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CAVITATION PERFORMANCE
OF 84° HELICAL PUMP INDUCER
OPERATED IN 37° AND 42° R
LIQUID HYDROGEN

by Calvin L. Ball, Phillip R. Meng, and Lonnie Reid

Lewis Research Center
Cleveland, Ohio

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IN 37° AND 42° R LIQUID HYDROGEN (U)

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SUMMARY

The performance of a flat-plate helical-pump inducer with a blade-tip helix angle of 84° and a constant lead was evaluated in 37° and 42° R liquid hydrogen. The tests were conducted at a rotative speed of 20 000 rpm, over a range of flow rates from 900 to 1635 gallons per minute at several values of net positive suction head. An improvement in pump cavitation performance was indicated at 42° R.

The required net positive suction head for a given loss in inducer head rise in 37° R liquid hydrogen was at least 90 feet less than that required with 80° F water at a flow coefficient of 0.076. Because of this difference in suction requirements, which is attributed to the effect of fluid properties, the inducer can pump boiling liquid hydrogen at low flow coefficients with no appreciable head loss. Photographs of inducer cavitation in liquid hydrogen are presented herein.

INTRODUCTION

The increased use of liquid hydrogen as a high-energy propellant has resulted in the need for an evaluation of the cavitation performance of liquid-hydrogen pumps suitable for rocket engines. Experience in pumping liquid hydrogen has shown the cavitation characteristics of this fluid to be far different from that of other fluids. Pumps operating in liquid hydrogen have performed satisfactorily at much lower values of net positive suction head than could be achieved in other liquid rocket propellants.

The marked improvement in cavitation performance of liquid hydrogen compared with cold water has been reported in references 1 to 3. Improved cavitation performance for a given fluid at higher temperatures has also been observed in previous studies (refs. 4 to 6). These differences in pump cavitation performance between different fluids and over a range of temperatures for a given fluid have been attributed to changes in the

physical and thermodynamic properties of the fluids. The heat required for vaporization that occurs as a result of a reduction in local static pressure must be supplied by the fluid adjacent to the vapor cavity. If the properties of the fluid are such that a significant reduction in the local fluid temperature occurs during vaporization, there will be a corresponding reduction of the local vapor pressure. This reduction in the local vapor pressure will retard further vapor formation in a pump passage. Thus, pump operation at lowered inlet pressure is possible without the formation of a volume of vapor sufficient to cause an appreciable loss in performance.

Various analyses have been made to explain the effect of fluid properties on the cavitation performance of pumps and other hydraulic equipment (refs. 3 to 9). These analyses are useful for predicting trends with changes in fluid or fluid temperature, but, because of the complex nature of cavitation, they do not attempt to predict quantitative values for a given fluid or pump. A method which does predict the magnitude of fluid property effects on pump cavitation performance is reported in reference 10. This method is based on an empirical correlation of data obtained on small centrifugal pumps of relatively low suction specific speed and with fluids which exhibit only moderate fluid property effects. However, some flow devices and fluids of current interest in the aerospace field fall well beyond the range of data used as a basis for the prediction method of reference 10, and, thus, additional data are required. In particular, cavitation data are needed on high-speed inducers that operate in fluids such as liquid hydrogen.

The objective of this investigation was to determine the comparative cavitation performance of a typical inducer operated in liquid hydrogen at nominal fluid temperatures of 37° and 42° R. These results are, in turn, compared with the cavitation performance obtained for a similar inducer operated in room-temperature water.

The test inducer was a flat-plate helical inducer of constant lead with an 84° blade angle at the tip. Its design parameters are in the range of interest for inducers used in rocket turbopump systems. The flow rate was varied from 900 to 1635 gallons per minute at a rotative speed of 20 000 rpm. The tests were conducted in a liquid hydrogen pump test facility located at the Plum Brook Station of the Lewis Research Center.

SYMBOLS

C_p specific heat, $(Btu)(lb)/^O F$

g   acceleration due to gravity, ft/sec^2

ΔH pump headrise based on inlet density, ft of liquid

H_{sv} net positive suction head, ft of liquid

ΔH_{vp} reduction in local vapor head accompanying vapor formation, ft of liquid

dH_{vp}/dT slope of vapor pressure head to temperature curve, ft/^{O}R

L   latent heat of vaporization, Btu/lb

U_t blade tip speed, ft/sec

V_a average axial velocity at inducer inlet, ft/sec

V_v/V_l vapor-to-liquid volume ratio

ρ_v/ρ_l vapor-to-liquid density ratio

φ flow coefficient, V_a/U_t

ψ head coefficient, $g\,\Delta H/U_t^2$

APPARATUS AND PROCEDURE

Test Rotor

The test rotor used in this investigation (fig. 1) was a three-bladed flat-plate helical inducer with tip helix angle of 84° (angle between the blade mean line and the axis of rotation). The inducer (6061-T6 aluminum) has a constant tip diameter of 4.986 inches and a constant hub-tip diameter ratio of 0.497. Values of the rotor design parameters and dimensions are as follows:

Helix angle (at tip), deg 84
Rotor tip diameter, in. 4.986
Rotor hub diameter, in. 2.478
Hub-tip ratio 0.497
Number of blades 3
Axial length, in. 2.00
Peripheral extent of blades, deg . . . 440
Tip chord length, in. 19.14
Hub chord length, in. 9.51
Solidity at tip 3.838
Solidity at hub 3.838
Tip blade thickness, in. 0.067
Hub blade thickness, in. 0.100
Calculated radial tip clearance (at
  hydrogen temperature), in. . . . 0.025
Ratio of tip clearance to blade
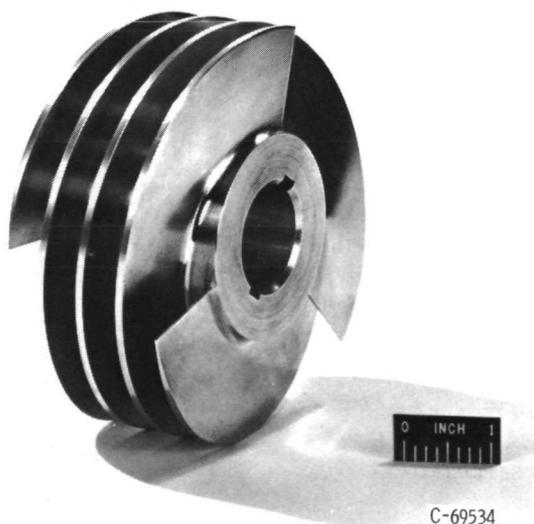 height 0.020

Figure 1. - 84° helical inducer.

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Test Facility

This investigation was conducted in the liquid-hydrogen-pump test facility shown schematically in figure 2(a). A photograph of the facility is shown in figure 2(b). The inducer was located near the bottom of a 2500-gallon vacuum-jacketed stainless-steel tank, 6 feet in diameter and 15 feet high, and incorporates several viewing ports located circumferentially about the pump test section. The fluid enters the test inducer through an inlet duct, flows through the inducer and booster rotor, and is then collected in a scroll and delivered back to the tank by a 4.0-inch-diameter discharge line which contains a venturi meter and a flow-control valve. The booster rotor was used to overcome system pressure losses. The tank is supported by three equally spaced columns containing jackscrews that lift the tank to provide access to the research hardware. The tank is sealed at the stationary parting surface by an inflatable stainless-steel O-ring and silicone rubber O-ring. The pump drive turbine, which operates on service air, is located directly below the research tank.

