Effects of Splitter Plates on the Wake Flow Behind a Bluff Body

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The effects of splitter plates on the wake behind a two-dimensional bluff body with fixed separation points has been experimentally studied for low Reynolds numbers between 0.35×10^3 and 1.15×10^3. A rectangular cylinder was chosen as a bluff body to have the location of the separation points fixed independent of the flow situation and the air velocity. Three sizes of splitter plates were used; these plates were mounted in the center plane of the cylinder at various distances downstream of the cylinder. Detailed measurements of shedding frequency, base pressure, coherence function, and correlation coefficient were obtained. The results indicate that splitter plates alter the manner of vortex formation in the wake causing a decrease in shedding frequency, an increase in base pressure, and a reduction in the overall drag by up to 50%. The effects of splitter plates on the wake-flow characteristics are discussed.

Nomenclature

Cc	= correlation coefficient = $\overline{U1'*U2'}/\overline{U1'^2}$
Cd	= drag coefficient = $D/(1/2.\rho Uo^2 d)$
Cpb	= base pressure coefficient = $(Pb - Ps)/(1/2.\rho U_0^2)$
d	= diameter of the cylinder
D	= drag per unit length of the cylinder
g	= gap between the cylinder and splitter plate
l	= length of splitter plate
N	= shedding frequency
Pb	= base pressure
Ps	= static pressure in the freestream
Re	= Reynolds number Uod/ν
Sd	= Strouhal number Nd/Uo
U	= axial velocity
Uo	= freestream velocity
U'	= fluctuating component of axial velocity
w	= width of the cylinder
x	= axial coordinate
y	= traverse coordinate
z	= normal coordinate
ν	= kinematic viscosity of the fluid
ρ	= fluid density

I. Introduction

A NUMBER of experimental studies have shown that the characteristics of the wake downstream of a circular cylinder can be considerably altered by placing a splitter plate on the wake centerline downstream of the cylinder. Roshko[1-6] was the first to study the effect of splitter plates on the wake of a circular cylinder. For a Reynolds number of 1.45×10^4, he found that a splitter plate of length $5d$ in contact with the cylinder inhibited the periodic vortex shedding and caused the pressure drag experienced by the cylinder to be reduced to approximately 64% of the value for the cylinder alone. A splitter plate of length $1d$ in contact with the cylinder did not inhibit the vortex formation, but it caused approximately 20% reduction in shedding frequency and approximately 35% increase in the base pressure as compared with the values for the cylinder alone. Grove et al.[7] investigated the steady separated flow past a circular cylinder with splitter plates $2d$ to $4d$ long in the Reynolds number range of 25 to 300. They found that the effect of splitter plate was maximum when its edge nearer to the cylinder was about $2d$ to $3d$ downstream from the cylinder. Bearman[8,9] investigated flow behind a two-dimensional bluff model with a blunt trailing edge fitted with splitter plates up to $4d$ long. He divided the flow in various regimes according to the length of the splitter plates. Gerrard[10] measured the vortex shedding frequency from a circular cylinder at a Reynolds number of 2×10^4 with splitter plates up to $2d$ long attached to the cylinder. As the splitter plate length was increased, the Strouhal number was found to decrease to a minimum for a plate length of approximately $1d$ and then to increase as the splitter plate length was increased to $2d$. Apelt et al.[11-13] investigated the effects of splitter plates on the flow past a circular cylinder with splitter plate up to $7d$ long. They found that the splitter plates longer than $2d$ in the wake of a circular cylinder progressively modified base pressure and vortex shedding until the length of the splitter plate reached $5d$. For splitter plates longer than $5d$, essentially there was no further change in base pressure and shedding frequency. It was concluded in some of the above mentioned studies that the effects of splitter plates on the wake-flow characteristics of a circular cylinder were caused by changes in the location of the separation points.

These studies clearly show the complexity of the effects caused by splitter plates in the wake of a cylinder; however, most of these are confined to circular cylinders with attached splitter plates at high Reynolds numbers and do not provide a complete picture of the splitter plate effects. There appears to be no extensive study of effects of splitter plates on the bluff body with fixed separation points. The present study also differs from essentially all existing studies as the effects of a wide range of cylinder and splitter plate gap lengths, $0 < g/d < 9$, have been studied.

In the present study, the effects of splitter plates on the wake flow behind a rectangular cylinder have been experimentally studied for low Reynolds numbers between 0.35×10^3 and 1.15×10^3. As mentioned earlier, a rectangular cylinder was chosen over a circular cylinder to have the location of the separation points fixed. Another reason for using a rectangular cylinder was that the results should assist in determining whether the cylinder shape has an influence on the effectiveness of the splitter plate. Three splitter plates, $3d$, $2d$, and

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1*d* have been used, and a wide range of cylinder and splitter plate gap lengths, $0<g/d<9$, have been studied. Detailed measurements of the base pressure, shedding frequency, coherence function, correlation coefficient, and drag coefficient were carried out in order to get a clear understanding of splitter plate effects.

