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RUAG's approach to develop a modular low shock separation and jettison system

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Abstract

Today, most separation systems rely on pyrotechnic solutions. This is due to the large flight heritage and simplicity of this technology. However, during recent years, there is an increasing demand from payload suppliers to reduce the amount of shock loads transferred from the launcher in particular during the separation event. In order to achieve this improved payload comfort, RUAG develops a low shock separation system free of pyrotechnics. This paper gives an insight of the ESA funded research and development activities at RUAG Space with respect to new Payload Fairing separation systems.

1. Introduction

One of the key events in a satellite launch mission is the separation and jettison of the payload fairing (PLF) from the launcher. RUAG Space, a leading independent supplier to the space industry, develops, designs and builds payload fairings. This includes the separation and jettison systems for which, during the last decades, RUAG has developed solutions for multiple launchers classes. To ensure 100% mission success, the separation and jettison mechanisms are designed to be reliable, robust and to actuate safely without harming the payload.

1.1 State of the art

Most separation and jettison solutions used today in payload fairings rely on pyrotechnics for the separation event. Many of them rely on a double pyrotechnic system to separate the two payload fairing halves. Typically, one detonation splits firstly the horizontal separation line, located at the bottom of the PLF. The controlled detonation breaks an aluminium frame along the split line and frees the fairing from the launcher. Immediately after the fracture of the horizontal separation line, spring packages located around the horizontal line between the payload fairing and the adjacent structure push the fairing upwards symmetrically. A few milliseconds later, a second detonation splits the vertical separation line with a pyrotechnic cord incorporated in the fairing edges. Once this is detonated, the two fairing halves are pushed apart. This event is extremely quick, requiring a precise synchronization between both detonations.

The main advantages of a fairing separation based on pyrotechnic systems include:

- High ratio of separation force versus system weight: the pyrotechnic separation system release a relatively high amount of energy and have a compact design, as the pyro cords are typically encapsulated inside the PLF frame rings that break during the separation.
- Low weight of the remaining parts on the launcher: the current solutions used in most of the PLFs are jettisoned with the PLF, leaving just a small section of the ring on the launcher. This is particularly important for the launcher prime, as it has a direct impact on the fuel consumption of the flight.
- Design simplicity if compared to more sophisticated mechanical systems: pyrotechnic systems are not only compact, but also have a simple design. This reduces the amount of components needed, also increasing the reliability of these systems.
- Flight-proven reliability and large heritage of the solutions: the large heritage of the pyrotechnic solutions with thousands of successful separations makes them a safe and reliable system consisting of only few components and fail safe solutions.

1.2 Potential for improvement

Despite the common use of pyrotechnical solutions by many launchers, there are still some drawbacks of such systems that need to be considered in future developments of space separation systems. They generate a relatively

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high shock load during the separation event that is transferred to the rest of the launcher structure, including the payload. This necessitates that all the components attached to the PLF, including the rest of the launcher and Payload, are designed to sustain this load case.

Another drawback of pyrotechnic separation systems is that they need to be synchronized and actuated with high accuracy in a very short period of time. This results in complex development and testing phases with development schemes that can take several years and high investments.

The separation event takes place once the aero-thermal flux decreases to values compatible with the payload. This typically occurs above 80 km of altitude, at the last layers of the atmosphere, where the conditions are similar to vacuum. This fact drives the reaction forces on the PLF during the separation event. If the separation system is tested in air, the air friction affects the long term trajectory of the PLF. This fact makes necessary to test pyrotechnic based separation system inside a vacuum chamber to have representative reaction forces and thus to qualify the separation systems.

One of the few test locations with a vacuum chamber able to fit a large payload firing is the NASA’s Glenn Research Plum Brook in Sandusky, USA. This test location was used to validate the current HSS 3+ used in Ariane 5 in 2012.

