NUMERICAL STUDY OF SHOCK GENERATION AT THE AFTBODY OF SLENDER BODY OF REVOLUTION USING NAVIER-STOKES EQUATION

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Abstract

The present work looks into the mechanism of drag due to shockwaves generated at the aft-part of a slender body, in another effort to optimize the total drag from physical consideration. In this regard, numerical approach is carried out following the well established computational fluid dynamic method in solving the Navier-Stokes equation around an axi-symmetric body in transonic flow. Various slender body configurations are investigated. The first one is the numerical investigation of a series of slender body geometries which were experimentally studied earlier by MBB. The second one is the Sears-Haack body, for which analytical results are well established. Next, we investigated a modified Sears-Haack body. The modification was made by introducing a shock wave generator on the aftbody surface of a Sears-Haack geometry. This artificial shock generator was positioned at selected location on the surface of the aftbody to force the shock wave to appear at that location. For the numerical computation of the flow characteristics (such as Mach contour, pressure coefficient (Cp), and Drag Coefficient (Cd)), commercially available flow solvers, known as RAMPANT Flow Solvers, are utilized. The results offer some clue on how the drag of a slender body of revolution could be optimized by geometrical optimization on the aft body.

1. Introduction

The drag minimization of slender axisymmetric body, particularly in the transonic flow regime, has received much interest. Such a case should be dealt with, for example, in the design of projectile geometries for minimum drag. Since, in the transonic regime shock waves appear on the surface of the body, we investigate the effect of shock location and strength to the overall drag of the body. Particular attention is given here to the Sears-Haack body since the geometry of this body, according to potential theory, has minimum drag. The body is modified by introducing a shock generator. The shock generator position was varied at various selected location on the afterbody in searching for shock location that yields minimum drag. The investigations are carried out by utilizing a Navier-Stokes solver.

2. Numerical approach by Numerical Solution of the Navier Stokes Equation(viscous case)

The numerical approach utilized for this study is the numerical computational procedure to solve the viscous Navier-Stokes Equation. For this purpose, commercially available *Rampant Flow Solver* is utilized, since Rampant Flow Solver provides comprehensive modeling capabilities for a wide range of incompressible and compressible, laminar and turbulent fluid flow problems. The following investigation deals with the geometry of MBB, Sears-Haack, and Sears-Haack bodies with shock generator positioned at selected location on the aft-body (in this paper this body will be called Modified Sears-Haack body).

a. MBB geometry.

MBB geometry is an axi-symmetric slender body created by MBB, consisting of two parts: forebody and aft body, with a total length of 800 mm and maximum diameter of 120 mm. Both forebody and aftbody are characterized by a power series represented by :

$$Y_h = a_h.x^3 + b_h.x^2 + c_h.x + d$$

Next we will look into MBB geometry with various aftbody geometries. This paper will discus three MBB geometries, namely MBB1 (MBB geometry with starting aft body at midpoint), MBB3 (MBB geometry with starting aft body at 0.6875 of the length of the body) , MBB5 (MBB geometry with starting geometry at 0.8125 of the length of the body). The free stream Mach number considered for this case is taken to be M = 1.2.

1) Mach number contour

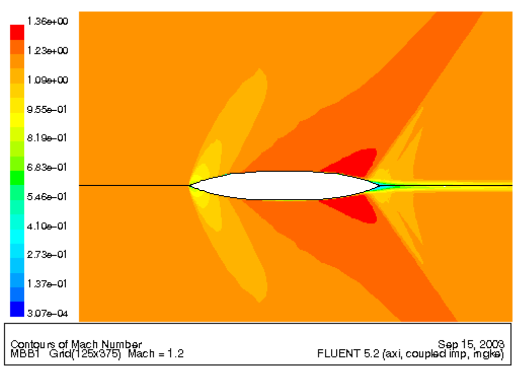

Fig. 1a Mach contour MBB1

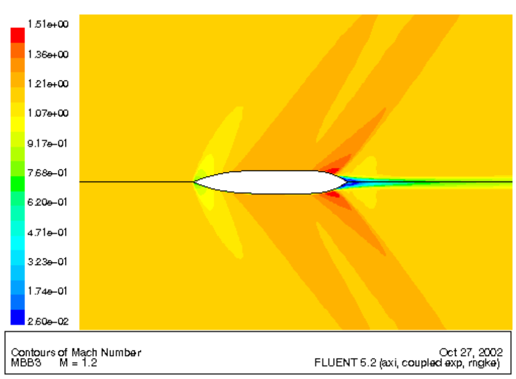

Fig. 1b Mach contour MBB3

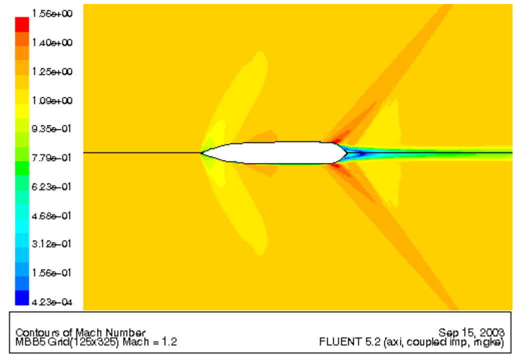

Fig. 1c Mach contour MBB5

The Mach number contours for the cases considered are shown in Figs. 1a-1c. For this various MBB configurations, at free stream Mach number = 1.2, the local velocity gradually increase downstream along the surface. The location of the shockwave tends to move backward according the increasing slope of the contour of the aft body.

