ENGINEERING TEST RESULTS OF NELS HOLD DOWN AND RELEASE SYSTEM

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ABSTRACT

The NELS (Non Explosive Low Shock) Hold Down and Release System (HDRS) has been developed from the breadboard concepts to an engineering model. The engineering model has been tested with a wide range of different tests to proof feasibility of the engineering model against its requirements. This paper reports both the test performed on the initial engineering model [1] that started the engineering model test program as well as the final engineering model that includes some design changes that were required based the results of the first engineering tests.

The first engineering tests showed overall good release performance, however, worst case cutting tests showed inefficient cable cutting due to unexpected low temperature behavior of Vectran.

Thermal cycling and release, shock testing and vibration testing have all passed successfully. Mass, bracket stiffness and ultimate cable load have been determined.

Some aspects of the initial design did not perform as expected. These have been evaluated and redesigned into the final engineering model.

The engineering test program has proven to 'shake out' some short comings and provides guidance for implementing design improvements.

1. INTRODUCTION

In an earlier presented paper [1] the development of the NELS HDRS has been described by Airbus Defence and Space Leiden. The development has resulted in a first Engineering Model (EM-1). After the engineering test program a second engineering model (EM-2) has been designed and tested. This model is an update of the first engineering model based on the results of the engineering tests. This paper will present the results of the tests performed on both the EM-1 and EM-2 engineering models. The objective of the engineering tests was to proof feasibility of the requirements set agreed for the NELS development.

The NELS design has two application variants: a Solar Array HDRS and an Antenna HDRS (Fig 2). The core of the system is identical for both applications. The core contains two Thermal Knives, one prime and one redundant, providing the release of the system by cutting the restraint cable (Fig. 4).

The EM-1 design is shown in figure 1. Most of the tests have been performed based on this hardware design. The tests have been successful to 'shake out' the design limitations.

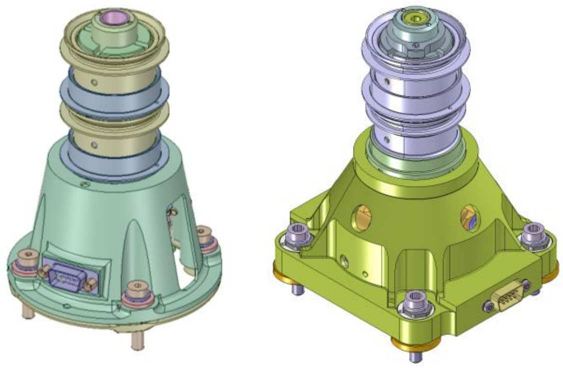

Figure 1. NELS Engineering Models: left: EM-1, right EM-2

A second engineering model was design based on the test results of EM-1. The redesign engineering model, EM-2 (Fig. 2, 3, 4) covers also some new requirements that were introduced in a later point in the project. Most important new requirements are: release sensor, symmetrical bracket stiffness and modified footprint 80mm x 80mm.

