QUALIFICATION TO SHOCK ENVIRONMENT IN VEGA PROGRAM BY FULL SCALE TESTS, MODELS AND SIMILARITY

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ABSTRACT

The stage separation events are crucial phases for the VEGA launch vehicle mission and therefore high reliability is demanded to the activation and functionality of the separation cutting system, nevertheless the associated shock environment is really harsh and the generated levels are critical especially for the electronic equipments installed in near areas. In order to characterise the Launch Vehicle shock environment, tests have been performed first at Pyro Alliance, supplier of the pyro-cord inter-stages 1/2 and 2/3 separation systems, and then full scale tests at system level. Prediction of the full scale test were based on the results acquired in the sample tests. The first full scale test was successfully carried out in Colleferro on February 2006. The article tested was the inter-stage between the 2nd and 3rd stage Solid Rocket Motors, consisting of a stiffened cylindrical structure about 2m height per 2m diameter implementing a pyro-cord actuated system cutting a 3mm thick flange to separate and free the launch vehicle of the expended stage. In this structure different equipments are installed with the related harness, in particular in the upper part (3rd stage) the Thrust Vector Control Batteries and Integrated Power Distribution Unit are implemented. The correct separation and distancing of the two separated parts is ensured by eight spring actuated mechanism, with a rather high stored energy.

Other two separation tests have been performed to characterize the shock environment on the 4th stage: the Payload Fairing Horizontal Separation System Test on December 2006 and the inter-stage ¾ Separation Test on February 2007.

The first one reproducing the shock environment induced by the separation of the Fairing Halves from the launcher is particularly critical for the Payload, while the second one is aimed to characterize the shock induced by the tight expansible tube which cuts symmetrically two 2.5mm thick walls. The shock induced by the inter-stage 3/4 Separation is critical for equipments mounted on the Avionic Platform of the VEGA 4th Stage and the equipments mounted on the inter-stage skirt itself. In this respect several shock attenuation systems have been tested and have been demonstrated to reduce significantly the shock levels.

In order to limit the development cost it was decided not to test all VEGA stage separations and in particular, since the same system is used for ½ stage and 2/3 stage separation, with the same thickness to be cut, the 1/2 stage separation will be qualified by similarity on the base of the 2/3 stage and ¾ stage test performed. The prediction has been based on source characterization, equipment supports modal identification in a low-medium frequency and, where available, on results achieved during similar tests.

The paper will describe the performed tests, will treat the prediction methods, will show their comparison with test results and the criteria of shock attenuation device definition.

1. OVERVIEW ON VEGA LAUNCH VEHICLE AND DIMENSIONING EVENTS

1.1. Vega Launch Vehicle

VEGA Launch Vehicle is the new small launcher belonging to European Space Agency launchers family that will allow a low cost access to space for small and medium satellites ranging from 300 kg to 2500 kg, with 1500 kg payload in polar sun-synchronous orbit at 700 km as a reference mission. VEGA Launch Vehicle consists of three solid propellant stages and a liquid propulsion module (AVUM), which ensures the orbital and attitude control, the satellite release and the following de-orbiting of the upper stage. The fourth stage provides interface for the thermal fairing for payload protection. VEGA is also designed to place multiple payloads into orbit.

1.2. Shock dimensioning events

During the mission, VEGA is subjected to a plenty of excitations, which have been in general analysed for the LV dimensioning. The events that are supposed to induce high shock on equipments and payload are here listed:

1. Fist stage ignition induced by igniter pyro-activation;
2. First stage separation achieved by cutting charge pyro-technically actuated (FIG 2);
3. Second stage ignition (identical to first stage);
4. Second stage separation whose principle is similar to the first stage one (FIG 2);
5. Third stage ignition (identical to first stage);
6. Third stage separation achieved by a pyro-actuated expansible tube cutting a symmetric flange (FIG 3);
7. Payload fairing separation achieved by an Horizontal Separation System and Vertical Separation System: the first one (HSS) is made of a pre-tensioned belt released thanks two bolt cutters and the second one (VSS) is an expansible tube cutting a series of shear rivets; the VSS being actuated few instants after the HSS actuation is considered as not dimensioning (FIG 4);

8. Payload separation achieved by a thermally pre-loaded clamp released thanks two bolt cutters (FIG 5);

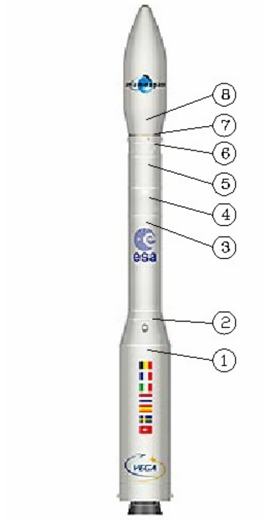

FIG 1. Pictorial view of VEGA items generating shock

1.3. Description of Separation Systems

1.3.1. Inter-stage ½ and 2/3 separation

Cutting systems mounted on Inter-stage ½ and Inter-stage 2/3 are supplied by Pyro Alliance. They are designed to cut 3mm wall in aluminium alloy on a circumference with diameter about 2390mm (separation ½) and 1900mm (separation 2/3). 100% successful acceptance is guaranteed to increased thickness 3.2mm. The cord (Hexogen-Lead) ends with detonator boosters and it is glued inside the circular charge holder sector (four sector to cover the circumference are foreseen – see FIG 2) and protected by a thin metallic cover at the front side. The transmission between two adjacent charge holders is guaranteed by the detonator booster, which transmits the signal to another booster through a 1 to 2 mm nominal air gap. The mechanical interface between the detonating transfer line and the ports of the equipped charge holder has included bipolaris junction, to allow 90° disposal of ignition transmission lines. When initiated at two position (for redundancy purposed) the cord release the needed energy to cut the wall.

