"DAMPING COMPOSITE CARRYING STRUCTURES FOR FUTURE LAUNCHERS"

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ABSTRACT

Satellites, as payloads of launch vehicles, are connected to the launcher by composite supporting structures. These structures are responsible for the transmission of dynamic excitations generated during the different launch phases, leading to a vibration environment around satellites potentially not friendly to be mastered. One simple way to reduce the payload dynamic environments is to isolate it from the rest of the launcher, by a soft mounting, and/or to damp the vibrations coming from the launcher.

On ARIANE launchers, both strategies are investigated in order to increase the payload comfort, based on Launcher system requirements:

- *passive isolation devices to isolate the payload from Solid Rocket Boosters thrust oscillations: this kind of devices can be efficient but introduces some unusual complexities to be managed at launcher level due to the required flexibility,*
- *damping carrying structures to damp launcher vibrations at the resonance, by integrating damping viscoelastic layers with moderate softness into composite carrying structures.*

In this paper, we focus on the damping carrying structures, with a presentation of the concept and an evaluation of associated benefits and drawbacks.

1 INTRODUCTION

The dynamic environment generated by launchers on satellites is often significant and can sometimes lead to potential problems. One simple way to reduce the payload dynamic environments is to isolate it from the launcher, by a soft mounting, and/or to damp the vibrations coming from the launcher. On ARIANE launchers, both strategies are studied.

For A5 Midlife Evolution (A5ME), a Passive Isolation Device (PID) has been developed to isolate the payloads from the Solid Rocket Boosters thrust oscillations, in order to improve payload comfort. This kind of solution has demonstrated a good efficiency but introduced some unusual complexities to be managed at launcher level due to the significant flexibility of the PID necessary to isolate.

For future launchers, with potential applications to ARIANE 6 in case of need, another solution is currently investigated in an R&T context. It consists to damp the launcher's vibrations by integrating damping viscoelastic material into composite carrying structures. The main idea is to add locally in the carrying structures (for example a payload adaptor or an inter-stage structure) some layers with moderate softness and high damping in order to attenuate the transmission of vibrations to the payload at the resonance. A prototype of such damping adaptor is currently developed in order to be tested on a full-scale demonstrator. The application of this technology is also studied to isolate the whole upper stage of a launcher, based on the same concept.

This paper gives the main requirements in terms of stiffness and damping, describes the concept retained, following a trade-off on damping materials, and then gives a preliminary status in terms of efficiency from analyses. Also, main advantages and drawbacks of this solution are highlighted for future launcher application.

2 LAUNCHER NEEDS AND REQUIREMENTS

2.1 Launcher needs

A launcher is a complex system presenting sometimes antagonist needs. For example, structural mass must be reduced to increase performance, but keeping sufficient stiffness to avoid controllability problems.This compromise leads to low damped structures and high transmissibility of vibrations. Moreover, Solid Rocket Boosters (SRB), used for the first phase of flight (first stage),generate high levels of vibration,at low frequencies, which are transmitted to payload and can be amplified in case of dynamic coupling at the resonance, due to the low level of structural damping, confirmed by flight analyses [1].

In order to mitigate this problem, an isolation device has been introduced on ARIANE 5 between the boosters and the central stage. This solution reduces very significantly the transmissibility of dynamic loads to the payload.However, residual vibrations can still cause troubles and must be managed. It is why a special damping device called "SARO" [2] has been introduced on the upper stage of A5E/CA, and a PID has been developed for A5ME (concept derived from a shock attenuation device called SASSA [3]), in both cases to reduce lateral vibrations of the payload.

For future launchers, ,AIRBUS investigatesalternative solutions in order to limit system impacts andto reduce the added mass by a functionalization of carrying structures. As an example, twotypes of structures are studied, more dedicated to longitudinal isolation needs:

- A damping payload adaptor,
- A damping launcher inter-stage structure.

