SHOCK ATTENUATION SYSTEM FOR SPACECRAFT AND ADAPTOR

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ABSTRACT

Shock problematic – Attenuation performance requirement

The coming on the launcher market of Ariane 5 has allowed to launch heavier spacecraft but has also introduced new important shock levels at the base of the spacecraft. Specific test campaigns or expertises have been necessary to qualify the spacecraft and to accept the Flight Aptitude Review. The objective of the proposed SASSA (Shock Attenuation System for Spacecraft and Adaptor) is to limit the spacecraft qualification to shocks on the basis of a clamp-band release test only (without any Shogun test). It means that the clamp band release event must be the sizing shock event in the whole frequency range compared to fairing jettisoning and VEB separation.

SASSA requirement

In addition of shock filtering, the main requirements of SASSA is to hold the spacecraft during all launch phase and to avoid large modifications in dynamic involved in attitude control law. In particular, the first frequencies and associated loads are examined.

At launcher system level, the SASSA will bring some additional flexibility to the upper part of the launcher. It is necessary to limit this extra-flexibility in order to ensure the attitude control of the launcher

The nominal interface is, on one side the ACU 1194 H in place of the dismountable ring, and on the other side, the clamp band profile. Anyway, generic aspects must also drive the design and the SASSA must be easily modified in order to be introduced at different diameters, for example ACU (2624 m or 1666 diameter) or above the clamp band to attenuate its release.

SASSA design and pre-qualification

SASSA is based on the use of elastomer in series at the base of the spacecraft. The system is composed with several separated devices in order to be easily customized depending on the mass and structural characteristics of the satellite. The development already performed was separated in 2 phases. Phase 1: the feasibility study sets up what are the risks and performed the associated risk reduction activities. The feasibility of SASSA design with several modular, adjustable and simple devices has been demonstrated

Phase 2A: The Shogun test with EUROSTAR 3000 performed in May 2006 shows the efficiency of the devices for shock attenuation. The objective of the phase 2B is to achieve a sine test in end of 2007 to determine the stiffness, the damping and to prove the strength ability in vibration tests.

1. INTRODUCTION

The feasibility study in phase-1 sets up what are the risks and perform the associated risk reduction activities.

This feasibility was demonstrated at the end of 2003. All the main hurdles are removed: the requirements are settled, the technologies are identified and supported by tests results and provide confidence for starting the design and test activities foreseen for phase-2.

A complete test campaign with mock-up 1 has provided compliances with respect to the specifications:

Stiffness and strength:

- Sizing with a complete test campaign (static and dynamic) has been performed to confirm SASSA ability to withstand flight load
- Mock-up 1 sizes lead to stiffness and strength suited for medium satellite (4.5 tons)
- Elastomer is not the sizing element (failure in aluminium)

Shock attenuation potential is confirmed with test at reduced scale (shock bench). Ariane 5 coupled analysis lead to a maximum increasing of 15% (QSL). Medium satellite with SASSA may be acceptable with respect to the attitude control law

Therefore feasibility of SASSA design with several modular, adjustable and simple devices is demonstrated, next step and objective of the phase-2 is a complete full scale test with SASSA system and STM3000 telecommunication satellite.

- Phase 2A: The Shogun test performed in may 2006 shows the efficiency of the devices for shock attenuation
- Phase 2 B: The sine test foreseen for the end of 2007 characterise the stiffness, the damping and prove the strength ability

2. MOCK-UP DESIGN EVOLUTION

Phase-1 had shown that it was necessary to decrease the stiffness. Two solutions have been selected:

- To equilibrate the ratio of surface of the different layers. Especially for the lower layer, the largest surface is divided in two parts. There are 6 identical layers with width of 10 mm
- To select a back-up elastomer more flexible. Twice as flexible natural CNXB862 is considered (same family of natural rubber with less black carbon). The previous CNXB861 has a modulus at 100% equal to 4.3 MPa, the new CNXB862 has a modulus at 100% equal to 2 MPa