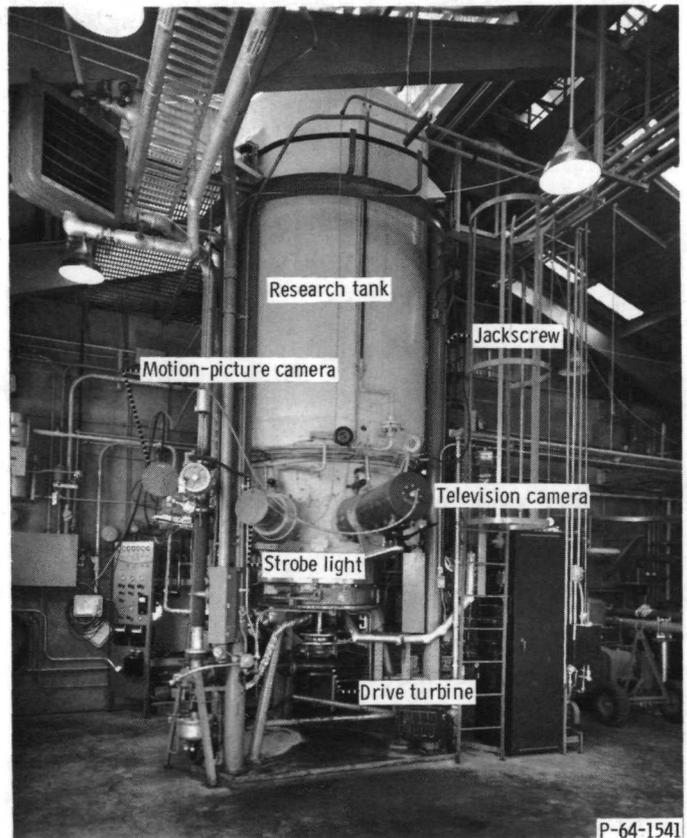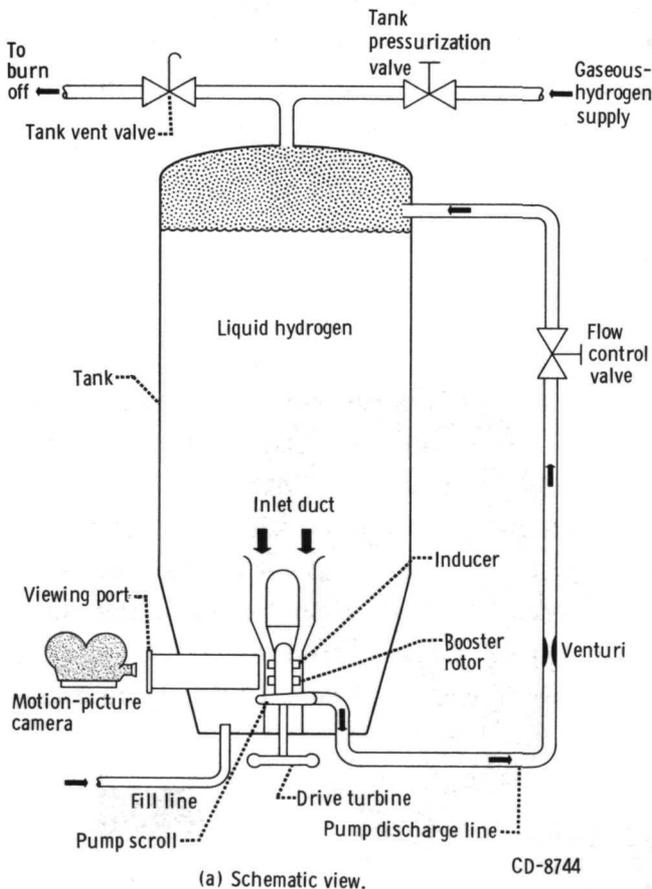(a) Schematic view.   CD-8744

(b) Photographic view.

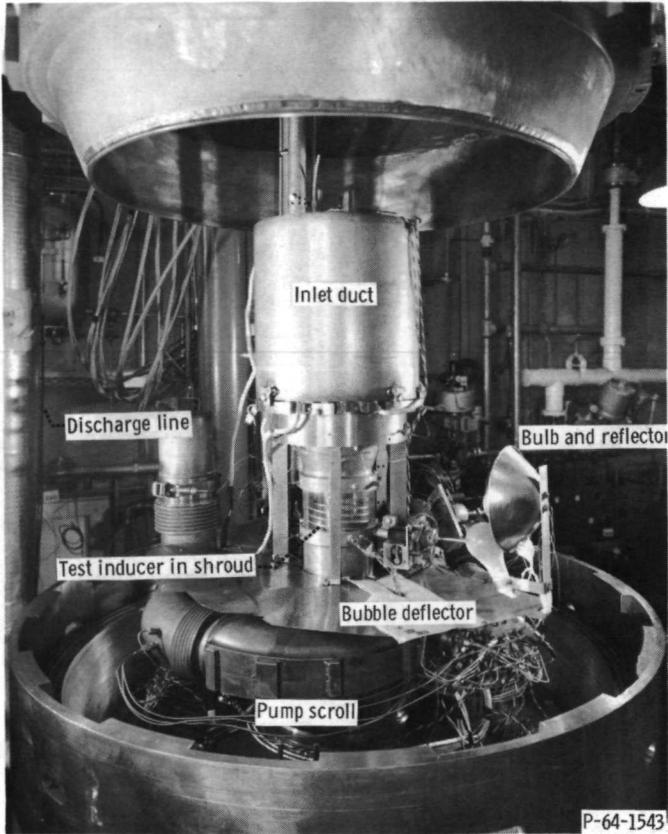Figure 2. - Liquid-hydrogen-pump test facility.

Figure 3. - Pump test section.

A photograph of the tank in the open position showing the research pump and associated hardware is shown in figure 3. The test inducer can be seen through the transparent plastic pump shroud that is provided for visual observation. The light bulb and reflector assembly was used to illuminate the inducer for television viewing during testing (see the appendix). A sheet-metal shield was mounted above the pump scroll to deflect the hydrogen bubbles, generated by the heat leak through the tank bottom, from the viewing-port area.

The pump rotor shaft was supported by a roller bearing (inducer end) and a ball bearing (turbine end) that were cooled by liquid hydrogen. These bearings contained self-lubricating, glass-impregnated polytetrafluoroethylene cages.

Test Procedure

The pump test data were obtained at nominal hydrogen temperatures of 37° and 42° R at a constant pump rotative speed of 20 000 rpm. A manually operated flow-control valve was used to vary the flow over a range from near shutoff to near zero head rise. Two methods were used to obtain performance data at each hydrogen temperature: (1) flow rate was varied over the full range while a constant rotative speed and net positive suction head were maintained and (2) with rotative speed and flow rate held constant, the net positive suction head was decreased (by tank venting) from a value considered to be noncavitating to one near zero with cavitation. All data were recorded on a 10 kilocycle digital recording system.

