Case study

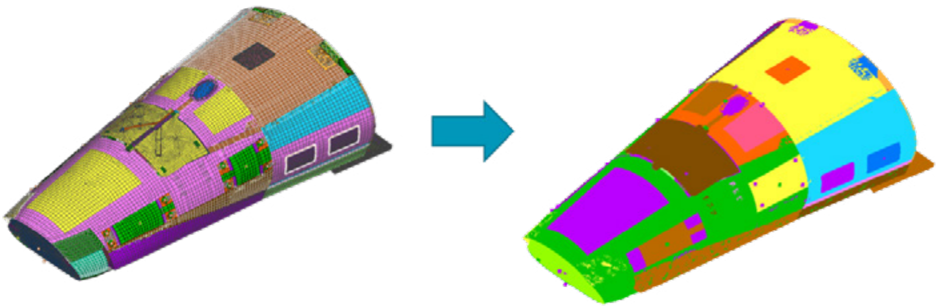
Predicting mechanical shock environments with vibroacoustic simulation

Actran's Virtual SEA helps Thales Alenia Space Italy obtain better predictions for shock environments.

Thales Alenia Space has been using Actran's Virtual SEA method for high frequency vibroacoustics to predict the behavior of mechanical shock environments during a space launch.

Space launches present an extreme challenge to engineering teams, given the severe conditions that the space launcher goes through while taking off and heading into space. Not only do designers need to ensure that the propulsion system works well, but also that the launcher's integrity is not compromised, withstanding the massive loads to which it is subjected.

Thales Alenia has for decades collaborated with space agencies and private companies alike, delivering satellites into space while ensuring they arrive at their orbit safe and functional. In Italy, activities include the study of the vibroacoustic behavior of both the launch vehicle and payload during launch. Such investigations include the evaluation of random vibrations, loads and stresses on the spacecraft internal units, and audible noise evaluation for astronaut acoustic comfort. For instance, the audible noise spectra is analyzed inside the pressurized modules under on-orbit operational conditions while designing the various noise control devices that improve the acoustic comfort of the astronauts.



Going from a finite element model (left) to a Virtual SEA model (right) is extremely easy and handled automatically.

Mechanical shock environments

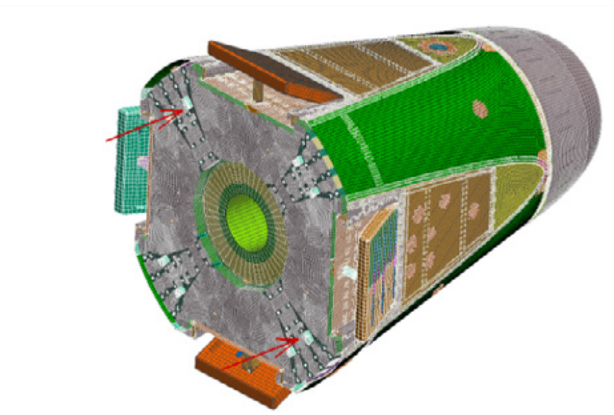
Every aircraft includes a variety of mechanical shock sources that are activated during various phases of the space flight. These involve separation systems, deployment systems, hold-down and release mechanisms, pyrovalves and pyroactuators among others.

To give an idea of the number of such devices on a spacecraft, the Apollo spacecraft featured more than 210 shock loading devices located in the spacecraft and launcher. These systems and mechanisms present a unique challenge as it is necessary to ensure that internal equipment such as on-board computers and electronics, stay safe during and after their activation.

