High-Angle-of-Attack Wind-Tunnel Investigation of a Multimission Vehicle

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Introduction

THE advanced missile-airframe flight demonstration program of the Naval Air Warfare Center Weapons Division, China Lake, is developing a configuration for a multimission propulsion technology (MMPT) advanced technology demonstrator (ATD) vehicle. The vehicle will be vertically launched, and will rapidly pitch over to a 20-deg flight-path angle within 3 s. This will be primarily controlled by a thrust vector control (TVC) system with some assistance from the fins. The vehicle will experience angles of attack (AOAs) as high as 45 to 50 deg during this maneuver, but at relatively low velocity. Stability during this phase of flight is critical, since even a brief loss of control may result in the loss of the vehicle. Past programs have experienced difficulties in this operating regime with what is called adverse yaw. This consists of large yawing moments on the missile even though it is at a zero or small yaw angle and no yaw control is being input. The cause of this is now known to be asymmetric shedding of vortices off the body.[1] The problem is usually most severe in the 20- to 40-deg AOA range, and it is essential to know the magnitude of the yawing moment to ensure that the control system can correct for it and maintain the desired flight path. Current missile aerodynamic prediction codes such as Missile Datcom[2,3] do not have the capability to predict the asymmetric vortex shedding or to estimate the adverse yawing moment.

The analysis of the critical initial pitchover phase of the MMPT ATD vehicle requires reliable high-AOA aerodynamic data. Such data are also needed for experimental verification of the Missile Datcom prediction of the vehicle. In particular, the data on the longitudinal stability and lift characteristics of the vehicle up to the expected 45- to 50-deg AOA are required in the analysis. Since the vehicle is expected to have roll control via the fins, an evaluation of the roll control capability, especially at the higher AOAs where the Datcom prediction is questionable, is also required. The present investigation was therefore undertaken to determine the aerodynamic characteristics of the MMPT ATD vehicle. The study was conducted in the low-speed wind tunnel of the Naval Postgraduate School (NPS) using a scale model of the proposed MMPT ATD vehicle and a six-component force and moment balance. Additional details of the investigation appear in Ref. 4.

Test Facility and Test Conditions

The NPS low-speed wind-tunnel facility has a 45 × 32 in. rectangular test section, with a nominal freestream turbulence level of

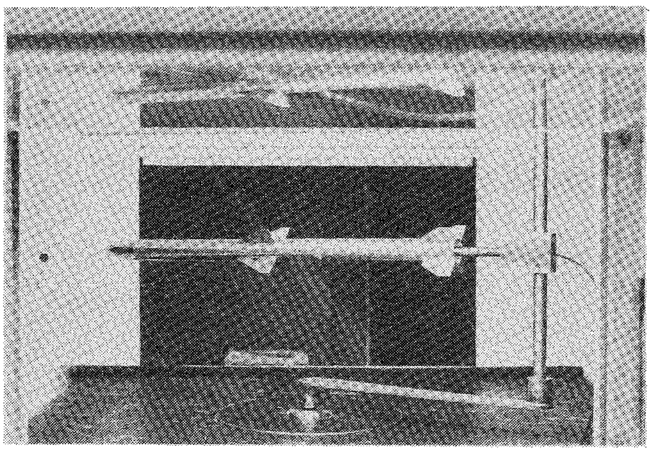

Fig. 1 MMPT ATD model sting-mounted in the NPS wind tunnel.

0.2%. The model support system was designed so that the model center remained on the wind-tunnel centerline as the AOA was varied (Fig. 1). The geometry allowed AOAs up to 90 deg, but data were not taken beyond 50 deg because the model nose would have been too close to the wind-tunnel walls. More details of the test facility may be found in Ref. 5. The model tested was of one-fourth scale and of conventional metal construction (Fig. 2). It was sting-mounted on a 0.75-in.-diam, six-component strain-gauge-type precision balance (Fig. 1). The forces and moments are presented for a reference center located 18.95 in. from the model nose. Both the reference length (2.00 in.) and the reference area (3.1416 in.^{2}) used in the data reduction are based on model body diameter.