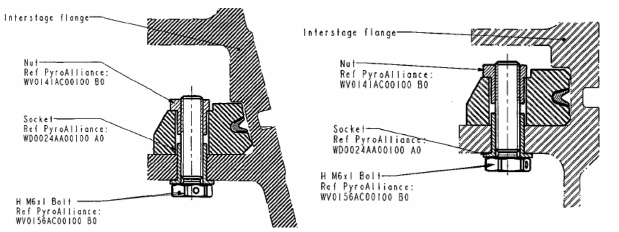

FIG 2. Inter-stage ½ and Inter-stage 2/3 separation cutting cords

1.3.2. Inter-stage 3/AVUM separation (A4)

The Inter-stage 3/AVUM separation tube is supplied by Dassault. It is composed of two expansible tubes connected via straight units and initiated at each end by transmission lines connected to cranked units. The tubes are inserted in the VEGA structure between two frames joined by bolts. The upper frame consists of two symmetrical sections as shown in FIG 3. The expansible tube is made of a partially flattened stainless tube and contains a lead-Hexogen transmission cord. The straight unit ensure the connection between the two expansible tubes and the cranked unit with the pyro-lines. They are made of aluminium alloy and include O-ring for seal tightness. The chain composed by the two linked tubes is initiated by the two pyro-lines. That insures the redundancy of the pyrotechnic circuit. When initiated, the transmission cord pressurises the tube, which expands and supplies cutting energy within the required margins. The expansible tube is seal tight before and after operation, therefore the structure is cut without casting debris.

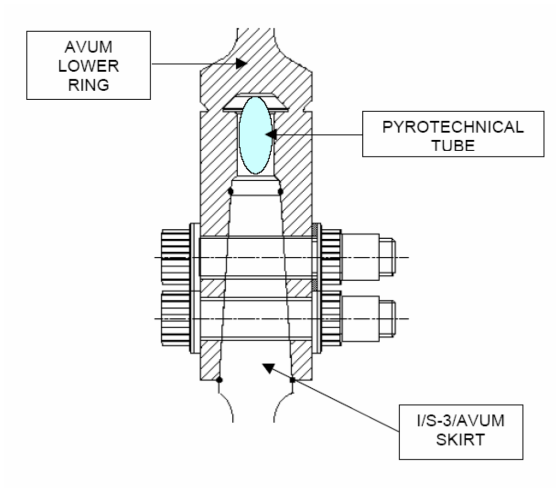

FIG 3. Expansible tube for Inter-stage 4/AVUM separation

1.3.3. Payload Fairing separation

For Payload Fairing separation the pyrotechnic impulses are distributed by pyro-lines that reach the bolt cutters for HSS and the initiators for the VSS. The bolts that retain the tension belt are instantly cut, whereas the VSS will take longer to inflate the bellow and provide the necessary energy first to cut the shear rivets and the to accelerate the two Payload Fairing Halves up to their separation velocity. Redundancies in the pyro-connections have been considered. The shock induced by VSS is not transmitted to the launch vehicle, being the Fairing halves no more in contact with it ant the moment of the activation. The HSS (see FIG 4) consists of a steel belt, wrapped around the separation ring at the lower end of the fairing structure. Two bolt cutters (supplied by Dassault) are used. They are fixed at each extremity of the tension band assembly.

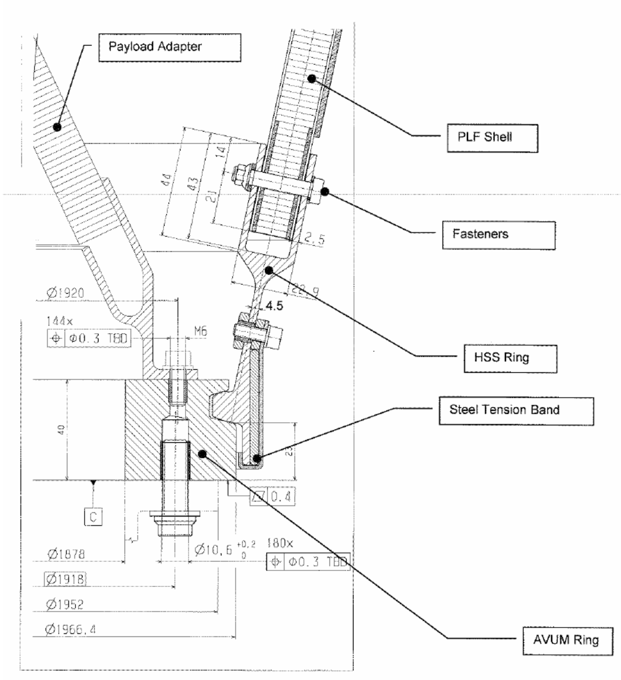

FIG 4. Payload Fairing Horizontal Separation System

1.3.4. Payload separation

The CRSS (Clamping Device Separation System) consists mainly of a ring cut in two halves attached together to maintain the payload interface and the adapter interface in contact, and 62 clamp pieces that compress both interface rings to avoid the separation of the interfaces and a loose of stiffness in the joined elements during the launch phase and its ground associated operations. The clamps are compressed by means of two circular bands in aluminium alloy. The ring has two end-fittings to provide the attachment between both half rings. One of the end-fittings (separable front end fitting) is pre-loaded by means of the pyro-bolt, and the other end-fitting (non separable back end-fitting) is pre-loaded. The 62 clamps made in composite material are mounted in the ring all around its perimeter. This material presents good properties for friction, strength and thermal expansion coefficient. Two pyrotechnic bolt cutters supplied by Dassault are used to cut the pyro-bolt and release the clamp-ring. A picture of the system is shown in FIG 5.

