Shaping A Smart and Connected World:

Avio to Ensure Spatial Launchers Structural Integrity

While the race to Mars is making headlines, another ongoing space race that will shape the digital era and the way the world is connected is getting less attention: satellites.

Satellites are essential for a lot of services that we use everyday. In the last decades the Low Earth Orbit (LEO) is becoming increasingly crowded due to the growing market demands. In order to meet the low latency and gigabit connectivity requirements of native 5G networks which enable the digital era and connect the world by delivering broadband access, there is a need to develop a universe of multi-orbit satellites.

Operating closer to Earth, they offer lower latency (delay in a round-trip data transmission) than any satellite orbit.

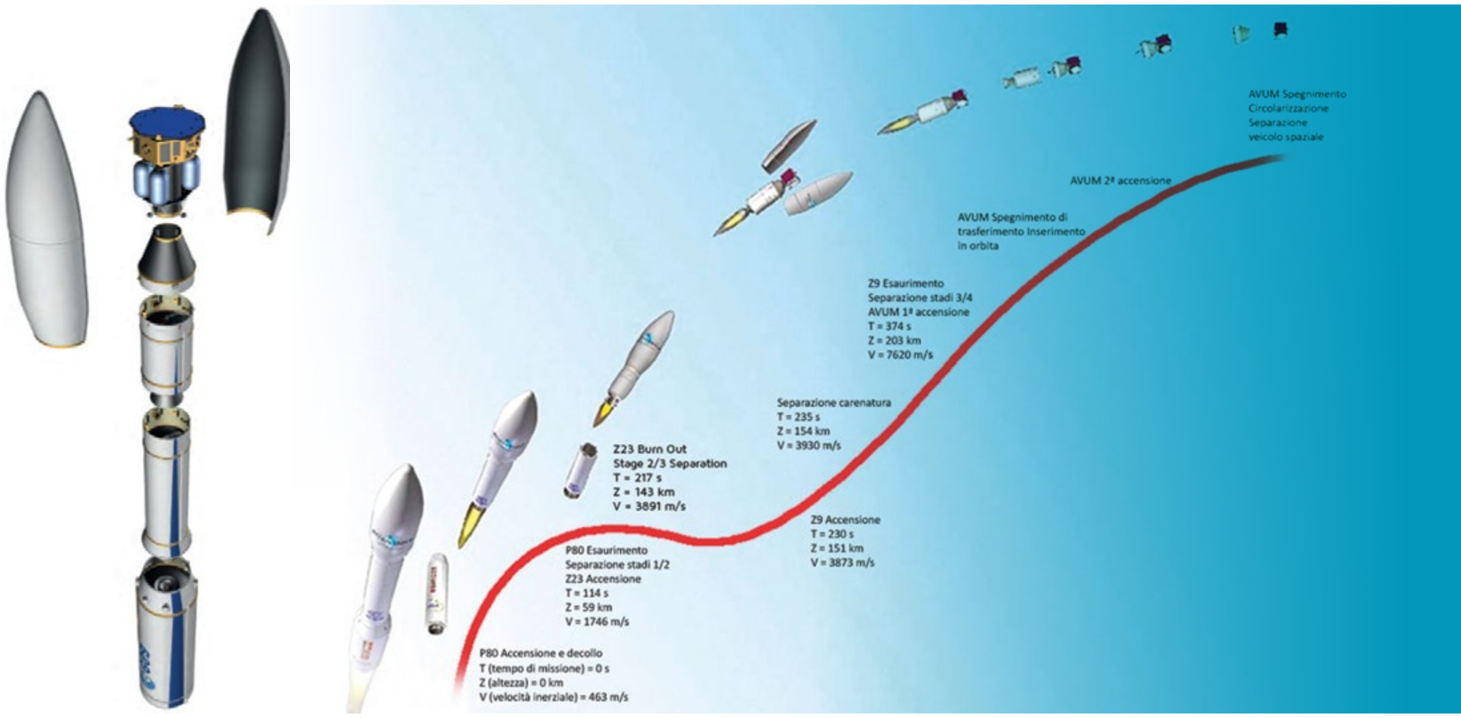


Figure 1: **Vega Launcher - Mission profile and stages overview - www.arianespace.com**

