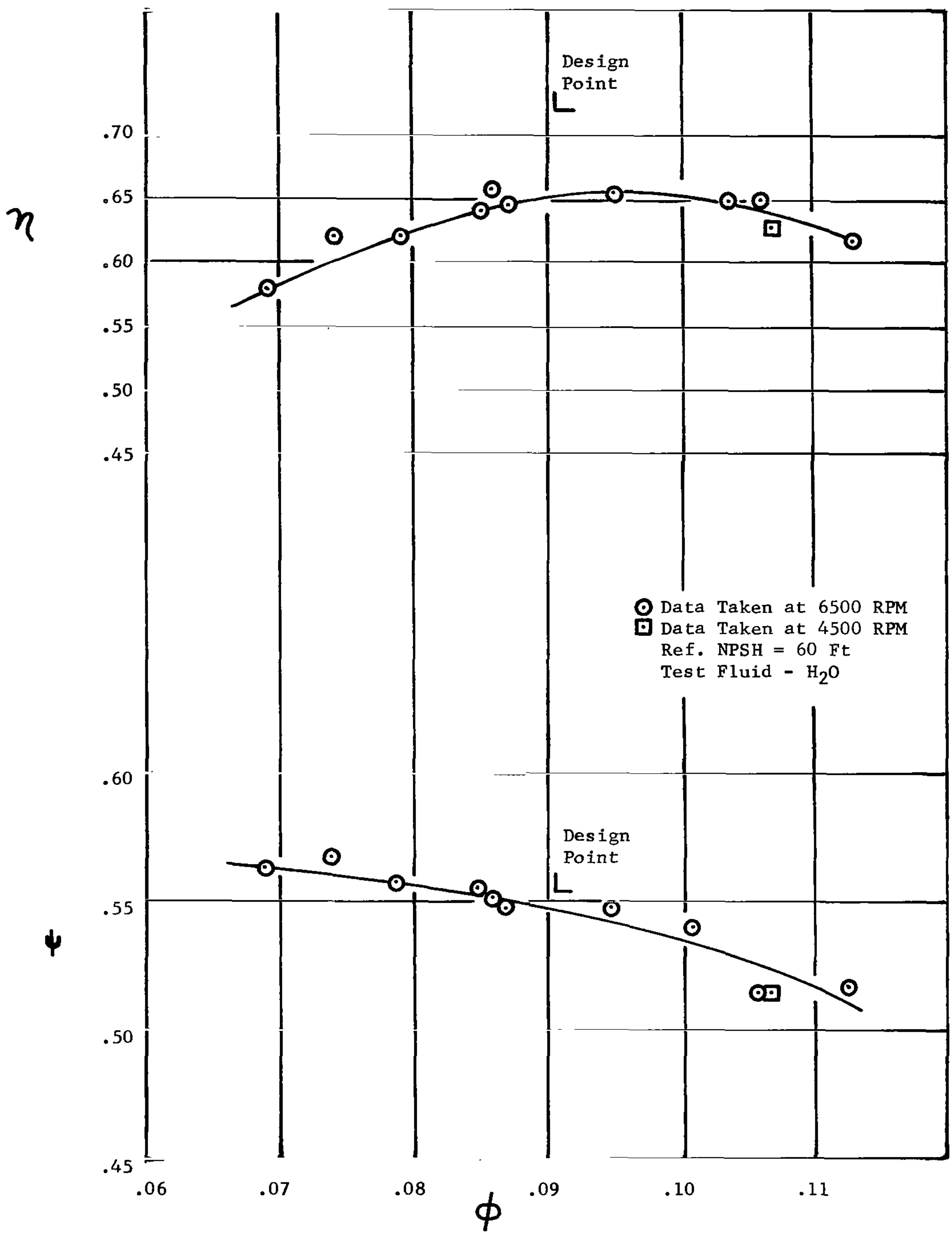

FIGURE 7. HEAD COEFFICIENT AND EFFICIENCY VERSUS FLOW COEFFICIENT (WATER TESTS)

