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Asst. Prof. Dr. Sutthiphong Srigrarom
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Self-excited Oscillation of Equilateral Triangular Wedge

Sutthiphong Srigrarom
School of Mechanical and Production Engineering
Nanyang Technological University, Singapore

ABSTRACT

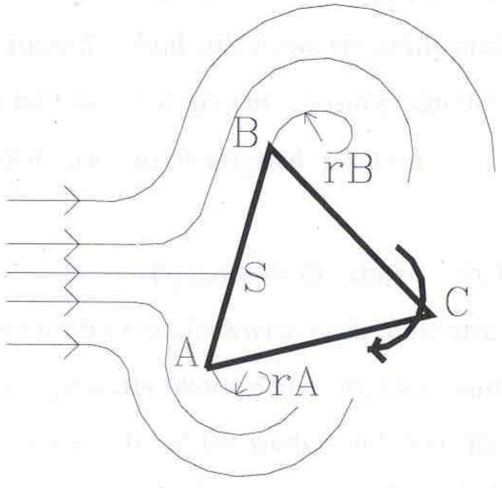
This paper investigates the characteristics of a particular fluid-structure interaction phenomenon, i.e. the continuous oscillation of an equilateral triangular wedge in the uniform incoming flow in the water tunnel. We propose the explanation of this self-excited oscillation. It is the unbalance force acting on the wedge's side faces that causes such movement. If the wedge is positioned initially asymmetrically against the freestream, on one side, the flow will be flow-past-flat-plate like, whereas the other side will be flow-past-sharp-edge like. Due to the unbalanced pressure exerting on the two sides, the wedge will rotate. When the wedge moves, these mechanisms switch side interchangeably, and bring the wedge to continuous oscillation. To understand more thoroughly, the simple wedge's dynamic behavior is examined, by considering incoming flow's hydrodynamic force acting on the wedge. Preliminary analysis indicates that the wedge could oscillate incessantly by initial positional perturbation or incoming flow fluctuation. Accompanied with, several experiments were conducted to investigate such behavior by means of Food coloring dye and Laser Induced Fluorescence flow visualization. The oscillating frequency is governed by Strouhal numbers, which appears within limited range of $0.12 < Str < 0.18$. Beyond this range, the wedge is either stationary or rotates only in one direction. Comparison with the results from the conventional vortex shedding behind the circular cylinder shows that the current self-excited oscillation of the triangular wedge is the unique phenomenon.

PROPOSED OSCILLATION MODEL

In the following figure 1, we consider the flow pattern around an equilateral triangular wedge, of which the front face *AB* inclines, making an angle with the freestream. The flow separates at both *A* and *B*, and the pattern is asymmetrical. The radius of curvature of the streamline separated at *A*, r_A, is smaller than the radius of curvature at *B*, r_B. As a result of conservation of angular momentum, the velocity at *A* is higher than at *B*; therefore, the pressure at *A* is lower than at *B* ($P_A < P_B$). The wedge rotates clockwise about the pivot, and the frontal surface *AB* becomes more inclined to the freestream.

Due to the continuing turning, the triangle is now is a position where *AC* is parallel to the freestream. The flow still separates at the upper tip of the wedge (*B*), but the flow in the lower part, after turning parallel to the front face, separates only slightly at the lower tip of the wedge (*A*), then reattaches to the lower lateral face (*AC*). The lower flow, then, changes behaviour to that of a flat-plate-like flow.

By virtue of the obvious difference between the two flow patterns, the local pressures differ at the upper and lower parts of the wedge. The upper part, with the existence of a large eddy, has lower pressure, especially at the core of the eddy, compared with the freestream; whereas at the lower part the pressure is equal to the freestream pressure, since the fluid still flows smoothly and parallel there. Therefore, the flow in the lower part now has greater pressure than the upper part, ($P_A > P_B$) and the wedge tends to rotate back to its original position.