Also Earth observation programmes such as ESA Copernicus aim to to achieve a global, continuous, autonomous, high quality, wide range Earth observation capacity. This will provide accurate, timely and easily accessible information to help understand and improve the management of the environment, understand and mitigate the effects of climate change, and ensure civil security. In this horizon, Low Earth Orbit (LEO) satellites are essential. Their proximity to Earth also means that launching such type of satellites is cheaper and requires less fuel than other types of satellites operating at longer distance.

The Avio VEGA program is a European Space Agency (ESA) program for missions in LEO and the associated Vega launcher is the ESA's satellite launch vehicle designed to send small satellites into LEO. Since its maiden flight in February 2012, of the small, flexible launcher, Vega successfully placed more than twenty payloads into orbit. In 2014, at the Ministerial Conference of ESA Member States, the dawn of the next phase for the Vega launcher was approved, leading to the new configuration of the VEGA launcher called VEGA C, offering improved performance with a maiden flight scheduled for 2020.

Among the multiple technical challenges overcome by the Avio technical teams, one of them was to ensure the integrity of the complete launcher, its structure and components to ensure a safe environment for the payloads. Indeed, any space rocket launcher is subject to severe external-pressure loading generated by the mixing of the rocket-engine exhaust stream with the ambient atmosphere. The acoustic load might be critical to the proper function of the vehicle and its components as induced structural vibrations and internal acoustic load can lead to malfunctioning of electronic and mechanical components.

Figure 2: **Vega and Vega C Launchers**

Hexagon | MSC Software Solutions

Avio's engineers used Hexagon CAE solutions MSC Nastran and Actran to predict the vibro-acoustic response of the complete launcher structures at lift-off. The computational approach is straightforward and uses MSC Nastran to efficiently compute the mode shapes and related eigenfrequencies of the launcher structure while Actran is used to model both the acoustic environment and acoustic load.

Avio's engineers used Hexagon CAE solutions MSC Nastran and Actran to predict the vibro-acoustic response of the complete launcher structures at lift-off.

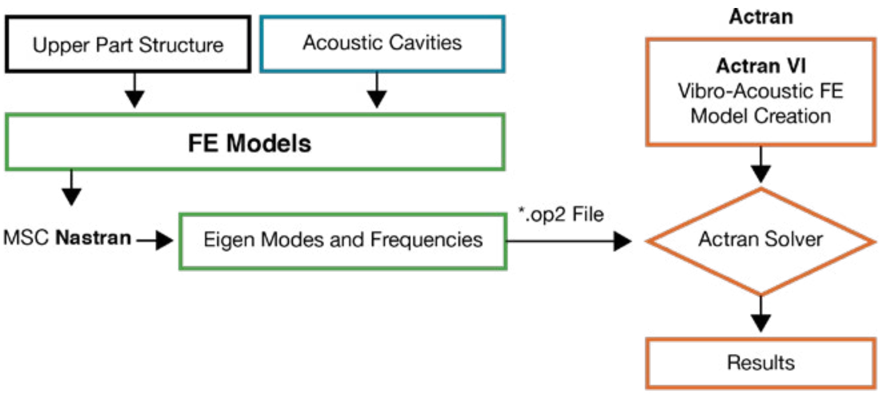


Figure 3: **Numerical Analysis Workflow**

The VEGA Launcher Upper Part

The Avio VEGA and VEGA-C launchers are made of multiple stages, each having a critical role in the success of the launch. Each part of the launcher has its own function during the mission and the payload fairing, also called Heath Shield, installed on the last stage of the launcher is responsible of the payload protection. It is an 7.8-meter-high – 2.6-meter-diameter shell made of composite CFRP sheets with aluminum core that protects the payload from the thermal load, aerodynamic fluxes, acoustic environment and contamination.

