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Technical Notes

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Effect of Splitter Plate on Bluff Body Drag

E. Rathakrishnan*
Indian Institute of Technology, Kanpur 208 016, India

Nomenclature

C_D = drag coefficient, drag force/$(\frac{1}{2}\rho_\infty V_\infty^2[h \times L])$
C_{P_b} = average base pressure coefficient, $(P_b - P_\infty)/(\frac{1}{2}\rho_\infty V_\infty^2)$
h = height of rectangular cylinder
L = length of rectangular cylinder
l = length of splitter plate
P_b = average base pressure
P_∞ = freestream pressure
Re_h = $(\rho_\infty V_\infty h)/\mu_\infty$
μ_∞ = viscosity of freestream air
ρ_∞ = freestream air density

Introduction

THE subject of drag reduction is an interesting problem with a wide range of applications. Because of the difficulties associated with theoretical analysis, the study of drag reduction has been almost entirely experimental.[1] At subcritical Reynolds numbers, the flow over bluff bodies is characterized by a large wake and periodic, alternative vortex shedding. Because of this, the time-averaged pressure drag coefficient assumes very large values.[2]

Several investigations have been reported on drag reduction of bluff bodies. Some of them directly relevant to the present study are Refs. 2–6. Even though both forward and backward splitter plates have been studied in the past, all of the studies were with either a single plate at the symmetrical location or two plates on either side of the symmetrical plane. Further, these investigations used either circular cylinders or bodies with rounded bases. Therefore, studies of shapes such as a rectangular cylinder will be of interest from the points of view of fundamental research as well as of applications. Hence, in the present study a rectangular cylinder has been studied. The selected configuration has the advantage of having nearly uniform base pressure, unlike a circular cylinder, which has a wide variation of pressures in the base region. Therefore, it is expected that increase in base pressure will be the major cause of drag reduction and that the magnitude of the drag reduction would be significant. Further, unlike the conventional way of keeping the splitter plate at the symmetrical plane, studies with splitter plates at off-centered locations also have been made.

Experimental Setup and Procedure

The experiments were conducted in a low-speed wind tunnel with 30 × 120 cm rectangular test section of length 150 cm. The model (shown in Fig. 1) was mounted across the width at the middle of the test section. Pressure taps for measuring the surface pressure distribution were provided at the middle section of the model, along the circumference. The splitter plates were made from 0.8-mm-thick aluminum sheets.

Measurements were made at freestream velocities of 16.18 and 28.4 m/s to ensure that the reduction in drag, if any, was not due to transition. The Reynolds number for these speeds, based on the cylinder base height, are 0.58×10^5 and 0.98×10^5. Splitter plate lengths used were $h/4$, $h/2$, h, $3h/2$, $2h$, and $3h$. The angles of attack studied were 0, 5, 10, and 15 deg both upward and downward. Total drag was determined using the wake survey method with measurements performed at $20h$ downstream of the model centerline. The pressure measurements were made with water manometers. They are accurate up to ±2%. The length measurements are accurate up to ±0.1 mm. All of the measured pressures were found to be repeatable within ±3%.

Results and Discussion

Variation of C_{P_b} with l/h is shown in Fig. 2. It is seen that, for a plate at the center, a backward plate results in a significant increase of base pressure when compared to a forward plate, for all l/h tested. This is because the backward splitter plate divides the wake into two parts, thereby preventing the formation of strong vortices at the base

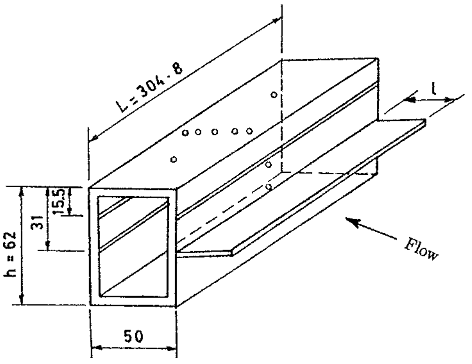

Fig. 1 Schematic of experimental model.

