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EXPERIMENTAL INVESTIGATIONS OF THE INCEPTION OF CAVITATION ON 60° SYMMETRIC WEDGES

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ABSTRACT

The effects of flow velocity and the size of the cavitation source on the inception and desinent cavitation numbers were investigated experimentally. To this end, visual observations of inception and desinent of cavitation on seven 60° symmetric wedges were made with the help of stroposcopic lighting through the prespex side of the tunnel working section. The experiments were conducted in a closed circuit water tunnel at the Faculty of Engineering and Technology Menoufia University, in which the velocity and the pressure can be varied independently.

The results indicated that there was no significant differences between inception and desinent cavitation numbers measurements. During the tests it was observed that one form of cavitation inception was found to occur. This form was travelling bubbles cavitation.

The investigation for all the seven 60° symmetric wedges showed that the inception cavitation number increased as the upstream velocity decreased and as the size of the wedge increased.

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INTRODUCTION:

Since Euler first recognized the possibility of cavitation in 1754, vast numbers of papers concerning cavitation have been published, and its harmful effects are still seen. Cavitation normaly occurs whenever the pressure at a point in a liquid is reduced below its vapour pressure at the corresponding fluid temperature and it is assumed that cavitation bubbles originate as microscopic bubble nuclei, which are widely supposed to exist in all liquids. Intiation of bubbles in this manner in the liquid is usually defined by the term inception.

As is well known, the principal effects of cavitation in hydrodynamic systems are erosion to all materials, loss of performance,change in flow pattern, and vibration and noise. Damage to diesel engine wet cylinder-liners is a relatively new problem caused primarily by vibration [1].

At present it is impossible to find the incipient of cavitation in hydrodynamic systems by theoretical calculation. Moreover, the desginer often lacks specific information on how design changes will affect cavitation behavior of his machine or structure. Increasing size, velocity and/or power loading has on many occasions, resulted in unexpected cavitation problems. This is because there is insufficient information about inception and the factors controlling cavitation available at present to help the hydraulic machine designer. Therefore, the model test becomes very important to predict the cavitation behavior in prototype and has supplied the desinger with useful recommendations which led to a better design.

Because of this situation the present investigation is intended to study the effect of altering the flow velocity and of the size of the cavitation source upon the inception of cavitation.

EXPERIMENTAL PROGRAMME

Apparatus and Cavitation Source:

Experiments were carried out in cavitation research water tunnel at Faculty of Engineering and Technology, Menoufia University, a diagram of which is shown in Fig,1. with a list of the major component and the actual physical details appear in Fig.2. A full description and design of this tunnel are given in El-Danaf [2]. The cavitation tunnel consists of a closed water circuit driven by a 44 KW centrifugal pump with a working section of 40 x 20 mm cross section. The front of the test section is built with a transparent prespex cover to permit visual study. The total length of the test section, over which the flow can be viewed is about 400 mm The rig pressure could be varied independently by an air vessel controller over a range of 0-8 bar. Flowrate through the test section was varied by bypass control to give upstream velocities ranging from 7-24 m/s. The average temperature of the test water was kept within 33 ± 4 °C by cooling coils which were fitted in the down-stream tank and were supplied by water from a laboratory tap. The velocity in the test section was measured using a calibrate electromagnetic flowmeter. The static pressure was measured using a pressure transducer. A thermometer was used to measure the temperature of the water in the downstream tank.

The inception cavitation number, σ_i, was defined in terms of conditions in the upstream as follows:

$$\sigma_i = \frac{P - P_v}{\frac{1}{2} \rho U^2}$$

where P and U are respectively the static pressure and flow velocity at the upstream of the cavitation body, P_v is the vapour pressure at the bulk water temperature. The possible errors in the inception cavitation number and the flow velocity are about ± 3% and ± 2%, respectively.

