MSC Software helps Avio ensure the VEGA launcher's structural integrity

Using MSC Nastran and Actran – engineers at Avio were able to accurately predict the effect of noise vibrations on the structural integrity of its launchers.

Avio used MSC Nastran to efficiently compute the natural motion of VEGA's structure, and applied Actran to model both the acoustic environment and acoustic load of that structure.

While the race to Mars is making headlines, there is another ongoing space race that will shape the digital era and the way the world is connected: satellites. Satellites are essential for many of the services we use every day, from location-tracking GPS to high-speed communication with 5G networks. Currently, over 2,000 active satellites have been deployed in space, many of which live very close to the Earth's surface in Low Earth Orbit (LEO).

In the last decade, there has been increasing demand for LEO satellites due to a need for faster networks and greater connectivity. For example, Earth observation programmes, such as European Space Agency's (ESA) Copernicus, need to be able to take continuous and high-quality images in order to provide accurate information for ground-monitoring use. LEO satellites are crucial for supplying this data in real time to observatories, and their launches are also less expensive and require less fuel than other satellites operating further away.

Artist's view of Vega-C on the launch pad - credit ESA

Launching into this orbit requires a great deal of technical precision, however. ESA's satellite launch vehicle, VEGA, was specially designed by Avio using simulation tools provided by MSC Software, which is part of Hexagon's Manufacturing Intelligence division, to send small satellites into LEO. Since its maiden flight in February 2012, the small and flexible VEGA launcher has successfully carried over 20 spacecraft into orbit. The next phase of the VEGA launcher, VEGA-C, has been approved and is now undergoing reviews.

The acoustic challenge

Among the many technical challenges in designing VEGA, the most important of all was to ensure the integrity of its structure and provide a safe environment for its cargo: the satellite payloads. Launchers are subjected to severe conditions at lift-off, from blazing heat to immense atmospheric pressure, but it is the acoustic load is the most critical. The noise generated by the launcher during ignition, lift-off, and flight can cause vibrations and lead to electronic and mechanical components malfunctioning in both the launcher and its cargo.

To ensure this doesn't happen, engineers at Avio used a computational approach to predict how sound affects the structure at lift-off. With the help of MSC Software's computer-aided engineering (CAE) solutions MSC Nastran and Actran, they were able to create accurate Finite Element Analysis (FEA) platforms for structural simulation. These simulation tools are used across nearly every kind of industry, from aerospace to medical technology. MSC Nastran has been trusted by the aerospace industry since NASA's Apollo missions, and is now used to optimize the performance and lifespan of all kinds of products. Avio used Nastran to efficiently compute the natural motion of VEGA's structure, and applied Actran to model both the acoustic environment and acoustic load of that structure.

Acoustic analysis of the upper stage of the VEGA Launcher

The Avio VEGA and VEGA-C launchers are made of multiple stages, with each playing a critical role and requiring extensive tests before being flown. The payload fairing, installed within the launcher's upper stage, is responsible for protecting the spacecraft. It is a cone made of composite carbon fiber reinforced polymer sheets that protect the spacecraft from the impact as launch. It shields it from atmospheric turbulence and heat while the launcher passes through the Earth's atmosphere, as well as protecting it and the payload from the damaging soundwaves during take-off.

To assess VEGA's upper stage's complete structural response, experimental acoustic tests were conducted at ESA's Large European Acoustic Facility, which can simulate the noise at lift-off. During the test, the payload fairing's interior acoustic environment was measured, and MSC Nastran was used to create a Finite Elements (FE) model of the entire upper stage structure.

The first step was to assess the general behaviour of the payload fairing while it endured exterior acoustic load. A study was performed to assess the different simulation opportunities provided by Actran and the required computational time when developing new launchers.

