MULTIPLE HOLD DOWN SEPARATION DEVICE FOR DISPENSERS (MSD)

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1. ABSTRACT

Airbus Defence and Space Madrid has developed and qualified a reliable mechanism that allows to release simultaneously the four hold-downs using a single actuator, reducing by a factor of 4 the number of actuators, harness and electronic equipment needed at the launcher side and without adding fly-away mass to the minisatellites deployed.

The shock induced during the separation is reduced by the use of a non-explosive actuator placed far from the minisatellites interface. The longer actuation time of this kind of non-explosive devices is not inducing any delay or tip-off at separation as the separation of the four hold-down is mechanically synchronized.

The presented mechanism was successfully flown since 2022.

2. INTRODUCTION

The minisatellite is expected to remain the largest and fastest-growing segment of the market during the next years. Minisatellites are satellites weighing between 201-500kg. These satellites are primarily employed for communication and broadband internet services and are built based on simple platforms joined to the launcher by means of four discrete points named hold-downs providing the connection stiffness during flight and the separation upon a release command.

Each dispenser could carry about 40 minisatellites per flight resulting in 4x40 hold-downs. Each hold down and release mechanism is activated by one dedicated actuator close to the spacecraft interface, resulting in hundreds of actuators per dispenser being needed a complex system of harness, sequencers and batteries at the dispenser to synchronize the deployment of all the satellites of the mission. The separation of these discrete hold downs generates a high shock during the separation due to the rapid release of the preload close to the spacecraft interface.

There are methods to reduce the shock by slowing down the release of the preload but increasing the activation time and its dispersion, penalizing the simultaneous separation of the four points. This simultaneous separation is highly desired so that the distancing system usually formed by springs can eject the spacecraft with the minimum angular velocity minimizing the risk of collision of all the spacecraft during the separation.

In this kind of dispensers for large constellations the launcher has to be prepared to manage a big amount of separation signals. The initiation system could limit the number of separation in some cases. In other cases the launcher has to install very expensive controller systems on the dispenser, converters and harness to manage the separations penalizing the cost.

Accordingly, there is a need to provide a multiple hold down and separation device for dispensers presented in this paper (named MSD) that reduces the output shock, reduces the number of pyrotechnic devices and therefore the cost, improves the simultaneous release of the discrete points, minimizing the risk of collision during the separation without adding flyaway mass to the spacecraft after the separation. In addition, this mechanism can be easily tested many times on ground improving the reliability of the design.

3. MSD DETAILED DESCRIPTION

The working principle of the MSD is based on preloading a cup-cone by means of a lever, instead of by means of traction on a release bolt. This preload is inferred by a central element that pushes all the levers together. When this central element is released upon command, all the levers simultaneously retract from their stowed position to a stored one, allowing the separation of the S/C deployable brackets.

The main assemblies that compose the MSD are:

- Central star assembly, in charge of maintaining the preload of the 4 HRM together during launch, and therefore releasing it at once. This structure is kept closed by the central actuator. After activation, this structure opens thanks to its own elastic energy and parked in the deployed position by a central spring.

- Hold-Downs & Release mechanisms, containing a deployable bracket which is preloaded against a fixed one on the dispenser by means of a release lever.

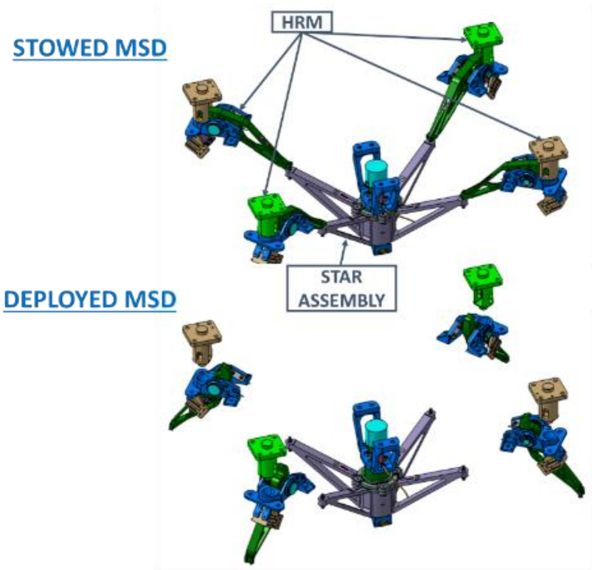

Figure 1. MSD stowed & deployed

Preload of this cup-cone contact is multiplied thanks to the law of the lever:

