Dutch Space simulates spacecraft launch and re- entry with SIMULIA

By Chris Hardee

Dutch Space uses Abaqus FEA from SIMULIA to virtually test a new metallic thermal protection system for hypersonic space vehicles. For a spacecraft to be reusable, it must first withstand a controlled explosion powerful enough to propel it through the Earth's gravitational grip. Then to come home intact, it must survive the blast furnace of atmospheric re-entry with temperatures hot enough to melt steel. Acceleration, vibration, shock, skin friction, heat flux and aerodynamic forces: These are not trivial design challenges. This is rocket science.

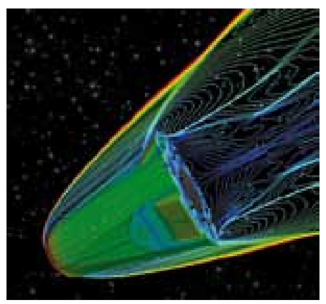

Figure 1. Simulation of the flow around EXPERT during atmospheric hypersonic re-entry. (Courtesy European Space Agency).

Dutch Space, located in Leiden, the Netherlands, is a supplier of high quality subsystems and products for the international space industry, and has been a key player in the development of metallic Thermal Protective Systems (TPS) and hot structures for reusable craft. The metallic TPS of the European Experimental Re-entry Testbed (EXPERT), an unmanned capsule developed by the European Space Agency and the prime contractor, Thales Alenia-Space of Italy, is one of Dutch Space's latest efforts (see Figure 1). Its pending launch in the summer of 2011 promises validation, not only of new materials, but also of simulation as an integral tool in the development process.

NEW TPS TECHNOLOGY : A TALE OF TWO MATERIALS

From the start, Dutch Space has focused on the use of metallic materials for TPS designs. According to Javad Fatemi, technical leader of the EXPERT's TPS project, metals have a lot of advantages over ceramics. "Metals are easy to use and maintain," Fatemi says. "They can handle impacts much better and inspection is easier."

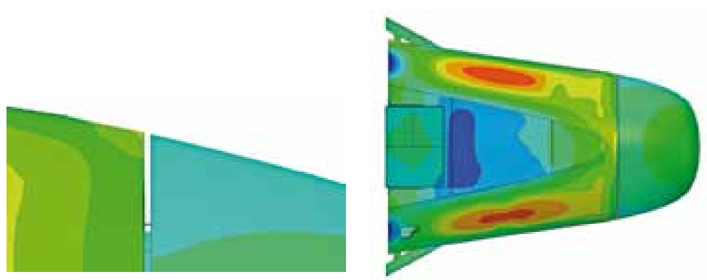

Figure 2. Abaqus FEA analysis showing side-view of EXPERT illustrates the temperature differences at the junction between the ceramic nose and the metallic after-body during re-entry.

But on the negative side, metals are heavier than other materials and cannot cope with high temperatures as well as ceramics. So to take maximum advantage of material properties, Fatemi is betting on a TPS that uses a combination of metallic and ceramic parts.

But while providing material advantages, a two-part, two-material design also introduced the project's greatest design challenge: the thermal expansion of the metal is eight times greater than that of the ceramic. "At the junction between the nose cap and the after-body, we had this huge thermal mismatch," Fatemi says. If the shape of the vehicle was to change during re-entry from the thermal mismatch—even just slightly—it could alter the flow from laminar to turbulent and, as a result, increase heat flux by a factor of two to three.

The solution was a structure that bridges the two components while allowing for differential heat expansion. "We needed to design the TPS so that we were sure it wouldn't trigger turbulence," Fatemi says. "Simulation was key to solving that problem."

REALISTIC SIMULATION OF LAUNCH AND HYPERSONIC RE-ENTRY

After conducting a tradeoff study, the group selected Abaqus FEA from SIMULIA, coupled with CATIA. "We imported the CATIA model directly into Abaqus CAE to make the FE model of the TPS," Fatemi says. "Every time we made a revision based on our analysis, the CATIA model would automatically update."

To accommodate the multiple physics that the EXPERT is subjected to, Fatemi developed both 3D structural and 3D thermal models "With Abaqus, you have a unified finite element (FE) model," Fatemi says. "That means if you want to create both a thermal and a structural model, you can use the same mesh and easily change the element type and the boundary conditions."

ANALYZING LIFT-OFF AND RE-ENTRY LOADS

The loads being analyzed during lift-off included quasi-static accelerations from the rocket, acoustic loads from the rocket engine, rapid depressurization at second-third stage separation, and random vibrations and shock each time a stage separates.

During re-entry, the vehicle is tested by even more extreme thermal and mechanical loads. As the approximately half-ton vehicle slams into a wall of air at fourteen times the speed of sound, it generates tremendous kinetic energy, which is translated into heat. Here Fatemi used a sequential thermo-mechanical analysis to calculate the thermal mismatch between the composite nose and the metallic after body to prove out the structural and material behavior of the design (see Figure 2).

