ADEO Passive De-Orbit Subsystem Activity Leading to a Dragsail Demonstrator: Conclusion and Next Steps

Clean Space Industrial Days, ESTEC

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Outline

- Space debris issue
- Objectives and requirements
- Project team
- Subsystem design
- Analysis
- Breadboard tests
- Demonstrator test campaign
- Conclusions and next steps.

Artist impression of space debris in LEO, source ESA

Objective

- Design, manufacture and test a sub-system constituted by a boom and a membrane
- Used in LEO to augment the drag of small satellites (fit within VEGA envelope)
- De-orbiting period shall not exceed 25 years
- High packaging density for low mass rati.o

Requirements

- **Ultra-light weight**

  lower mass than propellant
- **Scalable**

  capability to simply enlarge the drag area
- **Generic**

  adaptable for multiple type of LEO missions
- **Passively stabilised**

  no active control system needed
- **Modular**

  also only ¼ or ½ ... can be used.

The ADEO team

- **ESA**

  Customer (GSTP activity, under contract 4000112253/14/NL/SW)

- **HPS (prime ADEO)**

  System Engineering, Subsystem Detailed Design, Analysis, Subsystem Assembly and Test

- **HTS (prime Deployable Membrane)**

  Mechanisms, Membrane

- **Etamax**

  Debris Modelling & Stabilisation Techniques

- **DLR Bremen**

  Reference Mission, Design Support, Testing

- **DLR Braunschweig**

  Deployable Boom Design & Manufacturing

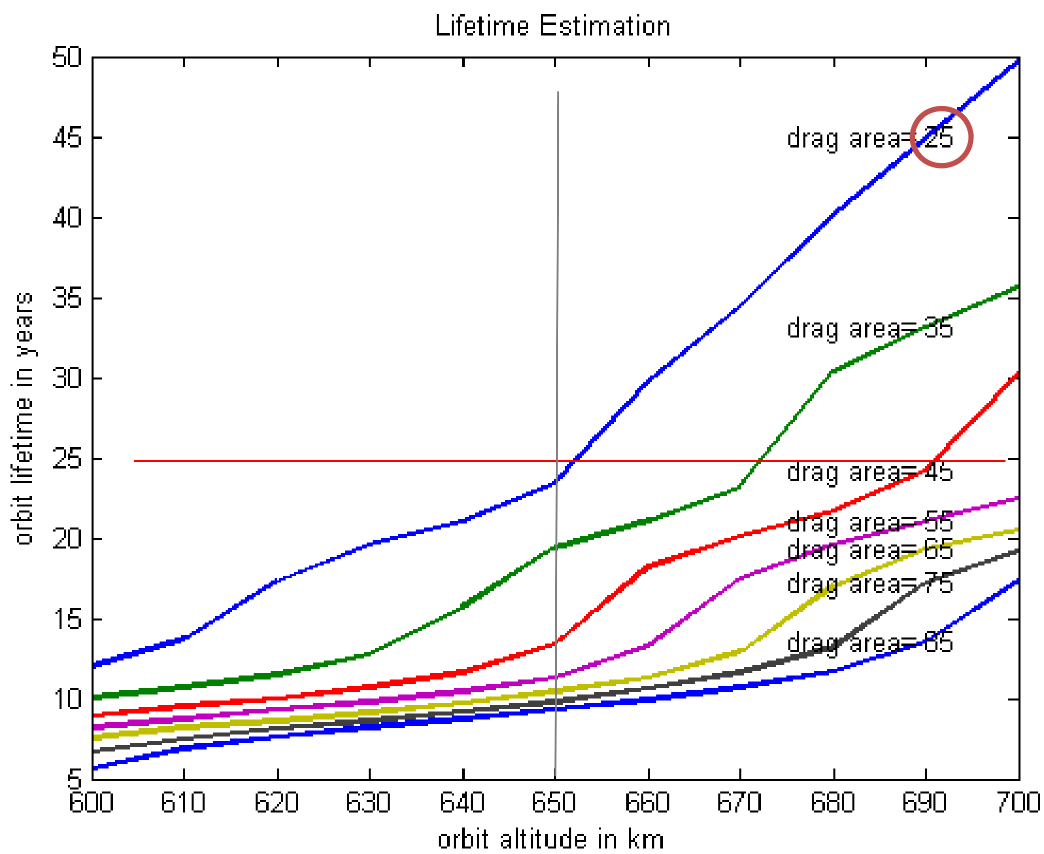
Preliminary De-orbiting Analysis

- 1000 kg satellite
- 650 km orbit altitude
- Top Requirement:
  De-orbiting within max. 25yrs

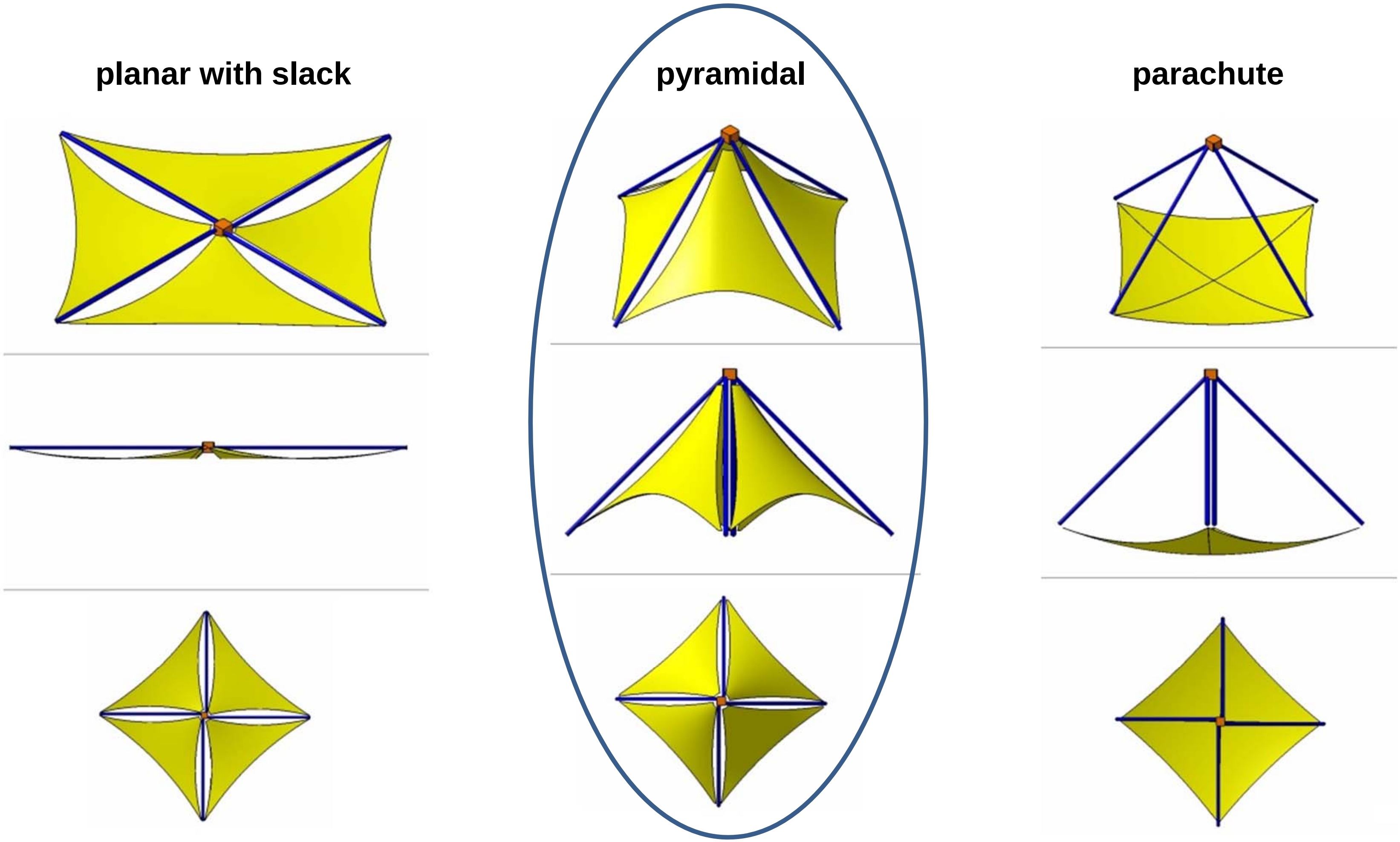
→ 25 m² drag area.

