Simulation driven design solves Lockheed Martin C5 cargo door problem

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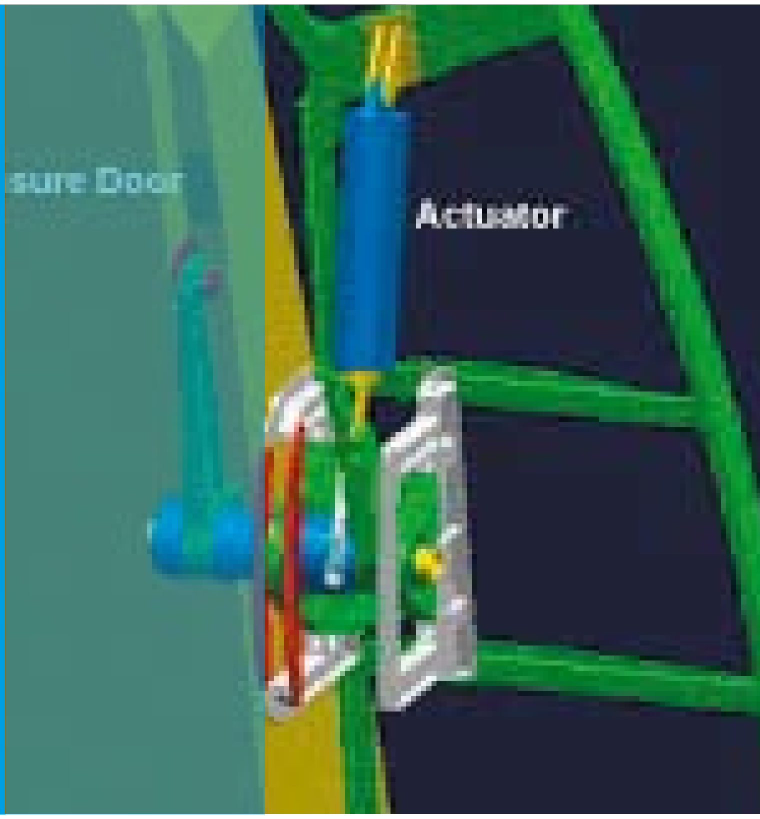


Simulation Driven Design helped Lockheed Martin Aeronautical Systems solve a fatigue-related problem on the cargo door of the C5 transport plane. Cracks in the area of the door's upper hinge had led the Air Force to impose a special visual inspection of the door prior to each ADS mission. Use of dynamics analysis software enabled Lockheed Martin to quickly find several solutions by allowing engineers to evaluate many alternatives without testing prototypes. Within four months of taking on the project, Lockheed Martin presented the Air Force with the three best options indicated by the analysis. These included altering the hydraulic door actuator by means of a restrictive device, beefing up the surrounding structure, and redesigning the basic door mechanism to improve the interaction between the actuator and the door.

The C5 transport plane, also known as the Galaxy, is a huge workhorse aircraft. It is used by the military to transport troops, equipment, and vehicles-everything from 18-wheel trucks to tanks to Humvees. The aft cargo door on the plane is a particularly complicated device because it performs multiple functions. On the ground, the door folds down to serve as a ramp for loading the plane. In flight, it serves to pressurize the cabin but also opens upward to permit unloading of troops and equipment by parachute in a maneuver called Aerial Delivery System (ADS). Because it can open from top or bottom, the door is equipped with hinges and actuators at both locations.

Air Force inspections of the door had revealed fatigue cracks and stress corrosion in area of the upper hinge and the surrounding support structure. Damaged parts were submitted to a metallurgical laboratory for testing, which confirmed the failure modes but indicated that the parts were per blueprint with no material alloy or heat treatment discrepancies. At this point, Lockheed Martin was put under contract to determine the cause and recommend a permanent solution. Their preliminary inspection confirmed the problem and indicated the potential for the hinge to break from the door during ADS. In a worst-case scenario, it could cause the door to separate from the aircraft.

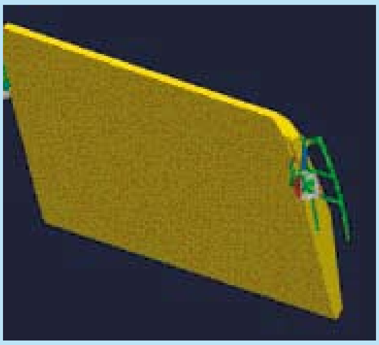
A visual inspection of the door during operation showed some bouncing that hadn't been accounted for when the door was originally designed. When the door first actuated, there was a slight delay between when the power was applied and when the actuator engaged the full weight of the door. This delay generated an impact force on the door mechanism and structure and made the door bounce as it started to move.

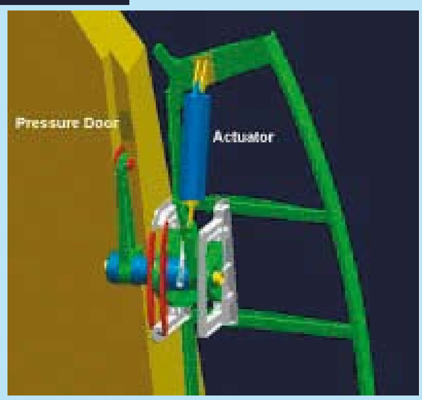
Even a casual observer could see the bouncing, as well as the flexing in the support structure caused by the bouncing. Lockheed Martin engineers concluded that the problem in the hinge area was related to the interaction between the actuator and the door, and this is where they started their investigation.

