Development of a Low-Shock Payload Fairing Jettison System

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Abstract

Today's robust and reliable separation and jettison systems safely actuate and execute the separation of the payload fairing from the launcher. However, shock-loads are exported from the pyrotechnic separation event. Furthermore, the verification of new or adapted fairings is typically carried out by extensive and costly test campaigns due to the installation of full-scale components in vacuum chambers. In recent years, there is an increasing demand from the launcher primes and satellite suppliers to improve the payload comfort and to simplify the verification process. Following this need, RUAG Space is developing within the ESA-funded Future Launcher Preparatory Program a low-shock separation and jettison system applicable to currently used and future PLFs. The concept is based on a simple and reliable low-weight system for a controlled separation using hinges and actuators to rotate and jettison the PLF halves. This paper describes the developed concept and the mechanisms for the rotation and jettison. The focus is on the event of separation and jettison, excluding the method for fixation of the fairing during launch and the initial release. The paper shows the advantages of the novel design and explains the verification activities performed to prove the system.

Introduction

RUAG Space is a leading supplier of products for the space industry in Europe and has as well a growing presence in the United States. RUAG Space develops, designs and builds payload fairings for several launch vehicles of different classes, having decades of experience in reliable and robust technical solutions with 100% mission success. Furthermore, RUAG Space is developing and manufacturing high reliable mechanisms for spacecrafts and launchers, as the herewith in this paper presented separation system.

One of the key events in a satellite launch is the separation and jettison of the payload fairing (PLF) from the launcher. In the following a short overview of the state-of-the-art separation system's main characteristics is given.

The central reasons for the use of current fairing separation systems, based on pyrotechnic solutions, include:

- High efficiency: the pyrotechnic separation system provides a high ratio of separation force versus system weight.
- After PLF separation only a small section of the interface ring remains on the launcher as the pyro cords are typically encapsulated inside the PLF frame rings that are broken for separation. This influences positively the fuel consumption of the mission.
- Simple and compact design: pyrotechnic systems are not only compact, but also have a simple design compared to other mechanical systems; less parts are included and no movable joints or interfaces are needed, 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.

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The need for a new separation system development is linked to the drawbacks of the current systems:

- A relatively high shock load during the separation event 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 dimensioned to sustain this load case.
- The fairing separation typically takes place at over 80 km of altitude, at the last layers of the atmosphere, with conditions similar to vacuum. For ground testing, however, the reaction forces from the pyrotechnic separation system are affected by the air resistance, driving the long-term clearances. For this reason, the pyrotechnic separation systems typically need to be tested in vacuum conditions to be fully representative of the separation event. Today there are few locations worldwide where this test can be carried out due to the size of the test items, structures over 20 meters in height. One of them is NASA’s Glenn Research Plum Brook Station in Sandusky, OH.
- Complexity of triggering: a drawback is the demand in accuracy to synchronize the horizontal and vertical separation systems in order to control the clearance.

Figure 1: RUAG fairing test at NASA Glenn Research Center Plum Brook in Sandusky, OH [1]

The main focus of the new developments described in this paper is to overcome the above drawbacks of the pyrotechnic based separation systems used today. The system under development is designed to cover the separation of different PLF classes with low shock, enabling on-ground testing while ensuring the reliability and robustness of current pyrotechnic based solutions. The envisioned system consists of a scalable horizontal and vertical separation system (HSS & VSS, not part of this paper), compatible with a passive jettison system using hinges and actuators that once triggered, rotates and pushes away both PLF halves in a controlled maneuver. The focus of this paper is on the developed mechanisms of the passive jettison system.

System Description

The within this paper presented mechanisms are developed for the payload fairing’s passive rotation and jettison after the HSS and VSS release. The system consists of two independent components:

- Pneumatic Actuators: to provide the kinetic energy for the PLF rotation.
- Preloaded Hinges: define the PLF rotation axis and provide the jettison kick-off energy.

The functioning principle of the PLF separation system under development includes three phases as visible in Figure 2:

1. Low shock actuated horizontal and vertical separation system (HSS and VSS), which are not part of this paper.
2. Passive PLF rotation: actuators push the PLFs to a controlled rotation, guided by the hinges.
3. Passive PLF jettison: the hinges release the connection of the PLF to the launcher at a given angle. Additionally, a jettison energy is implemented to the PLFs by pre-loaded springs, in order to ensure clearance.