Simulation:

- 2014 start solar activity
- >700 km solar pressure is dominant.



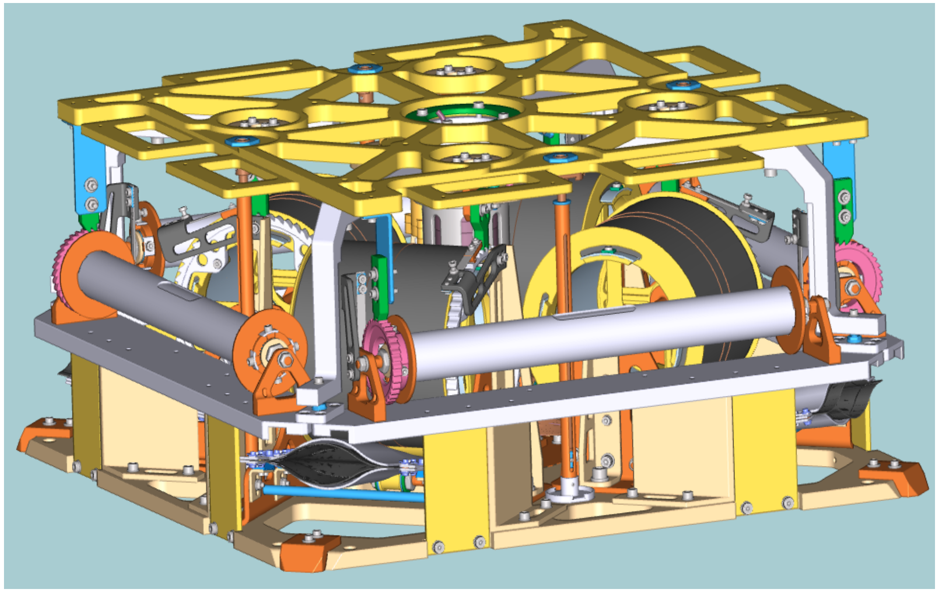
Initial Concepts



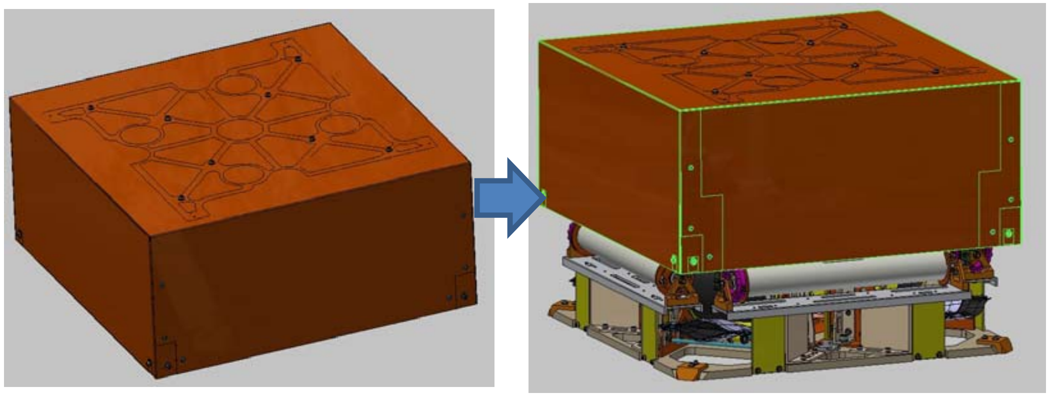
ADEO design trade-off

ADEO Subsystem Design

- 4 boom spools, 4 membrane spools
- 1 stepper motor for boom deployment
- Protective cover for in orbit storage period
- Lifting cover solution limiting number of mechanisms & complexity, HDRM with pin puller
- Launch locks on all spools released with HDRM activation.



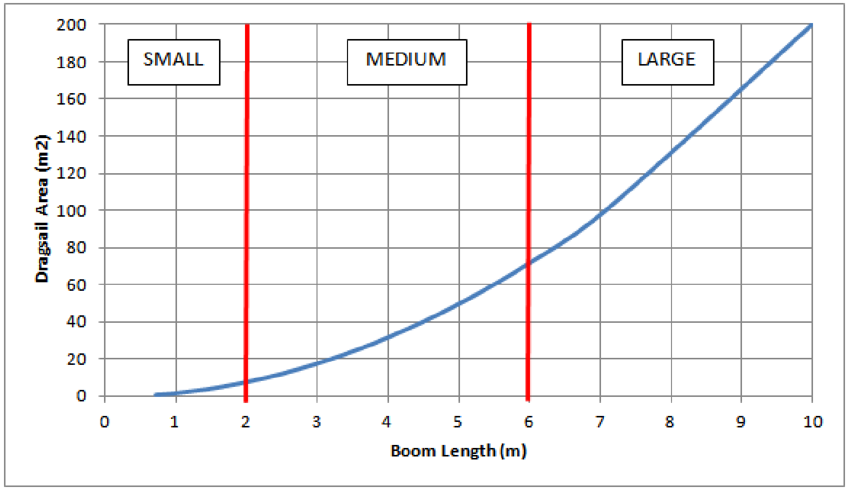
CAD of ADEO with hidden cover



CAD of ADEO in stored configuration and with lifted cover

ADEO Subsystem Design

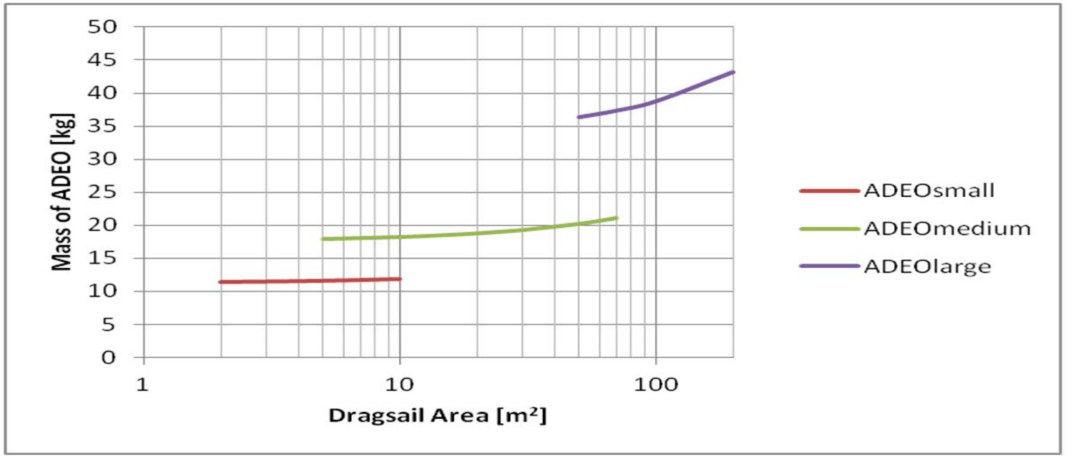
Three size groups (boom length unlimited):

