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DESIGN, DEVELOPMENT AND VALIDATION OF FIRE PROTECTION SCHEME FOR THE ENGINE FIREWALLS AND COWLING OF A TYPICAL LIGHT TRANSPORT AIRCRAFT

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ABSTRACT

In an aircraft, engine firewalls refer to the structural components which isolate engine hot section and accessories section from plenum chamber and cowling refer to the outer skin of nacelle. As per the federal aviation regulation (FAR) requirement, the firewalls should be "fire proof" and the engine cowling should be "fire resistant". This can be achieved by selecting proper material and suitable surface protection. The present work deals with design and development of a fire protection external coating scheme for a light transport aircraft (LTA) fire wall and cowling, its validation through acceptance tests and simulation (using FE software) of stiffness variation of structure due to variation of temperature-thus estimating the residual strength and integrity of structure.

Keywords: fire proof, fire resistance, intumescent coating, thermal barrier coating, firewall, flammability test, elevated temperature.

INTRODUCTION

In an aircraft, engine firewalls refer to the structural components which isolate engine hot section and accessories section from plenum chamber and cowling refer to the outer skin of nacelle. The plenum chamber needs to be sealed so that firewalls contain the spreading of fire and hence a catastrophic failure. As per the federal aviation regulation (FAR) requirement,

1) The firewalls should be "fire proof" (definition: The capability of a material or component to withstand a 2000^0F flame $\pm150^0$F for a minimum duration of 15 minutes while still fulfilling its design purpose) and

2) Engine cowling should be "fire resistant"(definition: The capability of a material or component to perform its intended functions under the heat and other conditions likely to occur at the particular location and to withstand a 2000^0F $\pm150^0$F flame for 5 minutes minimum).

It is very important to meet the compliance requirement by selecting a proper material for firewalls and cowling or by other suitable scheme which will also maintain the overall integrity of the structure. The present work deals with the details of the execution of the above mentioned challenges and successful implementation of the certified scheme on the aircraft.

DESIGN DETAILS

In a typical LTA considered, two pusher type turbo prop engines are located at the rear part of the aircraft structure, mounted on individual steel rings called engine mounts. Each mount is interconnected to engine nacelle/cowling frames (L frame and M frame) with truss-type structure to achieve fail-safe design and effective sealing. These frames are made of aircraft standard aluminum alloy, whereas cowlings are made of CFRP material (Figure-1).

The L and M frames form the firewalls which seal plenum chamber, cowling forms an enclosure to the chamber. To meet the FAR requirements, these materials need to be given a fire protection scheme and their flammability characteristic compliance needs to be shown by coupon level tests.

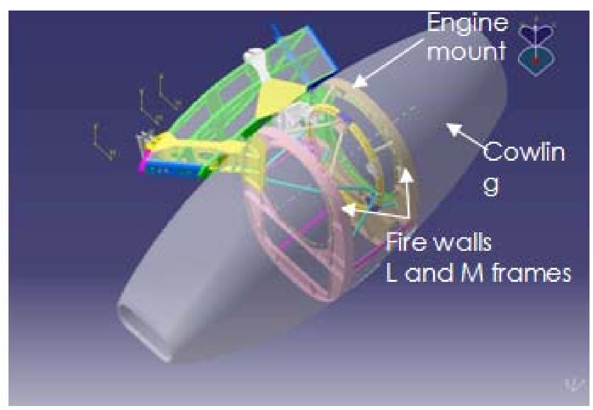

Figure-1. Engine mount-cowling-stubwing assembly (nacelle frames other than L and M not shown for clarity).

Fire protection coating

In the present LTA, to comply the fire proof and resistant requirements, the fire walls and cowling have been given fire protective coatings as follows:

1st coat: Epoxy primer with Chromate coating, IP 9064-6362 (for metal) and Epoxy primer without chromate coating, MPC 50015 R3 (for composite material).

2nd coat: Heat resistant coating, MPC 50019 R3 (Thermal Barrier coat)

3rd coat: Intumescent coating (IP9189A/B)

4th coat: Polyurethane coating (IP6) for surface protection and glossy finish.