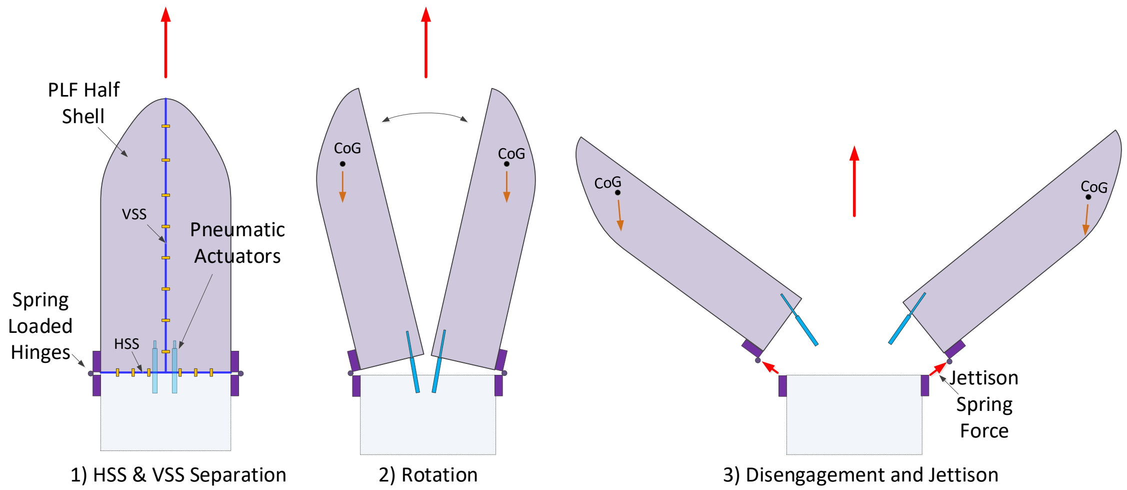

Figure 2: Separation System Principle

This approach has several advantages:

- Signals do not need to be synchronized: Due to the use of passive systems, there is only a single triggering signal to release the HSS and VSS and initiate the fully passive separation.
- Modular: The separation and jettison systems are independent, which allows individual customization or even replacement of each sub-system for a different product without affecting the other subsystem. Additionally, the actuators and hinges can be outlined and tested independently.
- Scalable: The solution under development and described here is meant for small and medium size fairing and may also be applicable to larger firings as well, keeping the same working principle and thus reducing the development effort.
- On-ground testable: The non-pyrotechnic separation is slower than pyro-based separations. As a result, the friction with air becomes less dominant, which makes ambient verification possible.
- Simpler modelling: The functioning principle allows for a simpler kinematic modelling.
- Low shock: The kinetic energy for the jettison is not provided by an instant impulse but by a continuous force from the actuator and the springs inside the hinges.
- Clearance control: the entirely guided rotation allows a higher control of the clearance to the launch vehicle.

In the following paragraphs the selection and development of the actuators and hinges for the separation system are described separately.

Actuators

Given the system concept described above, the actuators need to provide the thrust to overcome the apex of the fairing half shells against the launcher's acceleration loads and provide the kinetic energy to reach separation. Commercial off the shelf gas springs have been chosen as passive actuators.

<u>Actuator Selection:</u>
The key selection criteria to fulfill best the system goals are:

- Aiming at a **cost-efficient** solution, the actuators are modified commercial of the shelf (COTS) products.
- The system should be usable in a broad range of launcher sizes and separation conditions. Pneumatic actuators give the advantage to tailor its performance by the **adaptable energy storage** via the pressure. This allows a mission customized, optimal rotation initiation. For this, the very same qualified actuator is compatible for a wide range of applications.
- To lower the shock coming from the separation process, the work to separate the PLFs is aimed to be applied with low force over a **long stroke** which leads to a very smooth transformation to the needed kinetic energy for the required movement.
  Gas springs provide a force over the full (adaptable) stroke, where the force reduction over stroke is depending on the (adaptable) gas volume ratio from contracted to extended configuration. This brings also a remarkable advantage in comparison to commercial steel springs where a long stroke providing continuous high forces leads to an increase in total length and with this a need for increased spring diameter or additional suspension structure due to potential instability.
- The gas spring stores the energy for the movement within the actuator itself. This has an advantage over other pneumatic actuators in terms of energy per weight ratio because **no additional gas storage** tank is needed.
- A high qualified pressure capability of the actuator leads to a relative high **energy per weight ratio** that can be achieved.
- Gas springs of this type are normally used in airplanes and trucks. Consequently, they have **high heritage** in demanding environment resistance and solidity against vibration.
- The preload (pressurization) can be done in the very last moment before flight in the contracted configuration. All installation work can be done safely without internal forces.

Given the goal for a scalable system and usage of the actuator on different launchers, together with the dependence of actuators location and launchers geometry to the required actuators force and stroke, the gas springs showed during the design development the advantage of being very flexible in application.

<u>Design Description:</u>
In Figure 3 the actuator is shown as a schematic with explanations for the individual parts.

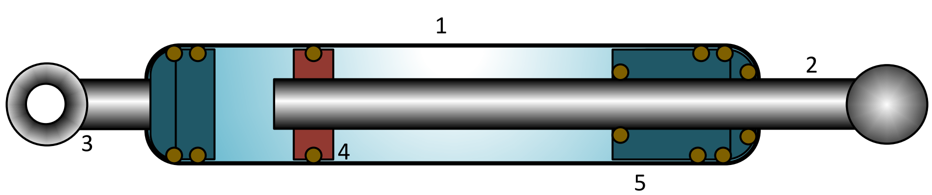

Figure 3. COTS Gas Spring Actuator Schematic

The COTS actuator is composed with the following parts:

1. Cylinder contains the pressurized gas (N2) and guides the piston movement.
2. Piston rod is the moving part of the actuator and defines the stroke. Its diameter defines the active area the pressure acts on for the force. It is covered by a very strong protection against corrosion.
3. Connecting parts are adapted to meet the INTERFACE to the fairing. They are designed to sustain the vibration during launch, to transfer the force during rotation and enable the actuator to stay completely on the fairing after separation.
4. Piston bearing is the small part inside the cylinder that guides the rod and contains a jet, enabling the use of the full cylinder cavity as pressurized volume and allows the control of the movement velocity.
5. Guiding piece that seals the pressure volume and guides, together with the piston adapter, the movable piston rod.

An important difference of the selected gas spring versus other pneumatic actuators is that the full cylinder is used as pressurized volume. The total amount of energy, the piston force and the force reduction over the stroke can be adjusted towards the systems requirement by the ratio between cylinder diameter, influencing the amount of energy, and piston diameter, influencing the force of the actuator.

Depending on these parameters, a force reduction from beginning of stroke to end of stroke of less than 15% can be achieved without increasing the total size of the actuator.

For pressurization a non-flammable, non-explosive and non-toxic gas is needed. For this the inert gas Nitrogen (N_2) is chosen, which meets all these requirements and is easy to purchase.

In collaboration with the supplier, the actuator is tailored to the needs of the project. These adaptions include:

- Material adaptions to meet ECSS standards[2] as coating for the housing and sealing for bearing elements.
- Construction of a pressure inlet valve adapter. The actuator is to be pressurized on launch site, right before launch, enabling easy and save mounting after PLF closure.
- Pressure sensor adapter in order to surveille the pressure processing. The sensor is mainly implemented for this project phase to verify the performance of the actuator. During the vibration and life testing the sensor provided important knowledge about the sealing qualities under external loads and the pressure behavior when exposed to temperature gradients and lifetime tests. As the sensor is also already qualified, the sensor can be used to monitor flight data or be omitted for standard implementation during flight to reduce the mass.

Together with the supplier customization, the interface to the fairing was constructed. They are constructed to fulfill the following requirements:

- The interface has to sustain the internally stored energy for the rotation during all phases before separation
- All vibration loads during launch before separation need to be accommodated by the interface.
- The interface needs to provide to the actuator the required degree of freedom to allow a smooth movement without jamming.
- After PLF separation, the actuator is to be separated from the launcher and gets jettisoned with the PLF.
- The concept needs to be adaptable to different launcher classes.