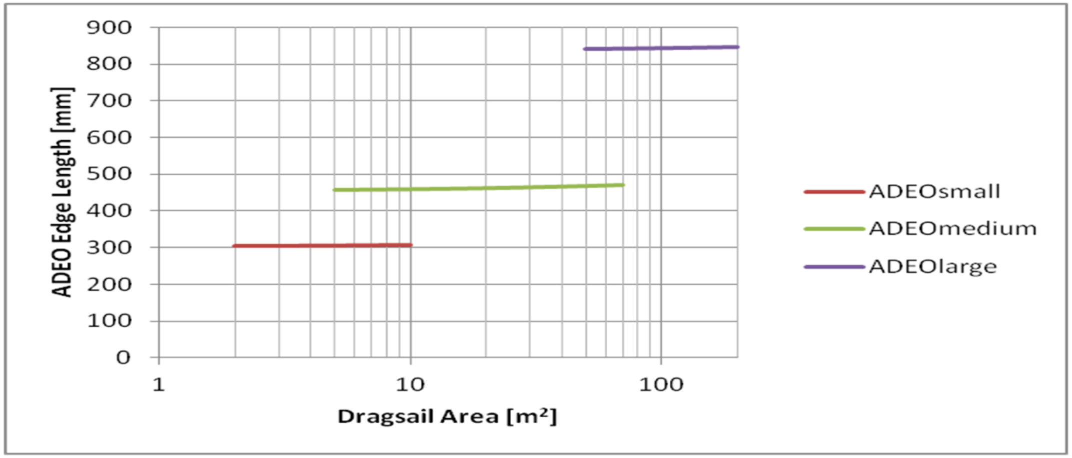


Demonstrator:

- Dragsail: 25 m^2 -> boom length: 3.5m
- Size: 470 x 470 x 240 mm^3
- Mass: 19 kg

Scalability (Mass & Size):

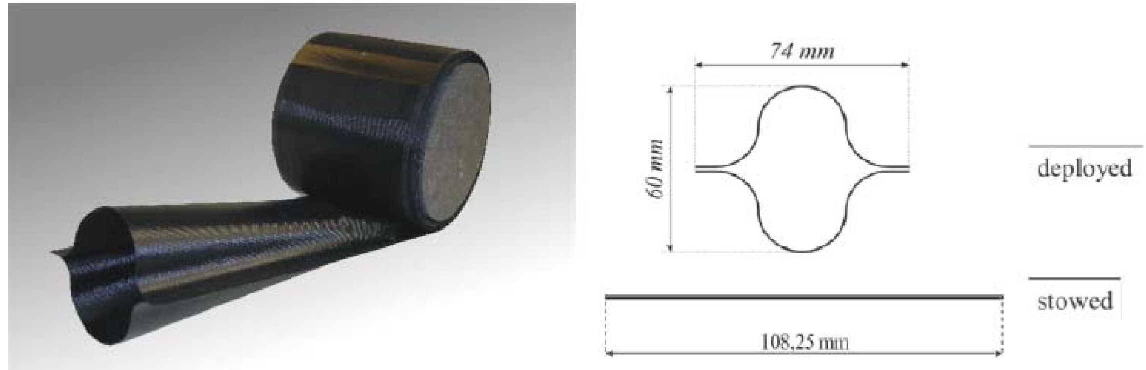




Boom and Membrane

Boom:

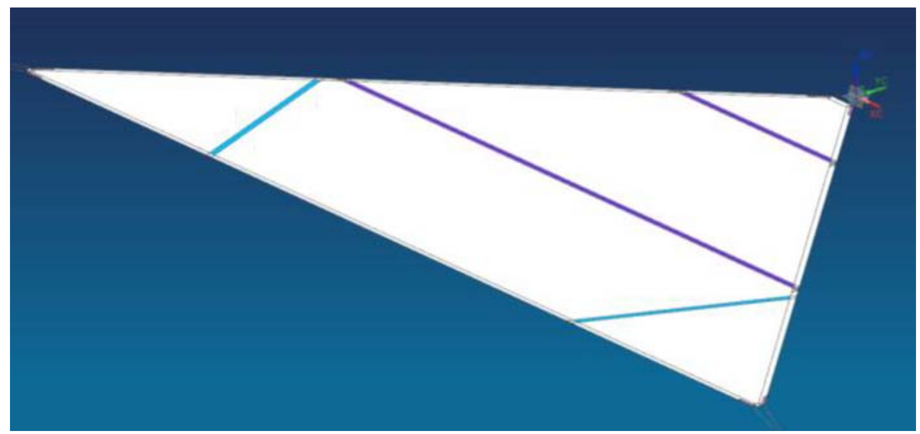
- CFRP boom (3.5 m length)
- Double-omega shape
- Flattened profile stowed on coil.



Stowed CFRP boom deployed from coil

Membrane:

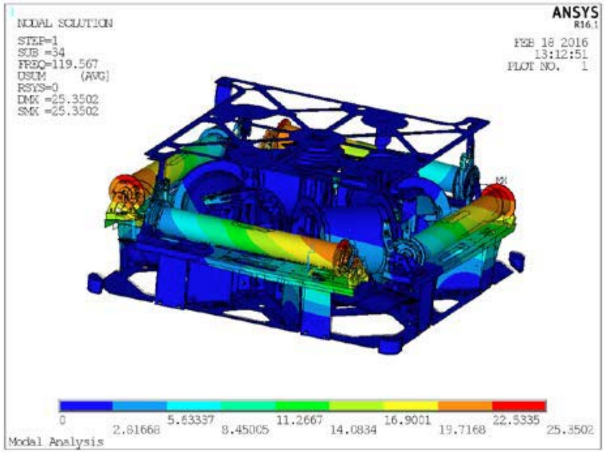
- Triangulars with 5 m edge length
- Stored on membrane spools
- Alluminized ultralight polyamid foil.



