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Thermo Structural Analysis of Airborne Structure

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ABSTRACT

An Airborne Flight Vehicle (AFV) is a self-propelled aerial vehicle meant for transportation of people, cargo, payloads or measuring instruments etc. AFV is constituted by Payload, propulsion, control, guidance and navigation systems. The structures inside airborne flight vehicles are intended for integrating the sub systems to the flight vehicles. Such structures are designed to carry intended subsystems under acceleration loads arising due to the movement of the flight vehicle. Outer shell of the flight vehicle is exposed to outer atmosphere and subjected to aerodynamic heating. This heat gets propagated to the internal structure and thus reducing the mechanical properties of the structure material.

This paper deals with Thermo-Structural stress analysis of a structure which is designed for carrying 134 kg fuel tank under given loading conditions.

In this paper, a cylindrical flight vehicle section is to be fitted with a toroidal fuel tank whose mass along with the fuel is given as 134 kg. During flight, flight vehicle section gets heated up due to aerodynamic heating with a heat input of 22.5 kW. In the total flight time of 90s, this heat gets propagated to internal structures through conduction. The heat transfer due to radiation is neglected due to rapid heating of airframe during flight.

A structure is designed after several iterations. This structure consists of two rings joined together by a 2mm thick shell. One ring is attached to the flight vehicle section where as other ring carries the fuel tank. Intermediate shell acts as a connecting member. Ribs are added in the longitudinal direction to improve the stiffness of interface structure. Material is removed at intermitted location to reduce the weight of the section.

The Thermo structural analysis is carried out on the structure and the design is continuously improved after each iteration. This paper shows the design of final configuration of structure. The structure is in realizable state and ready for fabrication.

KEYWORDS: *Airborne Flight Vehicle; Toroidal bottle; and Thermo-Structural analysis.*

I. INTRODUCTION

Flight Vehicle is a kind of transportation device which is equipped for going inside the air/air or to the space. It includes the simple hot air balloon, the conventional airliner, fighter aircraft, rockets, missiles and even the sophisticated space shuttle. Basically flight vehicle moves through the atmosphere or ahead of it without any direct support from the surface.

1.1 Components of Flight vehicles

1. Flight vehicle compositions
2. Aerodynamic Lift surfaces
3. Propulsion systems
4. Aerodynamic Control surfaces
5. Guidance, Navigation and Control systems
6. Flight Instrumentation
7. Payload or Cargo

1.1.1 Flight Vehicle Structures

Flight vehicle consists of many structural elements viz. Fuselage, Wings, Horizontal and vertical tails, Aerodynamic control surfaces and internal structural components for attaching all propulsion systems like engine or Rocket motor and electronic subsystems to aircraft. These structural components house all the sub-systems together. These structures are designed to take all the loads (forces and moments) which are due to flight vehicle acceleration loads, Aerodynamic loads such as lift, drag forces, Propulsion loads, Thermal stacks because of Aerodynamic warming and heat from Propulsion systems etc.

II. Requirement Specifications

2.1 Need for development

Presently, flight vehicle is mounted with liquid propellant based 0.5 ton thrusters for controlling the flight vehicle in end phase. Toroidal tank of 80 liter capacity is used for storing propellant / fuel. The tank is to be mounted on a mounting structure in a cylindrical airframe. The tank mounting location is finalized based on the mass property and assembly requirements.

Geometric model of the Fuel Tank is made of Titanium alloy. It is a torodial bottle with elliptical cross-section. It is provided with six lugs which are welded to the body as shown. The bottle should be mounted on the flat faces of these lugs and fastened using M10 bolts of six numbers. Fuel Tank is provided with an inlet port and an outlet port. Fuel from the tank is supplied to the thruster from outlet port based on the requirement.

III. Thermo Structural Analysis

3.1 Material behaviour at high temperature

Materials working outside room temperatures are exposed to thermal loads that may arise from different sources:

Hot sources: from hot gasses, fire, proximity to heat sources such as boilers, incinerators and engines, hot process fluids, or belonging to heat generating equipment such as heat engines.

Cold sources: from low temperature process fluids, cold storage, or cold winter temperatures.