II. Experimental Equipment and Procedure

The wind tunnel used in the experiments was a low speed, open return, blower-type wind tunnel driven by a centrifugal fan. The cross section of the settling chamber was 2.25 m^2 at its largest section, and the size of the test section inlet air stream was 40×60 cm providing a contraction ratio of about 9 to 1. To protect the test section from the air currents in the laboratory, it was enclosed in a large wooden chamber, which measured approximately $115 \times 125 \times 190$ cm. This chamber was open to the room at the top and back. The tunnel blockage ratio was less than 2%; therefore, no blockage correction was made in the present experiments. The tests were carried out at test section velocities of between approximately 0.4 and 1.35 m/s; this gave a Reynolds number range of approximately between 0.35×10^3 to 1.15×10^3. In the freestream, the velocity fluctuations were found to be less than 0.25% of the local mean velocity at all velocities.

For the cylinder without a splitter plate, the spanwise base pressure measurements at midspan showed considerable three-dimensional effects. In order to keep the flow two-dimensional in nature, plexiglass end plates of about 30 diameters high and 15 diameters long were used on both the ends of the cylinder and splitter plates. With the end plates fixed, spanwise measurements of base pressure for the cylinder with and without a splitter plate showed essentially no three-dimensional effects. It was also established that two-dimensional flow did exist in the region of the wake where measurements were obtained. For this purpose, measurements of the velocity profiles across the flow in the *x-z* plane were obtained with the help of a hot-wire probe at downstream distances of up to 60 diameters. The results showed that there was essentially no transverse velocity gradient out to a distance of 125 mm from the center plane of the wake. Thus a two-dimensional region approximately 250-mm wide existed in the wake, which was considerably larger than the region in which measurements were obtained.

The basic flow configuration is shown in Fig. 1. The cylinder which was used to generate the wake had a height (called diameter hereafter) d of 12.7 mm, a thickness w of 5 mm and a length of 40 cm, stretching completely across the working stream of the wind tunnel. The width to diameter ratio of the cylinder was kept less than 0.35 so that the reattachment of the shear layers could not take place on the sides of the cylinder.[14] Three splitter plates of length, 3*d*, 2*d*, and 1*d* were used. The splitter plates were made of 0.2-mm thick aluminum sheet and stretched completely across the working stream of the wind tunnel. The gap between the trailing edge of the cylinder and the splitter plate could be varied from $g/d=0$ to $g/d=9$. A Hewlett Packard 3582A spectrum analyzer was used in conjunction with a DISA single hot-wire anemometer for power spectrum measurements and with two DISA, single, hot-wire anemometers for coherence function and correlation coefficient measurements. The cylinder used had static pressure tappings of about 2-mm diameter at the center of its rearward facing side. These were connected to a Barocel pressure transducer system, which allowed the base pressure to be measured. The Barocel pressure transducer was a Datametrics Integral Pressure Transducer type 590, which gave an output signal between 0 and 10 V dc proportional to the pressure. Profiles of mean velocity in the wake were measured using a DISA hot-wire probe at distances of up to approximately 60*d* downstream of the cylinder. The probes were mounted on a motor driven traversing mechanism, which could move them in both the transverse directions across the wake and the longitudinal direction downstream of the wake. The hot-wire probes were calibrated against a pitot tube outside the wake flow. In all the above measurements, the probe positioning as well as data collection and reduction were carried out automatically using a Hewlett Packard computer-controlled data acquisition system.

III. Results

A. Shedding Frequency

As mentioned earlier, vortex shedding frequency was determined with the help of a spectrum analyzer. The output from the spectrum analyzer was plotted on an *XY* plotter and was proportional to the amplitude of velocity fluctuations at the hot wire anemometer location. A typical plot of power spectrum with the hot-wire probe located at $x/d=9$ and $y/d=1$ is shown in Fig. 5. A very sharp peak produced by the velocity fluctuations at the shedding frequency can be observed at 12.8 Hz. The magnitude of the velocity fluctuations associated with vortex shedding was found to be much greater than those caused by general turbulence. The power spectrum measurements showed that the most predominant peaks for the shedding frequency were obtained when the hot wire was placed at about 3*d* downstream from the trailing edge of the splitter plate. However, no shedding frequency could be observed after a downstream distance of about 20*d* from the cylinder. It seemed that the vortices were forming behind the cylinder and were shedding alternately from both sides of the cylinder. These vortices traveled about 20*d* downstream before becoming fully turbulent, all traces of periodicity having disappeared. The power spectrum measurements with the hot wire placed at 3*d* downstream from the trailing edge of the splitter plate and with varying transverse distance y showed that, although distinct shedding frequencies could be observed from $y/d=0$ to $y/d=4$, the most predominant shedding frequencies were obtained when the hot wire was at about $y/d=1$. There-

