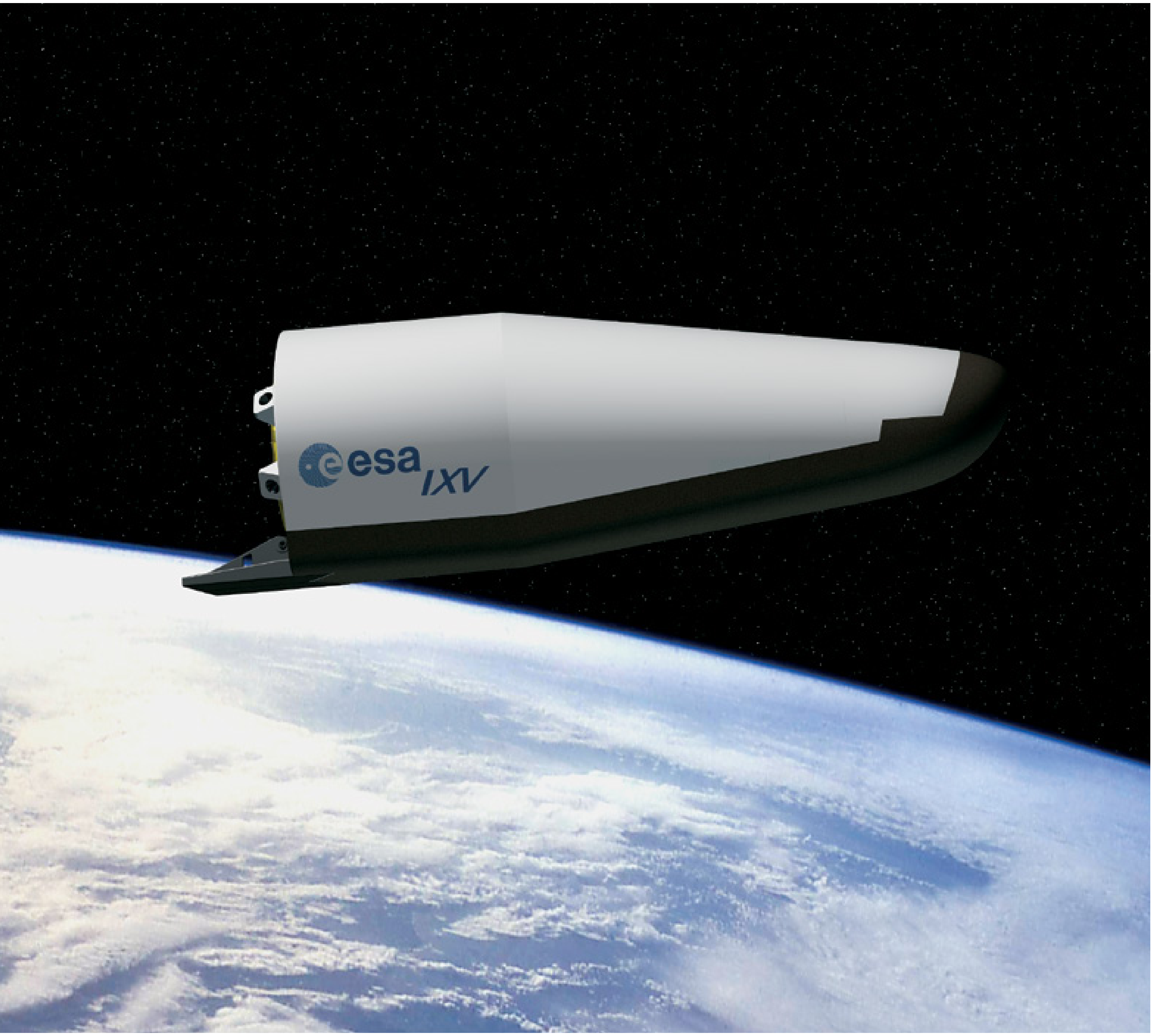
Thales Alenia Space Italia

Aerospace & Defense Case Study



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Challenge

Designing and optimizing hypersonic reentry vehicles involves consideration of a variety of physics disciplines, large data sets of design and flight condition variables, and the inability to test prototypes under real-world conditions.

Solution

The Isight environment enabled aerospace design engineers at Thales Alenia to build complex, multi-step workflows and automate the optimization and verification of their designs.

Benefits

The ability to integrate multiple simulations using extensive real-world flight condition measurements resulted in the elimination of conservative design assumptions, while also saving development time and encouraging departmental design collaboration.

