Comprehensive Missile Aerodynamics Programs for Preliminary Design

M.F.E. Dillenius* and M.J. Hemsch†
Nielsen Engineering & Research, Inc.
Mountain View, California
and
W.C. Sawyer,‡ J.M. Allen,§ and A.B. Blair Jr.¶
NASA Langley Research Center, Hampton, Virginia

Contents

MODERN missile designs are aimed at high maneuverability and low profiles. Nonaxisymmetric body shapes and forward or tail lifting surfaces with tailored planforms are of interest. Missile configurations also may incorporate monoplane wings and interdigitated tails. Conventional missiles in use today require knowledge of nonlinearities caused by vortical interference between forward and rear finned sections. For high angles of attack, the nonlinear effects of body-shed vortices should be included in the design process. Rational methods of analysis capable of handling complete missile shapes and nonlinear effects are scarce.

Two classes of missile aerodynamics prediction programs are summarized herein and selected comparisons with experimental data are shown for two missile shapes. Further details and additional information are given in Ref. 1. The programs have been designed for different purposes, but both approaches account for high-angle-of-attack effects and include methods to account for the effects of forward fin wakes on the afterbody and tail fins.

Programs MISSILE1 (Ref. 2) and MISSILE2 (Ref. 3) belong to the first class of programs based on engineering methods and data bases for rapid estimates of overall and component forces and moments acting on missiles with axisymmetric bodies. In program MISSILE1, afterbody vortex characteristics are related to cross-flow drag theory, whereas MISSILE2 is equipped with a more sophisticated vortex cloud theory. The salient features of programs MISSILE1 and MISSILE2 are the data bases containing fin normal forces and centers of pressure derived from measurements on fins of varying aspect and taper ratios. The maximum angle of attack is about 45 deg, and the data base presently covers the range $0.8<M_\infty<3.0$ and $0.5<\mathcal{R}<3.5$. A new version, MISSILE2A, will work for $M_\infty \leq 5$ and $\mathcal{R} \leq 5$ for $\alpha_c \leq 20$ deg.

The set of supersonic missile programs DEMON2 (Ref. 4) and automated NSWCDM (Ref. 5) specialized to missiles with axisymmetric bodies are aimed at predicting pressure distributions as well as forces and moments. In essence, these programs are based on supersonic paneling and line singularity methods. Angles of attack can range up to about 25 deg and the range of application covers the low supersonic Mach numbers, $1.1<M_\infty<3$. The set of programs DEMON2 can handle an elliptic or axisymmetric missile body cross

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*Research Scientist. Associate Fellow AIAA.

†Manager, Missile Aerodynamics Department. Associate Fellow AIAA.

‡Assistant Head, Supersonic Aerodynamics Branch.

§Aerospace Technologist, Supersonic Aerodynamics Branch. Associate Fellow AIAA.

¶Aerospace Technologist. Supersonic Aerodynamics Branch. Member AIAA.

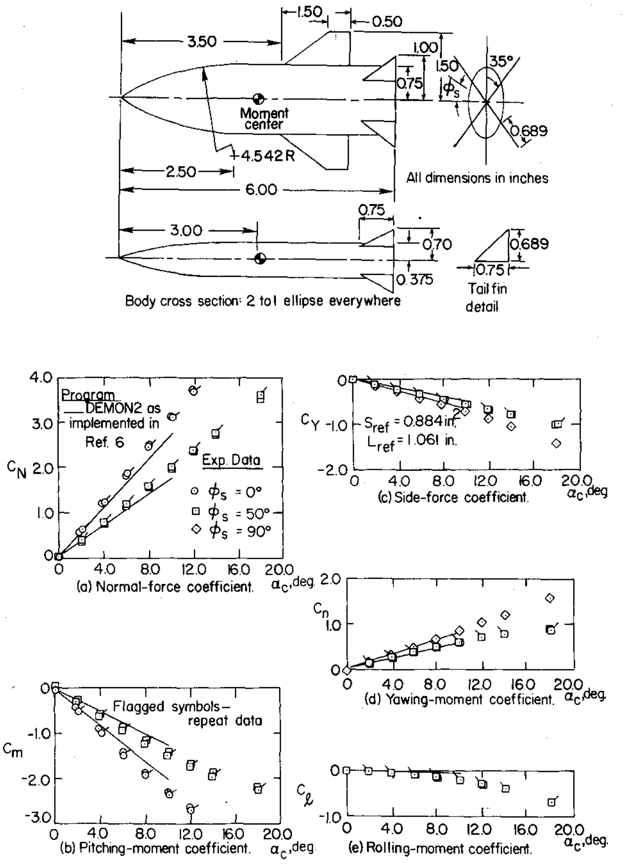

Fig. 1 Forces and moments acting on elliptic cross-section body with a monoplane wing and interdigitated tails, $M_\infty=1.5$.