When the plane was originally designed, in the 1960s, CAD was not available. So the first step for Lockheed Martin in this project was to create a CAD model of the door, actuator, hinge, and support structure. Engineers used the CATIA 3D modeling system from Dassault Systemes. Using CATIA's integrated kinematics module, they added joints and animated the mechanism.

During the original design, hand calculations had been used to predict the performance of the door and its components. Door dynamics were accounted for by multiplying the weight of the door by a dynamic factor to estimate the increased load it would create when it was opened and closed. But the door is a complicated mechanism with centers of gravity that change throughout the opening and closing cycle. The load on its components constantly changes. To understand why the hinge and support structure was experiencing fatigue problems, engineers needed to determine the dynamic loads imposed throughout the complete door cycle.

To obtain these loads, Lockheed Martin used a dynamics analysis software





package called DADS from LMS Computer Aided Design Simulation, Inc. (LMS CADSI), Coralville, Iowa. They chose this package because it is fully integrated with CATIA. Using a module called CATDADS, an engineer transferred CATIA geometry to DADS. CATDADS converted the CAD model including the CATIA Kinematic constraints into DADS elements automatically. The engineer then supplied DADS with information about the hinge mechanism and support structure, such as spring rates and damping forces. This information was obtained from calculations and was used to generate a preliminary analysis model.

For absolute accuracy, Lockheed Martin wanted to measure actual actuator forces during a typical door cycle and use them as the input driver for the analysis model. At that point, the company requested an amendment to the contract to include a ground test. The request was granted and the test was performed on a fleet aircraft. Test technicians instrumented various points of the structure to obtain forces and determine how the actuator reacted to the bouncing of the door.

Forces were measured during a normal-speed door cycle, and also during a slower-than-normal cycle. Slowing the door speed was done to minimize the hydraulic transients so that stress due to structural flexibility or joint movement could be isolated from the dynamic effects. The test data was used to calibrate the dynamics analysis model to both the normal-speed and slow-speed cycles. Since all of the following analyses were performed using a test-calibrated model, Lockheed Martin had great confidence in the results.

Engineers performed a series of dynamics analyses to evaluate various aspects of door operation. They were run on an IBM RS/6000 workstation and provided a great deal of information about the problem at a fraction of the cost of testing. They evaluated parameters such as a linear versus non-linear actuator, door weight, door speed, and inertial factors.

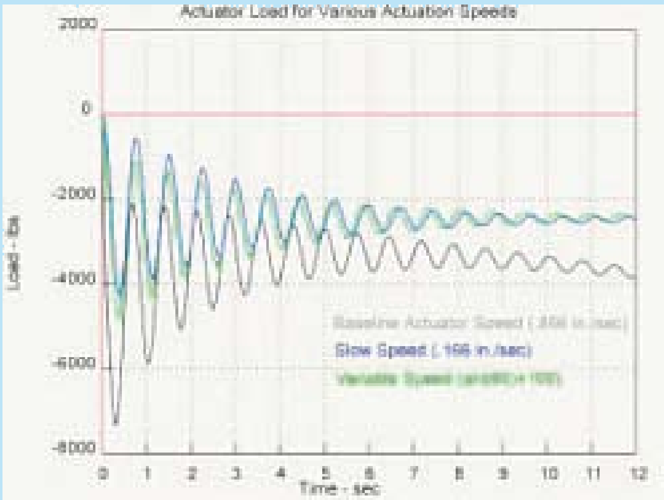
Results indicated that the actuator supplied a constant force and that the flexing was due entirely to the dynamic loading on the structure and door components.More analyses were then run to find a way to stop the bouncing or minimize its effect. They showed that the dynamic loading was not reduced substantially by slowing the actuator or using a non-linear actuator that would allow the door to go slowly at initial opening and again just prior to full actuator extension. However, they indicated that the dynamic load was being applied to the door at the instant of door motion as the full door weight shifted from overhead rollers to the actuators.

The simulation indicated that altering the actuator so that the full weight of the door was settled against it before the load was applied eliminated the bouncing almost entirely. Stiffening the structure so it could handle the bouncing without fatigue was another solution, as was redesigning the door mechanism.

These remedies were presented to the Air Force in a report along with their associated costs and benefits. The report was available quickly because Lockheed Martin was able to find the various solutions on the computer model without building and testing prototypes.

In all, the project took less than four months. Creating the CATIA model took three weeks, setting up the DADS model took another week, ground testing took several weeks, and integrating the test results into the analysis model took another week. After that, engineers spent two weeks investigating possible solutions. The remainder of the time was spent writing the report.

The use of LMS DADS integrated with CATIA enabled Lockheed Martin to recommend effective changes to Air Force in a timely manner. This was important to eliminate the mandated special visual inspection, and ultimately to ensure reliable operation of the door during military maneuvers. ■



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