Instrumentation and Calculation Procedure

The location of the instrumentation used is shown schematically in figure 4. Carbon
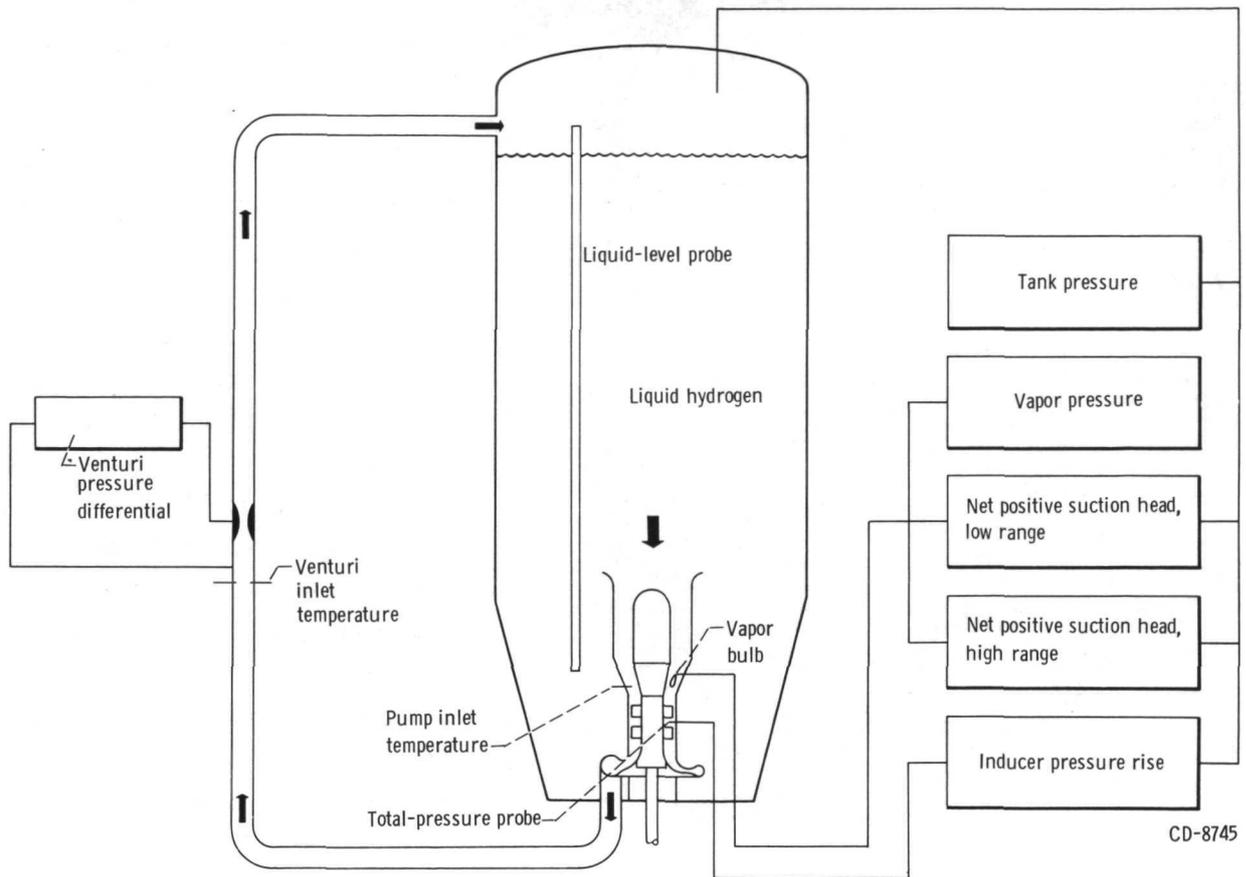
Figure 4. - Instrumentation for liquid-hydrogen-pump facility.

resistor probes were used for temperature measurement at the pump and venturi inlets, and strain gage transducers were used for all pressure measurements. Differential pressures were measured wherever possible to allow use of smaller range transducers for improved accuracy. All transducers were electrically calibrated before each test and, the calibration was checked after the test.

Tank pressure, measured in the ullage space, was used as the reference pressure for the differential pressure transducers. The liquid level above the pump inlet, measured by a capacitance gage, was added to the reference pressure to correct the differential pressures to pump-inlet conditions. Net positive suction head was measured directly as the difference between the vapor-pressure-bulb reading and the corrected pump-inlet total pressure. The vapor-pressure bulb was charged with liquid hydrogen from the research tank. Low- and high-range transducers were used to increase the accuracy of this measurement. Pump flow rate was obtained from a venturi flowmeter that was calibrated in air and water. Pump rotative speed was indicated with the use of a magnetic pickup in conjunction with a gear on the turbine drive shaft.

The estimated maximum instrument systems errors are listed in the following table:

Pump inlet temperature, ^{O}R . . . . ±0.15
Venturi inlet temperature, ^{O}R . . . . ±0.15
Inducer pressure rise, psi . . . . ±0.5
Low-range net positive suction head, H_{sv}, psi . . . . ±0.05
High-range net positive suction head, H_{sv}, psi . . . . ±0.25
Vapor pressure, psi . . . . ±0.25
Venturi differential pressure, psi . . . . ±0.15
Inducer flow rate, gal/min . . . . ±16
Rotative speed, rpm . . . . ±100
Liquid level, ft . . . . ±0.5

The parameters used in presenting the overall performance are defined in the section SYMBOLS. The inducer head coefficient was based on the discharge total head taken at a mean radial location at a distance of approximately 1 inch behind the test inducer.

EFFECTS OF FLUID PROPERTIES ON CAVITATION PERFORMANCE

The effect of changes in fluid properties on the cavitation process and on the cavitating performance of pumps is discussed in references 2 to 7. In essence, it has been shown that when vapor is formed in a region of low pressure, the heat of vaporization required to form the vapor must be derived from the surrounding liquid. Consequently, the liquid temperature is lowered and its vapor pressure is reduced, which retards the tendency for additional vapor formation.

A pump inducer is designed to operate with cavitating flow, consequently, some vapor will be present in the low-pressure region along the blade suction surface. As the net positive suction head is lowered, the cavity size increases until a critical vapor volume is reached; further vapor formation causes the inducer head rise to decay rapidly. The net positive suction head corresponding to this critical condition is lower in fluids for which the liquid vapor pressure is appreciably reduced as a result of vaporization than in fluids which do not have this desirable fluid property effect.

From a static heat balance that satisfies the heat transfer between the liquid and the vapor, it can be shown that the vapor-pressure depression due to vaporization can be expressed as

$$\Delta H_{vp} = \frac{L}{C_p} \frac{\rho_v}{\rho_l} \left(\frac{dH_{vp}}{dT} \right) \frac{V_v}{V_l} \tag{1}$$

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In the development of this equation, it is assumed that thermodynamic equilibrium exists and that the heat required for vaporization is uniformly removed from the remaining fluid and, thus, the fluid vapor pressure is uniformly lowered throughout the fluid. For cavitating flow in a pump blade passage, however, it seems unlikely that this ideal condition is applicable because the vapor forms in regions of high fluid accelerations and, as a result, is not uniformly distributed. Also, because of the high fluid velocities involved, it is doubtful that sufficient time is available for a uniform temperature to be established throughout the liquid within the blade passage. Consequently, the depression in fluid vapor pressure depends on the local conditions existing in a given pump. The results of references 8 and 9 show that local pressures measured within the cavitating region of liquid nitrogen and Freon 114 corresponded to vapor pressure based on the locally reduced temperature; thus, the assumption that thermodynamic equilibrium exists at the fluid-vapor interface appears to be valid.

