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Drag Reduction of V Shaped Ring Gutter of an Afterburner by Tandem Bluff Bodies Using Cfd

S Srinivasan[1], J J Isaac[2], C.Rajashekar[3], A.Arokkiaswamy[4]
[1&4]*Department of Aeronautical Engineering, MVJ College of Engineering, Visveswaraya Technological University Channasandra, Near ITPB, Bangalore-67, Karnataka, India*
[234]*National Aerospace LaboratoriesBangalore-17, Karnataka, India*

Abstract: *It is a well known approach that having bluff bodies in tandem will comparatively reduce the drag generated by single bodies. Several experimental and numerical results in the past have proved this phenomenon of drag reduction due to flow interference and patterns of vortex shedding. A V shaped gutter is being used in afterburner of an aircraft gas turbine engine which serves to hold the flame when the afterburner is switched ON. But when the burner is switched OFF the presence of gutter offers excess drag and total pressure loss. Hence it is necessary to reduce the total pressure loss and drag generated by the gutter. In this work an attempt has been made to understand the flow physics involved in keeping bodies in tandem and the effect of change in drag coefficient. Several types of cross section of bodies are investigated both upstream and downstream of the gutter and the drag coefficient is calculated. The flow simulation is done using CFD-ACE+, commercially available CFD Software.*
Key Words: *Bluff bodies, Drag reduction, Tandem bodies, V gutter*

I. INTRODUCTION:

Over the years, various research and development are carried out to improve the performance of afterburner, both experimentally and theoretically. Computational methods have become highly useful tool to design, develop, and analyze the performance of an afterburner with ease. The amount of drag generated by the presence of flame stabilizer and the recirculation zones in the wake of the stabilizer are very important factor to be considered for better performance of an afterburner. In the past, various research activities have been carried out to reduce the drag of bluff bodies, by changing the orientation and arrangement of the bluff body with respect to the flow such as, tandem, staggered, normal, and perpendicular to the flow. The above said researches were carried out through experimental, theoretical and CFD methods. In this chapter a brief review of literature closely related to the above mentioned studies are presented.

Nakanishi et al.. [1] Conducted experimental investigations on the effect of flame holder gutter shape on afterburner performance. Conventional V-gutter has minimum drag and minimum pressure loss both in burning and without burning condition and the flame holder shape had less effect on stability limits. In another study by Kareem et al..[2] on cylinders in tandem, the flow in tandem arrangement in two regimes such as, for spacing up to the critical spacing, the vortex street is suppressed behind the front cylinder and beyond this critical spacing, both cylinders form vortex streets. Large values of drag co-efficient occur at ratio of cylinder spacing to diameter of cylinder between 3 and 4. When the spacing is kept below the above mentioned value the drag value is found to be less than the value obtained for the above mentioned spacing to diameter ratio. Similar works has been carried out by various researchers to show the effect of flow interference and drag characteristics' when two bodies are in tandem.

II. PROBLEM STATEMENT

Computational Modelling of Flow over a V-gutter is done using CFD-ACE+ software. The flow boundary conditions are given in the table 1. A steady, viscous flow model is considered and K-E turbulence model is chosen. A convergence criterion of 10^{-6} is taken for the solution to converge. The gutter and bluff bodies are considered as wall and the drag coefficient is calculated by summing up pressure and shear forces to calculate the drag force and using the equation 1. The fig 1 shows the computational model chosen for the analysis. The duct model surrounding the gutter is considered to be same in geometry as that of afterburner and a cyclic symmetry boundary condition is applied to the side walls. The analysis is carried out for flow conditions as shown in the table and for different configurations of bluff bodies in tandem as shown in figure.

TABLE I BOUNDARY CONDITIONS

Boundary Parameters	Values
Inlet Mach number	0.35
Inlet Total Pressure, N/m^2	225400
Inlet Total Temperature, K	1009.1
Inlet Air Mass flow, Kg/s	8.3
Inlet Velocity, m/s	220
Turbulence Level (%)	5
Turbulance kinetic energy,k	187.8
Dissipation rate, ε	655.57
Ratio of specific heat, γ	1.35
Exit Static Pressure, N/m^2	224000

$$C_d = F_d / 0.5 \times \rho \times V^2 \times A \text{---------------------------1}$$

Where,

C_d - Coefficient of drag
F_d - Drag force in Newton
A - Projected area in m^2
ρ - Density of the flow ahead of the gutter in Kg/m^3
V - Velocity of the flow ahead of the gutter m/sec