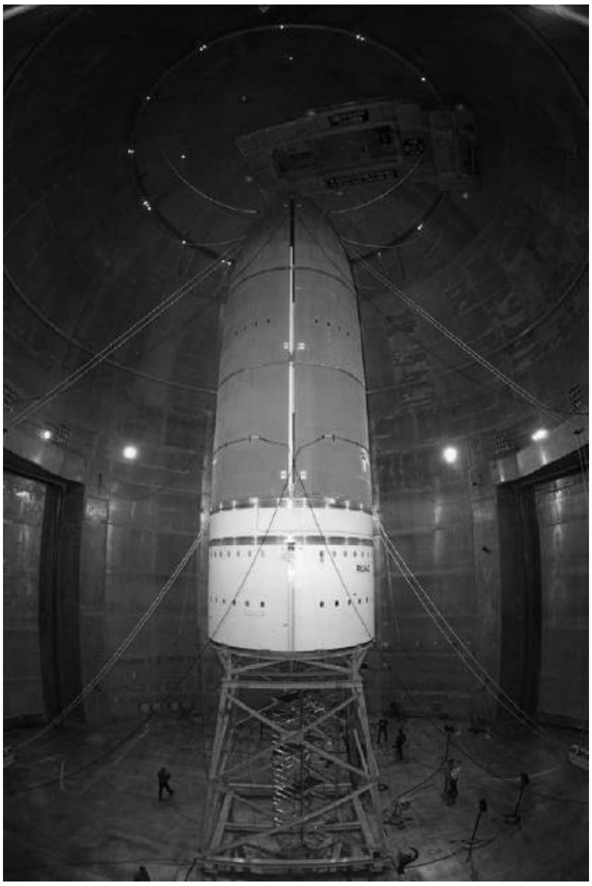

Figure 1: Image of the HSS 3+ horizontal separation system tested in 2012 in the world’s largest vacuum chamber at NASA’s Glenn Research Plum Brook in Sandusky, USA (1).

In addition, acceptance testing of pyrotechnic separation systems requires to fire a part of the batch before flight as part of the acceptance test. This means that some of the items procured are not used as flight hardware, increasing the recurring costs of such systems. It also means that the flight hardware cannot be tested prior to the flight for functionality as no non-destructive test can be carried out. Finally, another drawback is the safety measures and protocols for explosives during handling, transport and pre-launch phase.

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1.3 Goal: Development of modular low shock separation and jettison systems

During recent years, launcher primes and satellite suppliers aim at improving the payload comfort. One of the measures focuses on reducing the loads transferred from the launcher to the payload, including the shock loads generated at the separation event. Aiming to supply our customers with products with more added value, RUAG Space is investigating at novel low shock separation and jettison systems for future launchers and upgrades.

The aim of this development process is to tackle the disadvantages of the pyrotechnic based systems named in the previous sections while maintaining most of the advantages of such solutions. As a result, the proposed solution consists of discrete separation systems connecting the different parts of the structures combined with a passive jettison system that pushes the parts away once the separation systems are actuated.

RUAG Space's approach targets a solution that is scalable to different PLF classes. In addition, as the envisioned solution allows for a more controlled jettison event compared to today's pyrotechnic systems, it enables non-destructive testing, ensuring a predictable response while maintaining the level of reliability of current pyrotechnic systems.

2. Low shock separation and jettison system solution

The envisioned separation and jettison approach under development at RUAG Space combines active pyro free separation solutions for both horizontal and vertical separation lines and a passive jettison system:

- Low shock pyro free actuated horizontal separation system
- Low shock pyro free actuated vertical separation system
- Passive jettison system

The system relies on a principle with rotation and jettison functions provided by a set of actuators and pre-loaded hinges. The configuration is composed by a set of pneumatic actuators to rotate each fairing half around the corresponding axis defined by separate hinges located at the bottom back of each half-shell. Once both vertical and horizontal separation systems actuated, the PLF is free to initiate its rotation around the hinges axis pushed by the actuators. Each fairing half rotates up to a predefined disengagement angle upon which the parts are disconnected and jettisoned by the action of the preloaded springs embedded in the hinges. The complete sequence can be divided in the following three phases, shown in Figure 2:

1. Horizontal and vertical separation: Upon fairing separation along both horizontal and vertical separation planes, the pressure of the actuators is no longer reacted by these interfaces. Then, the PLF is free to initiate phase 2.
2. Actuation / Rotation: The rotation of the PLF around the pivoting axis of the hinges is induced by the force provided by pneumatic actuators. This motion continues up to the disengagement angle, where phase 3 starts.
3. Disengagement and jettison: When the rotation reaches the disengagement angle that depends on the design of the hinge the two elements of the hinge are disconnected, and the half-shells are jettisoned by the action of the preloaded kick-off springs embedded in each hinge. The actuators and the forward part of the hinges are ejected together with the half-shells, reducing the mass remaining in the launcher side for the rest of the mission.