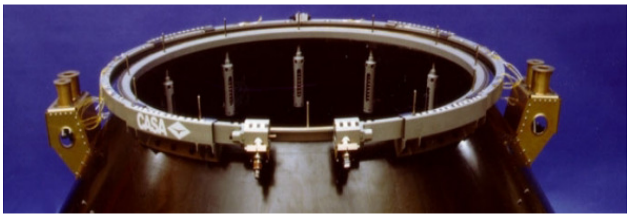

FIG 5. Clamp release separation system at Payload Interface

2. QUALIFICATION PHILOSOPHY AND DEVELOPMENT PLAN

During the initial phase of the program an estimation of shock levels induced by the events listed in §1.2 has been performed based on data provided by the separation system suppliers and heritage from previous similar systems. This estimation led to the establishment of required qualification spectra for equipments: based on the equipment position 5 severity levels have been specified. Also 2 qualification levels for the Payload have been prescribed (1 maximum allowed and 1 target). The verification qualification is made in primis drawing up an applicability matrix where the dimensioning events for each equipment are detected on the basis of the events occurrence during flight and the equipment operational life. The comparison is made for each equipment comparing the maximum expected Shock Response Spectrum SRS_e achieved on the same equipment to its own qualification SRS_q. The qualification is then achieved when 3dB margin is demonstrated according to the following relation

$$SRS_e(f) < SRS_q(f) + 3dB \qquad \forall f \in [100Hz, 10000Hz] \tag{1}$$

For all the equipments SRS_q has to be demonstrated by test within a prescribed tolerance of [0,+4dB]. Because of the low cost approach followed by the program, most of the equipments mounted on the launch vehicle are inherited from Ariane programs together with the qualification status achieved on those programs. Therefore several waivers to the specified levels have to be managed. The max expected SRS_e for each equipment in the initial phase of the program has been estimated with theoretical and empirical methods as described in §4. Then several tests have been carried out to fully reproduce the shock environment on most of parts of the launcher. The expected SRS levels for each of the events listed in §1.2 have been derived according to the following approach:

1) 1st stage ignition: Solid rocket motor firing test
2) 1st stage separation: Extrapolation from Inter-stage 2/3 separation test for similarity of cutting devices (see § 4.2)
3) 2nd stage ignition: Solid rocket motor firing test
4) 2nd stage separation: Full scale test on Inter-stage 2/3 (see § 3.1.1)
5) 3rd stage ignition: Solid rocket motor firing test
6) 3rd stage separation: Full scale test on UCMEC (Upper Composite Mechanical Model) (see § 3.1.3)
7) Fairing separation: Full scale test on UCMEC (see § 3.1.2)
8) Payload separation: Full scale test on Payload Adapter (see § 3.2)

Based on measurements performed during the above tests the max expected SRS_e envelope for each equipment has been derived. The pre-post processing of signals and the verifications have been performed with Dynaworks™.

2.1. Payload Qualification

The payload qualification is achieved once the condition (1) is demonstrated with:

SRS_e : the maximum envelope level induced by all the events in § 1.2 from 1) to 7).
SRS_q : the payload qualification levels achieved at payload/adapter Interface by full scale test simulating the event 8) in § 1.2.

3. TEST OVERVIEW

3.1. System tests

3.1.1. Inter-stage 2/3 separation test

This test has been performed at AVIO facilities in Colleferro on February 2006 in the frame of the Inter-stage 2/3 campaign under ELV supervision and management. The test article (see FIG 6) was composed by Structural Models (practically Flight-like) of Inter-stage 2/3 supplied by Oerlikon Contraves Italia, Qualification Model of the Cutting Charge, dummy skirt of adjacent structures, Qualification Model of harness and connectors and dummy equipments. The integration of cutting cord has been performed by Pyro Alliance team. The objectives of the test were:

- Inter-stage 2/3 pyro-chain: evaluation of correct functionality;
- Short time disengagement verification;
  - Separation connectors: verification of pull-up;
  - Separation springs assembly: evaluation of correct functionality;
  - Raceway: evaluation of correct functionality, disengagement and integrity and pressure peak;
  - Body's kinematics: collection of data for supporting stage separation analysis;
- Separation shock environment characterization;
  - Inter-stage 2/3 structure (+ Zefiros dummy flange): shock level and attenuation measurement;
- Equipment shock level compliance demonstration and qualification for QM passengers;
  - Equipment dummies supports (without dampers): evaluation of shock environment;
  - Equipment + dumpers: validation of shock attenuation;
- Harness and connectors qualification to Launch Vehicle environments;
  - Verification of the correct shielding during the separation;

The shock signals from about 50 accelerometers were acquired. All the signals files were processed in order to have a common file format to facilitate the treatment and to remove not significant contribution in the signal. The post-processing of signals consisted in static and dynamic offset elimination, spurious spike removal, band pass filtering between 100 and 100000 Hz and SRS calculation with "maximax" criterion and Piersol verification. Signal acquisition was performed by AVIO and INTESPACE up to 1 MHz, while post-processing has been made by ELV.

