Engineering Notes

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Vortex Development on Slender Missiles at Supersonic Speeds

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Jerry M. Allen*
NASA Langley Research Center, Hampton, Va.
and
Marnix F.E. Dillenius†
Nielsen Engineering and Research, Inc., Mountain View, Calif.

Introduction

THE vortex patterns that develop on slender missiles can have a strong influence on their aerodynamic performance due to the induced velocities created by these vortices. The ability to predict the strengths and locations of these vortices over the entire missile would therefore be very desirable in evaluating aerodynamic performance. This Note describes a theoretical and experimental effort to develop such a vortex-prediction capability. The theoretical work is part of a larger effort to develop a linear-theory method of predicting detailed pressure distributions and fin loadings on complete missile configurations. A detailed description of the theory and the resulting computer codes required for the calculations can be found in Ref. 1.

Wind Tunnel Test

In order to investigate the validity of the computed vortex patterns, a companion experimental study was undertaken to obtain wind tunnel vortex data by the vapor-screen technique. The tunnel test was conducted at a freestream Mach number of 2.36 and a Reynolds number based on body length of 2.7 million. The test configuration is shown as a sketch in Fig. 1, and is a typical cruciform fin-circular body-cruciform tail model with a tangent ogive nose section. The forward fins could be deflected to simulate roll control. The camera used to record the vapor screen images was mounted inside the tunnel downstream of and a slightly above the test model. Three model attitude parameters—angle of attack α, angle of roll ϕ, and forward fin deflection angle δ—were varied during this test to gather data for comparison with the theoretical predictions.

Effect of Angle of Attack

The effects of angle of attack on the vortex patterns are shown in Fig. 1, which contains both vapor-screen photographs and theoretical calculations for the test missile. The data station is at the aft end of the missile, and the calculated results are plotted to the same scale as the photos. In the calculated results, the size of the black dots which represent the vortices indicates the relative strengths of the computed vortices, and the small tails indicate their direction of rotation, the rotational flow spiralling inward from these tails.

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*Aero-Space Technologist. Member AIAA.
†Research Engineer. Member AIAA.

At each angle of attack for the computed vortices the upper pair of vortices originated near the tips of the horizontal fins, while the lower pair originated on the nose. At the lowest angle of attack, the experiment and theory show a very similar pattern in terms of the number, location, and relative strengths of the vortices. As the angle of attack increases, both data and theory show that the vortices continue to grow in strength, and the data show that a sheet of vorticity develops which feeds onto the tip vortices.

At the largest angle of attack, there appears to be a continuous sheet of vorticity extending from one tip vortex to the other. Although the theory predicts very strong vortices, it cannot predict these sheets of vorticity. Hence the modeling of the vortex flowfield by a few discrete vortices is inadequate at these higher angles of attack. The present theory is thus limited to angles of attack α below about 20 deg.

Effect of Roll Angle

The effects of roll angle ϕ on the vortex patterns are shown in Fig. 2 which contains both data and theory for roll angles of 0, 22.5, and 45 deg. As the angle of roll increases, the vortex pattern becomes more complicated because of the vortices which develop on the vertical fins, and because of the interaction which develops between the top vertical fin and the nose vortices as this fin is rolled into the path of these vortices.

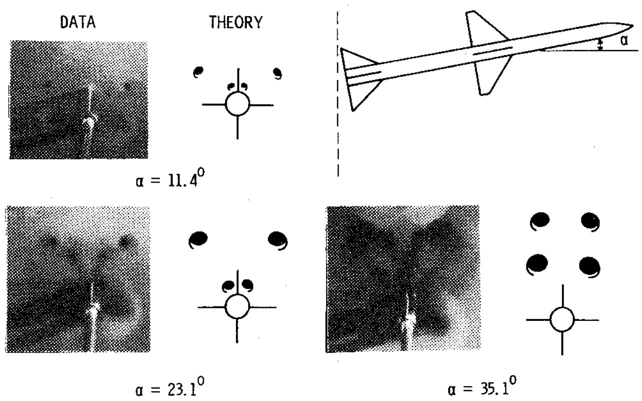

Fig. 1 Effect of angle of attack on vortex patterns: $\phi = 0$ deg, $\delta = 0$ deg, $x/l = 1.02$.

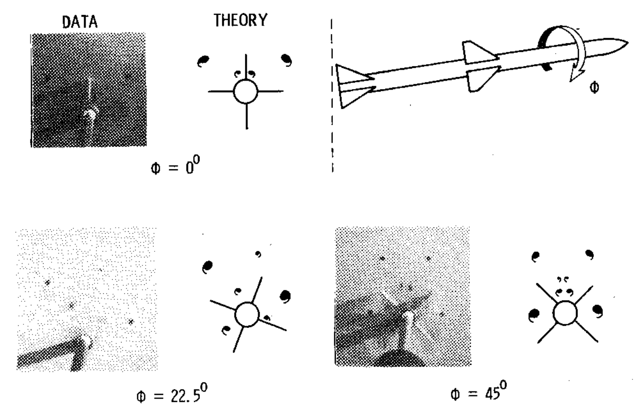

Fig. 2 Effect of roll angle on vortex patterns: $\alpha = 11.4$ deg, $\delta = 0$ deg, $x/l = 1.02$.

