N71-11683

NASA TECHNICAL MEMORANDUM

NASA TM X-2131

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CAVITATION AND NONCAVITATION PERFORMANCE OF 78° HELICAL INDUCER IN HYDROGEN

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1970

1. Report No. NASA TM X-2131	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CAVITATION AND NONCAVITATION PERFORMANCE OF 78^{o} HELICAL INDUCER IN HYDROGEN		5. Report Date November 1970
		6. Performing Organization Code
7. Author(s) Phillip R. Meng and Royce D. Moore		8. Performing Organization Report No. E-5745
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		10. Work Unit No. 128-31
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The performance of a 78^{o} helical inducer mounted in an inlet line with a stationary centerbody was determined in hydrogen over a temperature range of 36.6^{o} to 40.1^{o} R (20.3 to 22.3 K) and a flow coefficient range of 0.088 to 0.130 at 25 000 and 30 000 rpm. The inducer NPSH requirement increased with increasing flow coefficient and rotative speed and decreased with increasing hydrogen temperature. Noncavitating head-rise coefficient, which decreased with increasing flow coefficient, was unaffected by liquid temperature and rotative speed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Hydrogen Cavitation Inducers	Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	13	$3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

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SUMMARY

The cavitating and noncavitating performance of a 78° helical inducer was evaluated in liquid hydrogen. The inducer was installed with an inlet annulus which extended 26.5 inches (67.3 cm) upstream of the blade leading edges. The net positive suction head (NPSH) requirements for the inducer were determined over a liquid-hydrogen temperature range of 36.6° to 40.1° R (20.3 to 22.3 K) and a flow coefficient range of 0.088 to 0.130 at rotative speeds of 25 000 and 30 000 rpm. For a given percentage of noncavitating head rise, the required net positive suction head increased with increasing flow coefficient and decreased with increasing liquid temperature. For a given flow coefficient and liquid temperature the net positive suction head required for a given performance level was greater at 30 000 rpm than at 25 000 rpm. The noncavitating performance of the inducer decreased almost linearly with flow coefficient and was unaffected by liquid temperature and rotative speed.

INTRODUCTION

In hydrogen-fueled rocket vehicles, large tanks are required to contain the low-density liquid hydrogen. The weight of these fuel tanks and thus the payload capability is sensitive to the tank pressure. It is, therefore, desirable to design the tanks for the lowest pressure that will satisfy the inlet pressure requirements of the turbopump. The cavitating inducer is generally used upstream of the main pump to reduce the inlet pressure requirements.

The water performance of flat-plate helical inducers with blade-tip helix angles of 84°, 80.6°, and 78° are compared in reference 1. Because the thermodynamic effects of cavitation (ref. 2) are essentially zero in cold-water testing, similar inducers were tested in liquid hydrogen. The performances of 84° and 80.6° helical inducers tested in liquid hydrogen are given in references 2 and 3, respectively. The effect of various inlet line configurations on the performance of the 80.6° helical inducer was investigated. The results of these tests are reported in reference 4.

The objectives of this investigation were to determine the overall performance and the net positive suction head requirements for the 78° helical inducer installed in an inlet annulus configuration. The inducer was tested over a liquid-hydrogen temperature range of 36.6° to 40.1° R (20.3 to 22.3 K). The flow coefficient was varied from 0.088 to 0.130 at rotative speeds of 25 000 and 30 000 rpm. These tests were conducted at the Plum Brook Station of the Lewis Research Center.