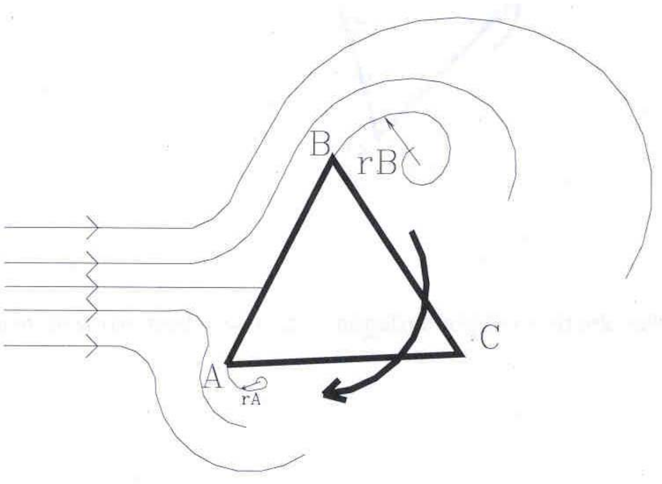
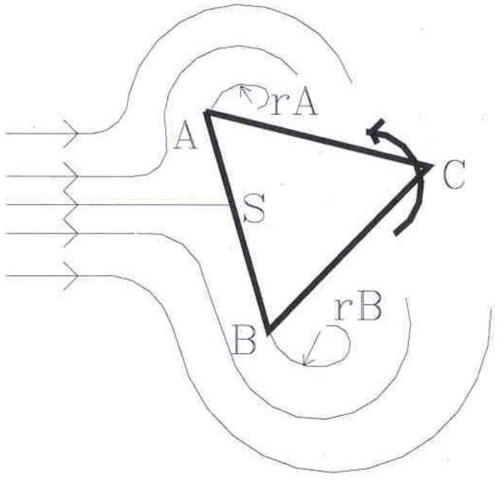


Fig. 1 (left): Flow past the equilateral triangular wedge at positive angle of attack.
Fig. 2 (right): Flow past the equilateral triangular wedge at positive angle of attack (continued).

As a consequence of the above step, the unbalanced pressure forces the wedge to rotate counterclockwise back to its original position (under the assumption that the wedge starts rotating in a clockwise direction, as described in the previous step). Due to the inertia of the wedge and flow, the motion of the wedge does not stop when it returns to the symmetric position (*AB* lies perpendicular to the freestream). Instead, the wedge continues to swing in the counterclockwise rotation. As a result, the flow pattern becomes as shown in figures 3 and 4, which correspond to those of figures 1 and 2 flipped upward.



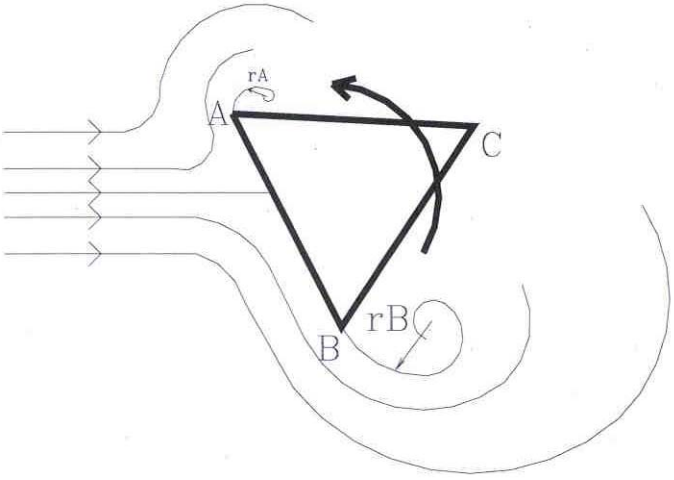
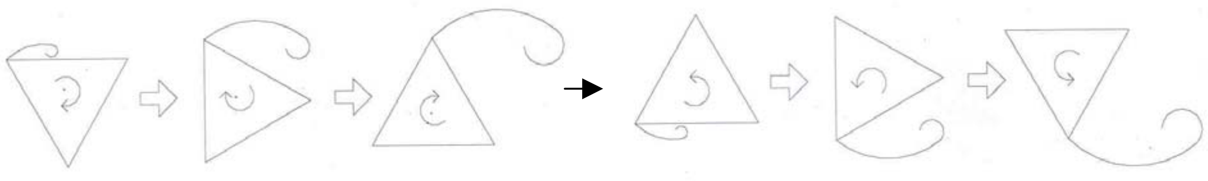


Fig. 3 (left): Flow past the equilateral triangular wedge at negative angle of attack.
Fig. 4 (right): Flow past the equilateral triangular wedge at negative angle of attack (continued).