Here, the intumescent coating resist the fire from penetrating through the material whereas the thermal barrier coating helps in reducing the elevation of

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temperature on the base material in the event of fire. An additional surface protection has also been provided. While the above mentioned intumescent and thermal insulation coatings were developed by M/s Indestructible Paint, UK, the coating scheme was developed, as well as applied, by M/s MATCON, Bangalore. It was important to carry out the tests on structural coupons with coatings to validate the flammability characteristic of the structure as well as to decide the optimal coating thickness to be provided on the component.

TEST DETAILS

Test acceptance criterion

Compliance with the flammability characteristics (fire proof and fire resistance) requirements of FAR 23.1182, FAR 23.1191 and FAR 23.1193 can be accomplished by demonstrating that the material will withstand a 2000°F±150°F flame for 15 minutes and 5 minutes, respectively while still fulfilling its design purpose. This testing should accurately simulate the fire containment to prove the materials and components will provide the necessary fire containment to retain its design requirements when exposed to a fire situation in service.

Test requirement

To show compliance with the regulatory requirements, series of tests on aluminum and composite specimen have been successfully conducted fulfilling the following FAR test requirements:

a) The flame to which the materials or components are subjected must be 2,000 ±150^{0}F (1,093+65^{0}C):
b) Sheet materials approximately 10 inches square must be subjected to the flame from a suitable burner.
c) The flame must be large enough to maintain the required test temperature over an area approximately five inches square.
d) The specimen should withstand flame penetration and not exhibit backside ignition for the required test time.

Test apparatus

i. A burner producing a 2000°F±150°F within ¼ inch of the specimen and engulf or provide representative impingement coverage, dependant on the specimen size is used for the demonstration (as given in AC20-135).
ii. A bare junction chromel-alumel thermocouple is used to measure the temperature by positioning in the flame ¼ inch in front of the specimen (as given in AC20-135) along with a standard calibrated indicator.
iii. Accurate stop watch to clock timing of flame exposure.
iv. A still photograph camera for producing photographic evidence.

Test procedure

a. The burner shall be lit, allowing a 5-minute warm up. The burner is calibrated to obtain a flame temperature of 2000°F. Immediately after successfully completing the calibration, rotate or move the burner to the test specimen, maintaining the same distance of the specimen from the burner as the thermocouple was from the burner during burner calibration. Do not shut off the burner between the calibration and the actual test. Ensure the thermocouple is positioned in the flame, l/4 inch in front of the test specimen. The specimen can be supported vertically/horizontally.
b. Sheet materials approximately 10 inches square must be subjected to the flame, ensuring the flame must be large enough to maintain the required test temperature over an area approximately five inches square.
c. Record the time and condition of the specimen.
d. Photograph evidence at each stage of test.
e. Temperature should be recorded continuously during Test.
f. Stop the test after 15 minutes/5 minutes or if the flame penetrates the Panel, whichever is earlier. Figure-2 shows the test set up at CPRI, Bangalore.

Test specimen

a) Aluminum panels with different thickness range of coatings to show compliance for fire resistance and fire proof characteristics of firewalls.
b) CFRP panels with different thickness range of coatings to show compliance for fire resistance of Cowling.

A parametric study was also conducted varying the dry film thicknesses (DFT) of intumescent and heat resistant coats separately with more than 100 specimens. To check the effectiveness of the insulation coating in reducing the temperature on the component, temperature on the backside of the component was measured using a thermocouple.

Figure-2. Test set up at CPRI, Bangalore.

Test results

From tests, it was observed that, the specimen is able to withstand this temperature without exhibiting any failure in terms of burn through, thus meeting the compliance/qualification requirements. Figure-3 shows a sample specimen after the completion of test for the prescribed time.

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Figure-3. Post test sample.

The backside temperature measured from test is plotted for each sample. The results indicate that on a generic basis, the rear surface temperature has a trend to form a grouping around a certain value notwithstanding the fact that there is a variation in the intumescent coating or thermal barrier coating. The same observation holds good for either of the material i.e., Aluminum or CFRP. A sample test result graph for a 2mm thick aluminium specimen is shown in Figure-4.