As computer-aided engineering (CAE) tools become increasingly sophisticated, engineers can now refine their designs to nearly final form virtually. They can also push physical prototype testing later and later in the product development cycle. While prototyping remains essential for most types of products, in some industries it is impossible to create a test environment that produces real-world conditions. Vacuum chambers and wind tunnels can assess certain aspects of space travel, but it is impossible to test for all conditions at the same time.

Such is the case for Thales Alenia Space Italia (TAS-I), an European space system solution provider, in its ongoing design of hypersonic reentry vehicles for the European Space Agency (ESA) and other commercial and government entities. As a result, TAS-I engineers involved in these efforts rely mainly on CAE from start to finish of the design/virtual test/build process.

Design exploration and process automation help optimize complex designs

Cosimo Chiarelli, head of the aeromechanics and propulsion unit at TAS-I, is part of a team charged with designing and testing every aspect of the company's space reentry vehicles on the digital drawing board. Given the complex physics of atmospheric reentry, this is a daunting analysis challenge requiring a multidisciplinary optimization (MDO) approach. The project's feasibility was demonstrated in the AeroThermodynamics Configuration for Space Transportation (CAST) program financed by the Italian Space Agency (ASI) and conducted by the Italian Aerospace Research Center (CIRA) in early 2007.

First there is the spacecraft's structure to consider: this includes its geometry (length and shape) and the dimensions and material characteristics of the shell and thermal protection system (TPS). Then there is the trajectory, comprised of the vehicle's speed, altitude, and angle of attack (a steep angle increases friction and heat, while a shallow angle does the opposite). Thermal conditions for the vehicle's windward, leeward, and nose zones also have to be taken into account, along with the aerothermodynamic loads—such as pressure distributions and aerothermal fluxes—that it encounters. The final design makes allowance for all of these variables, with a focus on a time window of approximately 150 seconds: the most critical portion of reentry.

To optimize their designs, the team conducts a separate simulation for each of the physics disciplines. They use a collection of software packages—including six commercial, five proprietary, and two aerodynamic codes. And they divide the analysis into seven major computational "tasks" and 40 "sub-tasks," many with their own input and output file types (see Figure 1).

"We did a trade-off study of several commercial software tools and selected Isight to run our optimization," says Chiarelli. "It has features and add-ons that allow us to integrate all of the different codes and interfaces used for our physics sub-routines." Isight facilitates the creation of flexible simulation workflows and automates design exploration. With such a vast design matrix, TAS-I engineers have used the software as a way to systematically evaluate the countless possible solutions.

To conduct a feasibility study of their new optimization methodology, the engineering group—working in close association with Exemplar, a value-added reseller for SIMULIA in Italy—chose a theoretical hypersonic reentry vehicle and applied simplified assumptions. Further streamlining the process, they decided to optimize globally for all variables combined, rather than locally for each individual variable. Identifying minimized cost as the primary

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design target, they applied Isight's adaptive simulated annealing algorithm, an exploratory technique that helped them search the envelope of design solutions; this approach is one of many statistical methods available in Isight, including Design of Experiments and Design for Six Sigma. The SIMULIA Execution Engine was used to implement Isight process flows across company compute resources and enabled the sharing of results throughout the enterprise. Performing two-hundred iteration cycles in only a day, the analysis identified strong correlations between variables and arrived at several designs that satisfied the requirements for the spacecraft. More importantly, it demonstrated that the various simulations could be integrated and that optimization could be successfully applied to the resulting workflow. "Isight played a key role. It helped us unify our process and saved a considerable amount of time," says Chiarelli.

Design verification also benefits from automated workflows

Having established a methodology to optimize their designs, the engineering team now turned its attention to verifying that the vehicle would actually function as designed during the harsh

