TRP – Shock Release System Classification

ESR
Executive Summary Report

Written by	***Responsibility*** + handwritten signature if no electronic workflow tool
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CHANGE RECORDS

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1. CONTEXT

Release devices are extensively used inside satellites, covering various functions such as deployment of appendages, release of payload mechanisms, or spacecraft release from the launch vehicle. Depending on the application and the type of release system selected, high shock loads can be experienced and propagated through the satellite structure. Experience shows that there is an insufficient reliability in the definition of shock specification for release devices, mainly due to the fact that non-fully representative test methods and test setups are used to identify the induced environment by release devices. The selection of the release system thus strongly depends on individual experience and heritage. The development of a standardized test set-up and the generation of an extensive shock database will be beneficial for the selection of a release systems and beneficial for new developments of release systems.

2. RESULTS

Many different types of release devices are used in satellites for various purposes, causing potentially high shock loads that propagate through the structure up to sensitive units and components. Specification for such devices could be made more reliable and efficient, based on a standardized test method, since numerical simulation of shocks is not reliable enough. The purpose of this activity has been therefore to define and validate a standardized test set-up useful to create a database of shocks induced by several release devices. In the following part, the main activity outcomes are provided.

This first step of the activity consisted in surveying existing release devices (and their mechanical implementation) and selecting most representative ones for the test campaign. A main constraint of this phase was to maximize the re-use of available representative device, and minimize the cost impact. Thales Alenia Space France has performed a collection of information available at Thales Alenia Space France and Italy, CNES and ESA, in order to have an exhaustive database. This has included the survey of the release device itself but also the survey of all the items that have an influence on the shock transmitted to the spacecraft and to the hold part (interface foot, tie-rod, fixed and released part, mass and inertia of the hold part, etc...). The tables below give the list of the selected high and low shock HRM configurations:

CONF	INTERFACE PART	RELEASE MECHANISM	RELEASED PART	PRETENSION VALUE
HS1	SOLAR ARRAY TRIPOD (TASF)	DASSAULT 7CCD45 CUTTER (CNES)	COLUMN + PANEL (TASF)	210daN < x < 225daN
HS2	PROTEUS SUPPORT (TASF)	ML036 CUTTER (TASF)	COLUMN (TASF)	5200N
HS3	PROTEUS SUPPORT (TASF)	ML036 CUTTER (CNES)	COLUMN (TASF)	4800N
HS4	ANTENNA TRIPOD (TASF)	ME0031– M6, CUTTER (CNES)	COLUMN (TASF)	6000 N +/- 300N

CONF	INTERFACE PART	RELEASE MECHANISM	RELEASED PART	PRETENSION VALUE
LS1	SOLAR ARRAY TRIPOD (TASF)	NEA (TASF)	COLUMN (TASF)	210daN < x < 225daN
LS1(*)	SOLAR ARRAY TRIPOD + LOAD CELL	NEA (TASF)	COLUMN (TASF)	210daN < x < 225daN
LS2	HRM-NG (TASF)	NEA (TASF)	INTERFACE ELEMENT (TASF)	639 daN < X < 641 daN
LS3	HRM-NG (TASF)	NEONUT (SOTEREM)	INTERFACE ELEMENT (TASF)	639 daN < X < 641 daN
LS4	ANTENNA TRIPODE (TASF)	NEA (TASF)	INTERFACE ELEMENT (TASF)	6595N ≤ x ≤ 6605N

Figure 1: Survey and selection of the HRM

Starting from the outputs of the first work package and based on past experience, Thales Alenia Space France has written a detailed requirements specification for the test set-up implementation. The consortium has first of all evaluated the existing test bench that is installed at CNES premises, in the ESA Laboratory of Excellence: including aspects related to lacks of representativeness of the panel stiffness and holding system (no physical separation), etc. Then a new test set-up has been specified to be complementary to the existing one. The specification has addressed the functional requirements (related to the final purpose of the test set-up that is to be able to generate information that can be compared from one configuration to the other and eventually be used for system analysis, whether by means of FEM or by exploiting ESA defined attenuation curves), operational requirements (related to the implementation of the test set-up and the easy manipulation) and interface requirements. A first iteration has been elaborated during the technical proposal, and finalized under the form of a standard requirements specification document in the end, with clear and objective criteria.