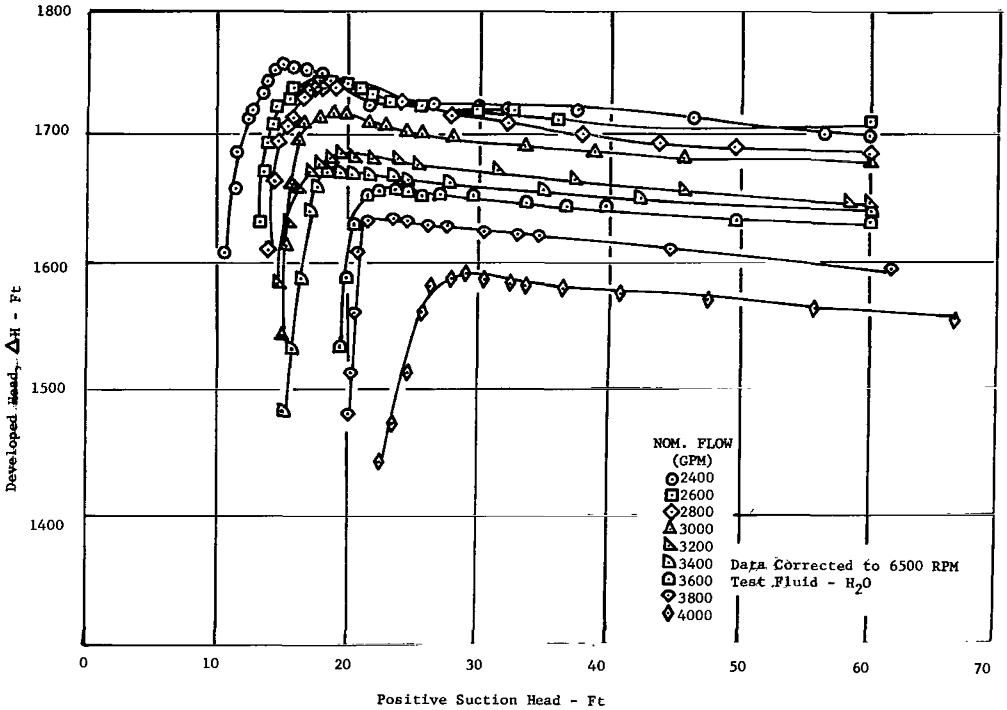

FIGURE 8. DEVELOPED HEAD VERSUS NPSH
AT 6500 RPM (WATER TESTS)

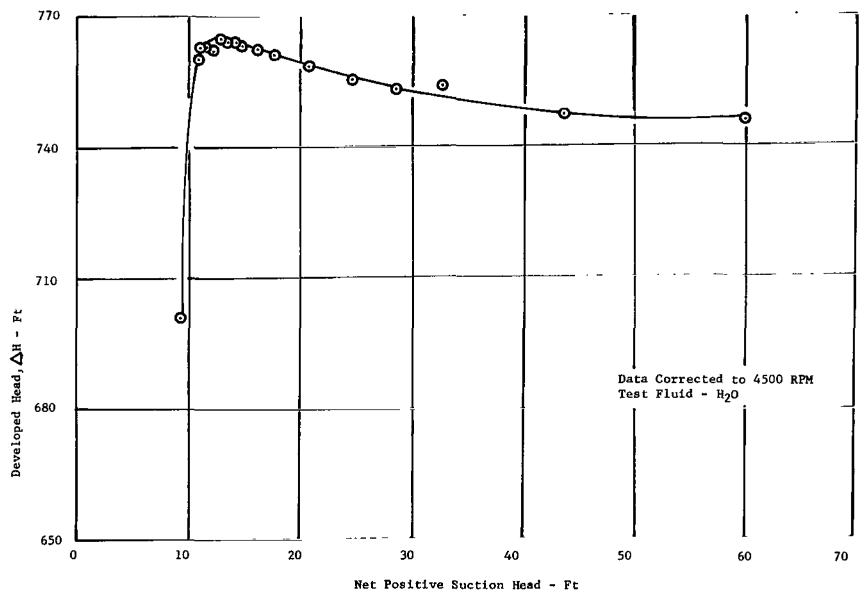

FIGURE 9. DEVELOPED HEAD VERSUS NPSH
AT 4500 RPM (WATER TESTS)