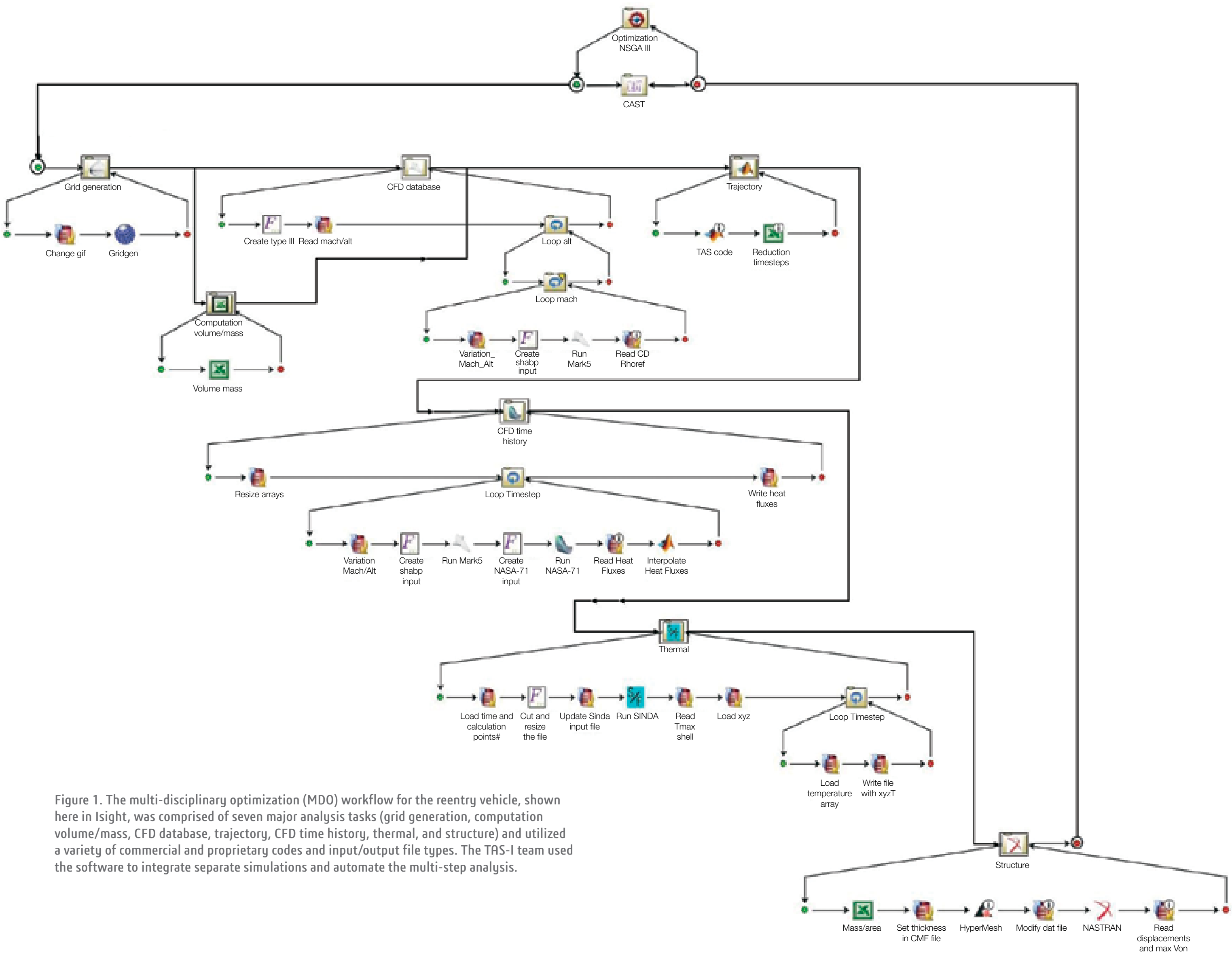

Figure 1. The multi-disciplinary optimization (MDO) workflow for the reentry vehicle, shown here in Isight, was comprised of seven major analysis tasks (grid generation, computation volume/mass, CFD database, trajectory, CFD time history, thermal, and structure) and utilized a variety of commercial and proprietary codes and input/output file types. The TAS-I team used the software to integrate separate simulations and automate the multi-step analysis.

conditions of reentry. As with their first analysis, the virtual testing process involved consideration of a large number of related variables—more than 25 parameters associated with flight conditions needed to be examined while computing aerothermal loads during reentry—to evaluate the design and performance of the vehicle's all-important guidance, navigation, and control (GNC) and thermal protection systems (TPS). Again, TAS-I engineers worked in collaboration with Exemplar and used Isight to manage the workflow.

In past design projects, once a reference trajectory had been defined, the identification of extreme aerothermodynamic (ATD) loads on the proposed design was divided into a series of separate steps. But this approach only allowed engineers to look at specific points on the vehicle (not at all points, or even at all zones) and only at the worst-case scenarios (worst attitude, angle of attack, flap deflections, and trajectory, for example). For these reasons, design assumptions were typically conservative and vehicles might suffer performance-degrading effects from overdesign.

To apply detailed real-world conditions, the team based the new Isight-driven methodology on a strong association between GNC and ATD simulations and plugged in an extensive proprietary ATD database for all 25 flight condition measures. The goal of the analysis was to assess each time step....for every possible trajectory....for any zone on the vehicle.