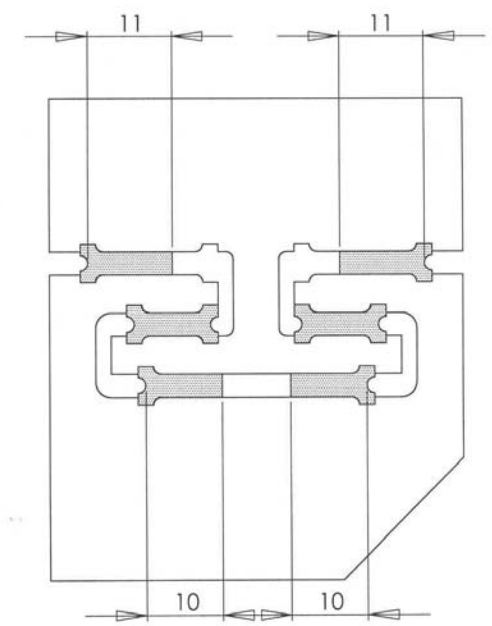

Figure 2-1 : Mock-up 2 for stiffness identification

3. NON-LINEAR PREDICTION AND CORRELATION WITH STATIC TESTS

Finite element analysis with MSC-MARC non-linear model becomes well correlated with tests results; therefore non-linear model provides accurate predictions for mock-up 2. The mechanical behaviour for large loads is equivalent to mock-up in phase 1

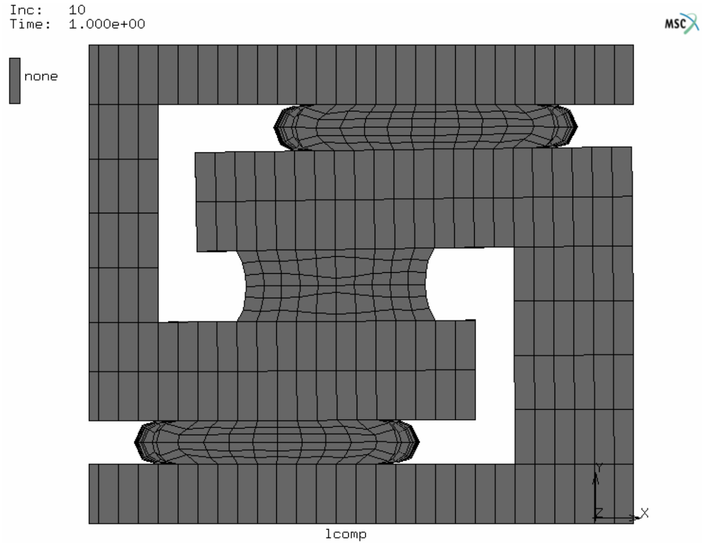

Figure 3-1: Strain for compression for 41250 N

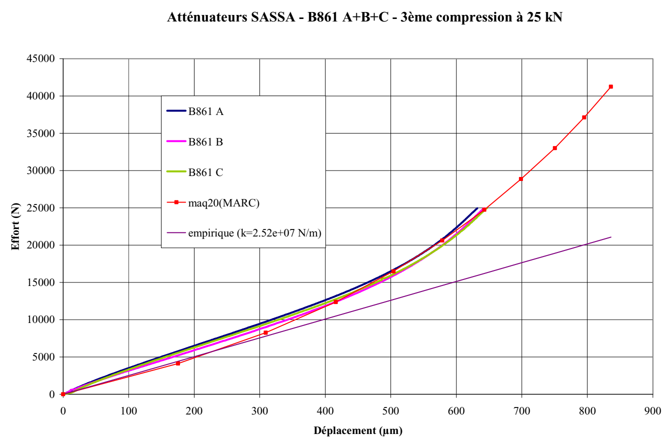

Figure 3-2: MARC results and test correlation in compression (Run A,B,C)

4. SASSA SYSTEM DESIGN AND STIFFNESS

4.1 SASSA configuration and design (sensibility analysis

SASSA configuration system is impacted by adaptor constrains. The main prohibited area correspond to 12 pushers every thirty degrees. Therefore the number of SASSA unit is 12 or 24. To meet the stiffness requirement, different combination of rubber, unit width and angle are possible.