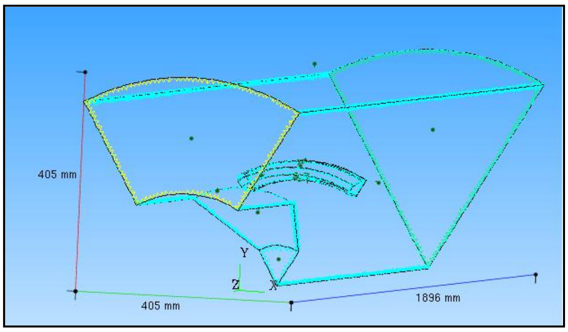

Fig 1: Computational domain

III. RESULTS AND DISCUSSION

The flow physics over the gutter when it is single and when bluff bodies are in tandem upstream and downstream are clearly captured and drag coefficient is estimated. Thirteen different configurations were studied. The flow phenomenon clearly captured the recirculation zone in the wake of the gutter. Since the wake width is also a measure of the drag coefficient, reduction in wake width brings a reduction in drag. The configuration of bluff bodies in tandem to the gutter has shown diverse change in the drag coefficient.

3.1 *CASE 1 - Bare gutter normal to the flow*

CFD predictions have been carried out with bare gutter kept normal to the flow. The velocity variation and flow pattern are shown in the figure. The drag force was found from the force summary output from the CFD-ACE+ analysis software along the direction of flow over the gutter. The drag force and the coefficient of drag are given below. It is seen from the results that, the coefficient of drag of the bare gutter is found to be 1.08 and the drag force (sum of pressure and viscous force) is found to be 286 Newton. The Fig 2 shown below clearly shows the wake region formed behind the gutter and the pressure variation and flow separation. Further analysis have been carried out for finding the possibility of reducing the C_d value below 1.08 of the bare gutter by putting bodies in tandem to the gutter. The density and Velocity ahead of the gutter is constant for all the configurations and their values are 0.76 kg/m3 and 130 m/sec respectively.

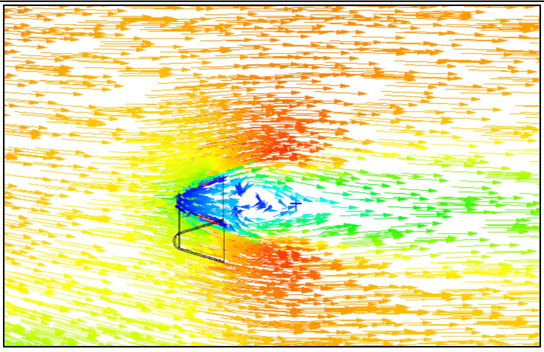

Fig 2: Flow pattern over the V-gutter

3.2 *CASE 2 - Flat edged disc downstream of the gutter*

Keeping the coefficient of drag of bare gutter as base, the flat edged disc of 35mm width is kept downstream of the gutter and the coefficient of drag was calculated using the equation 1. The disc was aligned axisymmetrically to the gutter and normal to the flow. The gap between the disc and gutter are varied as 10mm, 20mm and 30mm and the coefficient of drag was found to be 0.52, 0.53, and 0.55 respectively. The C_d of bare gutter is 1.08 and hence a maximum of 31% of drag reduction has been achieved by keeping the disc in tandem. The graph (Fig 3) shows the variation of C_d with spacing between the disc and the gutter. The reduction in drag takes place by improved stream lining of the flow that is evident from the flow pattern shown in Fig 4. Since the C_d is asymptotically increasing when the spacing is increased the analysis has been terminated with 30 mm gap.

