International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:12, No:2, 2018

Numerical Study of Base Drag Reduction Using Locked Vortex Flow Management Technique for Lower Subsonic Regime

Kailas S. Jagtap, Karthik Sundarraj, Nirmal Kumar, S. Rajnarasimha, Prakash S. Kulkarni

***Abstract*—**The issue of turbulence base streams and the drag related to it have been of important attention for rockets, missiles, and aircraft. Different techniques are used for base drag reduction. This paper presents the numerical study of numerous drag reduction technique. The base drag or afterbody drag of bluff bodies can be reduced easily using locked vortex drag reduction technique. For bluff bodies having a cylindrical shape, the base drag is much larger compared to streamlined bodies. For such bodies using splitter plates, the vortex can be trapped between the base and the plate, which results in smooth flow. Splitter plate with round and curved corner shapes has influence in drag reduction. In this paper, the comparison is done between single splitter plate as different positions and with the bluff body. Base drag for the speed of 30m/s can be reduced about 20% to 30% by using single splitter plate as compared to the bluff body.

***Keywords*—**Base drag, bluff body, splitter plate, vortex flow, ANSYS, Fluent.

NOMENCLATURE

Cd = Drag coefficient
ΔCd = Change in requisitioned
Cp = Pressure coefficient
D = Main body diameter
D1 = Diameter of larger discs
x = Distance of larger disc from base
t1 = Thickness of larger disc
d = Connecting rod diameter

I. INTRODUCTION

A body advancing in the fluid experienced the drag force. All bluff bodies have some base drag or afterbody drag. This force has two components:

1. Frictional drag
2. Pressure drag

Due to friction between the fluid and the body surface frictional drag occurs and due to eddy formation pressure drag occurs. These drags are caused due to viscosity (for the inviscid fluid body will not experience any drag). For attached flows which are not having separation, the frictional drag is significant. This drag is related to body surface which is exposed to the fluid. The flows are separated flows then the flows are concerned with the cross-section of the body and the drag is very less.

Locked vortex method is introduced mainly to reduce drag on aircraft afterbodies. One of the common technique to reduce base drag of bluff body effectively is 'boat-tail'. In the first case, the analysis is done using bluff body base. The improved configuration accomplishes substantial pressure recovery on the boat-tail exit zone of the base at subsonic speed [1]. The same situation is visualized by manipulating the downstream of the blunt base using one or more discs (having less diameter than base) so as to formulate smooth near-wake flow. This formation can reduce the base drag of body- disc combination. Importance is given to the drag reduction concept for aircraft afterbodies.

Here we are considering 1. Boat-Tail base 2. Single disc with a spindle for base drag reduction. The axis symmetric body is having a disc of diameter 'D1' placed at a distance 'L1' behind the base. The flow parameters consist of free stream Mach number (M_∞) and Reynolds number. (Re_L). Therefore for $M_\infty \to 0$, from dimensional analysis,

$$\text{Base pressure coefficient, } C_{pb} = f_1\left(\frac{D_1}{D}, \frac{L_1}{D}, \frac{d}{D}, \frac{t_1}{D}, Re_L\right)$$
$$\text{Total afterbody drag coefficient } C_{DA} = f_1\left(\frac{D_1}{D}, \frac{L_1}{D}, \frac{d}{D}, \frac{t_1}{D}, Re_L\right)$$

Each of these non-dimensional parameters has some effect on drag. Also, the rim shape of the disc has some influence on drag. Present work is a numerical study of Base drag reduction in which different analysis is carried out by varying all the disc parameters.

Experimental work by Gillieron and Kourta shows that proximately 28% drag is reduced by using splitter plate in presence of lateral wind. Kumar and Parammsivam investigated on the reduction of Aerodynamic drag for hatchback model by using vertex lock generator. In this study, they optimized the Aerodynamic characteristics in Sedan cars by experimental work and by using the computational tool [2]. Another paper by Viswanath explained different base drag reduction techniques using different afterbody attachments. The Survey of different base drag and afterbody drag reduction techniques includes base cavities, ventilated cavities, locked vortex afterbodies, multi-step afterbodies and non-axisymmetric afterbodies. These techniques give effective drag reduction at different Mach numbers [3].