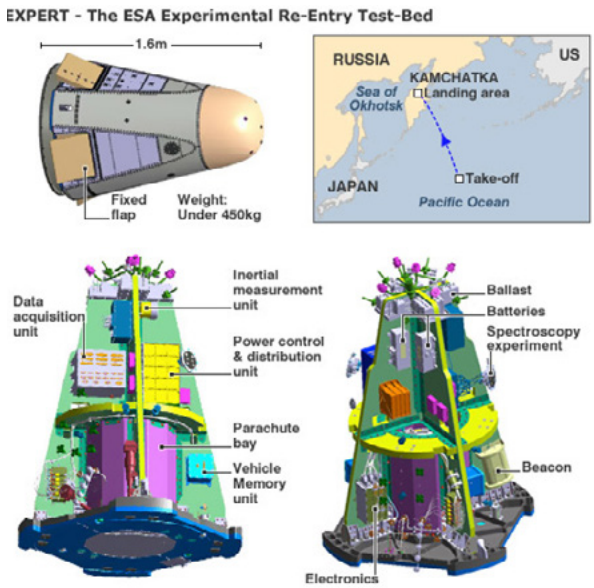
Simulation for prediction

Accurately predicting the response from mechanical shock sources is crucial to ensure that no damage is provoked on the internal systems of the spacecraft. These systems often have resonances at high frequencies hence traditional frequency-domain finite element (FE) methods, where the frequency of a solution prescribes the size of the problem, are not suitable in an industrial frame. Time-domain FE methods are also used but have drawbacks such as damping management and shock source definitions. Such components are typically defined in the frequency domain while their application in a transient analysis would require a conversion. Traditionally, semi-empirical methods have been used to evaluate these systems leading to non-optimal structures and higher costs. In order to evaluate this problem, a more precise method is required. Thales Alenia Space has employed Actran's Statistical Energy Analysis (Actran SEA) method for high frequency vibroacoustics to solve this issue.

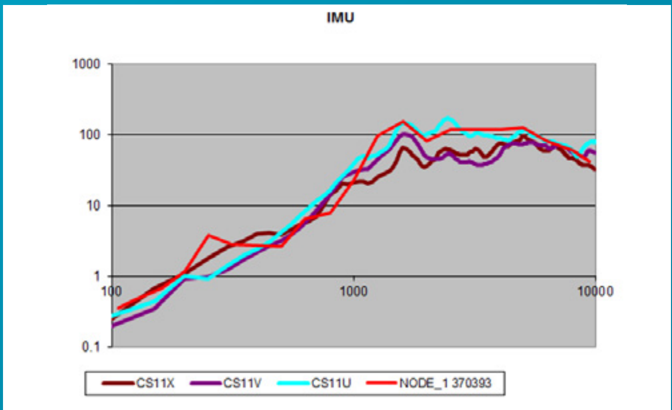
Actran SEA is uniquely positioned to solve shock response problems, starting from existing FE models and extending results higher into the frequency spectrum. Inputs are defined directly in the frequency domain to ensure that all resonant frequencies are correctly excited; such an approach would be difficult if the inputs were defined exclusively in the time domain. Local outputs may be defined which are required for evaluating the acceleration of the various systems. Additionally, the damping management is eased by allowing a definition of damping with respect to the frequency of solution. Using Actran's approach it is relatively straightforward to create an SEA model from an existing FE model as Actran SEA can automatically generate the SEA subsystems required, easing the workload for the engineer.

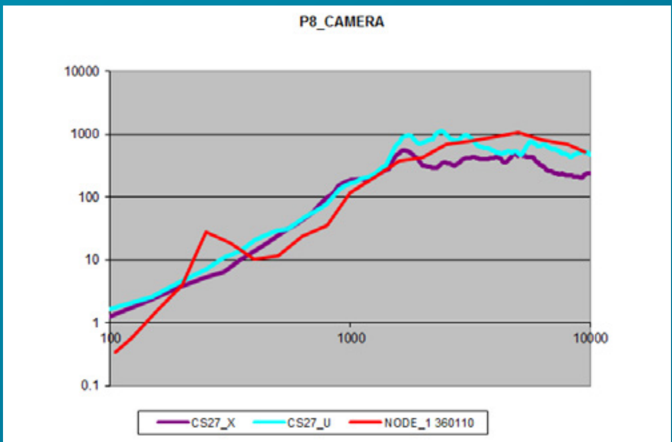


A finite element model of the EXPERT experimental re-entry test-bed vehicle.