Figure 4: **Vega Fairing at ESA ESTEC Large European Acoustic Facility during the Upper Composite Acoustic test**

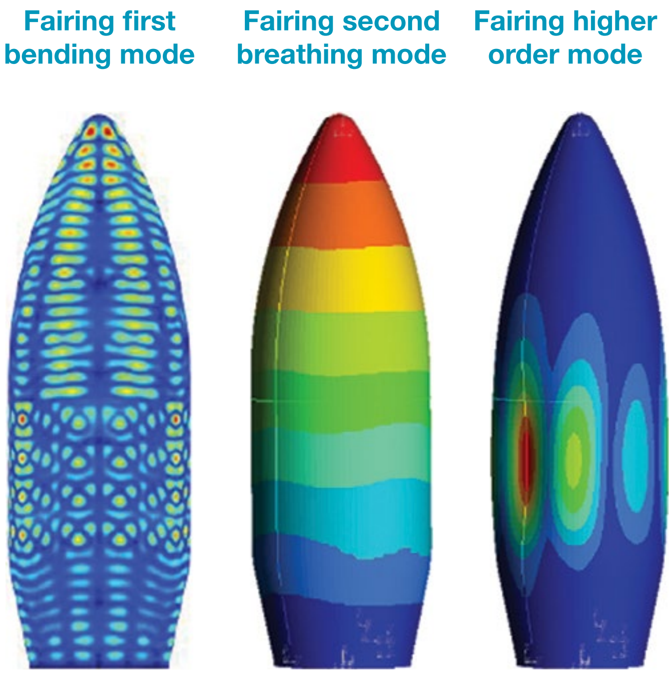


Figure 5: **Eigenmode shapes extracted with MSC Nastran**

Experimental tests were conducted in ESA ESTEC Large European Acoustic Facility in qualification flight configuration in order to assess the complete structural response of the launcher upper part during the lift off phase. During test, the standard payload was replaced by a microphone tree measuring the fairing interior acoustic environment. In addition, multiple accelerometers were located on the structure.

An MSC Nastran Finite Elements model of the entire upper stage structure was created by Avio's engineers, allowing them to compute the structure mode shapes and related eigenfrequencies. The data acquired by the acoustic test were used both for the correlation of the VEGA upper stage and for the evaluation of different simulation solutions provided by Actran software. This study was performed in order to make a tradeoff between the different simulation opportunities provided by Actran and the required computational time with a view to developing new launchers. As a first step, and in order to quickly assess the general behavior of the structure submitted to the exterior acoustic load, the fairing interior and exterior acoustic environment was not modeled. A Diffuse Sound Field (DSF) excitation with frequency dependent intensity level corresponding to real acoustic environment at launch and numerically created by superposition of multiple plane waves was applied directly on the structure. This quick and useful numerical strategy provides an accurate insight of the structure vibrations at locations where structure and acoustic do have weak interactions but it is not able to represent the internal sound pressure level inside the acoustic cavity and its interaction with the internal structures.

In order to overcome this limitation a second solution explored the simulation of the internal acoustic cavities. The finite element models of the 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 considering also the computational time. The diffuse acoustic random field was obtained through random plane wave superposition applied directly on the external surface of the structures.

As a final simulation, a very detailed reconstruction of the test configuration was performed. In this case also the external environment and the internal acoustic cavities were modeled. The diffuse acoustic random field was applied on the surrounding external fluid domain. The main benefit of this kind of simulation is that all the environments, external and internal, are accurately modeled but the large amount of degree of freedoms involved in the analysis require very demanding solution in terms of RAM capability and computational time.

The simulations are performed using finite element model up to 2000Hz in order to explore the high frequency capabilities of this kind of analysis and the different approaches have proved to be suitable for different phases of a developing strategy for new launchers. Also possible simulation improvements have been identified as, for example, the use of the Non-Parametric Variability Method (NPVM), a non deterministic approach in modal frequency responses through a Monte-Carlo solution framework included in the Actran software.