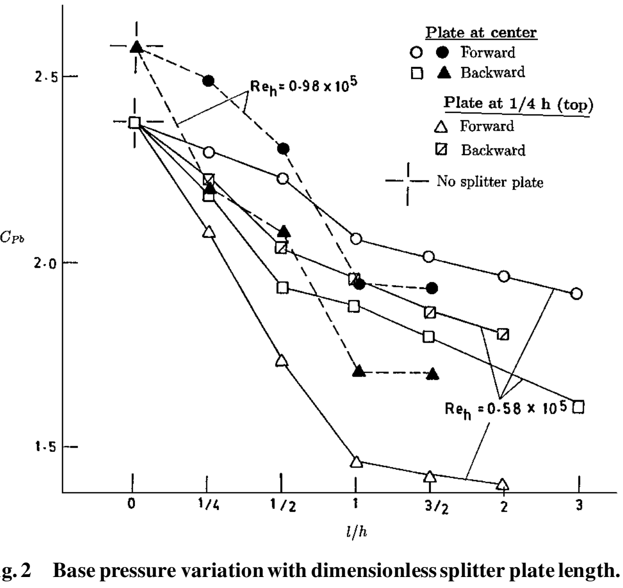

Fig. 2 Base pressure variation with dimensionless splitter plate length.

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*Professor, Department of Aerospace Engineering. Member AIAA.

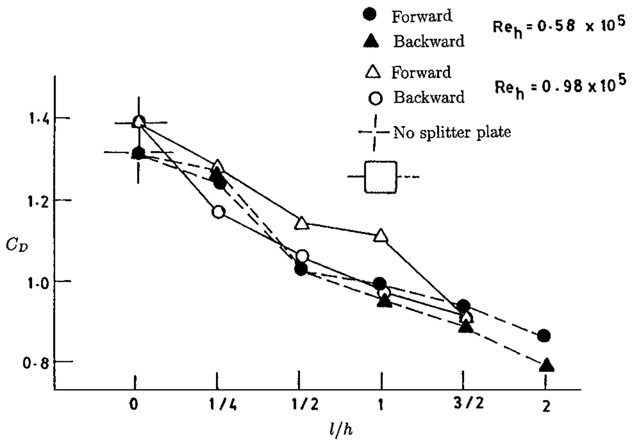

Fig. 3 Drag coefficient variation with dimensionless splitter plate length (splitter plate at the midplane).

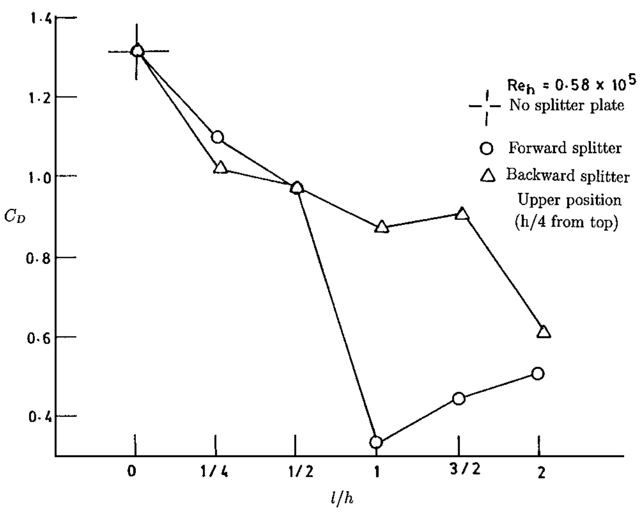

Fig. 4 Drag coefficient variation with dimensionless splitter plate length (splitter plate at *h*/4 from the top).