The interface brackets, designed to fulfill these requirements, comprise two different adapters for the PLF and launcher interface. Whereas on the PLF side an eye bearing provides the needed free moving space but close connection to hold the actuator at the payload shell, a ball joint on the launcher side prevents the actuator from jamming and releases the actuator after the stroke of the actuator has been reached. In Figure 4, the actuator with the interface brackets for the implementation to a PLF is shown.

In addition to the analysis of the bracket’s load sustainability, an analysis has been run showing that the fairing can accommodate the actuator’s loads during launch and separation. A focus has been on the fairing’s deformation caused by the actuator’s force. It has been found that the deformation is negligible for the developed system as clearance towards possible fairing breathing is ensured during the rotation phase before jettison.

The interface brackets have been designed and analysis for a medium launch vehicle. For the qualification campaign, described in the next section, the full set-up, including the interface joints, has been tested.

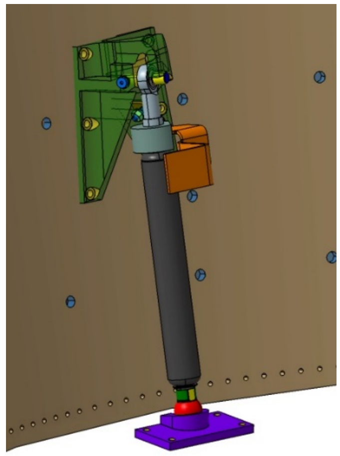

Figure 4: Actuator I/F schematic

<u>Characterization and Qualification:</u>
Using a gas spring as the actuator brings the difficulty of a changing pressure and resulting force with changing temperature. Pressurization needs to be adapted in a way to have the required force at separation, but the actuator needs to sustain a possible high temperature increase. Thus, the characterization and qualification campaign enveloped a broad range of temperatures, for different launcher classes and different missions. This temperature range includes possible low temperatures when the actuators are installed near a cryo stage of the launcher as well as the temperature increase caused by air friction during launch.

The qualification campaign (including lifetime and thermal characterization) has been performed on different COTS actuator sizes, applying full mechanical and thermal loads as per medium launch vehicles PLF qualification requirements. As a result, a fully qualified pneumatic actuator at low mass and broad application possibilities has been found.

<u>Lesson Learned:</u>
One of the lessons from testing is that the material for the sealing is critical in terms of heat capability and sustainability to the vibrations loads during launch. Dedicated testing has been performed to select a suitable material enveloping the range of temperature, the range of pressure and the high vibration load requirements.

Hinges

The hinges guide the PLF during the rotation and provide the kick-off force to jettison the PLF halves. Two hinges are used per PLF half shell to ensure a balanced guidance of the PLF during rotation and enabling separation in the launcher's rotational accelerated cases by avoiding high moments. The hinge's main functions include the following:

- Provide the mechanical interface during the fairing rotation phase.
- Transform the actuators forces to rotational movement of the fairing.
- Guide the fairing during rotation with low friction.
- Accommodate external forces during rotation.
- Disconnect the mechanical connection at a given angle.
- Provide a kick-off energy to jettison the PLF halves ensuring clearance.
- Provide the correct force direction for the kick-off.

The developed solution is a very simple design to ensure passively the release at a given angle providing a kick-off energy to ensure clearance to the launcher. The hinge, in disassembled condition, consists of two parts as visible in Figure 8:

- The **launcher bracket** is attached to the launchers last stage. It includes the bolt for the rotation axis and the protuberances that lock the hinge in closed configuration and counteract the kick-off-spring. This part is fixed on the launchers last stage and cannot be jettisoned with the fairing.
- The **hinge housing** is mounted to the fairing halve-shell and is jettisoned with the PLF. It accommodated the kick-off-spring and the guiding pins, located in the slid of the launcher brackets protuberances in closed configuration.

During launch, the hinge is in 'closed' condition as visible in Figure 8. The geometry provides the separation of the hinge parts and the release of the loaded kick-off-spring. The preloaded spring is accommodated within the hinge housing, pressing against the rotation axle bolt and counteracted by the launcher brackets protuberances.