CONFIDENCE HIGH IN SIMULATION RESULTS

As the EXPERT project neared completion, the Dutch Space team validated the predictions of analysis with actual measurements. "These comparisons gave everyone—the customer, the prime contractor, and Dutch Space—high confidence in the Abaqus FEA results," Fatemi says. "This is important since budgets were limited, full-scale thermo-mechanical tests are extremely expensive, and the EXPERT is going to fly without any full-scale thermo-mechanical tests."

"My objective is to build our capability for virtual testing and replace as much physical testing as possible," Fatemi says. "With EXPERT, we proved that simulation shortens the time-to-market and reduces costs. We have done all of our design verification using high-fidelity analysis and have confidence in the power of FEA to predict outcomes we can rely on."

For more information:
www.dutchspace.nl

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Technical Leader, EXPERT's TPS project
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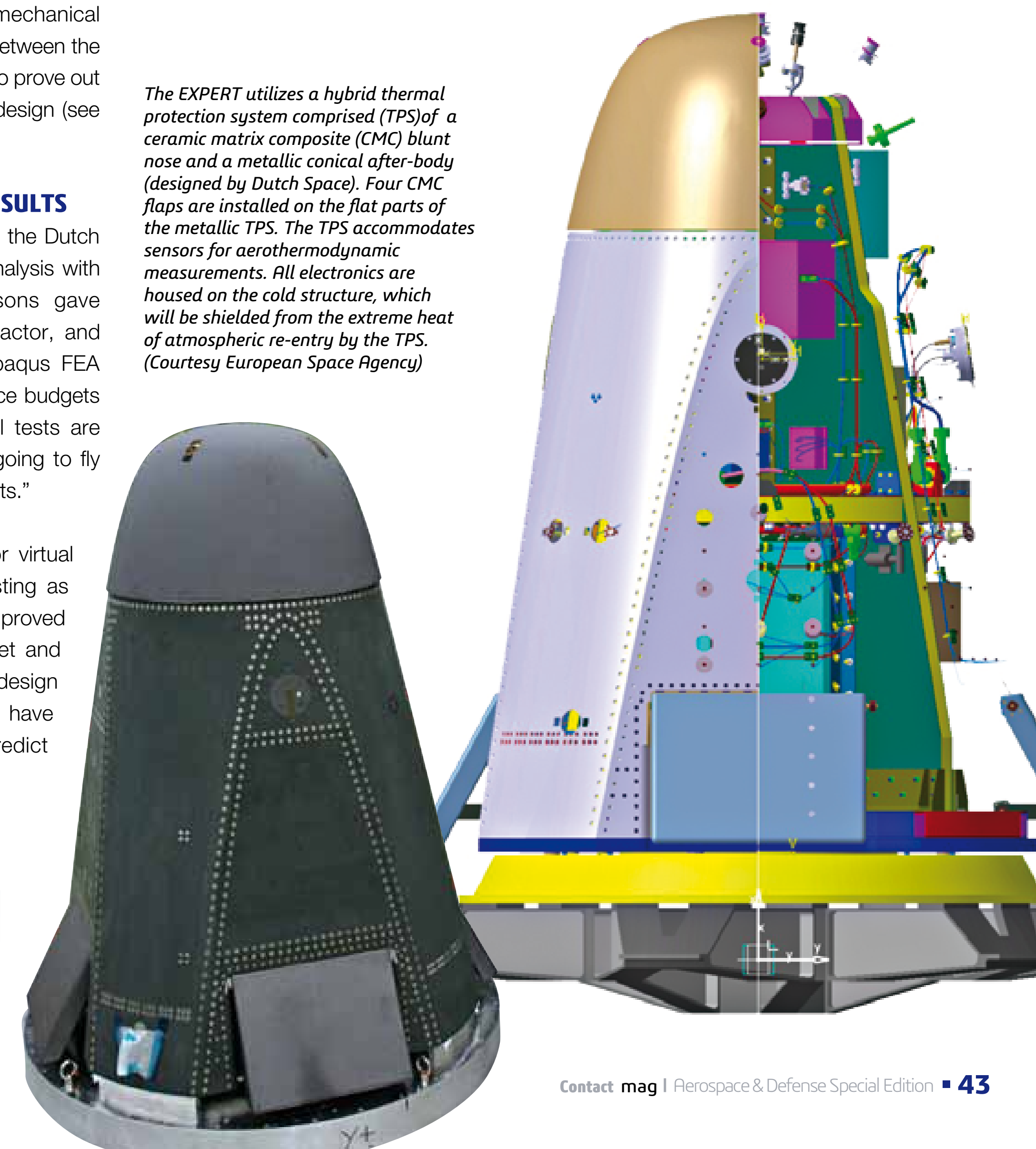

The EXPERT utilizes a hybrid thermal protection system comprised (TPS)of a ceramic matrix composite (CMC) blunt nose and a metallic conical after-body (designed by Dutch Space). Four CMC flaps are installed on the flat parts of the metallic TPS. The TPS accommodates sensors for aerothermodynamic measurements. All electronics are housed on the cold structure, which will be shielded from the extreme heat of atmospheric re-entry by the TPS. (Courtesy European Space Agency)