The first structure is a prototype dedicated to demonstrate the efficiency of the concept by dynamic tests on-ground. The second one constitutes the main industrial potential target: indeed, the main idea is not to improve only payload comfort but also to reduce the dynamic environment of the whole upper stage of a launcher, including the payload of course but with less sensitivity to its characteristics in this case (low payload mass compare to upper stage one).

2.2 Launcher requirements

From preliminary future launchers studies, the main objective is to maximize the attenuation of SRB vibrationsduring the first phase of flight essentially in axial direction, and to minimize also launcher impacts associated to lateral motion (e.g.launcher controllabilityandpayloadrelative displacements). Consequently, a set of functional requirements has been determined at launcher level, expressed in terms of suspension modes characteristics targets:

- Minimum lateral frequency: sufficiently high to avoid problems of controllability, but sufficiently low to reduce lateral vibrations (by isolation)
- Maximum longitudinal frequency: sufficiently low to reduce longitudinal vibrations (by isolation)
- Minimum damping: sufficiently high to attenuate excitability of the suspension modes and to increase the damping offirst launcher modes to improve launcher controllability, but not too much in order to avoid complexities at system level and increase shock transmissibility.

It remains that this set of requirement is quite over-constrained, leading more or less to an optimal solution.

In order to verify the strength and the functional performances of the product, thermo-mechanical environment(ranges and cycles) has been specified.

3 TRADE-OFF ON DAMPING MATERIALS

3.1 General material trade-off analysis

A trade-off has been initially performed in order to investigate existing solutions to increase structural damping on stiffstructures. It is well-known that there is a natural antagonism between damping and rigidity, illustrated by the diagram here below: polymers offers excellent damping but associated to low stiffness, contrary to metallic materials which have high stiffness and low damping.

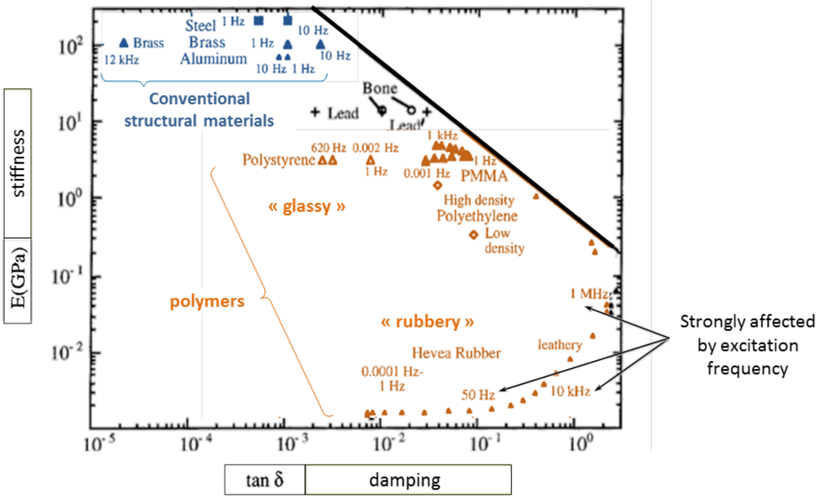

Figure 1. Generic properties of materials (stiffness-damping compromise)

Main conclusions of this trade-off were that:

- for short term applications with high TRL required, only the introduction of elastomeric layers in a structure (metallic or composite) could be envisaged

- for long term applications, a dedicated R&D program is foreseen in order to design functionalized materials, byinnovative architectures constituted for example of polymers embedded at subscales in a special core of composite materials.

This paper deals only with the first short term applications.

Another problematic is the sensitivity of elastomers to thermo-mechanical environments, self-heating, ageing, creeping, etc. In order to minimize associated dispersions, a dedicated set of requirements have been written to identify the most promising elastomer.

Also, the bonding of the elastomer on metallic or composite parts constitutes a special challenge with respect to industrial constraints for manufacturing of large space structures.