As the fluid temperature is increased, the resulting change in the physical properties of a fluid provides a greater depression in fluid vapor pressure for a given volume of vaporized fluid. This is shown graphically in figure 5 where the vapor-to-liquid volume ratio V_v/V_l is presented as a function of ΔH_{vp} for liquid hydrogen at 37° and 42° R. The curves are nonlinear because of changes in fluid properties as the temperature decreases due to vaporization. Values of the vapor-to-liquid volume ratio V_v/V_l were
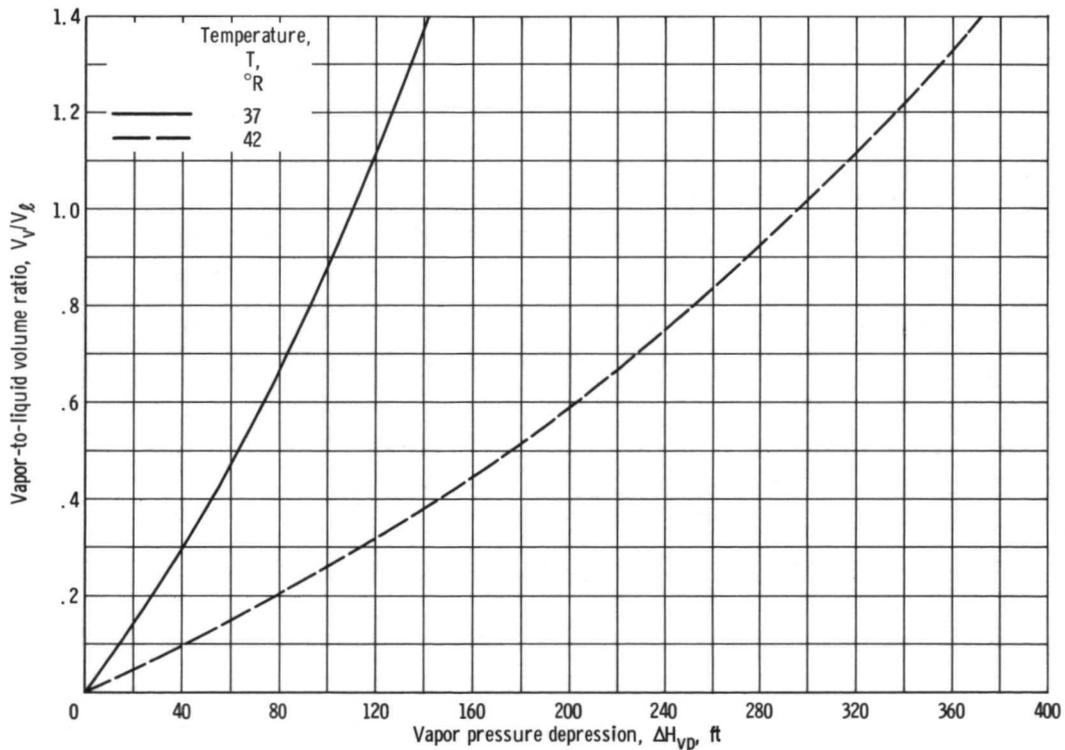

Figure 5. - Calculated vapor-to-liquid volume ratio as function of vapor pressure depression for liquid hydrogen at 37° and 42° R.

obtained by numerical integration of equation (1) by using 1-foot increments of ΔH_{vp}. For a given value of V_v/V_l, an increase in hydrogen temperature from 37° to 42° R results in a marked increase in the magnitude of the vapor-pressure reduction. The vapor-pressure depression for room-temperature water is negligible and, thus, its curve would lie essentially along the ordinate of figure 5.

In practice, the absolute value of V_v/V_l is not known. Although, in a cavitating pump, it may be possible to evaluate V_v, the vapor volume of the cavity, V_l represents only that volume of liquid actually involved in the cavitation process and cannot be determined. However, because improvements in cavitation performance are related to the degree of vapor-pressure reduction, a determination of ΔH_{vp} values over a range of initial fluid temperatures and vapor-to-liquid volume ratios is useful as a means for determining trends in pump cavitation performance. Use of figure 5 to determine trends in cavitation performance implies that, for a particular pump and given fluid (liquid hydrogen in this case), a constant V_v/V_l value corresponds to the same given loss in pump performance independent of temperature. Thus, if it is assumed that the improvement in required net positive suction head H_{sv} is directly proportional to the change in calculated vapor-pressure reduction within the cavity ΔH_{vp}, the curves of figure 5 indicate that pump cavitation performance (for a given loss) should improve significantly with only a modest increase in hydrogen temperature. Also, the cavitation performance of a particular pump operated in 37° or 42° R liquid hydrogen should show a marked improvement over that for room-temperature water.

RESULTS AND DISCUSSION

Noncavitating Performance

The noncavitating inducer performance is defined herein as that performance which shows no measurable decay in pump head rise when the net positive suction head is reduced. This does not mean that the inducer is operating cavitation free. Visual observation showed that cavitation occurs as a result of blade tip vortices even at relatively high inlet pressures. As the inlet pressure is lowered, the limited cavitation that first develops on the blade suction surface has a negligible effect on performance. If the inlet pressure is further reduced, blade-surface cavitation becomes well developed, and the head-producing capability of the pump is impaired.

The noncavitating performance data (fig. 6) were obtained at values of net positive suction head H_{sv} of 350 and 171 feet and at fluid temperatures of 37° and 42° R. The data were taken at two levels of H_{sv} to verify that the performance was noncavitating. The inverse relation of head coefficient with respect to flow coefficient is typical for this
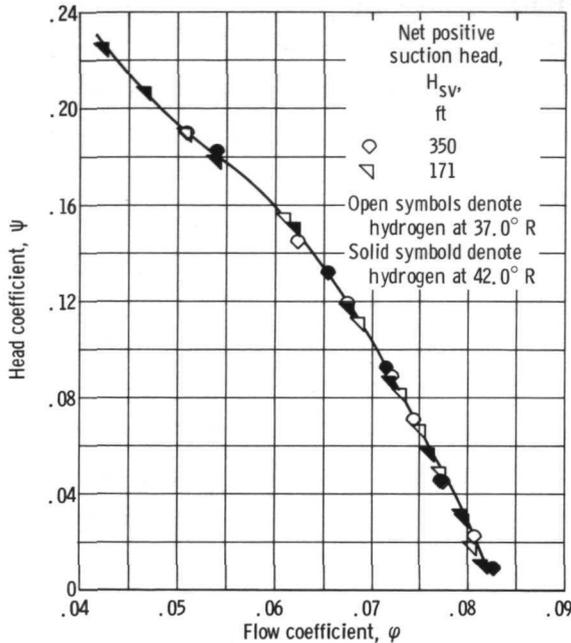
Figure 6. – Noncavitating inducer performance in hydrogen at 37° and 42° R. Blade tip speed, 433 feet per second.

type helical inducer. As expected, noncavitating performance is unaffected by fluid temperature.

