DEVELOPMENT OF NON EXPLOSIVE LOW SHOCK (NELS) HOLDDOWN AND RELEASE SYSTEM

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ABSTRACT

The NELS holddown and release system is an evolution of the hold-down and release systems used by Airbus Defence and Space Netherlands for solar arrays with over 500 successful releases in orbit without failure. The NELS HDRS is based on the principle of cutting a high-strength fibre-based restraint cable with a Thermal Knife resulting in a reliable, very low shock release

1. INTRODUCTION

Airbus Defence and Space Netherlands (formerly Dutch Space) is developing a new holddown and release system in response to market needs in the satellite industry.
Satellites require external, deployable items to be stowed during launch in such a way that the accompanying launch loads in combination with the thermal environment in space can be survived with adequate margin against failure. These items must then be released in a controlled manner to neither harm the item to be deployed, nor the surrounding satellite elements.
Various holddown and release systems exist already, each covering a limited portion of the total application range and each with its own draw-backs and issues, such as:

- Safety (unintended release)
- Mechanical loads (in case of high release shocks)
- Interfaces (mass, dimensions, positioning tolerances)
- Operation and accessibility
- Limited number of elements to be tied down
- Logistics (for some existing systems, the element has to be returned to the supplier for resetting and arming the device prior to re-use)
- Limited range of allowable operating temperatures
- Export licenses
- Repeated use on system

The key differentiators for the NELS systems will therefore be the combination of:

- Non-explosive
- Low shock
- Compact and low mass in combination with high mechanical load capability
- Constraint & release of multiple elements with flexible positioning tolerances
- Multiple functional testing pre-launch
- Broad operating temperature range
- Redundant release system
- 100% European building blocks, ITAR free

2. APPLICATIONS

The NELS system targets to serve a broad range of applications covering antennas, booms, protective covers and solar arrays from small up to large and very large sizes. Based on our experience, and looking at the existing competitors solutions, we must anticipate that the development of NELS may result in several different designs using the same technology, complementing each other while being optimized for a specific part of the complete load range.

3. DEVELOPMENT APPROACH

The common design approach with the existing ARA Mk3 HDRS design is the application of a polymer restraint cable which is degraded with an electric heater element. For NELS this technology and the ARA Mk3 HDRS footprint are used. This allows Airbus Defense and Space Netherlands on one hand to substitute the new NELS design in the existing solar array families without large modifications, and on the other hand focus on the development to increase the load capability for the solar arrays application from 7.5kN to 15kN. Also measures are developed to increase the thermal survival range from + 100°C to +150°C.
The NELS holddown system contains three key components that define the system design.

- The restraint cable delivering the required hold down force.
- The Thermal Knife as ignition mechanism to initiate the release of the holddown and release system.
- The structural parts transferring the load for the object to be held to the Space Craft.

Proc. '16th European Space Mechanisms and Tribology Symposium 2015',
Bilbao, Spain, 23–25 September 2015 (ESA SP-737, September 2015)

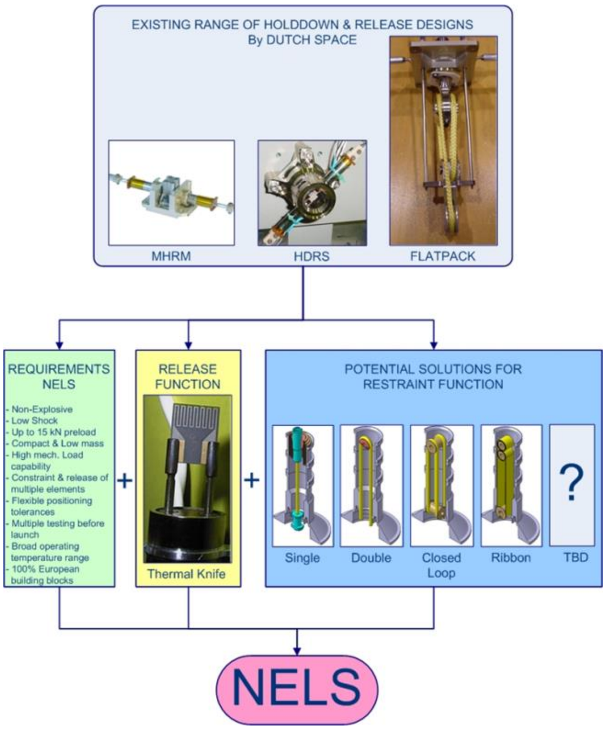

Figure 1. Segmentation of NELS products to serve a broad range of applications

4. KEY REQUIREMENTS

The key performance requirements are separated in hard targets and soft target, listed in Tab. 1 and Tab. 2.