In order to design and select the right configuration, analyses has been performed for the lateral frequency sensibility with the satellite inertia (COG position, pure inertia, unbalance or lever arm without pure inertia), with ratio of compression and shearing stiffness of one sector and with angle of one sector.

Impact of inertia (pure inertia, unbalance without pure inertia): Lateral frequency is mainly due to unbalance value. With pure inertia, the optimum angle for sector is 0° (highest stiffness due to compression). For an unbalance at 1,50 m, the optimum angle is -20°.

Impact of ratio stiffness between compression and shearing: The longitudinal stiffness in traction/compression withstands the pure rotation and the lateral stiffness in shearing withstands the translation. Therefore the ratio between these stiffness has a direct impact on the coupled lateral mode. With the proposed design, the ratio stiffness between compression and shearing is 10. Analyses with ratio 5 and 20 have been performed; results show that it is very efficient to increase the shearing stiffness in lateral. Nevertheless it is difficult to modify the design in this way; it is easier to change the angle.

Impact of angle Unbalance leads to an optimum angle at -20°. It is important to note that this angle must be considered towards the centre of SASSA system.

These general results are applicable for the different configuration of SASSA: 12 or 24 sectors, length of 50 mm or 80 mm and elastomer CNXB861 or CNXB862

4.2 Trade-off and baseline selection

Next table presents for each SASSA solution the lateral frequency in the different configuration:

- SASSA with rigid satellite provide the isolation frequency in a clamped configuration.
- ACU with SASSA and rigid satellite provide the influence of adaptor and the configuration for stiffness compliance.
- SASSA with STM 3000 provide flexible satellite dynamic with SASSA

Ref: ACU + rigid satellite (20 Hz)	**SASSA + rigid satellite**	**ACU + SASSA + rigid satellite**	**SASSA +STM3000 (13 Hz)**
SASSA12-80-xb61	8.8 Hz	7.8 Hz	7.1 Hz
SASSA24-80-xb62	10.6 Hz	9 Hz	8.1 Hz
SASSA24-80-m30-xb62	**9.6 Hz**	**8.35 Hz**	**7.7 Hz**
SASSA24-50-xb61	9.3 Hz	8.2 Hz	7.4 Hz
SASSA24-50-m30-xb61	8.4 Hz	7.55 Hz	7 Hz

Tableau 4-1: Synthesis for lateral configuration. Notation: SASSA24-80-m30-xb62 : 24 unit, width=80 mm,m30 :angle=-30, elastomer CNXB862°

Shock attenuation performance

Shock test results show that for a sector length of 80 mm, the more flexible elastomer CNXB862 is better than the CNXB861. Furthermore, it is better to have an angle to equilibrate longitudinal and lateral stiffness, which allows having a good attenuation for all different modes excited in longitudinal or in lateral.

Therefore SASSA24-80-m30-xb62 (24 sectors of 80 mm at -30° in CNXB862) is the best solution in term of lateral frequency and shock attenuation

4.3 Strength compliance by TEST

To validate baseline strength, static test in traction has been performed with mock-up 2 to confirm strength measured with mock-up in phase 1

The need for a medium satellite of 4.5 tons with a lateral acceleration of 2 g is 40 KN for a couple of unit. Therefore it is important to confirm margins with respect to a need of 20 KN by unit. Six Mock-ups 2 have been used (three in CNXB861 & three in CNXB862) to perform proof tests in traction.