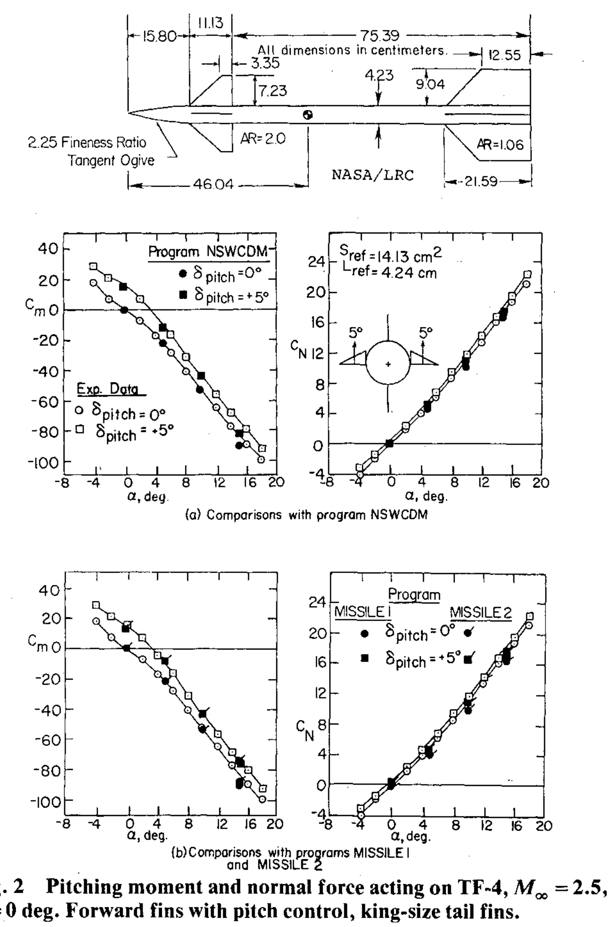

Fig. 2 Pitching moment and normal force acting on TF-4, $M_\infty=2.5$, $\phi=0$ deg. Forward fins with pitch control, king-size tail fins.

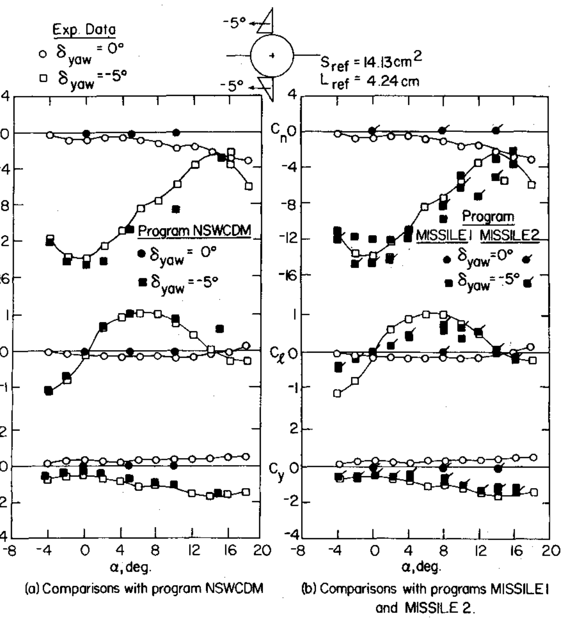

Fig. 3 Yawing moment, rolling moment, and side force acting on TF-4, $M_\infty = 2.5$, $\phi = 0$ deg. Forward fins with yaw control, king-size tail fins.