SYMBOLS

g	acceleration due to gravity, ft/sec^2 (m/sec^2)
ΔH	inducer head rise based on inlet density, ft (m) of liquid
NPSH	net positive suction head, ft (m) of liquid
U_t	blade tip speed, ft/sec (m/sec)
V_a	average axial velocity just upstream of inducer inlet, ft/sec (m/sec)
φ	flow coefficient, V_a/U_t
ψ	head-rise coefficient, $g\,\Delta H/U_t^2$

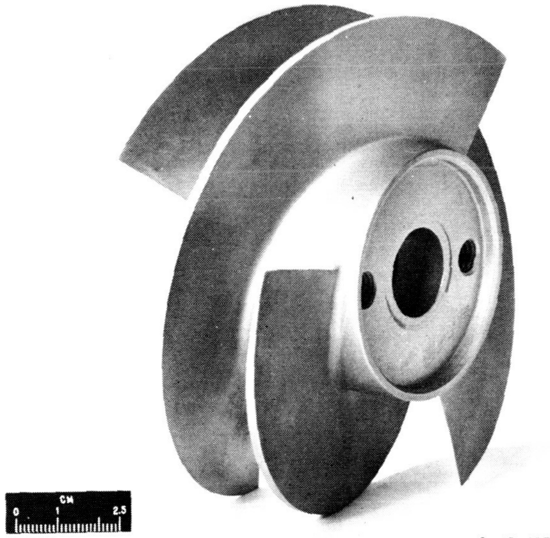
Subscript:

NC	noncavitating

APPARATUS AND PROCEDURE

Test Inducer

The test inducer used in this investigation was a three-bladed, flat-plate helical inducer with a tip helix angle of 78°. The inducer had a constant tip diameter of 4.980 inches (12.65 cm) and a hub-to tip-diameter ratio of 0.496. Significant geometric features and a photograph of the inducer are shown in figure 1. The leading edge of the inducer blades were faired on the suction surface only (see fig. 1).



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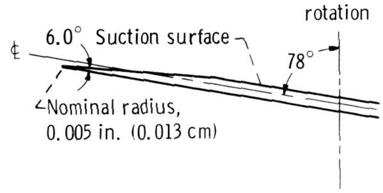
Tip helix angle (from axial direction), deg	78
Rotor tip diameter, in. (cm)	4.980 (12.649)
Rotor hub diameter, in. (cm)	2.478 (6.294)
Hub-tip ratio	0.496
Number of blades	3
Axial length, in. (cm)	2.00 (5.08)
Peripheral extent of blades, deg	240
Tip chord length, in. (cm)	10.42 (26.47)
Hub chord length, in. (cm)	5.12 (13.00)
Solidity at tip	1.856
Tip blade thickness, in. (cm)	0.100 (0.254)
Hub blade thickness, in. (cm)	0.190 (0.483)
Calculated radial tip clearance at hydrogen temperature, in. (cm)	0.025 (0.064)
Ratio of tip clearance to blade height	0.020
Material	6061-T6 Aluminum



Leading edge fairing

Figure 1. - Photograph and geometric details of 78° helical inducer.

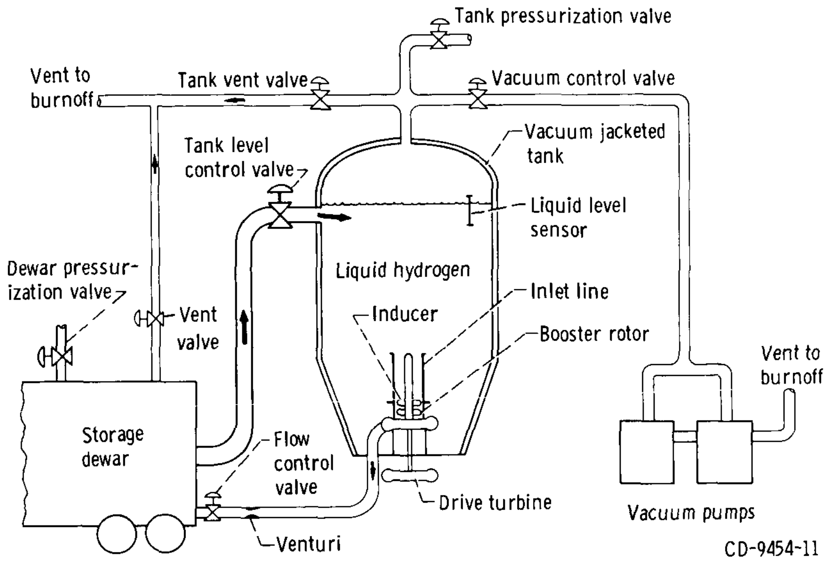


Figure 2. - Liquid hydrogen pump test facility.

