Engineering Notes

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Missile Loads at High Angles of Attack

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Introduction

THE conceptual and preliminary design of missiles requires the use of aerodynamic prediction methods that are computationally efficient and accurate within some predetermined margin. These methods must be able to handle a wide range of configuration geometries and flight conditions. Discussed in this Note is the application of a general method to the case of subsonic, high angle-of-attack flight of a vertically launched missile. A comparison of the predictions is made to experimental results.

Missile DATCOM

The Missile DATCOM computer program[1] uses a number of separate prediction schemes to treat a wide range of geometries and flight regimes. For the current application to subsonic, high angle-of-attack flight, Missile DATCOM handles the body as a tangent-ogive nose attached to a slender cylinder, the wings and tails by subsonic fin-alone predictions for $C_{N\alpha}$ based on United States Air Force Aircraft DATCOM,[2] and component interference and external vortex flowfield effects by the equivalent angle-of-attack method. See Ref. 1 for a more complete description of the prediction methods. The Missile DATCOM authors note that acceptable accuracy criteria were taken to be ±20% for the normal force coefficient C_N and the pitching moment coefficient C_M.

Vertically Launched Missile

The recent introduction of a vertical-launch capability for ships carrying surface-to-air missiles represents a major advancement in weapon system development. But due to requirements for certain trajectories, such as for sea-skimmer defense, high angle-of-attack demands may be placed on the missile. Angles of attack for anti-aircraft missiles may reach up to 50 deg during subsonic pushover maneuvers,[3] and requirements for ship-launched anti-submarine weapons may demand angles of attack up to 70 deg during the launch phase.[4]

An experimental investigation is under way studying the effects of a very-low-aspect-ratio strake/wing configuration on asymmetric-vortex-induced side forces at high angles of attack. A review of the formation of asymmetric vortices and a presentation of the initial results are given in Ref. 3. In that study, side forces were presented for various conditions over a range of angles of attack up to 90 deg. Presented here is a comparison of the experimental data with Missile DATCOM predictions for the normal forces.

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Wind-Tunnel Program

The vertically launched surface-to-air missile (VLSAM) model is a 1/7-scale representation of current ship-based missiles. The model is of a cruciform tail-control missile with narrow strakes and long dorsal wings, with a tangent-ogive forebody of fineness ratio 2.29 (see Fig. 1). Forces and moments were measured by an internal sting-mounted six-component strain-gauge balance. Runs were made for three configurations: 1) without wings and strakes, 2) at 0-deg roll angle (ϕ = 0 deg) in the + orientation, and 3) at ϕ = 45 deg in the *x* orientation.

Because of particular tunnel requirements described in Ref. 3, pressure losses limited the available Reynolds number to 1.1×10^5 and Mach number to 0.1. Though the actual Mach number is lower than expected during pushover maneuvers, it is anticipated that the results may give an indication of the behavior at higher Mach numbers but still well below the transonic regime. For a more complete discussion of the wind tunnel and experimental apparatus see Ref. 3.

Results

Figure 2 shows the normal-force results for the case without strakes and wings. The tail surfaces were left intact on the model during these runs. Modeling of the tail surfaces was included in the computer program input.

The figure shows the comparison between the wind-tunnel data for C_N and the Missile DATCOM prediction values. The correlation over the angle-of-attack range is extremely good. Between 5 and 30 deg the C_N values are overpredicted; between 30 and 50 deg both the values of C_N and the slope $C_{N\alpha}$ are predicted extremely well. From 50 to 90 deg the error remains within a 10% margin for C_N. Evidently the prediction scheme used for tangent-ogive bodies holds at low Mach and Reynolds numbers well within the required accuracy specified for a preliminary design code.

Figure 3 shows the normal forces for the complete configuration at ϕ = 0 deg. The prediction is well correlated in C_N and in $C_{N\alpha}$ up to about 10 deg; a poor prediction in $C_{N\alpha}$ between 10 and 40 deg results in C_N errors of about 40%. Between 40 and 55 deg, the values of C_N are in error but the predicted slope $C_{N\alpha}$ is good. The maximum value of C_N over the angle-of-attack range is fairly well predicted, but at much too high an angle of attack. An apparent limitation relates to the method of subsonic fin-alone prediction. Applications are noted for aspect ratios above 0.5, whereas the VLSAM has wings of much lower aspect ratio. Nonlinear normal-force predictions are based on typical wing stall behavior at subsonic speeds, obviously not applicable to the low-aspect-ratio VLSAM wings/strakes.

