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Pressure distribution phenomena over a wedge and sphere surface in uniform flow

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ABSTRACT: In this paper, experimentally the pressure distribution over wedge and sphere surface in uniform flow has been investigated. Fluid flow over a smooth wedge surface was investigated experimentally to determine the pressure distribution at different values of Reynolds numbers and wedge angles as well as pressure distributions around the sphere of different size are reported for different Reynolds numbers. The variation of static pressures is larger near the wedge vertex and gradually decreases along the length of the wedge surface. At the forward stagnation point the pressure distribution depends on the size of spheres. Separation of flow takes place at an angle of 78° from forward stagnation point for all sizes of spheres. At the rear stagnation point of the sphere the pressure distribution predicts negative pressures. Experimental results provide useful information of interest to potential industrial application. It helps in determining the shape of various wedge and sphere surfaces used in industries for cooling or heating of different wedge surfaces. In the present experiment, it has been found that the pressure near vertex lower as the included angle of the wedge decreases and at lower values of Reynolds number.

Keywords: *Pressure distribution, uniform flow, wedge shape, sphere shape, reynolds number*

INTRODUCTION

The fluid flow characteristics on various bodies are encountered in many environmental and engineering situations, it is very important to know the nature of the distribution of pressure over those bodies. The shape of the sphere and flow characteristics around it was of primary importance for the determination of skin friction and heat transfer characteristics. In industry it is required to cool or heat the wedge and sphere surface. It is an interesting external type flow problem involving complex laminar free share. As such, the nature of flow of a real fluid is complex and not always subject to exact mathematical analysis. Several problems involving the flow of fluid around submerged objects are experienced in the various engineering grounds. Such problems may have a fluid flowing around either a stationary submerged object or an object moving through a large mass of stationary fluid or both the object and the fluid may be in motion. The highest pressure is obtained at the frontal stagnation point and the rear stagnation point and the lowest pressure at right angles to the direction of flow. Due to lack of sufficient knowledge about the flow characteristics over a wedge surface, required performance was not achieved. In practice, it is necessary to investigate the flow fluid over a body having a wedge shape. Experimental investigation is carried out for the distribution of pressure on the wedge surface for different included angles and different Reynolds numbers. Experimental investigation of fluid flow characteristics on smooth wedge surfaces, already been started long ago. Recently, fluid flow over smooth wedge and sphere surfaces has attracted considerable attentions to the researches. Many investigators have observed that the pressure near the vertex lowers on the wedge surface as the included angle a decreases. Yamada, *et al.*(1990) investigated the impingement of

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two dimensional turbulent jet on wedge surface. The wedge-included angles were 60° and 90° and Reynolds number was 2.2x 10^4. It is observed that the production, diffusion, dissipation, and convection are higher than the two-dimensional wall jet except advection term. The mean flow properties of this flow field and the turbulence properties were also investigated by Yamada, *et al.*(1985 and 1988). Experiments on the turbulence properties of a two-dimensional wall jet were performed by Kobayashi and Fujisawa (1982). Sparrow and Lovell (1980) have investigated the heat transfer characteristics from an included surface by impingement of circular air jet. The value of maximum heat transfer coefficient decreases with the increase of inclination angle within 15% to 20% range. The surface average heat transfer coefficient was found not to be highly sensitive to inclination. Chu and Chow (1997), have numerically investigated the jet–plate interaction by hodograph transformation and obtained well agreement with the result of momentum equation. They obtained the pressure coefficient for arbitrary shaped wedge surfaces. Many investigators was interested for long time about fluid flow over a sphere, but recently Morshed and Faruque (1997), have carried out an research on this problem involving complex turbulent free shear. They have investigated pressure distribution at different Reynolds number 1.837 x 10^5, 2.088 x 10^5 and 2.3390 x 10^5. They observed that the separation of the boundary layer occurs at 1.57 radians. The co-efficient of pressure is maximum at the forward stagnation point and minimum at the point of the separation. Alam and Faruque (1998) have investigated the effects of Reynolds number and diameters of sphere on drag and pressure co-efficient ($C_p = \frac{\Delta P}{\frac{1}{2}\rho V_\infty^2}$).