All test runs were made at a nominal Mach number of 0.2 and a nominal Reynolds number of 2.4×10^5 (based on the model diameter), which corresponds to a dynamic pressure of 59 lb/ft^2 at a tunnel freestream velocity of 225 ft/s. The six-component force and moment data were obtained at 5-deg intervals in the 0- to 50-deg AOA range of 0-, 45-, and 22.5-deg roll angles of the model. The tests covered seven fin pitch-control deflection-angle settings ($\delta = 0, \pm10, \pm20$, and ±30 deg) and a 10-deg roll control input. The wing surfaces remained undeflected for all the runs.

Results and Discussion

The reduced data from all the test runs have been presented in standard coefficient form in Ref. 4. Only a few selected results from this data set are discussed below. The balance was rated at ±0.5% full-scale accuracy, but was believed to be better in view of experience with similar balances. The results of the previous tests with another model of about the same size have shown that the overall data repeatability was satisfactory.[6] Typical results for zero fin deflection are shown in Figs. 3 and 4. The 1985 version of Missile Datcom was selected for comparison because the pitching moment is usually the most critical item for use in missile flight simulations and the previous investigations[6,7] had shown that this version gives better agreement with the pitching-moment data than does the 1991 version. Note that, contrary to the expected zero value for the coefficient of pitching moment for a symmetric missile at 0-deg AOA and zero fin deflection, the data indicate a small, nonzero value for this coefficient. It is suspected that this was caused by the inability to establish exact pitch attitude (i.e., to ensure the AOA was really zero at its zero setting).

In general, the test data show the expected trends and agree well with the Missile Datcom predictions up to 20-deg AOA. The Missile Datcom predictions of normal-force and pitching-moment coefficients agree well with the test data up to about 20-deg AOA, but then diverge, with the prediction showing a stall and loss of lift at about 25-deg AOA that did not occur in the test data (Fig. 3). A close examination of the lateral aerodynamic moment characteristics shown in Fig. 4 reveals substantial yawing and rolling moments above about 25-deg AOA, even though the configuration is symmetric. This was expected, and is due to asymmetric vortex shedding off the missile model.[1] The Missile Datcom does not predict asymmetric vortex

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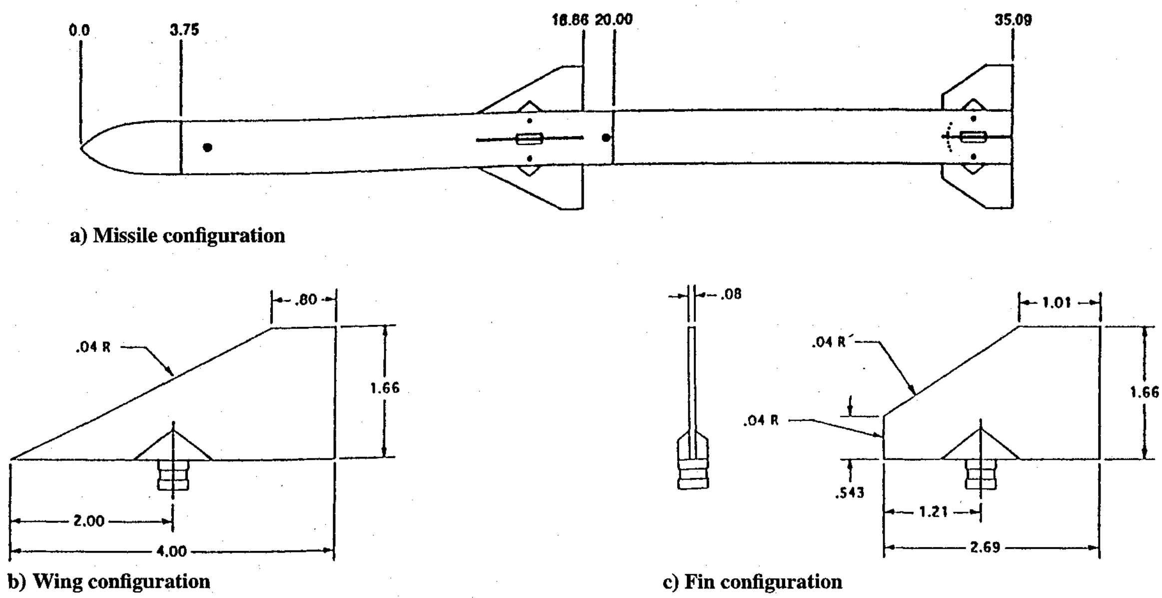

Fig. 2 MMPT ATD model configuration. (All dimensions are in inches.)