In the first simulation, a Diffuse Sound Field (DSF) excitation was applied directly on the exterior structure, using data acquired by the acoustic measurements, to test the spacecraft's structural integrity during launch when subjected to acoustic pressures. This quick and useful numerical strategy provided accurate insight into the structural vibrations, but it was not able to model the sound pressure inside the structure and how that affects it, as the fairing's interior and exterior acoustic environments were not modelled.

In order to overcome this limitation, a second simulation was performed to explore the internal acoustic cavities. The FE models of the fairing cavities were added to the entire structures and two possibilities were investigated: a hybrid solution with the structure as modal components and the cavities as physical components, and a fully modal solution with both structural parts and acoustic cavities as modal components. The latter solution proved to be more flexible and versatile.

A final simulation was conducted to provide a very detailed reconstruction of the test launcher. This extensive simulation allowed the external and internal environments to be accurately modelled, but was very demanding in term of memory (RAM) capability and computation time due to the degrees of freedoms involved in the analysis.

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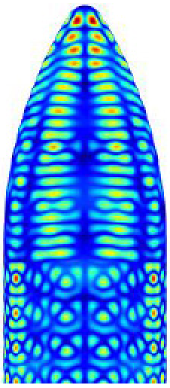
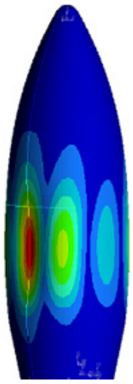
Eigenmode shapes extracted with MSC Nastran - fairing first bending mode



Eigenmode shapes extracted with MSC Nastran - fairing higher order mode



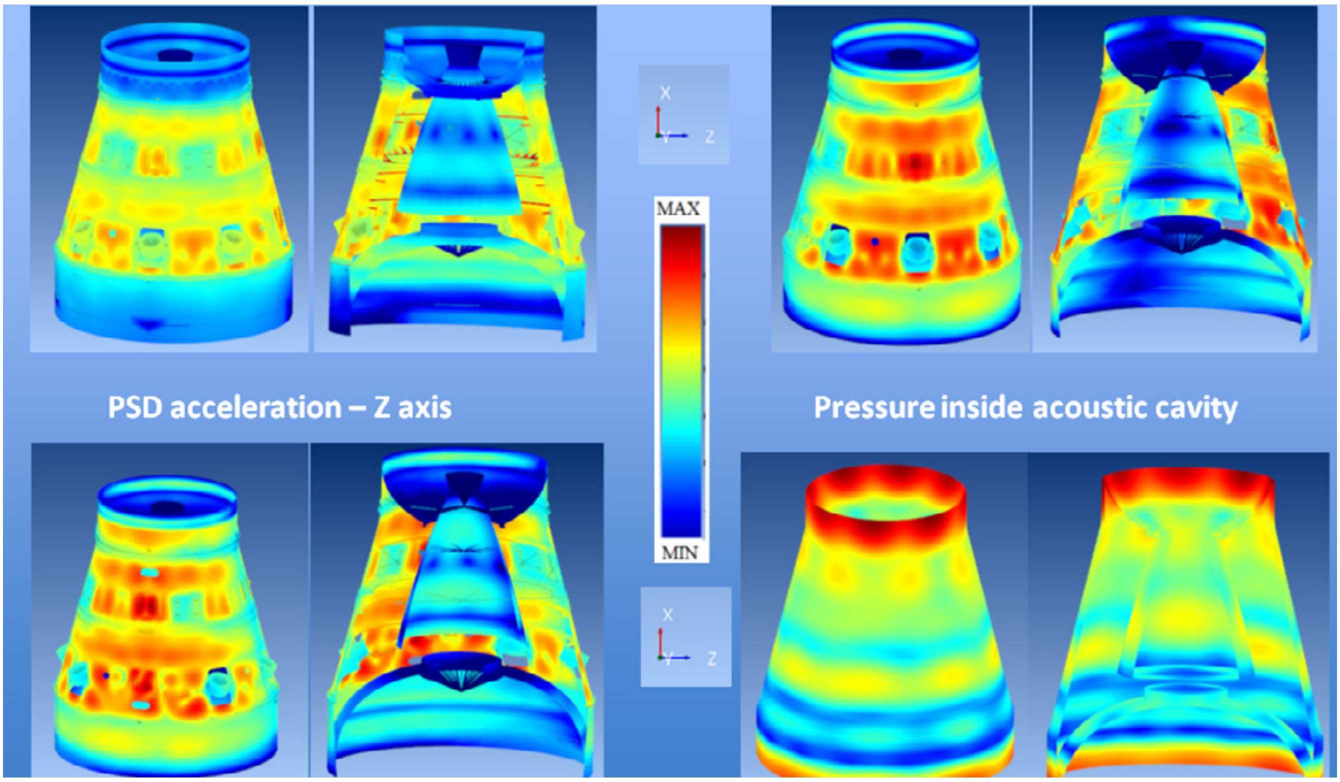
Eigenmode shapes extracted with MSC Nastran - fairing second breathing mode