DOI: 10.13009/EUCASS2019-745

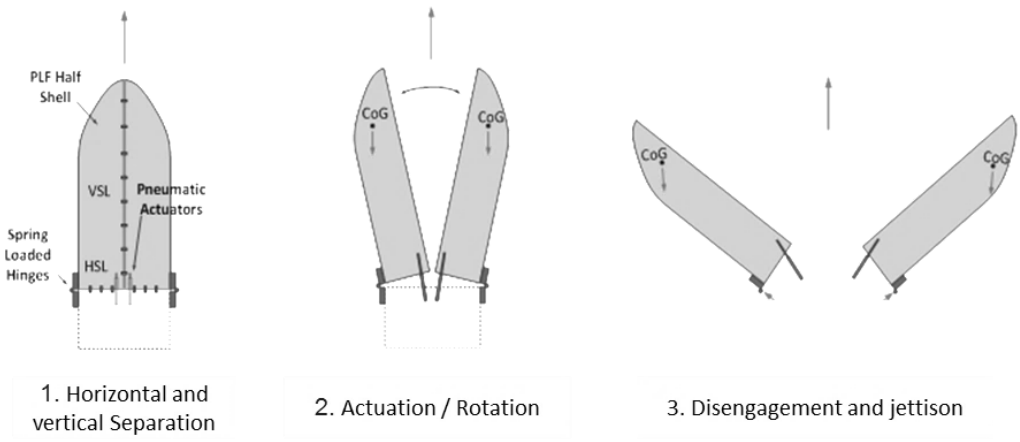

Figure 2: Functioning principle of the low shock separation and jettison system.

The low shock solution under development at RUAG has a number of advantages compared to the current pyrotechnic based separation and jettison systems:

- No need to synchronize the triggering signals: As all the actuation occurs at the same time, there is no need to define the triggering timing of the different subsystems actuating. That reduces the development and testing effort of the solution.
- Modular system: The solution is based on a modular approach, meaning that the separation and jettison subsystems contribute to the separation event, but each of them is developed individually and can be possibly replaced, if needed, by an improved solution without affecting the other subsystems.
- Scalable solution: The subsystems under development are all meant to be scalable for different PLF classes, starting from Small Launch Vehicles (SLV) classes of ca. 1 m diameter up to Large Launch Vehicles (LLV) with a diameter above 5 m. The scalable solution needs tailoring for each class, but generally keeps the same working principle.
- Testing on ground: The non-pyrotechnic separation is one order of magnitude slower than pyro-based separations. As a result, the friction with air becomes a less important effect, that while being still considered does not limit the possibility of performing on ground test. In addition, the non-pyrotechnic separation principle allows for a more simple kinematic modelling, which can be used to evaluate the system limitations and robustness.

3. Current development stage of a low shock jettison system

3.1 Background

This development approach was initiated with a project in collaboration with the European Space Agency (ESA) under the Future Launchers Preparatory Programme (FLPP). In this project, a concept study for the hinge and actuator jettison solution was initially designed up to the Preliminary Design Review (PDR) for a Large Launch Vehicle (LLV) fairing class.
In the ongoing follow up project, the hinge and actuator solution is being further developed, in this case for a Medium Launch Vehicle (MLV) Class up to the Critical Design Review (CDR). This project aims at defining the actuation needs to rotate and jettison the PLF in a safe manner while establishing the limitations of such systems for a MLV PLF. The design developed consist of two hinges and two cold gas actuators installed in the lower end of the PLF. The actuators are pressurized on ground, pushing all the time against the PLF that would initiate the rotation only once the horizontal and vertical separation systems are triggered. A concept of the design with a MLV PLF is shown in Figure 3.

