Up, Up and Away

Simulation-driven innovation delivers a new ejection seat design for a military aircraft in less than 14 months.

By Park O. Cover, Jr., Senior Mechanical Engineer, Concurrent Technologies Corporation, Pennsylvania, U.S.A.

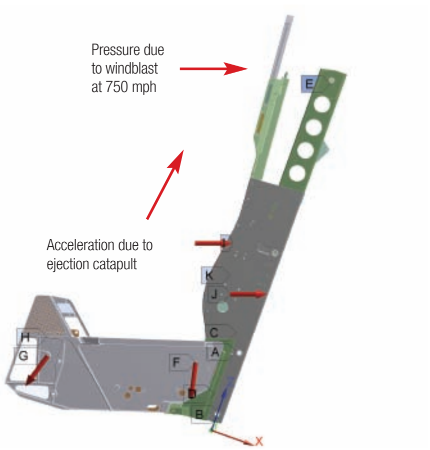
An ejection seat, used in emergency situations in military aircraft. An explosive charge or rocket motor thrusts the seat out of the aircraft, carrying the pilot with it. Once airborne, a parachute is deployed. This photo shows the ACES II ejection seat. U.S. Air Force photo by Staff Sgt. Bennie J. Davis III.

The military's advanced concept ejection seat, ACES II®, is one of the most successful aircrew escape systems in U.S. Air Force history and is credited with saving more than 456 lives since it was introduced in 1976. With more than 8,000 seats delivered to date, the ACES II is currently used on F-15, F-16, B-1B, B-2, A-10, F-117 and F-22 aircraft. Using the strengths of the ACES II as a foundation, Goodrich Aircraft Interiors and Concurrent Technologies Corporation (CTC), both in the United States, developed the next-generation ACES 5 seat for the F-35 Joint Strike Fighter (JSF). The new seat was optimized to enhance safety for aircrew, to reduce maintenance downtime, to reduce weight and to integrate with the F-35 cockpit. However, the biggest challenge was developing and delivering a brand new seat structure in less than 14 months.

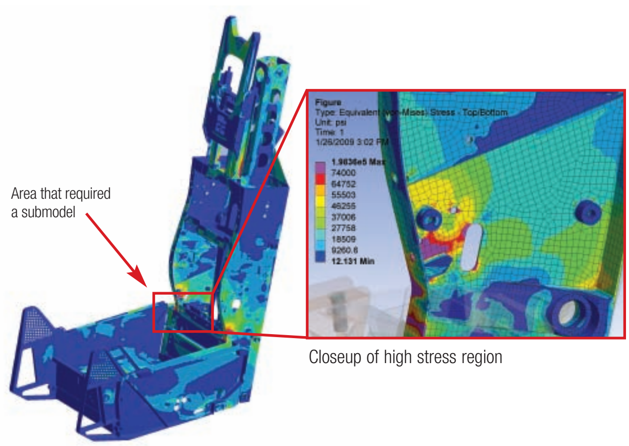
The parametric link between the ANSYS Workbench platform and Pro/ENGINEER® Wildfire® software was a critical factor in successfully developing a design that met all the requirements while maintaining the aggressive schedule. Engineers at CTC were able to quickly update simulations for multiple design iterations. This concurrent design and analysis approach enabled the team to optimize the seat for both function and weight from the earliest developmental stage.

Analysis of the seat was split into three phases. The first analysis phase was conceptual design development. During this time, engineers designed the seat structure to meet functional requirements, while simulation was used to verify that the structure was sound and weight was optimized. Functional, structural and safety requirements were derived from the performance-based specification supplied by aircraft manufacturer Lockheed Martin for the JSF ejection seat. To reduce maintenance downtime, a modular seat structure was developed to allow the seat to be easily removed from the aircraft. The modular seat consists of the seat back, seat bucket, parachute, survival kit and aircraft interface module. Assembly costs and part count were reduced by designing the new seat to use a few machined components instead of many sheet metal components. Engineers evaluated designs for tough load requirements, such as ejection from an aircraft travelling at 750 mph, parachute load and crash loads.