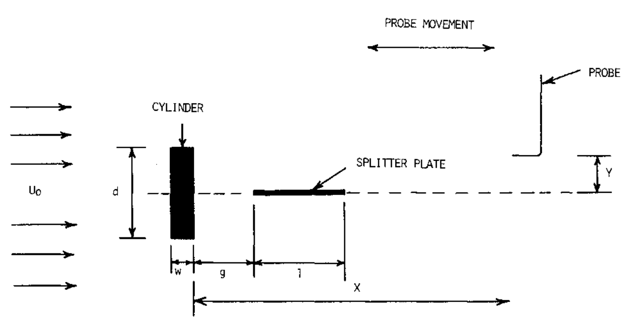

Fig. 1 Flow situation and probe positions.

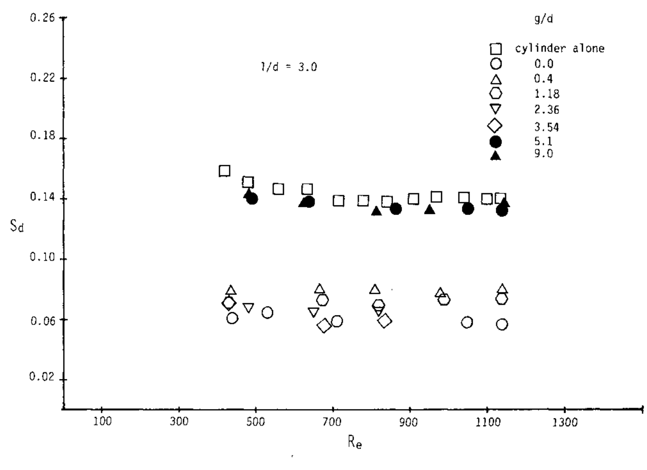

Fig. 2 Variation of *Sd* with *Re* for cylinder with 3*d* splitter plate.

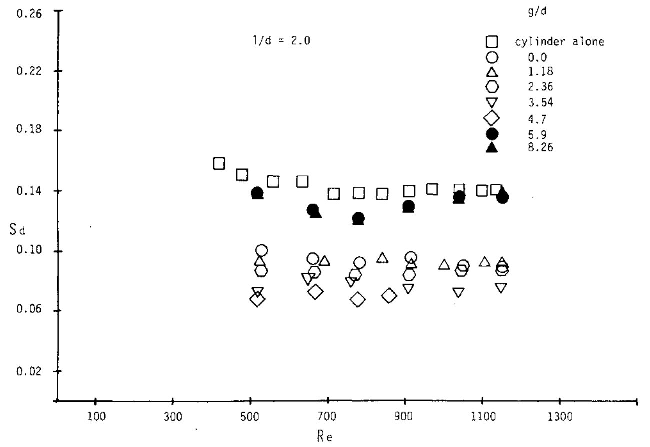

Fig. 3 Variation of *Sd* with *Re* for cylinder with 2*d* splitter plate.

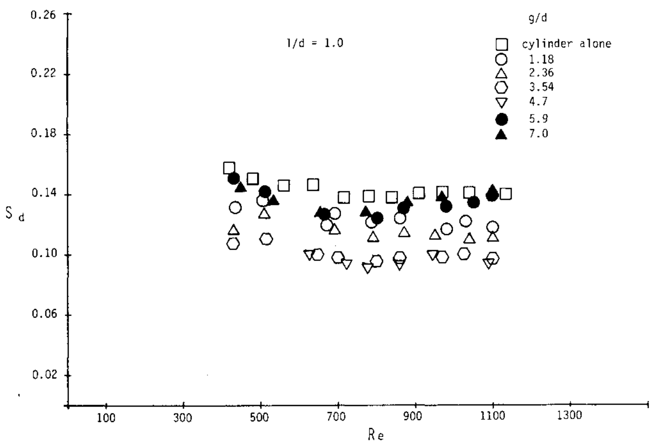

Fig. 4 Variation of *Sd* with *Re* for cylinder with 1*d* splitter plate.

fore, all the spectrum measurements were performed with the hot wire placed at $y/d = 1$ and at about 3*d* downstream from the trailing edge of the splitter plate. The hot-wire anemometer was held so that it was mainly sensitive to velocity fluctuations in the main flow direction. From these power spectrum measurements, the shedding frequency was determined, and the Strouhal number *Sd* based on the cylinder diameter was calculated.