Cavitation Performance

Inducer cavitation performance at liquid-hydrogen temperatures of 37° and 42° R is presented in figure 7, which shows the variation in head coefficient ψ as a function of flow coefficient φ for several values of net positive suction head. In general, for a given net positive suction head, improved cavitation performance was obtained with 42° R hydrogen, as evidenced by the higher values of flow coefficient attained without a performance loss. For a fluid temperature of 37° R at lower values of net positive suction head, cavitation performance begins to de-
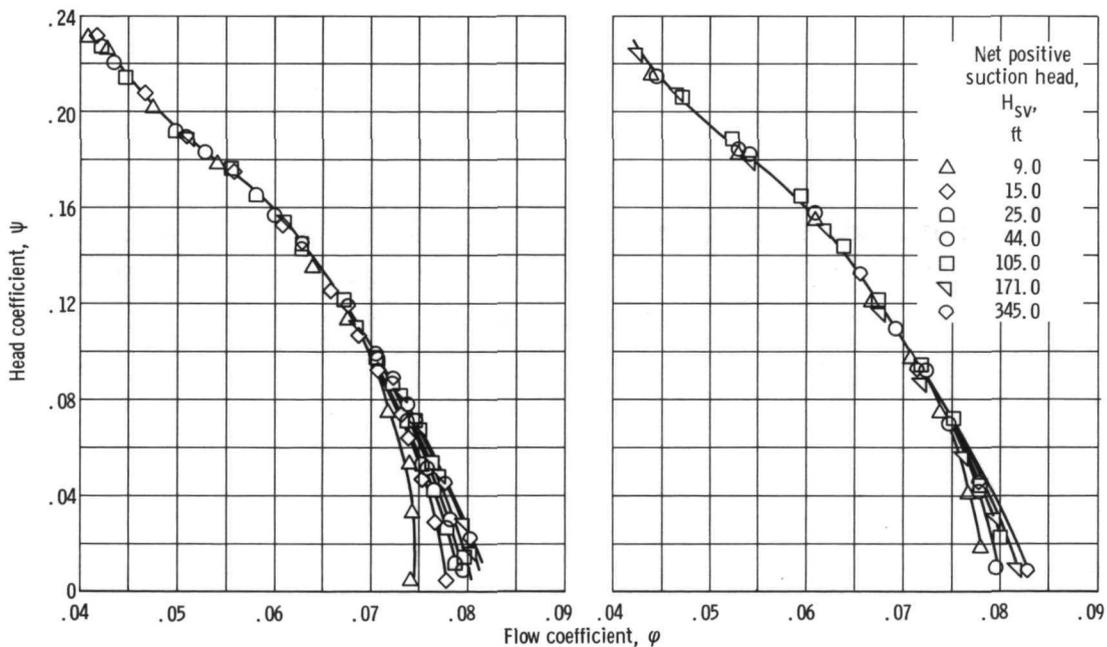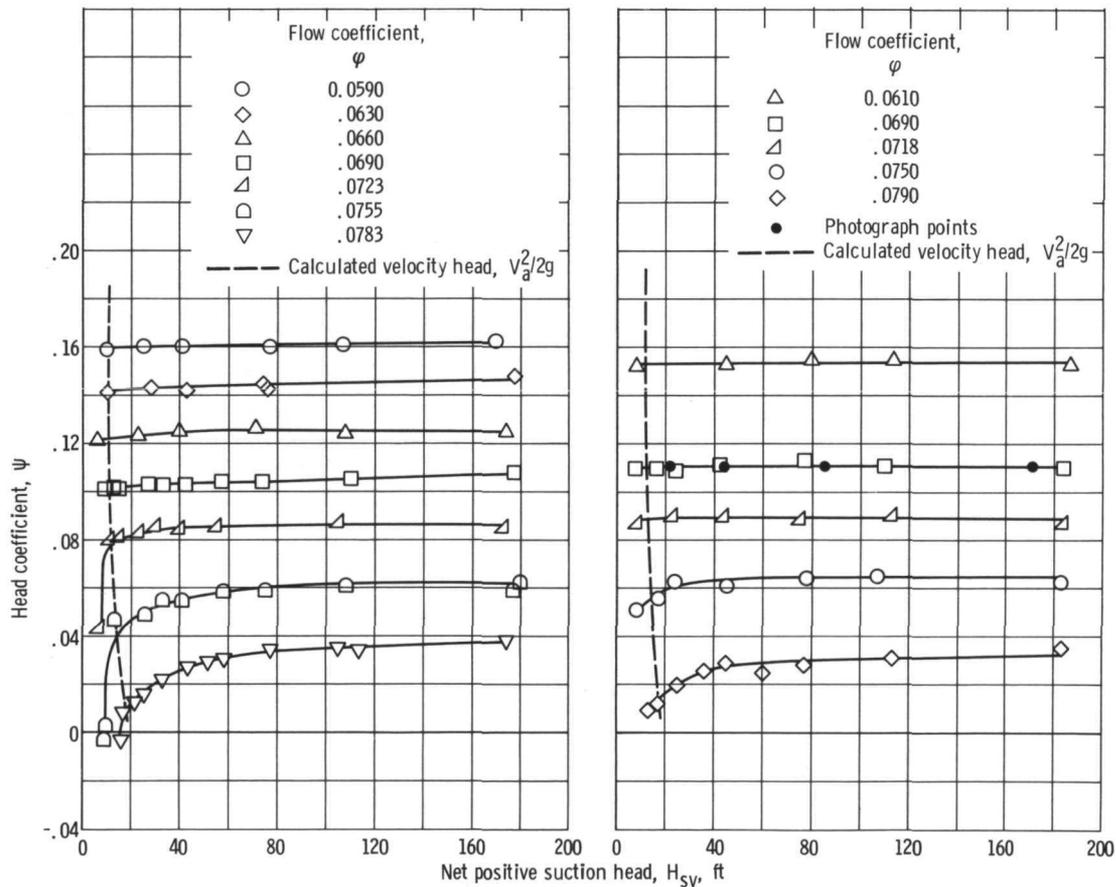

(a) Fluid inlet temperature, 37° R.

(b) Fluid inlet temperature, 42° R.

Figure 7. – Inducer cavitation performance in liquid hydrogen. Blade tip speed, 433 feet per second.

cline at a flow coefficient of 0.067; at 42° R, this break occurs at a flow coefficient of 0.072. Also, there is a smaller spread in the cavitation performance curves at high-flow conditions for hydrogen at 42° than at 37° R. This change in cavitation performance is attributed to the relatively large differences in the physical properties of hydrogen at 37° and 42° R.

The effect of cavitation on performance is shown more clearly in figure 8, where the head coefficient ψ is shown as a function of net positive suction head H_{sv} for several values of flow coefficient. At the lower flow coefficients, there is no significant dropoff in head coefficient even at the lowest values of net positive suction head. The data for liquid hydrogen at 37° R (fig. 8(a)) indicate that, as flow was increased, the loss in performance becomes steadily more pronounced until at the lower values of H_{sv}, inducer performance decays rapidly. The data for 42° R hydrogen show similar trends; however, the rate of performance loss with decreasing H_{sv} was somewhat less and a complete breakdown in inducer head rise was not observed.

The dashed lines in figure 8 represent values of H_{sv} that correspond to the velocity head $V_a^2/2g$ at the pump inlet and, thus, for these conditions, the static pressure at the

(a) Fluid inlet temperature, 37° R. (b) Fluid inlet temperature, 42° R.

Figure 8. - Cavitation performance in liquid hydrogen. Blade tip speed, 433 feet per second.

pump inlet corresponds to the fluid vapor pressure. It is significant that the inducer was capable of pumping the hydrogen that entered the pump in a boiling condition, that is, at H_{sv} values less than those represented by the dashed lines of figure 8. For the lower values of flow coefficients studied, the presence of boiling hydrogen at the inducer inlet had no appreciable effect on cavitation performance. The data indicate that at the lower flow rates, particularly for 42° R hydrogen, the inducer could have been operated at even lower values of net positive suction head without an appreciable decrease in head rise. The minimum operational net positive suction head was limited to the hydrostatic head of fluid in the research tank.

Visual observations indicated that vapor bubbles were present in the bulk liquid at H_{sv} values greater than the calculated inlet velocity head. Some of this vapor may have been ingested by the inducer, thereby, causing the deterioration in cavitation performance noted at $H_{sv} > V_a^2 / 2g$ (a further discussion is included in the Visual Observation section).

For a given pump, it is generally assumed that the vapor volume required to cause a given loss in performance is independent of fluid or fluid temperature. Thus, to ensure, insofar as possible, the similarity of flow and cavity geometry, comparisons of pump cavitation performance are generally made on the basis of the required net positive suction head for a given, but significant, dropoff in head coefficient at a constant flow coefficient. For the hydrogen data presented herein (figs. 7 and 8), any comparison of cavitation performance is limited to a relatively large value of flow coefficient where a rapid falloff in performance occurs.

The test results obtained with 37° and 42° R hydrogen are presented in figure 9 for a nominal flow coefficient φ of 0.076 along with comparable data for a similar inducer operating in water.