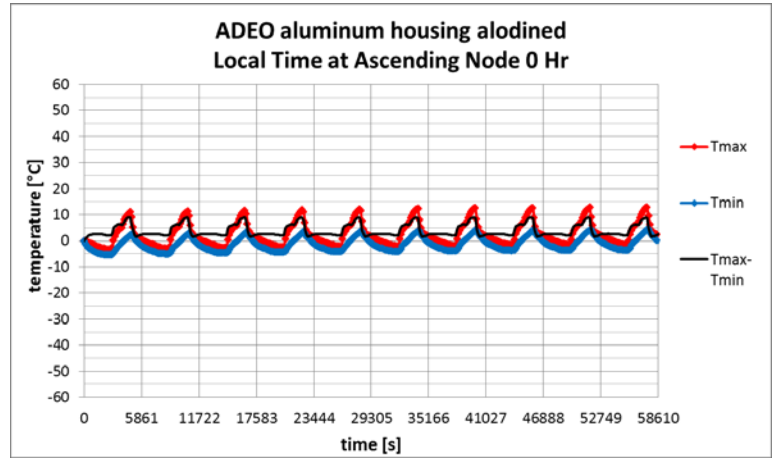
CAD model of membrane traingular

Analysis

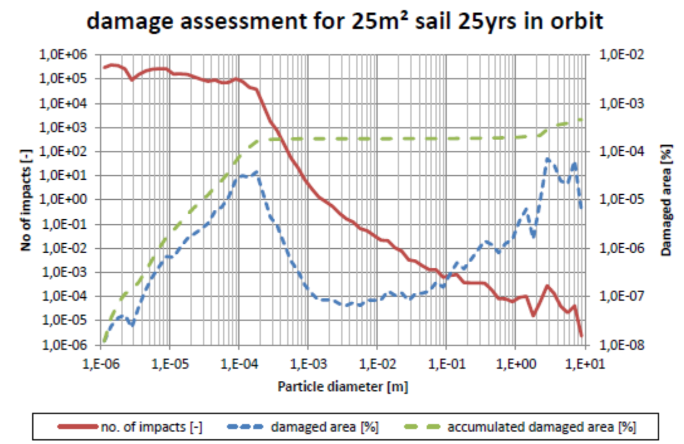
FEM



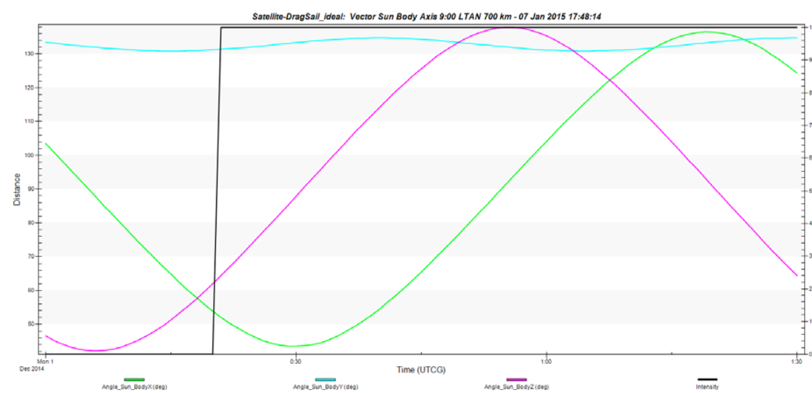
Thermal Analysis



Space Debris Assessment



Stability



The ADEO De-Risk Activity Team

- **ESA**

  Customer (GSTP De-Risk activity).

- **HPS GmbH**

  Project Management, Reference Mission Review, Input from ADEO Activity.

- **Astos Solutions GmbH**

  Dynamic Analysis, De-Orbit & Stability Assessment and Analysis.

Goals of the Analyses (ADEO De-Risk)

- The activity is a de-risk pre-cursor activity and analysed if passive de-orbiting with the ADEO sub-system is feasible, effectively advantageous or not.
- Demonstration of the performance robustness of the drag sail de-orbitation system with respect to uncertainties in the environmental conditions and satellite design!
- The dynamic stability of the system had to be studied to better understand the performance of the sail. In particular, it shall be understood under which conditions (orbit, environment, satellite and sail properties), stability cannot be guaranteed or becomes unlikely. In this case it shall be understood if the instability reduces the sail performance and if it could damage the sail due to high rotation rates.

Conclusions ADEO De-Risk

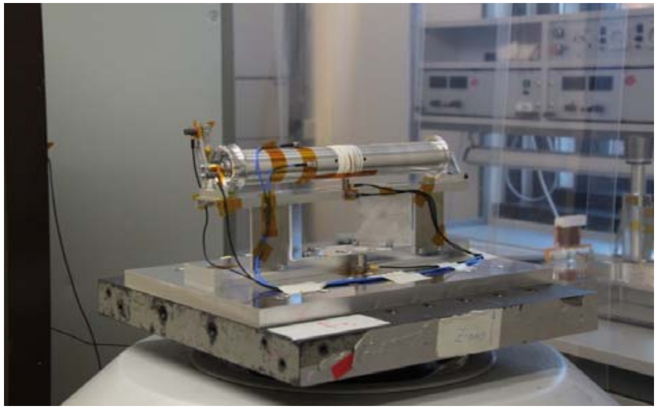
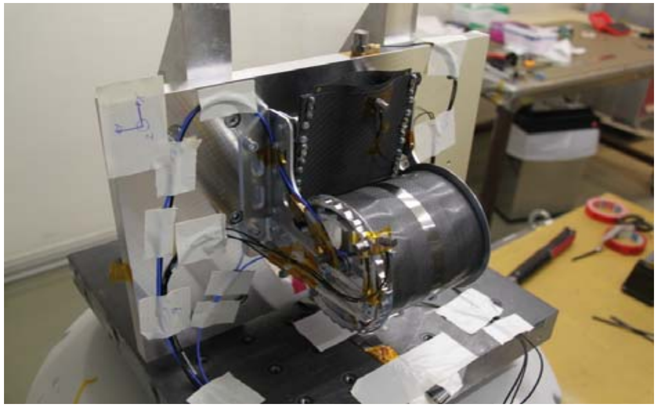
The main outcomes of the ADEO De-Risk Dynamical Analysis are:

1. The drag sail shortens the post mission life time significantly (e.g. 97% faster de-orbit time with a $25 m^2$ sail on a 300 kg satellite from a 600 km orbit compared to the same satellite without a sail: 5 years instead of 140 years).
2. Depending on the satellite (mass, inertia, …) and the start altitude the best de-orbit behavior can be optimized using different sail angles (change of pyramidal angle between 0° to 60° already realized in former ADEO GSTP activity).
3. No active GNC is required, passive de-orbit is possible. In high altitudes (>500 km), the dragsail will slightly tumble. But a tumbling rate of non critical 1.4°/sec and a maximum torque moment of only 4.0×10^{-4} Nm will not be exceeded over the de-orbit time (assuming worst case conditions).
4. Analysis and tests during ADEO and previous activities (e.g. DLR's Gossamer) showed that the ADEO subsystem has a safety factor of well over 100 to the worst case tumbling loads (tumbling rate and maximum torque).

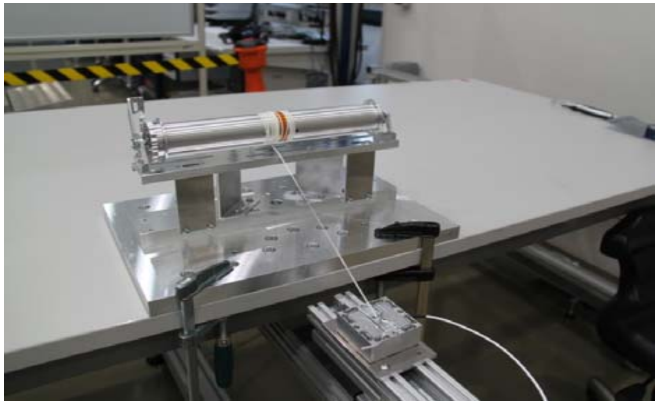
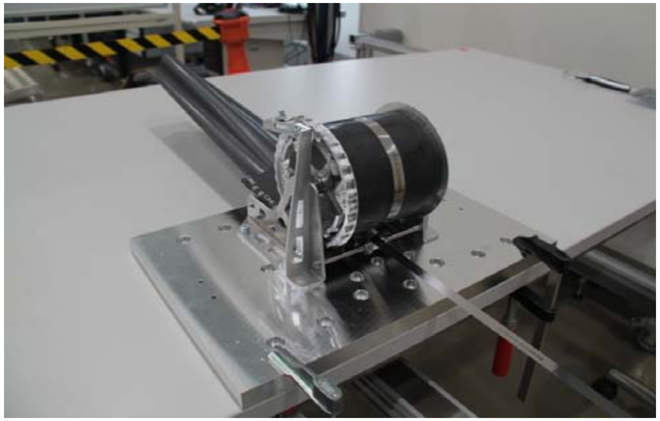
IN CONCLUSION IT HAS BEEN VERIFIED THAT THE DE-ORBIT WITH DRAGSAILS IS FEASABLE AND THAT IT IS A VERY EFFICIENT PASSIVE DE-ORBIT SOLUTION FOR SMALL SPACECRAFTS.