The slope of the pressure co-efficient is obtained steeper near stagnation point and maximum value of the pressure co-efficient at stagnation point. The objectives of this investigation were to study the effect of wedge angle (α) and Reynolds number on distribution of pressure along the wedge surface. The pressure distributions on the sphere of various diameters at different angular locations and at various Reynolds numbers were investigated in the present analysis.

MATERIALS AND METHODS

Wooden wedges of length 350 mm and width 30 mm of included angles 50°, 80°, 90° and 110° have been chosen for the experimental study. The wedge surface is drilled by 1.5 mm drill starting from vertex and 4 mm apart. The wedge surface is well finished so that disturbance of flow remains lowest. The wedge surface is placed in the test section of a sub-sonic wind tunnel as shown in the Fig. 1. Wooden sphere of 76.2 mm, 114.3 mm and 152.4 mm diameters are used in the setup. On the sphere's surface 31 holes of 2 mm diameter are drilled in radial at various angles. Copper tubes of 2 mm outside diameter and 25 mm length are fitted in these holes. These tapings are connected to an inclined manometer for the measurement of wall static pressure distribution. There is a provision of holding pitot tube for the measurement of free stream velocity. A speed regulator controls the flow rate.

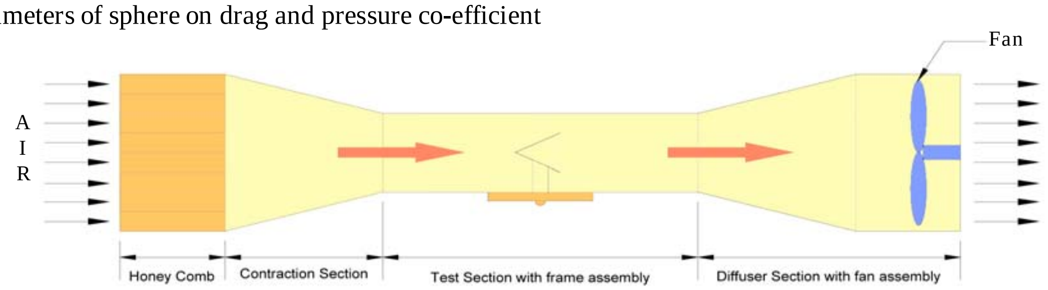

Fig. 1: Experimental setup for wedge surface

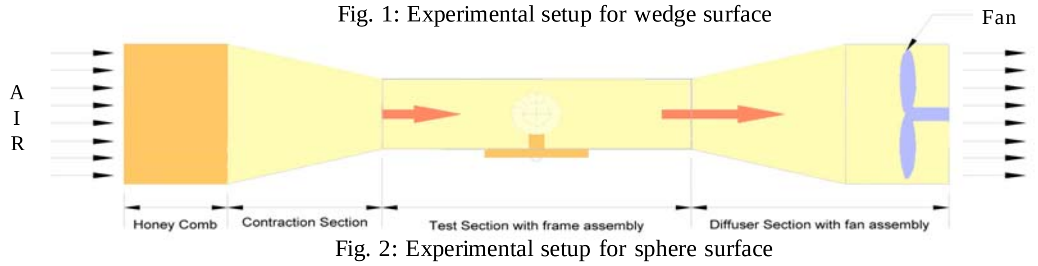

Fig. 2: Experimental setup for sphere surface

The wooden sphere is placed in the test section of a sub-sonic wind tunnel as shown in the Fig. 2. The induced type sub-sonic wind tunnel is connected to AC supply. The centerline velocity of air was measured by a pitot tube for a particular setting and Reynolds number; Re is calculated at this velocity. The wedge surface is placed at test section. The flexible manometer tubes are then inserted in the drilled hole of the wedge surface. An inclined manometer shows the pressure on the wedge surface at different locations. The ambient temperature is recorded for determining the kinematics viscosity of flowing air. Such a way, the procedure is repeated for different Reynolds number and different wedge angles. Pressure at the test section wall is considered as the reference pressure and pressure difference is calculated as $\Delta P = P - P_{WALL.}$

At different Reynolds numbers pressure distribution on the sphere is measured with the help of an inclined manometer. The sphere is fixed on the stand and the alignment of the stagnation point with the free stream velocity is confirmed and during the experiment from the fact that the stagnation point shows maximum pressure. The flow rate of air is controlled to a desired value and wall static pressure at different angular locations and measured by inclined manometer. The whole experiment has been carried out in a subsonic wind tunnel. All the works were done throughout the period 2002 to 2005 in Bangladesh Atomic Energy Commission.