Figure 2 shows the variation of Strouhal number with Reynolds number for a cylinder with and without the 3*d* splitter plate. It is seen that for a cylinder alone the Strouhal number remains essentially constant at approximately 0.16 for a Reynolds number greater than about 800 but shows a small increase as the Reynolds number decreases from about 800 to 400. However, in the presence of a splitter plate at $g/d = 0$, the Strouhal number drops by about 60% from 0.16 to 0.06. With a splitter plate at a gap between about $g/d = 2$ to $g/d = 5$, no shedding frequency can be observed for Reynolds number more than 800. As the gap increases further, $g/d > 5$, shedding frequency can be observed at full range of the Reynolds number, and the Strouhal number values jump and approach the plain cylinder values showing no significant effect of the splitter plates.

Figures 3 and 4 show the variation of the Strouhal number with the Reynolds number for the 2*d* and 1*d* splitter plates respectively. It can be seen that the nature of the splitter plate effect with the 2*d* plate is similar to the 3*d* splitter plate; however, the magnitude of the drop in the Strouhal number is smaller. For the case of the 1*d* splitter plate, however, the Strouhal number slowly decreases as the gap length increases

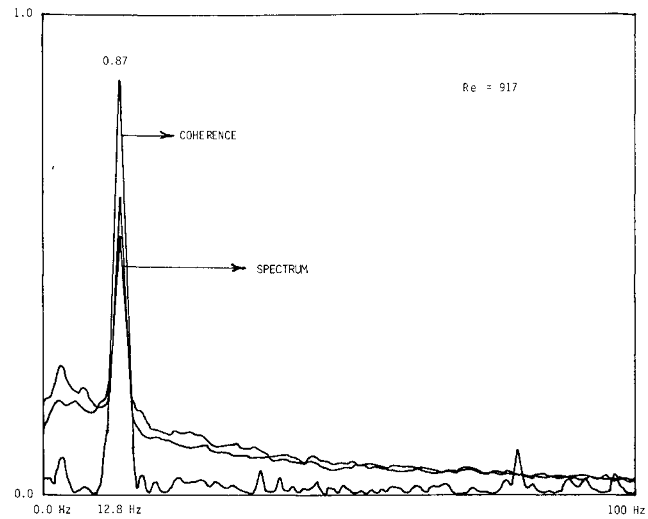

Fig. 5 Coherence and spectrum measurements for cylinder at $x/d = 9$, $y/d = 1$.

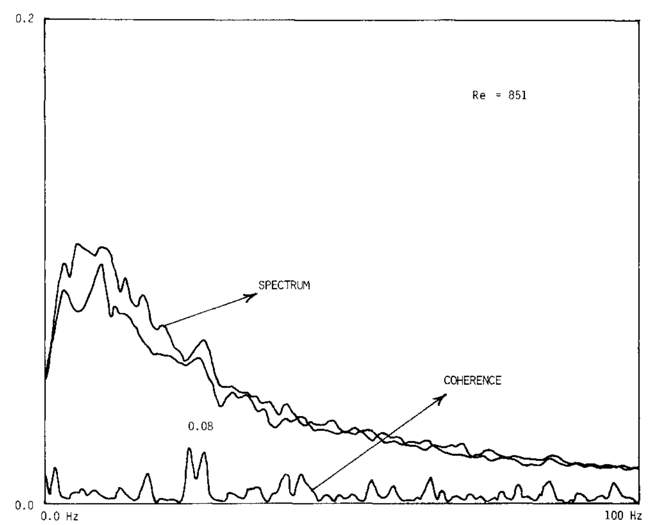

Fig. 6 Coherence and spectrum measurements for cylinder with 3*d* splitter plate at $g/d = 3$, $x/d = 9$, $y/d = 1$.

from $0 < g/d < 5$. Then for $g/d > 5$, the Strouhal number jumps back and approaches the values for the cylinder alone. It should be noted that for the 1*d* splitter plate, the shedding frequency can be observed at all the gap lengths and at full range of Reynolds numbers. As mentioned earlier, no distinct shedding frequency can sometimes be observed when a 3*d* or 2*d* splitter plate is placed at a gap between about $g/d = 2$ to $g/d = 5$ for a Reynolds number greater than 800. Figures 5 and 6 show the typical power spectrum measurements for the cylinder alone and for a cylinder with the 3*d* or 2*d* splitter plate placed at a gap of $2 < g/d < 5$. It can be seen that for the cylinder alone there is a predominant shedding frequency at 12.8 Hz. However, in the presence of the splitter plate at $g/d = 3$, the power spectrum results show no distinctly predominant shedding frequency.