3.2 Elastomer characterization

Elastomer selection was the result of a first set of optimisation loops (see next section), where the material properties played a first order role. The achievement of static and dynamic performance of the damping adaptor lead to the definition of a set of material specifications, regarding mechanical strength but also dynamic behaviour.

Once a suitable elastomeric material was selected, a series of elementary testswas performed by LRCCP laboratoryon dedicated samples in shear and compression. Combination of static and dynamic loads wasapplied, in order to define hyperelastic and viscoelastic laws. In addition, the effect of cycle numbers wasalso investigated in order to verify the acceptability of self-heating effect (e.g. slightdecrease instiffness with time), an important topic in order to guarantee stiffness stability during flight:

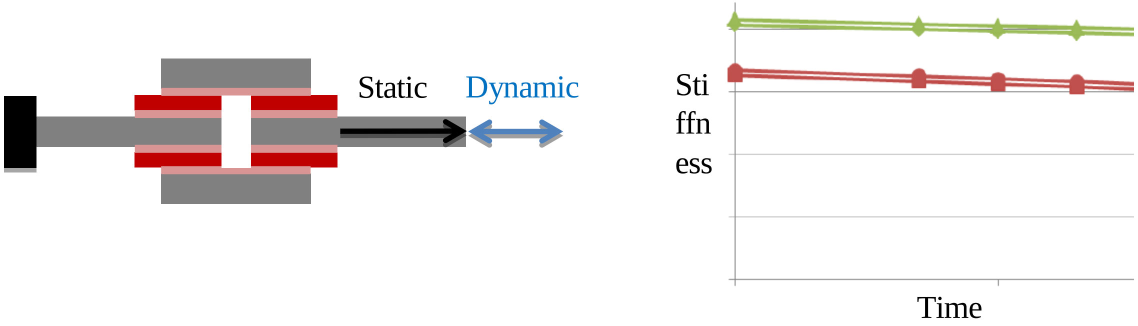

Figure 2. Shear sample test for elastomer characterization

This fine characterisation of elastomer behaviour allowed the final tuning of the damping adaptor, described in the next section.

Finally, elastomer bonding on composite materials is being investigated in order to identify the most efficient manufacturing process with respect to industrial constraints.

4 PRELIMINARY DESIGNS

4.1 Damping Payload Adaptor

The payload adaptor in launch vehicles is the intermediate structure connecting the payload (satellite) to the launcher structure. It is generally constituted of truncated conical shapes, and quite a few variants exist, meeting different sets of requirements. The following picture shows the overall geometry of payload adaptor:

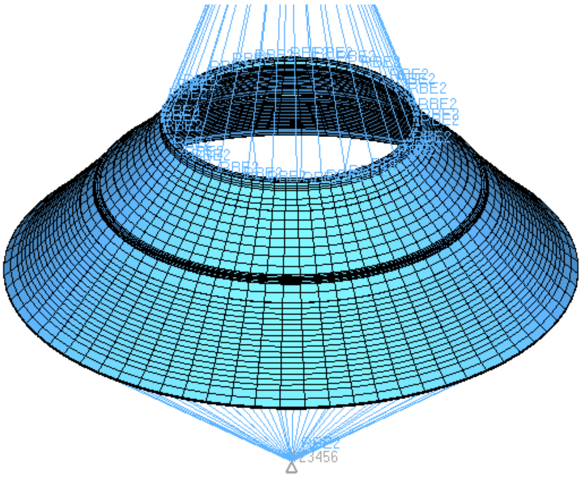

Figure 3. Global geometry of a typical payload adaptor structure

For the definition of a damping adaptor, a first decision was made to keep the upper interface (interface to payload) and the lower interface (interface to launcher) unchanged, making future integration easier. Some adaptors have an intermediate structure allowing flexibility in the longitudinal direction for adaptation to various payload geometries. This intermediate location was chosen as a potential candidate for the implementation of a "damping layer".