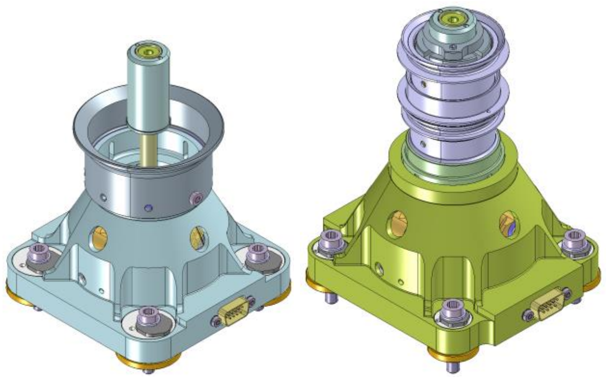

Figure 2. NELS application variants: Left: Antenna HDRS, Right: Solar Array HDRS

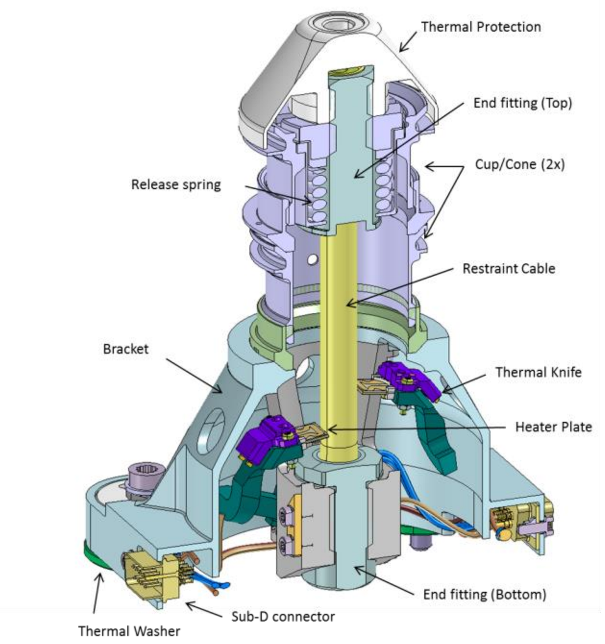

Figure 3. *Cross section of NELS (EM-2)*

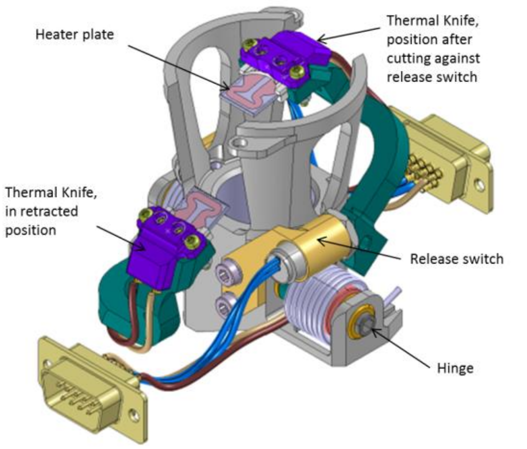

Figure 4. *Thermal Knife assembly (EM-2)*

The EM test program has the objective to prove feasibility of the requirements. In table 1 the design driving/key requirements are given.

Table 1: NELS Requirements

Property/parameter	***value***	***remark***
Stack height	68-170mm	
Axial preload cap.	15kN	
Ultimate load	> 45kN	Safety factor 3
Lateral load cap.	7400N	
Operating. Temp.	-144°C +152°C -80°C +97°C	End fitting (top) Bracket
Release time	< 90 sec.	
Release Shock	< 300g	up to 10kHz
Release Power	< 30W	
Mass of system	max. 620g	excl. cup/cone
Interface voltage	20V, 50V, 100V	
Isolation	double isolated	according ECSS
Storage time	1 year	pre-tensioned

2. TEST PROGRAM

The Engineering model is tested on different assembly levels. The restraint cable, thermal knife and bracket are tested separately on unit level. The system test required the full assembled system. The following tests are performed on the engineering models assembled from the procured hardware.

Restraint Cable testing (unit)

- Ultimate load (ambient, hot and cold)
- Ultimate load with rotated upper end fitting
- Ultimate load with tilted upper end fitting
- Long duration storage tests

Thermal Knife testing (unit):

- Ambient cutting
- Low pre tension cutting
- Hot and cold vacuum cutting
- Inrush current
- Maximum power test (glow test)
- Torque & friction of knife arm
- Redundant Thermal Knife test
- Vulnerability tests of the heater plate to various contaminants

Bracket testing (unit)

- Bracket stiffness
- Bracket sliding

System testing (full assembly):

- Mass
- Hold down and release test after 20 TVAC cycles
- Random vibration
- Shock generation

3. TEST RESULTS

Restraint Cable testing

The restraint cable has been tested on ultimate load for different environments and lengths. All results meet the target of a minimum of 45kN before the cable partly breaks or slides out of the end fitting. Typical ultimate load value for the end fitting cable design is for short cables 52kN and for longer cables 54kN. The difference can be explained by the improved setting of the longer braided cable.

The ultimate load under hot (+150°C) conditions drops due to the sliding of the cable in the end fitting to ~5kN. Since the release of the system is not dependent of the pretension in the cable and the mechanical loads are low during orbiting this is acceptable and is in some cases even preferable. The ultimate load under cold (-150°C) conditions drops to 37kN.

The cable braiding has its function to release the shock gradually but makes the cable inherently sensitive to twist. The influence of the braiding twist on the ultimate load has been tested. It can be concluded that the cable shall not be twisted more than 30 degrees to maintain its ultimate load properties.