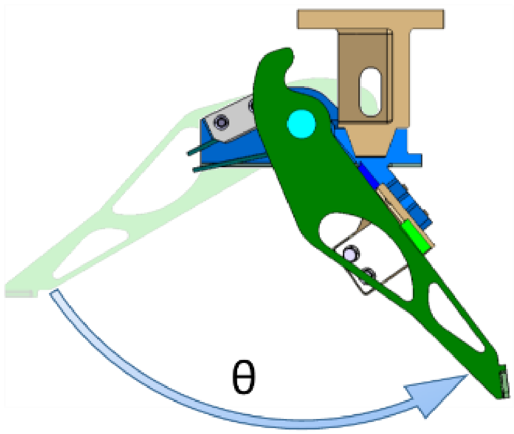

Figure 2. HRM preloaded & released

After the release order, the central star moves axially allowing the levers to rotate unloading the cup-cone contact.

The mechanism can be configured to be assembled with the separation system and the umbilical connector on a Spacecraft Adaptor Frame as an option to ease the AIT activities.

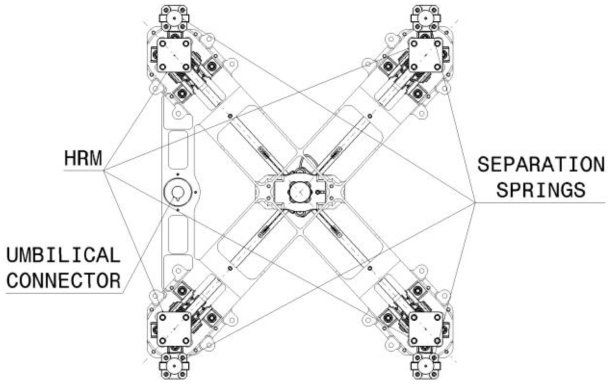

Figure 3. MSD on a Spacecraft Adaptor Frame

The MSD is capable to be adapted to diverse patterns of HRM with minimum efforts: keeping the design of the HRMs and only modifying the central star to provide the interface.

