# SEPARATION MECHANISMS AND RELEASE/MOTION ANALYSIS FOR EXOMARS 2016


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## ABSTRACT

The first mission of the ExoMars programme (ESA) scheduled to arrive at Mars in 2016, includes an Entry, Descent and Landing Demonstrator Module (EDM).

The thermal shields that protect the EDM need to be released with a high degree of reliability before reaching the Martian Surface. Therefore, the performance of the EDM separation devices is crucial for the success of the mission and a key point for ESA's contribution to subsequent missions to Mars.

SENER, with TAS-I as Prime Contractor, is responsible for several structures and mechanisms which are part of the EDM. This paper is focused on the separation mechanisms; in particular, the Front Shield Separation Mechanisms (FSSM) and the Surface Platform Separation Mechanisms (SPSM).


## 1. INTRODUCTION

The EDM descent & separation sequence is shown in Fig. 1. The FSSM allows ejecting the Front Shield and the SPSM allows ejecting the Back Shell.


*Figure 1. EDM descent & separation sequence (ESA credit: http://exploration.esa.int/science-e-media/img/e8/EDM_Descent_p2.jpg)*

Both the FSSM and the SPSM consist of six units whose main function is to provide mechanical and electrical interface between the lander and the thermal shields until the separation phases take place. Each unit is basically composed of two brackets that maintain the separating bodies in position. After the command signal, the links are released by a pyrotechnical nut and the bodies immediately jettisoned by a set of springs.

Developing a tool to validate the design of a separation device is often a challenging task. Not only is it important to focus on the structural behaviour and the performance of the unit itself but also on how it affects to the separating bodies. In fact, the disturbances introduced on the bodies due to the jettison are to be carefully investigated to avoid potential unbalance, undesired kinematic effects, etc. With this purpose, a set of mathematical models are produced to simulate a large amount of separation scenarios and their consequences.

In addition to the mathematical simulations, a full scale test campaign is on-going to validate the performance of the SPSM and the FSSM. This campaign includes different tests at unit level and at assembly level, among which a set of functional tests are included to demonstrate the capability of the devices to perform safe releases. With the Qualification of the separation mechanisms, the design, analysis and test activities will be finished.

To summarise, design effectiveness and reliability is achieved through the following activities described in the paper:

- Development of a C++/Matlab/Simulink mathematical model reproducing the effect of every variable affecting the separation kinematics and dynamics.
- Running a Multivariate MonteCarlo analysis campaign to cover the potential uncertainties of the parameters involved and all the possible separation scenarios. Unlike the usual deterministic analyses considered in the frame of release systems, the paper introduces the novelty of using a statistical approach based on randomly generated cases.
- Evaluation of the structural features of the design by means of a MSC.Nastran FEM model.


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- Design qualification by means of two Full Scale Test Campaigns, one for the FSSM and another one for the SPSM, under flight representative conditions. The results from a correlation campaign are also presented in the paper to give evidence of how the analytical model represents Reality with a high degree of similarity.
- Development of a MSC.Dytran mathematical model to support the predictions of the test results.

Details on the Design, Analysis and Tests carried out to qualify the units of the FSSM and SPSM are provided in paragraphs 3, 4 & 5.

## 2. REQUIREMENTS

Obviously, the design, analysis and test of both FSSM and SPSM are driven by a large amount of constraints and requirements. Paragraphs 2.1 and 2.2 provide the most significant ones.

### 2.1. Design Requirements

Apart from the specific design constraints such as Interfaces, External Envelope, Layout, Tribological Design, Actuation Parameters, Mass Properties, etc. the most representative ones are provided as follows.

- Accessibility: The mechanisms provide the necessary access to handle, actuate, substitute, etc. the operative parts of the device without removing any other surrounding equipment.
- Motorisation Margin: The mechanisms provide a total motorisation force which is able to overcome the specified overall external and internal resistive effects, considering the uncertainty and motorisation factors usually required for European Space Projects.
- Redundancy: achieved in both FSSM and SPSM thanks to the implementation of redundant springs and redundant electrical initiators with separate power supply lines.
- Electrical Disconnection: Both the FSSM and the SPSM isolate electrically the bodies through the demating of a set of the umbilical connectors.
- Misalignments and Movement Allowance: The design of the separation mechanisms is compatible with the linear and angular misalignments allowed by the umbilical connectors.
- Release Operation: The jettisoning of the bodies is compatible with a potential delay of 5ms in the firing of the pyronut initiators.
- Shock Level: In the case of the SPSM mechanisms, which are located very close to delicate equipment, the actuation of the active parts does not induce a shock level higher than 1200g. To achieve this level, ultralow-shock pyronuts are implemented in the design.
- Separation Disturbance: Some constraints are applied to the velocity variation. In particular, the axial velocity, the lateral velocity, the ratio of them and the angular rate must not exceed certain values that are verified by analysis and test.