2) Cp Distribution

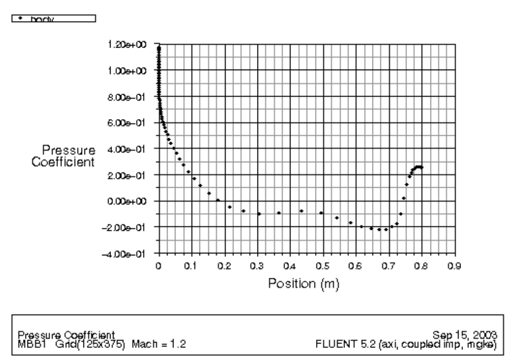

Fig. 2a Cp Distribution MBB1

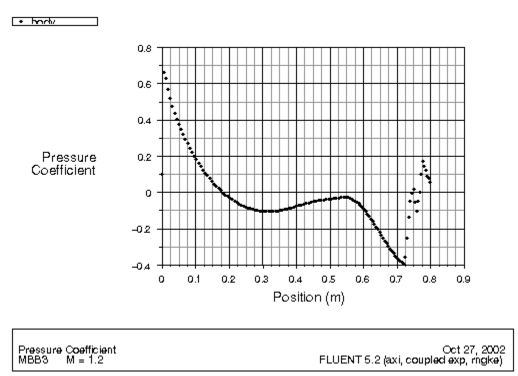

Fig. 2b Cp Distribution MBB3

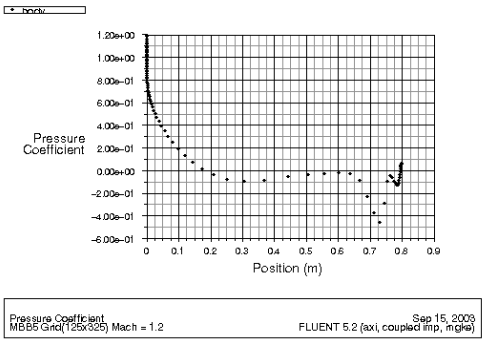

Fig. 2c Cp Distribution MBB5

From the Cp distribution obtained one can conclude that the gradient of the slope indicate the strength of shockwave. The stronger the shockwave, the pressure drag will also be larger. Upon comparison of these results, fig. 2c exhibits the steepest change of adverse pressure gradient. Hence consequently MBB5 geometry has relatively higher pressure drag.

b. Sears-Haack Geometry.

In the 1950's Sears and Haack solved for the shape of a body of revolution with minimum wave drag. These results provide guidance for initial estimates of volume wave drag, even before the detailed geometry is known. This is the minimum wave drag shape for a given length and volume according to potential theory. The body is closed at both ends and has a very slightly blunted nose, and is symmetric about the mid point. The basic geometry of Sears-Haack is characterized by the following equations :

$$\varsigma = 1-2\left(\frac{x}{l}\right) \;; \qquad \frac{r}{l} = \frac{1}{2f}\left(1-\varsigma^{2}\right)^{3/4}$$

In this work, the Sears-Haack geometry will be modified by placing an artificial shock generator positioned at the selected location of the aft body.

1) Mach number contour

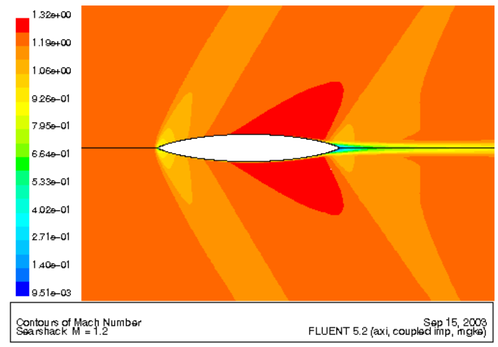

Fig. 3a Mach contour Basic Sears-Haack

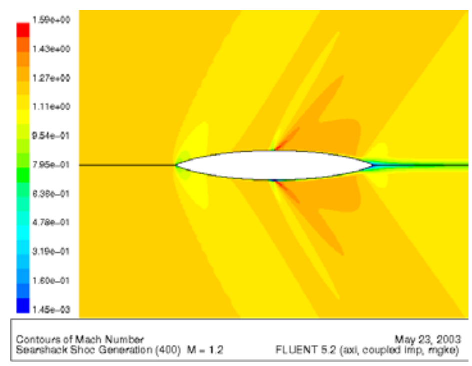

Fig. 3b Sears-Haack shock generator at 400 mm

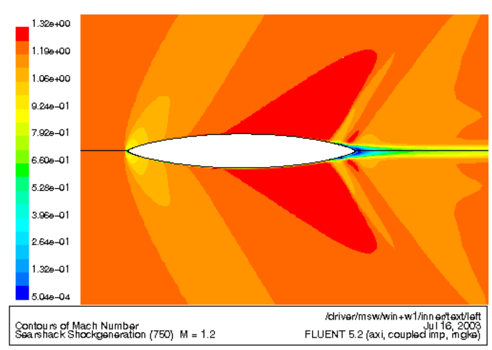

Fig. 3c Sears-Haack shock generator at 750 mm

Fig. 3a shows the Mach number contour of the Sears-Haack body; it has a weak shockwave appearing near the end of the body.