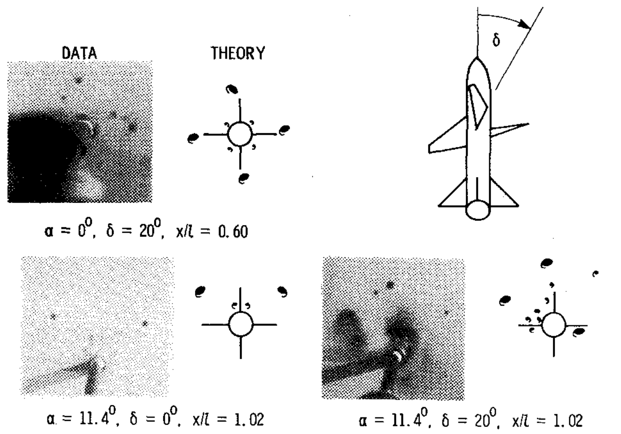

Fig. 3 Effect of forward fin deflection on vortex patterns: $\phi = 0$ deg.

At a roll angle of 22.5 deg, the top vertical fin is directly in the path of the right nose vortex. The rear fins have been removed from the missile in this photograph so as not to obstruct the view of the vorticity on the afterbody. This nose vortex appears in the data to have been displaced downward and to the right relative to the left nose vortex, and also appears weaker than the left vortex.

The corresponding theoretical calculations show that the observed movement of the right nose vortex is also predicted by the theory; however, no provision as yet exists in the theory to modify the strength of a vortex due to its interaction with a fin. There appears to be a fairly good agreement between the data and theory on the locations of the various vortices. The relative strengths also appear to agree, with the exception of the aforementioned right nose vortex.

At a roll angle of 45 deg, the nose vortices are no longer displaced and pass between the two upper fins. The theory plot reveals that all six of the primary vortices shown by the vapor screen photograph are predicted in approximately the same locations and relative strengths. The theory also predicts two additional vortices which are rather weak compared to the primary vortices. These weak vortices were predicted to originate on the inboard sections of the forward, upper fins as a result of the modified aerodynamic loading on these fins caused by the presence of the nose vortices. This weak vorticity does not appear in the experimental data as separate vortices.

Effect of Fin Deflection Angle

The computer codes developed in this study contain the capability to account for the effects of fin deflection on the computed vortex patterns. In order to investigate this aspect of the theory, vapor-screen photographs were obtained on the test missile in which all four of the forward fins were deflected 20 deg clockwise, as shown in the sketch contained in Fig. 3. The angle of roll is zero in this figure, and the fin deflection angles δ are 0 and 20 deg.

The data and theory in the upper left in this figure are for an angle of attack of zero and a fin deflection angle of 20 deg. The screen was located at 60% of the body length ($x/l = 0.60$). The data show that two vortices are created on each fin. One appears to be a normal outboard vortex, while the second is a weaker vortex which occurs on the inboard section of the fin, and is slightly counterclockwise relative to the outboard vortex.

The calculated vortices show exactly the same pattern as the data, except that the weaker vortices are somewhat more inboard and counterclockwise relative to the outboard vortices than they appear to be in the vapor-screen photographs. It should be noted that these vortices are caused entirely by the fin deflections since the angles of attack and roll are both zero. No vortices would be created, of course, if the fin deflection angle was zero.

The effects of fin deflection at an angle of attack of 11.4 deg are shown at the bottom of the figure, which contains results taken at the aft end of the missile. The deflected fins appear to create a rather complex pattern of vorticity in the vapor-screen photograph, including several discrete vortices and some areas of vorticity which are not rolled up into vortices. The computed results, which can only deal with discrete vortices, cannot duplicate these large areas of vorticity. In their place, however, the theory places a large number of individual vortices, as can be seen in the theory plot in the lower right part of Fig. 3.

Concluding Remarks

A theoretical and experimental effort has been made to develop a vortex-prediction capability on slender missiles at supersonic speeds. Using a slender fin-control missile as a test model, comparisons have been made between the calculated results and experimental data to assess the accuracy of the theory for various combinations on angle of attack, angle of roll, and fin deflection angle. The theory, based on a sparse number of discrete vortices, is capable of accurately predicting the number, location, and relative strengths of individual vortices which develop over the missile, but cannot predict vortex sheets or diffuse vorticity whenever they occur.

References

[1] Dillenius, M.F.E. and Nielsen, J.N., "Computer Programs for Calculating Pressure Distributions Including Vortex Effects on Supersonic Monoplane or Cruciform Wing-Body-Tail Combinations with Round or Elliptical Bodies," NASA CR 3122, April 1979.

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Differential Absorption Factors Between Two Area Elements in a Cylinder

90005

Masao Furukawa*
National Space Development Agency of Japan, Tokyo, Japan

Introduction

In connection with the thermal design of spacecraft, several computational procedures have been developed for dealing with radiant interchange between gray surfaces. One of them is the absorption factor method first introduced by Saunders[1] and then elaborated by Gebhart.[2-4] This method has not attracted as much notice as the radiosity approach which has been commonly used for temperature prediction. This is because, for many engineering purposes, the absorption factor concept is not as practical as the radiosity concept.

However, this method has a remarkable feature that absorption factors are independent of the temperatures of participating surfaces, whereas radiosities are dependent on them. Hence, for some configurations, the absorption factor method may greatly facilitate mathematical treatment of radiative heat transfer. Cylinders are of interest from this point of view. In addition, cylinders can be regarded as

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*Engineer, First Group of Satellite Design.