Development of a test facility to simulate pyroshock environments in a laboratory
F. Cambier\textsuperscript{a}, C. Conti\textsuperscript{a}, P. Dehombeux\textsuperscript{a} & E. Filippi\textsuperscript{b}
\textsuperscript{a}Faculté Polytechnique de Mons, Service de Mécanique Rationnelle, 31 Boulevard Dolez, B-7000 Mons, Belgium
Email: fabcamb@mecara.fpms.ac.be
\textsuperscript{b}Alcatel Eteca, Environmental Tests Department, 101 rue Chapelle Beaussart, B-6032 Mont-sur-Marchienne, Belgium
Email: enrico.filippi@etca.alcatel.be

Abstract

When used for spatial applications, electronic equipments undergo pyrotechnical shocks, for instance during the separation steps of the launcher vehicle stages or when the solar panels of a satellite are deployed. These shock environments are characterized by test specifications defined by shock response spectra. The frequency range usually extends up to 10 kHz and the acceleration amplitude exceeds in some cases several thousand g’s at frequencies above 1000 Hz. The vibration resistance of electronic equipments is verified in laboratory conditions by reproducing similar pyrotechnical shocks. Usual laboratory test facilities such electrodynamic shakers or drop tables are not suitable to represent such severe shock environments.

The purpose of this paper is to describe the procedure of development of a test facility to reproduce pyrotechnical shock environments in laboratory. A test fixture has been developed, based on single or double plates configuration. Different excitation systems such as a dropping hammer, pneumatically fired projectiles or explosive charges can be used. A set of adjustable parameters affecting the structural properties of the test fixture influences the shape and the amplitude of the generated shock response spectrum. With this test facility, most of the pyrotechnical shock test specifications can be met: some parameters give a control on the low frequency range (below about 1000 Hz), some others on the high frequencies spectrum (above about 4000 Hz) or on the full frequency range.

This test facility has been already used to perform shock tests on equipments produced by Alcatel-Eteca but also on equipments of foreign customers.
1 Test level specification

The nominal shock test levels are defined as shock response spectra for each of three axes. The amplitude level and shape of these specifications can be very diversified. Figure 1 illustrates this situation on basis of specifications for three different projects: the ARIANE 5 launcher, XMM and ARABSAT spacecrafts. These specifications characterize shock environments which must be endured by the equipments during their functioning. For instance, the XMM shock test specification has been derived from the shock loads measured at the ARIANE 5 launcher/payload interface during fairing and VEB separation. In some cases, the nominal specification can be different for the out-of-plane testing axis and for the two in-plane testing axes.

Usually, tolerances on the amplitude of the nominal shock response spectrum [1] are ± 6 dB below 3000 Hz and +9dB/-6dB above 3000 Hz.

2 Description of the shock test facility [2], [3],[4]

2.1 Single plate and double plates configurations

There are two main configurations for the structure of the shock test facility: a single plate (figure 2a) or a double plates (figure 2b) configuration. For each of these two configurations, the plate(s) is (are) in free-free condition (suspended with wire ropes or set on a foam pad). For the single plate configuration (SPC), the excitation can usually be perpendicular or parallel to the plate plane, like shown at the figure 2b. For the double plate configuration

![Figure 1: Examples of pyroshock environment specifications.](image-url)
(DPC), the test item is screwed on the response plate and the excitation is perpendicular to the base plate. When used the single plate configuration, a corner plate (CP) is sometimes used. This corner plate is fixed on the main plate and the test item is screwed on this corner plate (cfr. figure 2c). For each configuration, an anvil plate is localized in the impact zone to protect the main plate against local distortions. All experimental results presented in this paper are obtained with an anvil plate in steel.

2.2 Excitation systems

Different excitation systems can be used to generate the shock environment. First possibility is a dropping hammer (DH), which is composed of:

- a cylindrical body with a diameter of 50 mm: the length and the material of this cylindrical body give the possibility to change the mass of the dropping hammer;
- an impact head of different materials to have various kinds of contact. During its drop, the mass is guided through an aluminium tube. All results presented in this paper are obtained with an impact head made of steel, except when mentioned otherwise.

A second possibility to generate the shock is to use a nitrogen gun (NG) to fire projectiles pneumatically. The body of these projectiles is cylindrical with a diameter of 14 mm. Their head is spherical and their length is about 60 mm. When not mentioned otherwise, all results of this paper are obtained with a projectile made of steel.

