Some Observations on the Adams Body of Minimum Wave Drag

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Nomenclature

B = body base area/$(\ell/2)^2$
D = wave drag
e = x at $S'(x)=0$
ℓ = body length
q = dynamic pressure of freestream
r = body radius at x
$S(x)$ = nondimensionalized body cross-sectional area $\pi r^2/(\ell/2)^2$
V = body volume/$(\ell/2)^3$
x = distance made nondimensional with respect to $\ell/2$ and measured along body axis from midpoint of body

Introduction

IN connection with arriving at a reference equivalent axisymmetric body shape of minimum wave drag (based on linearized supersonic theory) for a given length and volume against which the performance of any wing-body configuration could be judged, a study of the Adams body of minimum wave drag[1] was made. During this study some interesting points came to light, as reported here.

Body Shapes

The cross-sectional area variation for an optimum body of given length, volume, and base area for minimum wave drag [Ref. 1, Eq. (24)] is

$$S(x) = \frac{8}{3}\,\frac{V-B}{\pi}\,(1-x^2)^{3/2} + \frac{B}{\pi}\,x\,(1-x^2)^{1/2} + \frac{B}{\pi}\cos^{-1}(-x) \quad -1 \le x \le 1 \tag{1}$$

The first term of RHS in Eq. (1) corresponds to the area variation of a Sears-Haack body (i.e., optimum body for given length, volume, and zero base area). The second and third terms together correspond to the area variation of a Karman-Ogive body (i.e., optimum body for a given length and base area). Thus, it is seen that the optimum body for a given length, volume, and base area is made up of two area distributions, the one corresponding to a Sears-Haack body and the other corresponding to a Karman-Ogive body, the tradeoff occurring between the two depending on the value of B/V. When $B=0$, it is completely a Sears-Haack body; when $B=V$, it is completely a Karman-Ogive body. The $S(x)/V$ variation for different values of B/V are plotted in Fig. 1. In Ref. 1, the location of the maximum thickness of such bodies is given by

$$e = \frac{1}{4[(V/B)-1]} \tag{2}$$

e is not necessarily the location of the maximum thickness, but the location where $S'(x)=0$ other than at the nose and the base, where $S'(x)$ is always zero for such bodies. For some cases this additional location of $S'(x)=0$ may correspond to the location of the maximum thickness as well.

It is interesting to see how e varies with B/V. When $B/V=0$, $e=0$; i.e., the location of $S'(x)=0$ occurs at the midpoint of the body. As B/V increases, e also increases, and at $B/V=4/5$, $e=1$; i.e., the location of $S'(x)=0$ occurs at the base. Between $B/V=0$ and $B/V=4/5$ the location of $S'(x)=0$ also corresponds to the location of the maximum thickness point. As B/V increases beyond 4/5, e increases beyond 1, and as B/V approaches 1, corresponding to a Karman-Ogive body, e approaches $+\infty$. As the value of B/V crosses the value 1, the value of e jumps from $+\infty$ to $-\infty$. As the value of B/V increases from 1 to $B/V=4/3$, e varies from $-\infty$ to -1. Thus, for values of B/V lying between 4/5 and 4/3 this additional location of $S'(x)=0$ has no physical significance. Since $S'(x)=0$ at the base in any case, the maximum thickness occurs at the base for B/V between 4/5 and 4/3. For B/V beyond 4/3, this location of $S'(x)=0$ lies again within the body length, but no physical body can exist since $S(x)$ becomes negative in some regions of the body.

In Ref. 1, the discussion was limited to those bodies for which e lies between 0 and 1, thus limiting B/V to 4/5.

Wave Drag

The wave drag of the Adams body is

$$D/q(\ell/2)^2 = [8V(V-2B) + 9B^2]/\pi \tag{3}$$

From Eq. (3), it is obvious that the optimum body of minimum wave drag for a given volume and length is $B/V=8/9$. Similarly, the optimum body for a given length and base area corresponds to $B/V=1$ (the Karman-Ogive body). The variation of drag with B/V is shown in Fig. 2.

In Ref. 1 drag is plotted vs B/S_{max}. It shows that drag is minimum when B/S_{max} is $=1$. It, however, does not bring out the point that all bodies with B/V ranging from 4/5 to 4/3 have $B/S_{max}=1$ and it is only the body with $B/V=8/9$ that has the minimum drag. It is to be borne in mind that it is drag that is being considered and not the drag coefficient based on maximum area. It may be further noted that the drag of the

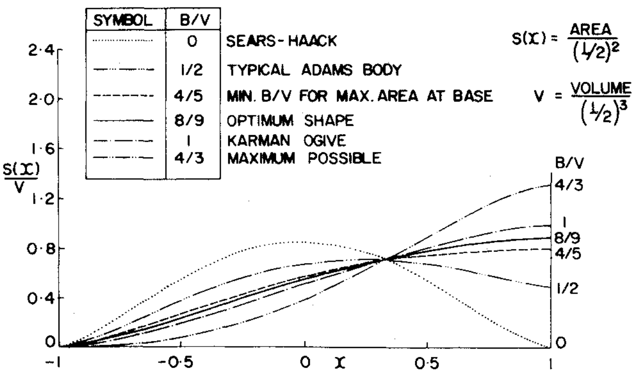

Fig. 1 Area distribution of Adams body for different base areas.

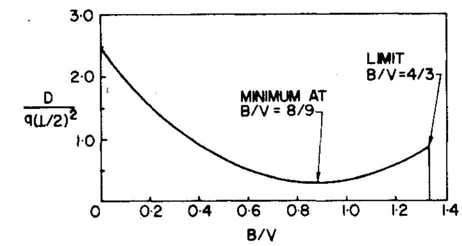

Fig. 2 Variation of drag of Adams body with base area for a given volume.

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optimum body for a given length and volume is 8/9 times the drag of the Karman-Ogive body of the same length and volume, whereas the drag coefficient based on the maximum area (i.e., base area) is the same for both. The body having minimum drag coefficient based on the base area has $B/V=(8/9)^{1/2}$, which lies between that of the optimum body and the Karman-Ogive body.

It may be mentioned that, since the base area of the optimum body is less than that of the Karman-Ogive body, the contribution of the base drag is also likely to be smaller and hence this body may be expected to be better than the Karman-Ogive body not only from the point of view of wave drag but even more so from the point of view of overall drag.

Conclusions

Reference 1 limits its discussion to bodies with B/V less than 4/5. It does not bring out the fact that (in the range of values of B/V from 4/5 to 4/3) there are several optimum bodies for which the maximum area occurs at the base. Among them the body with $B/V=8/9$ has the minimum drag for a given length and volume, and its drag is 8/9 times the drag of a Karman-Ogive body of the same length and volume.

Reference

[1] Adams, M.C., "Determination of Shapes of Boattail Bodies of Revolutions for Minimum Wave Drag," NACA TN 2550, Nov. 1951.

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