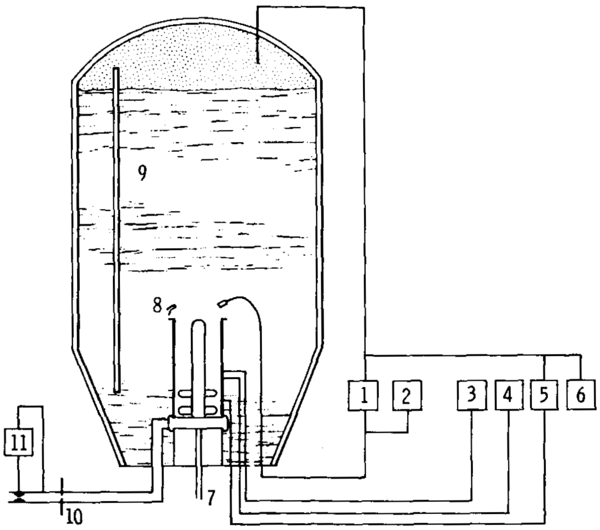
Test Facility

This investigation was conducted in the liquid-hydrogen pump-test facility, which is shown schematically in figure 2. The facility is basically the same as that described in reference 2. The inducer was located near the bottom of the 2500-gallon (9.5-m^3) vacuum-jacketed research tank. The inducer was installed in an inlet annulus that extends 26.5 inches (67.3 cm) above the blade leading edges. A booster rotor located downstream of the inducer was used to overcome system losses. The flow path is down the inlet annulus, through the inducer and booster rotor to a collector scroll, and into a discharge line to the storage dewar.

For the tests reported herein, the inlet annulus configuration used was formed by an extended inlet with a centerbody and was previously used for the tests reported in reference 4. The stationary centerbody extends from the entrance to the inlet line to the inducer hub, and it is held in place by four vanes at the entrance and three centering rods at the inducer end. The annulus formed by the inlet line and the centerbody has the same wall and hub diameters as at the inducer inlet.

Test Procedure

The research tank was filled with liquid hydrogen from the storage dewar. Before each test, the hydrogen in the tank was conditioned to the desired liquid temperature.



Item number	Parameter	Estimated system accuracy	Number used	Remarks
1	Tank net positive suction head	Low range ±0.05 psi (0.035 N/cm^2) High range ±0.25 psi (0.17 N/cm^2)	1 1	Measured as differential pressure (converted to head of liquid) between vapor bulb at line inlet and tank pressure corrected to line inlet conditions
2	Vapor pressure at line inlet	±0.25 psi (0.17 N/cm^2)	1	Vapor bulb charged with liquid hydrogen from research tank
3	Static pressure (line)	±0.05 psi (0.035 N/cm^2)	1	Average of three pressure taps (120° apart) located 10.5 in. (26.7 cm) above inducer inlet
4	Total pressure (line)	±0.05 psi (0.035 N/cm^2)	1	Shielded total pressure probe located 0.065 in. (0.165 cm) in from wall and 10.5 in. (26.7 cm) upstream at inducer
5	Inducer pressure rise	±1.0 psi (0.69 N/cm^2)	1	Shielded total pressure probe at midpassage 1 in. (2.54 cm) downstream of inducer
6	Tank pressure	±0.5 psi (0.35 N/cm^2)	1	Measured in tank ullage and corrected to inducer inlet conditions for reference pressure for differential transducers
7	Rotative speed	±150 rpm	1	Magnetic pickup in conjunction with gear on turbine drive shaft
8	Line inlet temperature	±0.1 R (0.06 K)	1	Platinum resistor probes 180° apart at inlet
9	Liquid level	±0.5 ft (0.15 m)	1	Capacitance gage, used for hydrostatic head correction to inducer inlet conditions
10	Venturi inlet temperature	+0.1 R (0.06 K)	1	Platinum resistor probe upstream of venturi
11	Venturi differential pressure	±0.25 psi (0.17 N/cm^2)	1	Venturi calibrated in air

Figure 3. - Instrumentation for liquid hydrogen pump test facility.

