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Hypersonic Aerodynamic Characteristics of Flat Delta and Caret Wing Models at High Incidence Angles

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Recent proposals concerning the space shuttle vehicle have revived interest in the aerodynamics of efficient lifting re-entry configurations. The flat-bottom delta has been extensively studied as a promising shape for the wide range of flight conditions encountered by the shuttle. An experimental study by Opatowski[1] has indicated that, in cruising flight, the caret wing has some advantage over the flat delta. There is, however, a lack of information on the force characteristics of caret wings under conditions appropriate to re-entry.

As a consequence of growing three-dimensionality and flow spillage from the windward surface at high incidence angles, the lift on flat delta wings is known to drop increasingly below the two-dimensional shock value. It appears reasonable to expect that a caret wing designed to support a two-dimensional shock at a high incidence angle will develop a significantly higher lift coefficient than the flat delta.

Based on such assumptions, an analysis by Townend[2] leads to the conclusion that the caret wing (or its variants) may prove superior to the conventional delta wing in re-entry performance.

This Note presents the results of comparative balance measurements on flat and caret delta wing models (with sharp leading edges swept back at 75°) undertaken to verify the preceding assumption, and also to obtain some quantitative indications. The tests were carried out in the 8-in. Gun Tun-

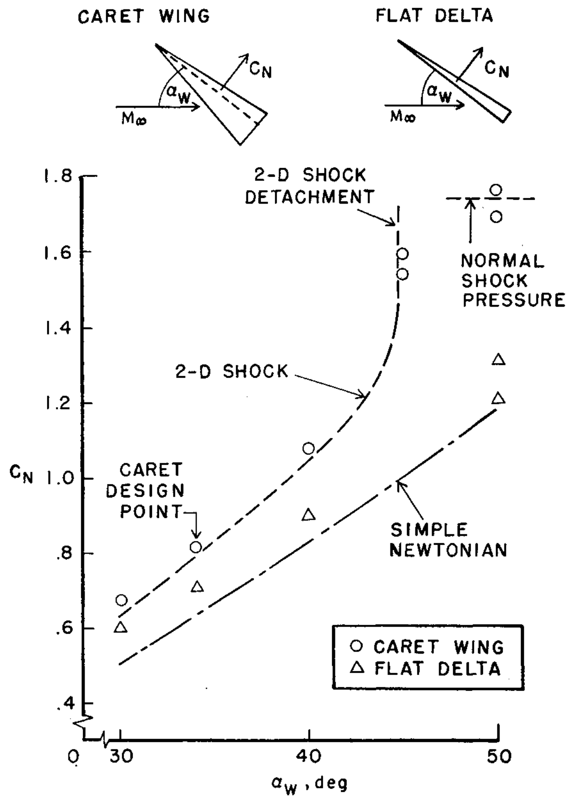

Fig. 1 Normal force measurements.

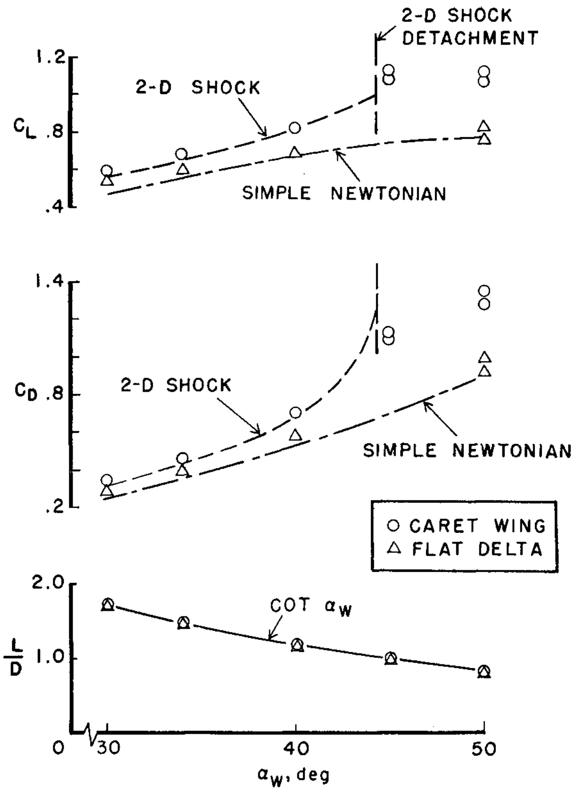

Fig. 2 Lift and drag data.