### 2.2. Performance Requirements

The main performance requirements applicable to the mechanisms are:

- To provide an adequate structural behaviour in terms of stiffness and strength.
- To guarantee a high degree of reliability in extreme environmental conditions.
  - Temperature: -65/+75ºC (FSSM) and -55/+75ºC (SPSM)
  - Vacuum: $1,33.10^{-5}$ mbar
- To provide compatibility with a Dry Heat Microbial Reduction (DHMR) sterilization process:
  - Absolute Humidity: < 1.2 g/m$^3$ water
  - Time/temperature: 32 hours / 110°C (FSSM) and 6 hours / 125°C (SPSM)
- To overcome all the external resistive forces, such as electrical connector demating friction force, aerodynamic drag, biosealing sticking load, etc.
- To ensure that the separation is produced minimizing the effects on final attitude and angular velocity.
- To minimize acceleration environment produced as a consequence of the pyrotechnical device induced shock.

## 3. DESIGN DESCRIPTION

The descent module consists mainly of three subassemblies: the Surface Platform (SP) which includes six separation mechanisms (SPSM), the Front Shield (FS) and the Back Shell (BS). The link between FS and BS is performed by another six separation mechanisms (FSSM). Both shields are consecutively jettisoned from the Surface Platform by means of the FSSM and SPSM.

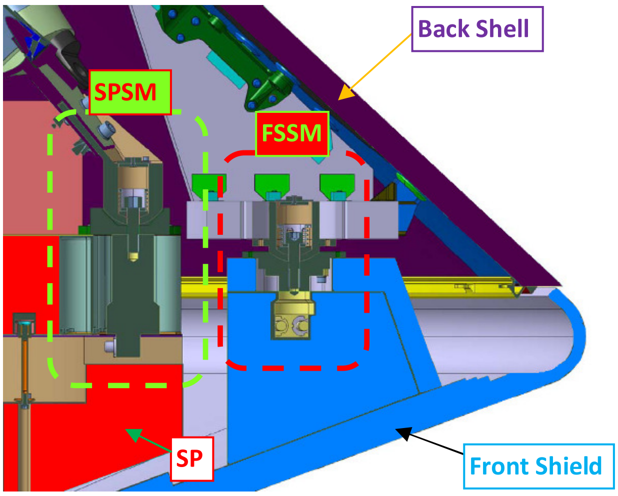


*Figure 2. EDM Front-shield and Back-shell separation mechanisms (FSSM and SPSM)*

As previously stated, the separation mechanisms allow disconnecting electrically and jettisoning the thermal shields by means of a pyronut and a set of preloaded compression springs. The design concepts of both the FSSM and the SPSM are analogous. Although the interfaces and the overall sizing of the units obviously are not the same, they share the main design drivers.

While the six mechanisms (from either FSSM or SPSM) provide stiff mechanical interfaces, only three of them provide also electrical interface. That is to say, there are two types of mechanisms depending on whether or not they accommodate the connectors:

- Type 1: Mechanisms without umbilical connectors. The only active part of these mechanisms is the pyronut that releases the corresponding pyro-bolt during the separation.
- Type 2: Mechanisms with umbilical connectors. These mechanisms include the corresponding pyro-nut and the separation springs that make possible the demating of the electrical umbilical connectors.

Fig. 3 presents the arrangements of both types of mechanisms (both FSSM and SPSM layouts superposed).

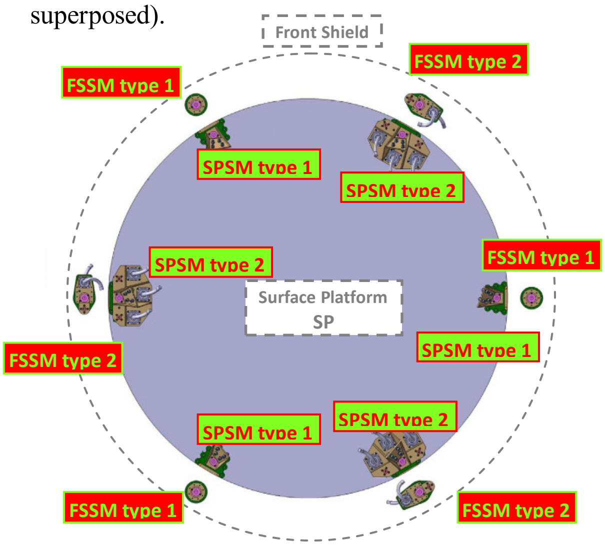


*Figure 3. EDM Front-shield and Back-shell separation mechanisms (FSSM and SPSM)*

### 3.1. Front Shield Separation Mechanism (FSSM)

The FSSM mechanisms are composed of two high resistance aluminium brackets which are preloaded one against the other by means of a bolt and a pyrotechnical nut. One of the brackets is rigidly attached to the thermal shield and the other one to the Backshell. The separation start is controlled by the ignition of the pyronut, which is required to be as quick as possible to minimise unbalance. Fig. 4 shows both FSSM types (the umbilical connector is not shown in the picture).