The effects of velocity and size were investigated for seven 60° symmetric wedges spanning the 20 mm direction of the test section. These wedges were made of copper. The lengths of the wedge side were 12,15,17.5,19,22,24.2 and 27 mm with 20 mm height. The 60° symmetric wedge is similar to the type of cavitation occuring in the flow past a bulf body. The wedges were placed in the working section in two different positions; one with apex upstream and the other with apex downstream as shown in Fig.3.

TESTING PROCEDURE

Cavitation inception and desinent were detected visually under the illumination of stroboscopic lighting. Visual observations of the flow past the test body started from an arbitary pressure in the test section in the range of 0.5-6.5 bar (gauge). The bypass valve was closed gradually so that the flow velocity in the test section could increased step by step until inception of cavitation occurred. Inception refers to the first appearance of a tinny cavitation zone. The measurements of the upstream pressure, flow rate and temperature corresponding to the inception condition were noted. Then the flow velocity was further increased until the cavity length was about four times the size of the test body. Thereafter, flow velocity was reduced in steps by opening the bypass valve gradually until the desinent condition occurred. Desinent means the disappearance of cavitation. The flow conditions corresponding to the desinent condition were recorded. These visual observations of inception and desinent conditions were repeated for many other arbitrary pressures and the coresponding readings were determined. The tunnel was stopped and the cavitation source was taken out from the working section to fix another cavitation source.

EXPERIMENTAL RESULTS

Visual observations of inception and desinent conditions were carried out for seven 60° symmetric wedges. A wide range of velocities was tested to observe the effect upon the inception and desinent cavitation numbers. The upstream flow velocity was varied from 6 to 22 m/s.

Fig.4. shows the exact variations of the inception and desinent cavitation numbers with upstream flow velocity for seven 60° symmetric wedges with apex upstream. In general this figure indicates that the inception and desinent cavitation numbers decrease with upstream flow velocity, for all the sizes. Fig. 5 indicates the variation of the inception and desinent cavitation numbers with flow velocity for the wedges with apex downstream. This figure indicates similar trends to that with apex upstream.

DISCUSION OF THE RESULTS

Difference Between Inception and Desinent Conditions

The cavitation numbers corresponding to the inception and desinent conditions are denoted as σ_i and σ_d, respectively. Figs 4 and 5 indicate the variation of the desinent and inception cavitation numbers with upstream flow velocity for 60° symmetric wedges with apex upstream and apex downstream, respectively. In general these figures show no appreciable differences between inception and desinent conditions. The same trend was reported by Chandrasekhore and Syamala Rao [3] and Hamilton et al [6] noted a slight differences between desinent and inception cavitation numbers with decreasing flow velocity. Billet et al [7] found that this differences increases as velocity and model size decrease; also in the same trend [8], [9] and [10]. Williams [10] reported that the hysteresis effect is due to the change in nuclei content between desinent and inception, though total air content remains constant. Knapp [8] stated that, hysteresis can be considerably increased by lowering the air content.

It is believed that in the present investigation because the velocity is high, no appreciable difference is evident between desinent and inception conditions.

Observed Forms of Incipient Cavitation

Visual observation of cavitation inception occuring by 60° symmetric wedge showed that the physical appearance of cavitation at inception was in the form of a travelling bubbles cavitation. Considerable problems were encountered to achieve clear photographs for inception condition, but Fig. 6 shows two photographs obtained at different velocities.

In all cases bubbles cavitation occurred within the shear layers of the water somewhat downstream of the base corners of the body. (see Fig.6). These bubbles had a milky appearance within the shear zone in the centre of finite vortices. The number of bubbles was observed to increase with an increase in the wedge size. Moreover, no bubbles were observed in a deadwater region behind the wedge. The same type of cavitation was observed by Holl and Corrol [11] on a hemispherical nose body, Kermeen and Parkin [12] on a disk, Arakeri and Ramarajan [13] on a backward facing step and Meulen [14] on NACA 16-012 hydrofoil.