The last possibility is to use linear-shaped explosive charges (12 gr/m)
(EC) to generate the shock. The amount of explosive charges and their location are two main parameters to modify amplitude and shape of the generated shock response spectra.

By combining the various excitation systems and the various structural configurations of the test facility, a large number of setups are available to generate the shocks. Table 1 lists the suitable setups to specify the test conditions for all experimental results presented in this paper.

Figure 3 shows typical shock response spectra (for the out-of-plane axis) obtained with the dropping hammer and a pneumatically fired projectile for the same structural configuration (setups 1 and 2). The amplitude of the low an middle frequency range of shock response spectra is smaller with the nitrogen gun than with the dropping hammer. Figure 4 represents shock response spectra obtained with nitrogen gun and explosive charges for the same structural configuration (setups 3 and 4). These two curves have a different amplitude level but about the same shape. These observations are presented as tendencies and not as general rules. It seems then to be possible to vary the amplitude of the shock response spectra in the low and middle frequency

<table>
<thead>
<tr>
<th>Setup n°</th>
<th>Configuration (dimensions in millimeters)</th>
<th>Excitation</th>
<th>Test item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SPC- 800x600x5-steel</td>
<td>DH-m=2 kg-H=1200 mm</td>
<td>4.5 kg</td>
</tr>
<tr>
<td>2</td>
<td>SPC- 800x600x5-steel</td>
<td>NG-p=2 bars</td>
<td>4.5 kg</td>
</tr>
<tr>
<td>3</td>
<td>SPC-1000x1000x10-steel + CP-aluminium-30 kg</td>
<td>EC-1.2 gr (=10 cm)</td>
<td>3 kg</td>
</tr>
<tr>
<td>4</td>
<td>idem n°3</td>
<td>NG-p=9 bars</td>
<td>3 kg</td>
</tr>
<tr>
<td>5</td>
<td>idem n°3</td>
<td>NG-p=8 bars</td>
<td>3 kg</td>
</tr>
<tr>
<td>6</td>
<td>SPC- 800x600x5-steel</td>
<td>DH-m=2 kg-H=600 mm</td>
<td>4.5 kg</td>
</tr>
<tr>
<td>7</td>
<td>SPC- 800x600x5-steel</td>
<td>DH-m=2 kg-H=200 mm</td>
<td>4.5 kg</td>
</tr>
<tr>
<td>8</td>
<td>SPC-800x600x5-steel</td>
<td>DH-m=2 kg-H=400 mm</td>
<td>4.5 kg</td>
</tr>
<tr>
<td>9</td>
<td>SPC-800x600x5-steel</td>
<td>DH-m=2 kg-H=800 mm</td>
<td>4.5 kg</td>
</tr>
<tr>
<td>10</td>
<td>SPC-1000x1600x10-steel</td>
<td>DH-m=2kg-H=1300mm</td>
<td>23 kg</td>
</tr>
<tr>
<td>11</td>
<td>SPC-1000x1600x10-steel</td>
<td>DH-m=2kg-H=1600mm</td>
<td>23 kg</td>
</tr>
<tr>
<td>12</td>
<td>DPC-BP-1000x800x10-alum.-RP-800x600x5-steel</td>
<td>N.G : p= 4 bars</td>
<td>4.5 kg</td>
</tr>
<tr>
<td>13</td>
<td>DPC-BP-1000x800x10-alum.-RP-800x600x5-alum.</td>
<td>N.G : p=4 bars</td>
<td>4.5 kg</td>
</tr>
</tbody>
</table>

Table 1: Experimental setups for shock response spectra of this paper
range by changing excitation systems. Let’s point out that a saturation of the amplitude of the shock response spectra is observed for high excitation levels with the dropping hammer or the nitrogen gun. This phenomenon doesn’t appair with explosive charges.

2.3 Repeatability

To illustrate the repeatability of generated shocks, five shocks have been performed on the single plate facility by using the nitrogen gun to excite the test structure (setup n°5). Figure 5 illustrates the upper and lower bounds of the obtained shock response spectra in the out-of-plane direction. The maximum differential between these two limits is 1.73 dB. The repeatability is good and stays widely in the tolerances of the specifications. For the double plates configuration and the other excitation systems, similar conclusions can be stated about the repeatability.

![Figure 3: Excitation with dropping hammer and with nitrogen gun](image1)

![Figure 4: Excitation with nitrogen gun and by using explosive charges](image2)
2.4 Shock response spectrum in the three directions.

In order not to overstress the equipment, meeting the 3D specifications with only one shock is preferred. In practice, this is not always possible but some configurations seem to be better to meet the required specifications simultaneously in several axes.