*Figure 4. Front Shield Separation Mechanism (FSSM) type 1 (left) and type 2 (right)*

The FSSM active side is placed in the Front Shield and consequently the separation nut is mounted on the bracket of that side. The preload between both brackets is applied through an intermediate plastic pad by a titanium fastener (pyro bolt) bolted to the separation nut.

The separation springs of each type 2 mechanism are mounted and compressed in the upper bracket before applying the preload. The nodes include two springs for redundancy purposes. The springs are accommodated one inside the other to reduce the mass and volume of the brackets. Each separation spring is sized to provide the load needed for the separation at mechanism level. This implies that only three springs, one per mechanism, could produce the separation.

Once the pyrobolt is released, the separation springs push the FSSM brackets in opposite directions in order to demate the umbilical connectors.

### 3.2. Surface Platform Separation Mechanism (SPSM)

The design of the SPSM is analogous to the one of the FSSM; therefore, most of what has been described for the FSSM is valid for the SPSM. The main reason for the differences between them is that the interfaces in both cases are different and that the SPSM type 2 mechanisms accommodate two umbilical connectors and concentric springs (while the FSSM type 2 mechanisms include only one umbilical connector and one pair of springs).

*Figure 5. SPSM, type 1 (left) and type 2 (right)*

In the case of the SPSM, the upper body (Back Shell) is attached to the mechanisms by means of a relatively flexible interface composed of 12 struts. The flexibility of these bars could introduce potential disturbances during jettisoning and could produce relative displacements (linear and angular) over the allowable tolerances of the umbilical connectors. Thus, a guiding system is implemented in the design to prevent jamming or locking during the disconnection of the umbilical connectors.

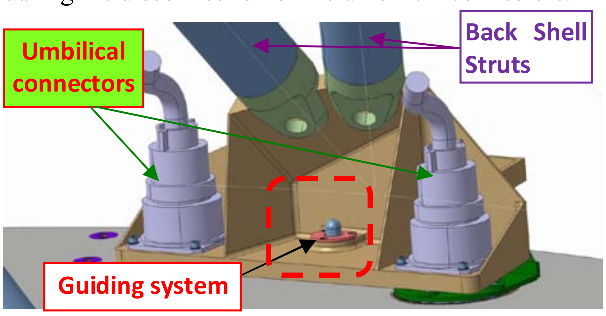


*Figure 6. SPSM type 2, detail of the guiding system*

Taking into account the shock limits of sensitive electronic components mounted on the Surface Platform, the pyronut is selected from the ultra-low shock nut series.

## 4. ANALYSES

Four different tools have been used to design and verify the proper performance of the separation mechanisms. A brief explanation of each is provided as follows:

- Patran / Nastran: Structural software is used to size the parts forming the mechanisms and to determine their stiffness and natural vibration modes.
- Dytran: Dedicated dynamic simulations of the functional separation tests are performed with Dytran software. The purpose of these simulations is to predict the behaviour the test jigs and test article will have during the tests.
- Matlab/Simulink: A MonteCarlo Analysis is performed to calculate all the possible combinations of variables, to generate a distributed spectrum of separation cases and to identify the more critical scenarios with a high level of confidence.
- C++ model: A simplified model, built in C++ language, is validated with the one built in Simulink. This model permits being implemented in higher level functional models to generate simplified separation cases.

This paper will only focus on the statistical simulations performed with Matlab/Simulink.

### 4.1. MonteCarlo Analysis

The analysis consists of reproducing a large amount of possible separation cases –randomly generated– and evaluating their outcomes from a statistical point of view. Some rationale is summarised as follows:

- Inputs: The inputs considered in the analysis are the geometric and mass parameters of the bodies, the initial state vectors, the internal and external forces, etc. Each significant variable is approximated to a statistical function whose mean value is the nominal value of the parameter and the shape of the function depends on the nature of the parameter itself.
- Random Number Generation: All the parameters involved in the calculation are considered on statistical base. Uniform and Gaussian random distributions are used depending on the type of parameter. Gaussian variables are assumed to be distributed with a probability of success higher than 99.7% (3$\sigma$ conditions).
  Taking into account that the parameters are usually specified in a range between two values, the statistical distributions are defined based on them. With that purpose, all the density functions and hence their statistical parameters (mean and standard deviation) are obtained from the boundary limits of each variable.

Sometimes, a group of inputs maintain a geometrical relationship as in the case of the initial attitude and initial angular rate, which are specified to be linked through an elliptical association (see Fig.7).