The reason for the effect of the splitter plates on the shedding frequency appears to be as follows. The free-shear layers, which separate from the cylinder, come together at the position of vortex formation behind the cylinder. When a splitter plate is placed behind the cylinder at a *g/d* up to 2.5, the vortex formation region shifts downstream extending the formation region. Due to a longer formation region, the shear layers elongate causing more vorticity diffusion in the layers themselves, which causes the shedding frequency to decrease. As the gap further increases, $2.5 < g/d < 5$, the shear layers sometimes reattach to the splitter plate. And when the reattachment takes place at the splitter plate, the two shear layers on either side of the wake behave in an independent manner of each other, and there is no stabilizing mechanism to form definite, periodically alternating vortices. Therefore, no shedding frequency can sometimes be observed. As the splitter plate is moved further downstream, $5 < g/d$, the vortices form at their normal position, between the cylinder and the splitter plate, and the splitter plates have essentially no effect. This is the reason that for larger gap lengths, the Strouhal number approaches the values obtained for the cylinder alone. However, as mentioned earlier, it is interesting to note in Fig. 4, that for the $1d$ splitter plate, vortex shedding is observed at all the gap lengths. The reason for this behavior appears to be as follows. Since the plate length in this case is only $1d$, the vortex formation position either moves downstream or upstream of the plate allowing regular vortex shedding to take place. In other words, the length of the plate is not enough to cause full reattachment of the shear layers and hence inhibit the vortex shedding. It must also be noted that the suppression of vortex shedding takes place only for Reynolds number greater than approximately 800, as distinct vortex shedding frequencies are observed at all the gap lengths for a Reynolds number less than approximately 800. The reason for this behavior appears to be a change in the flow characteristics at a Reynolds number of approximately 800.

The typical variation of the Strouhal number with the gap length for various Reynolds numbers is shown in Fig. 7. It is seen that the jump in Strouhal number occurs at g/d of 3 to 6. However, it is Reynolds-number dependent, and generally the gap length at which jump takes place decreases as the Reynolds number increases. Zdravkovich[15] also observed a jump phenomenon for the cylinders in tandem arrangement. A comparison between his results and present results is shown in Fig. 8. It can be seen that in both the cases, the jump in Strouhal number is observed at g/d of 3 to 6.

B. Correlation Coefficient and Coherence Function

In order to verify the fact that splitter plates can sometimes inhibit vortex shedding, extensive correlation coefficient and coherence function measurements were performed. For these measurements two single, hot-wire anemometers were placed at $x/d = 9$, $y/d = +1$ and $x/d = 9$, $y/d = -1$. These anemometers were connected to a spectrum analyzer for the coherence function measurements and to a data acquisition system for correlation coefficient measurements. The hot wires were maintained at the same positions during measurements for the cylinder alone and for the cylinder with a splitter plate.

The correlation coefficient, which relates the velocity fluctuations at two points in the wake, and describes their general dependence on each other was defined as

$$Cc = \overline{U1' \cdot U2'}/\overline{U1'^2}$$

where $\overline{U1'}$ and $\overline{U2'}$ are the fluctuating velocity components measured by the two hot-wire anemometers. The correlation coefficient is a real valued quality, which varies from $+1$ or -1 to 0. In the wake flows, negative values are obtained due to existence of alternating vortex shedding.

The coherence function is a dimensionless, frequency-domain function, which at each frequency represents the dependence of one signal to the other. In the present study, it relates the velocity fluctuations at two points in the wake and represents their general dependence on each other at each frequency. When the coherence function is zero at a particular frequency, the velocity fluctuations are said to be incoherent at that frequency. However, when the coherence function is one for all frequencies, the velocity fluctuations are said to be fully coherent. The mathematical definition of the coherence function is given in Bendat.[17]

Figure 9 shows a typical variation of the correlation coefficient with Reynolds number for the cylinder alone and the cylinder with the $3d$ splitter plate placed at a gap between $g/d = 2$ to $g/d = 5$. It is seen that Cc remains essentially constant at about -0.5 for the cylinder alone. This high negative value of Cc reflects the regularity connected with the periodic alternating vortex shedding. When the splitter plate is placed at a gap of $2 < g/d < 5$, the correlation coefficient values jump to approximately zero for Re of more than 800 and slowly increase from zero at a Re of 800 to about -0.3 at a Reynolds number of 375. The low values of the correlation coefficient for Reynolds numbers more than 800 show the existence of the turbulent fluctuations and no evidence of the periodic vortex shedding. However, for lower Reynolds numbers, the values of the correlation coefficient increase with decreasing Reynolds numbers showing increasing presence of the periodic vortex shedding.

