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AERODYNAMIC CHARACTERISTICS OF A DELTA WING IN HYPERSONIC FLOW

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In space programs there has been a marked interest lately in the construction of a high-altitude aerospace vehicle (ASV) capable of making shuttle flights to earth orbits for the delivery of various payloads (including spaceship units and components). The various geometries and assembly configurations of such a vehicle are a topic of ongoing discussion among developers at conferences and in print, ground tests are being performed on models, and mathematical model computations are in progress.

The actual conditions of flow past an ASV cannot be fully modeled by ground-based wind tunnel research, so that mathematical modeling plays a fundamental role in determining the vehicle aerodynamic characteristics, and experimental data are used to verify the mathematical models. The Hermes aerodynamic research program utilizes test configurations and test regimes discussed in [1]. Considering the complexity of the experiments, it is important to perform measurements under various conditions (on different test facilities using several different methods) so that reliable data can be obtained.

Here we give the results of balance tests of a prototype delta wing model of the Hermes program for two sets of freestream Mach numbers M_∞ and Reynolds numbers Re_L calculated along the length of the model: 1) $M_\infty = 20.6$, $Re_L = 0.26 \cdot 10^5$ and $0.45 \cdot 10^5$; 2) $M_\infty = 8.0$, $Re_L = 7.1 \cdot 10^5$ and $8.5 \cdot 10^5$, and we compare the results with data from other authors.

1. EXPERIMENTAL APPARATUS AND PROCEDURE

The investigations at $M_\infty = 20.6$ are carried out in the T-327 nitrogen wind tunnel at the Institute of Theoretical and Applied Mechanics, Siberian Branch of the Russian Academy of Sciences (ITPM SO RAN) [2]. The apparatus has a working section in the form of a pressure chamber, and flow is generated by means of a conical nozzle with an orifice diameter of 220 mm. Off-model three-component strain gauges equipped with an innovative cooling system, are used for the measurements. The ranges of the measurements are as follows: longitudinal force X = 0 to 0.5 N; normal force Y = −0.5 N to 0.5 N; longitudinal (pitching) moment $M_z = -0.05$ N·m to 0.05 N·m. According to the results of numerous static calibration runs, the measurement error limits expressed in percentages of the measurement ranges are 0.5% for X, 0.5% for Y, and 0.25% for M_z. More detailed information about the balance and the procedure for balance experiments in the T-327 may be found in [3, 4], and the results of control model tests (a sphere, a truncated cone, and AGARD models HB-1 and HB-2) are given in [5].

The experiments at $M_\infty = 8.0$ are carried out in the T-236 wind tunnel at ITPM SO RAN. The ranges of the modeled parameters are $M_\infty = 6$–16 and (Reynolds number at unit length) $Re_1 = (50$–$700) \cdot 10^5$ m^{-1}. A resistance heater capable of reliably heating the air in the prechamber to 800 K is used for the operating regimes $M_\infty = 6$–10. The apparatus has an Eifel chamber and is equipped with interchangeable profiled nozzles having orifice diameters of 200 mm, which impart a high degree of uniformity to the flow core. The overall dimensions of the tested models are 50 × 50 × 150 mm.

An off-model three-component balance using silicon resistance strain gauges has been developed and fabricated for the T-326 wind tunnel, along with the analog balance of the kind used in the T-327, but engineered for large loads [6]. The balances are equipped with a high-efficiency thermostatting system, which permits the aerodynamic characteristics of models to be investigated experimentally in wind tunnels with high stagnation temperatures, and they are designed to operate in wind tunnels having a transverse flow diameter of 200–250 mm. The measurement ranges are X = 0 to 20 N, Y = −10 N to 10 N,

