

Finite Element Analysis Simulation of a Fireproof Test for an Aircraft Propulsion Engine Mount Structure Made of Titanium

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ABSTRACT

Aviation regulations requires that engine mounts, and other flight structures located in designated fire zones must be constructed of fireproof material so that they are capable of withstanding the effects of fire. Historically, steel is defined as being inherently fireproof, however, titanium was not. Therefore, a fireproof test was conducted using 6AL-4V titanium structure for the attachment of the propulsion system on a mid-size business jet to satisfy FAA Federal Aviation Requirement 25.865. To determine if the titanium structure would be able to support normal operating loads during the fire event, finite element analysis was performed on the titanium structure simulating the fire test. The fire test simulates a fire on the aircraft from the propulsion system by using a burner with jet fuel exposing the component to a 2000 °F (1093°C) flame. The 2000 °F (1093°C) Flame is calibrated based on FAA Advisory Circular AC20-135. The 2000 °F (1093°C) flame is modeled as a series of convection coefficients across the entire surface of the component. The conductive and convective thermal properties are used for the finite element analysis (FEA) model to simulate the heat transfer effects of the flame. A thermal transient analysis was performed to determine the component temperatures and correlation to the fire test showed excellent agreement. The peak temperatures in the vicinity of the flame on the titanium structure was about 1500 °F (816°C) but much lower at locations that were shielded by the structure. The transient thermal analysis also showed that after about 10 minutes the temperatures appeared to be at steady state conditions.

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INTRODUCTION

Aviation regulations [1, 2, 3] require that engine mounts, and other flight structures located in designated fire zones, must be constructed of fireproof material defined as being equivalent or better than steel. Fireproof is defined in the definitions and abbreviations of the Code of Federal Regulations Section 1.1 [3] as the following: (1) With respect to materials and parts used to confine fire in a designated fire zone, means the capacity to withstand at least as well as steel in dimensions appropriate for the purpose for which they are used, produced when there is a severe fire of extended duration in that zone; and (2) With respect to other materials and parts, means the capacity to withstand the heat associated with fire at least as well as steel in dimensions appropriate for the purpose for which they are used. The latter definition is what was used for the definition of fireproof for the Titanium structure.

The engine mount support system for an aircraft with fuselage mounted engine(s) consists of a top and bottom front mount attached to a yoke and one aft mount as shown in Figure 1. The airframe to engine attachment system includes a forward yoke structure attached to the engine intermediate case, with elastomeric isolators. The forward yoke structure made of 6Al-4V Titanium was analyzed and tested to comply and certify its use against the fireproof requirements.

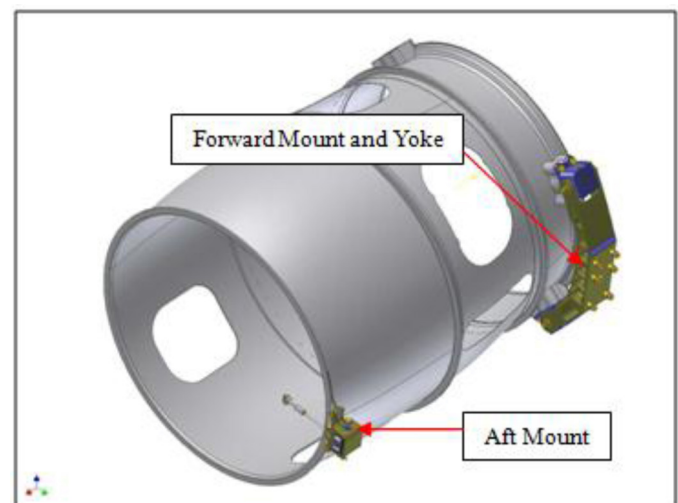


Figure 1. Side Engine Mount System.

MATERIAL SPECIFICATION

The material used to manufacture the yoke was made from Titanium 6AL-4V beta annealed. The material composition is defined in AMS 4928 Q with 6% Aluminum, and 4% Vanadium in the annealed condition (2 hours at 1375 °F (746°C) and a cooling rate of 100 °F/min) and heat treated to the beta anneal condition which is defined in SAE

AMS-H-81200B as having the part soaked at a temperature which is $50^{\circ}\text{F} \pm 25^{\circ}\text{F}$ ($10^{\circ}\text{C} \pm 3.9^{\circ}\text{C}$) above the pre-determined beta transus of about 1850°F (1010°C) of the lot for a minimum time of 30 minutes [5]. The part is then air cooled and followed by a mill anneal, which is aging at 1350°F (732°C) for 2 hours [5].

EXPERIMENTAL METHODS

A development fireproof test was conducted using 6Al-4V Titanium structure for the attachment of the propulsion system on a mid-size business jet to understand if the FAA Federal Aviation Requirement 25.865 [1] could be satisfied. The testing provided data on the thermal distribution during a fire event and the ability of the yoke in the mounting system to carry normal flight loads during exposure to a flame of $2000^{\circ}\text{F} \pm 150^{\circ}\text{F}$ ($1093^{\circ}\text{C} \pm 66^{\circ}\text{C}$) for a minimum of 15 minutes per Advisory Circular AC20-135 [2]. The basic torch or burner used in the fire test produced a $2000^{\circ}\text{F} \pm 150^{\circ}\text{F}$ temperature within 0.25 inch of the specimen. Figure 2 shows a total of sixteen (16) thermocouples were placed on both sides of the yoke and in the air at both the forward and aft sides of the yoke near the clevis as shown in the red circle.