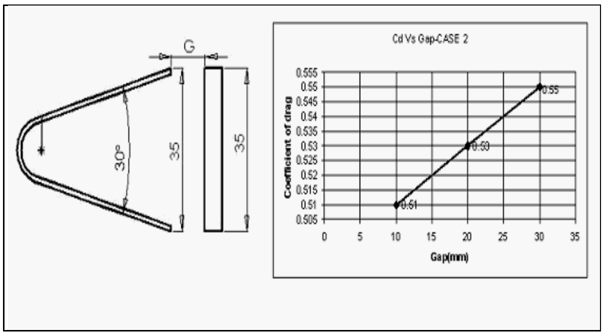

Fig 3: Coefficient of drag Vs Gap between the flat edged disc and gutter

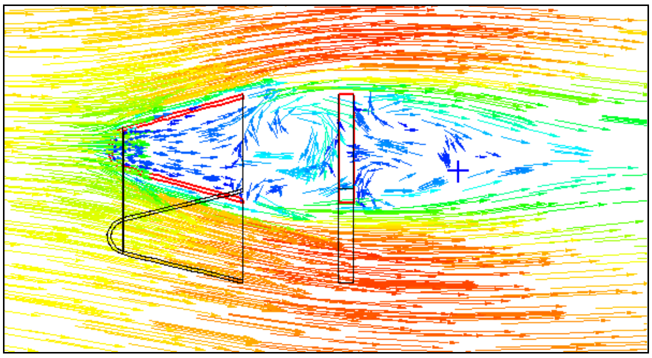

Fig 4: Flow pattern over the gutter with flat edged disc in tandem

3.3 *CASE 3 - Rounded edged disc downstream of the gutter*

The disc of 35mm width with its corners rounded is kept in tandem at spacings of 10mm, 20mm and 30mm and the coefficient of drag value has been predicted at these spacings. The difference between case 2 and case 3 is change in the edges. It is found that the coefficient of drag with round edged disc has C_d value less than that of the flat edged disc. The C_d values at the spacings 10mm, 20mm, and 30mm are found to be, 0.29, 0.49 and 0.5, which is clear from the graph shown in Fig 5. This shows that rounding the corners will create less drag than the body with sharp corners, which enhances a smooth flow over the bodies. Also the flow is smooth over the bodies and wake length has been increased which is evident from Fig 6.Here also as the spacing is increased the drag is increasing due to the flow interference.

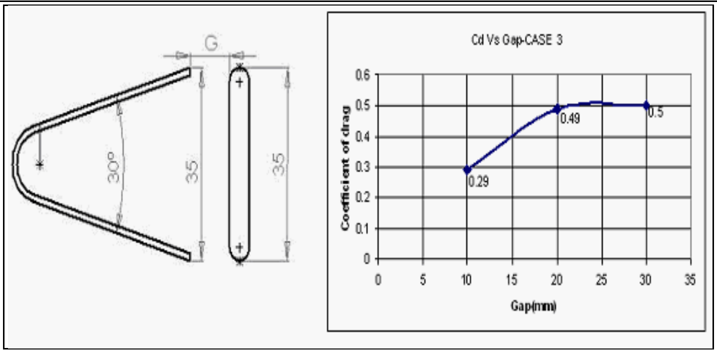

Fig 5 Coefficient of drag Vs Gap between the rounded edged disc and gutter

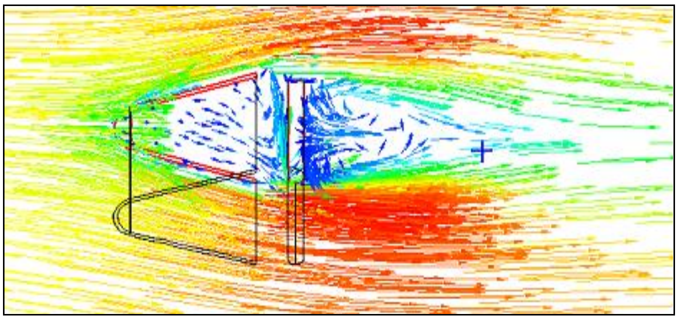

Fig 6: Flow pattern of rounded edged disc downstream of the gutter

3.4 *CASE 4 - Rounded edged disc of width 25mm downstream of the gutter*

In case 4 analysis is carried out with reducing the width of the disk from 35mm to 25mm with rounded edges and kept at spacings of 10mm, 20mm, 30mm and 40mm.The results obtained showed a notable thing that the coefficient of drag was reducing up to 30mm and it increased rapidly for 40mm.The values of C_d up to 30mm are 0.57, 0.54 and 0.52. For 40mm spacing the C_d value has again raised and reached to 0.55.Thus the critical spacing for this configuration is found as 30mm.After the critical spacing the bluffbody in tandem behaves as a separate body and contributed higher drag force. In this configuration the body in tandem is well kept in the wake of the gutter and hence the drag reduction has been achieved. Further a low-pressure region exists in between the bodies causing reduction in base pressure.