FIG 6. Inter-stage 2/3 test article after separation

3.1.2. Payload Fairing HSS Test

This test has been performed at the clean room of the EADS CASA Espacio facilities in Madrid on December 2006 in the frame of the UCMEC campaign under ELV supervision. The test article (see FIG 7) was composed by Structural Models (practically Flight-like) of AVUM and Inter-stage 3/AVUM, Qualification Model of the HSS and Fairing Boattail, Qualification Model of harness and connectors and dummy equipments. The pre-tensioning of HSS belt has been performed at nominal level by Oerlikon team. The objectives of the test were:

- Separation shock environment characterization
  - UCMEC Payload Fairing HSS shock level and attenuation measurement;
  - Verification of the generated shock levels;
  - Verification of Soft Release Device implementation need;
  - Launch vehicle / Payload interface shock payload environment verification;
- Equipment shock level compliance demonstration and qualification for QM passengers;
  - Equipment dummies supports (without dampers): evaluation of shock environment;
  - Equipment + dampers: validation of shock attenuation;
  - Verification of RACS (Roll and Attitude Control System) dampers shock attenuation;
- Harness and connectors qualification to Launch Vehicle environments;
  - Verification of the correct shielding during the separation;

The shock signals from about 170 accelerometers were acquired. The signals acquired with the RACAL system needed to be digitised, and then all the signals files were processed in order to remove not significant contribution in the signal. The post-processing of signals consisted in DC offset elimination, zero shift removal, band Pass filtering between 100 and 25000 Hz and SRS calculation. Acquisition and post-processing of signals has been managed by EADS CASA team.

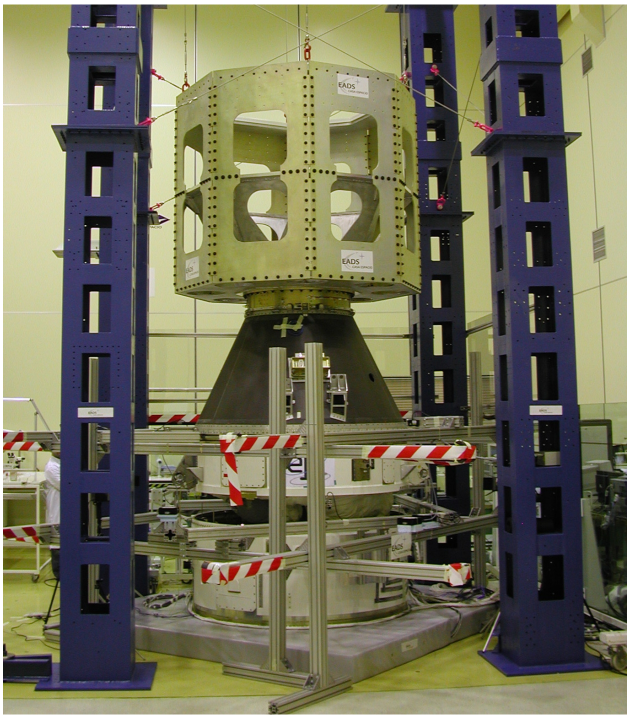

FIG 7. UCMEC test article

3.1.3. A4 Separation Test

A4 (4th stage assy) separation test has been performed at the clean room of the EADS CASA Espacio facilities in Madrid on February 2007 in the frame of the UCMEC campaign under ELV supervision. The test article is the one described in §3.1.2 and shown in FIG 7. The objectives of the test were:

- Short delay disengagement verification;
  - AVUM-Inter-stage 3-AVUM pyro-cutting cord: evaluation of correct functionality;
  - Separation connectors: verification of pull-up;
  - Separation springs assembly: input collection for separation analysis;
  - Separation analysis uncertainties characterization;
- Separation shock environment characterization
  - AVUM-Inter-stage 3-AVUM structure: shock level and attenuation measurement;
  - Shock payload environment verification;
- Equipment shock level compliance demonstration and qualification for QM passengers;
  - Equipment dummies supports (without dampers): evaluation of shock environment;
  - Equipment + dampers: validation of shock attenuation;
  - Verification of RACS dampers shock attenuation;
  - LPS shock qualification;
- Harness and connectors qualification to Launch Vehicle environments;
  - Verification of the correct shielding during the separation;

The shock signals from about 160 accelerometers were acquired. Signal acquisition and post-processing have been performed by EADS CASA as made in the HSS test and described in §3.1.2.

3.2. Sub-system tests

Beside the qualification shock tests required for all those equipment development in VEGA, other important tests have been carried out to characterize shock induced by sub-systems or attenuation at part level:

- Test on ½ and 2/3 cutting cord performed in Pyro Alliance on linear specimens representative of the configured item and linear panels. The results have been widely used before having system tests results especially for what concerns the shock at source.
- A campaign on a shock table took place in EADS CASA to characterize the attenuation of dampers as described in § 5.
- Measurement of shock induced by Payload Adapter CRSS has been performed by EADS CASA in the frame of Adapter development.

4. PREDICTION METHODS

During the initial phase of the program, before the execution of the full scale testing an estimation of the shock level on the different parts of the launcher has been made. The prediction of SRS_e at each equipment interface has been made using the approach of the linear transmissibility function along the structures, starting from the SRS_s estimation at the shock source according to

$$SRS_e(f) = T_{skirt}(f) \cdot T_{bracket}(f) \cdot T_{damper}(f) \cdot SRS_s(f)$$

where $T_{skirt}(f)$ is the transmissibility of the launcher skirt from the shock source and the equipment bracket connection, $T_{bracket}(f)$ is the transmissibility of the bracket itself and the $T_{damper}(f)$ is the transmissibility of the damper, where existing.

4.1. Attenuation along the structure

The estimation of $T_{skirt}(f)$ before tests has been made using rules as per [1] where for each kind of structure the maximum peak attenuation is given as a function of distance from the source. Those curves were built on a series of data collected by NASA during several test campaign. This approach has been used to have a rough estimation of maximum levels along the skirts, but, in general, measurement obtained during VEGA Inter-stage 2/3 test and UCMEC test gave results only partially in accordance with [1] rules (see § 6.1).

Therefore, for the Inter-stage ½ $T_{skirt}(f)$ to be used for qualification purposes it has been preferred to assume the unitary value.