Figures 5 and 6 show typical coherence function results for the cylinder alone and for the cylinder with the $3d$ splitter plate placed at a gap between $g/d = 2$ to $g/d = 5$. It is seen that for the cylinder alone, the value of coherence function at the shedding frequency is about 0.87. This high value of the coherence function again reflects the regularity connected with the periodic vortex shedding. However, in the presence of a splitter plate at a gap of $g/d = 3$, it is seen that the coherence func-

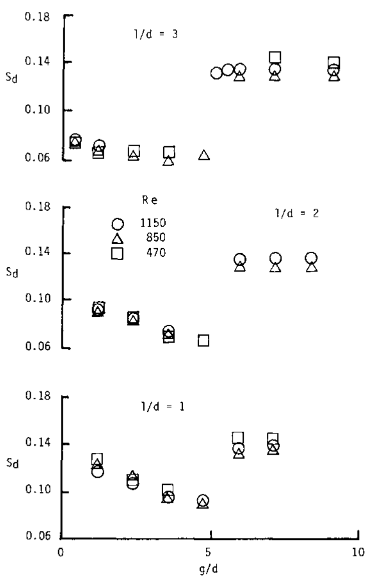

Fig. 7 Variation of Sd with g/d for various Re.

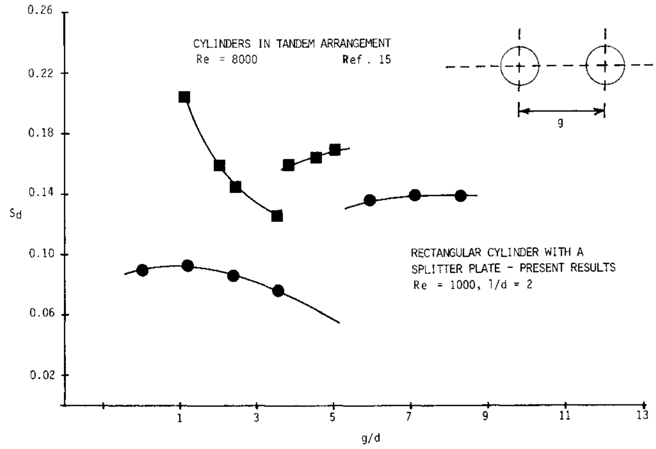

Fig. 8 Variation of Sd with g/d.

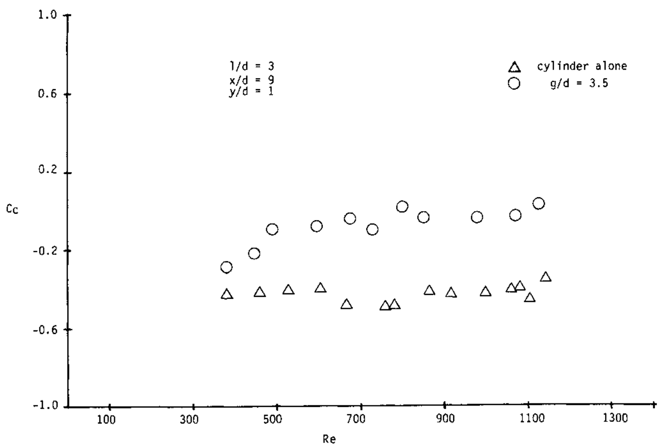

Fig. 9 Variation of *Cc* with *Re*.

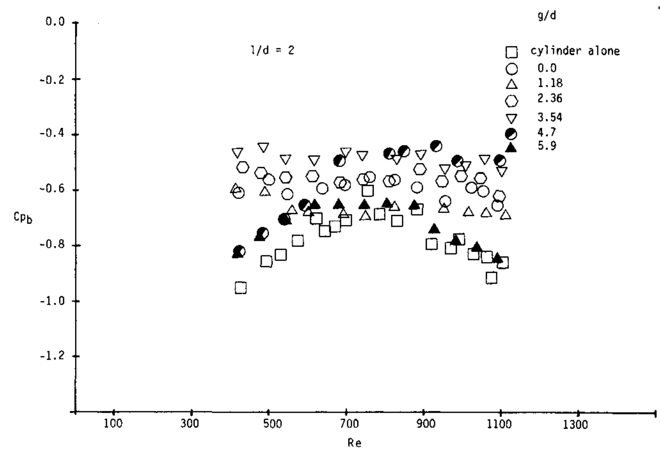

Fig. 11 Variation of *Cpb* with *Re* for cylinder with 2*d* splitter plate.