ADEO Breadboards

› Vibration and functionality tests

Boom and sail assembly vibration tests

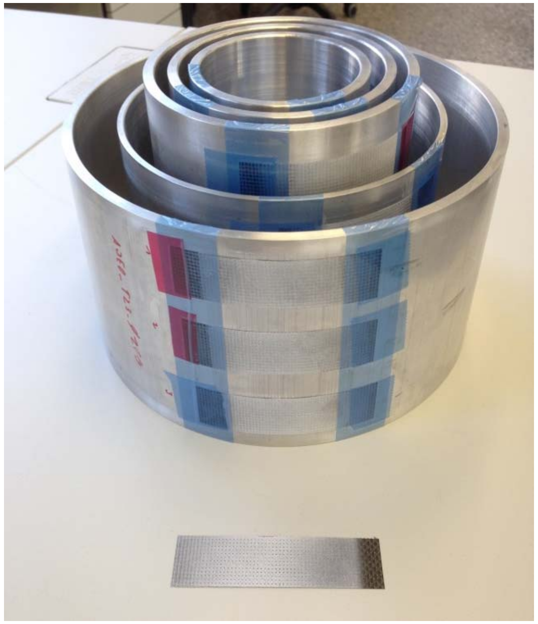



Boom and sail assembly functionality breadboards

Fully deployed ADEO boom

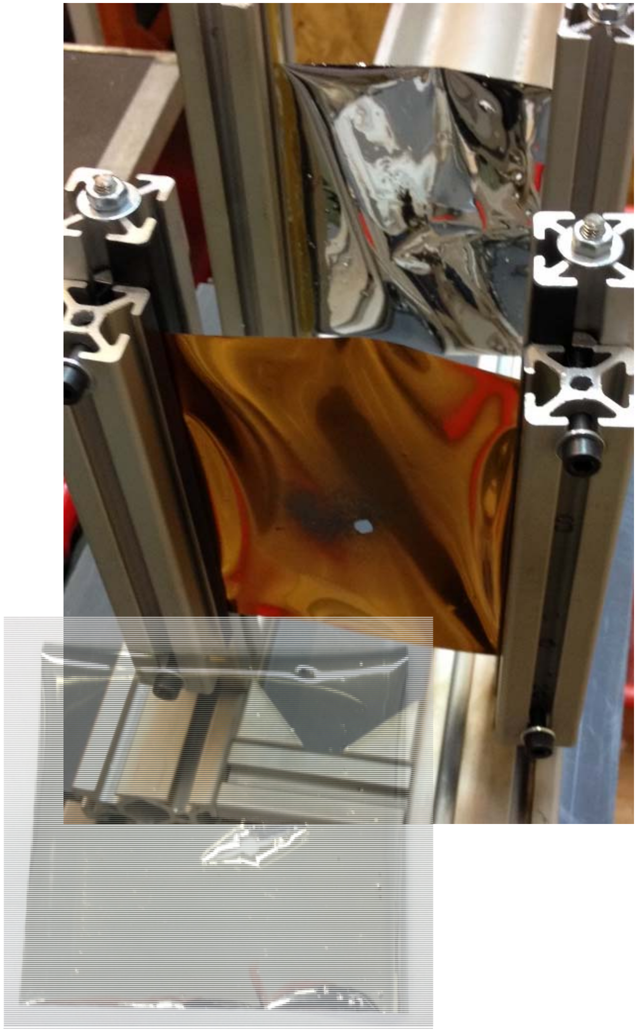
ADEO Breadboards

› Creep and Impact BB Tests



Boom creep tests

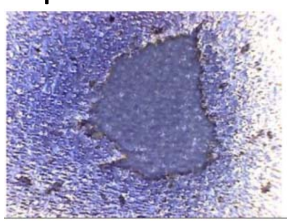
Boom impact tests

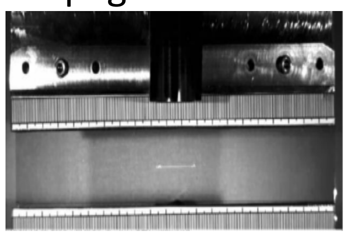


Sail impact tests

Membrane Tests
(as part of DEPLOYABLE MEMBRANE (HTS prime, HPS & DLR sub))

- **DEPLOYABLE MEMBRANE parallel project to ADEO**
- **Sail design & fabrication**
- **Environmental survivability**
  - Vibration, thermal cycling, rapid decompression, full sail deployment
  - Impact and Crack Propagation





  - ATOX & UV radiation

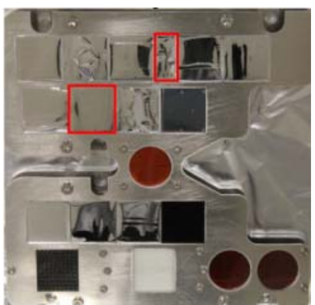


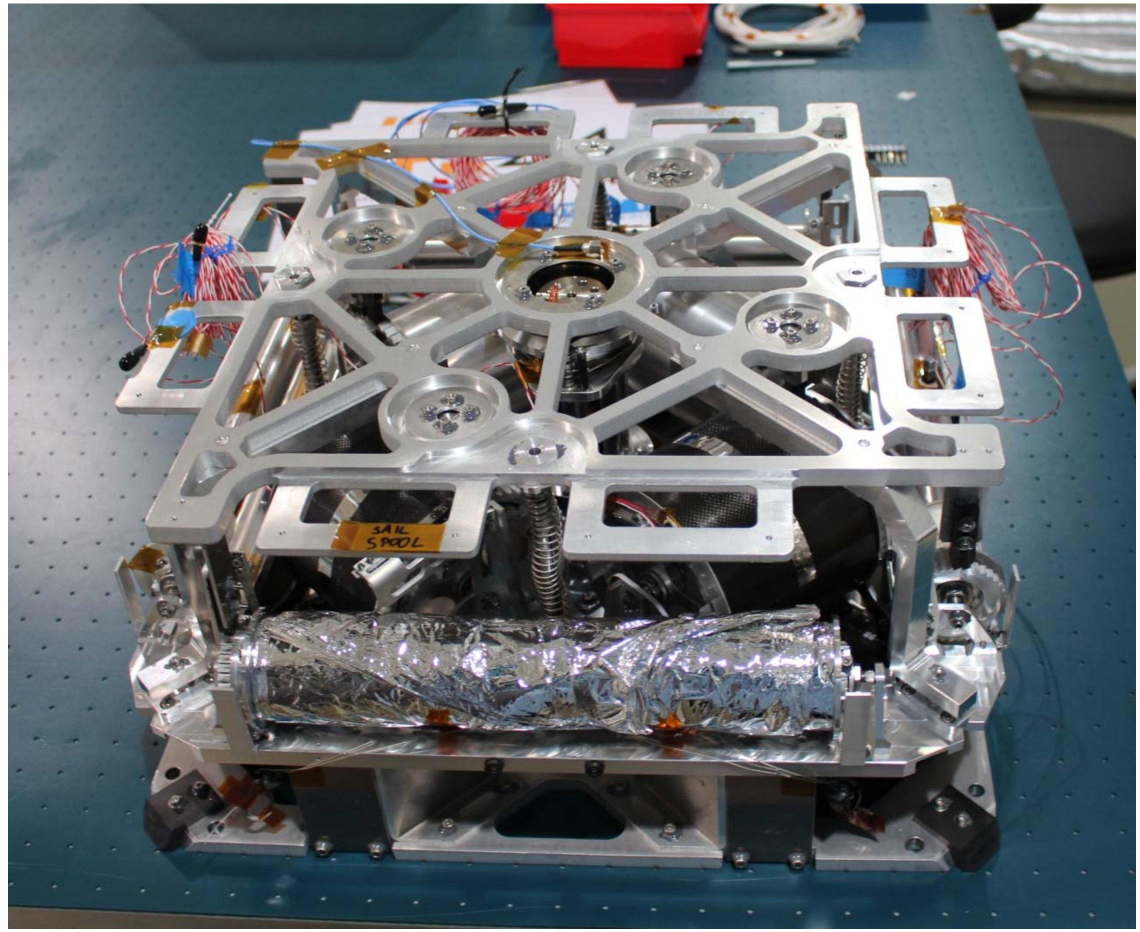
Figure 16 A set of samples after 150h of the irradiation time.

Folding of sail segment

Deployment of sail segment

ADEO Demonstrator

- Complete subsytem with flight representative mechanisms and components
- Designed for 25 m^2 drag sail area with 4 sails (testing with 1 sail)
- Deployment via 4 CFRP booms (testing with 2 booms).