Mock-up 1 in CNXB861 has shown a failure for 60 KN in aluminium insert. For mock-up 2, separation of lower elastomer layer in two parts leads to a small decreasing of strength, failure occurs at 53 KN for CNXB861 and

51 KN for CNXB862, always in aluminium part. Nevertheless margin greater than 2.5 is sufficient.

Figure 4-1: Traction set-up for CNXB862

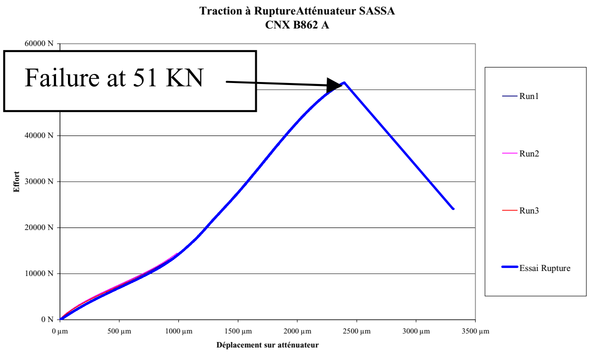

Figure 4-2: Force/displacement for CNXB862

4.4 Overfluxes compliances

The results must obey the following criterion: the longitudinal shell forces calculated at the interfaces ACU/SASSA in the configuration (ACU+SASSA+4t Payload) must not exceed the longitudinal shell forces calculated in the configuration (ACU+6t Payload).

In this coarse model, a pair of SASSA blocks is represented by a single block consisting of 12 solid elements. To integrate the SASSA blocks, the ring of the ACU and the payload are translated from a distance equal to the SASSA's height. In this configuration, the contact area between the SASSA blocks and the ring (or the cone) represent 66% (20°/30°) of the total area of the ring.

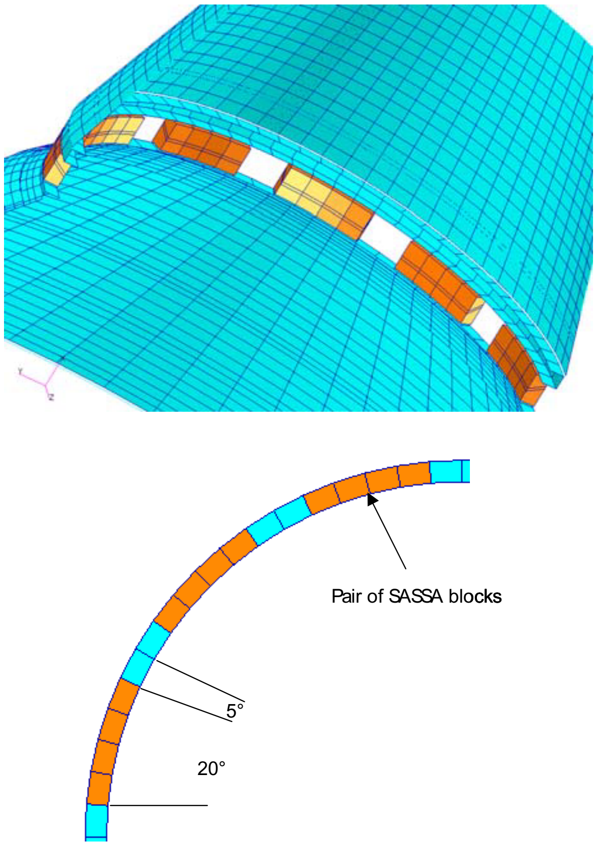

Figure 4-3: Model with SASSA.

In lateral load case, the system (ACU+Payload) is submitted to a transverse acceleration. The longitudinal shell forces are shown on Figure 4-4 for the three configurations.

The curves represent a tensile/compression behaviour.

We observe that Nz(4 tons+SASSA) vary globally like Nz(4 tons). Some perturbations appear where the SASSA blocks are. The SASSA blocks increase the effect of tensile or compression, depending on their position.

These results indicate that the critical value of Nz (4 tons+SASSA) / Nz (6 tons) = 1 is not exceeded for maximum flux.