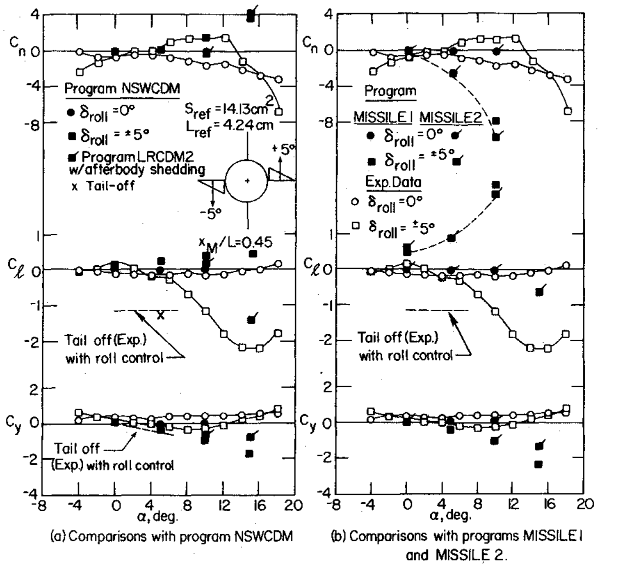

Fig. 4 Yawing moment, rolling moment, and side force acting on TF-4, $M_\infty = 2.5$, $\phi = 0$ deg. Forward fins with roll control, king-size tail fins.

section with monoplanar or cruciform wings and interdigitated tails by user organized repeated application of various subprograms. Program NSWCDM was extracted from DEMON2 and can handle canard-tail missiles with axisymmetric bodies without user intervention. This program contains forebody vortex characteristics, but afterbody vortex shedding is not accounted for.

The elliptic cross-section model at the top of Fig. 1 was treated by a DEMON2 version adapted to a supersonic store separation program.[6] Forces and moments acting on the complete configuration are shown as a function of the included angle of attack α_c for angles of roll ϕ_s equal to 0 deg (unrolled), 50 deg, and 90 deg. Positive roll is right wing down. The coordinate system in which the forces and moments are expressed rolls with the store. Effects of forebody vortices are not included in this instance and consequently predicted normal forces are somewhat low for α_c larger than 6 deg. Generally, effects of angle of roll are predicted very well.

Programs NSWCDM, MISSILE1, and MISSILE2 have been applied to the canard-controlled configuration of Fig. 2 for cases with pitch control, yaw control, and roll control by means of deflection of canard fins. An additional case for nonzero roll angle is given in Ref. 1. Pitching-moment coefficient C_m and normal-force coefficient C_N are shown in the upper and lower portions of Fig. 2 as a function of angle of attack α with and without horizontal canard deflection. The major effect of canard/tail interference including pitch control is to generate increased pitching moment with the normal force essentially unchanged. Predictions obtained with NSWCDM, MISSILE1, and MISSILE2 agree well with experiment.

Yawing moment C_n, rolling moment C_l, and side force C_y are shown in both the left and right portions of Fig. 3 for the case of yaw control. These quantities should be zero for zero control. At low angles of attack, the major effects of the canard/tail interference is to generate total side force less than that of the deflected vertical canards alone and to add to the yawing moment. More importantly, for nonzero angles of attack the canard vortices induce a considerable amount of nonlinear rolling moment. Programs NSWCDM, MISSILE1, and MISSILE2 repeat the essential features of the nonlinear behavior well. At higher angles of attack, the latter two programs predict the induced rolling moment very well due in part to the inclusion of afterbody vortex shedding effects.

Finally, for the case of roll control with the right and left horizontal canards deflected differentially as shown in Fig. 4, the lateral characteristics are shown on both the left and right sides. For zero control, these quantities should be zero. Tail-off rolling moment is also indicated. The essential effect of adding the tail fins is to cancel the roll control of the horizontal canard fins up to about 6 deg. Above this angle, the total rolling moment exhibits nonlinear behavior and actually exceeds the canard rolling moment. Program NSWCDM agrees well with the experimental data up to 6-deg angle of attack. The nonlinear behavior of the rolling moment above this angle is not predicted. Tail-off data are predicted well. Some results calculated by program LRCDM2 are also shown. This program is an extended and improved version of NSWCDM presently being finalized and includes an afterbody vortex shedding model similar to program MISSILE2. It is seen that this addition definitely improves the nonlinear portion of the rolling-moment prediction. Programs MISSILE1 and MISSILE2 predict erratic results for the moment coefficients for this case involving considerable flow asymmetry at the tail fin section. However, at 15-deg angle of attack, the MISSILE2 rolling moment appears to approach the experimental data, possibly due to the afterbody vortex cloud model included in that program.

In conclusion, the two different classes of missile aerodynamics programs summarized above are generally capable of predicting longitudinal characteristics well and can give good estimates of the nonlinear lateral characteristics for cases with yaw control. Program NSWCDM is capable of estimating rolling moment for roll control at low angles of attack. The addition of afterbody-shed vorticity appears to extend the range of application of NSWCDM.

Acknowledgments

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