Figure 4 shows normal-force results for ϕ = 45 deg. In contrast to the previous case, values of C_N and $C_{N\alpha}$ are poorly predicted up to 15 deg but are better predicted at higher angles of attack. Between 15 and 60 deg $C_{N\alpha}$ is well predicted with the value of C_N being underestimated by a nearly constant amount. The error for C_N between 40 and 60 deg falls within

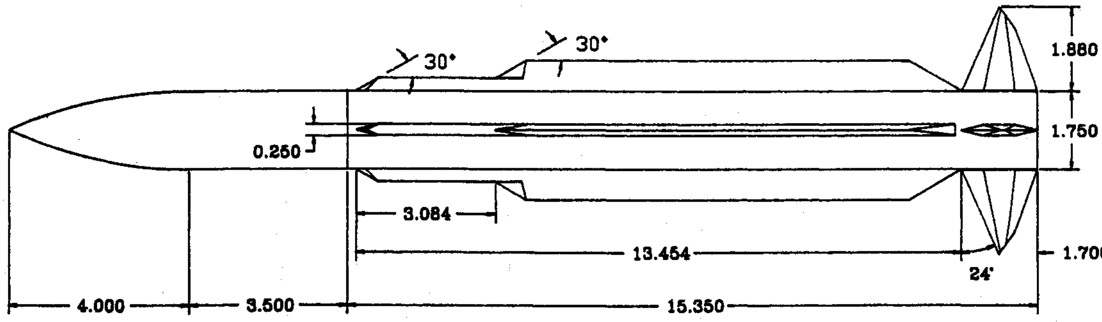

Fig. 1 VLSAM model (dimensions in inches).

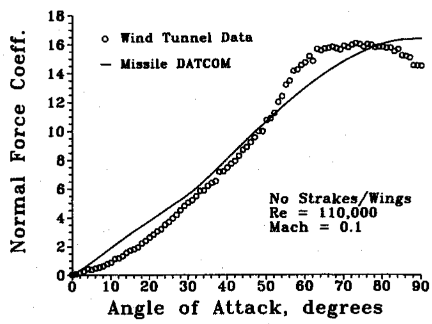

Fig. 2 Normal-force data and prediction—without strakes and wings.

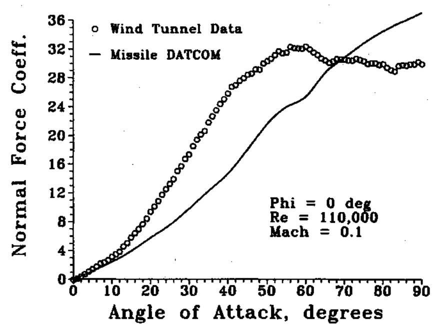

Fig. 3 Normal-force data and prediction—0-deg roll angle.

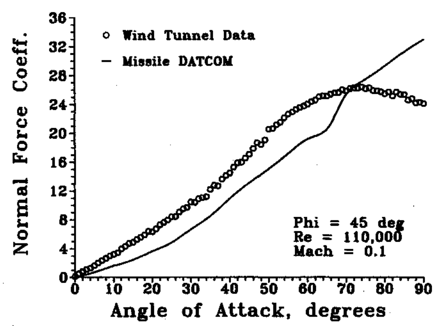

Fig. 4 Normal-force data and prediction—45-deg roll angle.

the specified margin allowable for preliminary design. However, as in the previous case, the experimental values of C_N fall off at higher angles while the predicted values tend to continue increasing. The curves for both roll angles cross at 70 deg.

To summarize, for the case studied, Missile DATCOM was found to predict normal-force behavior very well for the body-tail configuration, up to extremely high angles of attack. Poorer correlation was found to exist for the complete configuration at roll angles of 0 and 45 deg. A method better than can be achieved from extrapolated aircraft data must be developed to treat unconventional wing planforms.

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Flight Stagnation-Point Heating Calculations on Aeroassist Flight Experiment Vehicle

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Nomenclature

q = wall heating rate, kW/m^2
R = nose radius, m
T = temperature, K

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