ADEO demonstrator stored configuration

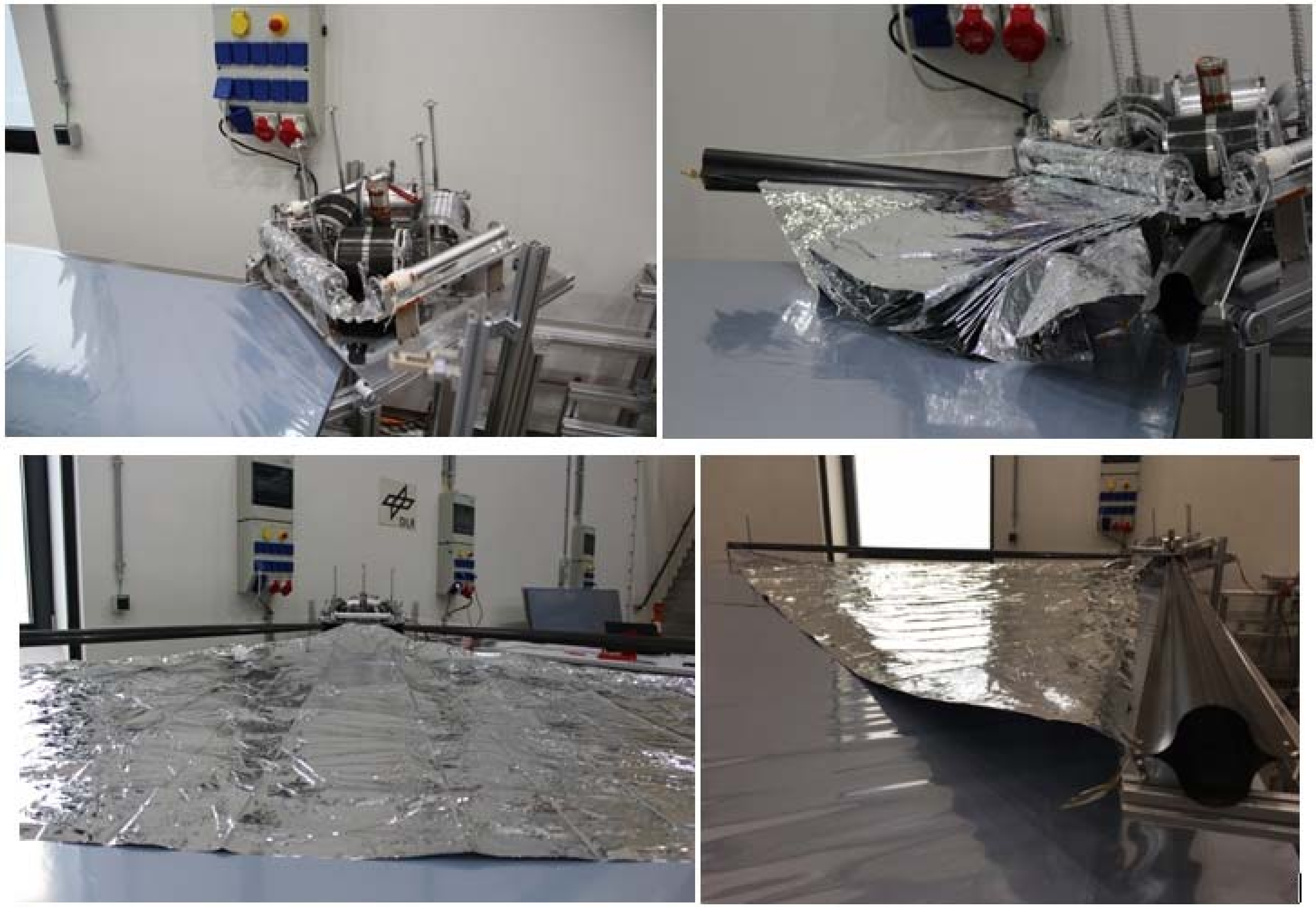
ADEO Demonstrator Test Campaign

Test as you fly approach:

Launch:	First a **vibration test** (representative sine and random loads on all three axes) was carried out simulating the launch loads followed by a **rapid decompression** test mimicking the pressure decrease during launch (Vega launcher depressurization profile).
In-Orbit Storage:	The temperature change of an orbiting space craft was mimicked via **thermal cycling** test.
Deployment:	The deployment was initiated with **mechanism activation in hot and cold TVAC conditions** leading to a **full deployment** (partial in **TVAC** and rest in ambient)
De-Orbit:	The **survivability** of the materials during the **25 year de-orbiting** time was verified by extensive **Atomic Oxygen (tested @ ESA/ESTEC labs), UV and thermal cycling** tests. Furthermore, the effect of **space debris impacts** was verified by crack propagation analysis and impact tests.

Full Functionality Test 1

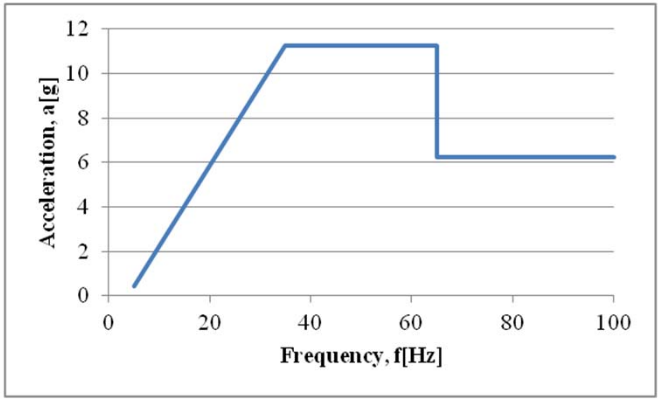
- Firing of HDRM
- Full Deployment at ambient conditions.



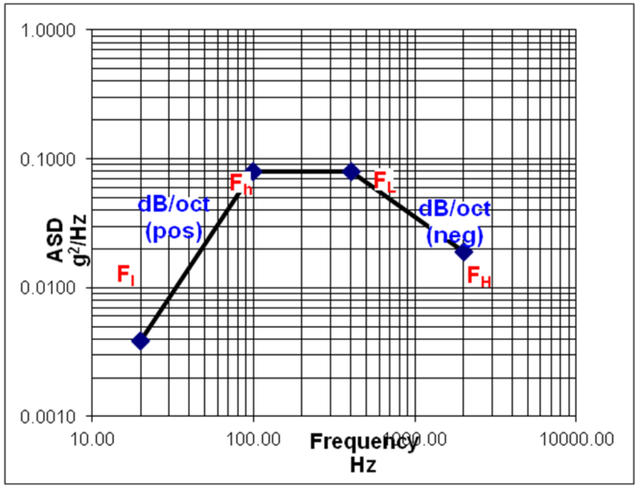
ADEO demonstrator deployment, functionality test 1