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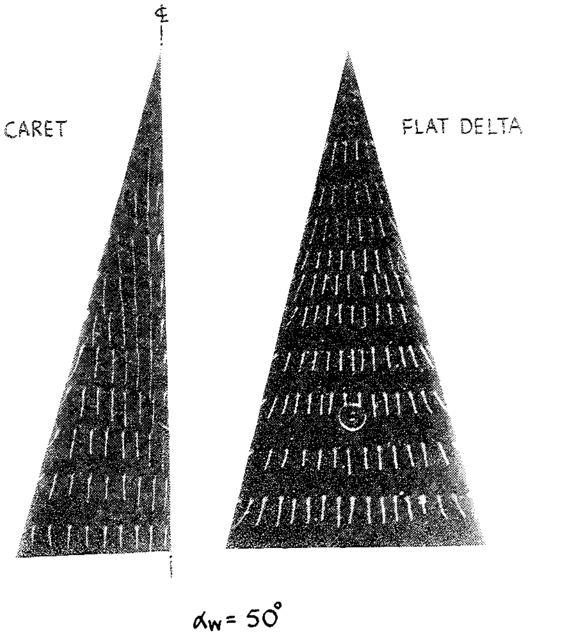

Fig. 3 Comparison of windward surface flow patterns on caret wing and flat delta.

nel at Imperial College, London, fitted with a contoured $M = 12$ nozzle, at a freestream unit Reynolds number of 0.15×10^6/in. (model Reynolds number based on center chord length 0.75×10^6). The 3-component strain-gage sting balance used for these measurements has been fully described in Ref. 1. The models were sting supported on the lee side, with a preset angle of 30° between the windward surface (or windward corner in case of caret wing) and the balance axis. The caret wing was designed to support a two-dimensional shock at $\alpha_w = 34°$ (incidence measured with respect to windward corner).

The normal force data for the two models, obtained from balance axial and normal force results are shown in Fig. 1. The caret wing develops a consistently higher normal force coefficient in comparison with the flat delta throughout the range of incidence. The two-dimensional shock theory predicts the caret wing characteristics quite well right up to the theoretical shock detachment, well beyond the design point. The measurements at higher incidence angles appear to continue to follow the two-dimensional shock trend. On the other hand, the flat delta normal force approaches the simple Newtonian value at the highest incidence of the test.

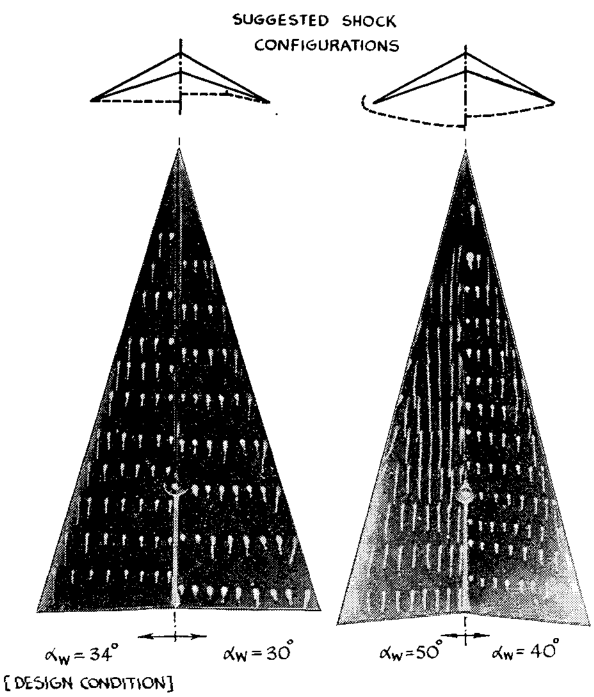

Fig. 4 Composite photographs of windward surface flow patterns on the caret wing.

The difference in terms of maximum lift coefficient (Fig. 2) is nearly 40% in favor of the caret wing under the conditions of the present tests. It may be noted that the lift/drag ratio coincides with $\cot\alpha_w$, indicating that at these high incidence angles the aerodynamic load is essentially generated by the windward surface pressure on both the wings, the axial force due to skin friction and base pressure being negligible.

Surface flow visualization on the windward surfaces at the maximum incidence of the test ($\alpha_w = 50°$, Fig. 3) reveals that the flow was essentially "contained" under the caret wing, the flow spillage being limited to a very narrow strip along the leading edges. With the flat delta, however, three-dimensional flow extends over a considerable portion of the pressure surface.

Additional oil flow results for the caret wing at different incidence angles (Fig. 4) show some interesting features. At design incidence, an essentially "two-dimensional" flow was achieved (i.e., flow parallel to the center chord). Regions of relatively high shear along the leading edge and low shear in the corner (along center chord) can be identified. At 30° incidence (i.e., only 4° below the design value) the flow entering the leading edge is directed inwards, a change to parallel flow apparently occurring along a conical ray close to the leading edge. As the incidence increases above the design value, coincident with the detachment of the leading-edge shock and the appearance of an attachment (or stagnation) line under the leading edge, the flow spills over the edge as seen for $\alpha_w = 50°$. These changes are, however, limited to the leading-edge zone, the flow over most of the windward surface of the caret wing remaining substantially "two-dimensional" over a large range of incidence. These flow visualization results serve to explain the superiority of the caret wing force characteristics over the flat delta.

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A Simplification Technique for Thermal Radiation in Gray Enclosures

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Nomenclature

A_i = area of i
F_{i-j} = over-all radiant interchange factor from i to j
G_{m-i} = over-all thermal conductance from node m to i
i = ith enclosure node
m = node number
M_i = number of nonenclosure nodes coupled to i

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