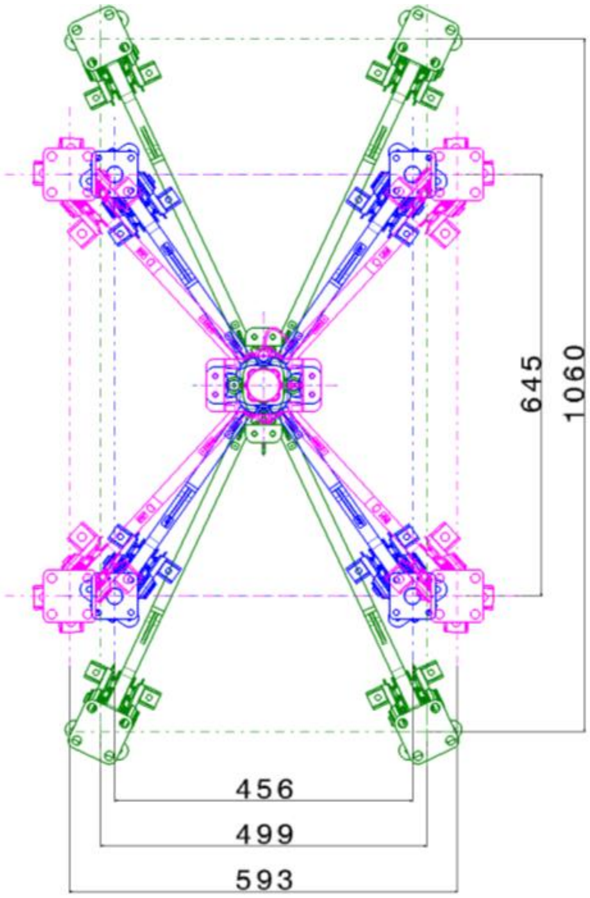

Figure 4. Several MSD I/F patterns

All the parts of the MSD remains at the dispenser side after separation without mass to the spacecraft:

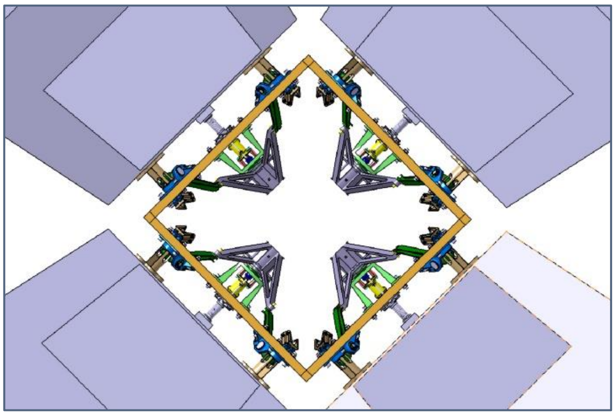

Figure 5. *Dispenser top view before separation*

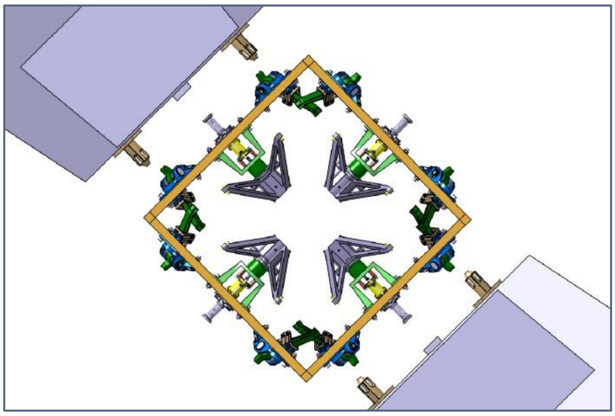

Figure 6. *Dispenser top view after separation*

AIT requirements were object of critical study during the MSD development. Its functionalities and integration flow has been conceived to reduce the intervention at S/C level, so as to minimize the risks for AIT personnel:

Installation and preloading: The mechanism can

- be easily installed and preloaded on the dispenser between 2 operators. Its preload can be monitored all over the operative life until launch, to check the health of the system.
- Refurbishment: No need to dismantle the HRM to refurbish and rearm the mechanism. Therefore there will be no loss of the S/C & dispenser I/F alignment, after on-ground firing.

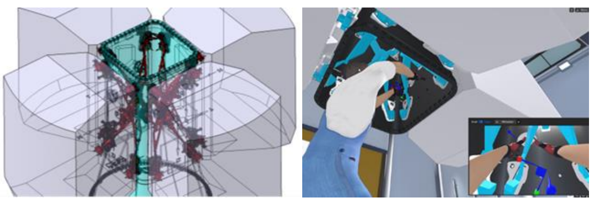

Figure 7&8. MSD preloading VR assessment

4. REQUIREMENTS

The design of the MSD is constrained by the usual technical requirements applicable to separation systems plus a couple of new very challenging ones:

- Exported shock reduction (< 500g)
- Reduction of actuators (large constellation deploy concern)
- Simultaneity in the release of each HRM.
- Negligible lateral impulse and tip of rates
- Small and medium size satellites (50-400Kg)
- Valid for several spacecraft platforms with minimum modifications: Airbus S150 (645x456mm rectangle), S250 (1060x499mm), Arrow (645x593mm), Falcon9 Rideshare (circular pattern Ø24")