In the present experiments for the 12 and 15 mm 60° symmetric wedges with apex downstream, it was observed that the appearance of cavitation bubbles was quite close to the surface of the wege slightly downstream of the sharp corners. For large sizes the appearance of cavitation was still in the form of bubbles but they appeared in the free shear layer away from the solid surfaces of the wedge. Arakeri and Romarajan [13] observed the same trends for backward facing step.

Effects of Flow Velocity

The variation of inception cavitation number with velocity for 60° symmetric wedges is shown in figures 4 and 5 with apex upstream and with apex downstream, respectively. These figures indicate that the inception cavitation number decreases with an increase in the upstream flow velocity. The same trend was reported by Kodma [16] using axisymmetric bodies in the velocity ranged from 6 to 15 m/s, and by Billet and Holl [17] on the pressure surface of 38.1 mm Joukowski hydrofoil. However they found that cavitation inception number increases with increasing velocity on the suction surface of the same hydrofoil which is somewhat contrary to the trend reported herein. Holl and Carroll [11] indicated that inception cavitation number tends to decrease with velocity using Hemispherical; Schiebe and DTNSRDC noses in the velocity range of 6.1 to 15.2 m/s. This trend is confirmed by Meulen [14] using Schiebe nose body.

Flow velocity affects both the local pressure difference generated by vortices and the strength and number of vortices generated in the shear layer of the flow. Also the flow velocity affects the level of turbulence. The inception of cavitation in the shear layer is a result of the local under pressure existing in small turbulent vortices created by the high-shear region around the submerged get discharging from sharp-edged of the wedge.

With increasing velocity, the flow field behind the wedge will be varied, as the wake region reduced. In sequance the microvortices which shedding into the wake, will diminshing according to turbulent pressure fluctuation in free shear layer, thes microvortices when lie in the region of minimum pressure (critical pressure) should be growth. Thus the nuclei size distribution and their response affected by the unsteady pressure. Negative pressure peaks that induce cavitation should have a statical occurrence that is relatively high, and a duration that is comparable to the natural period of the nuclei for cavitation to occur at a local pressure approaching the vapour pressure. If all the energy in the pressure field has a frequency content much higher than the natural frequency of the nuclei, there would be a lowering of inception cavitation number.

Separated flows have very long time of exposure of bubbles to under pressure and tend to entrain nuclei within their low pressure core where gaseous cavitation occur. Typically the inception cavitation number may be written in the form [15].

$$\sigma_i = - C_{pm} + (P_g/\tfrac{1}{2} \rho\ U^2)$$

where $P_g = B\ K \alpha$ and α , B and K are the dissolved gas content; Henery's law constant and an emprical adjustment factor, respectively. The previous equation predicts that inception cavitation number is monotonically decreasing function of velocity for constant values of P_g and C_{pm}. Also the equation predicts excessively large value of inception cavitation number at low velocities.

Effects of Size and Wedge Position

Size scale is of interest for scaling from models to prototype as well as in understanding the phototype as well as in understanding the phonomenon of cavitation inception.

Figure 7 and 8 show the variation of inception cavitation number with the tunnel blockage ratio or body size at different flow velocities for 60° symmetric wedges with apex upstream and with apex downstream, respectively. The general trend of these figures is that the inception cavitation number increases considerably with increasing the blockage ratio up to 0.3, increases at a low rate up to 0.6 with apex upstream and 0.5 with apex downstream and then increases rapidly. However, these figures show that for lower values of blockage ratio some scatter in the results was observed and may attributed to non-geometric similarity due to machining errors and differences in surface finish. The same trend of increasing inception cavitation number with size shown by Figs. 7 and 8 was reported by [3], [12],[17] and [18]. However, Kermeen et al [12] reported that the inception cavitation number decreases with increasing the size of Joukowski hydrofoils, this trend is somewhat contrary to the trend reported herein.