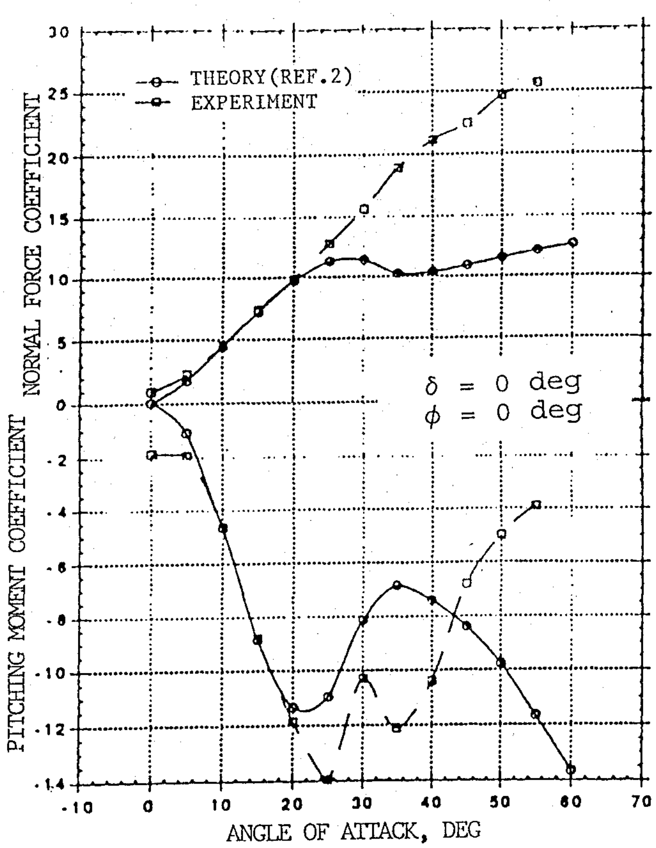

Fig. 3 Normal-force and pitching-moment data.

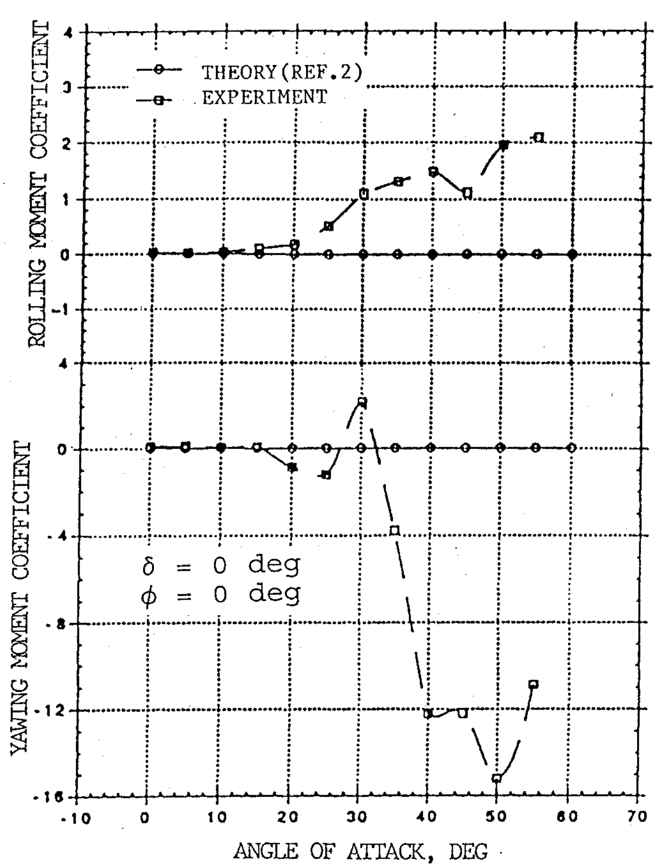

Fig. 4 Yawing- and rolling-moment data.

