Experimental Stress/Strain Analysis of an Aircraft Platform Using Experimental Data

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Abstract

In preparation of a flight test for a deployable sensor pallet system extensive stress/strain analysis must be performed to ensure safety of the aircraft and crew members involved in the flight. This experimental analysis looks at the sensor pallet system's reaction to specified flight conditions while being deployed outside of the rear ramp of a C-130 aircraft. The aerodynamic loads simulated in this analysis are taken directly from experimental data collected through pressure tubes (and data collection equipment) while on-board a C-130 aircraft during a test flight. These loads will be added to the loading produced by the system during its deployment cycle procedure.

Strain gage and data collection equipment was used to take and reduce stress/strain data at locations of known high stress concentrations found through simulated Finite Element Analysis (FEA). This data will be used to verify the current system's structural integrity and to ensure safety of flight.

Background

A sensor pallet system was designed and built as a standardized roll-on, roll-off system for a C-130 aircraft to be deployed in-flight. The idea was developed by the National Guard and the Counter Narco Terrorism Technology Development Office to aid in the combat of drug trafficking and cultivation in the United States. The system was constructed on a standard 463L type cargo hauling pallet, and consists of a sensor pod attached to four arms that suspends the pod from the rear cargo ramp of the aircraft. The system is initially stored completely within the body of the C-130 until deployment. During deployment the sensor pod and arms are rotated into position via an electric motor and a gear reduction box with two output shafts. The model of the sensor pallet is shown in Figure 1.

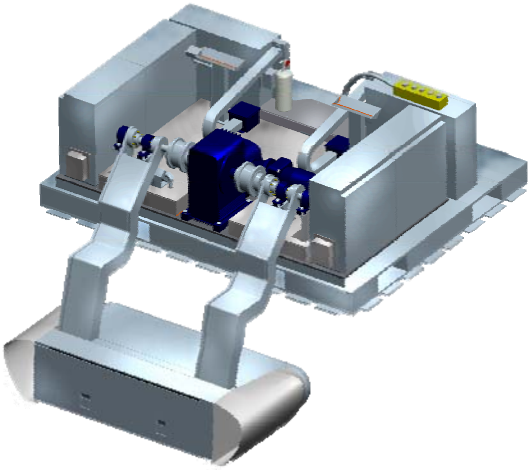

Figure 1 - Model of the sensor platform system in the final operating position.

Introduction

This study concentrates on the stresses caused by the aerodynamic drag (parallel and lateral) on the mechanical arm/pod system while in the final operating position located underneath the aircraft ramp. Several alternative studies have been performed on the mechanical arm/pod system including vibration analyses looking at the reaction of the system subjected to the harmonics of the aircraft, and stress analysis on the arms caused by the weight of the sensor pod and a maximum sensor payload of 500 pounds. But there has not been an analysis performed relating the simulation effects (FEA) of drag loading on the arms to actual experimental strain gage measurement using known drag loading from experimental flight data.

To briefly illustrate the deployment of the system the stowed and final operating positions of the system are shown in Figures 2 and 3.

Figure 2 – Sensor pallet system in stow position in a C-130 aircraft.

Figure 3 – Sensor pallet in deployed position

Loading Criteria

The design of the sensor pallet system assumes that the rear cargo ramp of the C-130 aircraft would always be in the horizontal position during deployment (when the ramp is raised the drag profile is minimal). During the deployment of the system the aircraft would fly a steady level pattern. Once fully deployed the pod is partially in the wake of the fuselage reducing the aerodynamic forces, which would then allow for banked and maneuvering flight.

The sensor pallet system is regulated to fly at a maximum limit of 150 kias on the C-130 aircraft. This maximum speed limit is a regulation for flight with the rear cargo area open. A series of total pressure probes was flown on 4 February 2004 by members of the project design team to generate data on the dynamic pressure experienced in flight by the sensor pallet system. This data showed a maximum parallel drag force of 350 pounds acting on the sensor pallet system. The flight test also generated data showing a maximum of 75 pounds of lateral drag force acting on the system [1].

The aerodynamics data was used to calculate a worst case loading scenario on the sensor pallet system. For this analysis it was assumed that each arm would be subjected to these total loading profiles. This extreme case would ensure a safe design and would cancel out any fabrication errors in the systems fastening components.

Finite Element Analysis (FEA)

A preliminary study was performed to analyze the stresses on the mechanical arm when the attached sensor pod is fully populated with a maximum payload (500 pounds). This analysis generated locations of high stress concentrations in the arms which were used as a concentration area for this aerodynamic loading analysis [2 ,3].