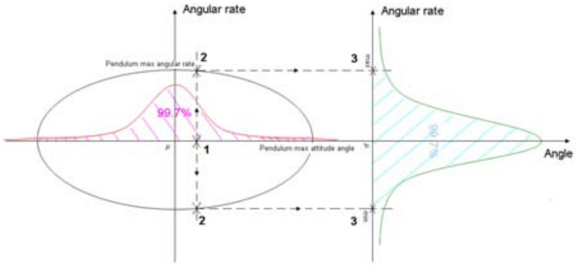


*Figure 7. Random Generation with Parameter Relationship*

Sometimes, different kinds of statistical distributions are mixed to fulfil different requirements at the same time. For instance, the friction force profiles of the umbilical connectors have to meet different requirements at unit level and at assembly level (see Fig. 8).

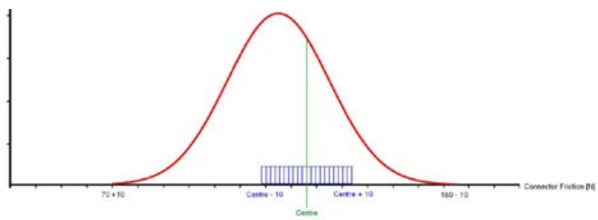

*Figure 8. Superimposing Different Kind of Distributions*

In the consecutive iterations, a set of Matlab routines generate the random values from each Uniform/Gaussian variable and assign them to the corresponding parameters. Basically:

$$N_{uniform} = a + (b-a) * rand$$
$$N_{gaussian} = \mu + \sigma * randn, \qquad (1)$$

*N → Random value belonging to the distribution*
*a → Uniform Distribution Lower Limit*
*b → Uniform Distribution Upper Limit*
*Rand → Matlab function which gives, as a result, uniform random numbers between 0 and 1.*
*μ → Mean*
*σ → Standard Deviation*
*Randn → Matlab function which gives, as a result, random numbers included in a normal (Gaussian) distribution of mean 0 and standard deviation 1.*

- Model: The calculations are performed by means of Matlab 2012 and SimMechanics toolbox on Simulink. The model is run in "forward dynamics mode" which provides the kinematics of the bodies involved in the analysis as a result of their initial cinematic/dynamic state. Fig. 9 presents an overall view of the mathematical model which shows the main relationships and constraints between the two separating bodies (two large blocks in the picture).

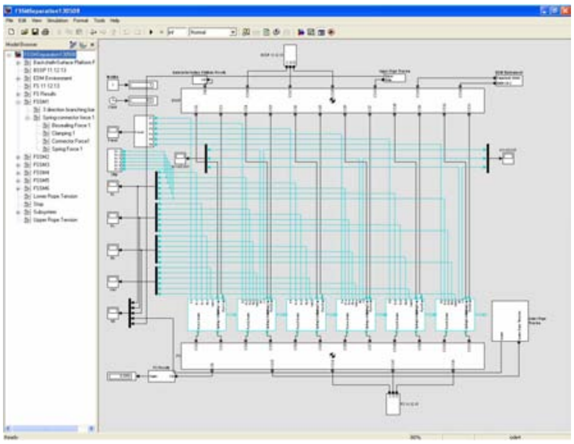

Figure 9. Separation Simulink Model

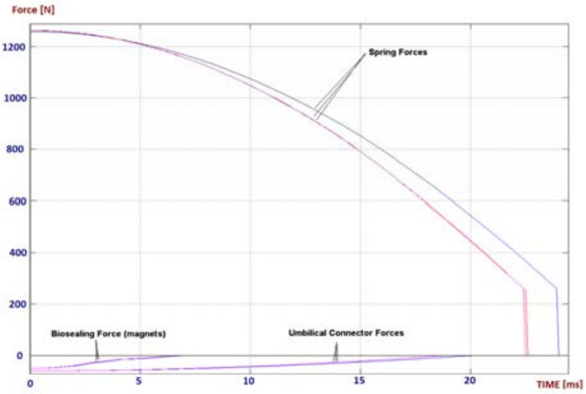


Figure 10. Example of external forces applied on the bodies along time

- Iterations: The simulation is based on several thousand iterations which run the above process to generate result cases. It is interesting to identify potential correlation between the different outputs, so that some result patterns can be inferred.
- Simulation: Both separating bodies (FS/BS+SP or SP/BS) are simulated as rigid bodies with some internal constraints (hold-down, separation springs, umbilical connectors, guiding devices if any, etc.) and some external boundary conditions (parachute pull, biosealing, aerodynamic drag, etc.) applied on them.