5. TECHNICAL APPROACH

The critical requirement which is the driver of the design is the exported shock. Other hold down systems commonly used in space industry exports shock levels from 1000 to 3000g (SRS peak) due to the use of pyrotechnics actuators and the proximity of them to the payload I/F. To solve this issue, a non-explosive actuator is needed. The problem of this type of actuators is the "long" actuating time and the possibility of delay between the HRMs, when combined with the springs forces would cause tip off rates during the spacecraft separation. The solution of that is to synchronize the deployment of each hold down with the others by means of using a single actuator mechanically linked to all the HRMs. This solution is totally compatible with the requirement of reduction on the number of actuators needed for each satellite.

The technical solution for this point is to place the NEA on a central position and to connect the hold downs to this point by a structure which is also used to maintain the preload on each hold down.

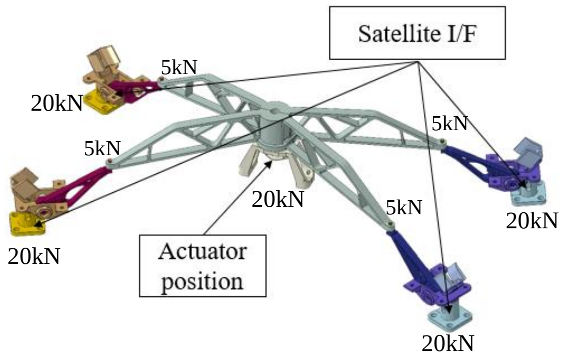

Figure 9. Technical solution. Example of preload distribution

To optimize these structures a cantilever-lever system was selected. The lever reduces the needed force for the hold down preload by 4. Them, the central structure applies this force and react it at the central point so, at the end, the actuator is subjected at the same preload than one hold down.

As a result of the use of only one NEA placed at the centre of all hold downs (away of the satellite interfaces) it is reduced even more the exported shock (already reduced by the use of a non-explosive actuator).

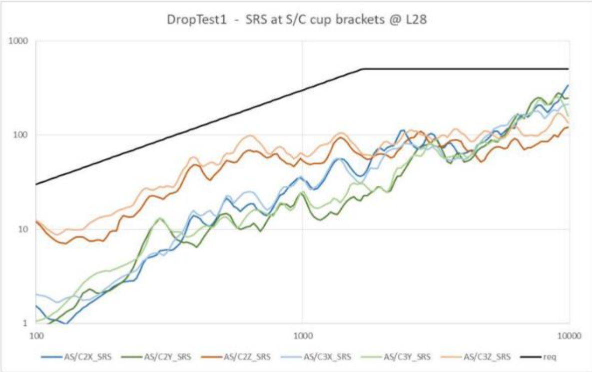

Figure 10. Exported shock

The final structural solution was selected after a total optimization loop. This topological optimization was made by a linear Finite element model with the specimen at preload state where the loads are maximum.

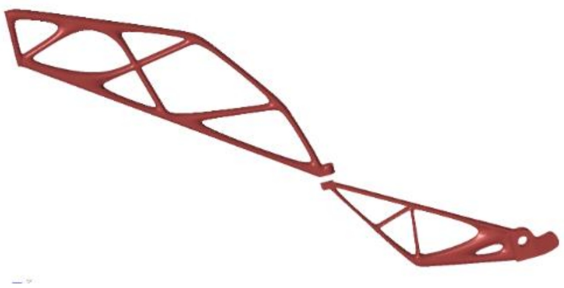

Figure 11. Optimization result example

After the preliminary definition of all the parts, a detailed non-linear model was performed to ensure the feasibility of the design for the steps:

- Preload of hold downs
- Flight phases load environment
- Deploy and parking

In all these phases, the non-linear effects are non-negligible so the FEM has to be enough detailed to capture all quasi-static load effects , sliding and gapping points for define critical loads and minimum preloads, and the most challenging one: the dynamic behaviour of all assembly to ensure a correct deployment of the payload.