The New VEGA C Launcher

After the validation phase using the VEGA experimental test, the acoustic simulation methodology was implemented in order to evaluate the vibro-acoustic response for the new VEGA C structures. In particular the

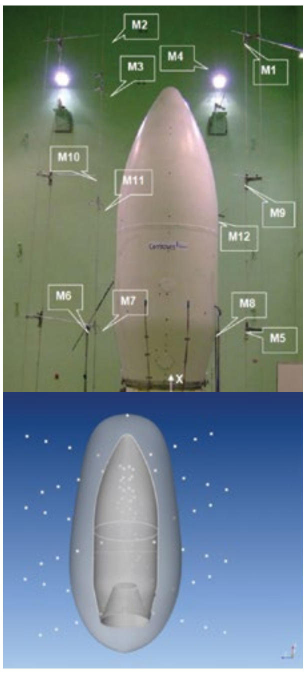


Figure 6: **External and Internal acoustic domains with the relative microphones and measurement points.**

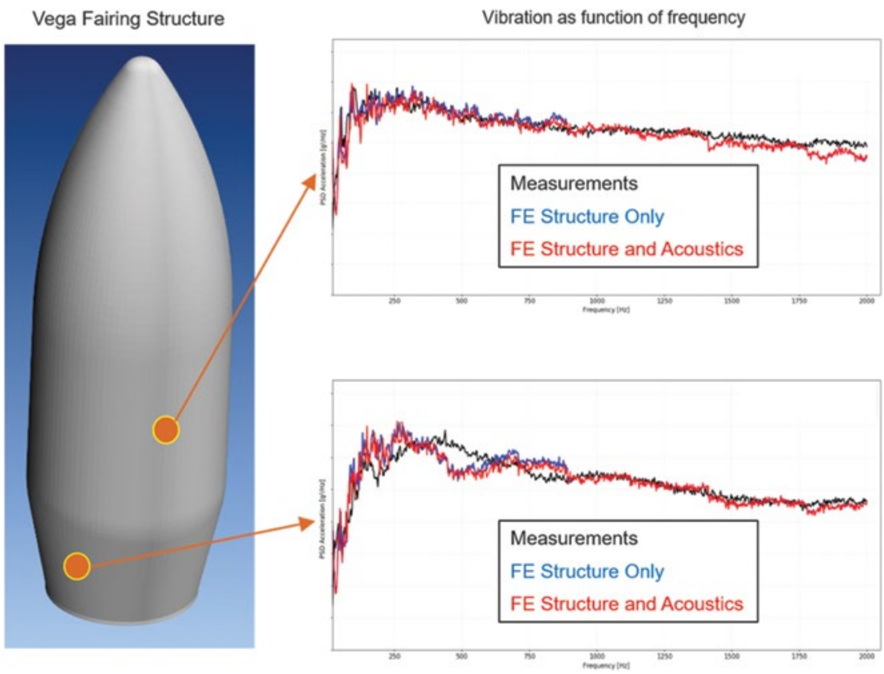
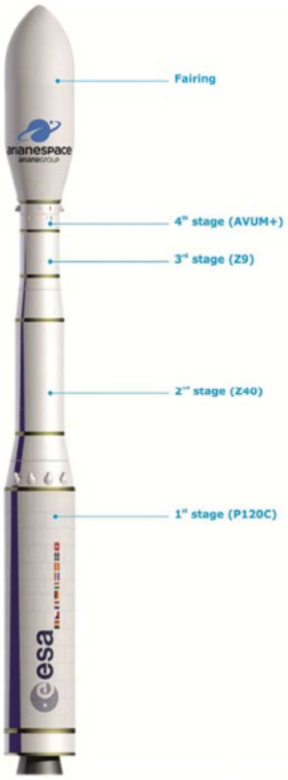