The design of the test set-up has been defined and justified by CNES after a dedicated pre-test campaign based on their past experience on the currently existing test bench and their expertise as the ESA Laboratory of Excellence for Pyrotechnics. In order to fulfill the technical requirements specified during the previous phase, CNES has performed a trade-off for test bench implementation, considering the following main configuration parameters:

- plate: sandwich or pure metallic plate
- interface bracket: to be representative of real satellites implementation

The trade-off results have allowed to take the best decisions in order to design the most representative test bench with respect to the real implementation of release devices on satellites. Selection of most representative satellites' panels has been performed with ESA and Thales Alenia Space. The plate in particular has been designed in order to behave in accordance with real sandwich panel. The table below presents the pre-test campaign results including the evaluations of the different test bench configurations according to the design parameters effect on shock response:

Test bench parameters	Impact on shock responses (ratio between 2 configurations)	Frequency range
Size	Low - ±3 dB	
Type : panel sandwich or aluminum plate TRIPOD FEET	High - untill 10dB	200-1000Hz : lower shock in sandwich panel 2,5 kHz - 10 kHz : higher shock in sandwich panel
Type : panel sandwich or aluminum plate TRIPOD	High - untill 10dB low frequency - 5 dB high frequency	200-1000Hz : lower shock in sandwich panel 2 kHz : lower shock in sandwich panel (aluminum plate mode) 7 kHz : lower shock in aluminum plate (sandwich panel mode)
Type : panel sandwich or aluminum plate HRM	High - untill 10dB	200 – 2kHz : ±5 dB 5 kHz : lower shock in aluminum plate (sandwich panel mode)
Stiffeners TRIPOD	Low - ±3 dB except at 1kHz	1 kHz : aluminum plate mode only without stiffeners
Stiffeners HRM	High - untill 7dB	200-500 Hz and 4 kHz : aluminum plate modes only without stiffeners
Shock source on shock release system or directly at shock release system interfaces TRIPOD vs. TRIPOD FEET	High - untill 7dB	200 to 500 Hz, 4 kHz : higher shock responses for TRIPOD configuration

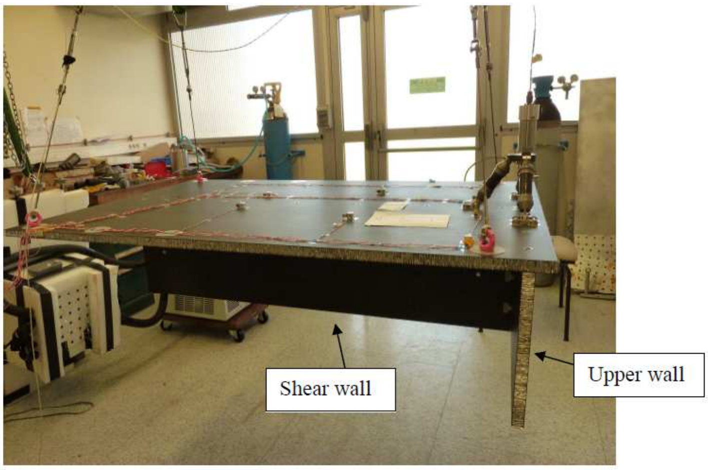


Figure 2: Definition and justification of baseline of the standardized test set-up

The shock response spectrum of the test bench has been evaluated as a function of different design parameters which determine in different way their impact on shock. According to the sensitivity of materials and stiffeners, the design has been mainly driven by the need to provide a solution as much flight representative as possible. In particular after a dedicated investigation of the real application cases, the solution of a sandwich panel with central and lateral stiffeners has been judged the most representative one. The figure above shows a view of the proposed solution. In particular test bench have been manufactured as well as additional pieces for the real flight items have been procured. The manufacturing of the test set-up parts has consisted in procuring the elements that were not already available in the CNES laboratory like sandwich panels stiffeners, adequate inserts, load cells, necessary screws, brackets and tools. The figures below shows all the manufactures interfaces suitable to accommodate the selected HRM (including the suspension cables):