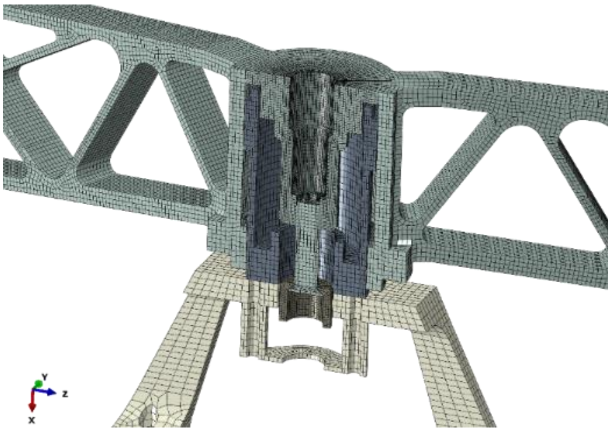

Figure 12. S250 detailed FEM cut

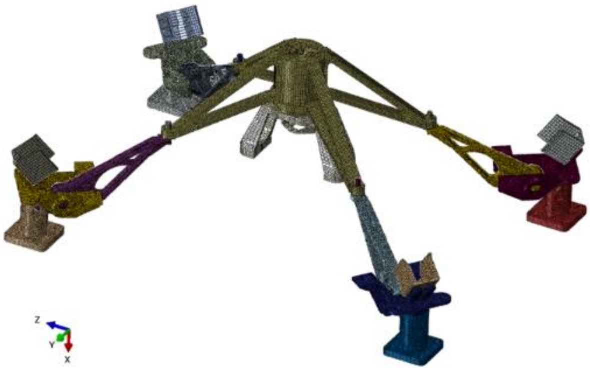

Figure 13 S150 I/F FEM general view

The preload of the hold downs was selected to avoid the sliding at maximum loads and taking into account the friction dispersion.

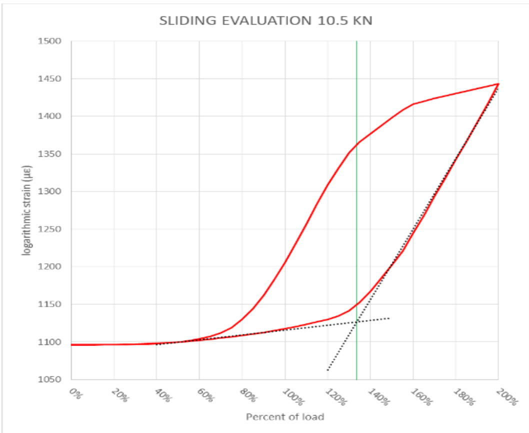

Figure 14. Example of sliding curve

Strength analysis was done by using the same non-linear approach. It is considered the critical load cases combinations plus the minimum and maximum preloads of the structure.

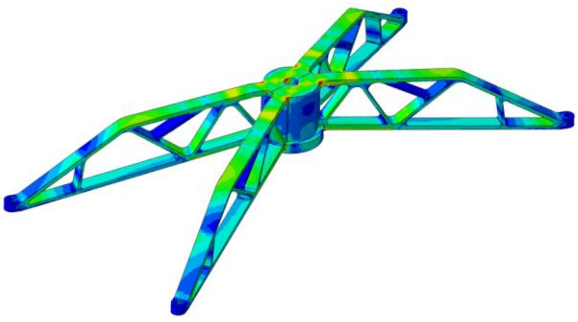

Figure 15. S250 I/F Example of Strength Analysis

The dynamic analysis of the deployment was used to define all parts involved on this step like slides, axis, stoppers and catchers.