4.2. Inter-stage ½ extrapolation

The extrapolation of SRS_e for the Inter-stage ½ equipments has been performed evaluating the level of similarity between separation ½ and separation 2/3 for the following aspects:

- equipments shock impedance
- similarity of supports
- attenuation along skirt
- similarity of shock at source

Since most of the equipments mounted on Inter-stage 2/3 are also mounted on Inter-stage ½, the starting reference for the estimation of level at the interface of each Inter-stage ½ equipment is the measurement on the same equipment made in the frame of Inter-stage 2/3 test. For few types of Inter-stage ½ equipment not mounted on Inter-stage 2/3, an equipment of similar mass has been assumed as a reference or very conservative assumptions have been made (for instance in the case of Retro-Rockets). For the other aspects, for each equipment, correction factors have been introduced according to the following criteria:

- Similarity of supports: most of the equipment supports are similar between Inter-stage 1/2 and Inter-stage 2/3; Inter-stage 2/3 supports consist of panels riveted on the skirt; for those equipments of Inter-stage ½ where a similar concept is used, the correction factor introduced is 1, while, where concept differences are found, a +3dB factor is introduced.
- Attenuation along skirt: the Inter-stage ½ is a conical shell with no stringers but only local longitudinal stiffeners around windows while the Inter-stage 2/3 is a cylindrical shell reinforced with stringers riveted on the skirt. The second one is supposed to attenuate more than the first because the high number of riveted junctions, but for the Inter-stage ½ most of equipments (with the exception of three) are mounted in the conical part at higher diameter. In this respect +3dB in general have been introduced Also differences in terms of distance from source have been evaluated and the situation in general is better for Inter-stage ½ with the exception of 2 equipments which are SRU (already damped) and UCAT (out of operational phase at the moment of shock event). Based on that and on what measured along skirts (see § 6.1), no attenuation factor has been considered to take into account the difference in distance from the shock source.
- Similarity of shock at source: the two systems are identical unless the separation wall diameter. The emitted energy per unit length is the same; therefore no correction factor is applied.

A table for the evaluation of the above aspects is shown in TAB 1.

	Reference	Skirt	Support
SRU	SRU IS 2/3	+3dB	-
DBAT	DBAT IS 2/3	+3dB	-
RR	Source IS 2/3	-	-
TVC BAT	TVC BAT IS 2/3	+3dB	+3dB
IPDU	IPDU	+3dB	+3dB
BMV1 & 2	SAD IS 2/3	+3dB	-
SAD	SAD IS 2/3	+3dB	-
EMA	EMA IS 2/3	+3dB	+3dB
DBAS Connectors	DBAS IS 2/3	+3dB	-
Separation Connectors	Sep. Conn. IS 2/3	+3dB	-
UCAT	UCAT IS 2/3	+3dB	-

TAB 1. Uncertainty budget for Inter-stage ½ equipments

Based on TAB 1 the SRS_e for the Inter-stage ½ equipments has been derived.

4.3. Equipment supports attenuation

The estimation of $T_{bracket}(f)$ is the hardest step of the prediction process. This function depends on the modal behaviour of the bracket, which is very difficult to characterize for high frequencies. For this reason transmissibility function $T_{bracket}(f)$ for qualification verification purposes during the initial phase of the program has been set to 1. The estimation of equipment SRS_e has been made taking into account 3dB margins to cover possible response increases where the bracket modal content is concentrated. The attenuation of equipment brackets in general is positive ($T_{bracket}(f) < 1$) but some energy transfer is observed from ranges of frequencies typical of pyro-shock spectrum (>10000 Hz) to frequency ranges where the bracket modal content is concentrated (500 Hz - 3000Hz).

A more accurate prediction of acceleration peaks is anyway necessary for accelerometers calibration before each test. For this purpose an empirical method based on the super-position of transmissibility function associated to each bracket mode has been put in place. The bracket has been assumed to behave like a series of 1 degree of freedom systems each one contributing to transfer the energy from high frequencies down to the bracket frequencies in accordance with [3].

$$T_{bracket}(f) = \sum_i^N m_i T_i(f)$$

(2)

$$T_i(f) = \sqrt{\frac{1+\left(2\varsigma_i \dfrac{f}{f_{n,i}}\right)^2}{\left(2\varsigma_i \dfrac{f}{f_{n,i}}\right)^2 + \left[1-\left(\dfrac{f}{f_{n,i}}\right)^2\right]^2}}$$

where $T_i(f)$ is the transmissibility function associated to bracket mode i, $f_{n,i}$ and ζ_i are respectively the resonance frequency and the modal damping factor of mode i and m_i is the modal participation factor initially estimated with the empirical formula

$$m_i = k f_{n,i}^{\alpha} \qquad \sum_i^N m_i = 1$$

where α is < 0. The estimation of the modal parameters associated to brackets comes from shock measurement performed on similar brackets. A modal characterization has been performed using measurements from pre-UCMEC vibration test, but the reliability of data was guaranteed only up to 1000 Hz for shaker control limits when vibrating high masses at high frequencies. The damper factor has been initially set equal to 2% and the resonant frequencies (in this example in number of 10) have been distributed with a logarithmic law. FIG 8 shows the comparison between this prediction and the measurement made during Inter-stage 2/3 separation test at the interface of UCAT equipment.

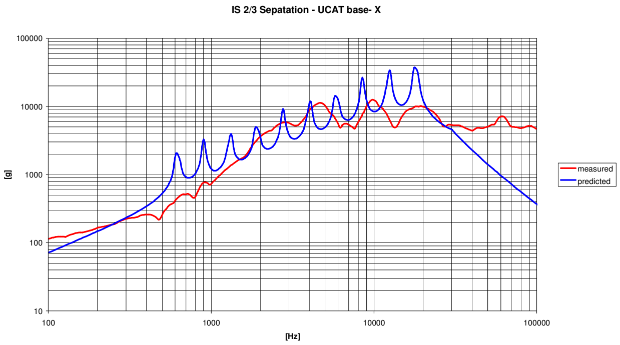

FIG 8. UCAT interface SRS – Comparison between measure and empirical prediction

As it can be seen from the peaks form a too small damping has been estimated, the modal participation also has been estimated with too simple assumptions while the range of frequencies seems to be catch. A curve fitting has been made playing on modal frequencies, damping and modal participation and the differences with respect to measurement become smaller as it is shown in FIG 9.

