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Automated Technique for Developing Low-Drag Nose Shapes for Supersonic Missiles

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Abstract

MISSILE noses can have arbitrary base cross-sectional shapes and local constraints such as surface shape, width, or height at any station. An automated technique has been developed for shaping these noses to provide low drag at high supersonic speeds. Sensitivity derivatives relating local surface pressure and skin friction coefficients to local radius are derived and used to guide the surface shaping. The surface pressure coefficients may be estimated with a variety of impact theories. Comparisons of predictions and wind tunnel data verify the results.

Contents

Minimum drag nonaxisymmetric nose shapes of a spatular shape have been established by Pike[1] using Newtonian theory. The nose no longer has a stagnation point but has a stagnation line at the tip. The shape is minimum drag based upon Newtonian impact theory if star-shaped noses[2] are excluded. To establish the optimum spatular nose shape, selected body points were perturbed until the change in drag due to changing the coordinates was zero for every point. For complicated nose shapes which may require flat bottoms, nonaxisymmetric base cross sections, or dimensional constraints at various stations this process is time consuming and costly.

The formulation described in this Synoptic uses sensitivity derivatives to guide the surface shaping. The geometry models and pressure methods of the Mark IV Supersonic/Hypersonic Arbitrary Body Program (S/HABP)[3] are used to provide arbitrary geometry modeling. This program models a body by replacing the surface with quadrilaterals that approximate the original surface shape. Figure 1 is an example of a nose sectioned for modeling with quadrilaterals. Impact pressure methods such as Newtonian, tangent wedge, or tangent cone are then used to compute the local pressure coefficients based upon the freestream Mach number and the angle between the quadrilateral normal vector and freestream velocity. The pressure coefficients are integrated over the entire surface to determine the aerodynamic coefficients.

The axial force coefficient is the result of the summation of quadrilateral pressure coefficient, skin friction coefficient, unit normal vector, and area. A sensitivity to changes in local radii can be established by differentiating these summations with respect to local radii. This results in analytical expressions of the pressure coefficient, unit normal vector, and area derivatives with respect to the original radius. Although the derivatives are lengthy, once they are developed and programmed, their evaluation is rapid.

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The equations were programmed in a CDC computer code and verification of the procedure obtained by considering a fully axisymmetric shape. The theoretical optimum axisymmetric shape of fixed length-to-diameter ratio and based upon Newtonian theory is given in several sources[4,5] as a 3/4 power law nose. The initial shape selected to begin the iteration was a conical nose with a length-to-diameter ratio of 5. Figure 2 shows the original cone shape, the intermediate iteration shapes, and the converged 3/4 power law shape.

Another check of the method was to run a skin friction only case. With no surface pressure, a fixed length, and a circular base the minimum skin friction shape is a cone. The 3/4 power law shape of Fig. 2 was the starting point for this iteration. The cone shape was obtained in a few iterations.

For a half-ellipse base and fixed length nose, a spatular nose was predicted as a low-drag shape. Wind tunnel data for this shape is compared with predictions in Fig. 3 and indicates that S/HABP prediction methods are excellent at Mach 5.0 as shown in Fig. 4. The triangular nose shape is provided as a relative comparison.

Once the procedure was verified, the pressure methods suggested by Krieger et al.[6] for advanced supersonic cruise shapes were incorporated. The primary nose drag method recommended was the Dahlem-Buck Empirical from S/HABP.[3] This method provides higher pressure coefficients than Newtonian at low impact angles but fares into Newtonian at high impact angles.

Final verification of the nose procedure was obtained when wind tunnel data for the nose shape shown in Fig. 1 were obtained and the predicted Mach 4.0 axial forces were within 10% of measured with a large amount of uncertainty due to aft body skin friction and internal duct drag.

The technique provides a rapid design tool for developing arbitrarily constrained noses at Mach numbers as low as 3.0. The model is compatible with the Mark IV Supersonic/Hypersonic Arbitrary Body Program quadrilateral surface elements and pressure methods. Any pressure method may be used for which the derivatives with respect to local surface deflection can be computed. The current iteration process uses a man-in-the-loop because of the complexity of defining acceptable surface shapes. The shapes become star-

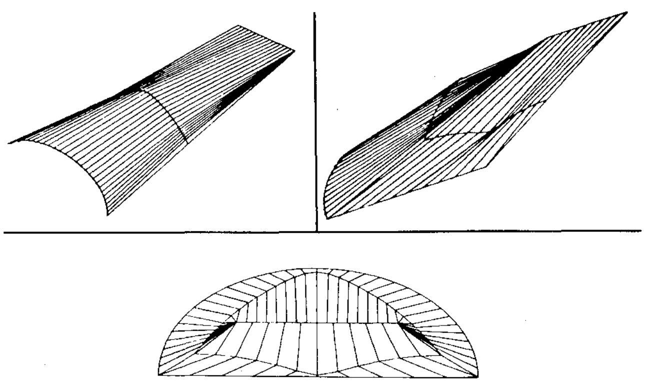

Fig. 1 Nose geometry is defined by quadrilaterals.