The correct representation of the local stiffness and damping of a thin elastomer layer requires the use of volume elements instead of the usual shell elements used for everyday modelling practice. An automatic mesh generator was developed in order to change very quickly the section of the adaptor and to explore many design options in a quick and efficient way. Some of the concepts explored in the study are displayed in the next figure:

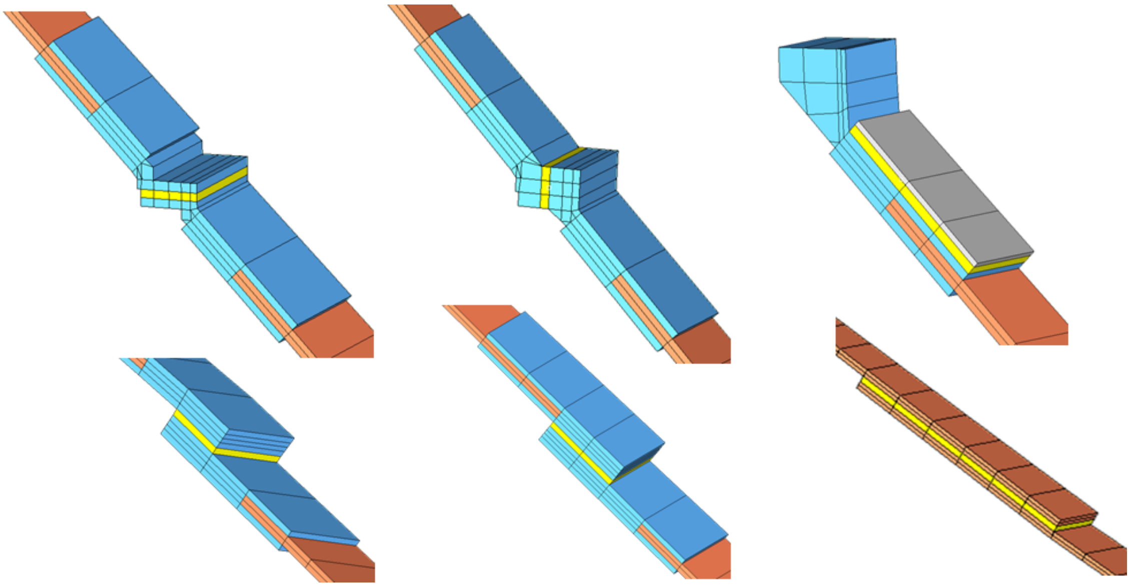

Figure 4. Illustration of possible elastomeric layer introduction

In this figure, blue elements correspond to metallic parts, pink ones to composite materials, and yellow ones to the rubber layer to be optimised. As visible in the figure, many options were compared, with various layer locations, inclination, and so on… It turns out that the dynamic behaviour of the overallsystem { launch vehicle+adaptor+payload } is very sensitive to the detailed design of the rubber layer.

Then the optimisation itself was based on a compromise between:

- The dynamic targets set in section 2 (expressed in terms of modal frequencies)
- The damping performance which is evaluated by the computation of frequency response functions for various excitations
- Static requirements for strength analyses

This design loop becomes even more complex where the nature of the elastomeric material is taken into account, together with its thickness in each configuration. The following graph shows the calculated longitudinal and lateral transmissibility obtained for a number of possible designs.