The inducer data obtained for water are taken from reference 11 and are supplemented with unpublished data from the same test series. Because these data were obtained at a rotative speed of 10 000 rpm, it was necessary to compute the H_{sv} values
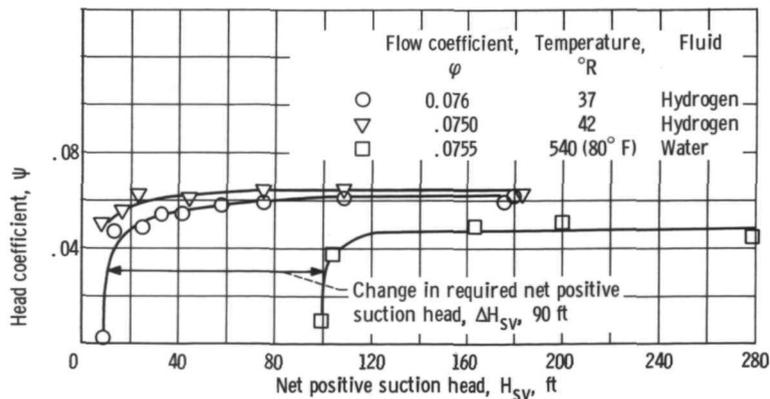

Figure 9. - Comparison of cavitation performance of inducer in hydrogen and water.

for 20 000 rpm on the basis of constant suction specific speed. The inducer used in the water tests was dimensionally identical to the inducer reported herein except for a difference in solidity (3.838 for the hydrogen inducer compared with 3.016 for the water inducer). Reference 12 indicates that inducer cavitation performance is unaffected by changes in solidity for values greater than 1.5. It is unlikely that this change in solidity had any appreciable effect on cavitation performance. The higher head coefficient obtained in hydrogen, compared with water (fig. 9), was caused by small differences in measured flow coefficient which resulted in a relatively large difference in head coefficient because of the steep slope of the head-flow curve for this type of inducer. Also, a variation between the actual running-tip clearance in water and the calculated running-tip clearance in hydrogen may have contributed to this difference in head coefficient.

The difference in net positive suction head requirements for different fluids (or temperatures) under similar operating conditions can best be determined where the head coefficient approaches the point of rapid falloff which, for the data of figure 9, is at a value of head coefficient of approximately 0.03. At this condition, the value of H_{sv} required for 37° R hydrogen is about 90 feet less than that for 540° R (80° F) water. At 42° R, only a moderate penalty in performance was indicated for the minimum measured value of H_{sv} of 9 feet. This improved performance at 42° R is attributed to changes in fluid properties of hydrogen and substantiates the expected trends indicated by the curves of figure 5 (p. 8).

The method of reference 10 was extended to make a prediction of this difference in head requirement between 37° R liquid hydrogen and room-temperature water. The calculated value of 100 feet is in good agreement with the experimentally measured value when it is considered that this empirical method is based on data for centrifugal pumps with lower suction specific speeds (about 8000) and with fluids that exhibited relatively small effects of fluid properties on cavitation performance.

If the reduction in the required H_{sv} is assumed equivalent to the calculated vapor-pressure reduction ΔH_{vp}, for the measured difference in required H_{sv} of 90 feet between hydrogen and water, the 37° R curve of figure 5 indicates an effective V_v/V_l of about 0.78. Based on this value of V_v/V_l of 0.78, the calculated value of ΔH_{vp} at 42° R shows almost a threefold increase over that for 37° F (about 245 ft). Although this indicates that the net positive suction head requirement for 42° R hydrogen should approach a zero value with no falloff in performance, the data of figure 9 show that a decrease in cavitation performance did occur for the lower values of H_{sv}. This falloff in performance with 42° R hydrogen at a flow coefficient of 0.075 may have been caused, in a large part, by the presence of a two-phase flow in the inlet line. As previously indicated, vapor was observed in the bulk liquid even at relatively high values of H_{sv}, and it appears likely that some of this vapor was drawn into the inducer. Similarly, vapor in the inlet line probably contributed to the falloff in performance at 37° R. In order to re-

late the falloff in performance specifically to cavitation occurring in the blade passages, it would be necessary to operate the inducer at rotative speeds significantly greater than the limiting value of 20 000 rpm.

The fluid velocities relative to the pump blading may also affect the magnitude of the depression in vapor pressure because of the time limitation imposed on the heat transfer and vaporization process. Thus, the magnitude of the change in inlet head requirements as affected by the fluid properties reported herein, may vary somewhat with the internal flow conditions existing within an inducer or other flow device.

Visual Observation

Photographs of cavitation in liquid hydrogen at 37° and 42° R are presented in figures 10 and 11, respectively. The photographic techniques used are discussed in the appendix. The photographs in figure 10 show cavitation at a nominal fluid temperature of 37° R for flow coefficients of 0.050 and 0.070 at two values of H_{sv}. The photographs taken at the lower flow coefficient of 0.050 (figs. 10(a) and (b)) exhibit a much larger tip vortex than
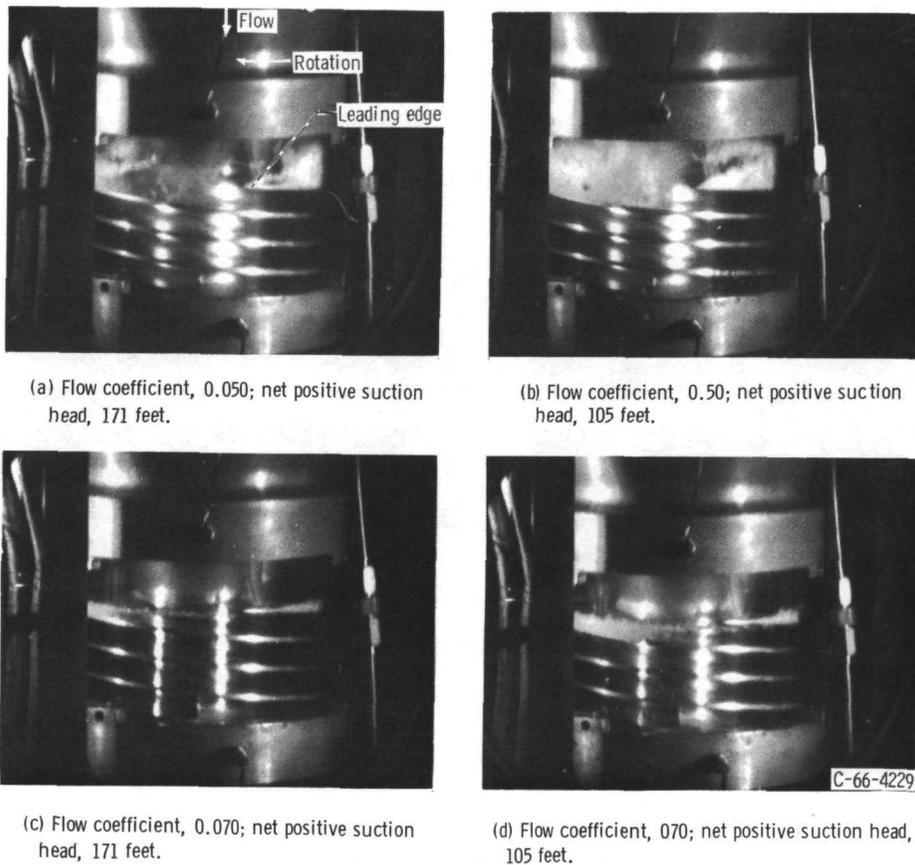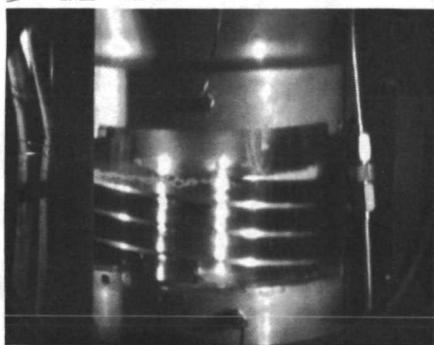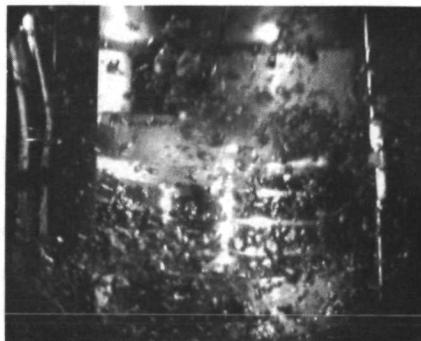

(a) Flow coefficient, 0.050; net positive suction head, 171 feet.

