# HSS3 - AN IMPROVED CONCEPT FOR THE HORIZONTAL SEPARATION SYSTEM OF THE ARIANE5 PAYLOAD FAIRING AND ITS QUALIFICATION STATUS

P. Bodagala, CNES, Direction des Lanceurs, 91023 Evry Cedex, France
M. Rendina, OERLIKON SPACE AG, Schaffhauserstrasse 580, 8052 Zürich, Switzerland

## ABSTRACT

HSS3 stands for the improved version of the Horizontal Separation System of the Ariane5 Payload Fairing, the concept of which is primarily driven by the stringent requirement to reduce the shock levels to the payload (at the event of the fairing separation). This stringent requirement called for a bi-rupture concept using a linear pyrotechnic device. This new and complex Horizontal Separation System is presently under development at Oerlikon Space (Switzerland), with the collaboration of Astrium (France) for the associated pyrotechnic subsystem. In the initial stages of this Project, extensive parametric studies and representative testing at “element level” had been undertaken independently by CNES in order to understand, with certain degree of credibility, the physics of this system and to optimize the geometry of the related interface frame (the principal parameters considered being: shock, mechanical strength, pollution, safe separation and jettisoning of the fairing taking friction aspects into account). The finally chosen optimized configuration has been further tested on a “scale one” test in association with a partial fairing structure, a short SYLDA5 structure, a P/L adapter and the Eurostar 3000 P/L dummy (test done in the premises of Oerlikon Space). During this first “Development Test”, performed in “ambient conditions”, a flight standard fairing separation was simulated, igniting both HSS3 and VSS (Vertical Separation System), thus permitting the horizontal separation of the fairing from the launcher and allowing at the same time, to record the separation dynamics of the separated fairing halves during the critical period of the first few milliseconds of the jettison phase. This Development Test contributed positively to the verification of the aspired reduction in the generated shock levels. But, from the point of view of the kinematics behaviour (separation and jettisoning aspects) of the payload fairing, further justifications proved necessary. Subsequently, after the necessary trade-off studies, it has been decided to carry on the rest of the Test Campaign in vacuum conditions (NASA - Plumbrook facility) and by using a representative scale one complete fairing structure, through a reoriented qualification logic. This paper is intended to give a brief account of the current status of this challenging HSS3 Development Program. The salient results obtained so far: analytical assessments, feasibility tests at elementary level, test results of the scale one development test, test predictions and comparison with test results, independent cross-checking activities, etc. are also intended to be presented in this paper.

## 1. PAYLOAD FAIRING AND THE ASSOCIATED SEPARATION SYSTEMS

The payload fairing (hereafter designated as PLF) constitutes the uppermost structural component of the European Launcher ARIANE5. The principal function of this PLF is to protect the payload against the natural and induced environment, on ground and until the end of the atmospheric flight phase. Another equally important function of this PLF is to allow its safe separation and jettison from the launcher. This latter function is accomplished by a Horizontal Separation system (HSS: which separates the PLF from the launcher) and by a Vertical Separation System (VSS: which separates the PLF into two halves and jettisons them laterally, in opposite directions). These two subsystems of the PLF are initiated by pyrotechnic devices, activated by a single electrical command signal (with redundancy). The existing definition of the HSS is based on a concept where the PLF is separated from the launcher by cutting horizontally a predefined single severance zone of the PLF interface frame. Consequent to this separation event, high shock levels are transmitted to the payload(s) via the associated launcher components (like VEB, SYLDA, ACU, …). In order to bring down these shock levels, an improved “bi-rupture” concept for the HSS (hereafter designated as HSS3) is currently under development at Oerlikon Space. The basic conceptual differences between these two versions are depicted in Fig.1. The purpose of this paper is to present the required technical performances of the HSS3 subsystem (in terms of generated shocks, separation and jettison kinematics, structural integrity and pollution aspects).