Comparing this situation to that associated with the MBB geometries, the Sears-Haack body produces weaker shock wave, hence the Sears-Haack body has smaller pressure drag. Fig 3b and 3c shows the Mach number contour of the Modified Sears-Haack body with shock generator located at 400 mm and 750 mm from the forward tip, respectively. It can be seen that the shock wave occurs at the location of the shock generator, as expected. As the shock generator is moved backward, the shock wave becomes weaker.

2) Cp Distribution

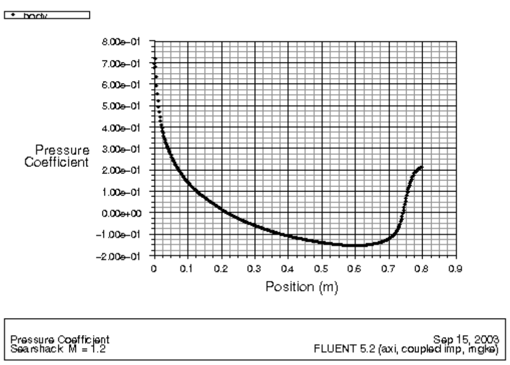

Fig. 4a Basic Sears-Haack

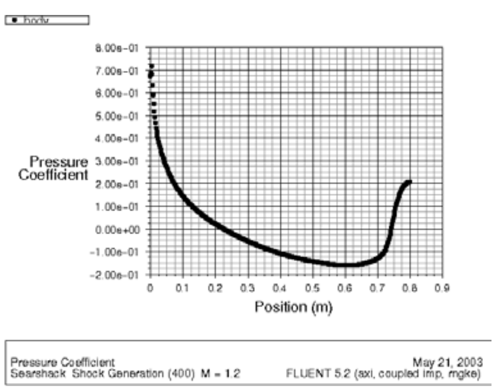

Fig. 4b Sears-Haack shock generator at 750 mm from the forward tip.

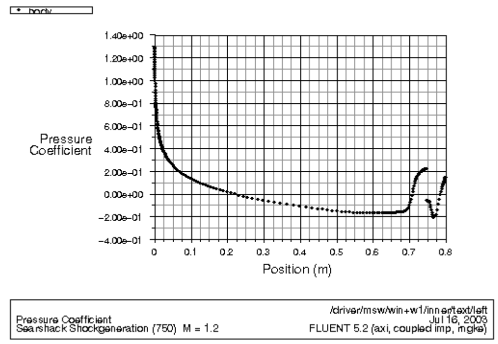

Fig. 4c Sears-Haack shock generator at 400 mm from the forward tip

3. Variation of drag due to location of shock generator.

The Navier Stokes flow solver has been applied for Sears-Haack geometry with various locations of the shock generator for Mach number = 1.2. The contours of Mach number for the Basic Sears-Haack body is shown in Figure 3a while for several cases with shock generator are exhibited in Fig 3b and 3c. The variation of drag (Cd) with respect to the location of shock generator is shown in Table 1. As already well known, the maximum drag occurs near the sonic free stream velocity. The search for the optimum geometry from the viewpoint of drag can be focussed to this figure. These results show that the configuration shown in Fig. 3c, i.e. Sears-Haack geometry with shock generator at 750 mm, produces the best (minimum) drag characteristics.

4. Conclusion

a. Flow characteristics of two geometrical configurations, i.e. MBB and Sears-Haack bodies, have been investigated within the transonic flow regimes (Mach = 1.2). This flow regime is characterized by the appearance of shock wave on the surface of the aft body. The pressure distribution along the surface that can be used to arrive at the most desirable aerodynamics characteristics.

b. The computational study of several geometries investigated shows that the Sears-

Haack geometry with shock generator at 750 mm yields the minimum drag compared to the other geometries at Mach 1.2.

c. Further study is in progress to look at more general situations, as well as carrying out a more structural optimization procedure.

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Table 1. Drag Coefficients (Cd) Summary at Mach = 1.2

No.	Geometry	Press	Viscous	Total
1.	MBB1	0.26352386	0.073817315	0.33734117
2.	MBB3	0.31749063	0.046469814	0.36396044
3.	MBB5	0.45696689	0.12505759	0.58202447
4.	Sears-Haack	0.19751272	0.054484563	0.25199728
5.	Sears-Haack – sg400	0.28412660	0.043204776	0.32733137
6.	Sears-Haack – sg500	0.26071091	0.044066008	0.30477692
7.	Sears-Haack – sg600	0.24511318	0.045278886	0.29039207
8.	Sears-Haack – sg700	0.23110209	0.049978036	0.28108013
9.	Sears-Haack – sg750	0.19765079	0.051216381	0.24886717