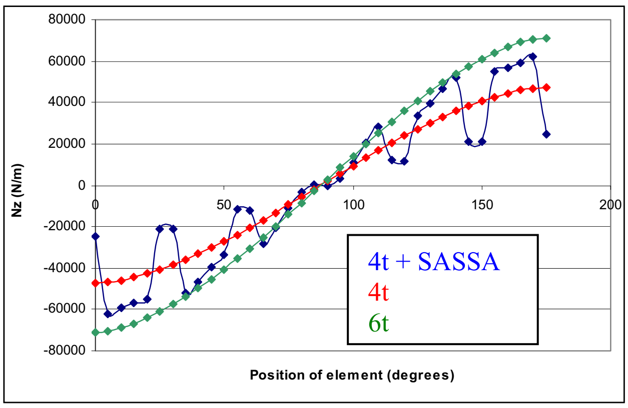

Figure 4-4 : Longitudinal shell forces with SASSA – coarse model submitted to a transverse load.

5. SASSA UNIT & SYSTEM DEFINITION

Precedent analyses allow to define the main characteristics for SASSA unit are:

- External sizes: 54 mm x 68 mm x117 mm
- Elastomer sizes:3 mm x 10 mm x 80 mm
- Unit mass = 850 g (20 Kg for complete SASSA system with 24 units)
- Angle is -30° towards the center of SASSA
- Flanges for force fluxes distribution
- Interfaces unit/adaptor and unit/ clampband ring: 5 screws M8

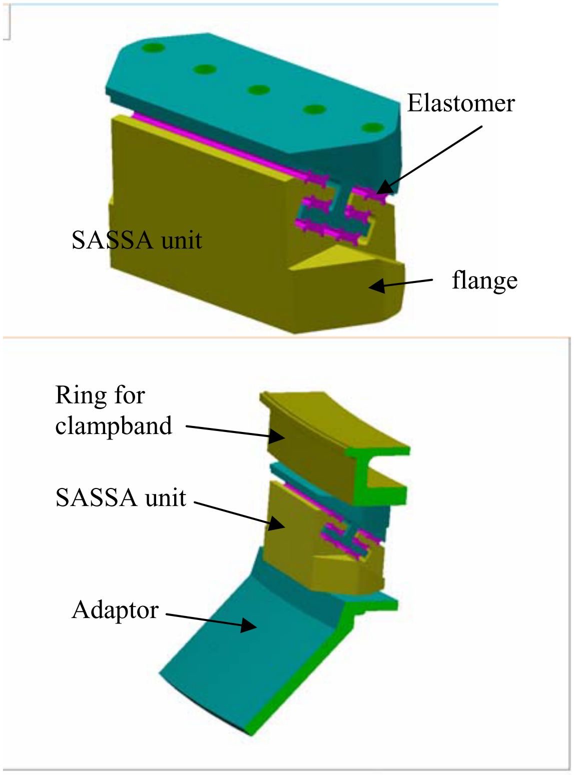

Figure 5-1: SASSA unit and assembly with adaptor and clampband ring

Main characteristics for SASSA system are:

- Twelve couple of unit each 30°. All allowable areas and screws are used to limit the forces flux at most.
- Inner space between two units makes easier the mounting, nevertheless these small spaces are negligible with respect to overfluxes
- Outer space of two units are for pushers

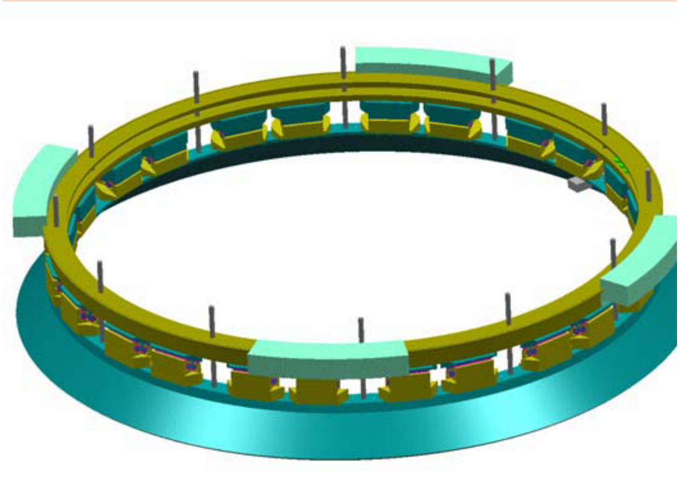

Figure 5-2: SASSA system overview

6. SHOGUN TEST

The first test with the full scale SASSA system is the SHOGUN test with EUROSTAR 3000 satellite. Following figure presents the complete test set-up.