Figure 6 shows the shock response spectrum obtained with a dropping hammer hitting the plate perpendicularly (setup n°6). The generated shock is mostly unidirectional, the two responses perpendicular to the shock direction exhibiting a spectrum of smaller amplitude. With the same test setup, the plate has been shocked on its thickness. Figure 7 shows the corresponding shock response spectra: the amplitude of the generated shock can be significant in two axes, the shock axis (i.e. in the plane axis 2) and the out-of-plane axis. This can be explained easily by pointing out that bending modes of the plate

![Figure 5: Repeatability of the shocks obtained with the nitrogen gun](image)

![Figure 6: Shock response spectra in the 3 axes for an excitation perpendicular to the plate](image)
are excited in the same way by these both kinds of impact.

By using the one plate configuration with a corner plate (setup 4), it's also possible to generate multidirectional shocks with the perpendicular excitation (figure 2.c), as it is depicted on figure 8. In this case, the shock response spectra have about the same shape and amplitude level in the three axes.

2.5 Influence of some parameters.

2.5.1 Excitation by using the dropping hammer.

2.5.1.1 Drop height of the hammer. Several shocks have been performed on the same structural configuration by dropping the hammer from different heights (setups 6 to 9). The obtained shock response spectra are shown on figure 9. When the drop height increases, the amplitude of the shock response

![Figure 7](image1.png)  
Figure 7: Shock response spectra in the 3 axes for an excitation parallel to the plate

![Figure 8](image2.png)  
Figure 8: Shock response spectra in the 3 axes with a corner plate
spectrum increases approximately in the same way over the full frequency range. Let’s point out (it’s not shown at the figure 9) that, for a given test configuration, a saturation phenomenon of the amplitude of the generated shock appears from a given drop height.

2.5.1.2 Influence of the pair “material of the head of the dropping hammer - material of the anvil plate”. A comparison is performed between shocks obtained with an impact head made of steel (setup 10) on one hand, and with an impact head made of brass (setup 11) on the other hand. The obtained shock response spectra (for the out-of-plane axis) are shown on figure 10. These spectra are about the same between 100 Hz and 1500 Hz, but for the higher frequencies, the amplitude of the shock response spectrum obtained with the brass-steel contact is smaller than that one obtained with the steel-steel contact. The nature of the metal-metal impact seems to be useful to modify the middle and high frequency range of the shock response spectrum.

Sometimes, changing the nature of the metal-metal impact can modify the shape of the shock response spectrum over the full frequency range (usually not with the same way over the full frequency range).

2.5.2 Excitation by using the pneumatically fired projectiles.

The same conclusions can be settled as for dropping hammer experiments. In this case, pressure acts as dropping height.

2.5.3. Influence of the structure of the test facility

Changing the dimensions and the materials of the plates modify the structure
of the test facility and so also the shape of the generated shock response spectrum. To illustrate this, two shocks have been generated by using the nitrogen gun when the material of the response plate is changed (setups 12 and 13). Figure 11 shows the shock response spectra obtained in the out-of-plane direction.

3 Application for testing various equipments.

The amplitude and the shape of the generated shock response spectra depend also on the inertia properties of the equipment under test. So, when an equipment must be tested in a shock environment corresponding to a given specification, the first test sequence consists of a set of preliminary tests on a dummy representative of the actual equipment, in order to adjust the various parameters of the test facility to obtain the required specification. Once the configuration of the test facility is suitable with the dummy, a low level shock
test is realized on the actual equipment to verify that this configuration is suitable for the real equipment too. Then the nominal shock is performed on the real equipment.

4 Conclusion

The shock test facility described in this paper allows the adjustment of a large number of parameters to reach the specified shock response spectrum. Some parameters allow to control the shape of the shock response spectrum in the low frequency range, some others give control on the high frequency range. Some parameters give control on the full frequency range, either proportionally or with a different weight according to the considered frequency range. The repeatability of this shock test facility being relatively good, the big concern is the adjustment of the parameters to meet the specification requirements. Furthermore, some test setups are preferred to others because they allow to not overstress the equipment for 3D shock specifications.

At the present time, the development of this test facility was mainly based on experiments and the parameters are adjusted on basis of tests which have already been performed. A next step in this development would consist of a numerical modelization of the test facility to orientate the adjustments of the test setup.

5 Acknowledgements

The research presented in this paper has been supported by Ministere de la Region Wallonne within the FIRST project RW9613370.

6 References

[3] Filippi E, internal documents, Alcatel Etca