Mathur and Viswanath used the non-axisymmetric technique from Drag Reduction from circular-Base

Kailas S. Jagtap and Prof. S. Rajnarasimha are with the K J Somaiya College of Engineering, Mumbai-77, India (e-mail: kailas.jagtap@somaiya.edu, rajanarasimha.sangam@somaiya.edu).
Karthik Sundarraj and Nirmal Kumar are with the ARK Infosolutions Pvt. Ltd. Bangalore, India (e-mail: karthik.sundarraj@arkinfo.in, nirmal.kumar@arkinfo.in).
Dr. Prakash S Kulkarni is the Chief Research Scientist at IISc Bangalore, India (e-mail: psk@iisc.ac.in).

Afterbodies at High Speeds. Non-axisymmetric afterbodies used for the experimental work of drag reduction. In the range of 0.95-1.60 Mach number, the total drag reduced by using non-axisymmetric afterbodies is larger as compared to circular boat tail [4].

Jodai et al. together investigated of the effect of splitter plate on the turbulent boundary layer of flow over the long flat plate near the trailing edge. In absence of splitter plate pressure coefficient considerably small for long plates when compared with the short plate. Because of the splitter plate the momentum thickness strongly affects and considerable pressure coefficient increases [5].

From Miar's experimental work we can summarize that the base drag can be reduced for bluff bodies using splitter plates. He found almost 35% drag reduction using single splitter plate and further drag reduced to 55% when two splitter plates are used [6].

Little and Whipkeyt's published the work on Locked Vortex Afterbodies. In this paper, Experimental analysis of drag and flow characteristics using splitter plate is done. To reduce the drag the splitter plate should be large enough so that locked vortex can exist [7].

A. Major Findings

1. Study of Base drag on Bluff Body
2. Study of Base drag on Single splitter plate attachment

a) Variation in Length for given diameter
b) For different lengths change the diameter.

B. Methodology

While solving in CFD problem we have to consider all the limitations from geometry to final simulation. Also, we have to consider the limitations of computational power that is the system requirements for the problem-solving. Here because of system limitation, we are considering only 2-D geometry to reduce the mesh count and computational time. After all these things we have to make the geometry. For our project geometry is made in SpaceClaim tool. Once the geometry is ready we have to extract the fluid region. After geometry meshing is one of the important part. We have to do proper meshing. For our problem, the missing is done in Ansys meshing tool. The meshing is done is unstructured type due to curves in the geometry. Also, near the wall hybrid meshing is done to improve the mesh quality.

After the machine boundary conditions should be applied properly to the fluid region to get accurate results. This is done in ANSYS Fluent. While applying the conditions and selecting the solver settings the necessary conditions are taken into consideration. After the boundary conditions are applied the solution is solved and the final output is compared with their reference paper and again the mesh is modified, and solutions are obtained. This process is repeated until accurate results came.

C. Setup

Fig. 1 shows the model used for analysis. The total length of modern is 457.2 mm with a rounded nose. The diameter of the model is 75.87mm. The rod connecting disc to the main body is having 9.53 mm diameter, the distance between the base and disc (L1) can be varied accordingly. A number of discs with different diameters are used for this simulation work.

The domain considered for the simulation is of a rectangular cross-section similar to a wind tunnel having 508 mm high and 711.2 mm wide. Reynolds number was $1.97*10^6$.

D. Mesh

As the geometry is considered is 2-D geometry, the mesh used are triangular and quadrilateral types for the entire fluid domain. To generate the good quality mesh the complete fluid domain is divided into three parts. Only middle part is having higher importance so here fine mesh is generated as compared to other two parts. This is only to reduce the mesh count in outer two parts. The ultimate aim of this is to reduce the computational time.