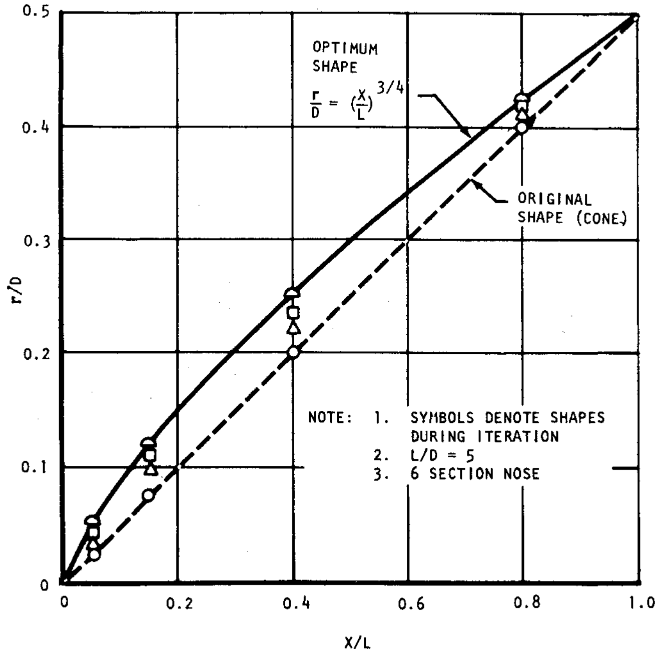

Fig. 2 Optimum Newtonian axisymmetric shape is predicted.

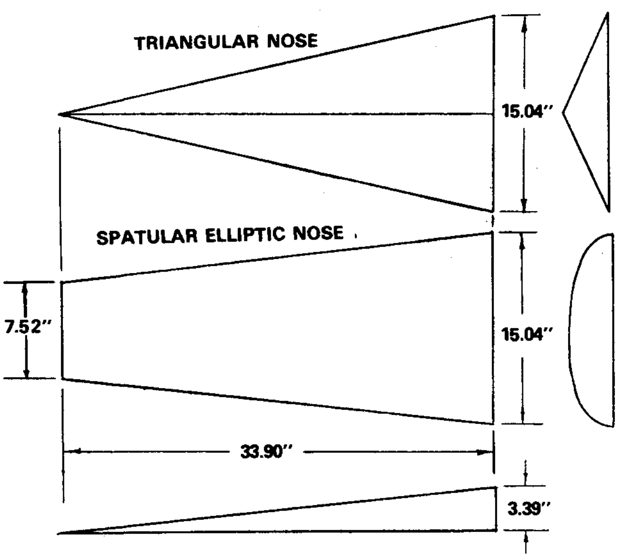

Fig. 3 Spatular and triangular nose wind tunnel models.

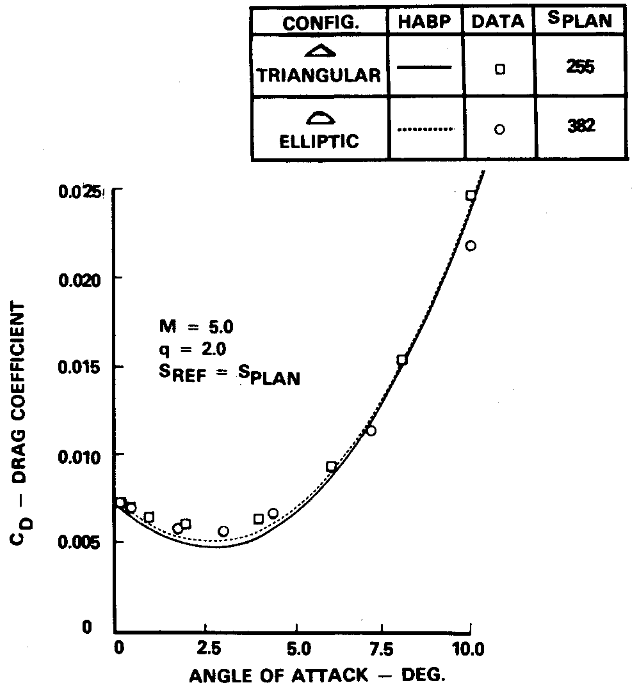

Fig. 4 Spatular elliptic drag coefficient is predicted.

shaped in cross section if they are total unconstrained. Wind tunnel data on several of the shapes have verified that the shapes are low drag.

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