Figure 7: **Vega Fairing - Vibration levels comparison**



PAYLOAD FAIRING

Diameter:	3.317 m
Length:	9.374 m
Mass:	860 kg
Structure:	Two halves - Sandwich panels CFRP sheets and aluminum honeycomb core
Separation:	Vertical separations by means of leak-proof pyrotechnical expanding tubes and horizontal separation by a clamp-band

PAYLOAD ADAPTERS, MULTIPLE LAUNCH STRUCTURE

VAMPIRE 937		**VAMPIRE 1194**	
Height (mm):	2 596	**Height** (mm):	1 861
Mass (kg):	120 TBC	**Mass** (kg):	95 TBC
VESPA C – Short version		**VESPA C – Long version**	
Height (mm):	3 222 TBC	**Height** (mm):	4 552 TBC
Diameter (mm):	2 620 TBC	**Diameter** (mm):	2 620 TBC
Mass (kg):	390 TBC	**Mass** (kg):	455 TBC
SSMS			
Piggy-Back			
Ride-Share			

AVUM+ UPPER STAGE

Size:	2.18-m diameter × 2.04-m height
Dry mass:	698 kg TBC
Propellant:	492 kg/248 kg of NTO/UDMH
Subsystems:	
Structure:	Aluminium cylindrical case with 4 Aluminium propellant tanks and supporting frame
Propulsion:	MEA (evolution of RD-869) – 1 chamber
- Thrust	2.45 kN – Vacuum
- Isp	315.8 s – Vacuum
- Feed system	Regulated pressure-fed 108 l (4.8 kg) GHe tank MEOP 328 barA
- Burn time/restart	Up to 612.5 s (max. cumulative firing time: 924.0 s) / up to 5 controlled or depletion burns
RACS:	Six 240 N hydrazine thrusters N_2H_4 ; 39 l (38.6 kg) N_2H_4 tank MEOP 26 barA
Avionics:	Inertial 3-axis platform, on-board computer, TM & RF systems, Power
Attitude control:	
- Pitch, yaw	*Main engine ±10 deg gimbaled nozzle → boosted phases* *Six RACS thrusters → ballistic phases*
- Roll	*Roll rate and attitude controlled by four of the six RACS thrusters*

	1st STAGE (P120C)	2nd STAGE (Z40)	3rd STAGE (Z9)
Size:	3.40-m diameter × 13.38-m length	2.40-m diameter × 8.07-m length	1.90-m diameter × 4.12-m length
Gross mass:	155 027 kg	40 477 kg	12 000 kg
Propellant:	141 634 kg of HTPB	36 239-kg of HTPB	10 567-kg of HTPB
Subsystems:			
Structure	Carbon-epoxy filament wound monolithic motor case protected by EPDM	Carbon-epoxy filament wound monolithic motor case protected by EPDM	Carbon-epoxy filament wound monolithic motor case protected by EPDM
Propulsion	P120 Solid Rocket Motor (SRM)	ZEFIRO 40 Solid Rocket Motor (SRM)	ZEFIRO 9 Solid Rocket Motor (SRM)
- Thrust	4 323 kN Max Vac thrust	1 304 kN Max Vac thrust	317 kN – Max Vac thrust
- Isp	279 s – Vac	293.5 s – Vac	295.9 s – Vac
- Burn time	135.7 s	92.9 s	119.6 s
Avionics		Actuators I/O electronics, power	Actuators I/O electronics, power
Attitude control:			
- Pitch, yaw	*Gimbaled ±5.9 deg nozzle with electro mechanical actuators*	*Gimbaled ±5.9 deg nozzle with electro mechanical actuators*	*Gimbaled ±6 deg nozzle with electro mechanical actuators*
- Roll	*Roll rate limited by four of the six RACS thrusters*	*Roll rate limited by four of the six RACS thrusters*	*Roll rate and attitude controlled by four of the six RACS thrusters*
Interstage:	**0/1 interstage:** Structure: Cylinder aluminum shell/inner stiffeners Housing: Actuators I/O electronics, power, safety/destruction subsystem **1/2 interstage:** Structure: Conical aluminum shell/inner stiffeners Housing: TVC local control equipment; safety/destruction subsystem		**2/3 interstage:** Structure: Composite grid structure Housing: TVC local control equipment; safety/destruction subsystem **3/AVUM+ interstage:** Structure: Aluminium cylinder with integral machined stringers Housing: TVC control equipment; safety/destruction subsystem, power distribution, RF and telemetry subsystems
Stage separation:	Linear cutting charge/Retro rocket thrusters		Linear cutting charge/springs Pyrotechnic tight expansible tube/springs