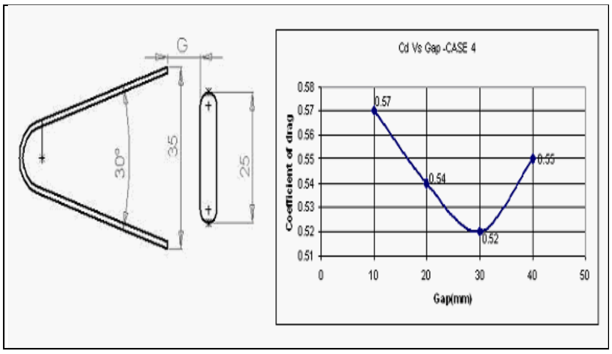

Fig 7: Configuration and C_d Vs Spacing gap for case 4

3.5 *CASE 5 - Tapered disc in downstream of the gutter*

In case 5 instead of a disc of rounded edge and flat shapes, a tapered disc having the taper angle of 99 degrees is kept in tandem behind the gutter. Then the spacing G between them is varied for 10mm and 20mm. It is predicted from the results that there is a reduction of C_d of about 59% (i.e. Cd=0.44) at 10mm and after that it has increased to a C_d value of 0.47 at 20mm.Since the C_d value was asymptotically increasing the analysis has been done only up to 20mm. The variation of C_d with the spacing is given in Fig 8. Since the disc is tapered the wake width is reduced and hence the C_d has reduced for the system.

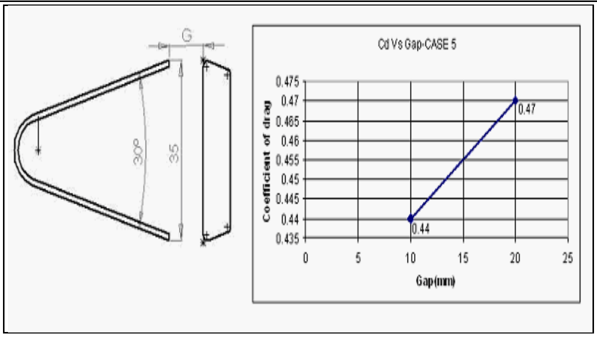

Fig 8: Configuration and Cd Vs Spacing gap for case 5

3.6 *CASE 6 - Slit of varying size made in 25 mm width disc downstream of the gutter*

In this case, in the 25 mm width disc discussed in case 4, a hole or slit was made and it is increased in size from 0 mm to 25mm i.e., with 25mm width disc to without disc configuration. Here only the slit size is varied and the disc is kept at 30mm for which optimum value has reached in case 4. It is seen from the results of case 4, that the coefficient of drag of gutter with disc of 25mm at 30mm spacing was 0.52. As the hole size is increased in steps of 5mm at 10mm hole in the center of the disc, the C_d value has increased form 5mm hole size to 25mm hole size. Hence providing the slit in the disc has only increased the C_d due to reduction in area though the size of the wake is small, which is evident from equation 1. The variation of C_d is shown in Fig 9.

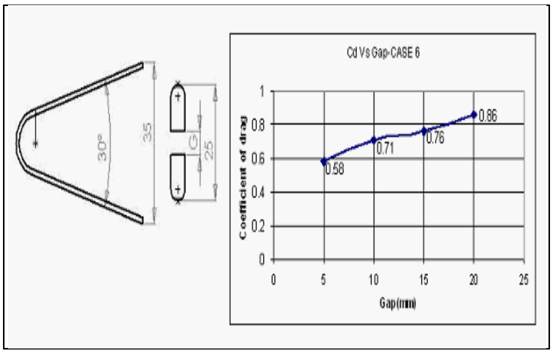

Fig 9: Configuration and C_d Vs hole size for case 6

3.7 *CASE 7 - Round edged disc of 35mm width upstream of the gutter*

In this case instead of having a body in downstream side of the gutter, because of its effect in recirculation zone behind the gutter, a disc of 35mm width is kept upstream side of the gutter and analyzed whether the C_d of the gutter can be reduced. The disc is also varied in spacing with respect to the gutter. From the results it is observed that, even in the upstream side the value of coefficient of drag is found to be less than that of the bare gutter for the spacings from 0mm to 20mm.The C_d values at various spacings shows a maximum of 26% reduction in the coefficient of drag is there than the bare gutter. It is seen that at zero mm spacing the C_d is 0.79 and then it increased to 0.82 for 5mm gap and the critical spacing has occurred at 10mm where the C_d has come down to 0.81 and after that increased. After the critical spacing sudden shift in the flow takes place and hence the drag has increased after critical spacing. Another reason is after that spacing the body will act as a separate body and hence contribute to drag separately. From the flow pattern it is clear that the flow separating from front body or disc again attaches to the rear end of the gutter there by not affecting the recirculation zone. Also a low velocity and pressure zone exists behind the disc and the gutter. The variation of C_d with spacing is shown in figure 10 and the flow pattern in figure 11