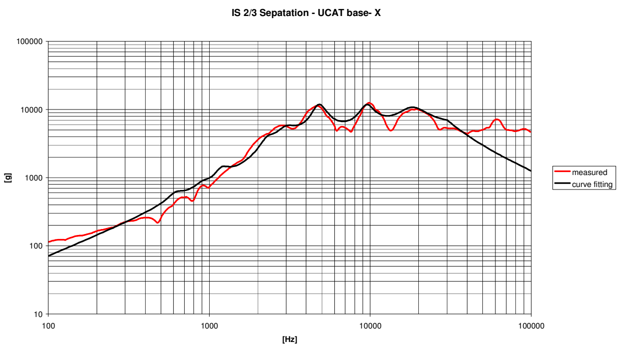

FIG 9. UCAT interface SRS curve fitting

The curve fitting for this specific case has denoted that the resonance frequencies falls between 400 Hz and 10000 Hz with a regular distribution (the frequencies > 5000 Hz are certainly associated to the interaction between support and skirt), the damping factor is between 5% and 10% and the modal participation is low in the range [300 Hz – 1000 Hz], high in the range [1000Hz-3000Hz] and low again for higher frequencies.

5. SHOCK ATTENUATION DEVICES DEFINITION

The equipments suitability status verification in some cases has determined the necessity to introduce shock attenuation devices. For some equipments developed in the frame of VEGA program the design and verification of those attenuation systems has been managed within the equipment supply perimeter and the demonstration of qualification levels has been requested for the system equipment+damper treated as a black box. This is the case of the TVC IPDU (Thrust Vector Control Integrated Power Distribution Unit), SRU (Safeguard Remote Unit) and RACS items.

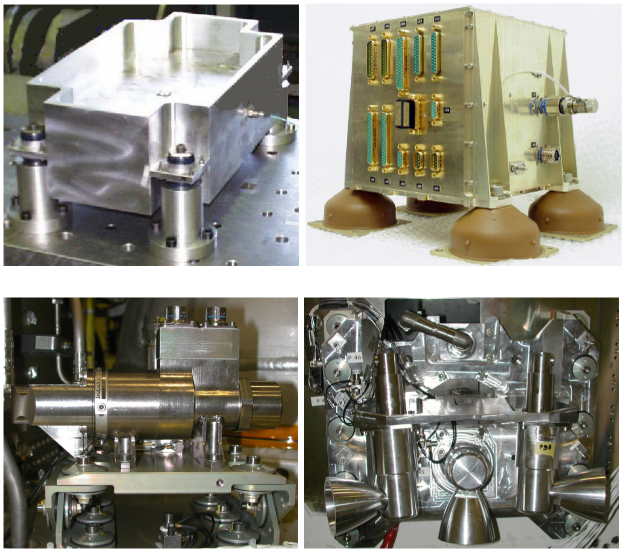

FIG 10. Damping systems for TVC IPDU, SRU, RACS Latch Valve and RACS Thrusters

Being the 4th stage equipped with a plenty of equipments belonging to avionics, but also to propulsion system, the development and definition of attenuation systems has been carried out by the 4th stage structure supplier (EADS CASA) on the basis of system needs. For each equipment the expected SRS_e at its interface has been compared with the desired levels at all frequencies and the approach for attenuation system design has been selected case by case. In general whereas a general reduction of levels is requested the design has been made with the aim to dissipate the energy so making the system work as a damper. Design rules adopted for the scope have been derived from [3]. For those equipments where the expected SRS_e exceeds the allowable levels only in a limited range of frequencies, the approach to introduce a system which "moves" the energy from a frequency band to a lower one is selected. In this frame the attenuation system acts as a suspension (or low pass filter) and the theory based on transmissibility function (2) is adopted. FIG 11 is an example of the first approach (damper), which is implemented on several equipments mounted on the Inter-stage 3/AVUM. This approach is the same used on RACS item and it is founded on the good attenuation provided by elastomeric washers along the lateral direction.

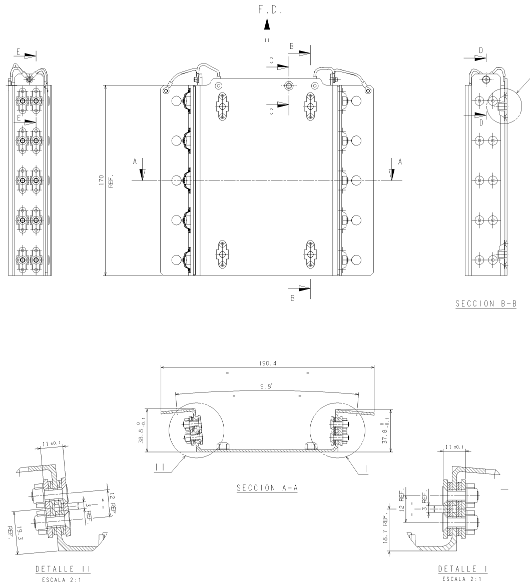

FIG 11. Attenuation device for Inter-stage 3/AVUM equipments

FIG 12 shows the way to solve the attenuation issue when the equipment is not hard-mounted on panels but is suspended along piping. This is the case of 4th stage Liquid Propulsion System Non Return Valves. In this case the attenuation system acts as a suspension.