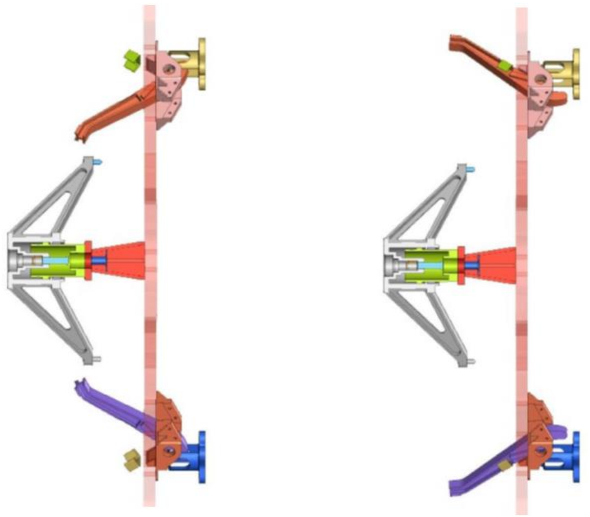

Figure 16 *MSD Release Analysis*

6. QUALIFICATION AND PERFORMANCE

MSD has been qualified according to the launcher specification, and adding the qualification margins specified in the ECSS.

On some test (e.g. vibration), the levels specified were well increased with their own margins, obtaining a very demanding environment in which the MSD demonstrated a perfect functionality and a glimpse of the great grown potential for further heavier missions than the ones foreseen during the development phase.

As said, the qualification covered the worst possible conditions that could occur during flight, and the MSD was submitted to the following tests:

Static Load Test

This test reproduced the loads (axial and lateral) specified by the launcher. The loads are applied on the S/C centre of gravity by mean of hydraulic jacks “Fig-17”.

This induced local loads on the MSD attachment points, have to be withstood by the MSD preload in order to avoid any separation of the cones.

Prior to this test, the minimum tension of the MSD was obtained by analysis.

The main aim of the static test was to prove that the MSD could withstand the loads (it was introduced up to 1.4 times the flight load) but the other main objective was to correlate the analysis prediction, which gives more confident to the simulation for further analysis.

The correlation can be achieved by monitoring strain gages on the structure and displacement transducers placed to measure the relative displacement between S/C dummy and MSD plate:

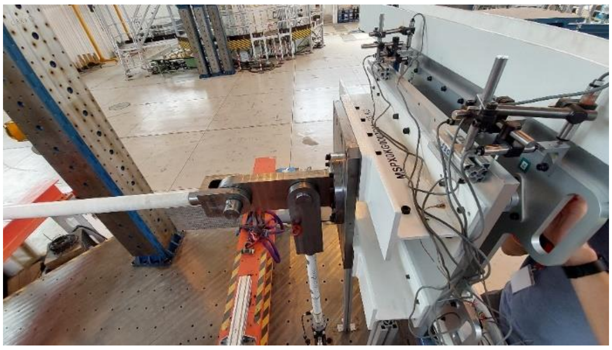

Figure 17. Static test set-up

It was confirmed during the test that the MSD can withstand a load of 14kN axial and 6.1kN lateral on each hold down -for the Airbus S150 platform- and 6.6kN axial and 6.1kN lateral -for the S250- without separation or degradation. After the test, the MSD was nominally released by activating the NEA to demonstrate the proper functionality after being submitted to the flight loads.

Thermal Vacuum Test

The behaviour under thermal vacuum is one of the main concerns for demonstrating the specimen functionality, as it demonstrates not only the good behaviour in extreme temperatures, but also that there is no degradation of the properties after several thermal cycles and in vacuum.