For liquid temperatures above 36.6° (20.3 K), the liquid was recirculated back through the storage dewar and into the research tank. The tank was then pressurized to 15 psi (10.3 N/cm^2) above the vapor pressure of the liquid. For each cavitation test run, when the desired rotative speed was attained, the tank pressure (NPSH) was slowly reduced until the head rise deteriorated because of cavitation. The flow rate and bulk liquid temperature were maintained essentially constant during each test. The noncavitating performance was obtained by varying the flow rate while maintaining a constant rotative speed and liquid temperature. The tank pressure for the noncavitating runs was maintained at 15 psi (10.3 N/cm^2) above the liquid vapor pressure.

Instrumentation

The location of the instrumentation used in this investigation is shown schematically in figure 3. The measured parameters and the estimated maximum system errors are also listed in figure 3.

The liquid vapor pressure was measured with a vapor-pressure bulb, which was charged with hydrogen from the tank and was located at the entrance to the annulus. Tank pressure, measured in the ullage space, was used as the reference pressure for the differential pressure transducers. The liquid level above the inducer, measured by a capacitance gage, was added to the reference pressure to correct the differential pressures to the inducer-inlet conditions. The differential pressure measured directly between tank pressure and the vapor bulb at the annulus inlet was converted to feet (meters) of head to obtain tank NPSH. Inducer NPSH was obtained by subtracting the annulus inlet losses from the tank NPSH. The losses were calculated by multiplying the annulus fluid velocity head by the loss coefficient, which was determined to be 0.2 from calibrations in air. A shielded total-pressure probe located at midstream approximately 1 inch (2.54 cm) downstream of the test rotor was used to obtain the inducer pressure rise. Two platinum resistor thermometers were averaged to obtain the hydrogen temperature at the inducer inlet. Pump flow rate was obtained with a venturi flowmeter which was calibrated in water.

RESULTS AND DISCUSSION

Noncavitating Performance

The noncavitating performance of the 78° helical inducer is shown in figure 4 where head-rise coefficient ψ_{NC} is plotted as a function of flow coefficient φ. The data are

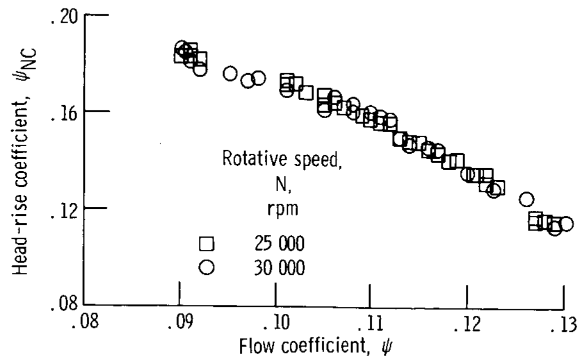


Figure 4. - Noncavitating performance of 78° inducer in liquid hydrogen. Net positive suction head, 500 feet (153 m); liquid temperature range 36.6° to 40.1° R (20.3 to 22.3 K).