The reason for increasing inception cavitation number with increasing body size can be attributed to the following. Since an increase of body size will increase the minimum pressure region within the shear layer of the water, the expected inception cavitation number will be greater due to the increase in the time available for growth of the nuclues from its initial size to a macroscopic size. For a given upstream flow velocity, the static pressure at the vena contractar of the flow decreases with increasing the blockage ratio (blockage ratio is the ratio between the body size (B) to the tunnel width (w)), it is obvious that the inception cavitation number should be increased with size. Moreover, the change in body size may influence the spectrum of the free stream nuclei and the turbulent pressure fields. Arndt [19] stated that as the scale of flow increase, cavitation nuclei are relatively more responsive to a wider range of pressure fluctuations and that large deviations from the mean pressure are more probable with increasing size. This would explain the observed increases in inception cavitation number with physical scale.

From figure 9 it is possible to compare the value of the inception cavitation number produced by wedges with apex upstream and with apex downstream operating at the same upstream flow velocity and source size. A comparison of inception carviation number reveals that the magnitude of ${}_i$ for wedge with apex downstream is greater than of that with apex upstream. The differences in the magnitudes should be attributed to the variation of many factors such as the length of the minimum pressure region, the magnitude of the critical pressure and the type of flow regime. Young and Holl [20] reported that the inception cavitation number increases with an increase of wedge angle, this to some extent confirms the present trend for 60° symmetric wedges in case of apex upstream and apex downstream.

CONCLUSIONS

The important conclusions which can be drawn from the forgoing investigations are:

1. There is no significant differences between the inception and desinent cavitation numbers.

2. One type of cavitation inception was observed on 60° symmetric wedge test bodies. This type was a travelling

bubble cavitation occurred with the shear layers of the water.

3. The results showed that the inception cavitation number decreased as the flow velocity increased and as the size of the wedge decreased.

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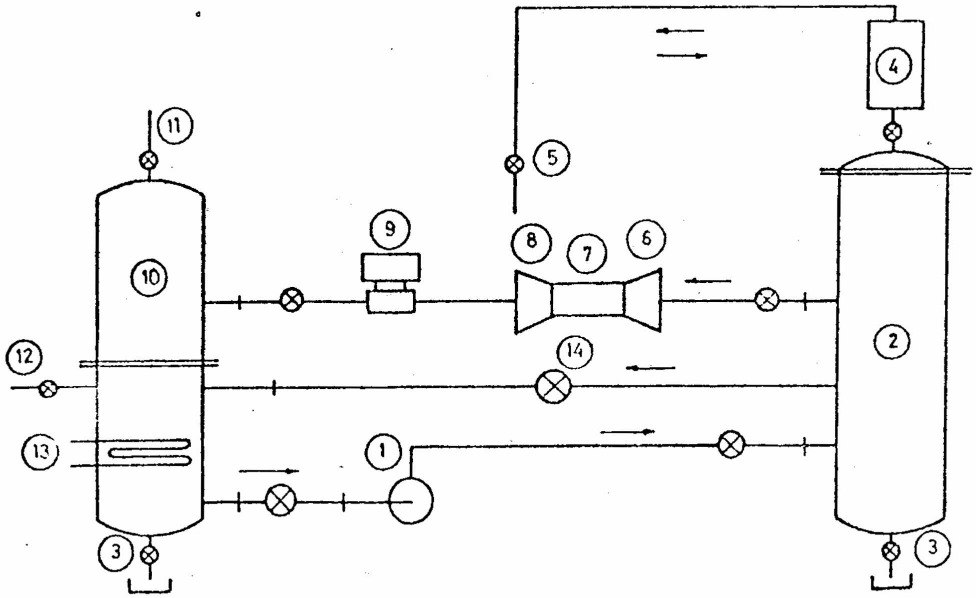


① Centrifugal pump
③ Drain
⑤ Compressed air supply
⑦ Test section 20x40 mm
⑨ Electromagnetic flow meter
⑪ Air vent
⑬ Cooling coil

② Upstream tank
④ Air vessel
⑥ Contraction nozzle
⑧ Diffuser section
⑩ Downstream tank
⑫ Water supply
⑭ Bypass line

Fig. 1: Cavitation research water tunnel line diagram and a list of its major components .