Table 1: Hard Targets

Property/parameter	*value*	*remark*
Stack height	68-170mm	
Axial preload cap.	7.5kN, 15kN	
Ultimate load	> 45kN	Safety factor 3
Lateral load cap.	6000N	
Operating. Temp.	-110°C +150°C	
Survival Temp.	-140°C +150°C	
Release time	< 90 sec.	
Release Shock	< 300g	up to 10kHz
Reliability	0.999	
Isolation	double isolated	according ECSS
Storage time pre-tensioned before launch	½ year	if possible 1 year
Storage time no pretension	5 year	

Table 2: Soft Targets

property	*value*	*remark*
Min. Stack height	34mm	1 panel
Release Power	< 15 W	
Mass of system	max. 620g	excl. cup/cone
Footprint	60mm x 60mm	
Interface voltage	20V, 35V, 50V, 100V	
Operations before launch	max. 10	
Number of installations	max. 25	
Supplier	European	

5. RESTRAINT CABLE CONCEPT

Existing Airbus Defense and Space Netherlands technology heritage on the use of Thermal Knives is applied in the development of NELS. The release function by Thermal Knives requires a high-strength fibre-based restraint cable that can be cut. Three materials (Dyneema, Kevlar, Vectran) have been selected and traded. Dyneema is not preferred due to considerable creep and its difficulty to use in combination with an end fitting. Vectran and Kevlar have very similar mechanical properties but have one significant difference, Kevlar can only be degraded by the Thermal Knife where as Vectran can also be melted and therefore does not require a high minimum pre-tension before cutting. This key difference made Vectran the ideal material to design the NELS system with.

The NELS requirements on pretension (15kN) and temperature range (+150°C) require a different cable approach. Development of a new cable concept was the starting point of the NELS development.

The design effort for the development of a new restraint cable was to find a trade-off between the key parameters using the extensive knowledge gained from our existing Kevlar cable [1]. Three cable concepts have been generated for the Vectran high strength fibre.

5.1 Looped cable / cord

The load performance of the ARA Mk3 Kevlar restraint cable is limited by the end fitting. The looped cable concept, as already executed in the Flatpack S/A, has the advantage of eliminating the interface between the cable material and the end fitting material (metal) to transfer the load.

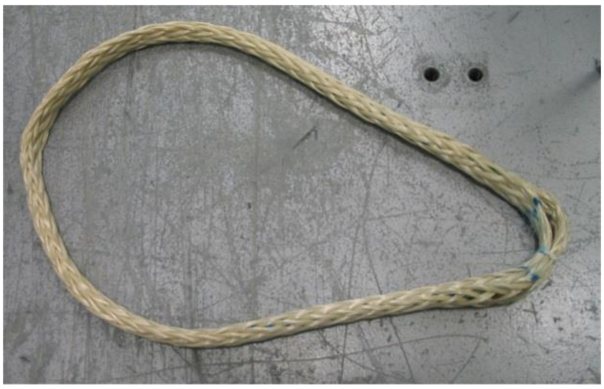

Figure 2. Looped Cable

A looped cable is a continuous cable made by splicing, see Fig. 2. One of the challenges of this concept is to find the most effective splicing method while not affecting the cable performance. The second challenge is the development of a structure to cable interface to transfer the load to the structure without limiting the cable performance. And the biggest challenge is to do this within a limited volume and footprint.

Figure 3. Looped Cord (after hotsoak and cutting test)

The looped cord concept is similar to the looped cable concept in that it is a continuous cable. The looped cord is made by winding a thin cord into a cable. The start and end of the cord are knotted. The looped cord has the advantage to increase or decrease the strength of the cable by adding or subtracting loops. Extra challenge with this concept is to develop a reproducible winding process and equipment.

5.2 Spike end fitting

The spike end fitting design is a classic way of a cable termination. There is a lot of heritage with this design as it has been used in the ARA Mk3 restraint cables. The heritage does not cover end fitting design that meets ultimate loads requirements of 45kN required for NELS when a safety factor of 3 is used.

Figure 4. Spike End Fitting (after test)

The NELS operational temperature requirements are higher than the ARA Mk3 qualification temperatures. A new optimized spike end fitting design is developed with Vectran cable material to meet the new NELS requirements.

5.3 Potted End fitting

The potted end fitting was used in earlier ARA Mk2 family but the loads were significantly lower (4kN). The potting technology has improved over the years and is a promising alternative that is considered as one of the cable end fitting concepts.
In practice finding a solution for the potted end fitting was mostly determined by finding the right potting material meeting the load and thermal requirements.

Figure 5. Potted End Fitting

The requirements on the potting material are demanding; high load capability, adherence to fiber material and keeping its strength combined with low relaxation and creep over a large temperature range.
Samples with potted end fitting have been successfully made, however at high temperatures (150°C) the resin failed to keep its strength and composition.