RESULTS

Figs. 3 and 4 show the variation of static pressure distribution on the wedge surface at an included angle 50° and 80° respectively. It is observed that the co-efficient of pressure Cp decreases with X as well as decreases with the decrease Reynolds number. At the stagnation point the values of Cp increases with the increase of Reynolds number. The pressure decreases sharply within short distance from the vertex and remains more or less constant for the rest of the length of the wedge surface.

Figs. 5 and 6 show the distribution of pressure co-efficient at an wedge included α = 90° and 110.The value of co-efficient of pressure Cp for Re = 7635, becomes zero at X = 0.9 but for other Reynolds number there is distinguishable difference is observed. All the cases co-efficient of pressure drops very short axial distance along the length of the wedge surface and remains constant for the rest of the length of the wedge surface.

Well agreement is observed with the results of Yamada *et al.* (1990). Fig. 7, shows the variation of co-efficient of pressure along the length of the wedge surface for Reynolds number, Re = 22621 at different wedge included angles. It is observed that the co-efficient of pressure increases with the increase of wedge included angle. The stagnation point pressure does not affected greatly at higher wedge included angle than α= 50°.The co-efficient of pressure decreases sharply within short distances along the length of the wedge surface and remains constant throughout the rest length of the wedge surface.

Fig. 8 shows the pressure distribution on the sphere of different diameters at Re = 1.0764×10^5. The static pressure at the forward stagnation point for the sphere of diameter D = 76.2 mm shows higher value compare to static pressure of other diameters. The value of static pressure at that point is -0.0251. The static pressure curve after = 66 decreases sharply and predicts maximum negative value at θ = 78°.