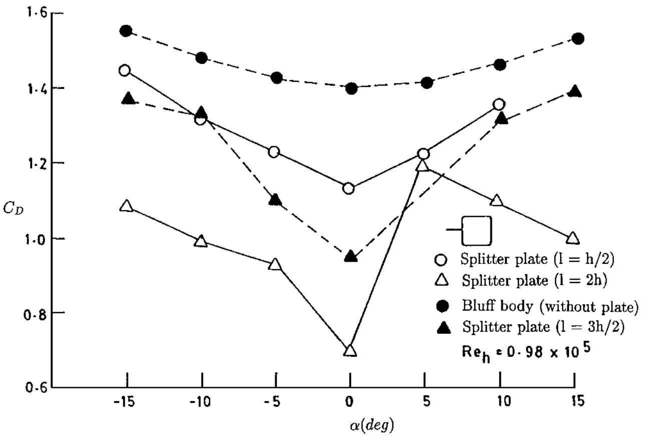

Fig. 5 Drag coefficient variation with angle of attack.

and resulting in a significant increase of the base pressure. Figure 2 shows that for the splitter plate at the symmetrical plane there exists a critical l/h beyond which the effect of l/h on C_{P_b} is insignificant. For $Re = 0.98 \times 10^5$ the critical l/h is about 1.0. Figure 2 also shows that for $Re = 0.58 \times 10^5$ the forward splitter plate located at $h/4$ from the top is more effective in increasing the base pressure when compared to other locations. Further, the plate located at the rear $h/4$ also results in a significant increase in base pressure compared to the plate position at the forward center though this increase is much smaller compared to that of the forward position at $h/4$. It seems that $l/h > 1$ is also effective in reducing C_{P_b}, even though the effect is very small compared to that for $l/h < 1$.

The C_D variation with h is given in Figs. 3 and 4. It is seen that for $Re = 0.98 \times 10^5$ there is sharp decrease in drag with an increase of l/h for both the forward and backward positions. However, a splitter plate at the rear always results in lesser drag compared to a forward splitter plate. However, for $Re = 0.58 \times 10^5$ the difference between the forward and the backward plate is less pronounced. For both of the Reynolds numbers in the present study, the effect of the splitter plate on drag reduction is significant.

Figure 4 gives C_D variation with l/h for a splitter plate located at $h/4$ from the top of the bluff body. It is seen that the splitter plate at the $h/4$ position for both the forward and the backward positioning results in significantly low C_D compared to its center positioning at $Re = 0.58 \times 10^5$. This implies that for a plate position at $h/4$ from the top, there exists some flow mechanism other than that which splits the flow into two parts, thereby weakening the vortices at the base and resulting in higher base pressure and reduced drag. In the case of $h/4$ positioning, the forward splitter plate of length $1h$ is found to give minimum drag when compared to other combinations of parameters. This suggests that splitter plate position that results in significant drag reduction is case sensitive. It is not necessary that splitter plate positioning at the centerplane will always result in maximum drag reduction.

From Figs. 2–4 it is evident that both C_{P_b} and C_D depend strongly on Reynolds number. For instance, for the present bluff body without a splitter plate, C_D changes from 1.3 to 1.4 when Reynolds number changes from 0.98×10^5 to 0.58×10^5. This is because the C_D for a bluff body depends on the combination of the positive pressure at the front face of the body and the suction at the base region. The Reynolds number of the present study, being in the range of transition values for bluff bodies, could have been able to influence the flowfield strongly, thus bringing about significant variation in C_D.

The pitch sensitivity of the bluff body splitter plate combination has been investigated for pitch angle in the range from −15 to +15 deg. The results for splitter plate lengths $h/2$, $3h/2$, and $2h$ are shown in Fig. 5. It is found that the splitter plate is most effective only at 0-deg pitch even though the C_D at other angles continue to be less than the basic body drag. Further note that under the pitched condition, the central position of the splitter plate is always advantageous compared to any other position, from a drag reduction point of view.

Conclusion

The results suggest that, for bluff bodies with splitter plates, a mechanism other than near wake manipulation might exist for drag reduction and for altering the vortex shedding characteristics. For centerline positioning, a backward splitter plate is more effective in drag reduction, whereas for $h/4$ positioning from the top, the forward plate gives less drag. The splitter plate is most effective when the pitch angle is zero.

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P. R. Bandyopadhyay
Associate Editor