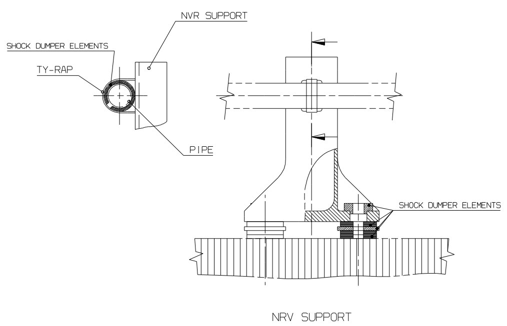

FIG 12. Shock attenuation device concept for items suspended on piping

The proposed solutions have been tested in a dedicated campaign at sub-system level conducted by EADS CASA with a shock table (see §3.2). After that some re-design activities have been undertaken for those sub-systems still non compliant with requirements. The improved configuration has been finally tested during UCMEC test campaign with satisfactory results.

6. RESULTS AND LESSON LEARNT

Measurements at shock source have been investigated for all the tested events. As far as the Inter-stage 2/3 separation is concerned, the maximum measured SRS is about 92000g found at 72KHz, while the maximum SRS for frequencies lower than 10KHz is about 26000g. The high frequency peak is strongly attenuated far from the source. SRS level measured at source in the frame of A4 test is in general lower than the shock measured during Inter-stage 2/3 test. This is explainable mainly by the geometrical difference between the cutting modality of A4 separation (symmetrical) and the one of Inter-stage 2/3 separation (unsymmetrical). Shock induced by HSS test presents a lower content of energy but in two peaks it exceeds the one measured at source during A4 test. This is the effect of the modal behaviour of parts excited by release of pre-stressed structures. In particular at 800 Hz it is possible to recognize the resonance of the tensioned ring at the Payload Fairing Interface.

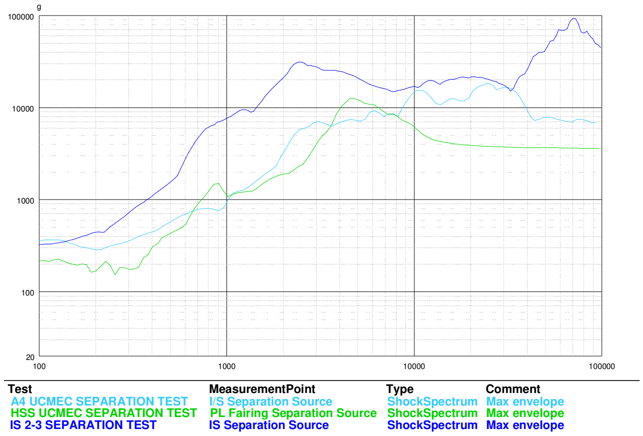

FIG 13. Comparison among measured SRS at source for the 3 tested events

6.1. Attenuation along skirts

The attenuation along cylindrical structures, as expected, for Inter-stage 2/3 is higher than Inter-stage 3/AVUM attenuation. This is mainly due to the difference of concept: the Inter-stage 2/3 is a cylindrical shell reinforced with 60 stringers riveted on the skirt while the Inter-stage 3/AVUM structure is a monolithic one derived from a forged cylinder by lathing and milling. Riveted connection acts as energy absorbers. This effect is more evident for the radial component of the measured acceleration as it can be seen from FIG 14.

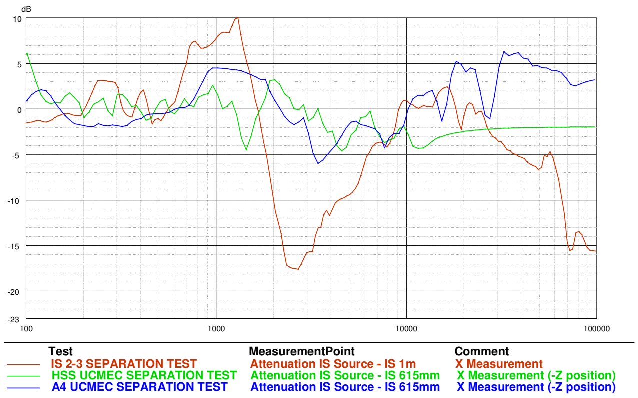

FIG 14. Measured attenuation in dB shock source and along skirt (X component)

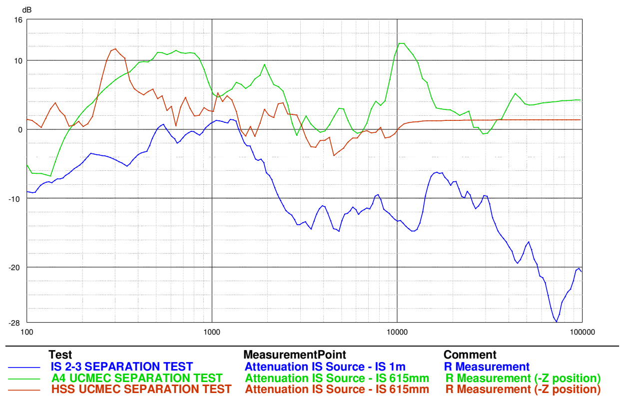

FIG 15. Measured attenuation in dB shock source and along skirt (R component)

6.2. Attenuation between external skirt and AVUM internal structure

The AVUM internal structure is the most complex structure of VEGA. It contains the avionic module, the 4th stage propulsion system, the VEGA roll and attitude control system, the local ventilation system and it carries the harness from the launcher to the payload. Therefore the attenuation between the external skirt and AVUM internal structure is of high importance.