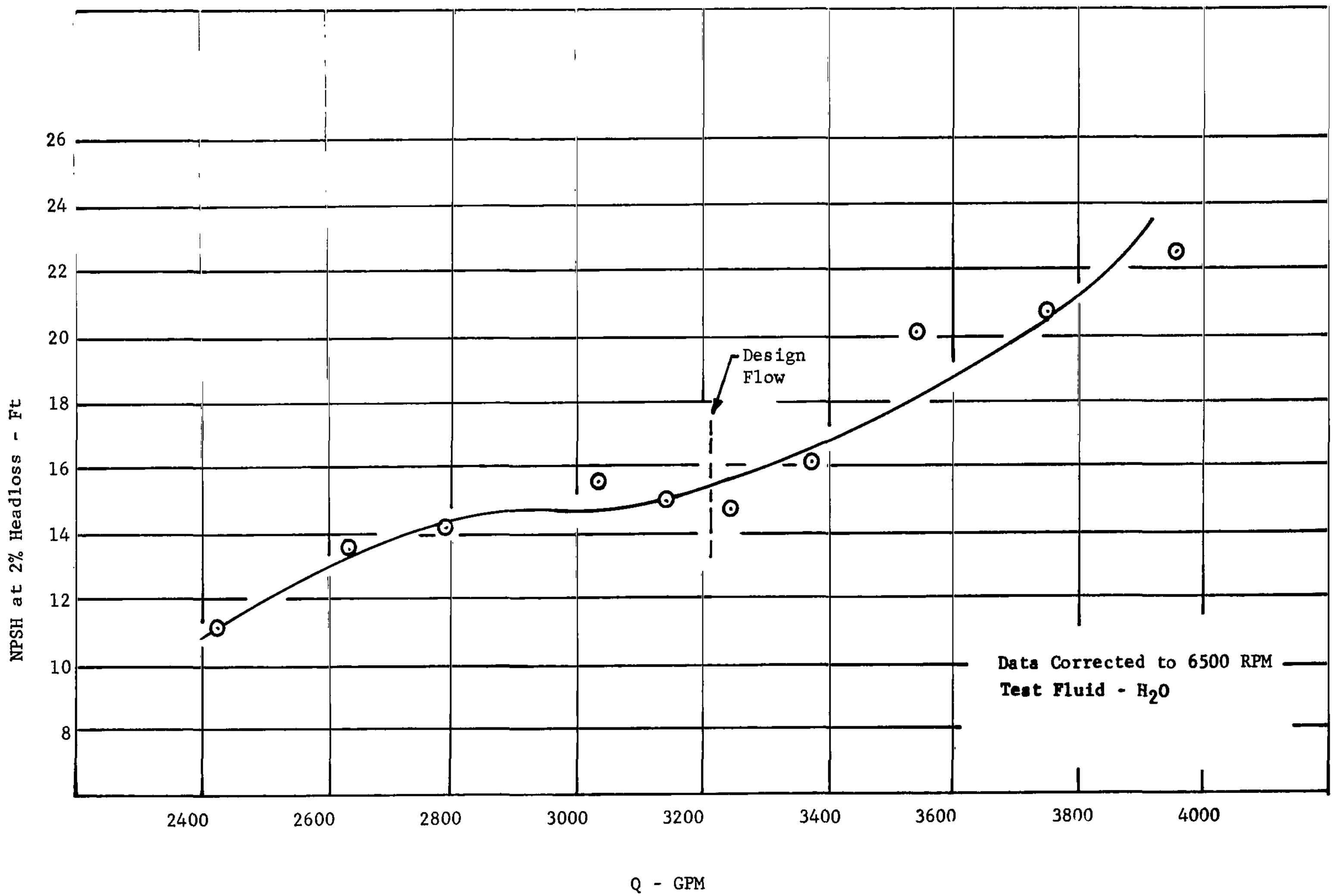

FIGURE 10. NPSH AT 2 PERCENT HEAD LOSS VERSUS FLOWRATE (WATER TESTS)