## 2. GENERAL DESCRIPTION AND MAIN PERFORMANCE REQUIREMENTS OF HSS3

The HSS3 consists of two interface rings: The bottom ring serves as the bolted interface to the launcher; lodges the confined pyrotechnic tube (TEE) between its two flanges (severance of these two flanges across their thickness occurs upon activation of the HSS3).The upper ring in turn provides the standard interface with the fairing sandwich structure; the bottom part of this upper ring forms a bolted interface with the two flanges of the bottom ring. See Fig.1 for details (before and after separation).

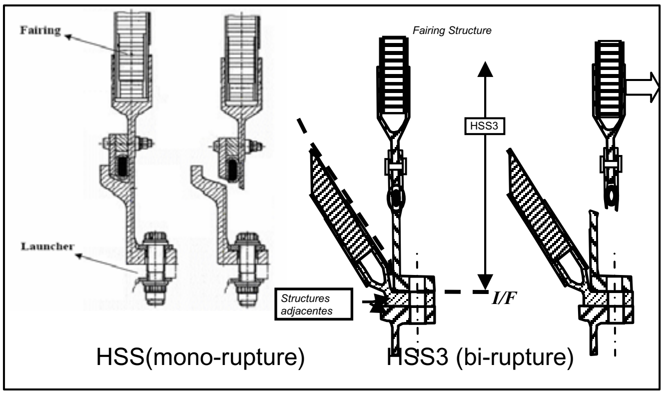


Fig.1: The basic conceptual definitions of the existing HSS (mono-rupture) and the proposed improved HSS3 (bi-rupture)

The Technical requirements to be fulfilled by HSS3 are stipulated in [R1]. The principal need for a new horizontal separation system is to generate (following its activation) substantially low shock levels at payload interface; still remaining compatible with the current design of the Ariane5 payload fairing, allowing safe separation and jettisoning of the fairing halves, and keeping the same qualification status for the adjacent structures. The shocks generated by the current HSS definition (mono-rupture), for some launcher configurations, were found to be dimensioning for the payloads [R2]. The related shock aspects are reiterated below for the sake of completeness. The shock levels measured at the payload interface level, for typical flight events, are reproduced in Fig. 2.

The requirement set for the new and improved concept of HSS (= HSS3) is that the generated shock at the payload interface must be lower than the line resulting from the equation: $\gamma(SRS) = 0,1*f$ (where, $\gamma$ is in g and f in Hz, see Fig. 3).

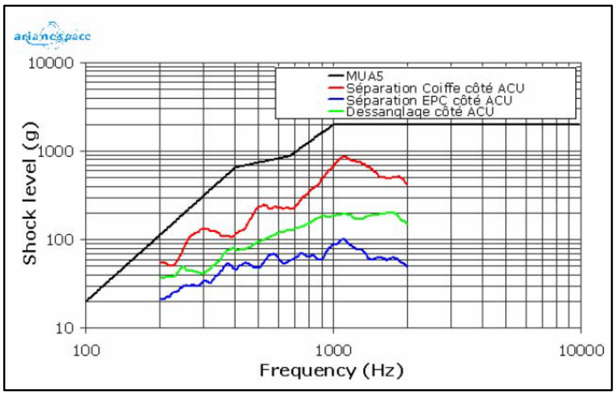


Fig. 2: Shock spectra for typical flight events (including the one resulting from the activation of the existing version of HSS)

From Fig. 2 we can observe that the performance of the current HSS is well within the limits set by the Ariane5 Users' Manual (MUA5).