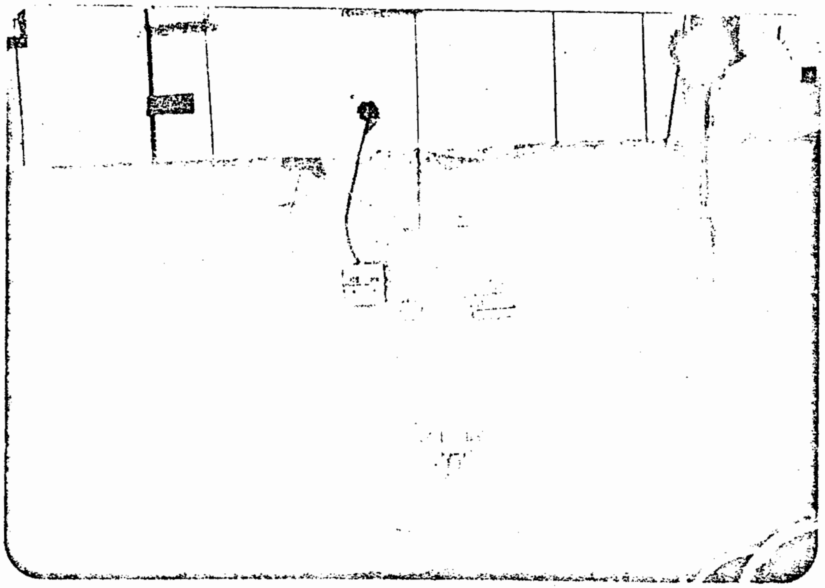
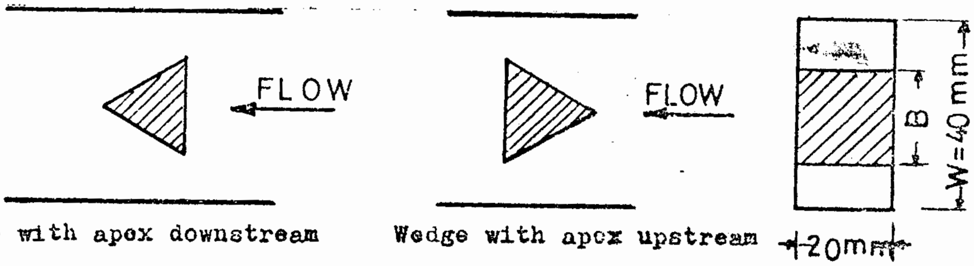


Fig. 2: General view of the water tunnel.



Wedge with apex downstream

Wedge with apex upstream

Position of the wedge in the test section.