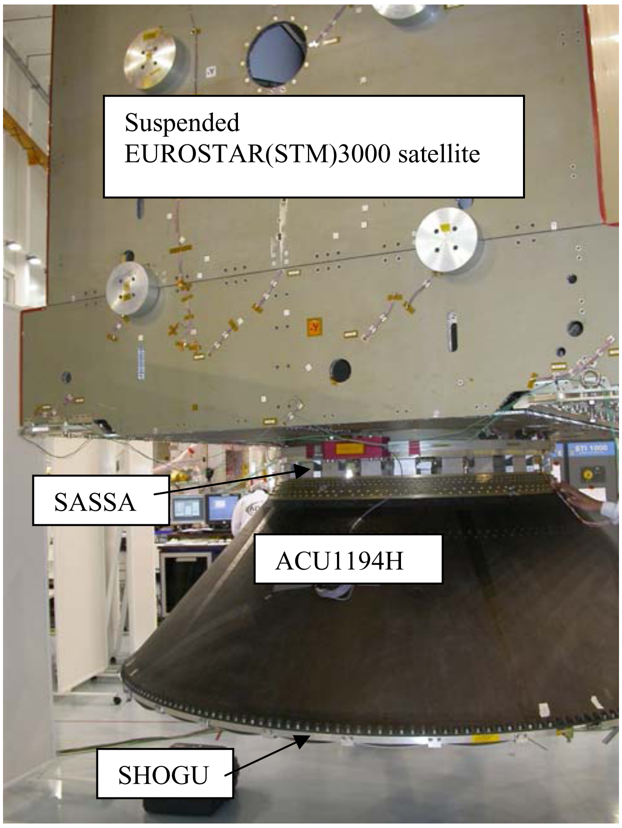

Figure 6-1: SHOGUN test set-up configuration

Following figures present SRS at interface and in satellite with (red) and without SASSA (green). Shock attenuation ratios are consequent and meet the objectives. SHOGUN is especially a high frequencies shock test bench, it is the reason why the levels are not so high at the interface in low frequency. Nevertheless, an axial mode at 400 Hz is present at the interface with a significant attenuation.