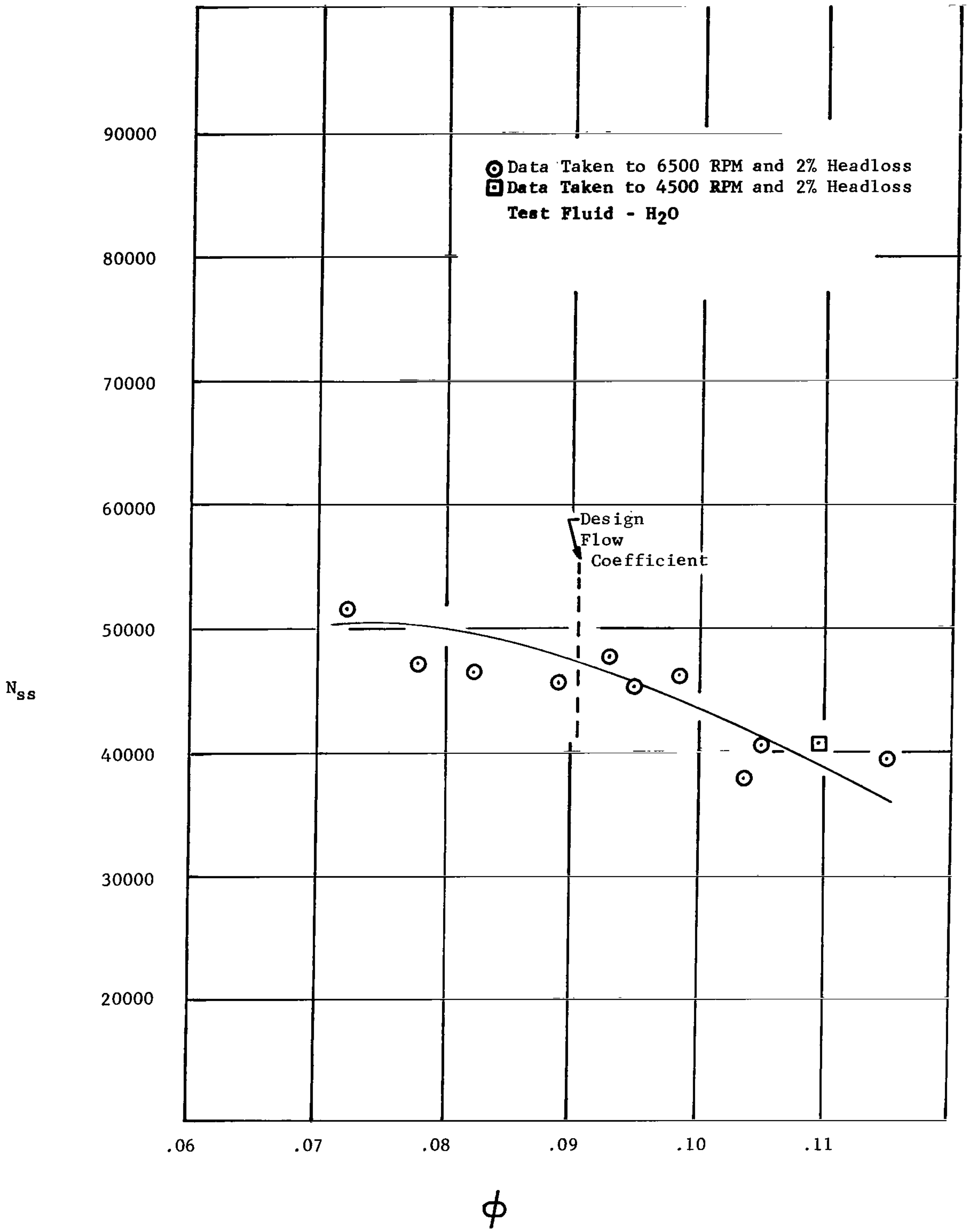

FIGURE 11. SUCTION SPECIFIC SPEED VERSUS FLOW COEFFICIENT (WATER TESTS)