E. Boundary Conditions

For the study H type computational domain is considered with Turbulence Intensity ranging from 0.2 to 0.4%. The free stream is having a velocity of about 25 to 35m/s with Reynolds number $1.97*10^6$/m. The mesh count is around 0.4 million. Spalart-allarams turbulence model is used for the simulation. 0.585, 0.795 & 0.919 are the d/D ratios used for simulation [5].

II. Drag Measurement

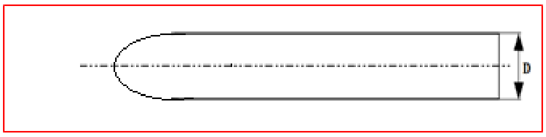

Fig. 1 Model for computational work

The fluid properties are used to determine the boundary layer thickness. By keeping the diameter constant some simulations are performed for different values of 'L1'. In the same way for three diameters, a number of simulations are performed.

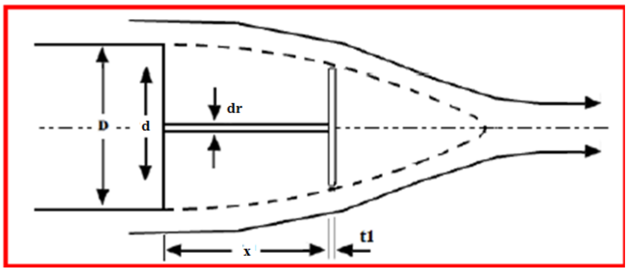

Fig. 2 Locked vortex afterbodies

The splitter plate is used is having thickness 3.175 mm [5]. In each case, the total length of the model is varied to get the optimized results. For all the simulations the model is kelp about 0.2°.

A. Grid Independence Test

To find the effect of meshing on the solution grind independence test is carried out. Here the meshing is done to check how the results are varying after changing the mesh. Here the meshing is carried out on the same body with splitter plate. After every meshing, the final results are obtained, and these results are compared with the reference paper. Until good result came the same procedure is repeated number of times to get the accurate results. Finally, for fine meshing, the mesh count is 0.4M approximately for all the cases. For blunt body 0.2M mesh count obtained. For this mesh count, proper results came for both blunt body as well as the body with splitter plate.