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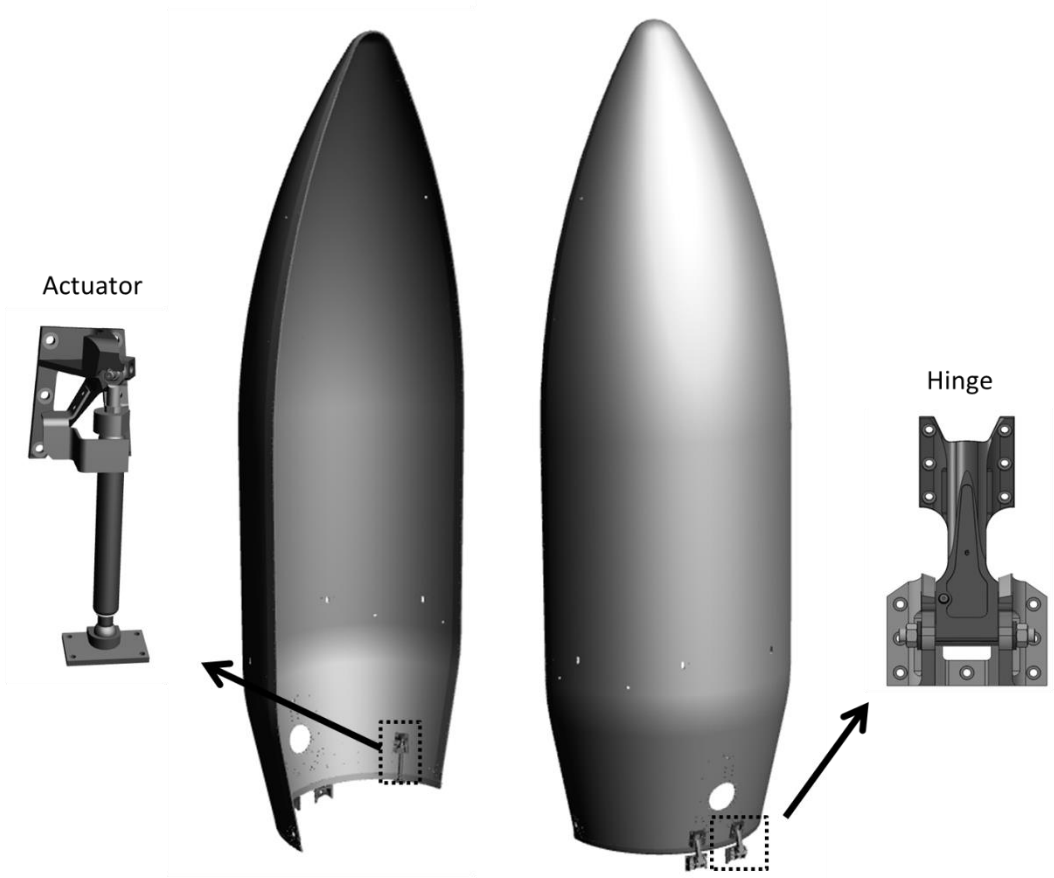

Figure 3: Low shock jettison system in a VEGA 2.6 m PLF.

3.2 Actuators

The actuator selected for the low shock jettison system is a COTS product. They are usually used as gas springs and the product range envelopes a broad range of forces and dimensions. For this application, a gas spring will be used as passive actuator using the stored energy of the compressed gas applied in retracted configuration. The gas considered is an inert gas that does not burn or explode and is not poisonous. The COTS actuator is shown in Figure 4.

Figure 4: COTS Gas Spring Actuator

- Cylinder containing the pressurized N2.
- Piston rod: is the moving part of the actuator, it is covered with a corrosion resistant protection.
- Connecting parts: adapted to meet the I/F to the fairing
- Piston adapter: guides the rod and contains a jet enabling the control of the movement velocity
- Guiding piece seals the pressure volume and guides the movable rod

The COTS product is selected to deliver the defined loads and movement and is adapted to cover the application needs, while some modifications become necessary:

- Materials changed to cover ECSS and lifetime (incl. temperature) related requirements

DOI: 10.13009/EUCASS2019-745

- Pressure inlet valve replaced to have accessibility for preloading
- Pressure sensor included to record possible changes
- I/F brackets designed to allow the needed movement and boundaries.
- A full qualification campaign has been driven on the COTS actuator, applying full mechanical and thermal loads as per MLV PLF.