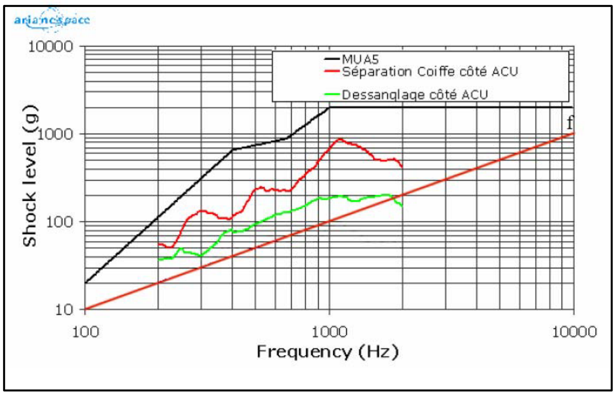


Fig. 3: The new Shock Requirement set for HSS3 and its comparison with that of MUA5

We can observe from Fig 3 that the new target shock levels (straight red line) call for a reduction of about 20 to 30 dB in the frequency range of 100 to 1000 Hz. Further, when the new requirement would be satisfied, the dimensioning shock for the payload qualification will no more be the one generated by the HSS3, but the one resulting from the payload's own separation system.

Other important requirements applicable to the HSS3 are related to:

- Severance performance of the used pyrotechnical subsystem,
- Synchronisation of the two pyrotechnical separation systems: HSS3 and VSS,
- Kinematics behaviour (safe separation and clearance aspects) of the jettisoned fairing parts taking the involved "friction aspect" into consideration,
- Absence of unacceptable debris (pollution aspects related to the possible contamination of payload, as a result of the activation of the HSS3),
- Structural integrity of the new geometrical concept under the applicable flight loads (w.r.t strength and stability aspects).

These aspects are treated in § 6 and §7.

## 3. EARLY RESEARCH WORK INITIATED BY CNES TO IDENTIFY THE MOST RELIABLE GEOMETRIC DEFINITIONS FOR HSS3

Based on the initial jettison trajectory calculations (of the two separated fairing halves) made by Oerlikon Space, a preliminary geometrical definition of the HSS3 interface frame was identified. From CNES side, further independent activities in terms of extensive parametric studies and representative testing at "element level" had been undertaken in parallel, supported by the help of some external services (ESI-France, MSC-Software, Dassault Aviation, Astrium, …). This initiative of CNES was mainly aimed at the reduction of the development risks, trying to understand - with certain degree of credibility - the physics of this system and to reach an optimized geometry for the related HSS3 interface frame as early as possible in the development phase. The principal parameters considered for these activities are: shock, structural strength, pollution, safe separation and jettisoning of the fairing taking friction aspects into account. Several element-level pyro-separation test campaigns were conducted under the responsibility of CNES on 1 meter wide straight panels in order to identify, among the many different geometries, the potential candidate designs for the HSS3 final geometry. The results of the last campaign carried out had been documented in [R3]. The finally chosen optimized configuration has been further tested on a "scale one" test in association with a partial fairing structure, a short SYLDA5 structure, a P/L adapter and the Eurostar 3000 P/L dummy (test performed in the premises of Oerlikon Space). The results of this last test and the requirements mentioned in the previous paragraph are dealt with in the next chapters.

## 4. SEVERANCE PERFORMANCE AND FRICTION CHARACTERISATION

These tests have been realised by ASTRIUM and OERLIKON SPACE.

The shock tests on 1 meter wide panels [R2, R3], with several geometrical definitions of the HSS3 rings have been realised in close cooperation with ASTRIUM. Through its vast experience in the pyrotechnical field, ASTRIUM brought forth a valuable contribution through these element-level tests towards arriving at the optimised definition of the severance zone of the HSS3 rings. Another example of the contribution of ASTRIUM is its realisation of several sample tests in "brochette" configuration (specimens with different thicknesses to be severed and with different geometrical definitions: tested in "one shot") to verify the severance capability and the required performance margins of the involved TEE. This kind of test ("brochette" configuration) was also performed by ASTRIUM in the context of determining the driving parameter to demonstrate the severance margin (between the thickness to be cut and the linear charge in the TEE). This interesting and simple "tooling" is shown in Fig 4.

Fig. 4: ASTRIUM Tooling used to conduct the element-level tests in a "brochette" Configuration

Just after the severance of the two flanges of the HSS3 ring the Fairing is jettisoned. The separated internal flange on the HSS3 upper part (which is jettisoned with the Fairing) would come in contact with the lower part of the I/F ring remaining on the launcher side as is clarified in Fig 5. On the other side, the outer flange of the HSS3 upper part bends externally during severance; and therefore does not constitute a problem for the Fairing separation kinematics.