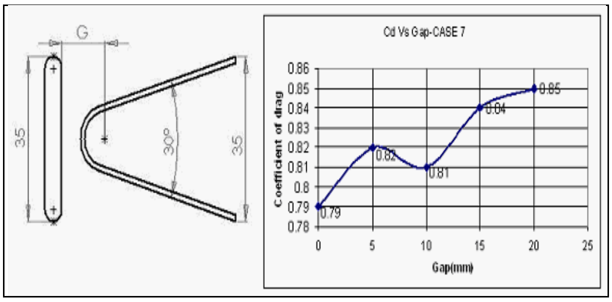

Fig 10: Configuration and C_d Vs Spacing gap for case 7

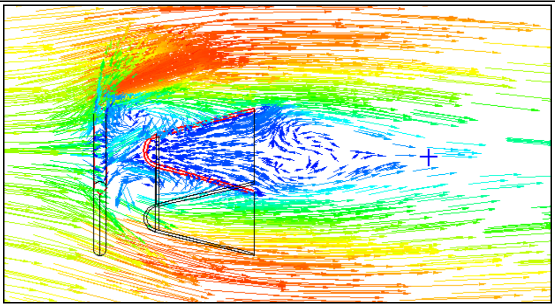

Fig 11: Flow pattern of the disc of 35mm width upstream of the gutter

3.8 *CASE 8 - 20mm hole in the disc of 35mm width upstream of the gutter*

In this case, the same disc taken in case 7 in the upstream side has been taken with a 20mm hole/slit in the center of the disc and the distance between them was varied in steps of 5mm from 0mm to 20mm. The results obtained shows that the coefficient of drag value has still increased than the plain disc. But it has dipped to a C_d value of 0.96 at 15mm gap, which is the critical spacing for this configuration, because after 15mm C_d is again increasing. After 15mm, as said in case7 the disc acts as a separate body and hence there is an increase in drag. The variation C_d values and flow pattern are shown in figure 12. It is very clearly seen that in all configuration there exist a low pressure and low velocity zone behind the gutter enabling flame stabilization.

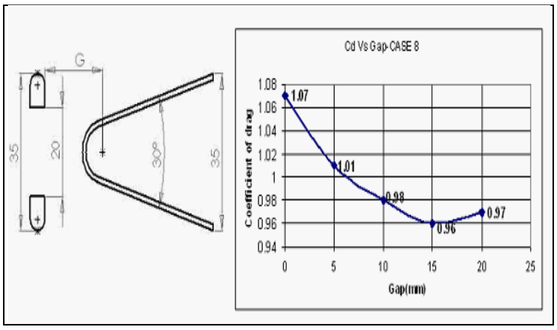

Fig 12: Configuration and C_d Vs Spacing gap for case 8

3.9 *CASE 9 - 20mm hole in the disc of 35mm width downstream of the gutter*

In this case, the same configuration discussed in case 8 is taken in the downstream side of the gutter to predict the drag changes. Here also the spacing is varied from 0mm to 20mm in steps of 5mm.It is observed from the results that the C_d value was less than the bare gutter and the percentage of reduction of drag is maximum of 33.3 percent which is for the spacing of 0mm, which is practically difficult. Further if the spacing is increased the C_d value increased than that of the disc without hole in the downstream side of the gutter as discussed in case 3. This is due to the reduction in area, which is inversely proportional to the coefficient of drag as said in equation 1. The length of the wake has also increased in this case. The C_d variation with gap is shown in figure 13.

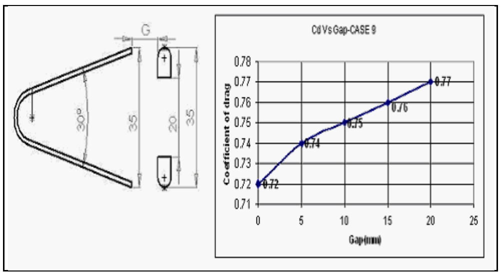

Fig 13: Configuration and C_d Vs Spacing gap for case 9

3.10 *CASE 10 - Two circular rings Upstream of the gutter*

In this case the analysis has been carried out with two circular rings of 10mm diameter separated by a distance of 15mm i.e., the width of the two rings is equal to the width of the gutter is kept upstream of the gutter. The analysis is done in such a way that the two rings are moved with respect to the gutter from their position of touching the gutter to a distance from the center of the ring to the center of the gutter of 20mm. The coefficient of drag has been calculated for this configuration and from the results it is found that the C_d value was very high compared to that of the C_d of the bare gutter. The variation of C_d with respect to spacing between them is shown in figure 14.