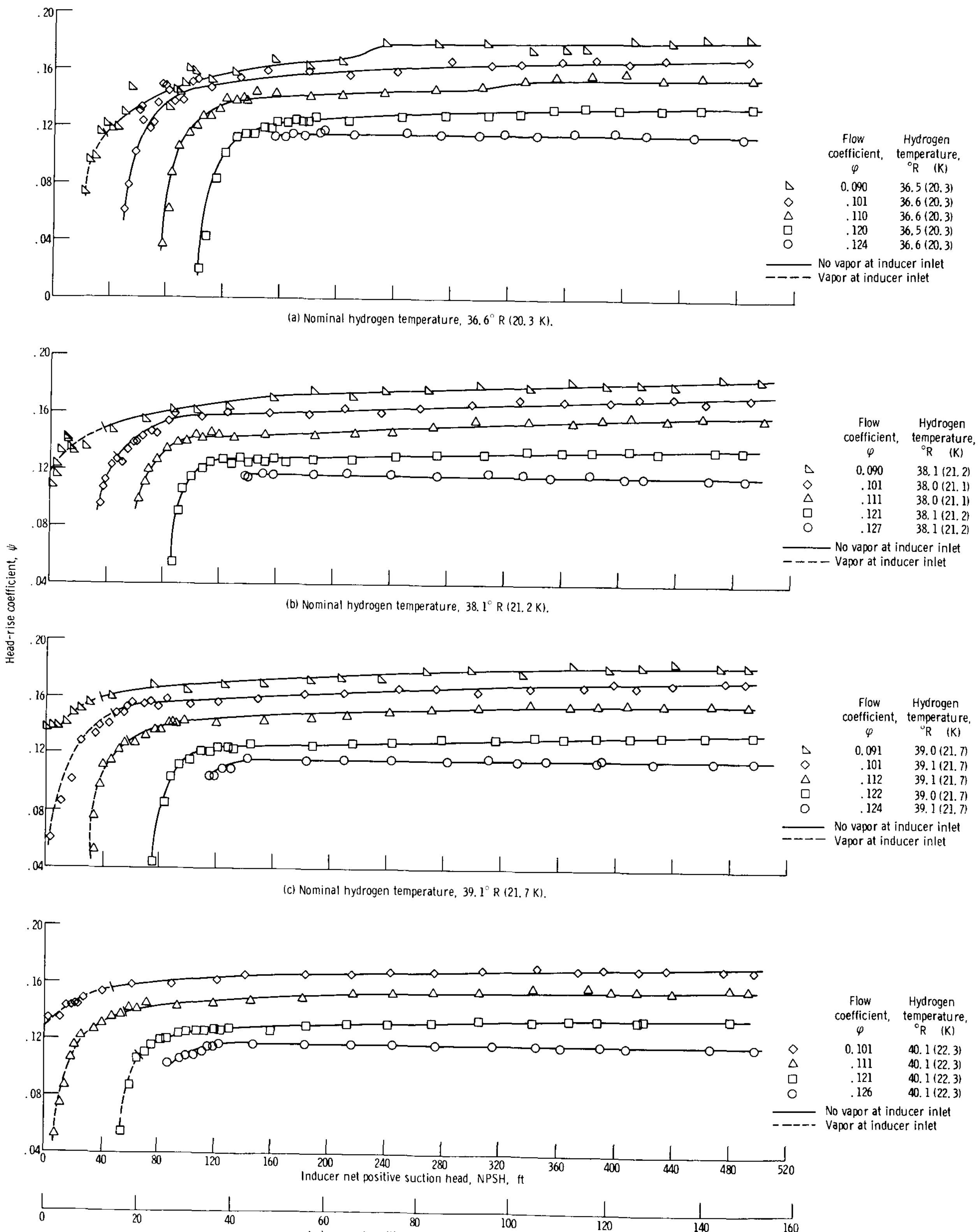
shown for a temperature range from 36.5° to 40.1° R (20.3 to 22.3 K) and at test rotative speeds of 25 000 and 30 000 rpm. As expected, neither liquid temperature or rotative speed has any measurable effect on the head-rise coefficient. The inducer head-rise coefficient decreases almost linearly with increasing flow coefficient.

Cavitation Performance

The inducer cavitation performance for the two rotative speeds is shown in figures 5 and 6 where head-rise coefficient is plotted as a function of NPSH. The data at each nominal hydrogen temperature is shown for several values of flow coefficient in figure 5 for a rotative speed of 25 000 rpm. Similar data are presented in figure 6 for a rotative speed of 30 000 rpm. The cavitation performance with no vapor at the inducer inlet is shown by the solid-line portions of the curves, and the cavitation performance with vapor in the inlet is shown by the dashed portions of some of the curves. When the NPSH is lowered to the inlet-fluid velocity head, the inlet static pressure is equal to the inlet-fluid vapor pressure. A further reduction in NPSH will cause the inlet fluid to boil and vapor to be ingested by the inducer.