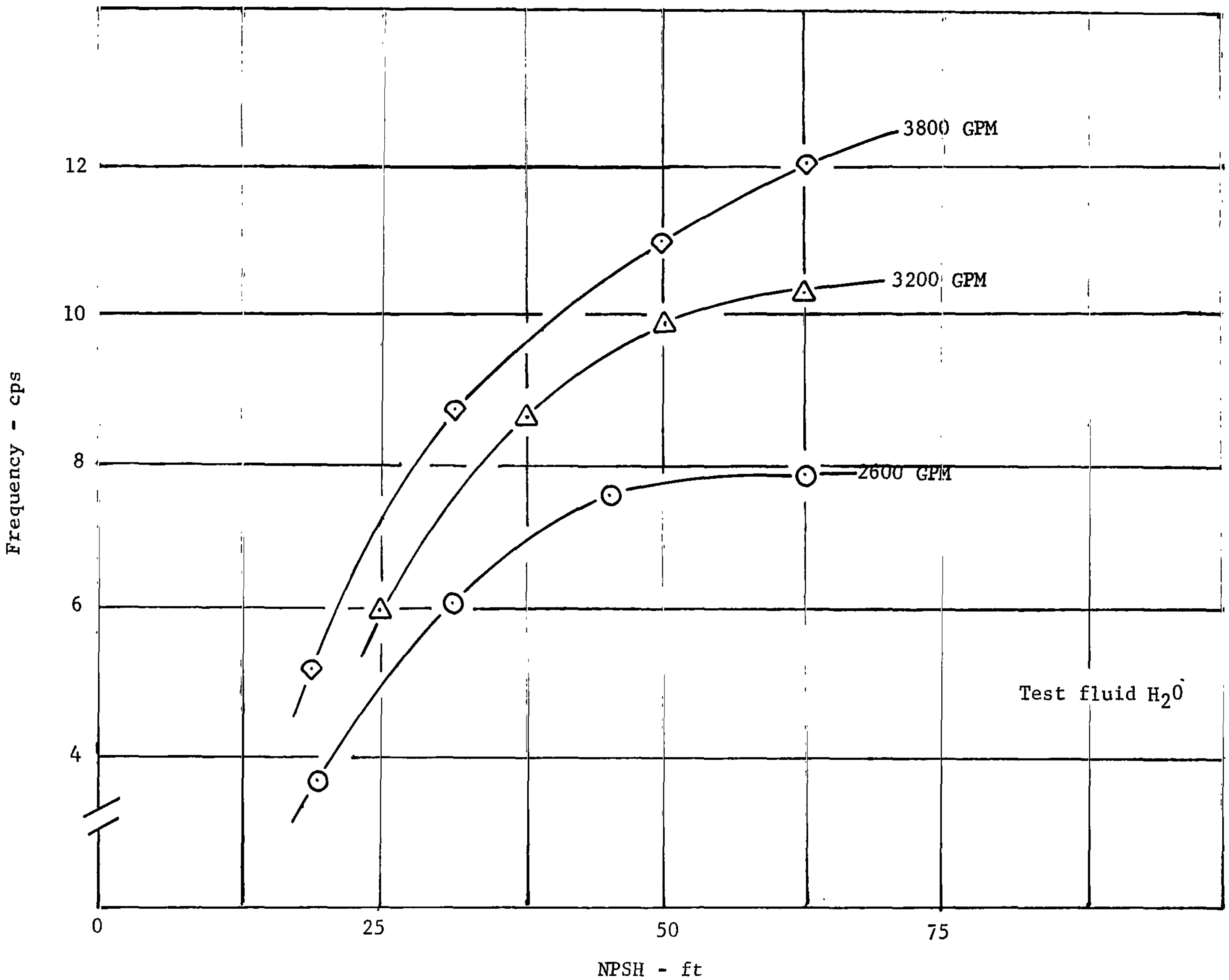

FIGURE 12. INLET OSCILLATION FREQUENCY VERSUS NPSH
(WATER TESTS)