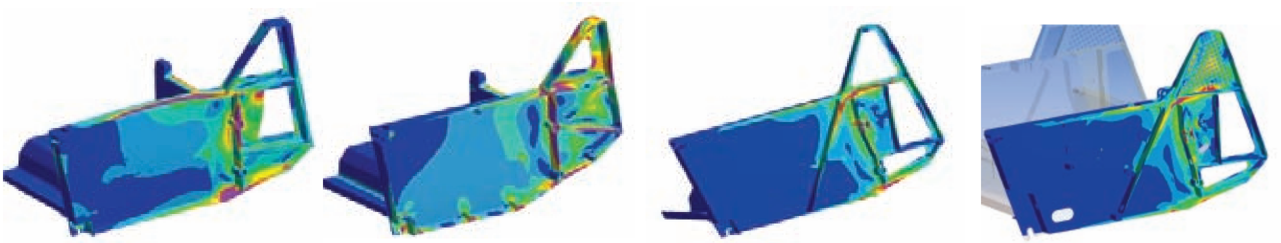
The first simulation phase evaluated individual components of the preliminary seat design. Equivalent stress plots of various stages of the bucket design evolution demonstrated how, during ejection, the occupant's legs are forced apart by the windblast. The structure had to be optimized to contain this splitting force, or else the



Loads imparted on the seat when ejected from an aircraft travelling at 750 mph



Stress loads that result from static analysis of ejection at aircraft speed of 750 mph



Iteration 1
2.1 pounds

Iteration 2
3.0 pounds

Iteration 6
2.7 pounds

Iteration 20
2.8 pounds

Equivalent stress plots from various iterations of the ACES 5 ejection seat bucket design. Weight of the bucket, one of the design considerations, is shown for each.

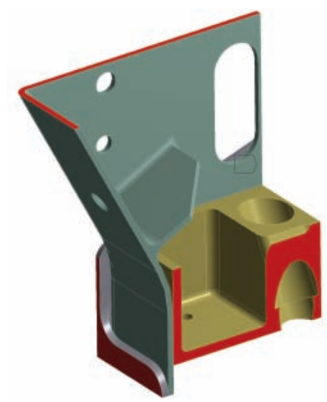
occupant would sustain critical injuries. The engineering team analyzed the structure for ejection and crash loads within the ANSYS Workbench framework. Once the simulation was set up, design iterations were quickly evaluated for all the applicable load cases simply by updating the geometry from the CAD system.

During the second analysis phase, the CTC team built a system model of the seat structure. Analyzing the seat structure as a whole gave the most representative view of how the actual seat structure would behave and eliminated compromises associated with analyzing individual seat subsystems or modules. To prepare the system model for analysis, the team imported the CAD geometry into the ANSYS DesignModeler tool where defeaturing operations, such as elimination of rivet holes, were performed. In addition, a few components were converted to mid-plane surface models using the software's automatic mid-plane feature.

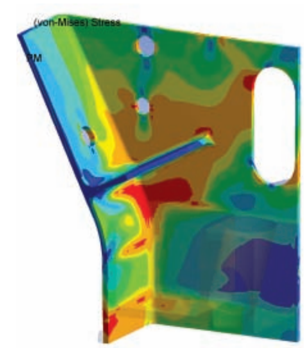
The CTC team assigned material properties, defined boundary conditions and applied loads to the system model. Contact regions were characterized for each riveted face on the seat. This allowed contact reaction forces to be used to determine the number of rivets required at each joint. Point masses were used to represent nonstructural seat subsystems, such as the parachute and survival kits.

The model was meshed using a hex-dominant mesh control and a 0.125-inch global element size. A single linear static structural analysis of the seat model was solved in less than 30 minutes using the direct solver within the mechanical software available through the ANSYS Workbench platform. The quick analysis turnaround time allowed the engineering team to quickly evaluate various what-if design scenarios.

Actual loads on the seat are very dynamic in nature, and the seat will experience these loads only one time during deployment. Because the system model used a static simulation approach without nonlinear material properties, the simulation revealed small areas of stress concentration that exceeded the allowable ultimate strength of the material. Engineers scrutinized these high-stress zones using submodels that allowed material yielding during the third phase of the analysis.



Submodel of high stress regions in ANSYS DesignModeler software. Cut boundaries are shown in red.



Submodel results provide more-accurate stress results than the global static model.

To produce the submodel, the team first cut out the area of interest using the ANSYS DesignModeler tool. The CTC team developed a submodeling subroutine using the commands object in the mechanical simulation area of ANSYS Workbench. The subroutine interpolated the system model displacements onto the submodels' cut boundaries. The submodel results typically showed that some permanent deformation occurred, but the ultimate strength of the material was not exceeded. Furthermore, the submodel provided more accurate stress results due to the finer mesh. Roughly 30 high-stress areas were evaluated using this technique to ensure that the structure would not fail when loaded in extreme conditions. These results proved that the ultimate load requirements were met.

After 10 months of development, five prototype seats were built for test purposes, and the first ejection test of the ACES 5 F-35 JSF seat occurred after 14 months. The seat performed flawlessly the first time out. This extraordinary outcome is the result of a great deal of teamwork between Goodrich and CTC and would have been unattainable without using engineering simulation software. ■