TAS-I engineers handled this huge computational challenge by dividing the analysis into three discreet tasks and relying on Isight's capability to combine the separate steps and run the entire process flow automatically (see Figure 2).

- The first task was a Monte Carlo simulation experiment (a powerful random sampling technique available in Isight) in which the GNC model's performance was evaluated for the 25 flight parameters during 1,000 sample trajectories.
- In the second part of the analysis, the Monte Carlo results were post-processed for three key variable time histories, at 100 different locations on the vehicle, for all 1,000 trajectories (a total of 300,000 time histories).
- In the third step, all of the time histories were analyzed to identify maximum heat loads and fluxes for every point on the vehicle during each trajectory.

As hoped, the new method enabled the TAS-I team to handle the data-rich aerothermal characterization of the vehicle, calculating the loads on the entire vehicle surface while taking into account all the inaccuracies affecting the trajectory itself. The traditional sequential process of design, analysis, and optimization, which used to take two weeks, now takes only about 48 hours in the automated Isight environment.

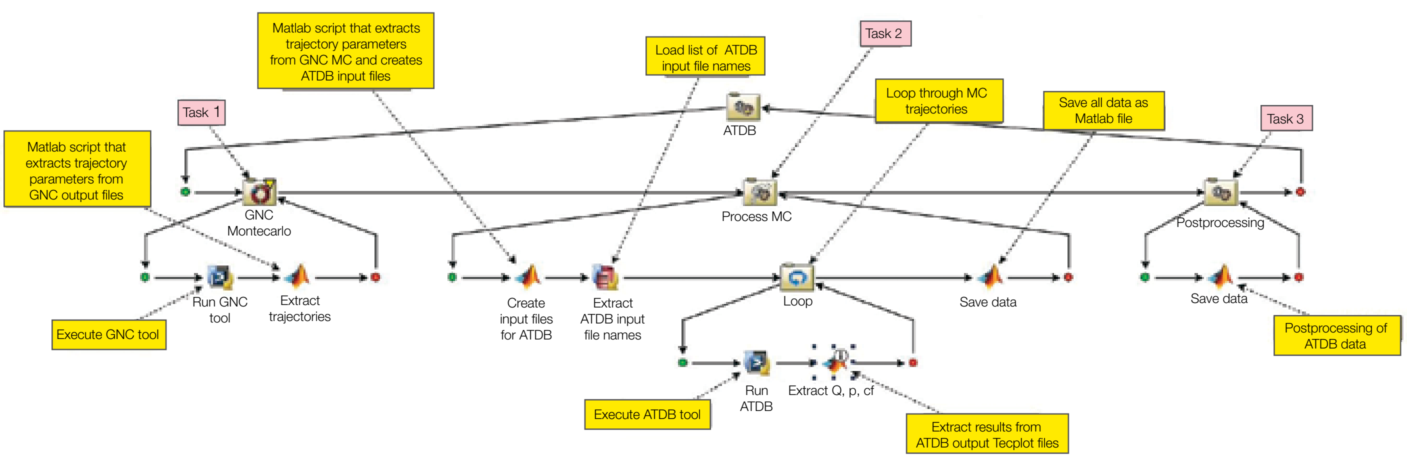

Figure 2. The workflow for verification of a theoretical reentry vehicle includes three major sub-routines. Isight's open integration technology allowed TAS-I engineers to include proprietary scripts, applications, and databases. The unified process flow has decreased time investment by an estimated 80 percent and eliminated data transcription errors.

"Our analysis is more robust now because we can process huge amounts of data," says Chiarelli. "Using the Isight environment, we have been able to reduce the use of conservative assumptions for our designs."

Probe payloads are the payoff

Because of the success of their optimization and verification studies, TAS-I engineers are now incorporating higher fidelity codes and applying the new methodologies to more complex reentry vehicle models. They are able to process larger data sets in shorter times: TAS-I estimates that man-hours for new simulation iteration could be reduced by about 80 percent once the automated process has been established and proved.

Design flexibility has been enhanced, as well, because a change in any parameter can be recalculated simply by running a new analysis loop within the established process flow. Moreover, the new workflow has decreased manual errors from data transcription, increased efficiency, and stimulated deeper collaboration between engineering disciplines and departments.

According to Chiarelli, integrating and automating analysis workflows are helping TAS-I engineers address the many design uncertainties of hypersonic reentry. The ultimate benefit to the scientific community will be the safe return of probes with valuable payloads from deep space.

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