Thermal Knife testing:
The Thermal Knife is the release initiation concept for the NELS system. The release shall be failure free under the worst case conditions. The Thermal Knife shall operate both on ground with ambient pressure under cleanroom conditions and in orbit under extreme thermal conditions. The worst case conditions for the release with Thermal Knife are at low temperatures and low pretension. This will increase the cutting time required to fully cut the cable. Several cutting tests have been performed to prove the on-ground cutting and also the on-ground life time of the Thermal Knife. Adjustments have been made to the Thermal Knife to optimize the cutting for both on ground cutting as well as in orbit cutting.

Figure 5. *Thermal Knife cutting Vectran cable*

In a vacuum chamber several cuttings at -80°C under high and low pretension have been made successfully. The cutting time is an indication of the efficiency of the cutting process and was used to tune the cutting angle of the heater plate.
The lifetime of a heater plate is determined by: the operating power, the number of cutting cycles and most important the pressure during cutting. In a low pressure environment (vacuum), the temperature of the heater plate will increase significantly. Tests have shown that life of the heater plate is mainly determined by the number of vacuum cuttings.

The Thermal Knife is spring driven. The spring shall take care that there is minimum pressure to make contact between the heater plate and cable. The contact is required to transfer the heat to the cable for the release of the hold down system. Torque and friction are measured in cold and hot case to verify the design and to determine the motorization margin. During the testing, it was found that the friction was rather high. Improvements were made on the hinge design to lower the friction of the Thermal Knife and these were successfully tested.

Besides the normal cutting tests some special situations are tested. The redundancy of the Thermal Knife is verified by starting the cutting with the prime Thermal Knife, then stop the activation and activate the redundant Thermal Knife to cut the cable successfully.
The cutting process has been stopped and restarted three times to verify the ability of the release process to restart. The test proved that the cutting is able to restart without large delays in overall cutting time.

The purpose of the vulnerability tests is to determine sensitivity of the heater plate in case of damage or contamination with materials commonly used in the space industry.
Heater plates have been tested on their sensitivity to damage or contamination. The heater plates are sensitive to MoS2 contamination but are not sensitive to finger print, Fomblin, salt water, IPA and scratches.

Bracket testing
The stiffness of the NELS bracket (EM-1) is tested using a 100kN pull bench. The interface towards the space craft is tested with and without thermal washers. The stiffness is also measured in two directions, see table 2. The analysed asymmetrical stiffness was verified by the measurements. The asymmetry of the bracket has caused some discussions. Finally it has been decided to add and requirement on the bracket stiffness symmetry and a corresponding redesign of the bracket. The figures 1, 2, 3 present the redesigned bracket.

Table 2: Measured Bracket stiffness with and without thermal washers

		Bracket Orientation	
		0°	90°
Configuration	*Thermal Washer*	*Stiffness [kN/mm]*	
NELS (EM-1)	*No*	*46*	*22*
	Yes	*20*	*11*
ARA Mk3 (reference)	*No*	*41*	*41*
	Yes	*29*	*29*

Note ARA Mk3 is the current base line hold down and release system for the Airbus Defence and Space Leiden Solar Arrays.

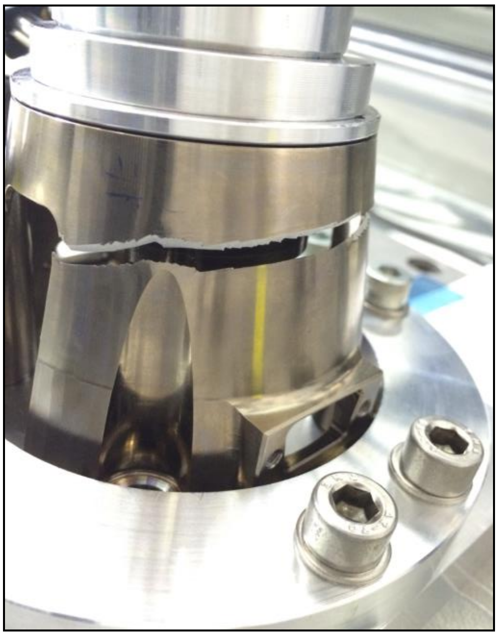

Figure 6. *Ultimate shear load of EM-1bracket: 20kN!*

Bracket sliding test revealed a design error in the thermal washers. The pretension of the interface bolts overloaded and cracked the thermal washers. The redesign of the washers will be tested during the qualification testing of NELS.