(b) Flow coefficient, 0.50; net positive suction head, 105 feet.

(c) Flow coefficient, 0.070; net positive suction head, 171 feet.

(d) Flow coefficient, 070; net positive suction head, 105 feet.

Figure 10. - Photographs of inducer tip vortex cavitation in hydrogen at 37°R.

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those taken at the higher flow coefficient of 0.070 (figs. 10(c) and (d)). The presence of tip vortex cavitation and vapor bubbles in the bulk fluid did not permit visual observation of blade-surface cavitation; consequently, a good comparison of blade-surface cavitation at the two temperatures could not be made from the photographs.

The photographs shown in figure 11 were taken at progressively lower values of H_{sv} at a flow coefficient of 0.069 and at a fluid temperature of 42° R. The cavitation performance of the inducer at points corresponding to the photographs is indicated by the solid symbols on the 0.069 flow coefficient curve of figure 8(b) (p. 11). The numerous bubbles shown in figures 11(b), (c), and (d) are located in the bulk fluid between the viewing-port window and the plastic-pump shroud. The large amount of vapor shown in these photographs at values of H_{sv} much higher than the calculated velocity head results primarily from turbulence as the fluid is discharged back into the tank and also to a small extent from heat leak through the tank bottom. These photographs indicate the condition of the fluid in the tank while the pump head rise has not yet severely deteriorated as a result of cavitation. Although the flow in the pump inlet duct was not observed directly under these conditions, it appears reasonable to assume that, as the bubbles rose past the pump inlet, some unknown quantity of vapor was drawn into the pump. The amount of
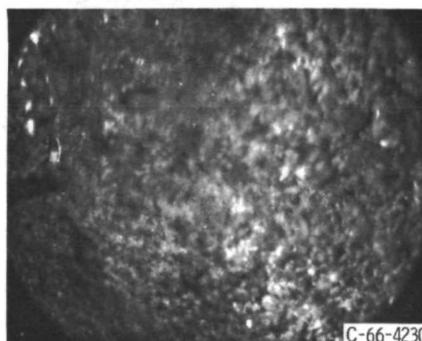

(a) Net positive suction head, 171 feet.

(b) Net positive suction head, 85 feet.

(c) Net positive suction head, 43 feet.

(d) Net positive suction head, 22 feet.

Figure 11. - Photographs of inducer cavitation in liquid hydrogen at 42° R. Flow coefficient, 0.069.

vapor in the bulk fluid was observed to increase as the net positive suction head was lowered (fig. 11); thus, it is likely that greater quantities of vapor were ingested by the pump under these conditions. The decrease in cavitation performance in 42° R liquid hydrogen may have resulted from this two-phase flow rather than from limiting blade-surface cavitation. A similar condition existed for operation at 37° R; consequently, an improvement in cavitation performance, over that presented herein, might be realized with single-phase liquid flow at the pump inlet.

SUMMARY OF RESULTS

The performance of a three-bladed flat-plate helical inducer with an 84° tip-helix angle, a 4.986-inch diameter, and a hub-tip ratio of 0.497 was evaluated in liquid hydrogen at nominal fluid temperatures of 37° and 42° R. The cavitation performance of the inducer in hydrogen and that obtained for a similar inducer in water are compared to determine the effects of changes in fluid properties. Visual observations of inducer cavitation were made over a range of operating conditions.

The results are summarized as follows:

1. An improvement in the inducer cavitation performance was indicated as the hydrogen temperature was increased from 37° to 42° R.

2. At low values of flow coefficient, the inducer is capable of pumping boiling liquid hydrogen with no appreciable head loss because of fluid-property effect.

3. For the same falloff in performance with cavitation, the net positive suction head required for operation of the inducer in 37° R liquid hydrogen was 90 feet less than that required in room-temperature water at a flow coefficient of 0.076.

4. Visual observation revealed that vapor bubbles were present in the bulk liquid even at high values of net positive suction head. The falloff in performance, which was observed at high values of flow coefficient in 42° R hydrogen, may have resulted from this two-phase flow at the pump inlet.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 3, 1966,
128-31-02-24-22.

APPENDIX - PHOTOGRAPHIC TECHNIQUES

The pump was photographed through a viewing port shown isometrically in figure 12. The port was designed for an external pressure of 100 pounds per square inch gage with normal operating pressure to 60 pounds per square inch gage. Four viewing ports were orientated as shown in figure 13.

A 16-millimeter motion-picture camera with an f/2 lens having a focal length of 4 inches was operated remotely at a framing rate of 24 frames per second. The best
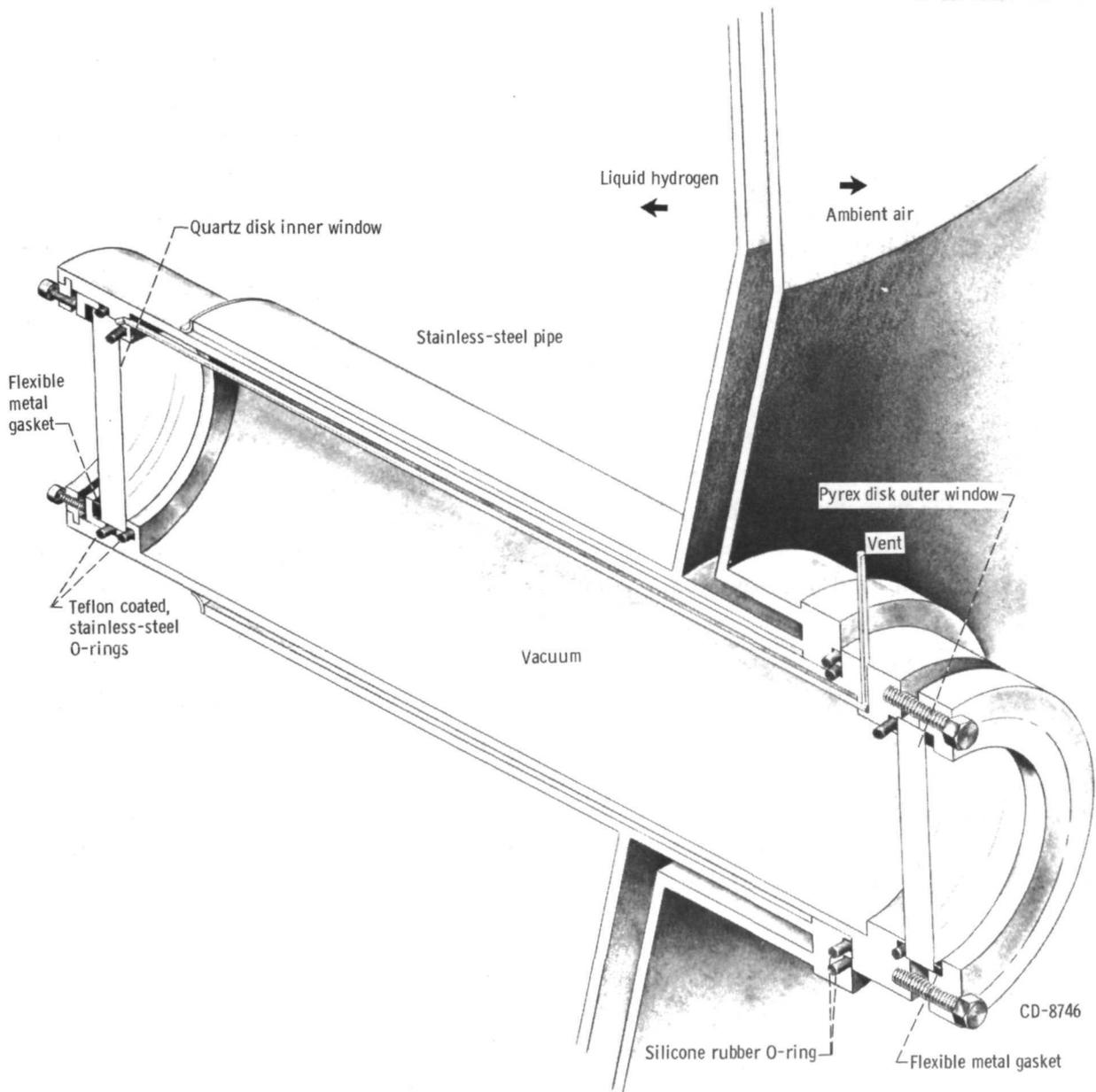
Liquid hydrogen