shedding for symmetric configurations, so the predicted rolling and yawing moments are zero. It should be emphasized here that significant amounts of adverse yaw were encountered during the tests, with yawing-moment coefficient as high as −15.0 for 0-deg roll-angle case at 50- deg-AOA. A yawing-moment coefficient of 15.0 corresponds to 206 ft · lb of yawing moment at Mach 0.2, while a 5-deg deflection of the TVC system of the MMPT ATD vehicle would yield 1734 ft · lb at the nominal motor thrust of 3500 lb. It is therefore expected that the TVC system should be able to easily handle the adverse yaw on the MMPT ATD vehicle.

Figure 5 shows the pitching-moment coefficient data for all seven fin control deflections. The data show generally good controllability, with nose-up or nose-down moment available for the entire AOA range, although the latter becomes weak at the higher AOAs. The results of a roll-control input, for which all four fins were deflected 10 deg in the right-wing-down roll direction, showed good roll control at low AOAs, but it actually reversed at higher AOAs.[4] The data for the 45-deg roll case were generally similar to those for the 0-deg roll case except for the fact that the normal-force coefficient agreed much better with the Missile Datcom prediction over a larger range of AOA. The results for the 22.5-deg roll case revealed substantial yawing and rolling moments with zero fin deflection.

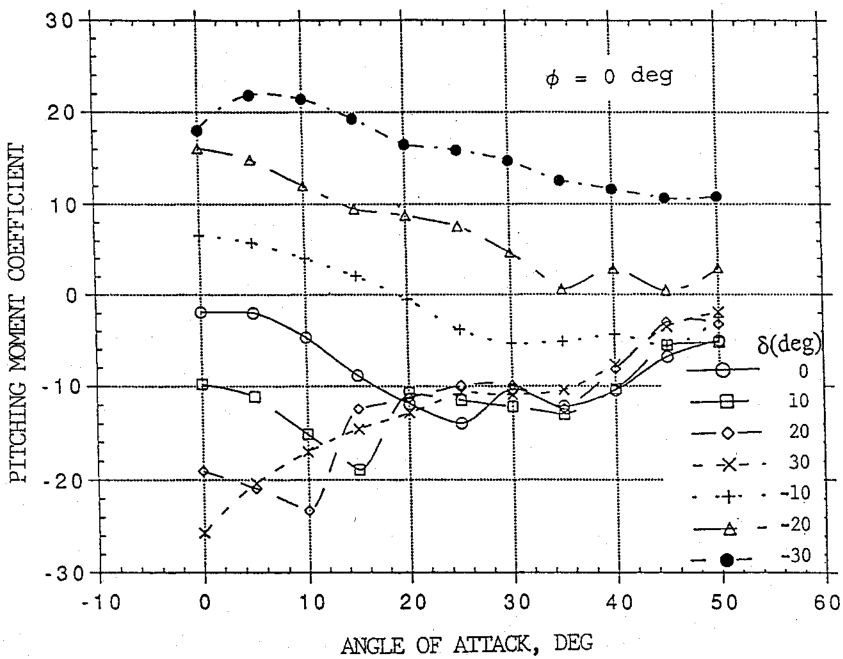

Fig. 5 Pitching-moment comparison for different fin deflections.

Conclusions

A low-speed wind-tunnel investigation was conducted on a one-fourth-scale model of a MMPT ATD vehicle to examine the high-AOA aerodynamic characteristics. The following conclusions are drawn from the results of the investigation:

1) The data show that the vehicle should be controllable, with the pitch control authority decreasing for AOAs above 30 deg and approaching zero at 50-deg AOA, especially for the 22.5-deg roll angle.

2) The data indicate a substantial amount of adverse yaw and rolling moment on the vehicle above 25-deg AOA.

3) The roll control authority is good at low AOAs, becoming weak or even negative at high AOAs.

4) The agreement between the experimental data and the Missile Datcom predictions is only fair, especially for AOAs above 30 deg.

Acknowledgments

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