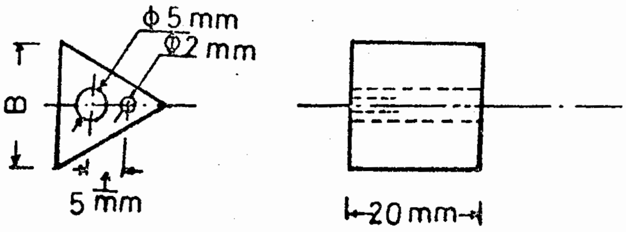
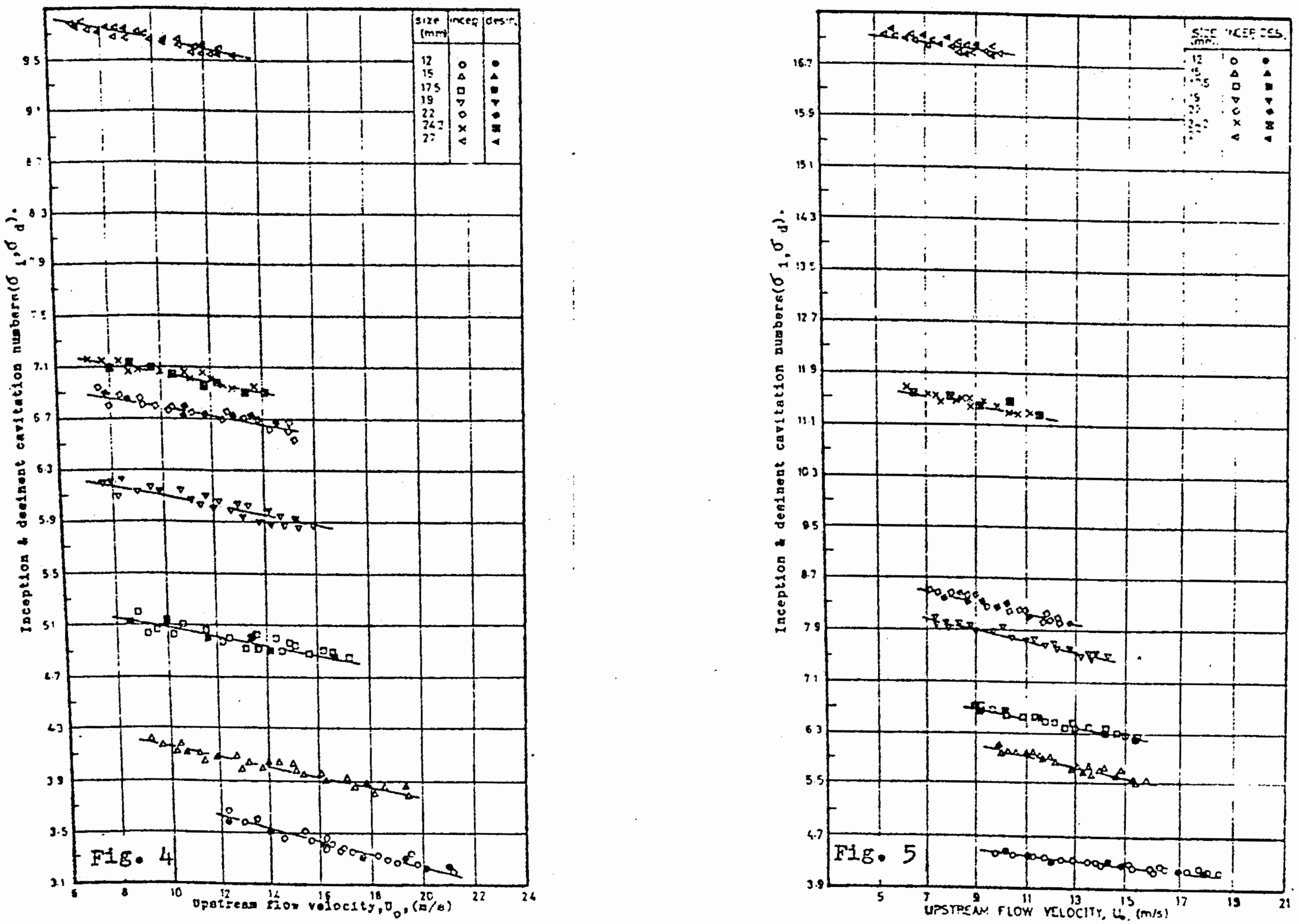


Fig. 3: Details of the 60° symmetric wedge test body and its position in the test section.



Figs. 4 and 5: Variation of inception and desinent cavitation numbers with upstream flow velocity for 60° symmetric wedges with apex upstream(Fig 4) and with apex downstream(Fig 5).

