NASA Uses Analysis Software to Assess Orion Crew Module Heat Shield

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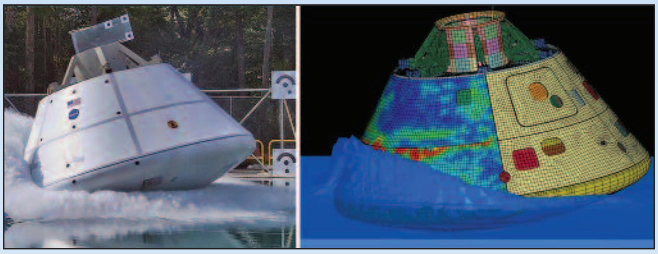
Collier Research Corp.
Newport News, VA
757-825-0000
www.hypersizer.com

Protected by the shell of its huge launch rocket during blastoff, NASA's Orion Multi-Purpose Crew Vehicle (MPCV) must get back to Earth on its own at mission's end. The flight plan for this next-generation craft includes a dramatic ocean splashdown reminiscent of the Apollo program that predated the Space Shuttle's smooth runway landings.

To keep capsule and crew safe under the huge re-entry and splashdown loads — temperatures exceeding 4800 °F and speeds up to 25,000 miles per hour — a 16.4-foot-diameter ablative thermal protection system is secured to the MPCV's base with a carbon graphite and titanium carrier structure. As the ablative thermal protection system of this heat shield reaches extremely high temperatures, portions of it fall away from the vehicle to remove excessive thermal energy. The remaining carrier structure has to survive the brunt of the impact when it hits the water to help keep the astronaut module intact.



(Left) The Orion Multi-Purpose Crew Vehicle splashdown test, and (right) software simulation of loads on the vehicle during the highly dynamic event.

The Orion ground test vehicle at NASA's Kennedy Space Center. The circular heat shield is visible at the very base of the vehicle. (NASA)

With the first unmanned launch-and-return test of Orion scheduled for December 2014, NASA engineers and contractors were highly motivated to get to a final design for the MPCV that achieved ideal weight and performance targets. In late summer of 2012, NASA's chief engineer for the Orion project, Julie Kramer, contacted the NASA Engineering and Safety Center (NESC) and requested some novel ideas for how to reduce the spacecraft's mass.

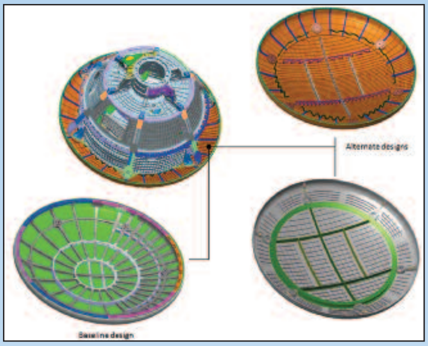
At 3,000 pounds, the "baseline" composite and titanium design for the wagon-wheel-shaped carrier structure that supports the MPCV's thermal protection system was one of the largest components of the crew module, and thus became a prime target for weight reduction. "The goal of the Orion program is to go well beyond Earth orbit, around the Moon, and eventually to an asteroid or Mars," said Mike Kirsch, project manager and principal engineer of the NESC's Orion Heat Shield Carrier Structure Assessment Team.

Kirsch's team, which included technical lead Jim Jeans, president of Structural Design & Analysis (a longtime contractor for NASA as well as private companies), chose HyperSizer software to apply to the heat shield design assessment program. The baseline design for the heat shield consisted of a solid laminate carbon-graphite skin secured to the capsule by a carrier structure with a spoke-like pattern of titanium I-beams in the aforementioned wagon-wheel shape. The concept is similar to the aeroshell that protected the rover for Mars entry. Carbon graphite designs are tailorable, in that modifications can continue to be made en route to final manufacturing. However, in this case, the result was a design that weighed more than it needed to. With an initial goal of cutting out 800 pounds, the NESC team considered both material and structural modifications to the baseline.

"We needed to come up with a lighter structure that could still withstand the aerodynamic pressure of the Earth's atmosphere re-entry, and support the thermal protection system so the ablative material in the heat shield could do its job," said Kirsch. "Re-entry is a pretty severe load case. But even more important is when the crew module actually hits the water. That water landing is the event that drives the design of the heat shield carrier structure. Using parachutes, we try to take as much energy out of it before that impact, which is a tricky, dynamic situation based on wind and wave conditions. Ideally you want the capsule to knife in, not bellyflop. The design must be robust to the wide range of possible wind and wave conditions."

The team developed a series of analytical models to predict how the heat shield carrier structure as a whole — particularly the internal support webs — would react under a wide range of splashdown scenarios. Landing simulations were run in LS-DYNA transient nonlinear finite element analysis (FEA) solver. The dynamic landing simulations were loaded into HyperSizer, which then controlled relevant parameters (such as material thickness and location of stiffeners) within each model to optimize and then compare different design solutions.

Sharing interim results among designers and analysts was enabled by the software's ability to display summary images showing critical load case, margins of safety, or failure modes. "This is so powerful from a presentation standpoint, as it



HyperSizer evaluated different structural concepts for the heat shield carrier structure. The baseline composite skin with Titanium I stringers (left, bottom) was evaluated against alternate metallic grid stiffened designs (right, top and bottom).

enabled the designers and the experts to readily visualize together what was going on," said Jeans.

In-depth evaluations of a variety of engineering concepts led the NESC team to consider alternative designs that incorporated load sharing with the crew module backbone, replaced the existing wagon-wheel stringer with an H-beam configuration, or switched the composite carbon graphite skin to a titanium orthogrid skin. The titanium orthogrid version emerged as their final proposal.

NESC built a test structure to verify that they understood the physics of the dynamic impact on this final alternative. The real-world tests provided sufficient data to validate the ability of HyperSizer to model those physics with its enhanced analytical tools.

As NASA's Orion team continued their own work on reducing the weight of the baseline design, NESC's insights from the HyperSizer analyses informed discussions that led to a reduction of the final weight of the baseline design by 1,100 pounds. "Our work provided some independent perspective on where the baseline design was in the spectrum of alternatives, and highlighted additional efficiencies that were possible," says Kirsch.

The lighter, stronger MPCV that resulted from the NASA/NESC partnership is scheduled for launch in 2016 with the redesigned version of the heat shield. As the Orion team finalized their own design for the crew module, the NESC and Collier Research continued to work on maturing the alternate carrier structure they developed for NASA.

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