<u>System testing:</u>
The mass of the NELS hold down has measured part by part. In this paper only the mass of the relevant assemblies are reported.

Restraint cable, 52mm:	117 g.
Restraint cable, 155 mm:	121 g.
Locking nut top assembly:	77 g.
Bracket assembly :	414 g.
Total NELS EM 2 panel stack(1)	612 g.

The total mass includes 138 gram for the remaining items that will remain on the deployed element

Functional test of the hold down was done after integration and pre-tensioning of a 155mm (5 panel) stack. A load cell was added to the stack to monitor the preload during cycling. The thermal vacuum cycles test required different temperatures at the bracket and upper end fitting. To establish a temperature gradient over the stack two shrouds are installed on the bottom and top of the stack, see figure 7. The bracket temperature is varied between -115°C / +72°C and the upper end fitting temperature between -124°C / +155°C. After the first hot cycles the pretension drops significantly. In the remaining cycles the pretension gradually reduces to 3kN after 20 cycles.

(1) Note: Only slight difference in mass for a 2-panel stack vs 5-panel stack due to only cable length difference.

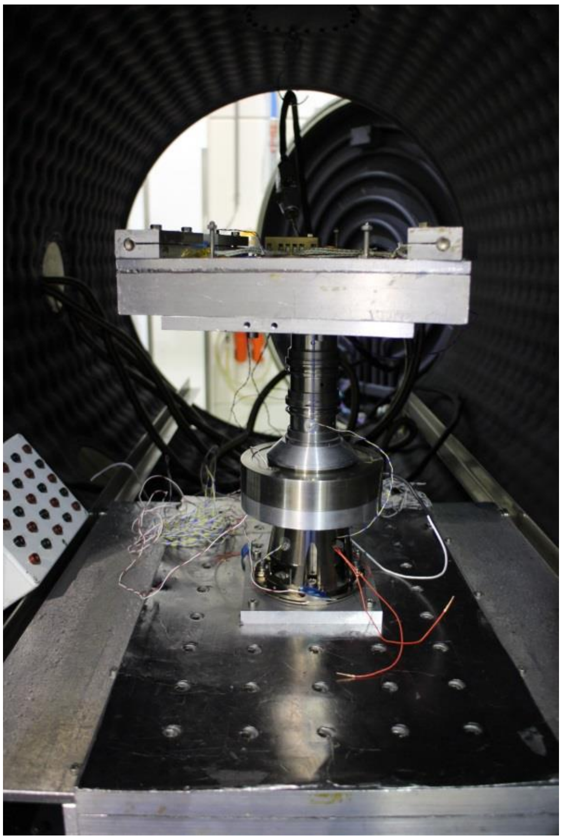

Figure 7. *NELS stack in vacuum chamber for thermal cycle test. Top and bottom cooling and heating establish a thermal gradient in the stack*

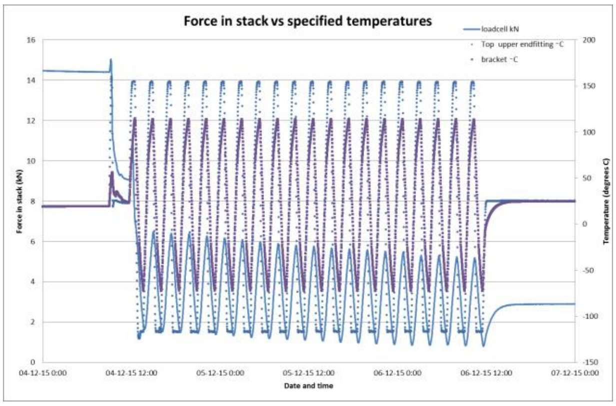

Figure 8. *Temperature and pretension during 20 cycles.*

After 20 thermal vacuum cycles a cut and release was done to proof the release function of the hold down system. The hold down was successfully cut and released. No sticking or degradation of the hardware was seen.

A random vibration test showed the robustness of the NELS design against vibration. The NELS system was tested in all its directions without dummy mass (Fig. 9). The Thermal Knife arm mechanism did not respond in the tested frequencies due to its low mass. The Thermal Knives are pressed against the cable in the launch condition. The potential abrasion of Vectran by heater plates during vibration has been investigated by test. The vibration test proved that polishing of the front edge of the heater plates reduced the cable damage to an acceptable minimum.