  It is to be taken into account that the problem is considered in 3D and every force and parameters of interest are to be applied on their corresponding application point. Therefore, the model solves iteratively the equation of motion for a non-viscous multidegree-of-freedom system (integrated in SimMechanics toolbox):

$$[M]\{\ddot{x}(t)\}+[K]\{x(t)\}=\{F(t)\} \quad (2)$$

- End Simulation Condition: The simulation stops once the two separating bodies are no longer in contact. In the case of the FSSM, this occurs when the last connector is unmated while in the case of the SPSSM, when the last guiding device is completely released (this implies that the last actuation spring is also at the end of its stroke and the last umbilical connector is unmated).
- Results: The mathematical model permits retrieving and plotting any cinematic parameter or force of interest along the separation. It is useful to obtain the final state vectors of the bodies after the separation as well as the transient response produced by the forces applied on them during the process. By way of illustration, Fig. 10 shows the forces produced by the separation springs that push away the bodies and some resistive effects such as the umbilical connector friction forces or the biosealing sticking force.
- Results Treatment: The outcomes are treated on statistical base to evaluate the potential variations of the main variables and the relationship between them. For this reason, it is of high importance to transform the results into covariance matrices that provide the way the parameters are interrelated. Statistical matrices and figures are provided as follows to show the usual results provided to the Customer as part of the project documentation: angular disturbance, linear and angular velocity variation and mechanical impulse.

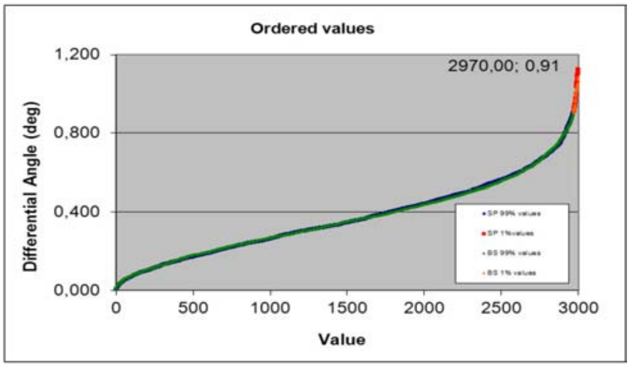


Figure 11. Example of results. Attitude Variation (values put in ascending order)

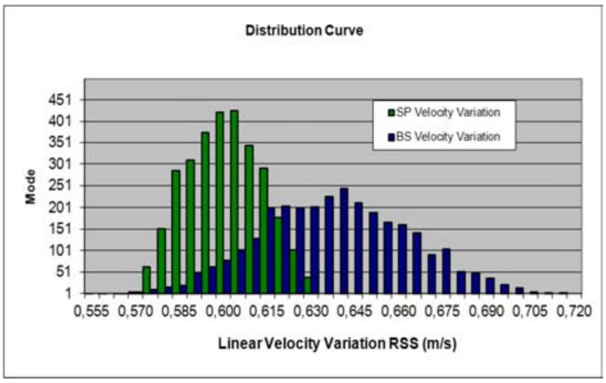


Figure 12. Example of results. Root Sum Square of Linear Velocity Variations

| FS LOCAL VELOCITY VARIATION | Vx [m/s] | Vy [m/s] | Vz [m/s] | Ωx [deg/s] | Ωy [deg/s] | Ωz [deg/s] |
|---|---|---|---|---|---|---|
| Mean (μ) | 0.73 | 0.00 | 0.00 | 0.00 | 0.11 | -0.19 |
| Standard deviation (σ) | 0.02 | 0.01 | 0.01 | 0.03 | 1.31 | 1.28 |
| Maximum (99% probability) | 0.77 | 0.03 | 0.03 | 0.10 | 3.80 | -3.65 |

| FS LOCAL VELOCITY VARIATION COVARIANCE MATRIX | Vx [m/s] | Vy [m/s] | Vz [m/s] | Ωx [deg/s] | Ωy [deg/s] | Ωz [deg/s] |
|---|---|---|---|---|---|---|
| Vx [m/s] | 0.00028 | 0.00000 | 0.00000 | 0.00002 | 0.00017 | -0.00001 |
| Vy [m/s] | -1.4% | 0.00018 | 0.00000 | 0.00000 | 0.00072 | 0.00008 |
| Vz [m/s] | -2.1% | -1.4% | 0.00017 | 0.00001 | 0.00041 | -0.00001 |
| Ωx [deg/s] | 4.0% | -1.0% | 1.5% | 0.00118 | 0.00070 | -0.00089 |
| Ωy [deg/s] | 0.7% | 4.0% | 2.3% | 1.5% | 1.85365 | 0.03045 |
| Ωz [deg/s] | 0.0% | 0.4% | -0.1% | -2.0% | 1.7% | 1.77057 |