3.3 Hinges

The hinges guide the fairings rotational movement, providing the jettison angle and kick-off force. The hinges have been designed, verified and tested by RUAG Space to meet the requirements of a medium-sized PLF. The functions of the hinges include, but are not limited, to the following:

- Provide the mechanical I/F during the fairing rotation phase
- Guide the fairing in the correct rotation
- Lead the actuators forces to the rotational movement of the fairing
- Accommodate external forced as launcher rotational acceleration, asymmetric actuation etc.
- Disconnect the mechanical connection at a given angle
- Provide a kick-off energy to ensure clearance of the fairing to the upper stage
- Provide the correct force direction for the kick-off

3.4 Hinge and actuator design guidelines

The actuators are designed to provide enough actuation force to overcoming the Centre of Gravity (CoG) of each half-shell by using only approximately half of the total stroke either in launcher accelerated case or to provide enough kinetic energy for the full rotation in 0 g case. The actuation continues up to the full-stroke position and after that point, the rotation is driven by the acceleration and inertia of the parts, up to the final jettison angle. To ensure this functionality the following criteria are being considered:

- Hinges located outside the PLF
- Actuators located inside the PLF
- Acceleration at separation event of 0 to 3 g
- Full rotation possible in degraded case

As one can see from Figure 3, the hinges are designed to be located at the outside of the PLF. Despite this has a clear drawback of the more harsh environmental loads meaning higher temperatures and dynamic pressure, and the need of an aero-thermal cover, the design of the hinge becomes simpler. This allows the hinge to rotate even with a boat tail PLF, without the need of a more complex mechanism that would be more expensive and less reliable.

The location of the actuators inside the PLF avoids the need of a complex aero-thermal protection that would need to cover the actuators during flight thus simplifying the design.

The hinge and actuator are dimensioned to rotate the PLF for a range of launcher accelerations between 0 and 3 g at separation event. In this context, the design load case for the actuator is the 3g case, where the actuation needs to compensate a higher reaction force at the CoG. On top of the nominal case and the degraded case with one actuator failing completely, a number of dispersion cases are investigated to show the robustness of the solution. These dispersion cases consider variations of:

- Mass
- Actuator pressure
- Thrust direction
- Launcher velocity
- Worse case envelope

Finally, the separation analysis is carried out to:

- Assess the impact of the new system in the forbidden volume
- Measure the clearances during rotation and disengagement
    1. Actuator to PLF shell while actuation
    2. Actuator to payload forbidden volume after actuator disengagement
    3. PLF lower edge to forbidden volume

DOI: 10.13009/EUCASS2019-745

4. PLF shell to payload forbidden volume
5. Payload fairing to launcher forbidden volume after jettison

The fact that some of the actuators are present in the inside of the PLF does not affect the current PLF forbidden volume, as they are located in the region below the forbidden volume. The current forbidden volume is shown in Figure 5 (2):

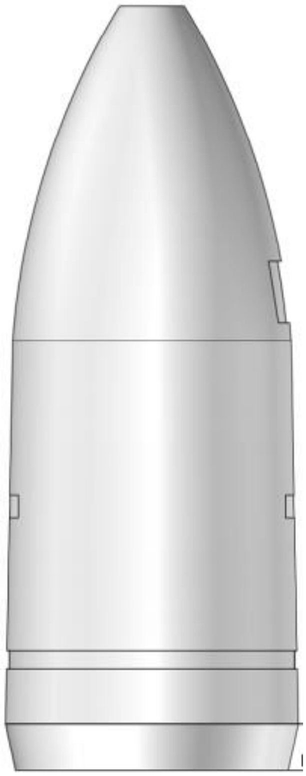

Figure 5: Current forbidden volume of (2), not affected by hinge and actuator systems.

The different clearances for the 3g (design case of the actuator), considering the updated forbidden volume, are calculated for the entire rotation and disengagement movements. The results show positive clearances, having in all cases the minimum values at the beginning of the rotation when all the elements are closer to each other. An illustration of the clearances at nominal case with 0 and 3 g are shown in Figure 6, where the effect of the higher acceleration is shown by the fact that the PLF stays closer to the Launch Vehicle when the acceleration is higher.