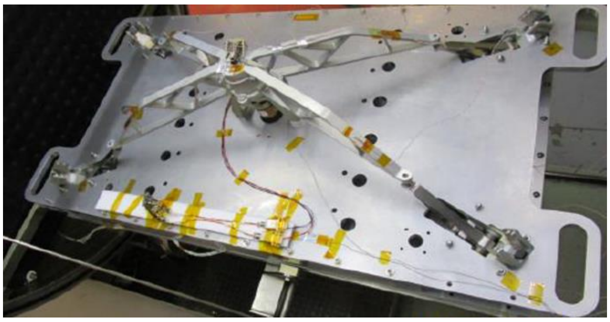

Figure 18. TVC Set-up

For this test, the MSD was submitted to cycles between –20ºC and +70ºC and finally to the extreme temperatures of –40ºC and +120ºC. These temperatures were held during 2h in order to stabilize the temperature among all the specimen. Once stabilized, the MSD was released to ensure the functionality (one release at each temperature):

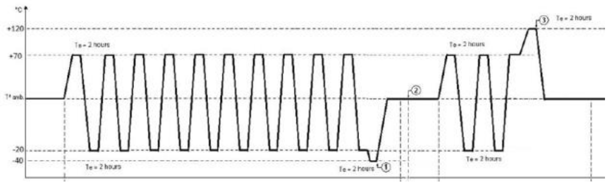

Figure 19. TVC cycles

Random and Sine Vibration Test

In this test it was required a very demanding level: it was submitted to 20.2GRMS on 3 axis during 4 minutes each one without losing any of its performances.

Before performing the functional release, it was also tested on sine vibration up to 2000Hz, reaching up to 22.5g.

This test was hard to performed, as the MSD had to be tested with auxiliary GSE representing the adaptor plate in which it has to be installed for flight “Fig-20”.

As this GSE has its own modes, which are not representative for flight, the test had to be notched, controlling on time any part of the specimen

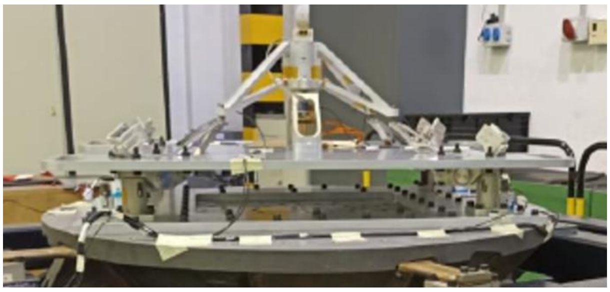

Figure 20. Vibration Set-up

Functional test

The last part of the qualification campaign was to record the opening and release of the S/C with high speed video cameras. This allowed to verify that the performances of the MSD have not been affected during the whole qualification campaign, and also to determine the good simultaneous release of the 4 S/C attachment points.

For this propose, two cameras were placed on the MSD axis “Fig-21”. The MSD was attached on a test structure simulating the launcher, and the S/C was represented by a plate with trackers on it to record the kinematics after the release.

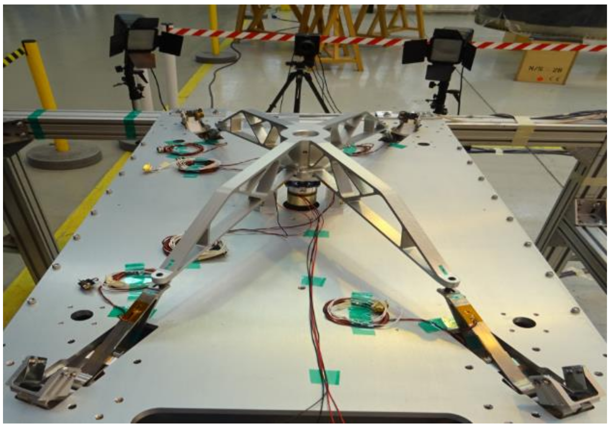

Figure 21. Functional Set-up

During the release “Fig-22”, it can be observed the perfect simultaneous release of the levers, freeing the 4 points of the S/C at the same time.

Due to this, it is induced a negligible lateral perturbation on the S/C, achieving a minimal tip-off rate induced by the separation system which otherwise it is always a concern on discrete release mechanisms.