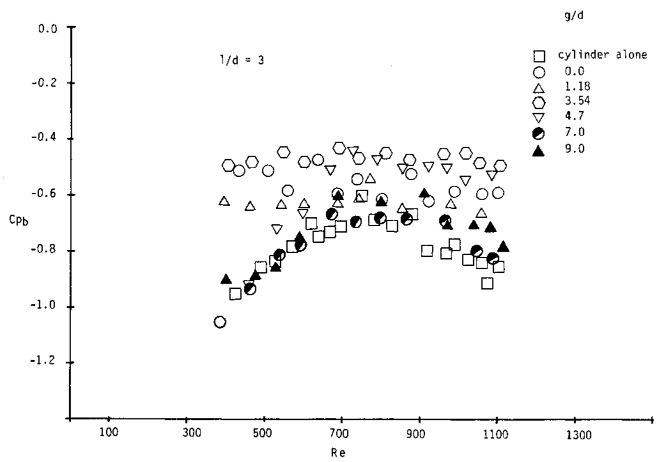

Fig. 10 Variation of *Cpb* with *Re* for cylinder with 3*d* splitter plate.

tion values essentially decrease to zero. The low values of coherence function once again reflect the existence of turbulent fluctuations and no evidence of the periodic vortex shedding. Therefore, the correlation coefficient and coherence function measurements do verify that splitter plates can sometimes inhibit periodic vortex shedding. As mentioned earlier the reason of the suppression of the vortex shedding in the presence of a splitter plate between gap lengths of $g/d=2$ to $g/d=5$ is related to the position of the plate relative to the vortex formation region and reattachment of the separated shear layers to the plate.

C. Base Pressure Results

Figure 10 shows the variation of the base pressure coefficient *Cpb*, with *Re* for the cylinder with and without the 3*d* splitter plate. It can be seen that for the cylinder alone, *Cpb* increases from -1 to -0.6 as the *Re* increases from about 400 to 800. At an *Re* of approximately 800, there is a drop in *Cpb* followed by a slow decrease with an increasing Reynolds number. For a cylinder with a splitter plate placed at gap lengths of up to about $g/d=4.5$, *Cpb* is relatively independent of the Reynolds number and higher than the values measured for cylinder alone; this is particularly true at values of *Re* that are significantly above or below 800. At a gap of about $g/d=4.5$, *Cpb* remains essentially constant for an *Re* greater than 800. However, for Reynolds numbers less than 800, *Cpb* decreases with *Re* approaching the values that exist for the cylinder alone. As the gap length further increases from about $g/d=5$ to $g/d=9$, *Cpb* increases with increasing Reynolds numbers for *Re* below 800, and then as *Re* increases to 1100, *Cpb* slowly decreases and approaches the *Cpb* values for the cylinder alone showing the decreasing effect of splitter plates.

The variation of *Cpb* with Reynolds numbers for the 2*d* splitter plate is shown in Fig. 11. It can be seen that the 2*d* splitter plate shows essentially the same characteristics as the 3*d* splitter plate; however, the increase in *Cpb* is smaller than with the 3*d* splitter plate. Although not shown here due to space considerations, 1*d* splitter plate also shows similar characteristics. It can be noted that the base pressure coefficient can increase up to approximately 40% in the presence of a splitter plate depending on Reynolds number and gap length. Associated with these increases in the base pressure coefficient are corresponding decreases in the cylinder drag coefficient. It is seen that the increase in *Cpb* is maximum when a splitter plate is placed at about 4.5*d* downstream from the cylinder, which is about the same gap length at which a jump in Strouhal number values is observed. The reason for an increase in the base pressure due to splitter plates appears to be as follows. It has been shown by Bearman[8] that the base pressure is inversely proportional to the distance of the vortex formation from the cylinder. Therefore, the farther the vortices can be persuaded to form away from the cylinder, the higher the base pressure will be. It was concluded earlier that a splitter plate placed up to a gap length of about $g/d=5$ forces the vortices to form further downstream. Thus an increase in the *Cpb* is observed for gap lengths of up to about 5*d*. For a gap length of more than 5*d*, however, vortices form at their normal position between the cylinder and the splitter plate causing relatively small changes in base pressure coefficient. These results also show that the characteristics of the flow above an *Re* of about 800 are different from that below an *Re* of about 800. It is interesting to note that, for two cylinders arranged in tandem[15] or for a circular cylinder with a splitter plate attached to the cylinder,[12] *Cpb* values are greatly effected by Reynolds number. However, for a rectangular cylinder with splitter plate the base pressure coefficient values are relatively independent of the Reynolds number. It should also be noted that the presence of the splitter plate behind the cylinder was found to have no effect on the front stagnation pressure.