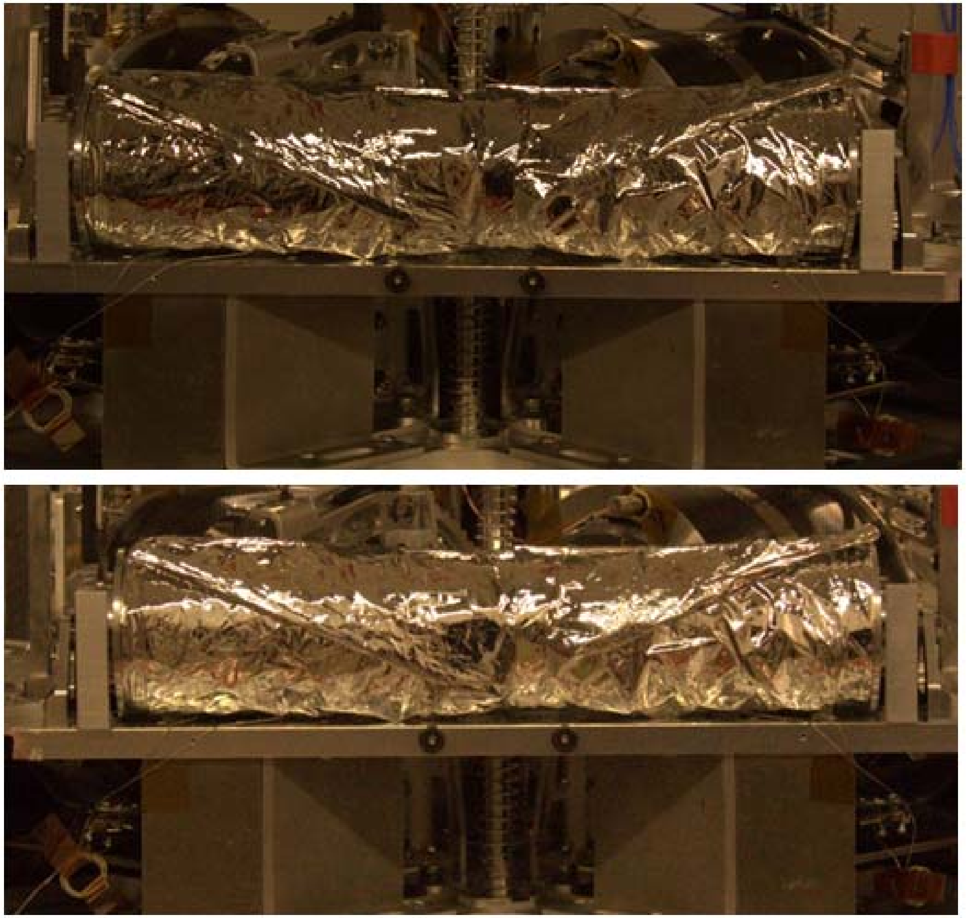
Vibration Test

- **Sine (x, y, z):**



- **Random (x,y, z):**

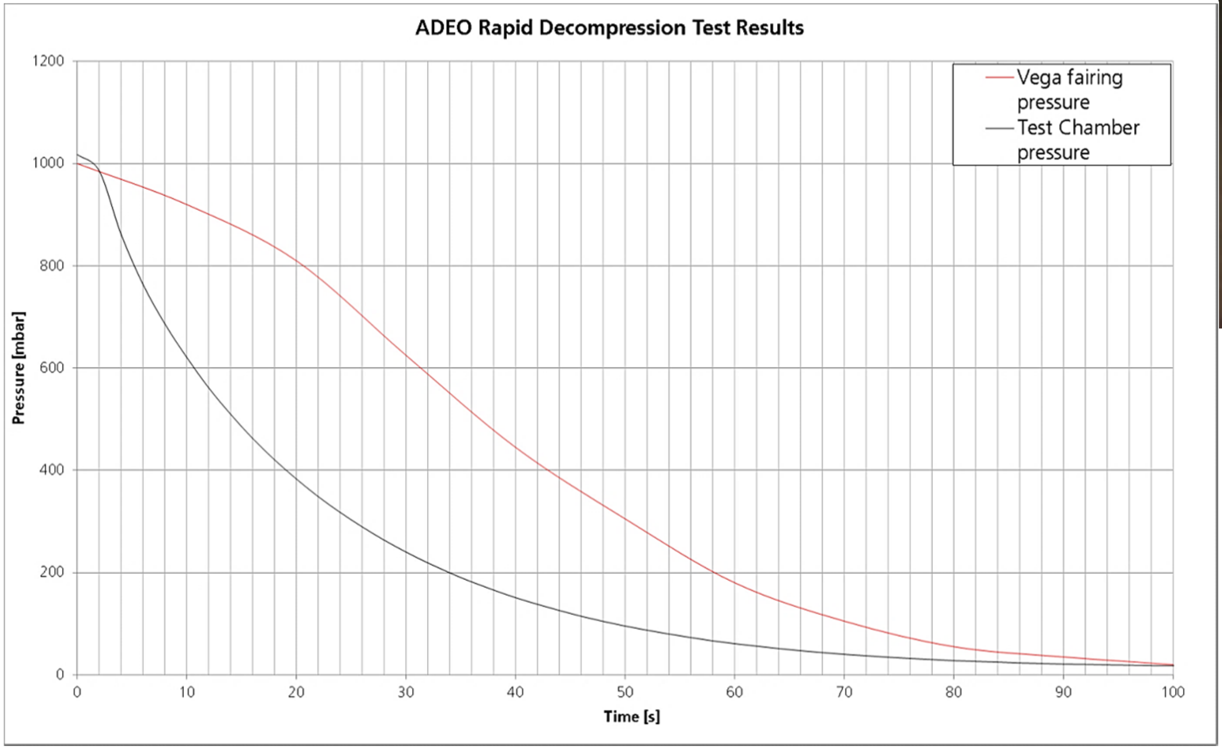


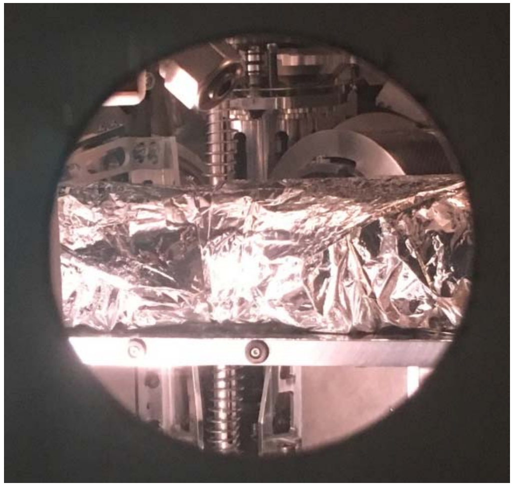


Sail package before (top) and after (bottom) vibration test

Rapid Decompression Test

- **Decompression Profile:**

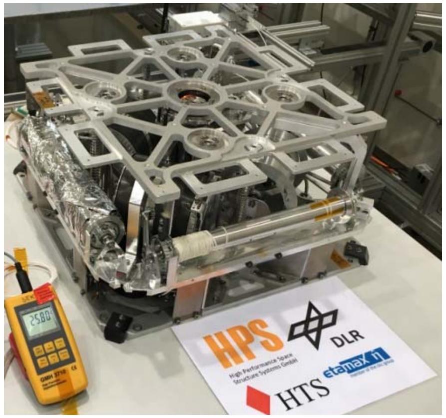


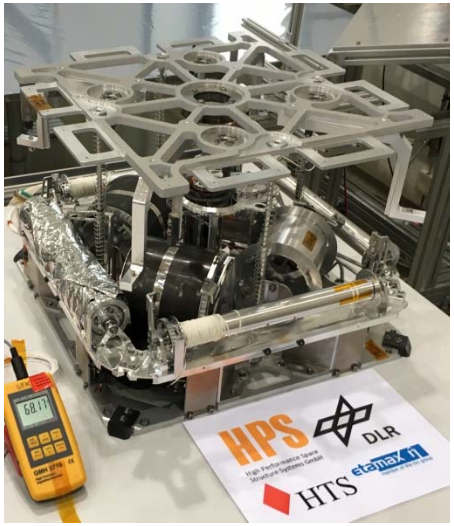