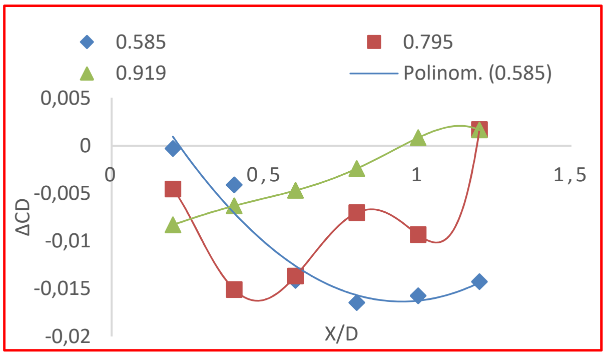

Fig. 3 ΔCd Vs x/D

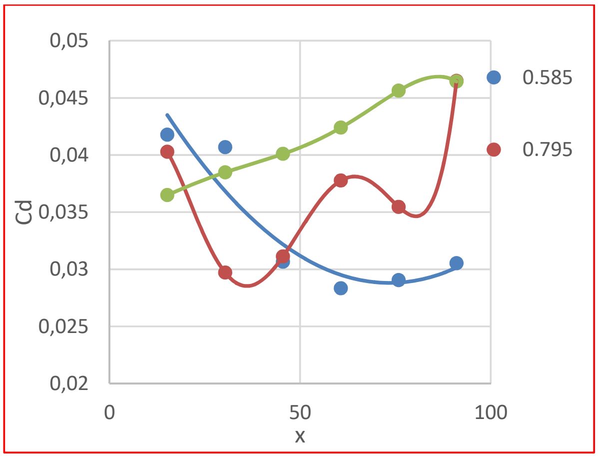

Fig. 4 Drag Vs x

For different x/D ratios, the values of ΔCd are obtained. From this graph, we observed that after attaching the splitter plate the reduces. We can observe that as the x/D ratio increases the more drag reduces. But after a certain limit, the drag started increasing. Therefore, the x/D ratio should be in permissible range. For different splitter plate diameter, the drag changes. Also, from the graph, it is observed that the maximum drag reduction is found for the d/D ratio 0.795 which lies in between 0.4 to 0.6 x/D ratio. For this case, maximum drag reduced is about 25%.

Fig. 4 shows the drag of the splitter plate for three different diameters. From the graph, it can be observed that for same x values the diameter of splitter effects the change in drag. For this case, the splitter plate having d/D ratio 0.795 is the optimum diameter for the model as vortex gets locked in between the base and plate. Also, the edges of splitter plate affect the drag [5]. If the sharp-edged plate is used then the drag reduction is less when compared with the drag reduction using splitter plate with curved edges. Disc edge curvature has an influence on the value of x/D as if the radius of curvature is increased the disc edge gives lower minimum drag.

The rod connects the base with the plate also has an influence on base drag reduction. But for this case, the rod diameter is kept constant. Also, the further drag can be reduced by increasing the number of plates.

III. Pressure Measurement

To get the additional information about the flow, some pressure coefficient measurements need to be carried out.

The coefficient of Pressure vs x/D graphs for different diameters are plotted above. In these graphs A, B & C are the positions for pressure measurement at the center of the splitter plate on the downstream side, Center of the disc on upstream side & point at 1/4th of the base respectively. For optimized splitter plate diameter, the pressure coefficient is minimum between the 0.4 to 0.6 x/D values. Also, there is a sudden change in the pressure at the base of the model as shown in Fig. 5 (a).

In Fig. 5 (b) at all positions, the pressure coefficient is increasing for change in the plate distance from the plate. Only at the center of the splitter plate, the pressure coefficient decreases between the same range of x/D ratio. But in Fig. 5 (c) the both base point and center of splitter plate on upstream side the pressure increases significantly as the distance changes. From this, we can say that the for the optimum condition the pressure coefficient also reduces.

The pressure Contour for the model at optimum diameter is shown in Fig. 6. At this condition, the vortex gets locked between the plate and the base. The flow in this region is shown in Fig. 6, this happens only when the optimum condition of plate diameter at a particular distance [8]. Flow characteristics of locked vortex varying this distance between the disc and body.

We can add more discs for proper results, such that we will be able to minimize the drag as well as pressure coefficient. If the disc is near the flow gets dominated. As the distance increases between plate and base, the reverse flow becomes weak and strong vertical flow sets up in the cavity.

IV. Conclusion

Trapped vortex splitter plate is a means of reducing the afterbody drag. With the disc, eddies will form between the base and the plate. To reduce the eddy formation some changes made in the model without using splitter plate.

A substantial drag reduction is obtained by using the splitter plate. After performing a number of operations Base drag calculation is brought down by 25% with the introduction of curved splitter plate at 90 degrees to the body when compared with bluff body drag. The position of the Splitter plate from the body is optimized by testing various distances. x/D ratio between 0.4 to 0.6 is obtained from simulation. There is not much effect of the boundary layer on drag reduction.