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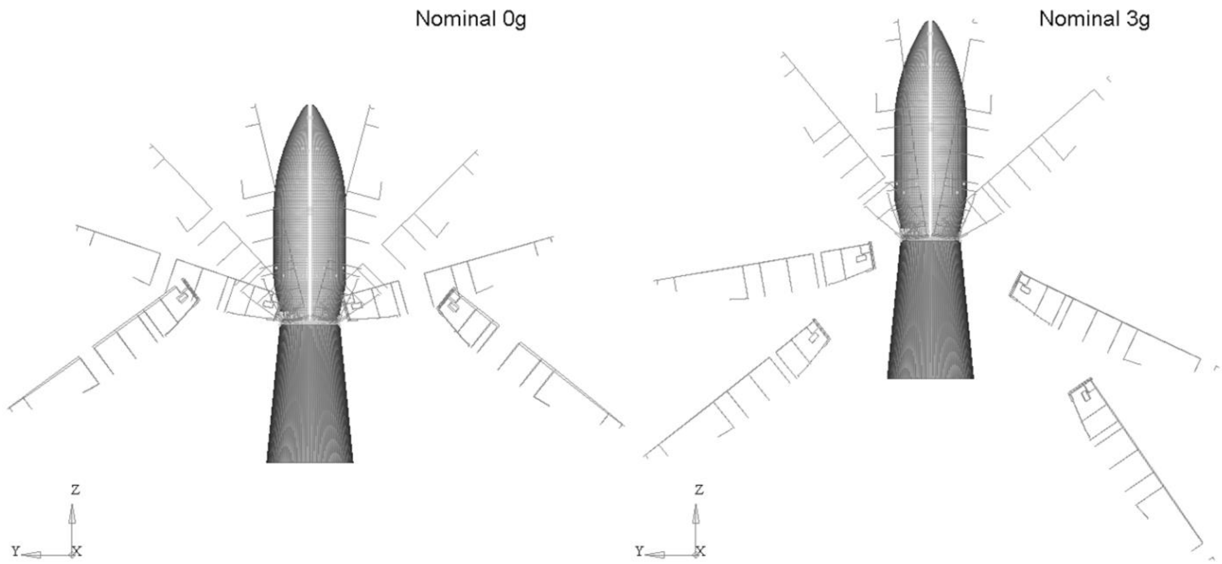

Figure 6: Example of a separation analysis with 0 and 3g.

4. State of the art of low shock separation systems compatible with the hinge and actuator jettison system

Once the jettison system has achieved a certain design maturity level, it needs to be combined with a compatible separation system on the horizontal and vertical lines. There are different options available in the market, including the following:

- Low shock pyro separation nuts
- Clamp band
- Non explosive actuated separation nuts
- Hold down release mechanisms (HDRM)
- Latches

Many of them are discrete attachment points, as the latches, nuts or HDRM. This type of connection has the advantage that it is relatively easy to install, as there are in principle few items and attachment points. However, the disadvantage is that this results in a peak load concentrated at the connection, that drives the dimensioning of the joint. This fundamental difference to continuous joints is to be considered when dimensioning the horizontal separation system (HSS) and Vertical separation system (VSS).

4.1 Low shock pyro separation nuts

Despite being an explosive system, these separation nuts generate a low shock if compared to current systems based on a frangible joint connecting the different PLF halves (3) and (4). An image of the Separation Nut PSM 3/8B and PSM 1/2B from RUAG Space RSE is shown in Figure 7.

DOI: 10.13009/EUCASS2019-745

Figure 7: Separation Nut PSM 3/8B (left), and PSM 1/2B covering respectively small and medium sized spacecrafts, from RUAG Space RSE (4).

This solution has the following advantages (marked with a '+') and disadvantages (marked with a '-'):

+ Low shock compared to other solutions
+ High preload leading to a stiff connection
+ Light weight
+ Simultaneous release
+ Commercially available off the shelf
+ RUAG Space design
− Pyrotechnic based element, suitable for today's application, but would not fulfil pyro free requirement

4.2 Clamp band

Clamp bands are used today in many launch vehicles, both for payload and fairing separation, the later being used in the HSS for VEGA and VEGA-C. RUAG Space has a large heritage in the design and manufacturing of these solutions (5). They consist of a metal band embracing the two interface rings. Examples from RUAG Space RSE are shown in Figure 8.

Figure 8: Payload Adapter System PAS 2624VS (left) and PAS 610S (right) from RUAG Space RSE (6).