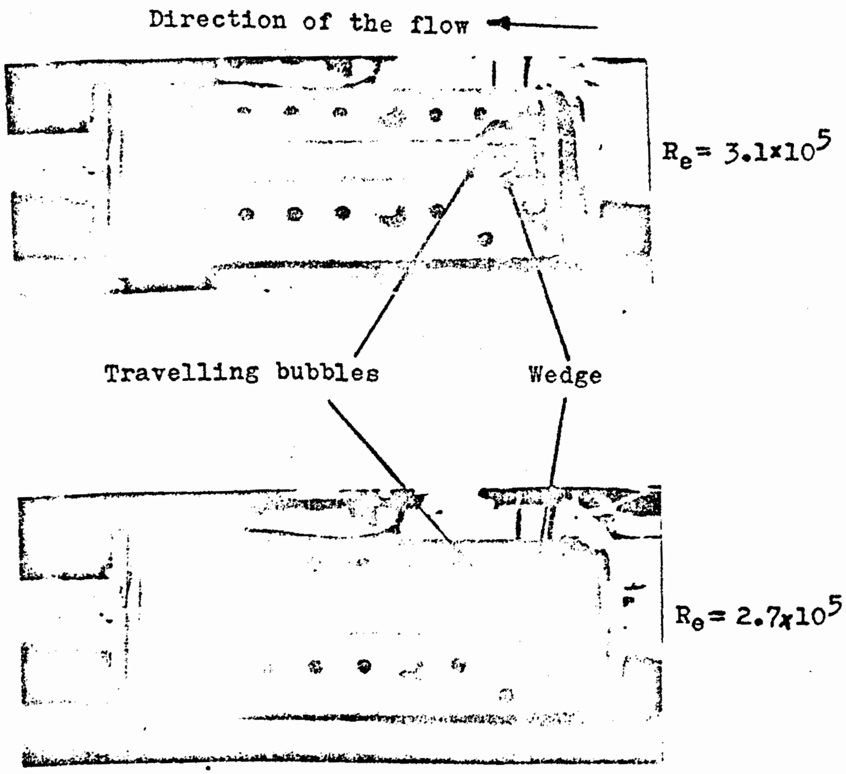


Fig.6: Form of cavitation inception produced by 60° symmetric wedge with apex upstream.

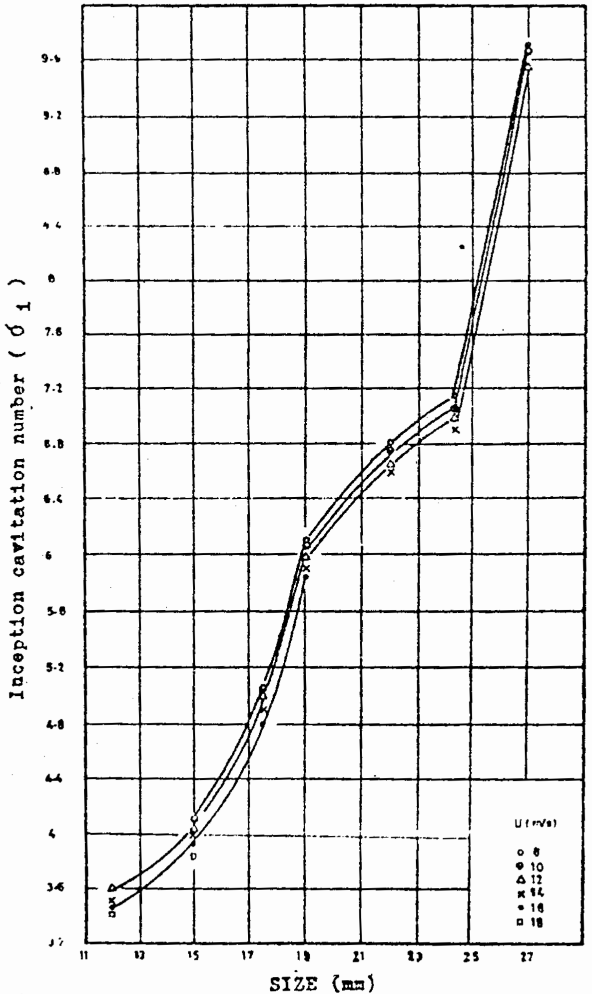


Fig. 7: Effect of size on inception cavitation number at different upstream flow velocities for 60° symmetric wedges with apex upstream.

