Structural Design and Analysis of Airframes for High Speed Aerothermal loads with different Material options

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1. INTRODUCTION & OBJECTIVE

Design of high speed airframe structure requires an exceptional attention to unique thermo-structural demands. In process of designing airframe,two primary functional requirements are high strength and light weight in selecting materials. Proposed airframe is a typical section of a Hypersonic vehicle (Mach no. >= 5). Airframe of a high speed vehicle is of unconventional shape. Vehicle flying at supersonic and hypersonic speeds experiences severe thermal environment and hence get heated up due to aerodynamic heating [1].

In hot structure design the base structure withstands the aerodynamic and thermal load. In passively cooled structural design the section is protected by thermal protection system(TPS). In this study we have addressed feasibility of hot structure design to meet design criteria. In order to study the structural behaviour of airframe section, linear static structural analysis is carried out on the stated sections and the stress and displacements are analysed for six different materials under three categories namely, Metallic, Composite and Refractory materials [2-5]. From present study, limit on thermal loads are arrived on different materials by meeting the design criteria.

Two airframe sections in present study, are shown in Fig.1 and Fig.2. These two sections, geometrically, are semi monocoque shell structures. Design criteria are to maintain a minimum factor of safety 1.25 and minimum Buckling Load Factor(BLF)1.5.Number of design iterations are carried out and results are evaluated to meet the design criteria.

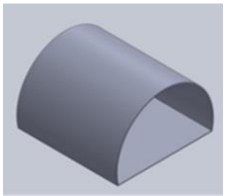

Fig.1: Middle Section

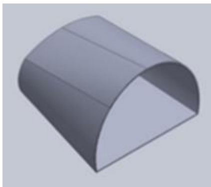

Fig.2: Forward Section

2. DESIGN METHODOLOGY

Analysis begins with the Basic Aerodynamic Configuration (BAC). From BAC to structural configuration (SC) is progressed in following steps,

1. Initial thickness arrived through empirical relations.
2. Shell model for Finite Element analyses is developed with the estimated thickness.
3. Front and Rear bulkheads are modeled with higher thickness (SC-1)
4. Static stress analysis performed imposing loads and boundary conditions, with commercial finite element software.

5. Based on results such as stress distribution and deformation, shell is stiffened with grids.
6. Grids spacing reduced to meet the design criteria.
7. Same procedure is followed for analyzing both forward and middle Section. Study was carried out for five different material options.

3. RESULTS AND DISCUSSION

The limit on temperature for various materials is obtained for the given configuration such that design criteria is satisfied with the thermo-structural loads. For the middle & forward section if we limit the temperature to 300°C and 400°C respectively, Titanium Alloy (Ti6AI4V) material option gives a minimum airframe mass. Similarly, if temperature is limited to 500°C and 600°C for middle and forward section respectively, Ceramic composite (C-SiC) gives a minimum mass design. C-SiC is a ceramic composite which is recently identified world-wide for airframe structures, subjected to very high speed environment.

4. CONCLUSIONS

The airframe sections have been designed successfully for the required strength and stability. Factor of Safety>= 1.25 and Buckling Factor >=1.5 for all material options. The two sections are designed for high thermal and structural loads.

It is observed that, for metallic design eventhough service temperatures are high, a safe design is feasible if only temperatures are limited to much lower value. This is because of thermal stresses and thermal deformations.

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