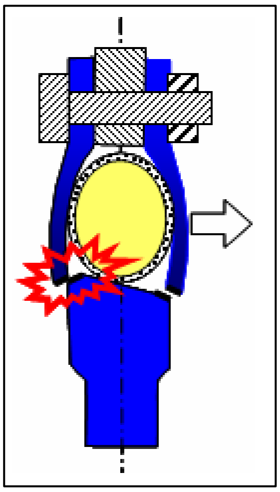

Fig. 5: HSS3 Lower Ring - Internal and External Severance Zones

The resulting friction aspect will have to be adequately represented in the analytical models which are used to evaluate the separation trajectories of the jettisoned fairing halves (clearance margins assessment). The related friction characterisation tests (element-level testing) were carried out by both ASTRIUM and Oerlikon Space. The obtained results are documented in [R4]. The values of the related friction coefficient for the employed aluminium alloy range between 0.3 and 0.9 with an average of 0.7.

## 5. CROSS-CHECKING ACTIVITIES TO ENSURE THE CREDIBILITY OF THE ACCOMPLISHED WORK

The theoretical assessments related to the dynamic behaviour of the jettisoned fairing halves during the initial phase of separation (clearance w.r.t launcher) are made by Oerlikon Space and by MSC-Software, in parallel. The independent assessments carried out by MSC-Software were intended to serve as cross-checking of the clearance calculations performed by Oerlikon Space. The close cooperation among the involved parties proved beneficial in understanding the importance of the involved parameters (energy delivered by HSS3 and VSS, friction, acceleration, finite element meshing, material properties, boundary conditions, adjacent structures, etc.), leading to improve the local mathematical models used to simulate the contact behaviour at the HSS3 I/F. Further cross-checking activities are envisaged to generate the adequate and more refined mathematical models that will be used during the qualification loop.

When the Fairing halves are jettisoned, after separation from the Launcher, some interactions in the form of contact/sliding at the HSS3 I/F occur. These are however limited to the very first instants. In fact the Fairing, unlike the other Launcher's stages, separates laterally. During the first 10 mm of this lateral separation, each Fairing half slides with the HSS3 part remaining attached to it on the counterpart remaining with the Launcher. This interaction lasts for about 10 to 15 ms. And it is during this time that perturbations to the Fairing kinematics could be generated, negatively impacting the separation clearance (minimum distance between the separating Fairing and the Launcher). An example of a PLF corner separation trajectory is given in Fig 6.

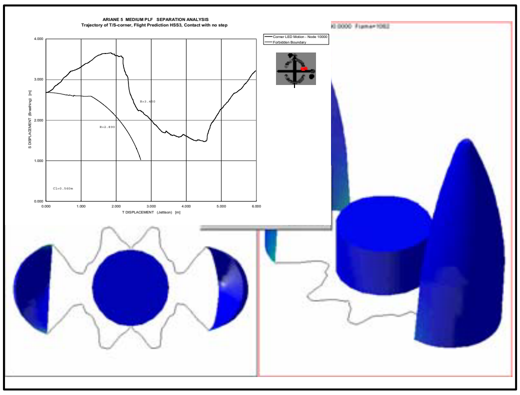

Fig. 6: Separation trajectory of a PLF corner point

## 6. STRUCTURAL ASPECTS OF THE BI-RUPTURE GEOMETRY OF THE HSS3 I/F FRAME

In the existing HSS configuration (mono-rupture, see Fig 1) only one flange takes the induced loads; whereas in the proposed HSS3 design (bi-rupture), the loads are transferred by two flanges of increased thickness, thereby increasing its load bearing capability w.r.t the strength and buckling aspects. Even if the HSS3 is dimensioned with external loads that are higher than those that were applicable to the HSS, the structural margins (against strength and stability) are considerably larger. The first loop of calculations shows that the margin of safety w.r.t HSS3 buckling is higher than 100 %. From the strength point of view, the minimum margin of safety is around 60 %. Brief details of the used mathematical models are shown in Fig 7.