At 25 000 rpm for the higher flow coefficients (φ = 0.124 to 0.127), the flow could not be held constant as the NPSH was lowered. This was apparently due to a head rise across the inducer and booster rotor that was not sufficient to overcome the system flow resistance. The data presented in figure 5 are therefore limited to those for which the flow coefficient could be held reasonably constant.

At 30 000 rpm and at a hydrogen temperature of 36.6° R (20.3 K) (fig. 6(a)) the data for flow coefficients of 0.090 and 0.101 cross at values of NPSH from 156 to 116 feet (47.5 to 35.4 m). The drop-off in head-rise coefficient at the 0.090 flow coefficient is



(a) Nominal hydrogen temperature, 36.6° R (20.3 K).

(b) Nominal hydrogen temperature, 38.1° R (21.2 K).

(c) Nominal hydrogen temperature, 39.1° R (21.7 K).

(d) Nominal hydrogen temperature, 40.1° R (22.3 K).

Figure 5. - Cavitation performance of 78° helical inducer in hydrogen at 25 000 rpm.

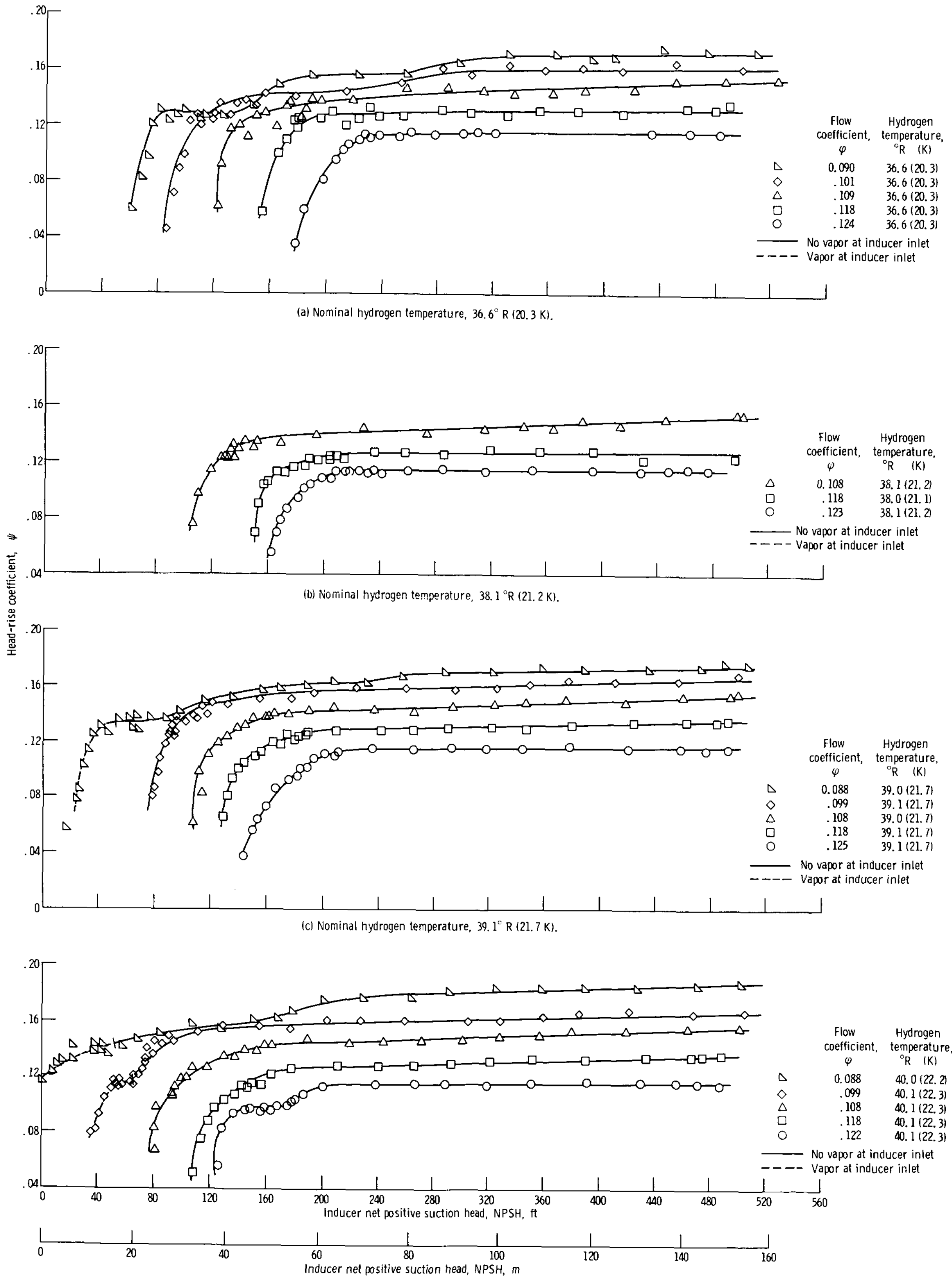


Figure 6. - Cavitation performance of 78° helical inducer in hydrogen at 30 000 rpm.

most likely caused by the instabilities associated with reverse flow conditions in the inducer. In an investigation of a geometrically similar 78° inducer in water (ref. 5), it was indicated that flow reversals did occur at the low flow coefficients.