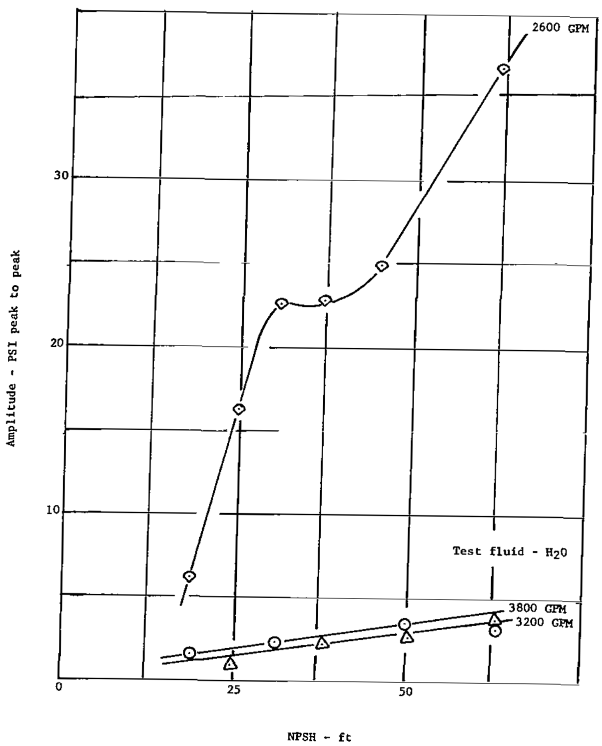

FIGURE 13. INLET OSCILLATION AMPLITUDE VERSUS NPSH (WATER TESTS)

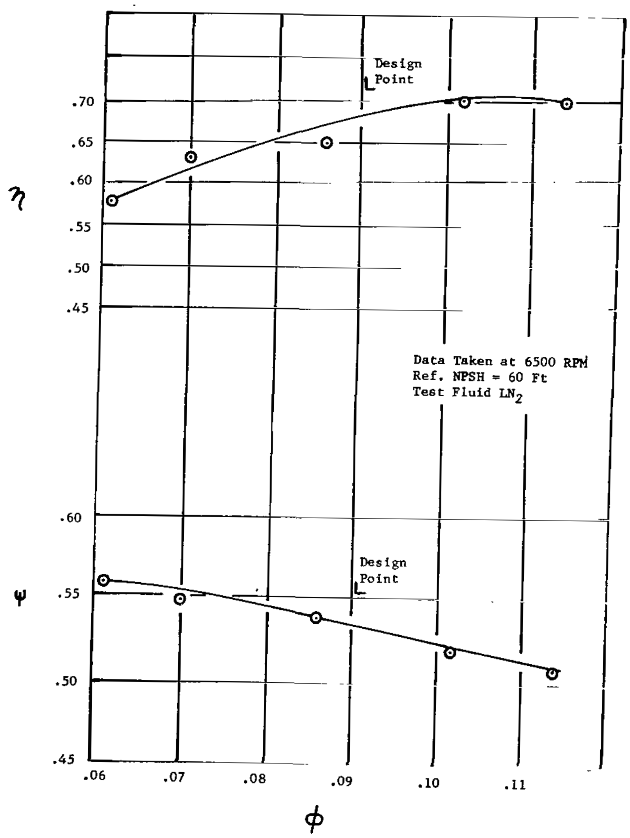

FIGURE 14. HEAD COEFFICIENT AND EFFICIENCY VERSUS FLOW COEFFICIENT (LIQUID NITROGEN TEST)