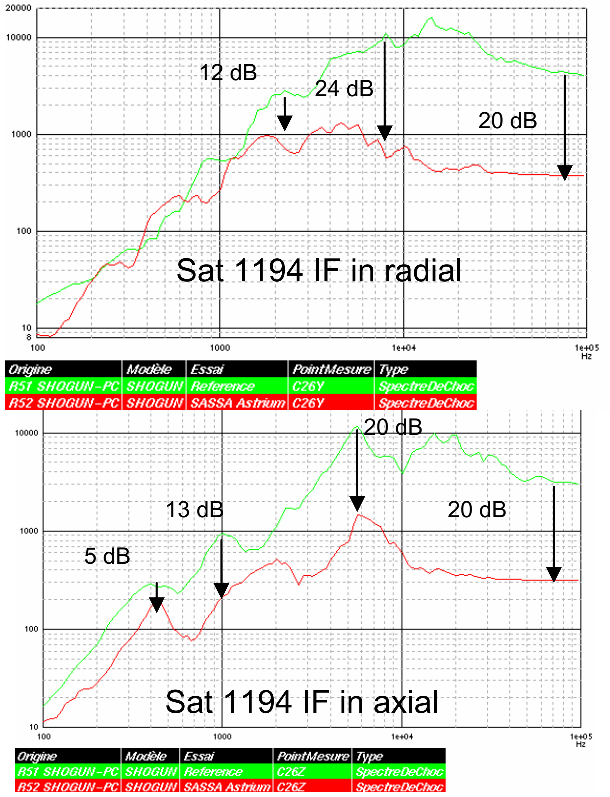

Figure 6-2: SHOGUN SRS at satellite interface

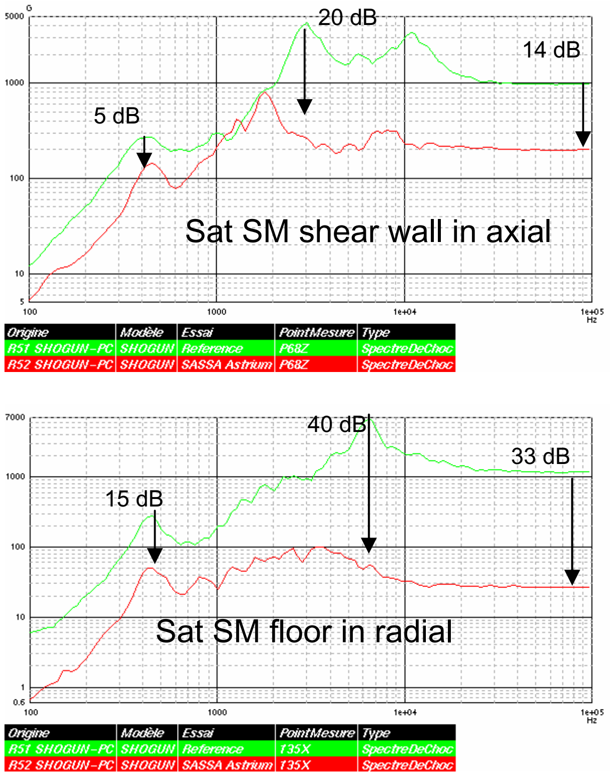

Figure 6-3: SHOGUN SRS in satellite service module

The next table provides an attenuation map in the satellite, axial and radial are coupled. Modal behaviour leads to more low frequencies responses in satellite than at the interface. Attenuation increase with levels of SRS, a maximum of 15 dB and a minimum of 5 dB is reached at 400 Hz, above 1 KHz, attenuation increases.

Location	**400 Hz-500 Hz**	**1 KHz**	**2 KHz - 4 KHz**	**8 KHz – temporal**
Sat I/F radial	0 dB to ampl.	0 dB	12 dB	15 dB to 20 dB
Sat I/F axial	5 dB	9 dB to 13 dB	9 dB	20 dB
Shear wall radial	10 dB to 13 dB	10 dB	14 dB to 20 dB	14 dB
Shear wall axial	5 dB		20 dB to 24 dB	14 dB
SM floor radial	5 dB to 15 dB		14 dB to 24 dB	10 dB to 40 dB
SM floor axial	5 dB to 8 dB		14 dB	14 dB
SM wall radial	5 dB		15 db to 24 dB	15 dB
SM wall axial		5 dB	15 dB to 27 dB	17 dB

Table 6-1 : Attenuation map in satellite

7. SYNTHESIS FOR SASSA PRE-QUALIFICATION

The Shock Attenuation System for Spacecraft and Adaptor developed by ASTRIUM Satellite is based on the use of elastomer in series at the base of the spacecraft. The system is composed with several separated devices in order to be easily customized depending on the mass and structural characteristics of the satellite. The development already performed was separated in 2 phases:

Phase 1: the feasibility study sets up what are the risks and performed the associated risk reduction activities. SASSA size allows withstanding with margins loads due to medium satellite of 4.5 tons. Moreover, the design allows avoiding complex non-linearity; therefore the system behaviour is like a classic linear isolation system. So that, there is no impact for the methodology for AR5 coupled load analyses. Furthermore, the attitude control is not critical and confirmed with this class of satellite.

Phase 2A: The SHOGUN test with EUROSTAR 3000 performed in may 2006 shows the efficiency of the devices for shock attenuation. Analyses, mechanical and SHOGUN test with a complete full scale SASSA system, show that it is possible to fulfil the requirements The objective of the next phase 2B is to achieve a sine test to determine the stiffness, the damping and to prove the strength ability in vibration tests.