Figure 8: **Vega C General data**

analyses were performed for all the most sensitive parts of the launcher with respect to the acoustic loads. The analysed structures are all the interstages between the solid rocket motors and the VEGA C upper part in its different configurations.

A multistage rocket is a launcher vehicle that uses several stages, each of which contains its own engines and propellant. The different stages are separated by interstage structures that are designed to allow the connection of the different stages and their disconnection during the separation phases. These structures are very sensitive to the vibro-acoustic environment because they contain a lot of electronic equipment needed for the flight. The same combination of MSC Nastran and Actran were used to evaluate the vibro-acoustic response of the structures as reported in Figure 10 where the acceleration spectral density is reported as an example for the 315Hz 1/3 octave band frequency.

A payload adapter is a technologically advanced structural element that is able, despite its very low mass, to withstand important flight load and contribute to

Figure 9: **Vega C - Interstages**

the overall stiffness of the launch system. Both Vega and Vega-C launchers provide great flexibility of mission thanks to the different offered payload adapters allowing to carry up multiple payloads at a time according to different configurations. Vibrations at the payload adapter are strongly impacted by the fairing cavity and related resonances. Accurate predictions of the payload adapter levels of vibrations require us to consider the acoustic environment as illustrated on Figure 11 where we report the foreseen configuration of the Upper Stage of the VEGA C launcher. The internal payloads are considered coupled with the launcher structure and the acoustic cavities in the analyses. As example is the different configurations reported in Figure 12 it is possible to recognize(central figure) also the future space RIDER (Space Reusable Integrated Demonstrator for Europe Return) that is a planned uncrewed orbital spaceplane aiming to provide the European Space Agency (ESA) with affordable and routine access to space. Its expected maiden flight is 2022.