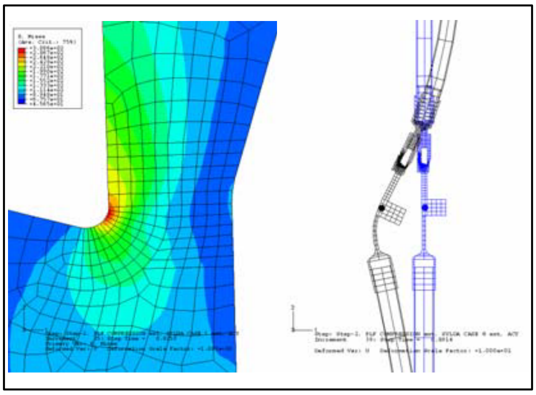

Fig. 7: Stress concentration in critical area (left) and buckling mode under compression loads (right)

## 7. FULL SCALE DEVELOPMENT TEST WITH FLIGHT-REPRESENTATIVE LAUNCHER COMPONENTS

The main objectives of this development test N° 1 (in ambient conditions) are:

- to make sure that the shock levels transmitted to the P/L interface are within the specified limit.
- to verify the correct severance of the HSS3.
- to ensure the expected synchronisation of the two pyrotechnical systems: HSS3 and VSS.
- to verify the Fairing kinematics behaviour and clearance w.r.t the Launcher and to validate the mathematical models used for making the test predictions.
- to make sure that the HSS3 subsystem does not generate unacceptable debris (pollution aspects related to the possible contamination of payload after activating HSS3).

The test installation and the involved launcher components are shown in Fig 8.

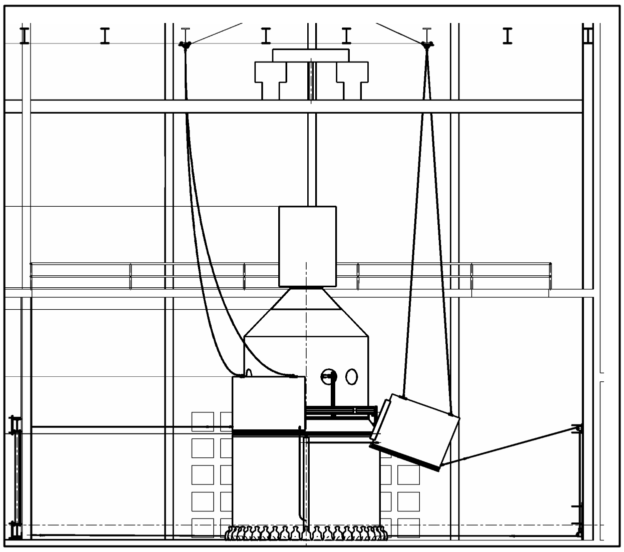

Fig. 8: Test Configuration of the Full scale HSS3 Development Separation Test

The evaluation of the recorded measurements of this development test permitted the following assessments:

- Shock aspects: The shock levels at the P/L interface were found to be in conformity with the specified limit and, encouragingly, even better in certain frequency ranges [R5]. See also Fig 9.
- Pyrotechnical performance aspects: The correct functioning of the HSS3 and its subsequent severance performance were demonstrated [R5].
- Synchronisation HSS3/VSS: The flight type “pyro timing” of both the involved systems HSS3 and VSS was found to be within the usual known norm [R5].
- Pollution aspect: no bad surprise was noticed from the point of view of debris, which could be detrimental to the payload components [R5].