*Figure 13. Example of results. Linear and Angular Velocity Variation Vector*

| BSSP LOCAL IMPULSE | Ix [kg*m/s] | Iy [kg*m/s] | Iz [kg*m/s] | Hx [kg*m2/s] | Hy [kg*m2/s] | Hz [kg*m2/s] |
|---|---|---|---|---|---|---|
| Mean (μ) | -54.558 | 0.125 | 0.031 | 0.000 | 0.926 | -0.969 |
| Standard deviation (σ) | 1.854 | 5.978 | 6.041 | 0.049 | 3.284 | 3.262 |

| BSSP LOCAL IMPULSE COVARIANCE MATRIX | Ix [kg*m/s] | Iy [kg*m/s] | Iz [kg*m/s] | Hx [kg*m2/s] | Hy [kg*m2/s] | Hz [kg*m2/s] |
|---|---|---|---|---|---|---|
| Ix [kg*m/s] | 3.43438 | -0.15385 | 0.01514 | 0.00074 | -0.05303 | 0.06637 |
| Iy [kg*m/s] | -1.4% | 35.72101 | -0.02104 | 0.09535 | -0.03374 | -11.81495 |
| Iz [kg*m/s] | 0.1% | -0.1% | 36.48000 | -0.09843 | 12.25403 | -0.17476 |
| Hx [kg*m2/s] | 0.8% | 32.3% | -33.0% | 0.00244 | -0.07905 | -0.08051 |
| Hy [kg*m2/s] | -0.9% | -0.2% | 61.8% | -48.7% | 10.78405 | -0.07586 |
| Hz [kg*m2/s] | 1.1% | -60.6% | -0.9% | -50.0% | -0.7% | 10.63931 |

*Figure 14. Example of results. Linear and Angular Impulse Variation*

## 5. TEST CAMPAIGN

### 5.1. FSSM Functional Tests

Although the qualification testing campaign consists of a wide variety of tests (Physical Measurements, Thermal Vacuum, DHMR, Static Load and Stiffness, Creep, Vibration and functional tests) this section focuses only on the functional tests (separation tests); that have been performed at CTA - Aeronautical Technologies Centre (Miñano, Spain).

The functional separation tests (both for FSSM and SPSM) have two main purposes:

1. To demonstrate the correct performance of the separation mechanisms in flight-like conditions and under different extreme situations: installing smaller separation springs (less elastic energy available for the separation), displacing the CoG location of the bodies, tilting initially the two bodies, inducing a delay in the pyro-nut firing, etc.
2. To correlate the mathematical model (described in paragraph 5.3) that is used to simulate the performance of the mechanisms and to predict the final state of the bodies after the jettisoning.

Some mass dummies are used to represent the separating bodies (as far as geometry, mass, inertia, interfaces, etc. are concerned). The separation tests are performed on the FSSM and SPSM Qualification Models.

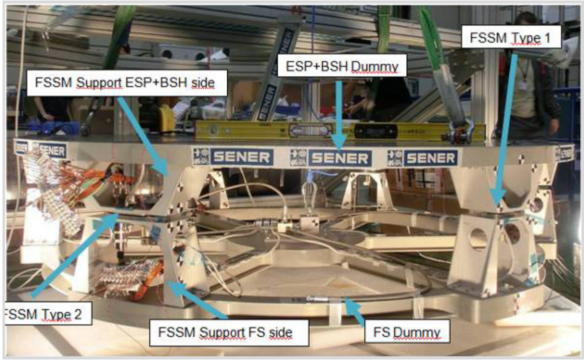


*Figure 15. FSSM separation test set-up*

The assembly is suspended from a system of pulleys that permits adjusting the tension of the cables so that the actual external forces (aerodynamic drag, parachute pull, biosealing, etc.) are applied on the bodies and Earth gravity is compensated. The external forces stay even during the separation thanks to the implementation of several low frequency tension springs. The actuation of the pyronuts is performed either with electrical initiators or with pressurised Nitrogen (Cold-Gas Actuation, so as to allow repeated tests with limited cost). Fig. 15 & Fig. 16 show the general arrangement of the FSSM Functional tests.

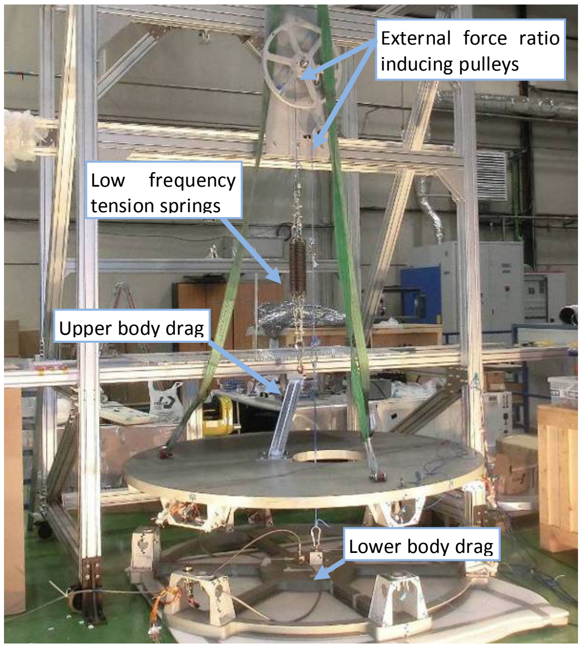


*Figure 16. FSSM functional test separation set-up after separation test*

The test data needed for the correlation of the Matlab-Simulink model are obtained by means of the following instrumentation:

- Pyro-shock near-field accelerometers (Endevco 7255A-01). The purpose of these accelerometers is to obtain the magnitude of the shock and the delay produced between the actuation of the pyronuts.
- Other lower range accelerometers, placed in several locations to provide information about the shock attenuation.