Several general trends can be observed from the curves of figures 5 and 6. For a given rotative speed and flow coefficient, the required NPSH decreased with increasing liquid temperature. At a given temperature and rotative speed, the required NPSH decreased with decreasing flow coefficient for a given performance level. The required NPSH increased substantially with the increase in rotative speed from 25 000 to 30 000 rpm for a given flow coefficient and liquid temperature.

These trends are summarized in figures 7 and 8 where the required NPSH for a

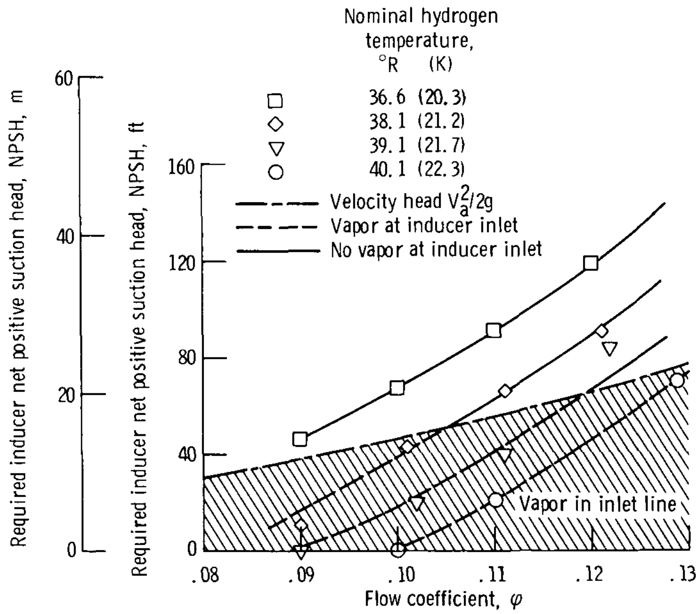


Figure 7. - Variation of inducer cavitation performance with flow coefficient at several hydrogen temperatures. Rotative speed, 25 000 rpm; head-rise coefficient ratio, 0.70.

head-rise coefficient ratio ψ/ψ_{NC} of 0.70 is plotted as a function of flow coefficient φ. The required NPSH is plotted for several nominal hydrogen temperatures at rotative speeds of 25 000 rpm (fig. 7) and 30 000 rpm (fig. 8). Values of NPSH less than the calculated velocity head $V_a^2/2g$ are indicated by the shaded area on these figures. The condition of vapor at the inducer inlet is indicated by the dashed portions on some of the curves of figures 7 and 8. The solid portions of these curves represent the performance with no vapor present at the inducer inlet. The performance with no vapor at the inducer inlet (solid lines) shows that the required NPSH increased with increasing flow coefficient. This trend is evident at the two rotative speeds, but the magnitude of the re-