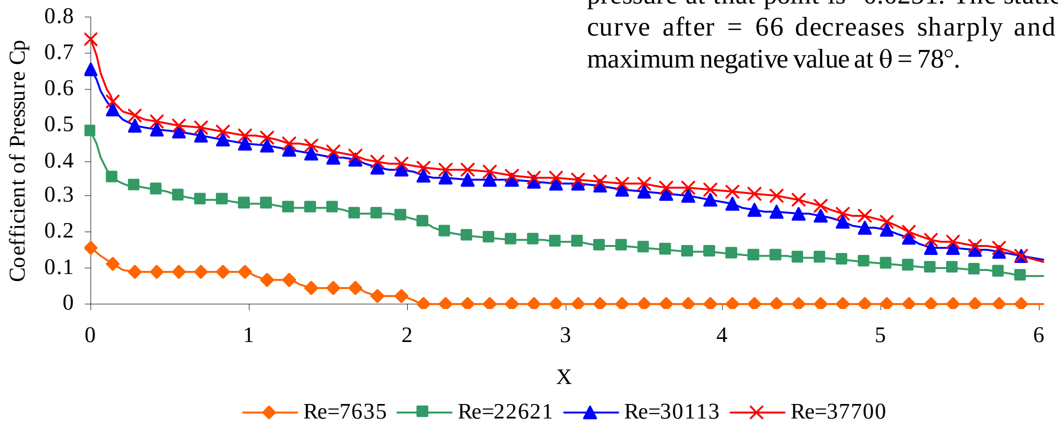

Fig. 3: Pressure distribution at wedge include an α = 50° at different Re

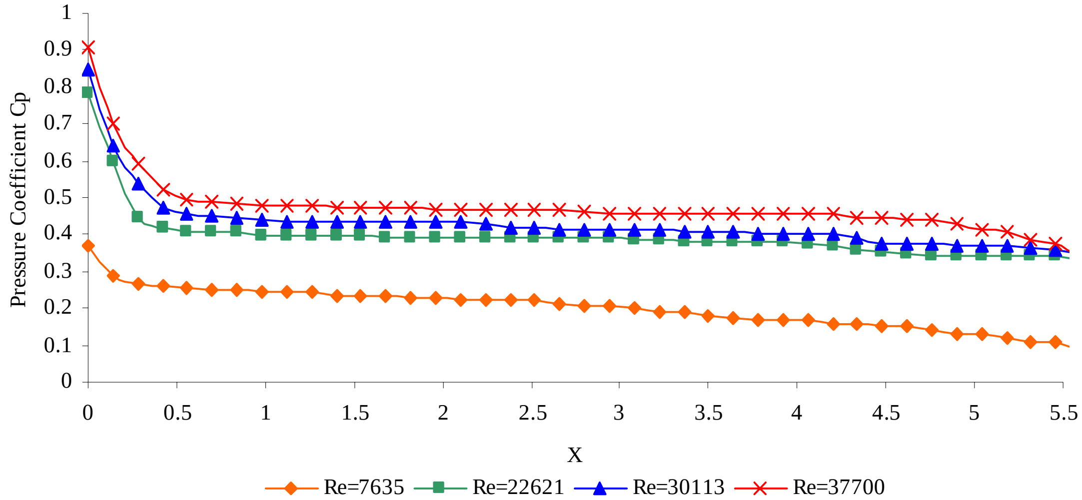

Fig. 4: Pressure distribution at wedge include an a = 80° at different Re

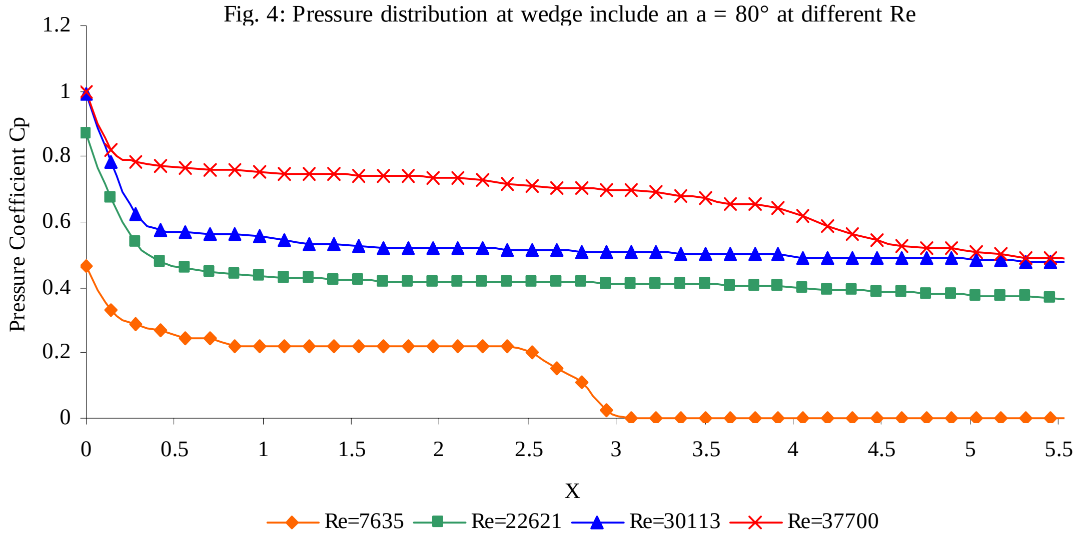

Fig. 5: Pressure distribution at wedge include an α = 90° at different Re

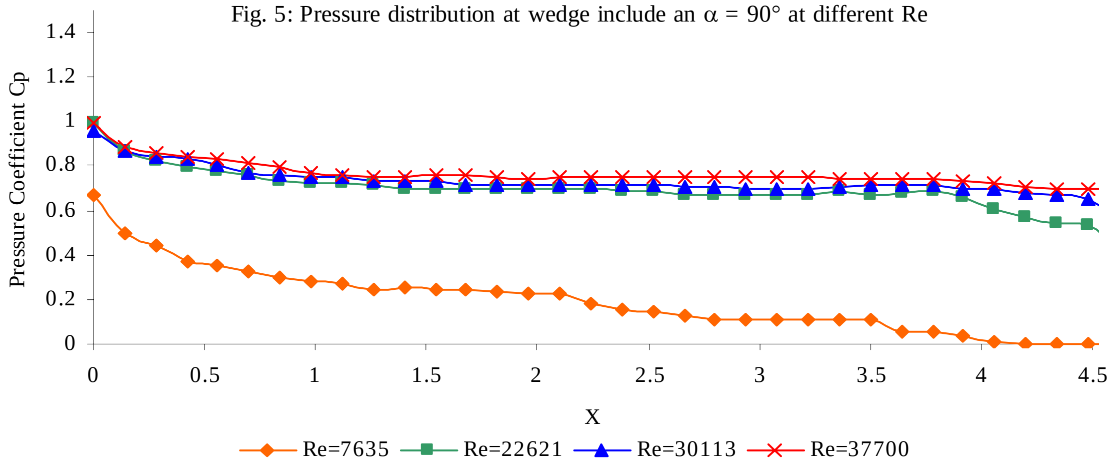

Fig. 6: Pressure Distribution at wedge include an a = 110° at different Re

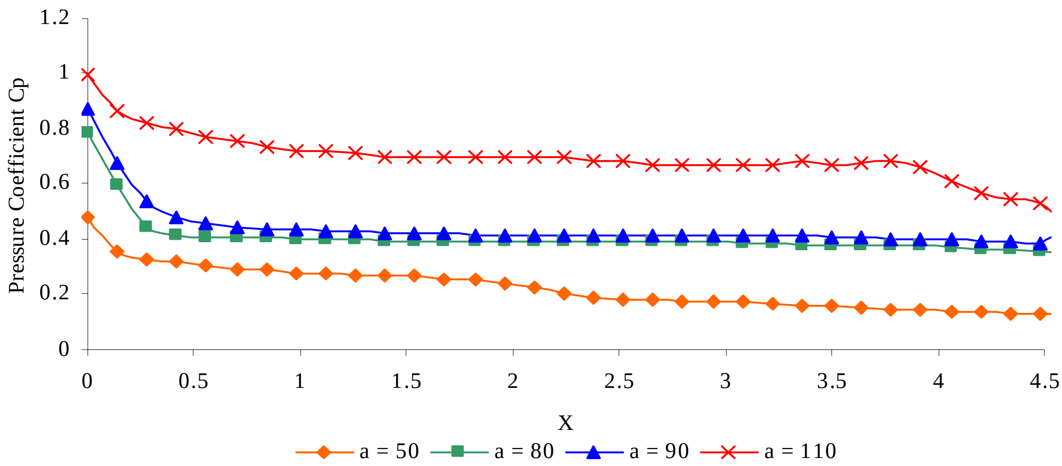

Fig. 7: Pressure distribution at different wedge included angle at Re = 22621

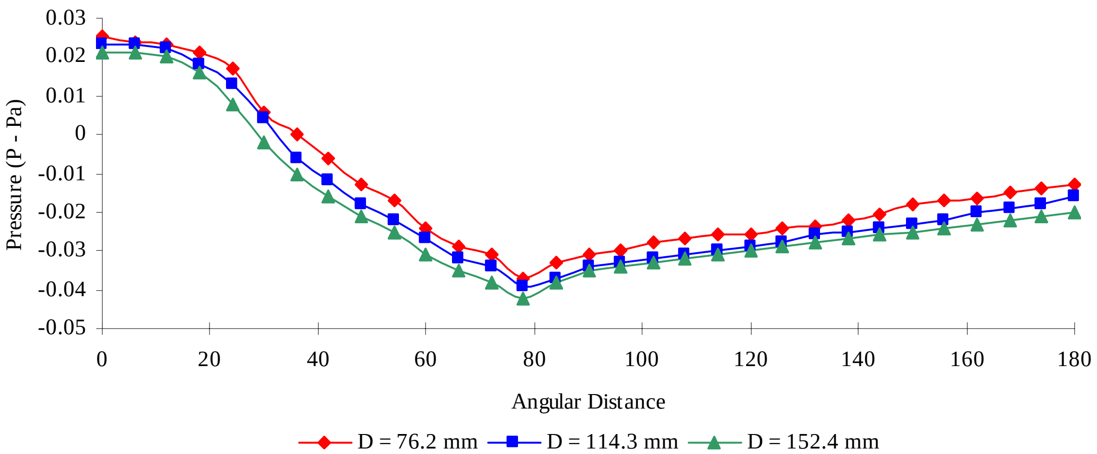

Fig. 8: Pressure distribution around a sphere at Re = 10764

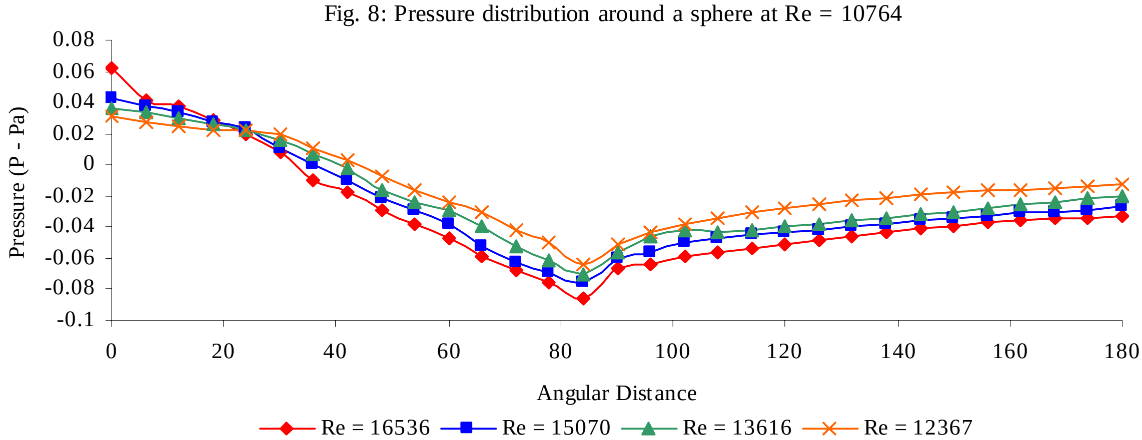

Fig. 9: Pressure distribution around a sphere, diameter 114.5 mm