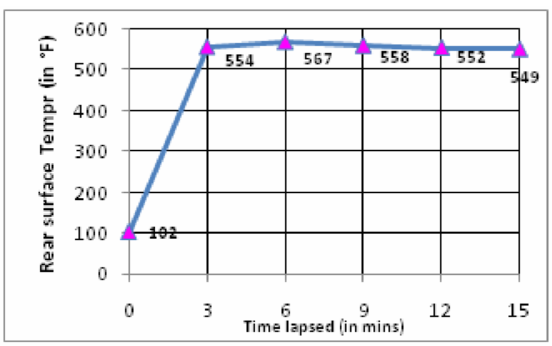

Figure-4. Sample graph for backside temperature on Aluminum test coupon.

From the complete test, it was seen that the average temperature at the end of prescribed test time from various tests was ~556^{0}F (291^{0}C) which is within acceptable range. A similar trend in variation of temperature was seen regardless of specimen thickness variation.

ANALYSIS

Even though the specimen was subject to a flame of 2000°F±150°F, due the presence of the protective coating the base material temperature was increased to 556^{0}F. Hence, it is essential to check the integrity of the structure at the elevated temperature of 556^{0}F. The elevation of temperature on component would alter stiffness and strength of the material which may result in redistribution of loads in the structure. The stiffness reduction and decrease in ultimate strength was estimated based on industry standard material data handbook [1]. The graphs (Figures 5a and 5b) show the residual stiffness of 75% at the max temperature of 556^{0}F that was observed from test. Similarly the decrease in ultimate tensile strength was found to be 52%. An extensive structural analysis of firewalls along with attached structure (Figure-1) was carried out considering the stiffness reduction of base material for various flight and landing conditions, to assess the change in load path and the safety margins. The linear static analysis was carried out using industry standard FE software MSC. Nastran.

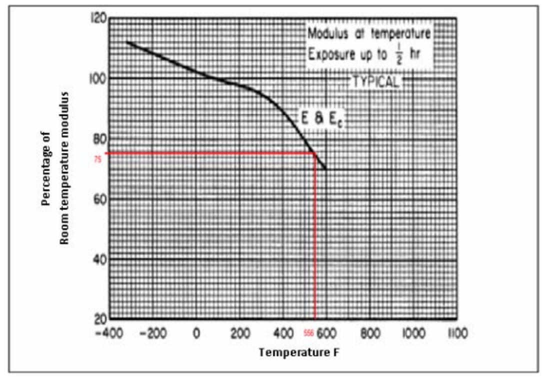

Figure-5(a). Effect of temperature on the tensile and compressive moduli (E and Ec) for Aluminum alloy [1].

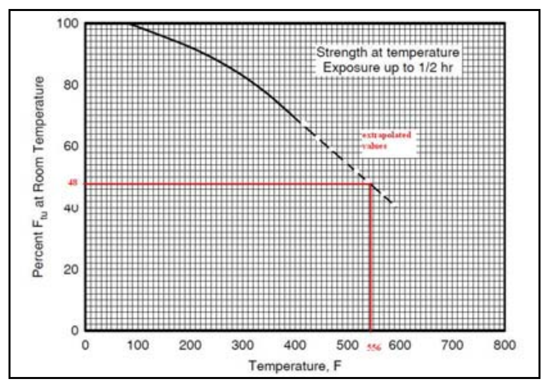

Figure-5(b). Effect of temperature on the tensile ultimate strength of Aluminum alloy [1].

Based on the above graphs, Table-1 gives the stiffness and ultimate strength variation due to increase in temperature for aluminium material:

Table-1. Mechanical property of Aluminum alloy.

Material	Young's modulus, kg/mm^2		Ultimate tensile Strength, kg/mm^2	
	A	B	A	B
Aluminum alloy	7382	5536.5	46.5	22.32

It can be noted that, the handbook [1] gives the stiffness variation for following scenario:

a. If the component is working in elevated temperature,
b. If the component is exposed to elevated temperature

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Though scenario 2 is relevant for present analysis, for a conservative estimate scenario 1 was considered, as it was found to be critical among two. Hence the analysis was carried out for the scenario 1. The cowling (CFRP material) being a non load bearing structure, no separate structural analysis has been carried out.

ANALYSIS RESULTS

The results from the analysis with the modified structural stiffness at elevated temperature of 556^0F were compared with the results of analysis for structural stiffness at room temperature. Figure-6 shows the overall displacement plot for the stubwing-engine mount-L and M frame assembly for a critical flight load case at room temperature and Figure-7 shows the displacement plot at elevated temperature. It is seen that the difference in displacement from both analyses is negligible. Similarly FE stress contour plots for the assembly at room and elevated temperature are shown in Figure-8 and Figure-9 respectively. No appreciable change in stress values from analyses was noticed.