The finite element model (FEM) was created in ProEngineer as a 1:1 scale model of the actual mechanical arm/pod component. The boundary conditions specified copy those of the actual systems connections (including key way's and bolts). Also, the load applied to the system was at the proper same magnitude and direction as specified by the aerodynamic data generated from the experimental test flight.

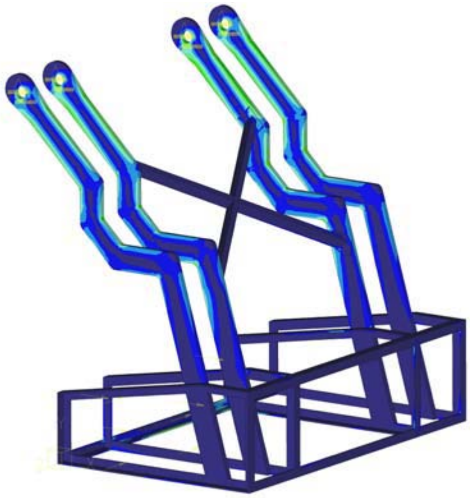

Figure 4 – Finite element model of the sensor pallet system mechanical arm/pod component.

Strain Gage Calculations

As in the FEA setup the location of the strain gages were determined from the previous FEA performed which analyzed the affect of the sensor weight on the mechanical arms. The strain gages used to find values of strain/stress in the arms were arranged in the form of three-gage rosettes. The rosettes were in a 0-45-90 degree layout, as shown in Figure 3. This three-gage arrangement allowed us to find the principal strains and the orientation of these strains. If a simple tensile stress in one direction was to be tested, a single strain gage would have been sufficient, because the principal stress directions would have already been known.

The principal strains and directions on the arms were calculated using the recorded rosette data with resistance read-out transformation equations shown below. These equations convert principal strain values into principal stress values using equations (7) and (8) [4, 5]. Then, calculations using equation (9) produce the von Mises stress, which can be compared to the simulated stress values found in the FEA [6].

$$\varepsilon_x = \varepsilon_a \tag{1}$$

$$\varepsilon_y = \varepsilon_c \tag{2}$$

$$\gamma_{xy} = 2\varepsilon_b - (\varepsilon_a + \varepsilon_c) \tag{3}$$

$$\varepsilon_1 = \frac{\varepsilon_x + \varepsilon_y}{2} + \frac{1}{2}\sqrt{(\varepsilon_x - \varepsilon_y)^2 + \gamma^2{}_{xy}} \tag{4}$$

$$\varepsilon_2 = \frac{\varepsilon_x + \varepsilon_y}{2} - \frac{1}{2}\sqrt{(\varepsilon_x - \varepsilon_y)^2 + \gamma^2{}_{xy}} \tag{5}$$

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{\gamma_{xy}}{(\varepsilon_x + \varepsilon_y)}\right] \tag{6}$$

$$\varepsilon_1 = \frac{\sigma_1}{E} - \nu\frac{\sigma_2}{E} \tag{7}$$

$$\varepsilon_2 = \frac{\sigma_2}{E} - \nu\frac{\sigma_1}{E} \tag{8}$$

$$\sigma_{vm} = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2)^2 + (\sigma_1)^2}{2}} \tag{9}$$

In the equations above ε_a, ε_b and ε_c are the strain values read from the strain gage rosettes. E is Young's Modulus of the Aluminum 6061material, which is approximately 10,000 ksi. υ is Poisson's Ratio of the material, which is approximately 0.33. ε_1 and ε_2 are the in-plane principal stresses, which are oriented to the original x and y axes θ degrees counter-clockwise. σ_{vm} is the von Mises equivalent stress.

Results

The von misses stresses from the FEA at each strain gage location were extracted and compared the values of the von misses stress found using the strain gage data. The von misses results of the 1500 pound parallel load analysis are shown in figure 5. Figure 6 shows the results of the 300 pound lateral load analysis.