Beyond $\theta = 78°$ the static pressure curve remains almost constant up to rear stagnation point but predicts higher negative value for larger diameter of sphere. In all the cases, the negative pressure is maximum at an angle of 78° from forward stagnation point. The pressure distribution more or less follows the third degree polynomials as shown below,

$$P - P_a = 0.0318 - 0.0015\,\theta + 1.0\text{x}10^{-05}\,\theta^2 - 3.0\text{x}10^{-08}\,\theta^3$$

Fig. 9 shows the pressure distribution around a sphere of diameter 114.5 mm at various Reynolds numbers ranging from 1.0764×10^4 to 1.6536×10^4. Pressure at the stagnation point increases with Reynolds numbers. Maximum negative pressure is observed at higher Reynolds number and after peak value; the pressure distribution remains more or less uniform up to rear stagnation point for all the Reynolds numbers. For all the Reynolds numbers the maximum peak value is observed at angular location of 84°.

DISCUSSION AND CONCLUSION

The experiments were carried out for pressure distribution on smooth wooden wedge surface in a sub-sonic induced type wind tunnel. From the experiment results the following conclusions may be drawn,

1. The co-efficient of pressure increases with the increase of Reynolds number Re and wedge included angle α. 2. The pressure at the vertex of the wedge surfaces increases as the included angle α increases and a distinguishable difference is observed for the wedge included angle $\alpha = 50°$. 3. Pressure distribution depends on sphere diameters and separation takes place at $\theta = 78°$. Third degree polynomials can predict the pressure distribution around the sphere. 4. Pressure distribution depends on Reynolds numbers and size of sphere.

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