From analysis, it was found that due to change in stiffness at elevated temperature, the overall load path remains unaltered. However, there was a redistribution of load between the frames and engine mount. A decrease of 10% load in the frames and increase of 12% load in the engine mount was noticed. The detail analysis showed the margins well within the acceptable range, thus ensuring the structural integrity.

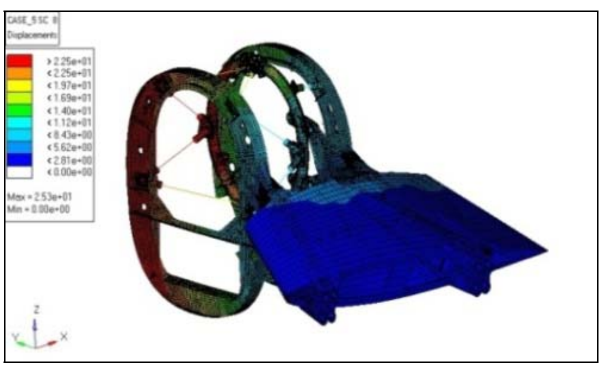

Figure-6. Displacement contour for stubwing-engine mount-L and M frame assembly at room temperature.

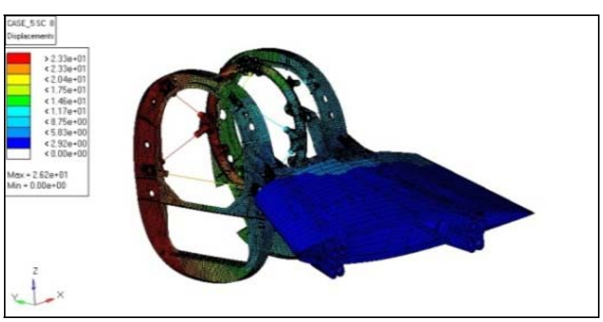

Figure-7. Displacement contour for stubwing-engine mount-L and M frame assembly at elevated temperature.

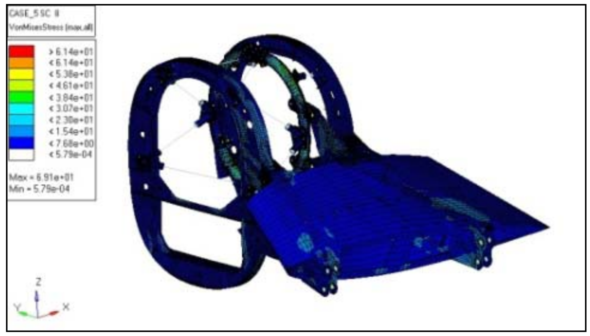

Figure-8. Von-mises stress contour for stubwing-engine mount-L and M frame assembly at room temperature.

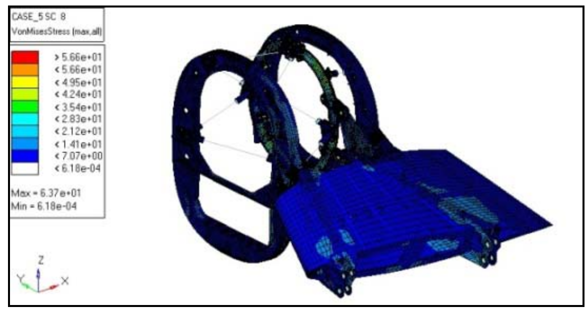

Figure-9. Von-mises stress contour for stubwing-engine mount-L and M frame assembly at elevated temperature.

CONCLUSIONS

From the present work the proposed intumescent and thermal barrier coatings were found to meet the fire proof and fire resistance as per FAR requirement. Also the fire resistance coating was found to be effective in reducing the base material temperature to an acceptable level in event of fire. The FE analysis confirmed that the structural integrity is well maintained even with the redistribution of load at elevated temperature, meeting the strength requirement, thus, ensuring the reliability of the structure. Based on test and analysis results, the fire protection scheme for the LTA was accepted by certification authority and is successfully realized on the aircraft.

ACKNOWLEDGEMENT

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REFERENCE

[1] Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures MIL-HNDBK-5J. 31st January 2003.