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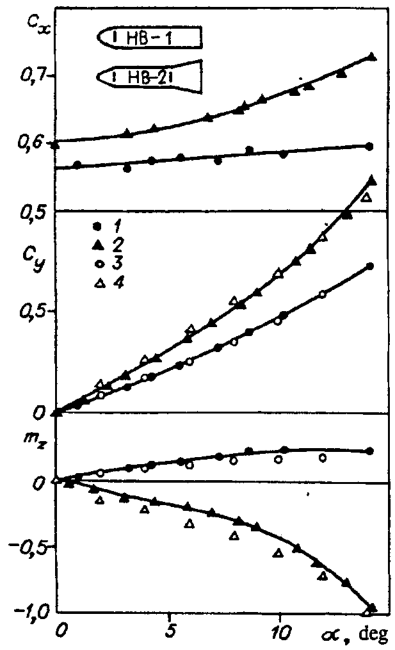

Fig. 1

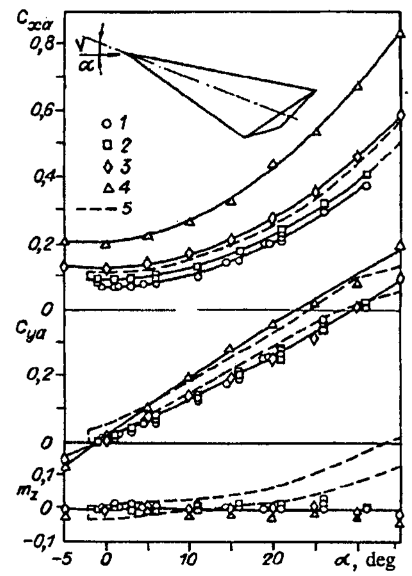

Fig. 2

and $M_z = -0.25$ N·m to 0.25 N·m. According to the results of numerous static calibration tests of each component, the measurement error limits are <0.2% of the measurement ranges. Here we give the first results obtained by means of these balances.

Two control models are tested in the T-326: HB-1 and HB-2, which are described in [7] and are shown schematically in Fig. 1. The cross-sectional area and diameter of the cylindrical part of the models are adopted as the characteristic area and length in the calculations of the aerodynamic coefficients and Reynolds numbers. The pitching moment is determined about the point on the longitudinal axis at a distance from the nose equal to 1.95 times the characteristic length. Graphs of the coefficients of longitudinal force C_x, normal force C_y, and longitudinal moment m_z as functions of the angle of attack for the control models are shown in Fig. 1, where the curves are numbered as follows: 1, 2) results of the present study ($M_\infty = 8.0$, $Re_L = 1.8 \cdot 10^5$); 3, 4) results of Ludwieg et al. ($M_\infty = 6.0$, $Re_L = 5 \cdot 10^5$); 1, 3) HB-1; 2, 4) HB-2. It is evident from the graphs that the HB-1 and HB-2 aerodynamic characteristics obtained in the T-326 are in good agreement with those reported in [8].

2. RESULTS OF DELTA WING TESTS

The model comprises a ten-percent delta wing with sweepback $\chi = 70°$ and blunted leading edges. It is described in [1, 9–11] and is shown schematically in Fig. 2, where V is the freestream velocity vector, and α is the angle of attack. The area in plan view and the length L of this model are adopted as its characteristic area and length. The pitching moment is determined about the point located at a distance from the nose equal to 2/3 of the central chord.

In the present study two delta wing models with L = 78 mm ($Re_L = 0.45 \cdot 10^5$) and with L = 47 mm ($Re_L = 0.26 \cdot 10^5$) have been tested in the range $\alpha = -1°$ to 30°. To prevent the model restraining devices from entering into the flow at large angles of attack $\alpha = 15°$, a special bracket is used, mounted at an angle $\alpha_0 = 20°$ relative to the axis of the balance. Figure 2 shows the aerodynamic characteristics of a delta wing, obtained at $M_\infty \approx 20$: 1, 2) results of the present study ($M_\infty = 20.6$, $Re_L = 0.45 \cdot 10^5$ and $Re_L = 0.26 \cdot 10^5$); 3, 4) results of Allegre et al. [9] ($M_\infty = 20$, $Re_L = 0.08 \cdot 10^5$ and $M_\infty = 20.2$, $Re_L = 0.03 \cdot 10^5$); 5) results of Chun [10] ($M_\infty = 24.3$, $Re_L = 0.26 \cdot 10^5$). The dashed curves represent the outer bounds of the points obtained in [10]. It is clearly visible that the drag coefficient C_{xa} increases as Re_L decreases for all the tested angles α in the transition region from continuous to free-molecular flow. The lift coefficient C_{ya} is far less dependent on Re_L. The results obtained here and reported in [9] for even smaller values of Re_L show that the pitching moment coefficient