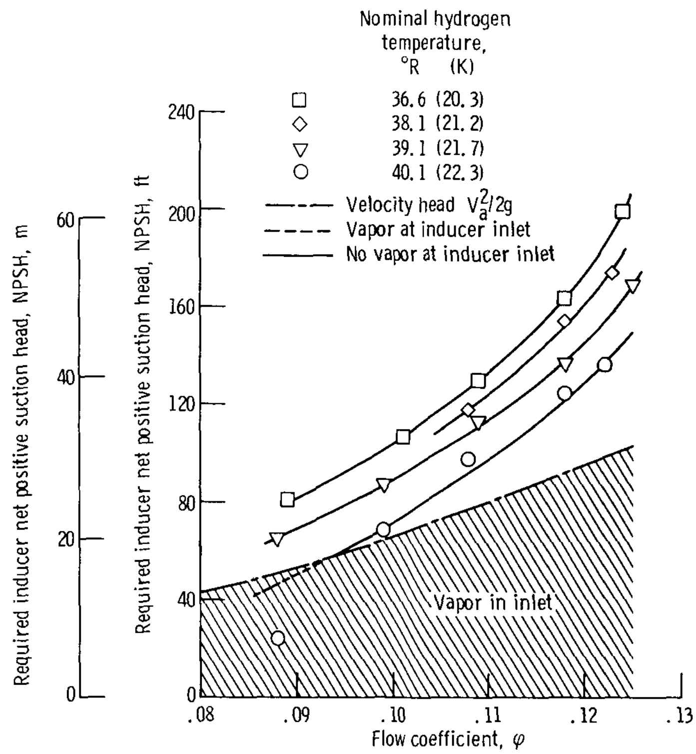


Figure 8. - Variation of inducer cavitation performance with flow coefficient at several hydrogen temperatures. Rotative speed, 30 000 rpm; head-rise coefficient ratio, 0.70.

quired NPSH is much greater at the higher rotative speed. Although the temperature effect was more pronounced at 25 000 rpm, the required NPSH decreased significantly with increasing liquid temperature at both speeds.

At a rotative speed of 25 000 rpm (fig. 7) with vapor in the inducer inlet (dashed lines) the required NPSH continued to decrease to values below the inlet fluid velocity head with increasing liquid temperature. At 30 000 rpm (fig. 8) the required NPSH did not decrease to a value below the inlet fluid velocity head for the 40.1° R (22.3 K) temperature curve except at the lowest flow coefficient.

SUMMARY OF RESULTS

The noncavitating and cavitating performance of a 78° flat-plate helical inducer was evaluated in liquid hydrogen at rotative speed of 25 000 and 30 000 rpm. The net positive suction head (NPSH) requirements were determined over a range of flow coefficients from 0.088 to 0.130 and a liquid temperature range from 36.6° to 40.1° R (20.3 to 22.3 K). The inducer was installed in an inlet annulus (inlet line with stationary centerbody) which extended 26.5 inches (67.3 cm) upstream of the blade leading edges. The following results were obtained:

1. At a given performance level the required inducer NPSH increased with increasing flow coefficient. The required NPSH increased as the inducer rotative speed was increased from 25 000 to 30 000 rpm.

2. Although the temperature effect was more pronounced at 25 000 rpm, the required NPSH decreased significantly with increasing liquid temperature at both rotative speeds.

3. At a rotative speed of 25 000 rpm and a head coefficient ratio of 0.70 vapor was present in the inducer inlet at most conditions for a hydrogen temperature above 36.6° R (20.3 K).

4. The noncavitating head-rise coefficient, which decreased almost linearly with increasing flow coefficient, was unaffected by liquid temperature or rotative speed.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 6, 1970,
128-31.

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