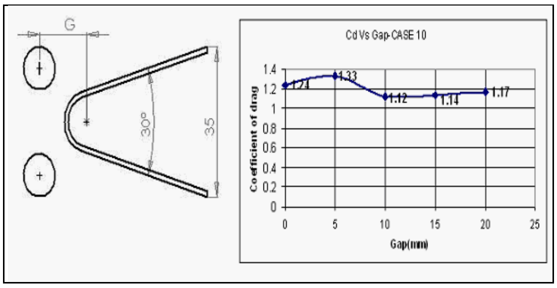

Fig 14: Configuration and C_d Vs Spacing gap for case 10

3.11***CASE 11: 35mm circular ring upstream of the gutter***

In this case, the analysis is carried out for a circular ring of 30mm diameter upstream of the gutter in various spacing. For this upstream configuration the coefficient of drag value has decreased to a maximum of 35 percentage than the bare gutter. From the flow pattern it is clearly seen that the flow separation is taking place in a highly streamlined way. From the results it is observed that there is a reduction in drag as the spacing is increased from 25mm to 35mm and again it has increased when the spacing is increased. This shows that the 25mm is the critical spacing for this case. The variation of Cd with respect to spacing is shown in figure 15.

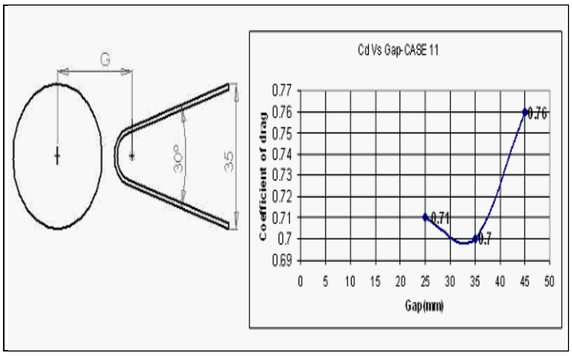

Fig 15: Configuration and C_d Vs Spacing gap for case 11

3.12 ***CASE 12 - 20mm circular ring upstream of the gutter***

In case 12, the diameter of the ring is reduced to 20mm compared to the earlier case where the diameter is 35mm, and kept upstream of the gutter in various spacings. From the results obtained it is seen that the value of C_d had reduced to a maximum of 25.9 percentage reduction than that of the bare gutter. From the flow pattern shown in figure 17, it is seen that the flow separating from the upstream ring again joins in the tail end of the gutter. Hence even the flow is stream lined the reduction in drag is not much. From the graph plotted for the values obtained it is seen that for 25mm the coefficient of drag has reduced to 0.8 from 0.81 and again increased to 0.82. Hence for this configuration the critical gap is 25mm after which the C_d increases asymptotically. Also flow interference is happening in the gap between the gutter and the ring.

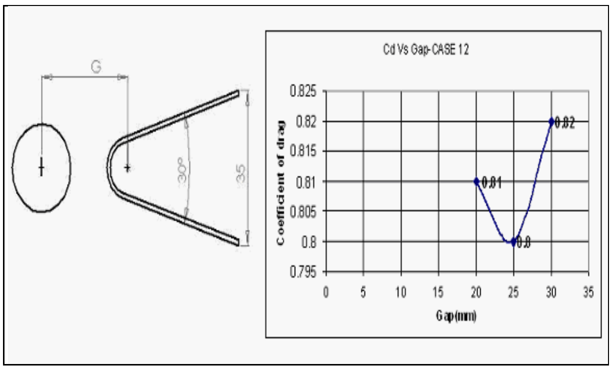

Fig 16: Configuration and C_d Vs Spacing gap for case 12

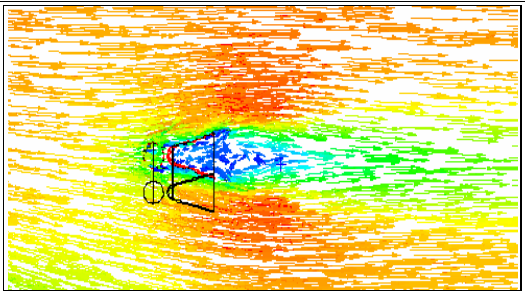

Fig 17: Flow pattern for 20mm circular ring upstream of the gutter

3.13 *CASE 13 - 10mm circular ring upstream of the gutter*

In this case, the analysis was carried out for the ring of 10mm diameter upstream of the gutter in various spacings i.e., the diameter of the ring discussed in earlier cases is reduced to 10mm. In this analysis, from the results obtained it is observed that the percentage of reduction is less as compared to earlier cases and it is almost approaching the value of the bare gutter as the spacing is increased. The maximum amount of reduction percentage is 15.7 percentage. From the flow pattern it is seen that the flow separating from the ring again joins at the upstream side of the gutter and hence the reduction in C_d is very less. Also since the ring diameter is 10mm which is less than the width of the gutter the flow over the gutter has changed and hence the reduction percentage is less. From the graph it is clear that there is a sharp increase in the value of C_d at various spacing. It is also clear that there is no dip in C_d value for this case. Hence for this case if the spacing is increased the Cd value also increases. The variation of C_d with respect to various spacing is shown in figure 18.