6. CABLE PERFORMANCE

A comparison between the end fitting cable concepts has been made by testing the cable concepts in a representative stack. For the Spike and Potted concept the available hardware (Fig. 7) could be used with some minor adjustments to fit the increased end fitting diameter.
The looped cord required a full new stack design with increased cup-cone diameter (62mm compared to 42mm for ARA Mk3) to fit the diameter of the looped cord design (Fig. 6).

The following Bread board tests have been performed on the three cable concepts:

- Ultimate load test
- Cutting test (ambient)
- Cold cutting test (-140°C)
- Emitted release shock test
- Hotsoak (130°C and 150°C)
- Storage test (pre-tensioned)

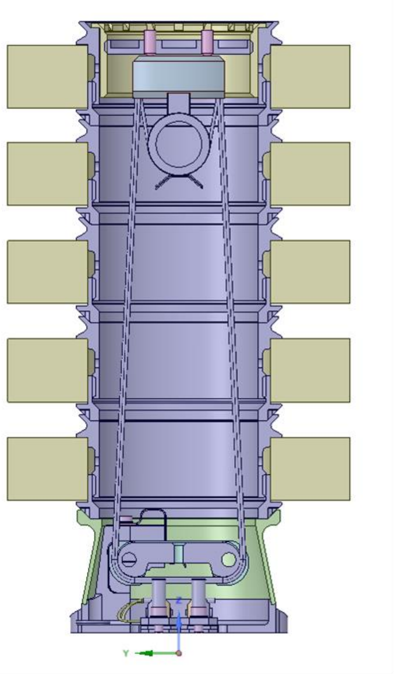

Figure 6. Looped cord concept design

The test results are summarized in Tab. 2.

Table 3: Cable Concept Test Results

15kN Concepts	Req.	Loop	Spike	Potted
Ultimate load [kN]	> 45	60	56	57
Cutting test [s]	< 90	Pass	Pass	Pass
Cold cutting [s]	< 90	20	120***	120***
Release force [N]	< 30	80	N/A	N/A
Emitted shock [g]	< 300	~2*	~2	~2*
Hotsoak 130°C	-	Pass	Pass	Pass
Hotsoak 150°C	-	Pass	Pass	Fail
Pretension loss [kN] (after Hotsoak)	-	7	15**	8
Pretension loss after 6 months storage [N]	-	600	1000	1300

** Assumed to be similar to tested on Spike configuration with 15kN pretension*
*** No pretension after hot soak test due to slip of cable in spike end fitting at high temperatures.*
**** ARA Mk3 thermal knife used for cold cutting does not meet cutting requirement. NELS will require a different thermal knife design*

7. CABLE DESIGN TRADE-OFF

The design process, the test results from Tab. 3 and the procurement experience have contributed to the cable design conclusions as given below:

- The Looped Cord concept shows the best cable performance on ultimate load, storage, pretension after hotsoak but has two major disadvantages. The loop minimum diameter required for the high ultimate load requires a larger system cross-section, increasing the weight and volume of the system. The second disadvantage is the high release force caused by sticking and high pull out force after hotsoak.
- The Potted concept showed good cable performance but was limited by the thermal properties of the potting material and storage time.
- The Spike concept showed good cable performance. The pretension loss after hotsoak is not critical since Vectran can be cut at low pretensions.

The Spike concept is chosen as baseline for the NELS system since this concept will allow a compact system design and the cable concept does not limit the system design to meet the requirements.

8. SYSTEM DESIGN

The system design has two primary goals. The design shall meet the hard targets (Tab. 1) and be downwards compatible with the ARA Mk3 Solar Array platform on the following points:

- Mounting footprint of square 60mm x 60mm with M6 fasteners
- Height target ≤ 64mm
- Existing ARA Mk3 cup/cone interface

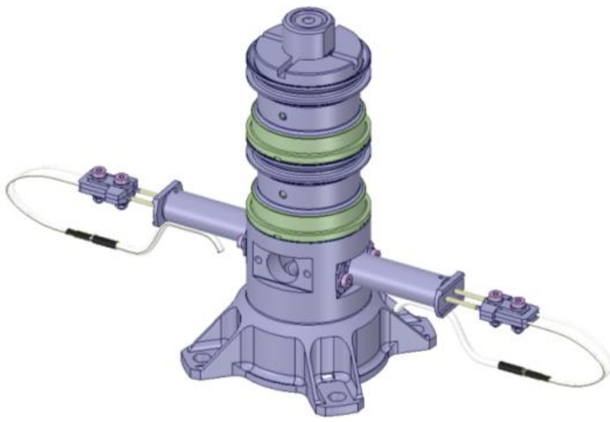

Figure 7. ARA Mk3 HDRS (current HDRS system)

Taking the above into account, using the footprint, cup/cone definition and previous concluded cable concept the NELS concept system design is made.