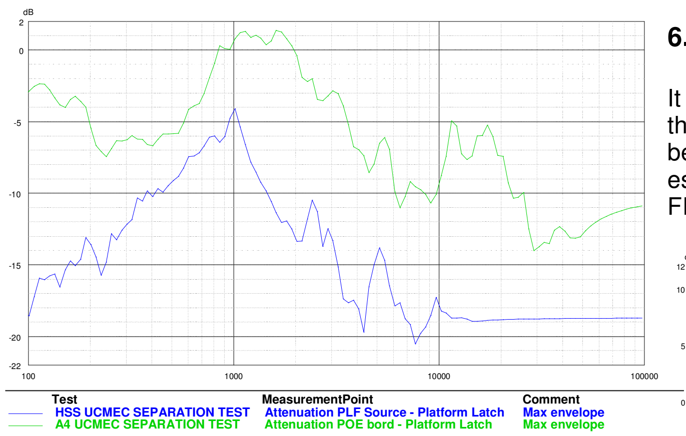

FIG 16. Measured attenuation in dB between AVUM skirt and internal structure

FIG 16 shows that with the exception of the band 1000-2000 Hz, a satisfactory attenuation is achieved for shock induced by A4 separation while the attenuation induced by HSS is everywhere noticeable. In fact, being the shock induced by HSS due to the radial release of a ring, the radial component is more prominent with respect to the axial one and the AVUM internal platform which is orthogonal to the skirt offers high impedance to the propagation of shock along the radial component.

6.3. Attenuation along Payload Adapter

The attenuation along Payload Adapter, as expected, is not uniform for the all the frequencies. As it is shown in FIG 17 the shock level produced during HSS separation is slightly decreased everywhere with the exception of the frequency range between 1000 Hz and 3000 Hz where even some amplification is measured. The behaviour is similar for shock generated during the A4 test, but with higher level of attenuation (but the AVUM contribution also is measured). Comparing the attenuation curves for single components it is evident that the attenuation is much higher for radial component than for the axial one. The high response at 1000-3000 Hz is supposed to be associated to modal behaviour and stiffness of Payload interface. As far as the HSS shock is concerned the levels generated close to the pyro-bolts are lower than levels generated at 90° and due to the smoothing effect of the cone, the attenuation along the Adapter is consequently different along the two directions.

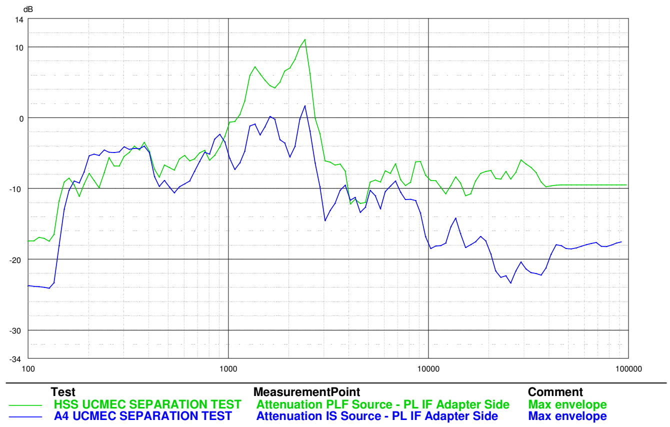

FIG 17. Measured attenuation in dB along the Payload Adapter

6.4. Attenuation of Payload Interface

It is observed both for radial and axial components that the attenuation of SRS at the Payload interface is different between the shock induced by HSS and A4 Separation especially at high frequencies. This is clearly shown at FIG 18.

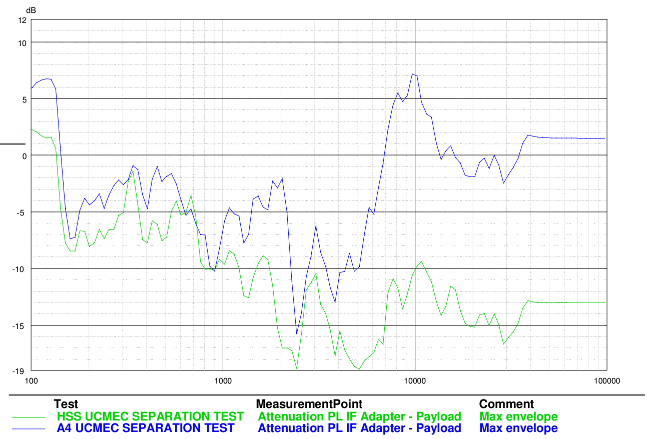

FIG 18. Measured attenuation in dB at Payload interface

7. CONCLUSION AND FUTURE STEPS

This paper reports a summary of activities performed (and not yet concluded) in VEGA program for the characterization of the shock induced by several dimensioning event and the qualification of the launcher itself under the shock environment. A description of dimensioning events and an overview on separation systems is reported. Then the launcher qualification philosophy is shown and a description of system tests is given. A description of analytical activities performed in the early phase of program and studies about attenuation of structural parts is reported together with the adopted shock attenuation systems. Finally an evaluation of most significant results is shown. At the moment of this paper issue the qualification is achieved for all the equipments with the exception of few of them, where some corrective actions have been put in place. Also at payload interface the shock achieved is slightly higher than the target and some activities are running to eliminate it.

For the next future a deeper investigation in the fields of $T_{bracket}(f)$ prediction in foreseen. Starting from acoustic test results where the power spectral density at the interface of each equipment has been measured up to 3000 Hz the aim is to derive the modal behaviour of brackets in terms of resonance frequencies distribution, modal participation and damping associated to each vibration mode.

8. REFERENCES

[1] NASA-STD-7003, Pyro-Shock Criteria
[2] MIL-STD-810-E, Environmental test methods and engineering guidelines
[3] C.M. Harris and C.E. Crede, Shock and Vibration Handbook, McGraw-Hill, New York, 1980.