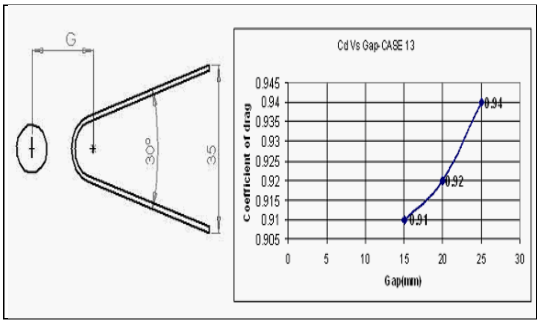

Fig 18: Configuration and C_d Vs Spacing gap for case 13.

The following table II shows the summary of the results achieved for various configurations under various orientations for the above discussed 13 cases.

TABLE II DRAG COEFFICIENT RESULT SUMMARY

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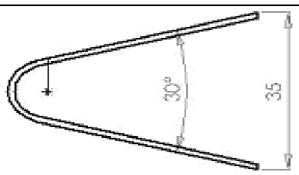
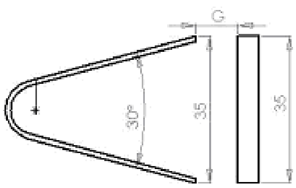
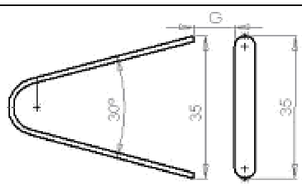
<tr><td>1</td><td></td><td>1.08</td></tr>
<tr><td>2</td><td></td><td><table><tr><td colspan="3">Spacing between bodies, G (mm)</td></tr><tr><td>10</td><td>20</td><td>30</td></tr><tr><td colspan="3">Coefficient of Drag, C_d</td></tr><tr><td>0.52</td><td>0.53</td><td>0.55</td></tr></table></td></tr>
<tr><td>3</td><td></td><td><table><tr><td colspan="3">Spacing between bodies, G (mm)</td></tr><tr><td>10</td><td>20</td><td>30</td></tr><tr><td colspan="3">Coefficient of Drag, C_d</td></tr><tr><td>0.29</td><td>0.49</td><td>0.5</td></tr></table></td></tr>
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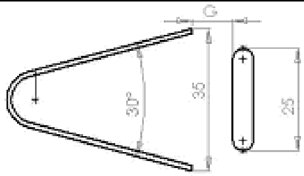
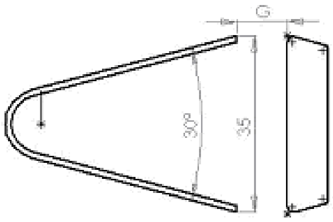
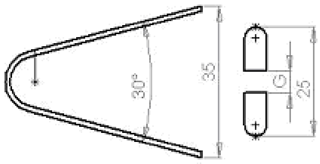
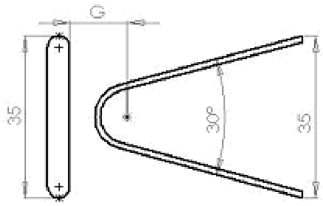
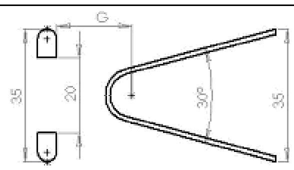
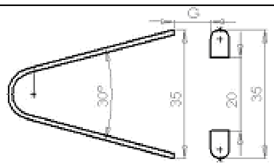
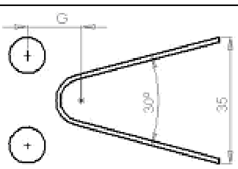
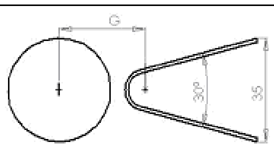
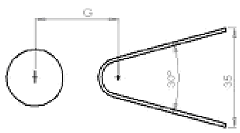
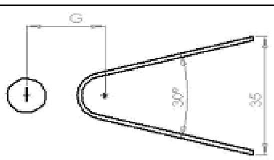
<tr><td>4</td><td></td><td><table><tr><td colspan="4">Spacing between bodies, G (mm)</td></tr><tr><td>10</td><td>20</td><td>30</td><td>40</td></tr><tr><td colspan="4">Coefficient of Drag, C_d</td></tr><tr><td>0.57</td><td>0.54</td><td>0.52</td><td>0.55</td></tr></table></td></tr>
<tr><td>5</td><td></td><td><table><tr><td colspan="2">Spacing between bodies, G (mm)</td></tr><tr><td>10</td><td>20</td></tr><tr><td colspan="2">Coefficient of Drag, C_d</td></tr><tr><td>0.44</td><td>0.47</td></tr></table></td></tr>
<tr><td>6</td><td></td><td><table><tr><td colspan="6">Spacing between bodies, G (mm)</td></tr><tr><td>0</td><td>5</td><td>10</td><td>15</td><td>20</td><td>25</td></tr><tr><td colspan="6">Coefficient of Drag, C_d</td></tr><tr><td>0.52</td><td>0.58</td><td>0.71</td><td>0.76</td><td>0.86</td><td>1.08</td></tr></table></td></tr>
<tr><td>7</td><td></td><td><table><tr><td colspan="5">Spacing between bodies, G (mm)</td></tr><tr><td>0</td><td>5</td><td>10</td><td>15</td><td>20</td></tr><tr><td colspan="5">Coefficient of Drag, C_d</td></tr><tr><td>0.79</td><td>0.82</td><td>0.81</td><td>0.84</td><td>0.85</td></tr></table></td></tr>
<tr><td>8</td><td></td><td><table><tr><td colspan="5">Spacing between bodies, G (mm)</td></tr><tr><td>0</td><td>5</td><td>10</td><td>15</td><td>20</td></tr><tr><td colspan="5">Coefficient of Drag, C_d</td></tr><tr><td>1.07</td><td>1.01</td><td>0.98</td><td>0.96</td><td>0.97</td></tr></table></td></tr>