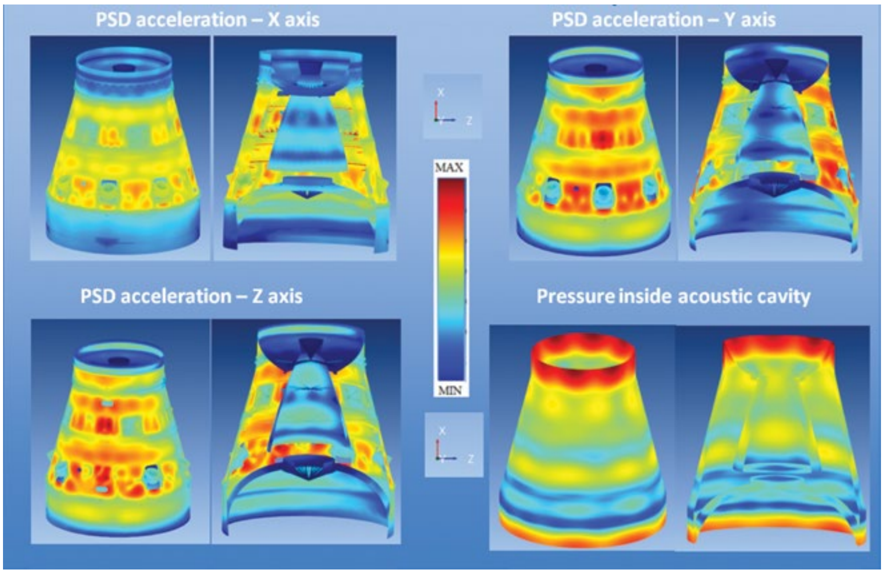


Figure 10: **Vega C - Interstage response map**

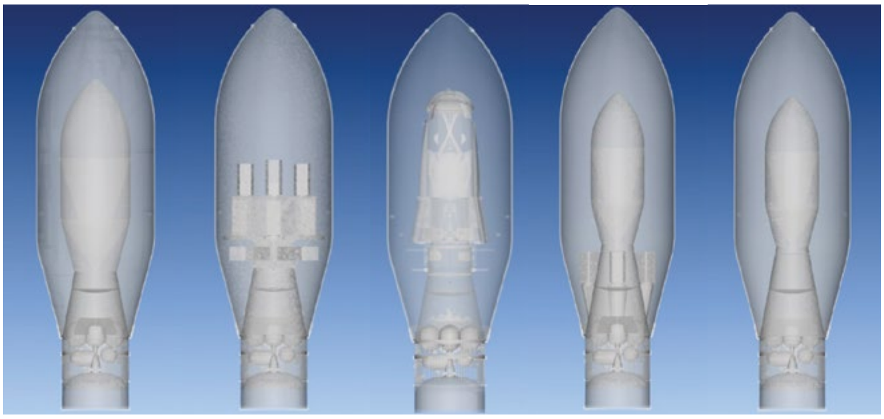


Figure 11: **Vega C - Payloads configurations**

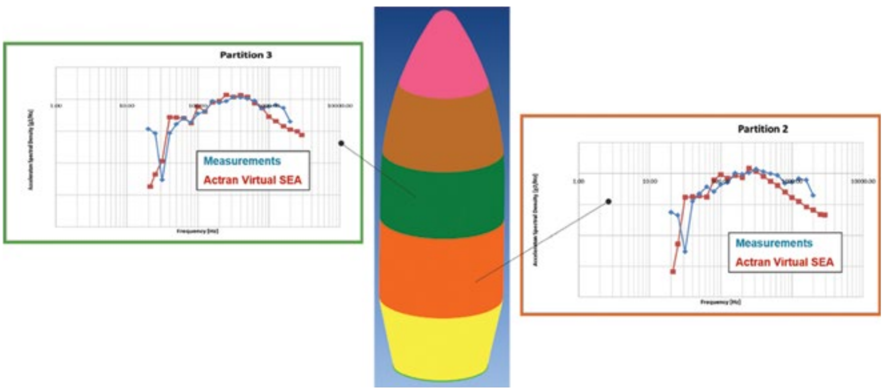


Figure 12: **Vega Fairing - Virtual SEA analysis**

Testing New Modeling Capabilities

In addition to the above FE approach, Avio's engineering team also performed a SEA analysis of the fairing structure using Actran Virtual SEA approach. Relying on the previously created FE models, a SEA model of the fairing structure was created. The Virtual SEA approach implemented in Actran does not require access to any experimental or analytical expression to build up a SEA model. It is a very efficient and affordable technique to extend the vibro-acoustic analysis of existing FE models to higher frequencies without SEA expertise requirements. Furthermore, as the Virtual SEA approach relies on existing low frequency FE models, obtained SEA results are valid at low/mid frequencies and a smooth transition exists in-between mid and high frequency results.

Comparison between available measurements and Actran Virtual SEA results on the fairing structure were made. In particular, the average vibration levels over different structure areas were analyzed. Very good matching in-between measurements and Actran Virtual SEA results were observed. It demonstrates the potential of this new approach to tackle such analysis and will further be used for the future launcher structural analysis.

About AVIO

Avio is a leading international group engaged in the construction and development of space launchers and solid and liquid propulsion systems for space travel. The experience and know-how built up over more than 50 years puts AVIO at the cutting-edge of the space launcher sector, solid, liquid and cryogenic propulsion and tactical propulsion.

Avio operates in Italy, France and French Guyana with 5 facilities, employing approx. 1,000 highly-qualified personnel, of which approx. 30% involved in research and development. Avio is a prime contractor for the VEGA program and a sub-contractor for the Ariane program, both financed by the European Space Agency ("ESA")