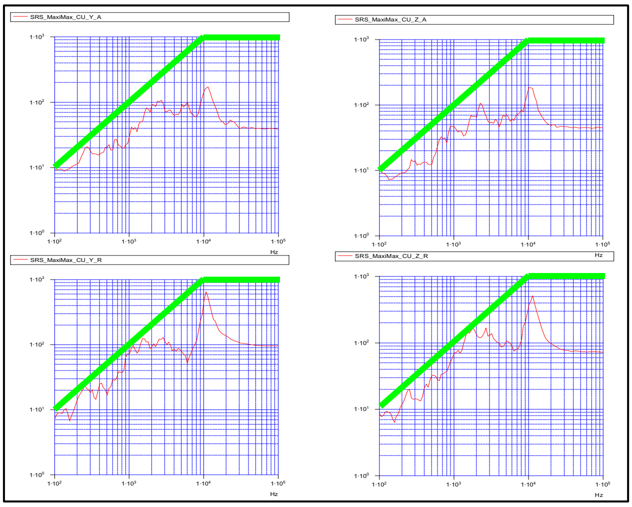

Fig 9: The shock levels at the P/L interface are below the required 0,1 * f limit

On the other hand, from the point of view of the kinematics behaviour (separation velocities and jettisoning aspects) of the payload fairing, further justifications proved necessary. In fact, the lateral velocity of the separated half cylinders representing the fairing was found to be much lower than the predicted one (See Fig. 10). Further analytical aerodynamic assessments led to the conclusion that this discrepancy could be attributed to the specific test configuration used in atmospheric conditions. The presence of the SYLDA5 in the internal volume of the test article caused a suction effect (depressurisation, during the activation of VSS) that absorbed part of the separation energy delivered by the VSS. This situation, consequently, did not permit to realise the needed kinematics evaluations and the transposition of the test separation trajectory of the tested cylinder to a complete Fairing. This situation led Oerlikon Space and CNES to consider a reoriented qualification logic for the remaining development and qualification activities.

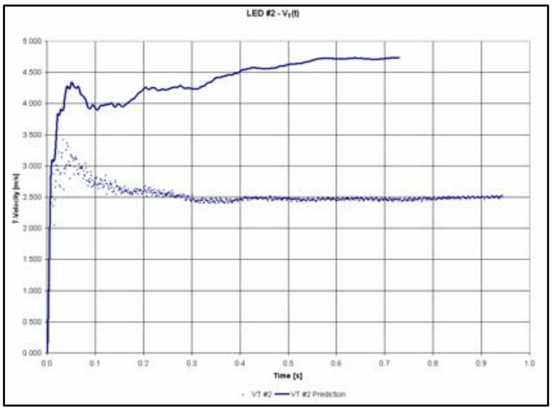


Fig. 10: Separation velocity, predicted (bolt) vs. measured (dots)

## 8. REORIENTED QUALIFICATION LOGIC AND THE MAIN TASKS REMAINING TO BE ACCOMPLISHED

On the basis of the evaluations of the recorded test data (cf development test §6) and the subsequent examination of the risks involved in the earlier qualification process, a decision has been taken to pursue the separation testing on a complete and representative fairing structure under vacuum conditions. The NASA vacuum testing facility at Plum Brook Station has been chosen for the purpose. Prior to starting the expensive qualification test campaign in the US, some development tests based on cylindrical panels have been proposed. The objectives of these tests are: a better understanding of the “contact/sliding” interaction at the HSS3 I/F and the validation of a contact mathematical model to predict, as close as possible, the expected Fairing separation kinematics. For the qualification separation tests campaign, two tests under vacuum conditions are foreseen:

a) “nominal” separation case (synchronous ignition of HSS3 and VSS)

b) “degraded” separation case (single side activation of the VSS).

With this reoriented qualification logic, the final qualification of the separation system HSS3 is foreseen for May 2008 permitting the first flight of an Ariane5 Launcher with a HSS3 integrated Fairing in early 2009.