<tr><td>9</td><td></td><td><table><tr><td colspan="5">Spacing between bodies, G (mm)</td></tr><tr><td>0</td><td>5</td><td>10</td><td>15</td><td>20</td></tr><tr><td colspan="5">Coefficient of Drag, C_d</td></tr><tr><td>0.72</td><td>0.74</td><td>0.75</td><td>0.76</td><td>0.77</td></tr></table></td></tr>
<tr><td>10</td><td></td><td><table><tr><td colspan="5">Spacing between bodies, G (mm)</td></tr><tr><td>Touched</td><td>5</td><td>10</td><td>15</td><td>20</td></tr><tr><td colspan="5">Coefficient of Drag, Cd</td></tr><tr><td>1.24</td><td>1.33</td><td>1.12</td><td>1.14</td><td>1.17</td></tr></table></td></tr>
<tr><td>11</td><td></td><td><table><tr><td colspan="3">Spacing between bodies, G (mm)</td></tr><tr><td>25</td><td>35</td><td>45</td></tr><tr><td colspan="3">Coefficient of Drag, C_d</td></tr><tr><td>0.71</td><td>0.7</td><td>0.76</td></tr></table></td></tr>
<tr><td>12</td><td></td><td><table><tr><td colspan="3">Spacing between bodies, G (mm)</td></tr><tr><td>20</td><td>25</td><td>30</td></tr><tr><td colspan="3">Coefficient of Drag, C_d</td></tr><tr><td>0.81</td><td>0.8</td><td>0.82</td></tr></table></td></tr>
<tr><td>13</td><td></td><td><table><tr><td colspan="3">Spacing between bodies, G (mm)</td></tr><tr><td>15</td><td>20</td><td>25</td></tr><tr><td colspan="3">Coefficient of Drag, C_d</td></tr><tr><td>0.91</td><td>0.92</td><td>0.94</td></tr></table></td></tr>
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IV. CONCLUSION

It can be concluded from the CFD analysis that the drag of the V-gutter flame holder of an afterburner can be reduced by providing a buff body in tandem either upstream or downstream. It is observed from the studies that almost for all the case the drag of the gutter has reduced except case 10. The coefficient of drag is comparatively less for the bodies having rounded corners than the bodies with flat edges as expected. Further, the coefficient of drag varied with respect to the spacing between the bodies for all the cases. Further, from the analysis it is evident that the drag reduction is more when the body is kept downstream of the gutter, where as it is comparatively higher when it is kept upstream of the gutter. In the downstream side of the gutter, a maximum of 73 percentage of drag reduction has been achieved for case 3 compared to that of the bare gutter and in the upstream side, a maximum of 35 percentage of drag reduction has been achieved for case 11. Thus by keeping the bluff bodies in tandem to the gutter with properly designed shape and size the drag of the gutter can be reduced and hence the dry loss can be minimized thereby enhancing the performance of the afterburner.

V. ACKNOWLEDGEMENTS

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