The new VEGA-C Launcher

Once VEGA was validated using these tests, the same acoustic simulation methodology was implemented to evaluate the vibro-acoustic response for the new VEGA-C structures. VEGA-C will be able to accommodate larger payloads such as Earth observational satellites of over two tonnes. Engineers at Avio conducted an analysis of its most sensitive parts: the interstages between the solid rocket motors and the upper stage.

Interstage structures connect the various parts of a multistage rocket. They are also responsible for the separation of the stages after launch. These structures are very sensitive to vibro-acoustics because they contain a lot of the rocket's electronic equipment, so the same combination of MSC Nastran and Actran was used to evaluate their response.

One example of interstage structures are payload adapters, which connect the satellite to the launch vehicle. Both VEGA and VEGA-C launchers are extremely flexible thanks to their ability to accommodate different payload adapters, allowing them to carry multiple payloads at a time according to different configurations. However, as payload adapters contribute to the overall stiffness of the launch system, they can be heavily affected by resonances in the fairing cavity, so it is important to accurately predict the level of vibration they will be subject to. The analysis therefore took the internal payloads into account, simulating them coupled with the launcher structure and the acoustic cavities.



Vega C - Interstage response map

Testing new modelling capabilities

In addition to the above FE approach, Avio's engineering team also performed a statistical energy analysis (SEA) of the payload fairing using Actran's Virtual SEA approach. This method allows engineers to predict how sounds and vibrations pass through a structure, especially at higher frequencies where noise can be more penetrable. Relying on previous FE models, the Virtual SEA approach implemented in Actran that enables the efficient vibro-acoustic analysis directly from existing FE models by extending them to higher frequencies without the need for specialist SEA expertise. Furthermore, as the Virtual SEA approach relies on existing low frequency FE models, SEA results are valid at both low and mid-frequencies and provide a smooth transition between mid- and high frequency results.

When the available physical measurements and Actran Virtual SEA results on the fairing structure were compared, the engineers found that both results were impressively similar, demonstrating the potential of this new approach to tackle such analysis. Moreover, Actran and the Virtual SEA approach provide a unified environment in which engineers can tackle their vibro-acoustic challenges across the complete frequency range, as opposed to having to use multiple tools for low, mid and high frequencies analysis. The approach has since been used for further structural analysis on VEGA-C.

Using MSC Software's solutions – MSC Nastran and Actran – engineers at Avio were able to accurately predict the effect of noise vibrations on the structural integrity of its launchers, VEGA and VEGA-C, ensuring the vital components of these launchers were able to withstand the extreme pressures of launch and lift-off. VEGA-C is scheduled for its maiden flight in 2020, bringing enhanced observation capabilities to communities all over the globe.

Vega launch - credit Arianespace

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Our technologies are shaping urban and production ecosystems to become increasingly connected and autonomous – ensuring a scalable, sustainable future.

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