## 9. CONCLUDING REMARKS

– An improved version of the Horizontal Separation System of the Ariane5 Payload Fairing (designated as HSS3) is under development at Oerlikon Space (Switzerland) in the frame of a contract from CNES (France).
– This development activity is primarily driven by the stringent requirement to reduce the shock levels to the payload (at the event of the Fairing Separation).
– The basic conceptual difference between the existing version (HSS) and the proposed improved version (HSS3) is that the former is a mono-rupture system and the latter is a bi-rupture system (both the systems are activated by a linear pyrotechnical device).
– An early and independent research work was initiated by CNES with the support of external Services (ESI-France, MSC-Software, Dassault Aviation, Astrium, etc.) in terms of extensive parametric studies and representative element-level pyro-separation tests (on 1m wide straight panels).
– Element-level laboratory tests were also conducted by ASTRIUM (to improve the severance performance of the involved pyrotechnical device associated with the candidate geometries of the HSS3 interface ring) and by Oerlikon Space (tests to determine the contact/friction behaviour of the two severed flanges of the HSS3 ring).
– Independent theoretical calculations are undertaken by Oerlikon Space and CNES (taking support from MSC-Software, to serve the purpose of cross-checking) to assess the clearance aspects of the jettisoned fairing halves.

- As for the structural integrity, the first calculation loop shows that the margin of safety w.r.t HSS3 buckling is higher than 100 % (significantly higher than the margin for the current HSS case). From the strength point of view, the minimum ultimate margin of safety is around 60 % .
- The finally chosen optimized configuration has been further tested on a “scale one” pyro-separation test in association with a partial fairing structure, a short SYLDA5 structure, a P/L adapter and the Eurostar 3000 P/L dummy (test carried out in the premises of Oerlikon Space under “atmospheric conditions”). This Development Test contributed positively to the verification of the aspired reduction in the generated shock levels. The measured shock levels at the P/L I/F are within the defined requirement, leading to the fact that, once the HSS3 will be installed on a Fairing, the dimensioning shock for the payload qualification will no more be the one generated by the HSS3, but the one resulting from the payload’s own separation system.
- On the other hand, from the point of view of the kinematics behaviour (separation and jettisoning aspects) of the payload fairing, further justifications proved necessary. After the necessary trade-off studies, it has been decided to carry on the rest of the separation test campaign in vacuum conditions (NASA - Plumbrook facility) using a representative scale one complete fairing structure, through a reoriented qualification logic. This reoriented qualification logic is under the process of being finalised. The test campaign at NASA-Plumbrook Facility is foreseen to be completed in the first quarter of 2008.
- The qualification of this improved HSS3 version is expected to be achieved by May 2008 and the delivery of the payload fairing, equipped with the flightworthy HSS3 is expected for the beginning of 2009.
- The related development activity is being carried out under a contract CNES-OERLIKON, in the framework of ESA’s ARTA Program.

## 10. ABBREVIATIONS

ACU : Adaptateur Charge Utile (Payload Adapter)

ARTA : Accompagnement et Recherche Technologique Ariane

HSS / HSS3 : Horizontal Separation System

I/F : Interface

PLF : Payload Fairing

P/L : Payload

SRS : Shock Response Spectrum

SYLDA5 : Système de Lancement Double Ariane 5

TEE : Tube à Expansion Etanche

VEB : Vehicle Equipment Bay

VSS : Vertical Separation System

## 11. REFERENCES

[R1] A5-ST-1525-X-01-CZ: A5 Arta – HSS3 Technical Specification of the Horizontal Separation System.

[R2] Matteo RENDINA and Philippe ROUX: HSS3-Low Shock Separation System for the Ariane5 Payload Fairing, Paper presented at the 6th International Symposium on Launcher Technologies, 8-11 November 2005, Munich, Germany.

[R3] A5-NT-1500000-X-15-CNES(1/1), dated 15/02/2005: HSS3-Exploitation des Essais Plaques, Campagne C4-Exploitation en Pied de Charge Utile.

[R4] A5-NT-1525-X-01-CZ: PLF Separation Cinematic, dated 06/06/2005.

[R5] A5-RE-1525-X-01-CZ: DM separation test evaluation report, dated 11/05/2006.