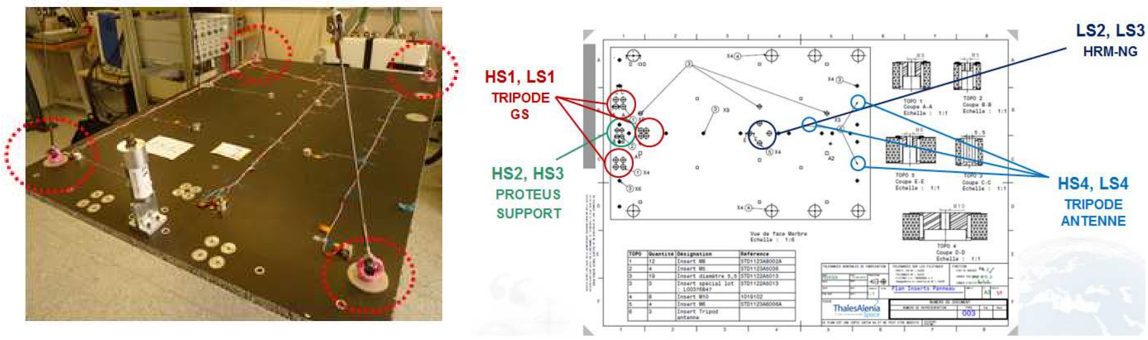


Figure 3 Test bench sandwich design

A detailed test campaign has been performed in order to demonstrate the performance of the selected test bench with respect to the specifications. CNES has performed this phase by using explosive and not explosive devices.
This phase has included post-processing of data, analysis of the compliance of the test set-up to the specifications, comparison of the results with measurements on the reference spacecraft (provided by Thales Alenia Space France). Preliminary limitations have been underlined and different improvements have been identified and proposed. CNES has also prepared a detailed test procedure. The selected test bench has been validated according with the standards defined by the ESA methodologies. In particular, during the preliminary test campaign, different shocks have been induced on the sandwich panel by an « Expert » type (PSH) shock sources integrated on the panel in three different ways: on a HRM Proteus supports, on a Tripods and directly on the sandwich panel. The shock propagation and transmission have been evaluated during each test using a dedicated instrumentation. The measurements have been judged exploitable when the Piersol criterion has been respected (=I(SRS+) – (SRS-)I<6dB). In all the cases, this criterion has been respected allowing to build confidence on the test bench validity.
The figure below shows en example of exploitable measurements accordingly with the Piersol criterion:

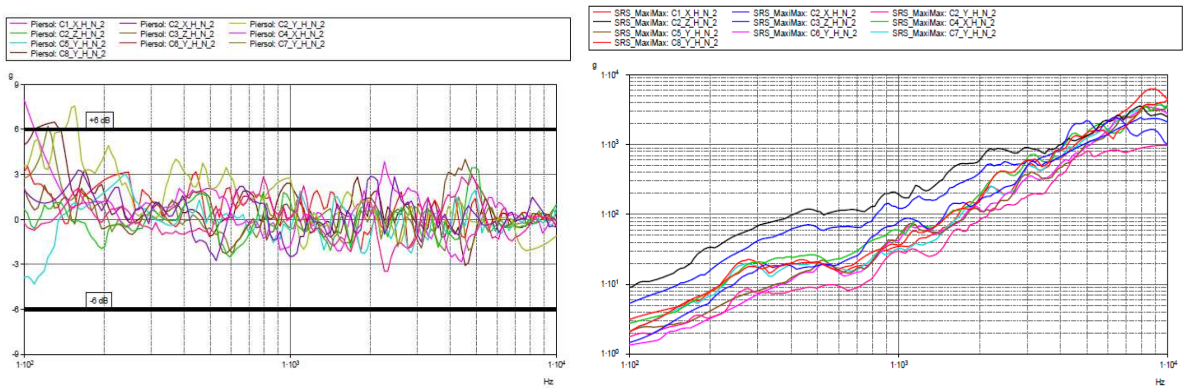


Figure 4 Demonstration of adequate performance of the standardized set-up

A test campaign using the selected real release devices has been performed in CNES and TAS-F laboratories in order to characterize 9 different HRM configurations. In particular, a sequence of 9 (*) shots (5 low shock and 4 high shock) have been performed with5 different release mechanisms in 9 (*) different Test Configurations, as described in the table below (Note: the name associated to the different test configurations has been defined in accordance with the name of the considered HRM assemblies; example: the test configuration called "LS1", includes the LS1 HRM assembly):

	Test Configuration	Release Mechanism	Show Level	Shots Number
1	LS1	NEA	LOW	1
2	(LS1*)	NEA	LOW	1
3	LS2	NEA	LOW	1
4	LS3	NEONUT	LOW	1
5	LS4	NEA	LOW	1
6	HS1	DASSAULT 7CCD45 bolt cutter	HIGH	1
7	HS2	Pyroalliance ML036 bolt cutter	HIGH	1
8	HS3	Pyroalliance ML036 bolt cutter	HIGH	1
9	HS4	Pyroalliance ME0031– M6	HIGH	1

Figure 5 Test plan

Test bench has been upside-down suspended by cables (panel height from ground equal to 1 meter). Cardboard boxes have been put in place below the released devices in order to avoid any damage.

The figure below shows the test configuration:

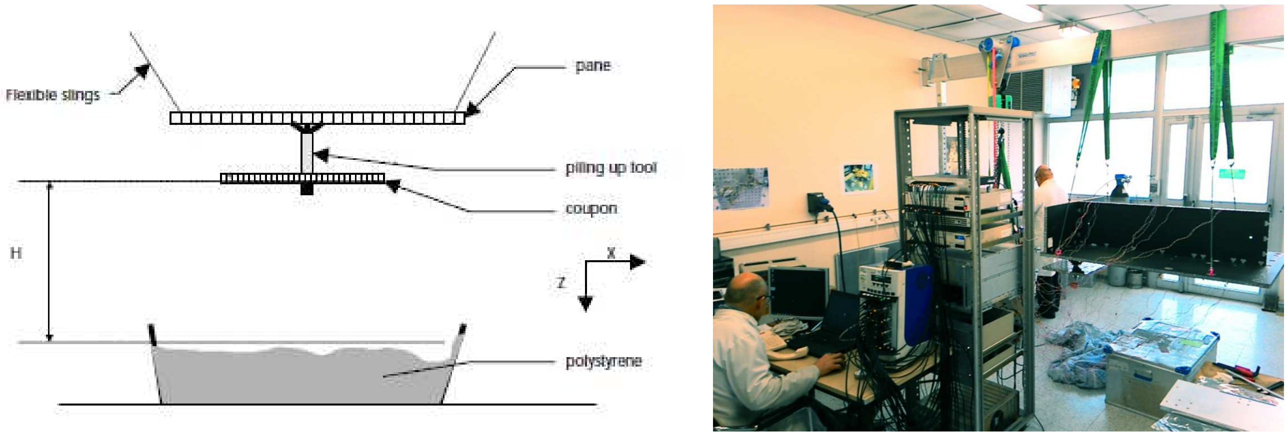


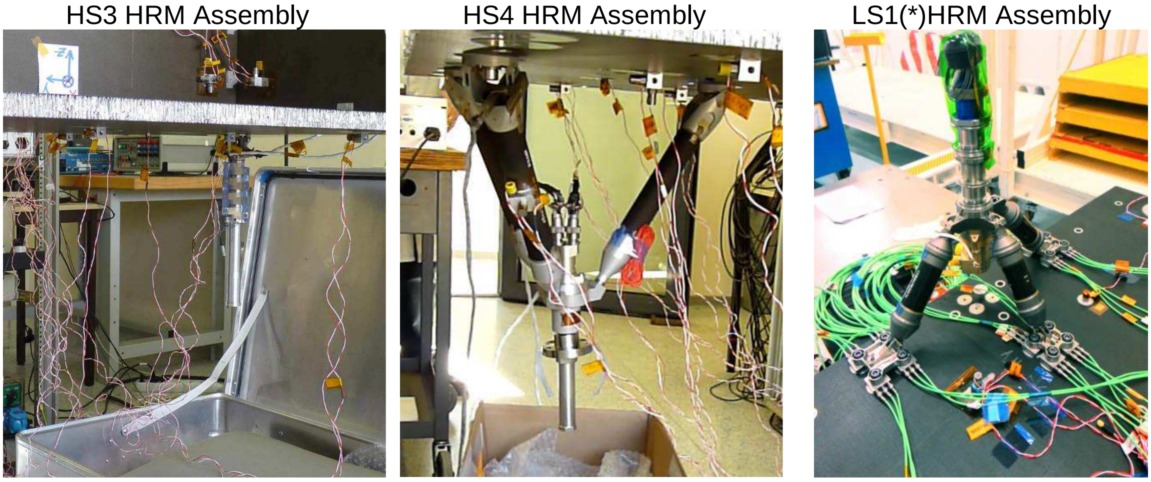
Figure 6 View of the test bench

The main panel and the stiffeners have been assembled with M5x20mm stainless steel screws and a washer; the applied torque is 4.5 (0, +0.5) N.m. The following list provides information on HRM mounting:

- Configurations HS1 and LS1: the SA Tripod has been screwed on the panel (Upper Wall side) with a torque value on nuts (M8) equal to 20Nm.
- Configuration LS1(*): the SA Tripod has been screwed on the panel (Upper Wall side) on 12 dedicated inserts (type M8) including a set of 12 load cells located between the HRM tripod and the main panel. A torque value between 26 [Nm] and 17.5 [Nm] has been applied on dedicated screw (RSAT) with a minimum length of 27.5 [mm] in order to guarantee a specified preload value of 25 kN on the load cells.
- Configurations LS2 and LS3: the HRM-NG pod has been screwed on the panel (central location) with a torque value on nuts (M6) equal to 8Nm.
- Configurations HS2 and HS3: the Proteus HRM pod has been screwed on the panel (Upper Wall side) with a torque value on nuts (M5) equal to 4.5Nm (Perma-glas thermal insulator on screws have to be also implemented).
- Configurations HS4 and LS4: the Antenna Tripod has been screwed on the panel (Upper Wall side) with a torque value on nuts (M10) equal to 20Nm.

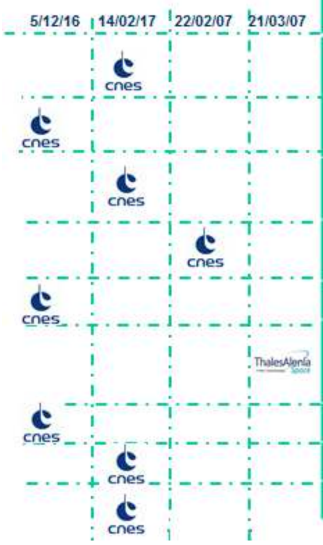
The following figure shows an example of three test configurations:

HS3 HRM Assembly HS4 HRM Assembly LS1(*)HRM Assembly



- **Figure 7 View of the HRM assemblies mounted on the main panel**

During the tests, the acceleration time histories (computed in SRS - [g] from 10 Hz to 50 kHz) at supporting panel level has been measured by a set of accelerometers dedicated to the evaluation of the shock source, propagation and transmission. For measuring the three orthogonal components of the dynamic and quasi-static force (in terms of [N]) acting between the HRM tripod and the main supporting panel, a set of 12 load cells has been proposed. The load cells characteristics have been identified after a dedicated survey in the TAS-F Cannes facilities.
The figures below show the details of the test plan:



CONF	SUPPORT FIXÉ	MECANISME DE GERBAGE	ELEMENT DEGERBÉ	VALEUR DE TENSION DU TIRANT
HS1	TRIPODE GS	CISAILLE DASSAULT 7CCD45	COLONNE + PANNEAU	210daN < x < 225daN
HS2	PROTEUS SUPPORT	CISAILLE ML036	COLONNE	5200N
HS3	PROTEUS SUPPORT	CISAILLE ML036	COLONNE	4800N
HS4	TRIPODE ANTENNNE	CISAILLE ME0031– M6,	COLONNE	6000 N +/- 300N
LS1	TRIPODE GS	NEA	COLONNE	210daN < x < 225daN
LS1(*)	TRIPODE GS + CAPTEURS DE FORCE	NEA	COLONNE	210daN < x < 225daN
LS2	HRM-NG	NEA	ELEMENT D'INTERFACE	639 daN < X < 641 daN
LS3	HRM-NG	NEONUT	ELEMENT D'INTERFACE	639 daN < X < 641 daN
LS4	TRIPODE ANTENNNE	NEA	ELEMENT D'INTERFACE	6595N ≤ x ≤ 6605N

Figure 8 Test plan

All the time histories have been processed in order to compute the Shock Response Spectra (SRS in terms of [g]). A sampling frequency of 1MHZ has been selected for the time history acquisitions. A Q factor equal to 10 and a proportional bandwidth of 1/24 octave have been considered for the SRS computation. The following figure provides an example of the SRS measured by the closest accelerometers to the source (glued and screwed sensors) (Note: Z direction is OOP and X, Y directions are in plane) during the test with the configuration HS1 (Solar Array Tripod + Dassault 7CCD45 cutter). The figure in particular shows the SRS computed from the time histories measured by the sensors C2X, C2Y and C2Z (glued on a cube for measuring the IP and OOP responses) and the sensor C3Z (screwed on the panel for measuring the OOP response).

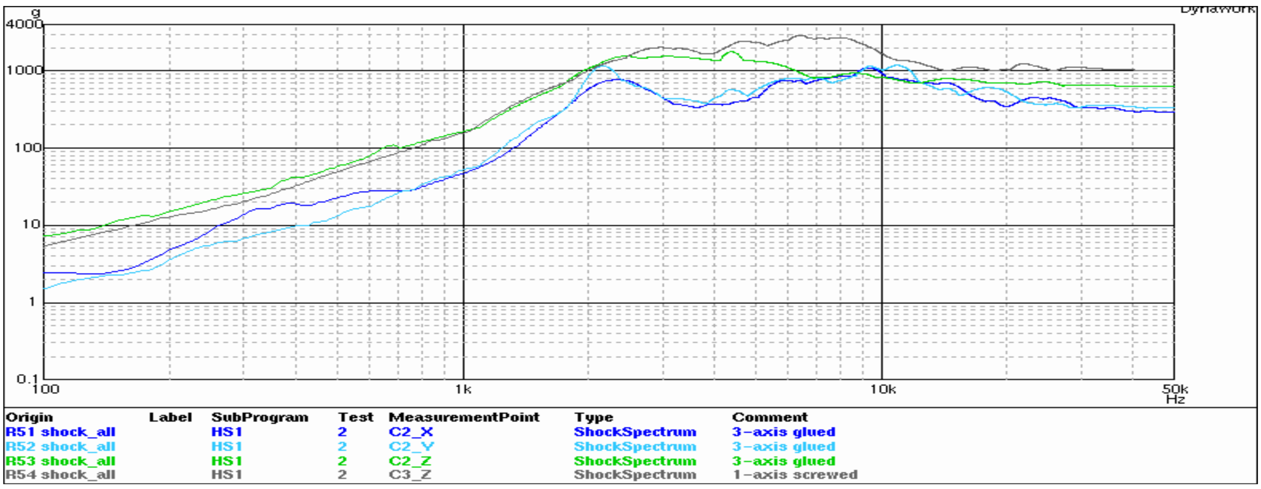
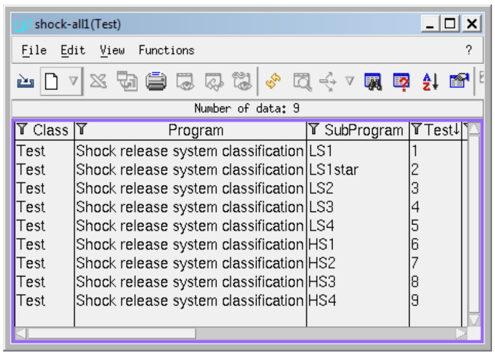