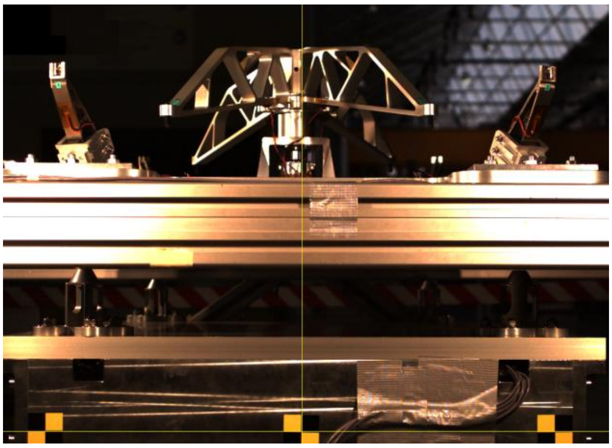

Figure 22. S/C dummy drop

The other main aim for this test, was to qualify the shock induced to the S/C during the release. Several accelerometers were placed on the S/C dummy plate for this purpose, measuring a maximum SRS shock below 400g.

7. HERITAGE

During the qualification phase, the specimen was prepared to fit an Airbus S250 S/C platform. Nevertheless, an opportunity came with the support for the ONEWEB constellation, whose platform is S150 type.

Then a delta qualification was performed.

Before the MSD maiden launch, the MSD was also tested up to its limits, performing several test simulating degraded installation conditions such as tensioning two or three levers at its maximum tension while the opposite one up to its minimum.

In spite of such an odd installations, none of this conditions had finally any impact on the MSD functionality, keeping the simultaneity of the four HRM release and increasing even more the confidence on the reliability.

On 9th Dec 2022, the first batch of 40 MSD flew on a Falcon-9 rocket, rewarding some spectacular pictures as the following one:

Figure 23. MSD on Falcon-9

Up to the redaction of this paper, 136 units have flown, and several others are being manufactured for different customers. Depending on the customer needs, the fixation of the MSD to the launch can be tailored installing one or several MSD per dispenser.

8. CONCLUSIONS

Airbus Defence and Space Madrid has developed and qualified a reliable mechanism that allows to release simultaneously the four hold-downs using a single actuator.

This mechanisms brings important advantages both for the spacecraft and launcher sides.

Advantages for the launcher:

- Reduce by a factor of 4 the number of actuators, harness and electronic equipment needed.
- Easy installation.

Advantages for the spacecraft:

- Low shock: the shock induced during the separation is reduced by the use of a non-explosive actuator placed far from the minisatellites interface.
- Low tip-off rates at separation: the separation of the four hold-down is mechanically synchronized. No delay is appreciated in the opening of the four points.

The presented mechanism was successfully flown. Today current flight heritage is 136 units.

9. FUTURE WORK

As future work, the MSD is currently being adapted for other spacecraft platforms.

MSD can be used as the separation system for platform S150 to fly on Falcon9 Rideshare:

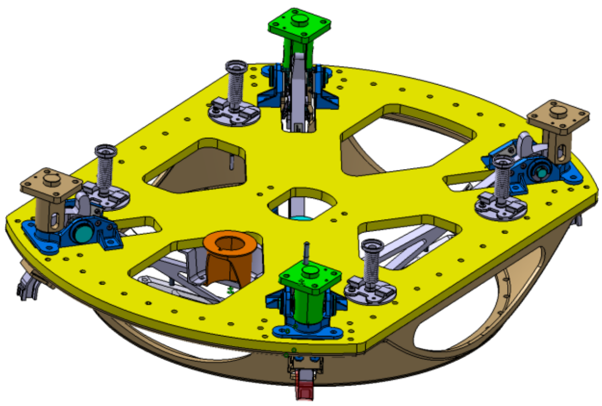

Figure 24. MSD for Falcon9 Rideshare: Spacecraft I/F S150, launcher I/F: Ø24inch circular bolted I/F