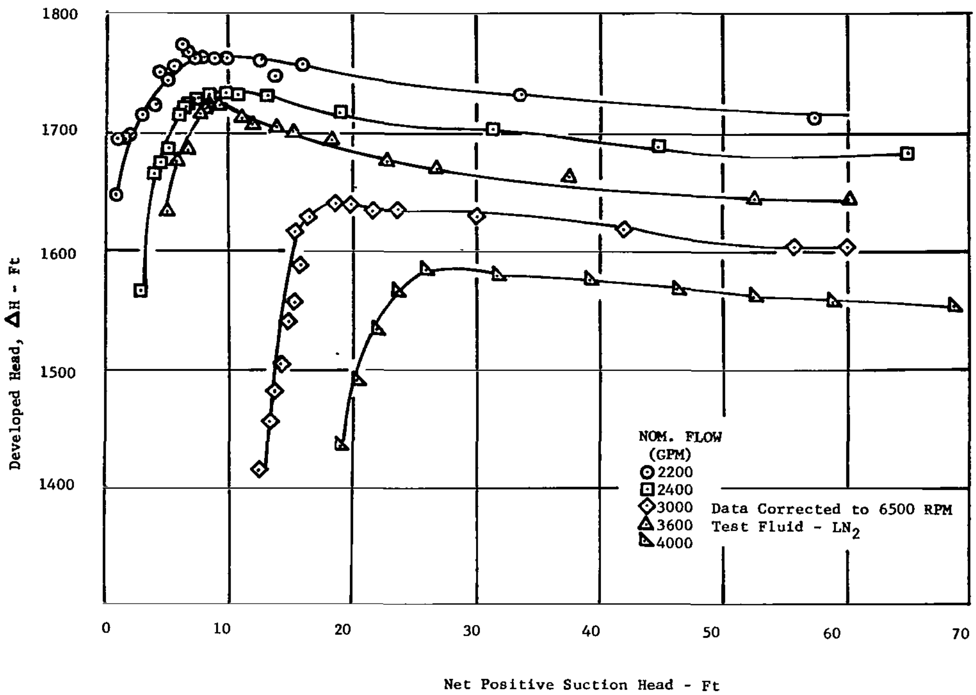

FIGURE 15. DEVELOPED HEAD VERSUS NPSH AT 6500 RPM (LIQUID NITROGEN TESTS)

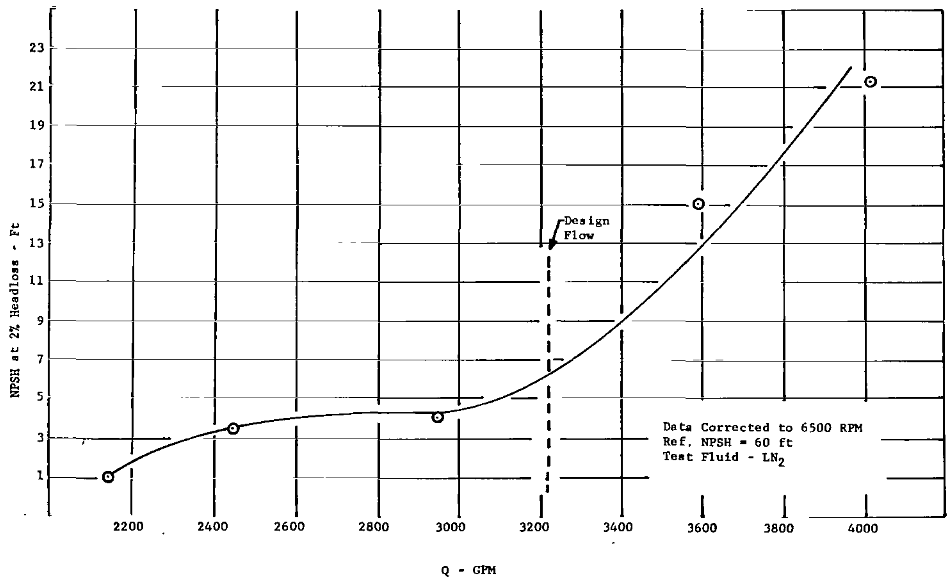

FIGURE 16. NPSH AT 2 PERCENT HEAD LOSS VERSUS FLOWRATE (LIQUID NITROGEN TEST)