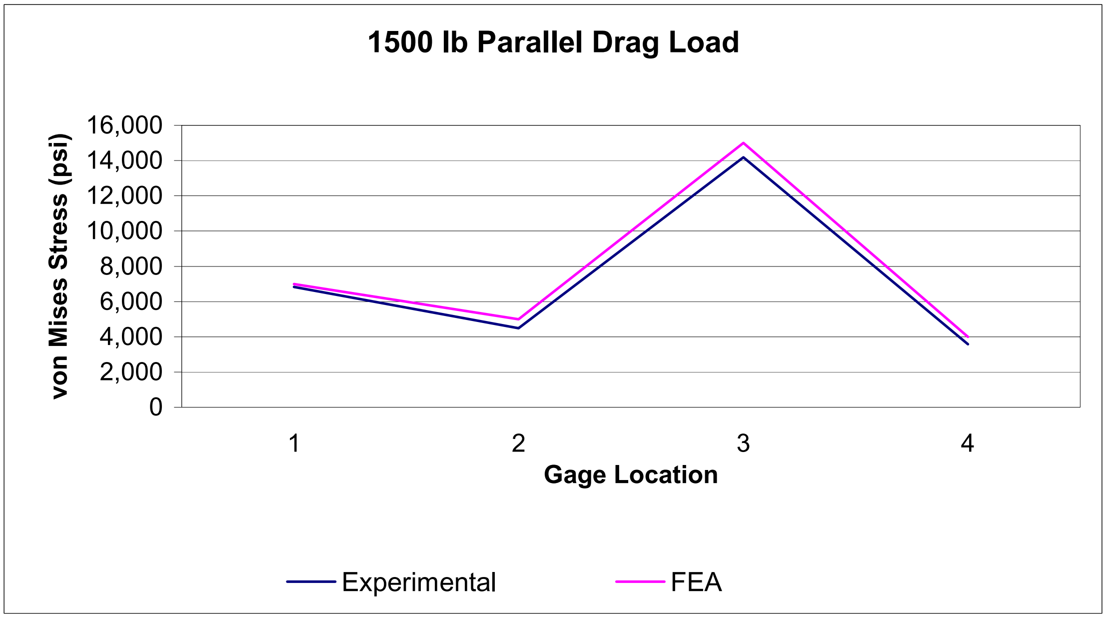

Figure 5 –Von misses stresses for parallel drag load experimental and FEA results.

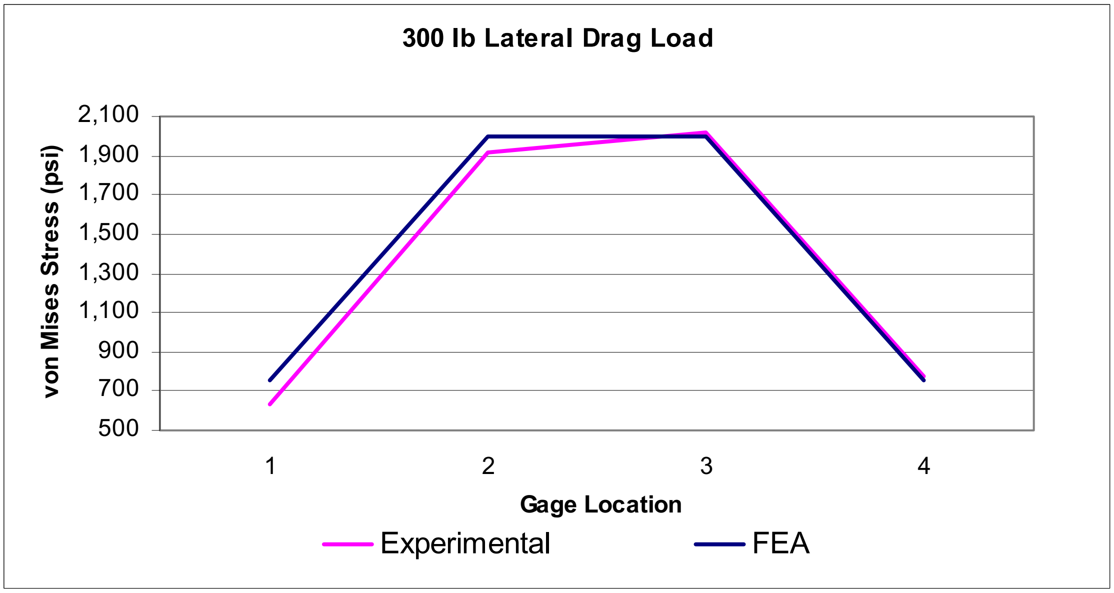

Figure 6 –Von misses stresses for lateral drag load experimental and FEA results.

Conclusions

The results show that the experimental values with loading representing actual aerodynamic loading are comparable to the finite element simulation result. The values show that the system's critical components are well below the yield values for the material used in the mechanical arms. A further study should be performed on the mechanical arms with a reduced cross section to optimize the material necessary for a safe structure.

This analysis provides invaluable data that can be used for the actual system's test flight. The data provides the locations on the mechanical arm that should monitored during the actual flight of the sensor pallet system.

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