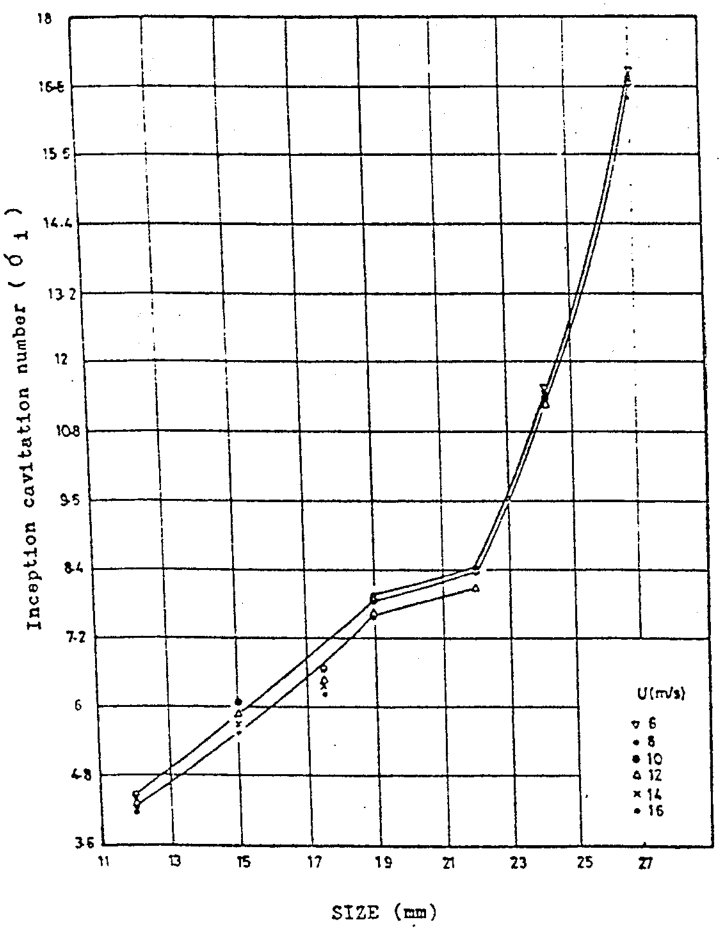


Fig. 8: Effect of size on inception cavitation number at different upstream flow velocities for 60° symmetric wedge with apex downstream.

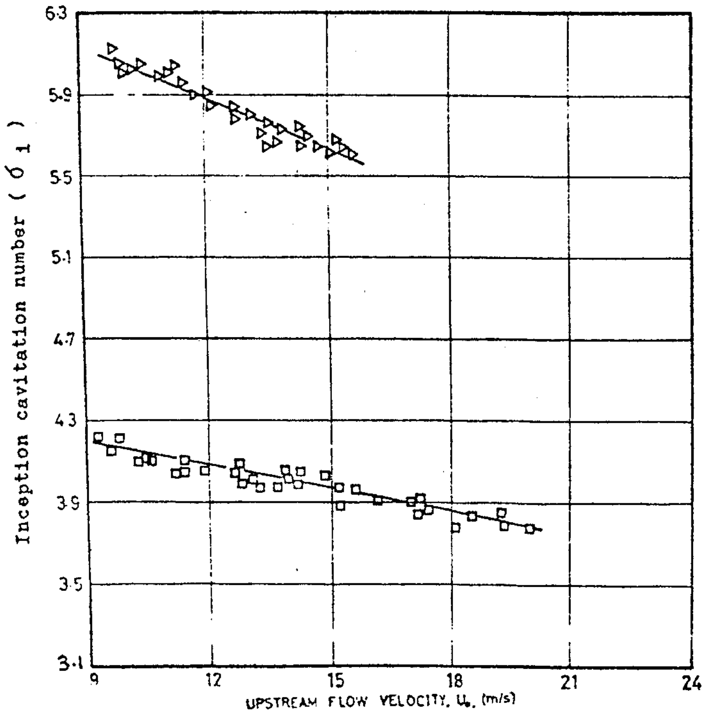


Fig. 9: Comparison of inception cavitation numbers between wedge with apex upstream(□)and wedge with apex downstream(▷) at fixed wedge size of 15 mm and different upstream flow velocities.