The Vectran cable is cut using a low force Thermal Knife. The motion of previous HDRS systems of Airbus Defence and Space Netherlands are typically a linear plunger. A trade off was made and an angular system was chosen with the advantage of system safety as the knife mechanism is no longer externally mounted (exposed). Further advantage of the Thermal Knives operating within the bracket is the reduced envelope, simple thermal protection, and being able to disarm the knife mechanism from above the solar array.
The heater plates that cut the cable have been redesigned with a new production process to improve their life time and robustness. Another benefit from the new production technique is that heater plates for different interface voltages can be produced.

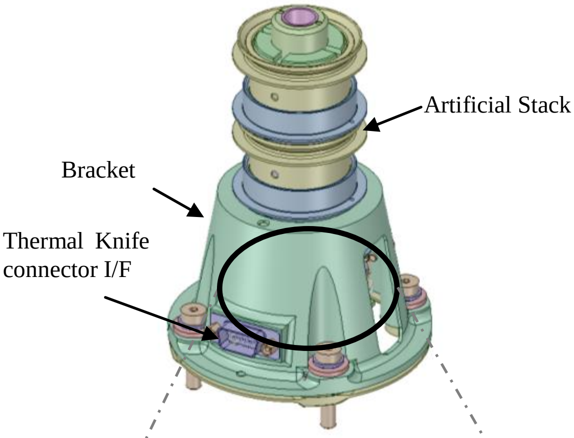

Figure 8. NELS system design

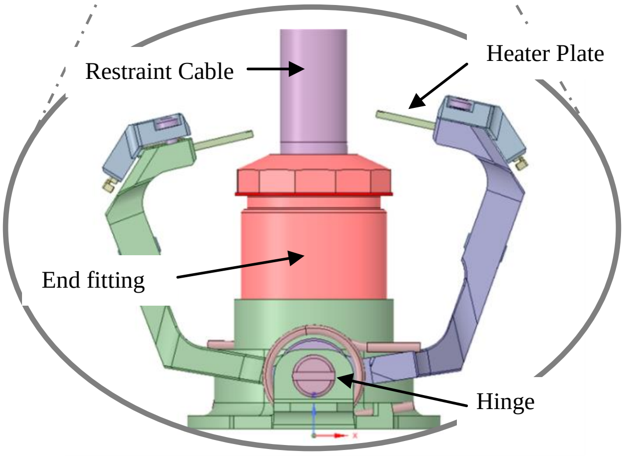

Figure 9. View on Thermal Knife assembly inside Bracket

Figure 10. NELS integrated EM hardware. Bracket with Thermal Knife assembly and connectors.

9. TEST RESULTS

Several ultimate load tests (24x) have proven that the restraint spike end fitting cable design and assembly process is reliable and meets the 45kN ultimate load requirement.

The NELS EM model has been built and a first cutting test was performed on both low (150N) and high (15kN) pre-tensioned restraint cables in the 2 panel stack. Both cable types were successfully cut in ambient conditions.

10. TEST PLAN

The coming months the EM test program will be started on component level for the Thermal Knife and on system level on the NELS EM system

Thermal Knife test program:

- Operating voltage window (vacuum & ambient)
- Inrush current
- Current limiter (functional check)
- Maximum power test (glow test)
- Motorization torque & friction test
- Thermal Knife resistance test
- Insulation measurement
- Redundant knife test
- Vulnerability tests of the heater plate to various contaminants

System level test program:

- Bracket stiffness and sliding
- Humidity test
- Release test after 20 TVAC cycles
- Long duration storage tests
- Random Vibration
- Repetitive cutting (hot vacuum, cold vacuum, ambient)

11. CONCLUSION

The first major steps in the NELS development have been taken. Three cable concepts have been tested and compared in a trade-off. The three cable concepts each represent a connection technique that has been optimized for the application in an HDRS system. The concepts have been manufactured and tested. The test results have been compared and based on a trade-off, the spike concept has been chosen as the baseline design for the NELS system design.

Based on the cable concept design, the NELS requirements and the requirement of interchangeability with ARA Mk3 a NELS system design has been made and EM hardware has been produced.

A new approach of angular moving thermal knives has been chosen to benefit from the advantages of smaller envelope, less exposure and less complex thermal protection.

The Spike end fitting concept has proven its ultimate load performance. The first cutting test on was a successful start of the next project phase, the EM testing program including the Thermal Knife and the NELS system testing.

Airbus Defence and Space Netherlands appreciates the support and cooperation received from the European Space Agency (ESA), and Netherlands Space Office (NSO).

REFERENCES

[1] E. Bongers, J. Koning, T. Konink, *Robustness Improvement of ARA Kevlar Holddown Restraint Cables*, 15th European Space Mechanisms & Tribology Symposium ESMATS 2013' Noordwijk, The Netherlands