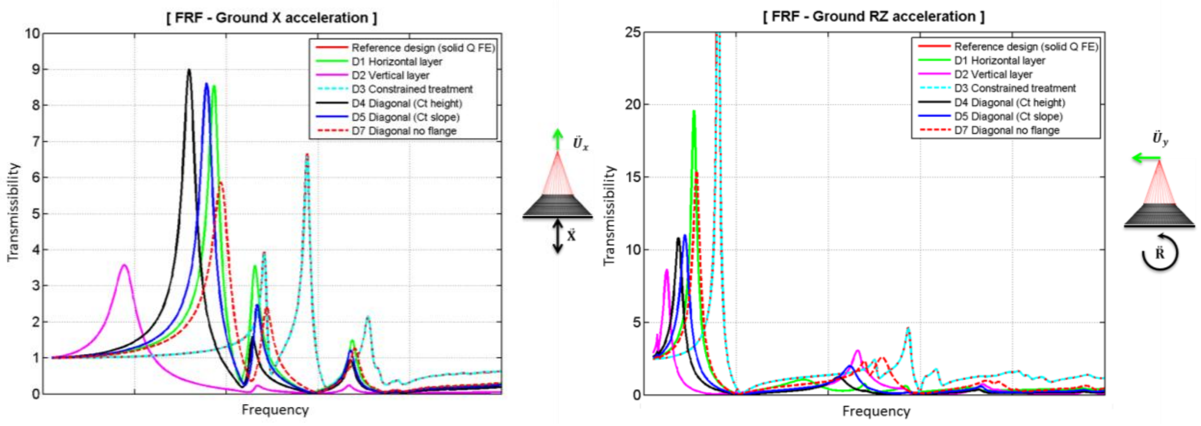

Figure 5. Acceleration transmissibility from damping payload adaptor (basis to top)

The modal frequency shifts are very large, and the comparison must be made simultaneouslyfor longitudinal and lateral directions. Since the requirement for longitudinal frequency is to lower it and the requirement for the lateral frequency is to keep it above a given threshold, the two graphs show that it is difficult to have a discriminating action on each of them.

After this global and very large optimisation process, best solution was chosen and some fine tuning was carried out: in fact, there are even other degrees of freedom to use, for example the distribution of rubber elements along the circumferential direction. A complete layer is not the only option.

4.2 Damping Launcher Inter-stage Structure

The same approach was extended in order to evaluate the potential of this damping layer concept to control vibration transmission for an entire launcher upper stage. Of course the requirements in terms of space and mass were quite different.

The optimisation and design process was carried out on a simplified model of a future launcher, not known with a high precision at the time of the study. The location of the possible viscoelastic layer was chosen to be in between the main launcher body and the upper stage, where a truncated conical structure is present. This conical structure connects a smaller diameter in the main body to a larger one in the upper stage.

In the following figure, the dynamic effect of such an inter-stage layer is computed in terms of acceleration transmissibility in a wide frequency range. The stiffness effect (lowering of typical lateral and longitudinal frequencies) together with the damping effect are clearly visible, in comparison to the reference stiff design.

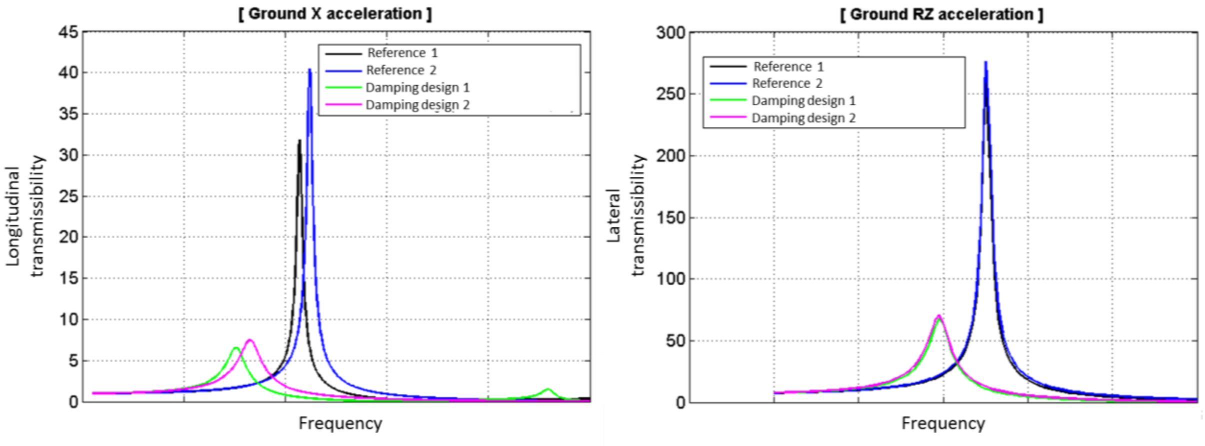

Figure 6. Acceleration transmissibility from damping launcher inter-stage structure (basis to top)