The overall phenomenon can be viewed as the interchange of the flow patterns, from the flow past the sharp edge to flow over the flat plate, and vice versa, as shown in figure 5.



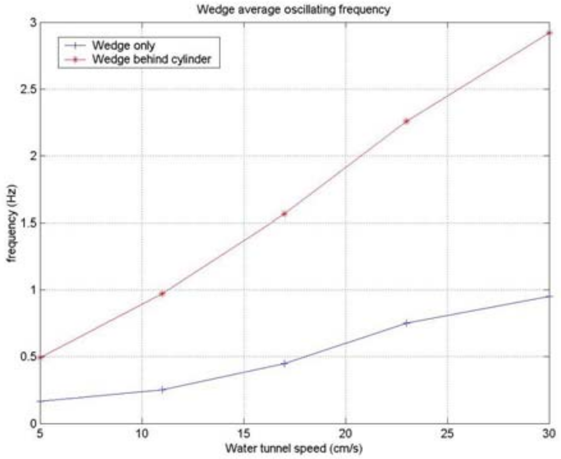
Wedge in clockwise direction

Wedge in counterclockwise direction

Fig. 5: The oscillating motion of the wedge continues with interchanging flow patterns.

EXPERIMENTAL RESULTS

From the experiments, the wedge started to oscillate by some initial perturbation, then kept oscillating forever. Under uniform incoming flow condition, the wedge oscillates within a specific range of Strouhal number (defined as: $Str \equiv fW/U_\infty$) of $0.12 < Str < 0.18$. This does not include the rotation of the wedge, which would occur when the freestream velocity exceeds upper limit, marked by lower Strouhal number of 0.12. The observed wedge's oscillating frequency (f) is in order of 1 Hz as is shown in figure 6 below. Here we consider the smallest tested wedge of which $d = 5$ inch and has the least polar moment of inertia (J), and hence, can start oscillating with minimum freestream velocity. The wedge starts vibrating at about 5 cm/s freestream velocity. The non-dimensionalized parameters (Strouhal and Reynolds' numbers) plot is shown in the following figure 7.



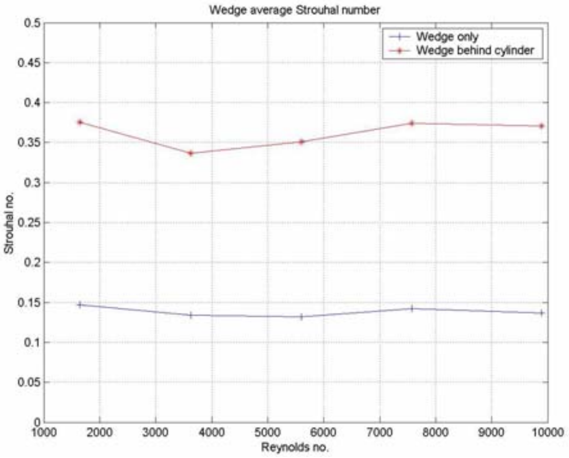


Fig. 6 (left): Wedge average oscillating frequency, both wedge only and wedge behind circular cylinder, for direct comparison between current self-excited oscillation of the equilateral triangular wedge and typical vortex shedding phenomenon behind a circular cylinder $(0.3 < Str < 0.4)$.

Fig. 7 (right): Wedge average Strouhal number, both wedge only and wedge behind circular cylinder.

In figure 7, for the wedge only, Strouhal number is obviously appeared to be constant at $Str \sim 0.14$, in considerable range of Reynolds number. We consider this is the natural oscillation of the wedge. In both figures 6 and 7, the results from the conventional vortex shedding behind the circular cylinder are also presented. This shows that the current self-excited oscillation of the equilateral triangular wedge is the unique phenomenon.