- High speed recording cameras. The purpose is to obtain the displacement and velocity signals of some targets that are attached to the upper and lower bodies and to calculate their cinematic parameters.

The results obtained in the FSSM separation campaign have shown that the mechanisms operate correctly in the whole range of foreseen separation conditions. The data obtained from these tests are used then for the correlation of the mathematical model (further details provided in 5.3).

### 5.2. SPSM Functional Tests

The SPSM functional tests are analogous to those performed with the FSSM regarding the instrumentation and set-up. The main differences are the masses of the bodies involved in the separation and the external forces that are introduced by means of the pulley system.

In fact, instead of using a mass dummy to represent the lower body (as it was done for the FSSM tests) the lower body in this case is a fully representative SP Qualification Model.

The test campaign is also equivalent to the one of the FSSM (smaller springs, CoG shifted, etc.) including an additional test in which the bodies are initially tilted.

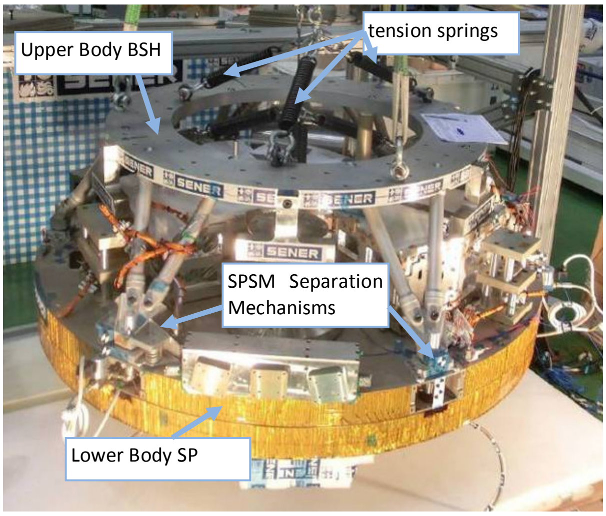


*Figure 17. SPSM Functional Tests set-up*

The SPSM tests performed so far (campaign is yet to be finished) have demonstrated the correct behaviour and performance of the SPSM mechanisms in a wide variety of separation conditions.

### 5.3. Correlation

The purpose of the correlation is to validate the Matlab/Simulink model, comparing the results both from model and real tests. The correlation methodology is equal for both the FSSM and SPSM: the velocity results measured in the actual tests are compared to the values obtained from specific mathematical simulations in which the test conditions are reproduced.

The correlation is focused on the derivation of the relative (lower body with respect to the upper body) separation velocity vector. Since the separation velocity is very sensitive to any source of unbalance, the correlation of this single parameter covers all the aspects that may have an influence on the separation dynamics i.e. delay among pyronut firings, separation spring forces, etc.

The methodology is described in the following paragraphs:

1. First, the sequence of pyronut firings and the delay among them is obtained thanks to the measurements of the accelerometers used in the real tests. These data are introduced in the mathematical model to reproduce and simulate the same initial conditions.
2. From the model, the relative displacement of homologous points located on the upper and lower parts of the mechanisms are calculated and differentiated to obtain the relative separation velocity at those points (mechanism locations). In the real tests, these data are obtained from targets placed following the arrangement shown in Fig. 18.

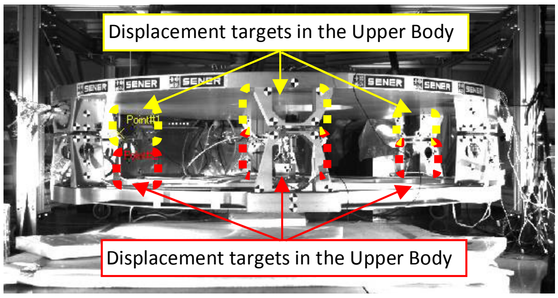


*Figure 18. Targets for the High Speed Camera*

3. The velocity profiles, both of test and simulation, are filtered in the same conditions: with a 20Hz LowPass Butterworth 3rd order digital filter (applied forward & backward).