D. Drag Coefficient

Profiles of mean velocity, turbulence intensity, and turbulence shear stress in the wake were measured up to about 60 downstream cylinder diameters to study the effect of splitter plates in the far wake and to determine whether the alteration in the initial wake formation affected the characteristics of the wake far from the cylinder. These quantities were measured at several downstream stations in the wake of the cylinder alone and cylinder with a splitter plate. A detailed discussion of the effect of splitter plates on the mean and turbulence properties

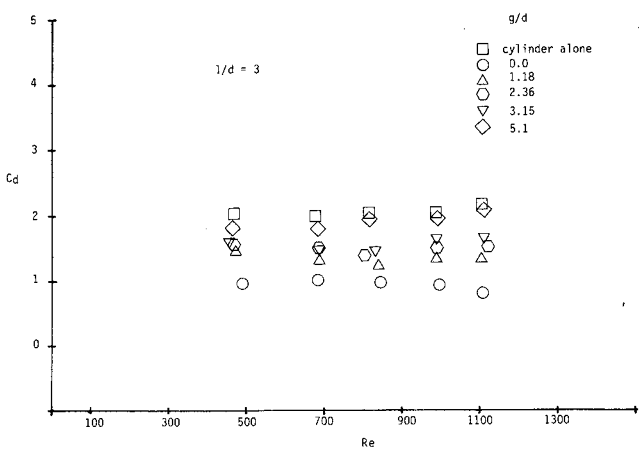

Fig. 12 Variation of *Cd* with *Re*.

of the wake flow behind a rectangular cylinder at low Reynolds numbers is presented in Ref. 16. Integration of the mean velocity profiles using the control volume approach was carried out to get an approximation of the overall drag coefficient. Figure 12 shows typical variation of the drag coefficient *Cd* with a Reynolds number for the cylinder with and without a splitter plate. It is seen that for the cylinder alone, *Cd* remains essentially constant at approximately 2. However, in the presence of a splitter plate at $g/d=0$, *Cd* reduces by about 50% to approximately 1. As the gap further increases, $0<g/d<5$, *Cd* increases with increasing gap length and after a gap length of $g/d>5$, splitter plates show essentially no effect on the drag coefficient. Similar characteristics are observed for the 2*d* and 1*d* splitter plate; however, the drop in *Cd* is smaller.

IV. Conclusions

An experimental investigation was carried out to study the effect of a splitter plate on the two-dimensional wake of a bluff body with fixed separation points. Particular attention was paid to the variation of shedding frequency and base pressure with splitter plate length and gap length between the splitter plate and cylinder. This experimental study has shown that the characteristics of the wake downstream of a bluff body with fixed separation points can be considerably altered by placing a splitter plate on the wake centerline downstream of the bluff body. The effect of splitter plates on the wake flow characteristics of a rectangular cylinder with fixed separation points is similar in nature to a circular cylinder with an attached splitter plate. However, compared to a circular cylinder with a splitter plate, a rectangular cylinder with a splitter plate shows a relatively small effect of Reynolds number.

For the cylinder alone, the shedding frequency decreases as the Reynolds number decreases. However, the Strouhal number remains essentially constant at approximately 0.16 for an *Re* of more than 800 and increases slowly as the *Re* decreases from 800 to 350. In the presence of a splitter plate up to a g/d of approximately 5, the Strouhal number decreases significantly. Beyond $g/d>5$, the Strouhal number jumps to approximately the same value that it would have in the absence of any splitter plate. For an *Re* above 800 with a splitter plate at a $2<g/d<5$, no clearly defined shedding frequency can sometimes be found. This behavior is related to the position of the splitter plate relative to the vortex formation region. The jump in the Strouhal number takes place in the same manner as with two circular cylinders arranged in tandem or with a circular cylinder with a splitter plate.

For Reynolds numbers below approximately 800, *Cpb* for the cylinder alone increases with an increasing Reynolds number reaching a maximum of approximately -0.7 at an *Re* of 800 and then decreases with an increasing Reynolds number. In the presence of a splitter plate within a g/d of approximately 5, *Cpb* can be higher by as much as 40% than the values that exist for the cylinder alone. Compared to two cylinders arranged in tandem or a circular cylinder with a splitter plate, *Cpb* values for a rectangular cylinder with a splitter plate are relatively independent of the Reynolds number. The base pressure values seem to be inversely proportional to the distance of the vortex formation position from the cylinder.

The overall drag coefficient of the cylinder can decrease up to approximately 50% depending upon the gap length and the length of the splitter plate.

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