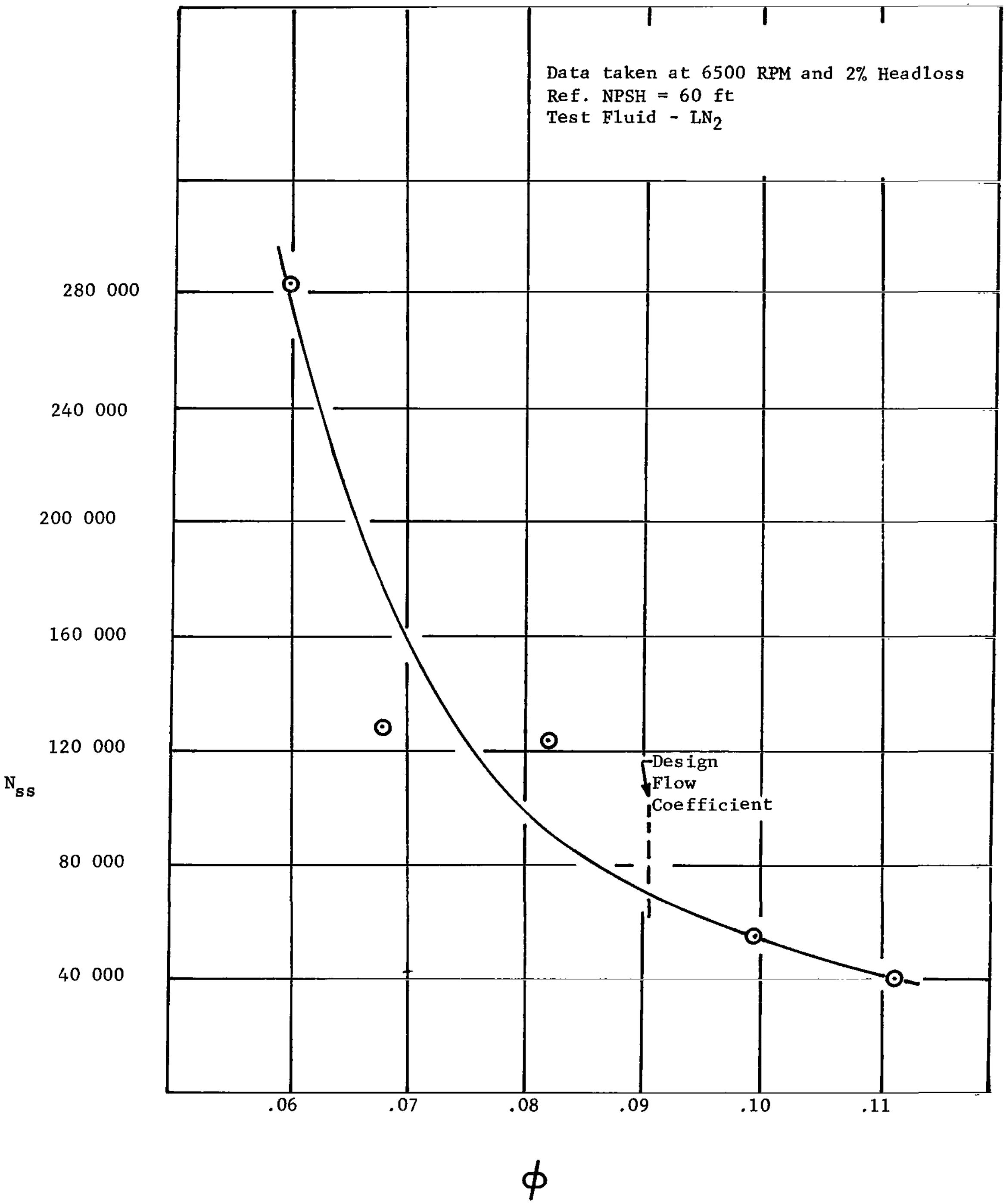

FIGURE 17. SUCTION SPECIFIC SPEED VERSUS FLOW COEFFICIENT (LIQUID NITROGEN TESTS)

REFERENCE

1. Jekat, W. K.: The Worthington Inducer. Contract NAS8-2680 Final Report, Feb. 20, 1964.

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