The temperature change not only affects mechanical behaviour as an additional load, but modifying all material properties.

Metals are generally specified for operating at or about the ambient /room temperature (about 20° C). When a metal is used away from this temperature its properties are affected. In general a metal gets to be distinctly weaker and more flexible at hoisted temperatures and gets to be distinctly fragile at exceptionally low temperatures. The metal standards often allow for this by specifying low temperature tests for metals to be used at lower temperatures.

Most ferrous metals have a maximum strength at approximately 200°C. The strength of non-ferrous metals is generally at a maximum at room temperature.

IV. Configuration Evolution

Configuration is the design and arrangement of parts collectively in a particular form, figure and combination to meet functional requirements.

4.1 Criteria considered for configuration

Considering the design requirements outlined in Chapter 1, the mounting structure design has undergone several design iterations.

Initial design started with modeling of airframe and toroidal fuel tank as per the given specification drawings.

Then interface structure is modeled. Mainly design started with adding mounting features to assemble the interface structure to both fuel tank and toroidal fuel tank.

Two flanged rings are created. The distance among two rigs is maintained as per the required distance between fuel tank and airframe. Mounting holes are provided in both the flanges as per the given input specification drawings.

These two rings can be joined by using number of ways viz. by trusses, shells, pipes etc.

V. Design of Interface Structure

Interface structure is prepared of Aluminum alloy 24345 (HF15) material; forged and machined from single block. Initially, design started with a single ring having 10 mm minimum wall thickness provided with two flanges at front, rear for interfacing with the Section airframe at rear, Fuel Tank at front. During the period of analysis, structure is optimized by decreasing the minimum thickness to 6mm and removing some material around the periphery and providing longitudinal ribs.

5.1 Thermo Structural Analysis

5.1.1 Design Input

The following Input is given for Analysis

1. Maximum longitudinal acceleration of Vehicle = 10g
2. Maximum Lateral Acceleration of vehicle = 5g
3. Aerodynamic heat on external surface of section = 22.5 kW
4. Time of flight = 90 sec

Heat input to the section varies with time. It starts from zero at start and increases with time. However, for this analysis, heat input assumed to be constant over the given flight vehicle time.

5. Mass of the Fuel tank = 134 kg (34 kg tank + 100 kg fuel)
6. Maximum inside temperature of section during flight = 50 C

5.1.2 Convective heat exchange coefficient

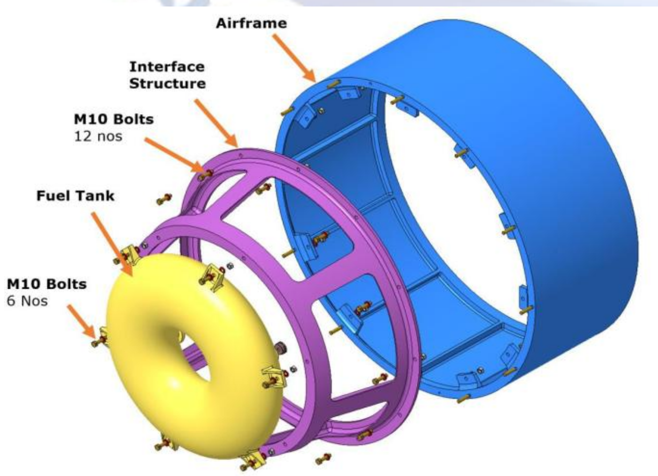
Section gets heated up during flight because of aerodynamic heating. It increases the temperature of section and part of heat is dispersed to surroundings through convection and radiation. part of heat is conducted to internal components. owed to very low duration of flight, heat loss due to radiation is neglected.

Heat loss due to Convection can be ascertained through FEM software.