During the rotation phase, driven by the actuators, the hinge gets tilted into 'open' position. During this movement, the guiding pins slides over the surface of the launcher bracket's guiding protuberances. When the guiding pins reach the end of the launcher brackets protuberance the hinge is 'open'. The geometric constraints are not given any more, the hinge housing is not locked to the launcher bracket anymore, and it gets pitchforked, with the fairing, by the released kick-off-spring system.

Two of the described Hinge systems are installed at each PLF half shell. This avoids moments on the hinges, coming from external forces on the PLF. The alignment of the hinges needs to be adjusted on each fairing type. This can be done in a simple way by building interface brackets to meet the launchers shape within the following geometrical constraints, mainly respective to the alignment of the fairing's rotation axis during the separation event:

- The hinges common rotation axis needs to be outside the launcher's envelope as visible in Figure 5. This is necessary as to avoid jamming or the need of transversal movement before the rotation phase.
- The rotation axis needs to be below the fairing's interface line to the launcher last stage, in order to avoid jamming at horizontal or vertical connection line. The correct placement is also dependent on the geometrical shape of the horizontal and vertical interface line.
- The hinge kick-off-spring force direction is to be aligned with the fairing center of mass. This avoids additional moments introduced by the kick-off and enables optimal use of the kick-off-energy for clearance.

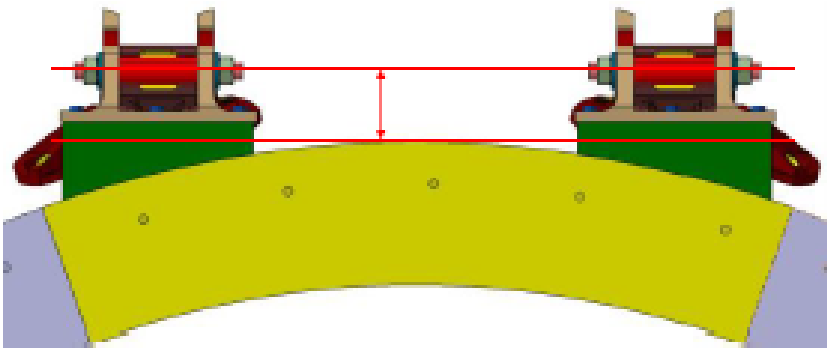

Figure 5: Hinge alignment (1)

In the following section, the development from concept to qualified system is shortly described including research studies and lessons learned.

Development:
In a preliminary development study, the principle of the hinge was developed and a functional verification was run with a modifiable demonstrator model, shown in Figure 6, to prove the concept functionality. The hinge for the demonstration model is designed to have a broad range of adjustable functional parameters as to accommodate different springs and featuring an adaptable spring force and stroke length to vary the kick-off energy. The demonstrator consists of a fairing dummy, down scaled from a large launch vehicle. The dummy was constructed with adaptable mass distribution, in order to simulate possible design changes on the fairing for the new separation system as well as asymmetric mass distribution to assess the robustness of the system by test. Only one hinge has been attached to the demonstrator, allowing to investigate and test occurrence of jamming due to asymmetric actuator force introduction.

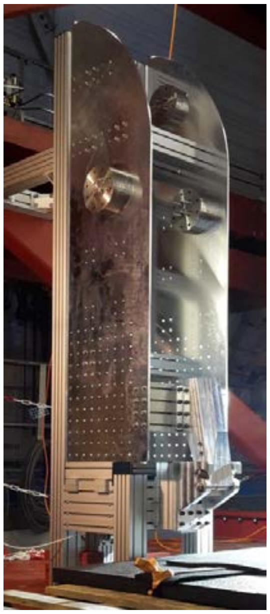

Figure 6: Early stage hinge during concept testing on the demonstrator model

The demonstrator test verified the principle of the system as well as the concept of the hinges. Several test variations in terms of initiated force direction, energy variation of actuator and kick-off-spring were conducted and showed the high robustness for the new jettison system. By varying a broad range of parameters, the concept also proved to be scalable to the use for different launcher classes with low additional work.

