CONCEPTUAL AERODYNAMIC DESIGN OF MARTIAN AIRPLANE

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Extended Abstract

Introduction

A conventional approach to explore Mars includes the orbiting satellites or rovers moving on the Martian surface. On the other hand, a Mars airplane (Fig. 1) is a new approach to explore Mars. It provides high resolution than the orbiting satellites and larger spatial coverage than the rovers. It offers an additional advantage of maneuvering to specific locations of interest over other airborne platforms/ systems (e.g., balloons and airships). Design of a Marian airplane is challenging from aerodynamic design and engineering viewpoint. In this paper, a Martian airplane is designed to meet the specific requirements of performance and packaging. The effect of propulsion on the aerodynamic characteristics is not considered in the present study.

Design requirements

The design requirements of the Mars airplane is unique and differs from typical aircraft design requirements. For example, there is no take-off or landing requirements. But the range and payload requirements still exist for this science mission. Based on the typical earlier Mars mission profile, the following design requirements are set for the conceptual aerodynamic design of Mars airplane. (i) To design a stable tailless airplane for the cruise altitude of 1.5 km and Mach number of 0.6, (ii) To stow the airplane within 3.5 m diameter *Viking* aeroshell derivative (refer Fig. 1), (iii) To minimize the number of folding events. (iv) To achieve a flight range of above 500 km, (v) To provide sufficient longitudinal and directional stability, (vi) To cruise with minimal use of trimming surfaces, all with on-board propulsion system.

Design of the aircraft configuration

Thin Martian atmosphere requires the airfoil with high maximum C_L. In the present airfoil design, the requirement of good lift coefficient with stable pitching moment coefficient was set as a design objective. The required design lift coefficient estimated for the 120 kg mass of airplane is 0.42. Hence, the selected airfoil must meet this design lift coefficient requirement. Moment reference centre (mrc) of the airplane was fixed at 50% of the airplane length. The objective is to get a stable pitching moment curve which must trim (i.e pitching moment coefficient=0) at certain angle of attack where the lift coefficient is sufficient enough for cruise condition. Cruising near the trim angle of attack requires minimal use of trimming surfaces; therefore it meets one of the conceptual design requirements.

The airfoil analysis was carried out using public domain software *XFOIL* Version 6.96. The aerodynamic analysis at Mach number 0.6 and Reynolds number of 0.17 million for existing airfoils showed that all the airfoils except ESA40 (reflex airfoil) haven't met the design objectives. However, the airfoils with upward deflected trailing edge partially fulfill the requirement. For the tailless aircraft, airfoils with small or negligible pitching moment are recommended in general. ESA40 reflex airfoil has stable pitching moment curve and positive pitching moment coefficient at zero degree angle of attack (shown in Fig. 2) and trims at α= 3.3°. The maximum lift coefficient of ESA40 is 0.73, which is comparatively lesser than other airfoils. The reduced lift coefficient is due to the reflex nature of the ESA40 airfoil and it has to be increased further. Hence the ESA40 was selected as a baseline airfoil and carried forward for modification to increase its maximum value of lift coefficient. The lift and pitching moment coefficient of ESA40 and modified ESA40 are shown in Fig. 2.

The wing was designed to fit into 3.5 m diameter *Viking* derivative aeroshell taking care to minimize number of folds in the wing. The winglets were designed to augment the wing lift coefficient. Vertical tails were sized for directional stability, without violating the packaging constraints. The perspective view of the designed configuration is shown in Fig. 3 and the configuration under stowed conditions is shown in Fig. 4.

The aerodynamic characterization of the vehicle was ascertained after a number of CFD simulations using in-house Cartesian grid based Navier Stokes solver employing k-ε turbulence model with wall function approach. Though, the Reynolds number is low in the Martian atmosphere for the given condition, thus calls for laminar flow simulation, but the current solver has some limitation with laminar flow simulation. Therefore, in the present study, turbulent flow simulation was carried out as a first step and laminar simulation will be carried out in the future. Figure 5 shows the Mach palette and pressure palette over the designed airplane. The CFD simulations indicated that the vehicle is longitudinally stable (negative pitching moment curve slope) and that the vehicle is controllable with elevon deflection of 10 deg (Fig. 6).