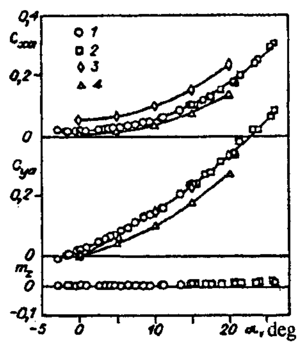

Fig. 3

m_z is close to zero, and the center of pressure is in practically the same position for all angles of attack. These results contradict the data in [10], which indicate that the center of pressure shifts upward with increasing α under the influence of viscosity, causing m_z to increase. However, the author of [10] mentions a large error in measurement of the longitudinal moment. The accuracy of the experiments reported in [10] is most likely inadequate.

In the present study two delta wing models have been tested at $M_\infty = 8.0$: one with $L = 120$ mm ($Re_L = 8.5 \cdot 10^5$) in the range $\alpha = -3°$ to $15°$ and the other with $L = 100$ mm ($Re_L = 7.1 \cdot 10^5$) in a bracket mounted at an angle $\alpha_0 = 20°$ relative to the balance axis in the range $\alpha = -15°$ to $26°$. Figure 3 shows the aerodynamic characteristics of a delta wing and a slender, flat, triangular wing with the same sweepback, obtained for $M_\infty \approx 8$: 1, 2) results of the present study for a delta wing ($M_\infty = 8.0$, $Re_L = 8.5 \cdot 10^5$ and $Re_L = 7.1 \cdot 10^5$, respectively); 3, 4) data for slender, flat, triangular wings from [12] ($M_\infty = 8.1$, $Re_L = 0.11 \cdot 10^5$) and [12] ($M_\infty = 8.2$, $Re_L = 8.5 \cdot 10^5$). It is evident from the graphs that the values of C_{xa} and C_{ya} for the delta wing are approximately 20% higher than their counterparts for the flat triangular wing, m_z is practically equal to zero for the delta wing, and the center of pressure remains constant, consistent with our measurements for $M_\infty \approx 20$.

A comparison of the aerodynamic characteristics of the delta wing at $M_\infty \approx 20$ and 8 reveals significant differences between them: The coefficients C_{xa} and C_{ya} increase more rapidly with the angle of attack for $M_\infty \approx 8$ than for $M_\infty \approx 20$, and the dependence of C_{ya} on α is almost linear for $M_\infty \approx 20$, but is strongly nonlinear for $M_\infty \approx 8$. The variation of the aerodynamic characteristics of triangular wings are known to be affected mainly by the conditions of flow over the leeward surface. Measurements of the density field [11] and heat-flux field [10] on this surface of a delta wing show that the flow is attached at $M_\infty \approx 20$ in the range of angles of attack $0 < \alpha < 30°$, and neither vortices nor separation zones exist. At $M_\infty \approx 8$ [14] strong vortices are formed on the leeward surface, creating additional rarefaction, which causes C_{ya} to increase nonlinearly with the angle α.

We have thus shown that thermostatting of the strain-gauge elements enables one to build aerodynamic balances well-suited to reliable measurements in a high-temperature, hypersonic flow environment, and we have determined the wind-tunnel aerodynamic characteristics of delta wings in flows with $M_\infty = 8$ and 20.

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