Lesson Learned and Research:
Along with the successful verification of the hinge's principle and initial correlation to analysis, those tests showed that an improvement of the tribological behavior of the hinge's gliding surfaces was necessary, i.e., the kick-off plunger to the axle and the suspension to the guiding pin. Consequently, a dedicated trade off and testing campaign was conducted to find a suitable material combination which ensures a low friction and avoids abrasion, jamming or cold welding.

Three different material combinations, including a bearing, were selected by a tradeoff and tested extensively for gliding movement with high forces towards each other. The involved materials for the gliding surfaces are aluminum with Ematal coating and stainless steel. For the counter-acting surface three different materials and corresponding coatings were tested:

- Material 1: Titanium with Dicronite coating
- Material 2: Stainless steel with fiber reinforced plastic composite bearing
- Material 3: Stainless steel with Teflon-filled coating

A hinge dummy has been built simulating the internal loads by the preloaded kick-off-spring and external loads, simulating forces and moments on the hinge caused by the separation actuators and the launchers vertical and rotational acceleration at separation. In Figure 7 the results in terms of friction are presented.

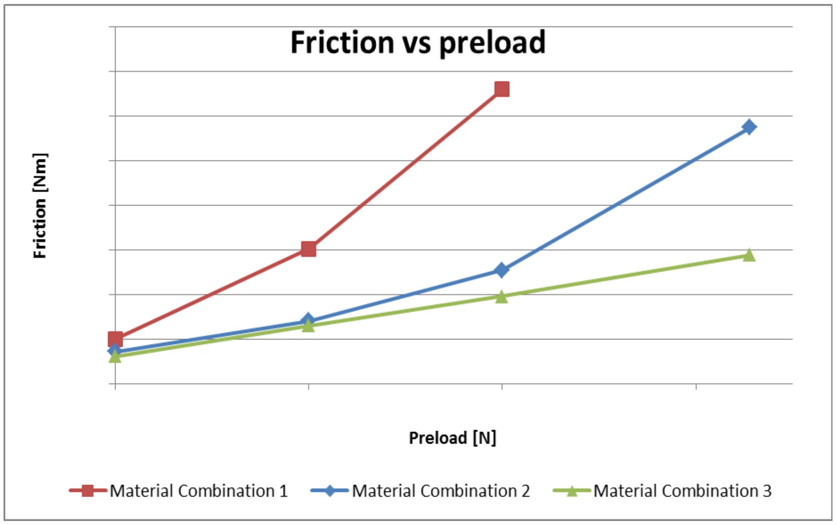

Figure 7: Material Test for the Gliding Surfaces; Test Set-up and Results

Material 1 was discarded due to the high friction increase occurred at high loads. In contrast, both materials 2 and 3 achieved the test success criteria of low friction and wear. Comparing material 2 and 3, combination 2 required additional parts (bearings), making the design more complex. In addition, material 3 also performed to high loads without change of the friction coefficient and no degradation was seen after exhaustive lifetime testing. As a result, the gliding surfaces material selection process was completed by the selection of material 3.

In addition to the material selection, the interfacing geometry of the hinge dummy for the material tests were built similar to the qualification model hinges, including a preceding analysis for the hinge tolerances to ensure that no jamming occurs in the full temperature range due to different material expansion. This allowed preliminary functional tests to verify the concept against jamming in case of lateral or torsional external loads on the hinge dummy set-up, including life-time tests for the material and surfaces.

Subsequently, dedicated flight model hinges were designed, built and tested to qualification loads according to the customer requirements for a middle launch vehicle (MLV) PLF. The campaign included thermal tests, vibration and lifetime. In Figure 8 the fully qualified hinge is shown, mounted on an MLV fairing with dedicated adapter brackets.

The generic layout of the hinge allows the use on several different types of launchers. The only part needing additional design work are the INTERFACE adapter brackets to align with the fairings and upper stage curvature with the above described geometrical constraints. Additionally, the hinge is outlined to be scalable, the size is adaptable to accommodate forces from different launcher classes, if required.