Internal instruments of the EXPERT vehicle. The functionality of these instruments should not be compromised due to shocks.





Comparison between simulation (in red) and various measurements (in other colors) of the shock on various instruments of the EXPERT space vehicle.

In order to get the required response, an approach based on transfer functions between the location of the shock sources and the various target systems is defined. To compute this transfer function, a unitary point load is applied at the shock source location and Actran SEA computes the resulting acceleration at both the source and the target locations. The acceleration at the target location is then divided by the acceleration at the source and the transfer function is obtained. In order to get the final response the specified shock response spectrum (SRS) is multiplied by the transfer function to obtain the expected shock environment at the target units.

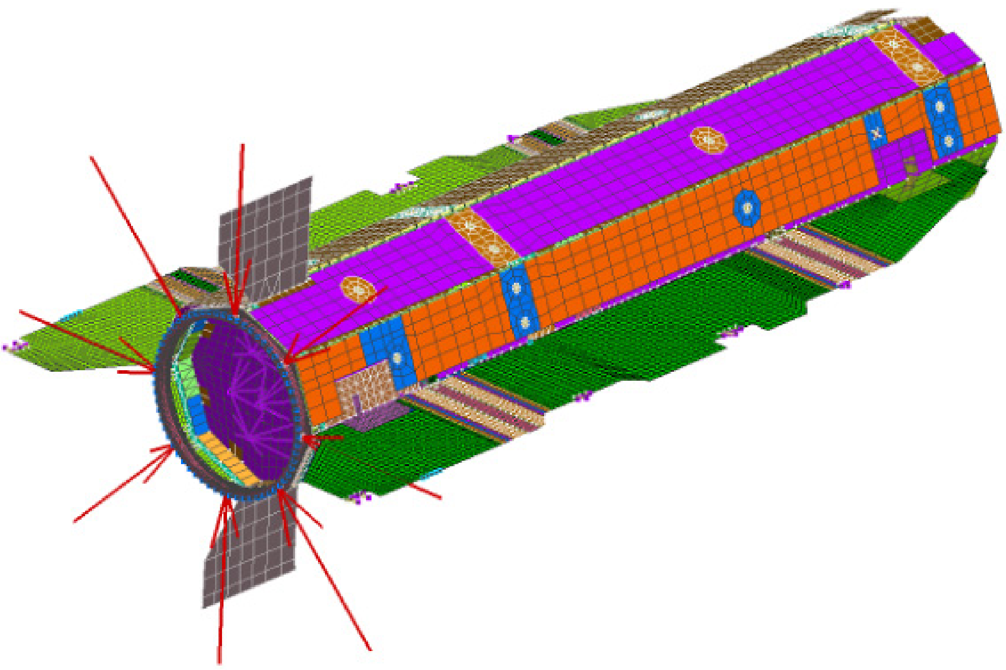
> **"An advantage that Actran SEA has is that there is no need to build a dedicated model from scratch. You can start from an existing finite element model and let the software automatically build all the necessary ingredients for the analysis."**

Actran SEA for shock response prediction

To validate the approach, Thales Alenia Space used EXPERT, the ESA experimental re-entry test-bed vehicle as the application. The shock source is defined as two pyro-hammers and the response is evaluated on all the spacecraft system. The modal basis was computed up to 1.5 kHz and the maximum frequency was set to 10,000 Hz. Test data is available for the full characterization of the shock input and responses on the spacecraft systems.