Conclusion

A stable tailless blended wing Martian aircraft configuration with minimum folds (one on each wing) has been arrived at. The designed airplane can be stowed within 3.5 m *Viking* aeroshell derivative and has been verified using *CATIA* modeler. The CFD simulations of airplane using Cartesian grid based CFD solver for the cruise conditions indicate that the airplane has longitudinal stability and is longitudinally controllable. The airplane trims at angle of attack 6.3° compared to 4° for the airfoil analysis using *XFOIL*. This difference in trim angle is due to the wing-body-tail combinations. Cruising at this trim angle of attack minimizes the use of trimming surfaces. The present conceptual airplane meets the entire design requirement except the range of 500 km; the achieved range is 461 km with an endurance of 53 minutes.

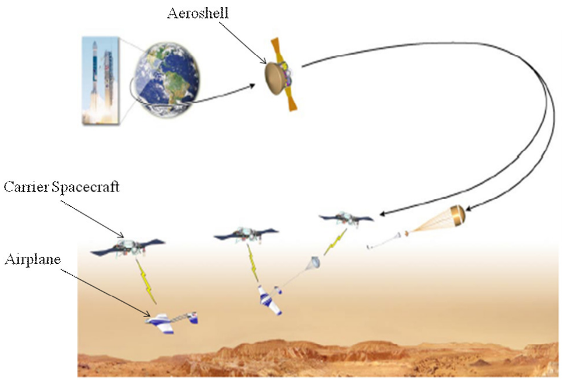

Fig. 1 Typical Mars mission profile (reproduced from AIAA 2003-6610)

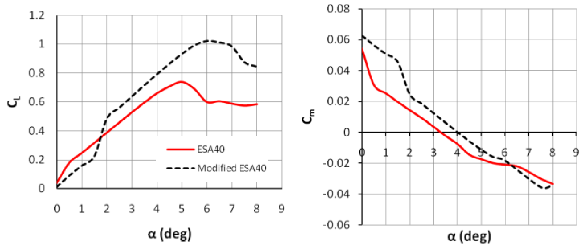

Fig. 2 Lift and pitching moment coefficient of the ESA and modified ESA airfoil

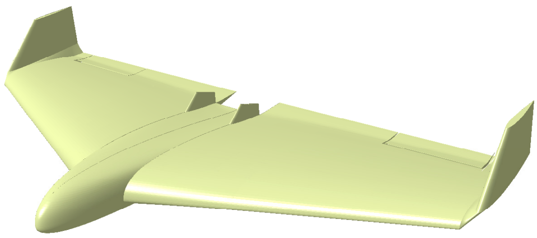

Fig. 3 Perspective view of the designed configuration

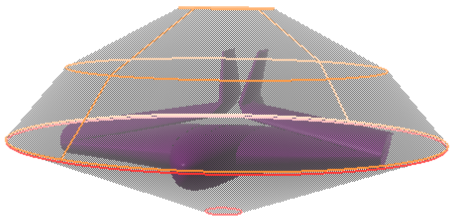

Fig. 4 Configuration stowed inside the 3.5 m Aeroshell

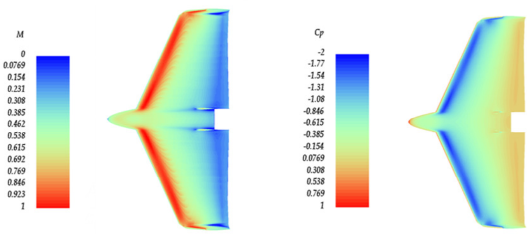

Fig. 5 Typical Mach and pressure contour plots over the Martian aircraft at M=0.6, α=6^0

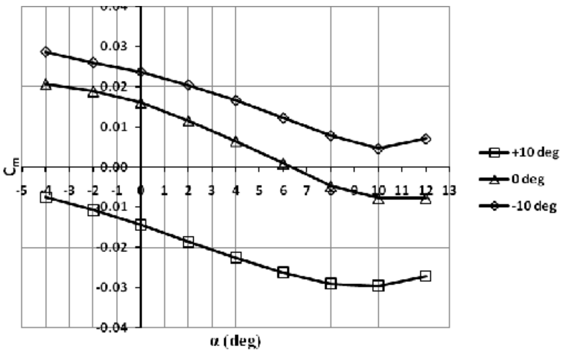

Fig. 6 Pitching moment coefficient of the configuration with elevon deflection