Convective warmth exchange coefficient, hc = $10.45\text{-}v+10v^{1/2}$

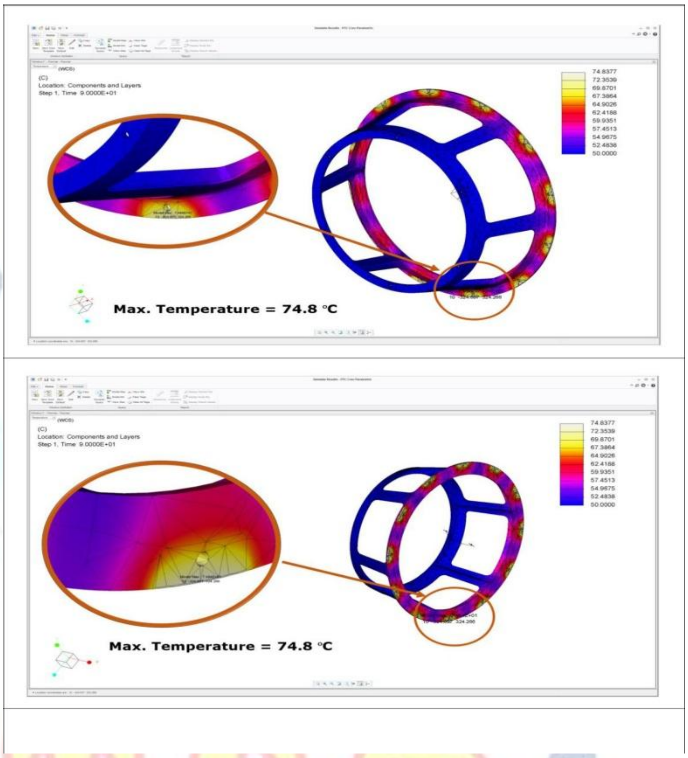
As relative speed between airframe and air inside the section is zero,

Assembly Procedure

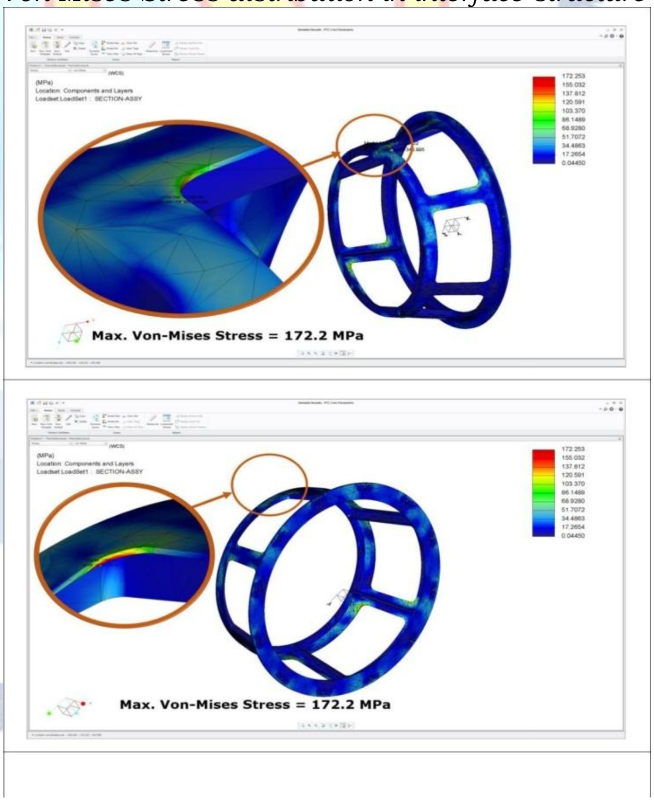


VI. Results and Discussion

Temperature distribution in Interface Structure



Von-Mises Stress distribution in interface structure



VII. Conclusion and Future Work

The design of Interface Structure was studied using Thermo Structural Analysis.

The interface structure aimed to carry a load of 134 kg of the fuel tank and fuel weight with 10g longitudinal and 5g lateral inertial loads with the given aerodynamic heat of 22.5 kW with the factor of safety of 2.3 and maximum deflection of 0.93 mm.

Fasteners are analysed for the stress and found safe.

Future work

- Further dynamic examination can be carryout on the interface structure to understand its adequacy in random vibration environment.
- Further Optimization of Interface structure can be done since the Factor of Safety of 2.3 is very conservative design (FOS = 1.2 for Flight Vehicle Structures)

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