Results for the various on-board devices correlate very well with the measurements from 100 Hz to 10,000 Hz, with good correlation demonstrated in both low and high frequencies as shown. The red curve represents the Actran SEA results while the other curves indicate experimental data. After validation the method was further applied to a more complex geometry, the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE), which is an observation satellite. Here, the shock source emulates the separation between the clamp and the band of the satellite; as before there is test data available for the characterization of the spacecraft. One particularity about this spacecraft is the construction. The satellite features long panels that are used to connect to each of the scientific instruments inside. As these panels act as waveguides, the shock was transmitted longer than usual; a response which was not identified by the semi-empirical methods.

Actran SEA was able to identify this longer propagation and provided results that are closer to reality than the semi-empirical curves used traditionally as shown in the following figure. In this comparison the red curve represents the Actran SEA prediction, the black curve is the semi-empirical curve prediction and all other curves come from experimental data.



A simulation model of the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE), which is an observation satellite. This satellite presents a unique problem for shock response predictions due to its unconventional structure.

These applications demonstrate the applicability of the Actran SEA method for shock response, even for highly non-conventional structures like GOCE. Thales Alenia Space plans to further apply this method to other geometries to take advantage of the unique features offered by Actran SEA for the prediction of shock response in spacecraft.

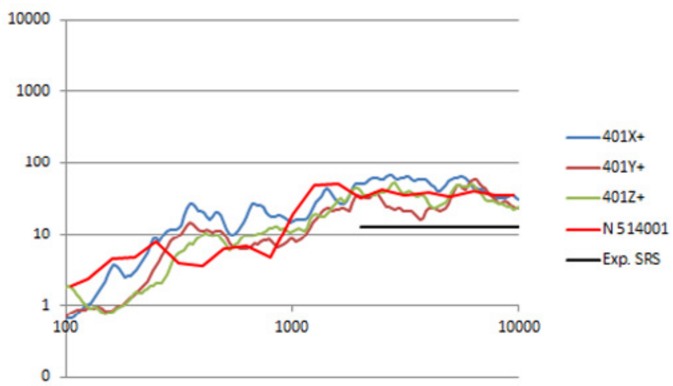
Summary

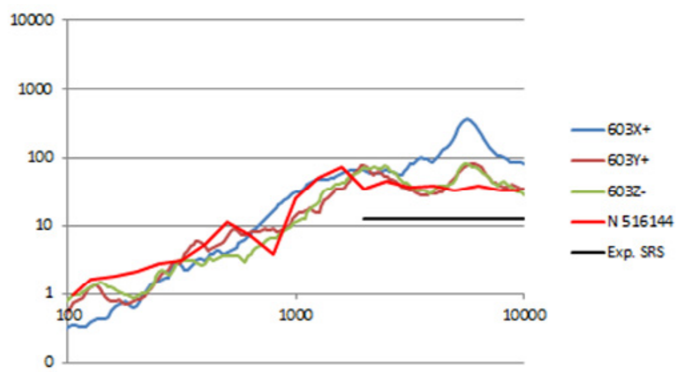
Actran SEA has proven that it can be used for reliably predicting shock environments, even when the structure of the spacecraft is unconventional and semi-empirical, industry-standard methods fail to provide accurate predictions.

The connection between the finite element and the SEA model makes it easy to get started. “An advantage that Actran SEA has is that there is no need to build a dedicated model from scratch. You can start from an existing finite element model and let the software automatically build all the necessary ingredients for the analysis” says Stefano Destefanis, vibroacoustic specialist for Thales Alenia Space.

With respect to reaching high-frequencies, which is required for shock environments, he adds “Actran SEA has a lot of potential for shock environments as it allows to extend the suitable analysis frequency range so that even at 10 kHz it is possible to produce fairly reliable results”.

Finally, Actran SEA provides unique features, such as the extension beyond a computed modal basis which makes it very attractive for large models.





Comparison between simulation (in red), empirical formulas (in black) and various measurements (in other colors) of the shock on various positions of the GOCE satellite.

“Actran can provide reliable predictions even for unconventional payload structures, potentially providing a powerful tool for shock predictions.”

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