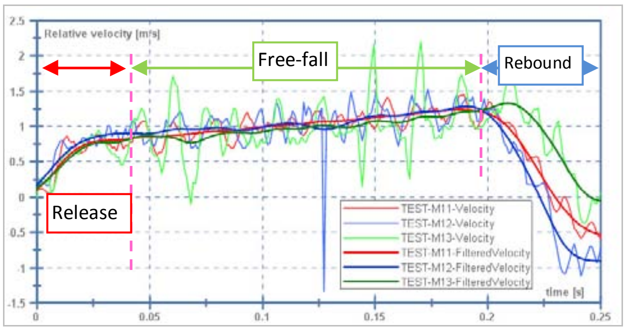


*Figure 19. Velocity signals obtained in one real FSSM test. The profiles show three regions: release, free fall, and rebound. The region of interest for correlation is the release*

4. The filtered velocity signals of each mechanism are compared and plotted over displacement. When the displacement reaches the demating stroke of the umbilical connectors (or guiding device in the case of the SPSM) the release is considered completed.

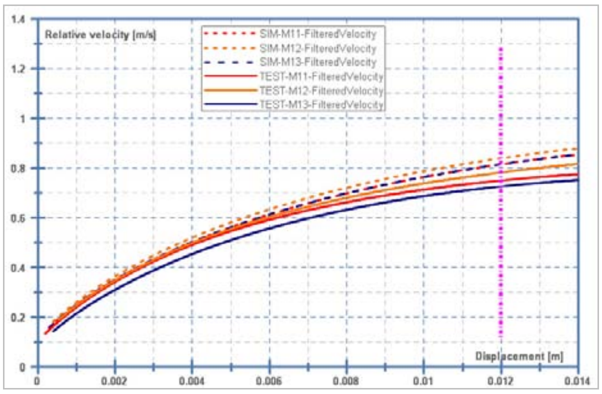


*Figure 20. Comparison of filtered velocity signals (test / simulation) for the correlation of FSSM. The dashed signals come from Simulation; the continuous signals come from the corresponding real test*

5. Finally, the relative velocity (linear and angular) at the CoG of the bodies is derived from the velocities at mechanism level.

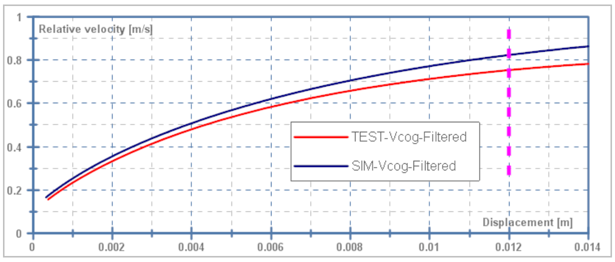


*Figure 21. Relative linear velocity at CoG (ESP-BSH) in an FSSM test / simulation correlation*

One individual correlation has been performed for each test case. From the correlations performed both for FSSM and SPSM the following conclusions have been made:

- The results obtained from the model and from reality are consistent. The results outcoming from the mathematical model are considered slightly conservative.
- Since the separation takes a very short time, it is almost flat and therefore the angular velocity is small. The differences between test and simulation for this parameter are not considered relevant.
- The correlation degree is considered successful, although some slight differences are found in the vertical velocity. In all cases the vertical velocity obtained from the real tests was slightly higher than the one obtained from simulations.

## 6. CONCLUSIONS

### 6.1. Lessons Learned

From the design, analysis and testing activity performed in the frame of the FSSM and SPSM mechanisms, it is learned that:

- Correlating a mathematical model of this type is possible.
- The model provides slightly lower vertical velocity than the real tests in the same conditions. These differences are attributed to the elastic energy absorbed by the upper and lower bodies during the test while they are represented as rigid bodies in the simulation. There could be other minor resistive effects, not considered in the model, which could absorb also small amounts of energy in the real test.
- During the testing campaign (both FSSM and SPSM) difficulties were found when trying to reach a simultaneous release of the three pyrotechnical devices in cold-gas actuations (this problem did not appear in actuations with pyrotechnical initiators). A big effort was done to determine the causes of the delay among pyros. The conclusion from this evaluation was to perform the cold-gas actuations pressurising the pneumatic system (and the pyronuts) in advance at 20 bar and then, actuating it at 100 bar with electro-valves accommodated on each mechanism.

### 6.2. General Conclusions

From the results obtained in the activities performed up to this point, it can be said that:

- Using a statistical approach is considered adequate to cover the largest possible spectrum of cases. The inputs are randomly generated from the corresponding statistical distributions and the outputs are statistically treated also to obtain conclusions with a high level of reliability.
- The model is validated by comparison with a full scale test campaign that represents different separation cases and by correlation with the results coming from it.

It is concluded also that the technology can be applied to other missions, taking into account that:

- The performance of the separation mechanisms is correct and can operate in extreme separation conditions with a high degree of reliability.
- The simplicity of the design makes possible to assure successful separations in extreme thermal and environmental conditions.
- The behaviour of the separation mechanisms can be simulated with Matlab-Simulink, C++ or any other programming language, giving accurate predictions, and allowing good reliability with limited tests campaigns.
- This technology can be easily scaled or adapted to the needed interface and providing any order of release forces.

Consequently, the solution can be used in a wide variety of missions, especially when the simultaneity of the actuation and the reliability of the separation are critical.