This, together with the static evaluation based on existing elastomeric material mechanical property data, proved that the introduction of an elastomeric layer between main launcher body and upper stage could have the required effect on payload comfort. Of course, given the structure size and weight, manufacturing process issues would still need to be solved.

5 PROTOTYPE, TESTS& PERSPECTIVES

In order to increase the maturity of damping structures for space applications, the manufacturing of a full-scale prototype ofdamping payload adaptor is foreseen. The objective is to perform dynamic tests on a representative payload mounted on such carrying structure exposed toflight-representative environments: transient excitation for lift-off, random excitationfor buffeting at transonic and sine excitation for SRB thrust oscillations.

The achievement of those demonstrator tests willallow the validation ofdynamic simulations and improve the maturity of this technology (TRL 6 expected). This step is needed in order to convince programs to integrate suchpromising damping structures, for example at the inter-stage of a new launcher.

6 CONCLUDING REMARKS

In order to reduce the transmission of vibrations generated by a launcher to the satellites, the solutions already developed for ARIANE 5 launchers are to add isolation devices,located at boosters and/or near payload attachments, or damping device. Both of these solutions are efficient butincreaselauncher system complexitydue tosoftening(lower modal frequencies)and/ornon-linearity induced.

An alternative solution, presented in this paper, consistsinincreasing the damping of carrying structures, limiting softening and non-linearity effects as far as possible.Based on a trade-off study on damping structures and materials, it remains that the simplest and efficient way could be to integrate elastomeric layers insides composite (or metallic) structures, based on mature materials.

Twoexamples of design were proposed and studied: a damping payload adaptor and a damping inter-stage structure. Asuitableelastomer materialwas identified and characterized by sample tests. Preliminary static and dynamic analyses have demonstrated the potential of such technology to transmit the flight loads correctly,reducingthe transmission of the dynamic environment by a promising factor (> 4) compared to current structures. Also, such technology correctly located on a launcher could improve both launcher and payload comfort, without significant system impacts.

However, the manufacturing process (especially the elastomer bonding on large space structures) remains to be matured in order to demonstrate the industrial feasibility.It is why a second step is foreseen to manufacture a full-scale prototype of damping payload adaptor, to be tested on-ground with flight-representativedynamic environments. This step is needed to reach a sufficient pre-industrial maturity level (TRL 6), in order to be onboard in new launchers developments.

REFERENCES

[1] V. Le Gallo, M. Goursat, and L. Gonidou. “Damping Characterization & Flight Identification”. 57th International Astronautic Congress. Valencia. 2006.

[2] V. Le Gallo andT. Romeuf. “ARIANE 5 new upper composite including a non-linear damper: prediction of the dynamic behaviour and validation during on-ground tests & flights”. 6th International Symposium on Launcher Technologies. Munich. 2005.

[3] P. Camarasa and S. Kiryenko. “SASSA”. European Conference on Spacecraft Structures, Materials and Mechanical Testing. Toulouse. 2009.

[4] Petitjean B., Jaumouillé V., Saad P., "Modelling non-linear effects in elastomer components, including uncertainties", Proceedings of ISMA2010, Leuven, Belgium, 20-22 September 2010

[5] Petitjean B., Hernandez O., Zoghaib L., "Vibration Control of Composite Structures, Issues and Challenges", Proceedings of the DYNACOMP Conference, Arcachon, France, May 2012

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