Figure 8: Hinges for MLV PLFs

Full Scale Test

One of the advantages of the system is the possibility to test under ambient conditions without the need to use a vacuum chamber. To verify the functionality and correlation to the analysis, a full-scale separation test on an MLV fairing has been performed. Figure 9 shows the test set-up at RUAG Space premises in Zürich/Switzerland. For this test, the fully qualified mechanisms (hinges and actuators), from the qualification campaigns as described above have been used.

Figure 9: Image of the PLF during rotation of the full-scale test

For several separations runs, tracing the fairings movement with high-speed camera targets and accelerometers at different failure modes and degradation cases, the separation and jettison hinge and actuator system have demonstrated to be a simple and robust system with repeatable and predictable results.

Figure 10 shows the trajectory of the fairing during and after rotation and jettison for several test runs with varying energy. The picture shows the movement of the hinge in radial (y) and gravitational (-x) direction, captured and tracked with a high-speed camera. The movement is robust against the variables that reduce performance of actuators and spring kick-off spring energy and can be adjusted very accurately.

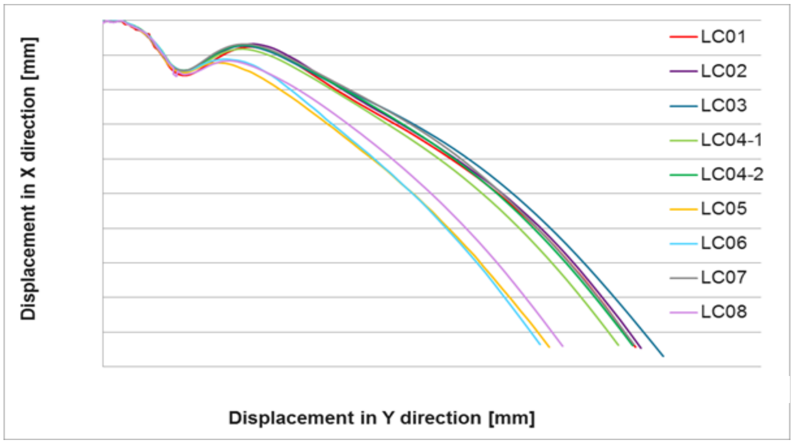

Figure 10: Full scale test trajectory

Each run showed similar rotation behavior, accelerations, trajectory and rotational speed. The test outcome comparison to FEM prediction results showed good correlation, considering the prediction of the effect of air resistance.

Besides the repeatability and good FEM correlation of the rotation and jettison system, the methodology and procedure to test in ambient air by tracking the trajectory and accelerations has proven to be a reliable methodology to verify the system for future separation tests on different launchers.

Conclusion

This paper summarizes the activities carried out by RUAG Space within the Future Launchers Preparatory Programme – separation and jettison project. In the frame of this project, a low-shock jettison system has been developed based on the functional principle of a rotation, disengagement and jettison by means of passive gas springs actuators and spring loaded hinges. Qualification models of the mechanisms have been built and qualification testing has been successfully completed on component level and on system level in a full-scale test (TRL 6). An extensive test campaign was carried out to verify the suitability and prove the advantages of the newly developed technologies with regards to simplicity and verification efforts. Additionally, a full-scale test has been successfully conducted for the validation of the separation analysis model proven functionality of the technologies developed. Overall, the test results are proving the functionality of the new jettison system.

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References

1. European Space Agency, 2012. ARIANE 5 fairing separation system undergoes testing. http://www.esa.int/spaceinimages/Images/2012/06/After_separation2 (accessed 28.01.2020)
2. ESA Standards: ECSS-Q-ST-70C rev2: Materials, mechanical parts and processes
3. Sanchez A., Halter B., Gerngross T., RUAG's development of a modular low-shock jettison system, *International Astronautic Conference IAC-19*, October 2019, Washington, USA
4. Caldirola L., Schmid B., Cattaneo M., Schiaffini A., 2017. Test HDRM" development for separation performance verification.. In *European Space Mechanisms and Tribology Symposium.*
5. Arianespace, 2014. VEGA User's manual issue 4. Online, available in http://www.arianespace.com/wp-content/uploads/2015/09/Vega-Users-Manual_Issue-04_April-2014.pdf (accessed on the 04.06.2019).