The clamp band has the following advantages and disadvantages:

+ Assembly with relatively few connection points
+ Proven concept for MLV HSS
+ Low Cost compared to other solutions
+ Low shock compared to other solutions

DOI: 10.13009/EUCASS2019-745

+ Simultaneous release
+ RUAG Space heritage (650+ in orbit separations)
– Large development effort for VSS.

4.3 Non explosive actuated separation nuts

During the last years, industry is pushing to replace the pyro separation nuts by similar non pyrotechnic actuated solutions (7). In this case, the input signal can be either electric or pneumatic. One solution is shown in Figure 9.

Figure 9: Non Explosive Release Mechanism with 16 mm thread (8)

The non-explosive actuated separation nuts have the following advantages and disadvantages:

+ Low shock compared to other solutions
+ Non pyrotechnic system
+ High preload → stiff connection
– Less simultaneous release compared to other solutions
– Cold gas storage needed if pneumatic actuated

4.4 Hold down release mechanisms

The Hold Down Release Mechanism (HDRM) is a non-explosive actuator that incorporates a separation nut, releasing with an electric signal (9). This solution is currently under development at RUAG Space, as shown in Figure 10.

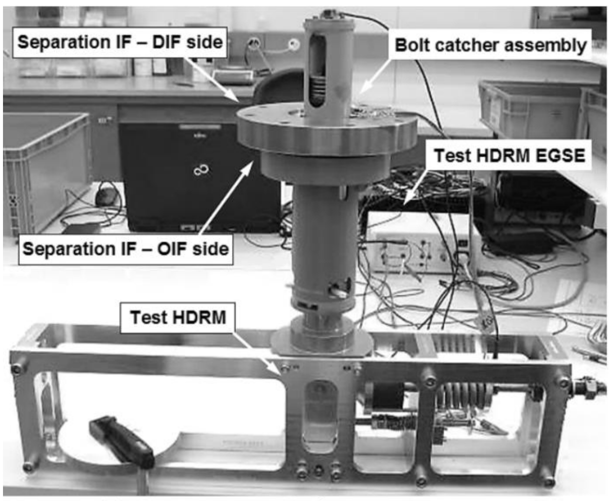

Figure 10: Test HDRM developed by RUAG Space in the frame of the Exomars program (9)

DOI: 10.13009/EUCASS2019-745

The HDRM has the following advantages and disadvantages:

+ Low shock compared to other solutions
+ Non pyrotechnic system
+ RUAG Space heritage
– Not commercially available today

4.5 Latches

Latches are currently used by SpaceX in the vertical separation system of the Falcon PLF (10). In this case, the mechanical system in typically pneumatically actuated. This solution is also under development at RUAG Space, as shown in Figure 11. The latches have the following advantages and disadvantages:

+ Low shock compared to other solutions
+ Light weight
+ Non pyrotechnic system
+ Low cost
– Less simultaneous release compared to other solutions
– Cold gas storage needed

Figure 11: Latches used in FlexLine products.

5. Conclusions

In this paper, the approach from RUAG to develop a novel low shock separation and jettison system for payload fairings is presented. The need for this development effort is to cover a market demand identified in the past years: to develop a reliable and robust separation system, thus reducing the shock generated by the separation systems used today and improving the payload comfort.

The advantages of these systems compared to traditional pyrotechnic solutions are described. These include not only to reduce the shock loads during the separation event, but also to have a more predictable system that can be tested on ground. This is aiming to reduce the development and testing efforts needed to develop and qualify pyrotechnic separation and jettison systems and thus reducing as well the development time.

In addition, this paper shows the current development status of the research project in collaboration with ESA in the frame of FLPP in which a pyro free jettison system is being developed. This system, composed of a set of passive actuators and hinges, enable the controlled rotation and jettison of both PLF halves once the horizontal and vertical

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separation systems are triggered. The clearance margins during rotation, disengagement and jettison are shown, proving the large margins once the forbidden volume is adapted to the new systems needed inside the PLF.

Finally, the jettison system presented in this paper is to be complemented with a compatible horizontal and vertical separation system. The solutions considered, compatible with the hinge and actuator systems, will enable a low shock solution to be used as alternative to today's pyrotechnic systems. RUAG has a wide product portfolio and extensive heritage on design and development of separation solutions, enabling tailored designs for each product. This will enable the development of modular and scalable low shock separation and jettison solutions for our customers in the following years.

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