Figure 9. *Stacks on vibration table at Thales. View on cutting area of restraint cable after vibration testing.*

One of the big advantages of this concept is of course the very low shock during release. The emitted release shock is determined on a free hanging sandwich panel. The hold down is installed with interface bolts into the panel inserts in the Aluminum sandwich panel. The shock levels are measured with accelerometers in the center of the hold down and at 100mm interval from the hold down (Fig. 10). The measurement results indicated the highest shock level in the accelerometer positioned in the center of the hold down. The level that has been measured for the NELS hold down with 15kN pretension is ~2g. The reference ARA Mk3 HDRS measured a shock of 900g, which is already considered as a low shock device.
The NELS shock level is even an order lower than other hold down and release systems. It opens new application options of installing shock sensitive hardware closer to the S/C side wall (e.g. ceramic mirrors)

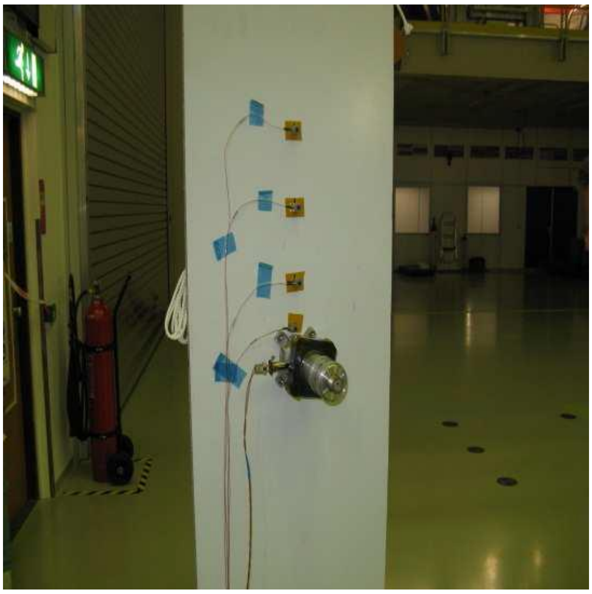

Figure 10. *NELS hold down mounted on free hanging sandwich panel. Accelerometers placed 100mm interspace*

4. EVALUATION OF RESULTS

The engineering test program started with the original engineering model hardware (EM-1). The engineering tests showed that some improvements were needed to meet the requirements for NELS.
One of the main points that was found during the engineering testing is the **cutting of Vectran** in extreme environmental case required more clearance between the heater plate and the already cut cable. The test showed that it is very important for the cutting process to move the already cut Vectran cable away from the heater plate. Heating the already cut cable slows down the cutting process and creates the risk of burning Vectran cable. The updated engineering model (EM-2) was improved with more clearance to have both in ambient and vacuum cold testing optimal cutting performance.
Another point found was the asymmetry in **bracket stiffness**. This was finally not acceptable due to the dependency of the hold down orientation on the Solar Array. Together with the redesign of the thermal washer this design improvement resulted in an increased S/C interface mounting pitch of 80mm x 80mm.
Functional testing of the NELS hold down after 20 thermal vacuum cycles proved that the concept and cutting process is well implemented in the design. The challenging requirements of pre tension, temperature envelope and overall system functionality are proven.
The **vibration testing** showed that the requirements are feasible and no damage to the restraint cable is made by a polished heater plate.
Shock testing revealed that the NELS hold down and release system has an ultralow shock that is an order lower than most available hold down and release

devices. This ultra-low shock creates new opportunities for the S/C developers. (e.g. new application area's: instrument payloads and ceramic mirrors)

5. CONCLUSION

The engineering test program on EM-1 has proven its function to 'shake out' the short comings that were still in the design. The short comings resulted in redesign activities, which were extensively tested and resulted in a final engineering model (EM-2) ready for qualification.
A qualification test plan has been written as part of the qualification work acknowledged by a C&G funding. The qualification program for the NELS hold down and release system will envelop of both the Solar Array application as well as the Antenna application.

REFERENCES

[1] J. Augustijn, M. Grimminck, E. Bongers, T. Konink, Development of Non Explosive Low Shock (NELS) Holddown and Release System, 16th European Space Mechanisms & Tribology Symposium ESMATS 2015 Bilbao, Spain