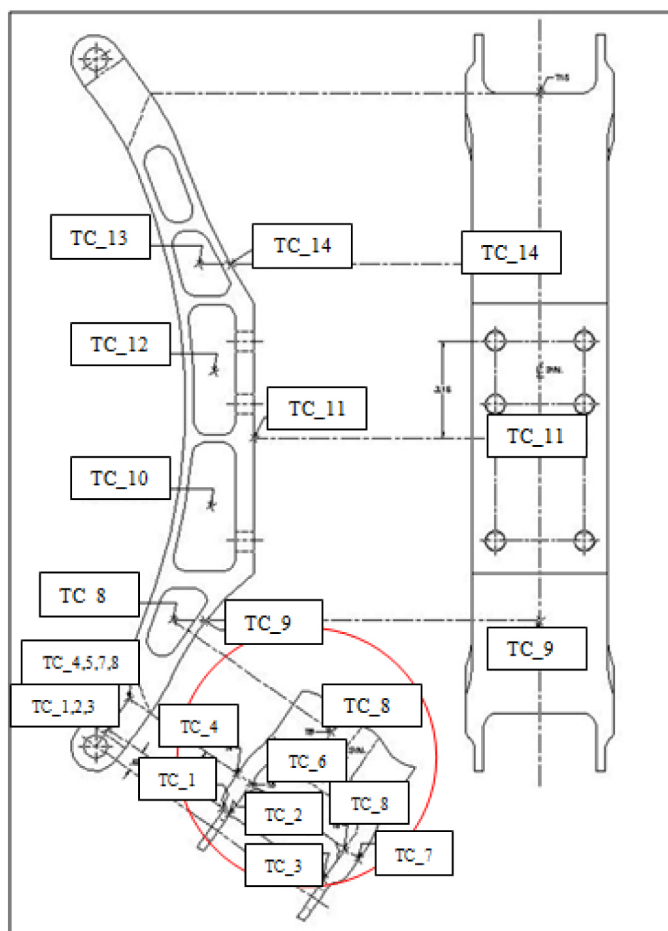


Figure 2. Thermocouple Locations on the Yoke.

Figure 3 shows the fire test frame capable of placing a load representing a landing limit condition on the titanium yoke structure, while also being exposed to the 2000°F (1093°C) flame. Linear

velocity differential transducers (LVDT) were used at each actuator to measure the deflection of the yoke test specimen at that load input. Load cells were used at each actuator to measure and control the load input to the specimen.



Figure 3. Fireproof Test Setup.

Before the actual fire test can begin, the burner must be adjusted to provide a $2000^{\circ}\text{F} \pm 150^{\circ}\text{F}$ ($1093^{\circ}\text{C} \pm 66^{\circ}\text{C}$) flame. This was done by adjusting the burner and using an array of thermocouples spaced apart to determine the flame temperature in air. Figure 4 shows the flame calibration per AC20-135 [2] using the array of thermocouples. The heat flux density was measured using a calorimeter and was found to be 9.5 BTU/ft²-sec ($104,467 \text{ W/m}^2\cdot^{\circ}\text{C}$), which meets the advisory circular requirement AC20-135 [2].

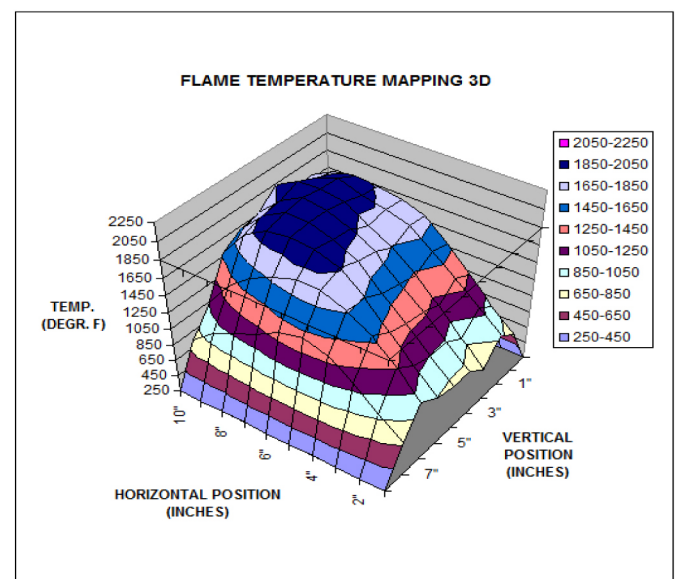


Figure 4. Fireproof Test Flame Calibration.

Figure 5 shows the load inputs simulating a landing limit condition of 2g forward, 6.31g down, 1.12g inboard and full thrust load, where g refers to gravity. With the burner still on after finishing the calibration; the fire test was initiated by directing the burner flame onto the yoke at the pre-defined location. A thermocouple 0.25 inches from the part was placed in the fire zone and the temperature was