Ambient air

Quartz disk inner window

Stainless-steel pipe

Flexible metal gasket

Pyrex disk outer window

Vent

Teflon coated, stainless-steel O-rings

Vacuum

Silicone rubber O-ring

Flexible metal gasket

CD-8746

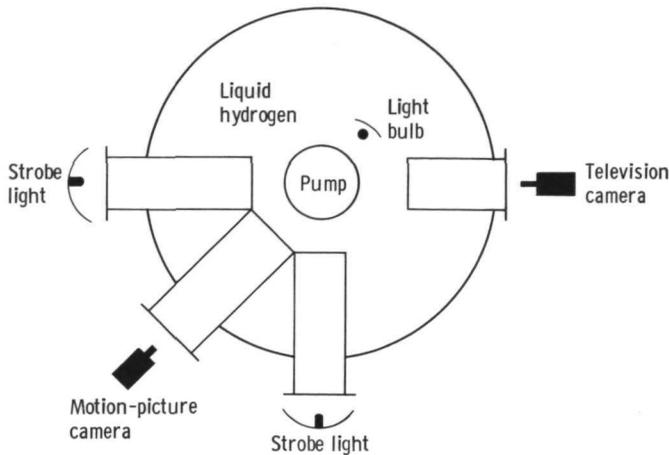Figure 12. - Isometric drawing of viewing port.

Figure 13. – Arrangement of cameras and lights (plan view).

photographs were achieved with a fine-grain negative black and white motion-picture film with an ASA rating of 64. High-speed stroboscopic lights with nitrogen-gas-cooled xenon bulbs were located at the viewing ports on either side of the camera port. A magnetic pickup in conjunction with a protrusion on the turbine drive shaft was used to trigger both stroboscopic lights at the desired test rotor orientation with respect to the camera. At a pump speed of 20 000 rpm, this photographic system is limited by the camera framing rate to one photograph per 10 pump revolutions.

The photographs taken at high values of H_{sv} are clear, but at lower values of H_{sv} the space between the end of the viewing port and the pump shroud is filled with boiling hydrogen; thus, the pump was obscured. These bubbles are generated by fluid turbulence in the tank and by heat flux through the bottom of the tank.

Another difficulty encountered during these tests was the formation of a white frost on the plastic pump shroud. This frost occurred as the tank was vented relatively fast from a condition of high pressure and temperature. The frosty condition persisted for a period of time after venting. To alleviate this situation, a slow venting procedure was used when photographs were being taken.

A television camera was used to observe the pump during testing and photographing. The light source for the television camera during pump operation, while the motion-picture camera is not in use, was a 150-watt rough service light bulb with a reflector located behind it (see fig. 3, p. 5). The "rough service" designation indicates that the bulb is evacuated. The leads were soldered to the bulb electrical contacts to eliminate the possibility of separation due to thermal contraction. The resistance of the bulb filament decreases at low temperature; consequently, a variable resistor was connected in series with the bulb to control its brightness and, thereby, reduce the glare on the metal pump parts. Vapor blasting the test inducer hub and the metal shroud parts reduced the glare and, thus, improved the photographs and television picture.

REFERENCES

1. Lewis, George W., Jr.; Tysl, Edward R.; and Sandercock, Donald M.: Cavitation Performance of an 83° Helical Inducer Operated in Liquid Hydrogen. NASA TM X-419, 1961.

2. DiStefano, J. R.; and Panosian, J. O.: Cavitation Characteristics of Tank Mounted, Centrifugal Type, Cryogenic Pumps. Paper No. 61-AV-43, ASME, Mar. 1961.

3. Wilcox, Ward W.; Meng, Phillip R.; and Davis, Roger L.: Performance of an Inducer-Impeller Combination at or Near Boiling Conditions for Liquid Hydrogen. Advances in Cryogenic Engineering. Vol. 8, K. D. Timmerhaus, ed., Plenum Press, 1963, pp. 446-455.

4. Stahl, H. A.; and Stepanoff, A. J.: Thermodynamic Aspects of Cavitation in Centrifugal Pumps. ASME Trans., vol. 78, Nov. 1956, pp. 1691-1693.

5. Salemann, Victor: Cavitation and NPSH Requirements of Various Liquids. J. Basic Eng., vol. 81, no. 2, June 1959, pp. 167-173.

6. Jacobs, Robert B.; Martin, Kenneth B.; and Hardy, Richard J.: Direct Measurement of Net Positive Suction Head. Rep. No. 5500, National Bureau of Standards, July 18, 1957.

7. Hartmann, Melvin J.; and Ball, Calvin L.: New Problems Encountered with Pumps and Turbines. Proceedings of the NASA-University Conference on the Science and Technology of Space Exploration. NASA SP-11, vol. 2, 1962, pp. 23-35.

8. Ruggeri, Robert S.; and Gelder, Thomas F.: Cavitation and Effective Liquid Tension of Nitrogen in a Tunnel Venturi. NASA TN D-2088, 1964.

9. Gelder, Thomas F.; Ruggeri, Robert S.; and Moore, Royce D.: Cavitation Similarity Considerations Based on Measured Pressure and Temperature Depressions in Cavitated Regions of Freon 114. NASA TN D-3509, 1966.

10. Stepanoff, A. J.: Cavitation Properties of Liquids. J. Eng. Power, vol. 86, no. 2, Apr. 1964, pp. 195-200.

11. Anderson, Douglas A.; Soltis, Richard F.; and Sandercock, Donald M.: Performance of an 84° Flat-Plate Helical Inducer and Comparison with Performance of Similar 78° and 80.6^O Inducers. NASA TN D-2553, 1964.

12. Acosta, A. J.: Experimental Study of Cavitating Inducers. Proceedings of the Second Symposium on Naval Hydrodynamics, Aug. 25-29, 1958. National Academy of Sciences - National Research Council, 1960, pp. 533-557.

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