Figure 13: SRS measurement

The shock levels generated by all the HRMs have been compared in order to extrapolate preliminary considerations. Comparing the test results, it has been possible to confirm that:

- The shock levels generated by the pyro-cutters are much higher than the shock levels generated by the NEA and the NEONUT:
- The tie rod pretension value plays an important effect on shock level,
- The tie rod dimension has an important effect on shock level,
- The load cells induce an additional shock attenuation,
- the ESA/ESTEC rules related to distance and junction attenuation effects are globally respected

All data monitored during the test (time history and SRS but also all test parameters) have been stored in an organized database (in the DynaWorks® v. 5.2D software), allowing easy retrieval of information and introduction of additional data. The database has not be only limited to gathering data, but it has allowed further post-processing such as statistical analysis (min, max, mean, standard deviation). The database has been delivered with a quick user's guide. The general database structure is reported below.



Class	Program	SubProgram	Test
Test	Shock release system classification	LS1	1
Test	Shock release system classification	LS1star	2
Test	Shock release system classification	LS2	3
Test	Shock release system classification	LS3	4
Test	Shock release system classification	LS4	5
Test	Shock release system classification	HS1	6
Test	Shock release system classification	HS2	7
Test	Shock release system classification	HS3	8
Test	Shock release system classification	HS4	9

Figure 24 Test Database

The key information reported in the database are the following:

- Program, SubProgram and IdTest are the same as the ones of Test view
- DataFamily column reports the sensors location / distance from shock source
- MeasurementPoint column reports the sensors name, inclusive of direction
- Axis column reports the sensors direction
- NodeNumber column reports the sensors order in the sensors list
- ResponseType column reports the sensors orientation
- Comments column reports the type of installation (mono- bi- or tri-axial) and the type fixation (glued or screwed)
- XUnit column reports the abscissa unit and Values unit reports the ordinate unit

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3. OVERALL CONCLUSIONS AND REMARKS

In the frame of the ESA TRP – Shock Release System Classification activity, a standardized test method to derive a database of shocks induced by several release devices has been developed and validated. An optimized design has been defined for the test bench in order to be representative of the flight configurations and in order to guarantee the standardization of the test bench itself. According to this the following results can be highlighted:

1. A standardized test bench useful to characterize the shock induced by the most common release devices used in space industries has been manufactured and its performances have been validated.

2. The most common HRMs used in space industry have been implemented in the test bench, including high-shock and low-shock release devices and flight like interface and released elements (like the deployment of solar array).

3. A physical propagation and transmission of shocks has been measured (thanks to flight like bracket and supporting structures) and, according to acceptance criteria, all the measurements have been validated.

4. The test set-up has allowed to compare high and low shocks devices in the same configurations and crucial information have been derived during data post-processing phase.

5. Test instrumentation has allowed to measure both accelerations and interfaces forces through load cells. The SRS measurements in different locations have been also exploited in order to verify the ESA/ESTEC shock attenuation rules.

6. The test set-up has proved to be easily transported and implemented in different test laboratories (CNES PyroLab and TAS-F Cannes Laboratory).

7. The test set-up has proved to be easily used by any users and to be easily adapted to any new device not foreseen in the frame of the study

8. All data monitored during the test (time history and SRS but also all test parameters) have been stored in an organized database (in the DynaWorks® v. 5.2D software), allowing easy retrieval of information and introduction of additional data.

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