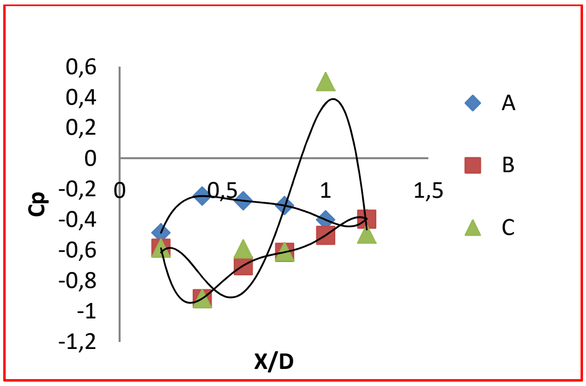

Fig. 5 (a) Coefficient of Pressure Vs x/D for d/D ratio 0.585

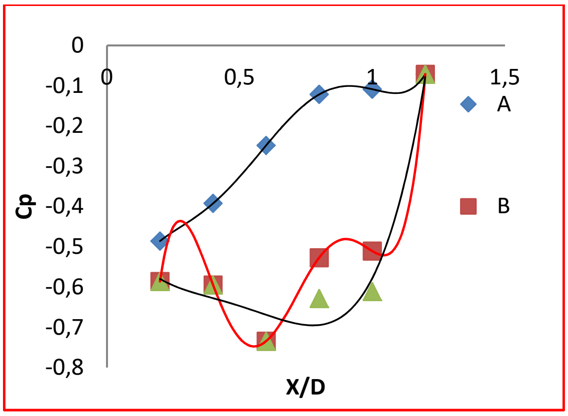

Fig. 5 (b) Coefficient of Pressure Vs x/D for d/D ratio 0.795

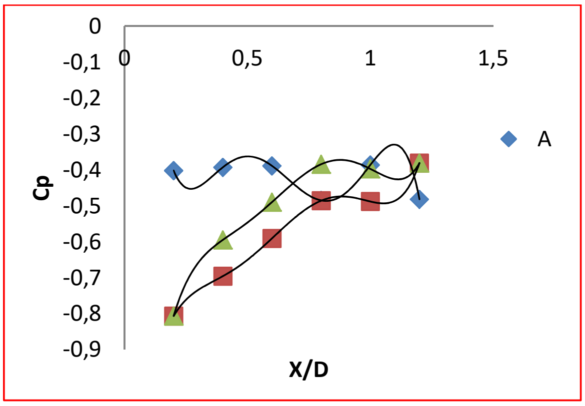

Fig. 5 (c) Coefficient of Pressure Vs x/D for d/D ratio 0.919

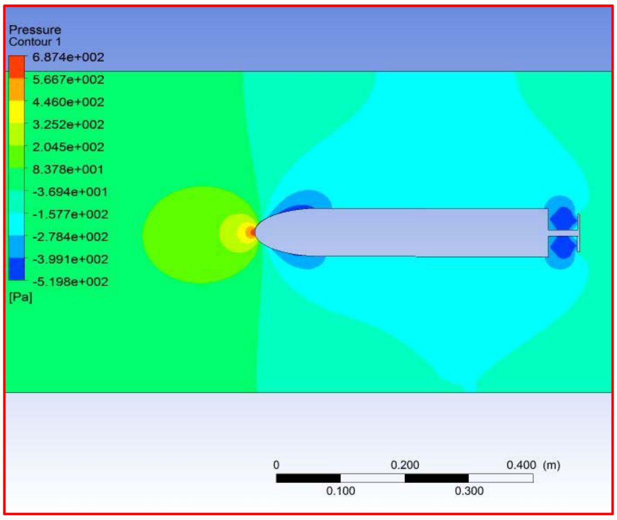

Fig. 6 Pressure distribution at optimum condition

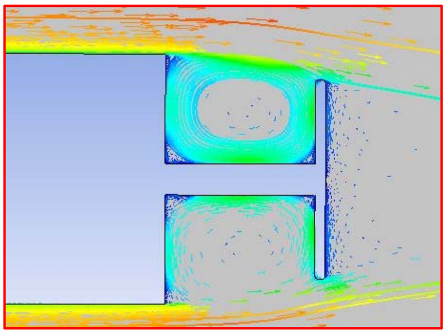

Fig. 7 The flow between splitter plate and the base

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