ADEO demonstrator in decompression chamber

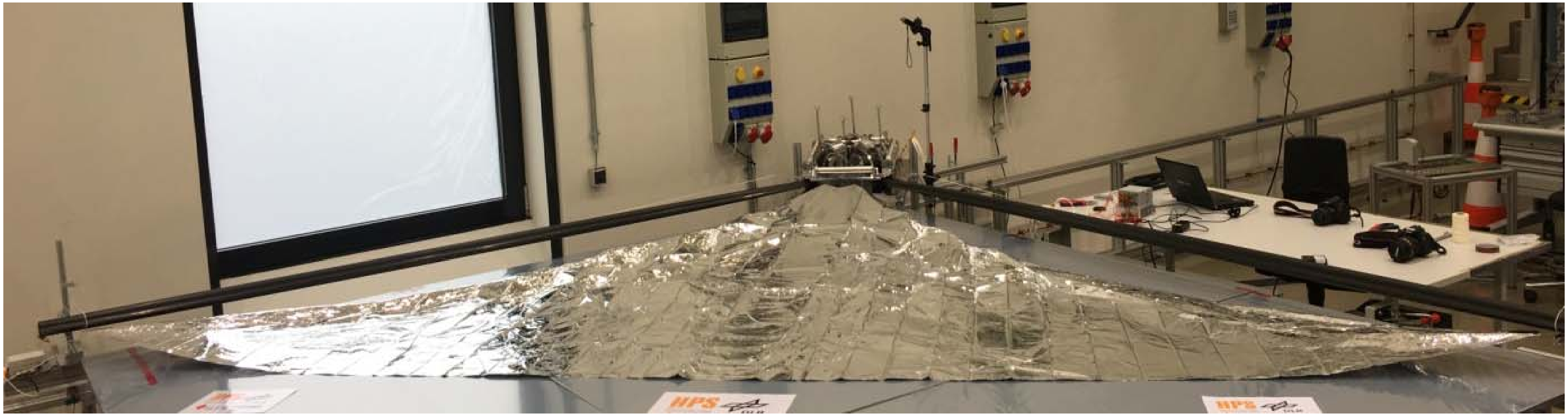
Full Functionality Test 2

- **Firing of HDRM:**



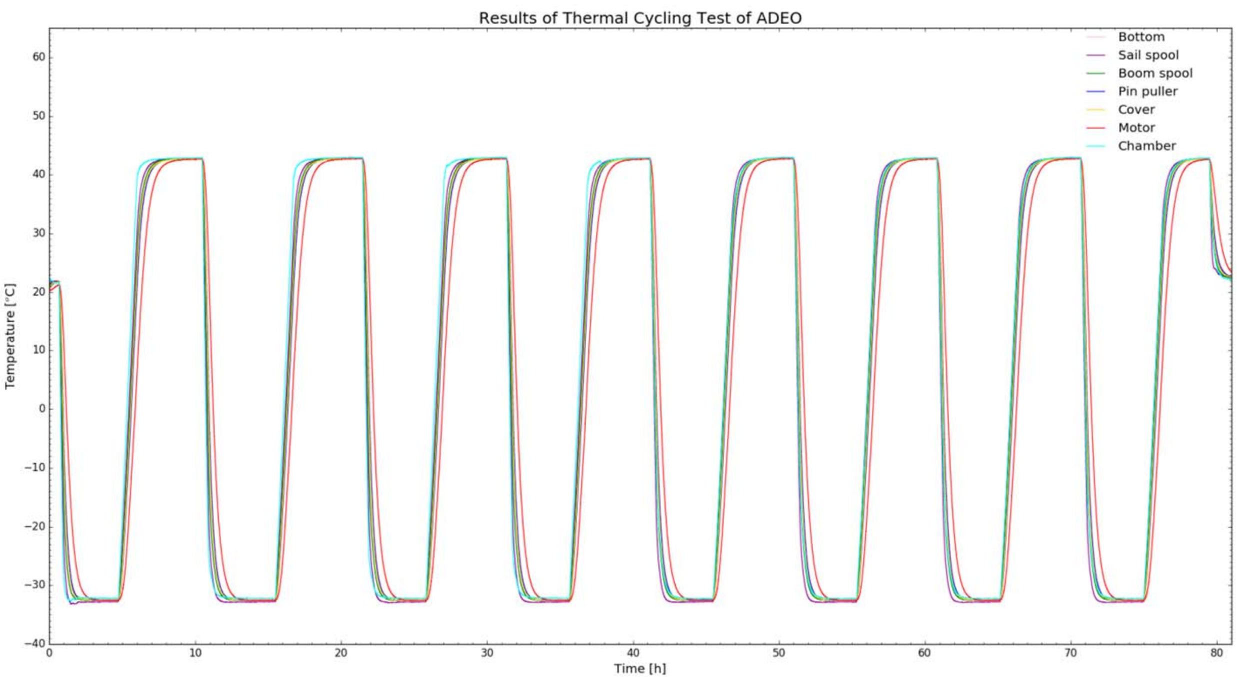


- **Full Deployment at Ambient:**

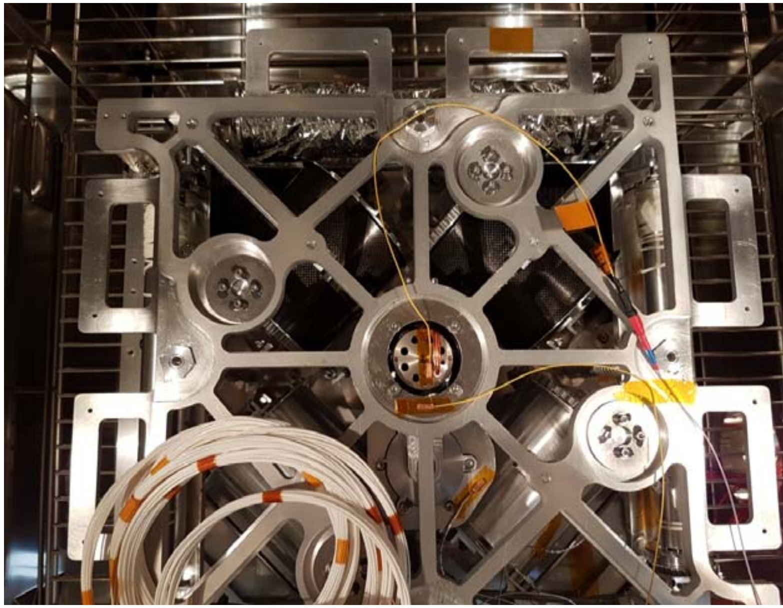


Environmental Test 1/3: Thermal Cycling

- 8 cycles
- -30°C to +40°C
- Climate Chamber



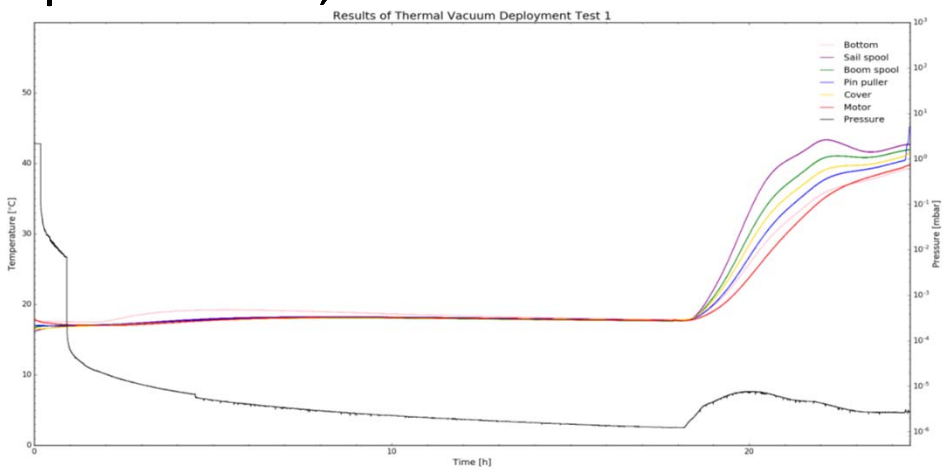
Thermal Cycling Temperature Profile



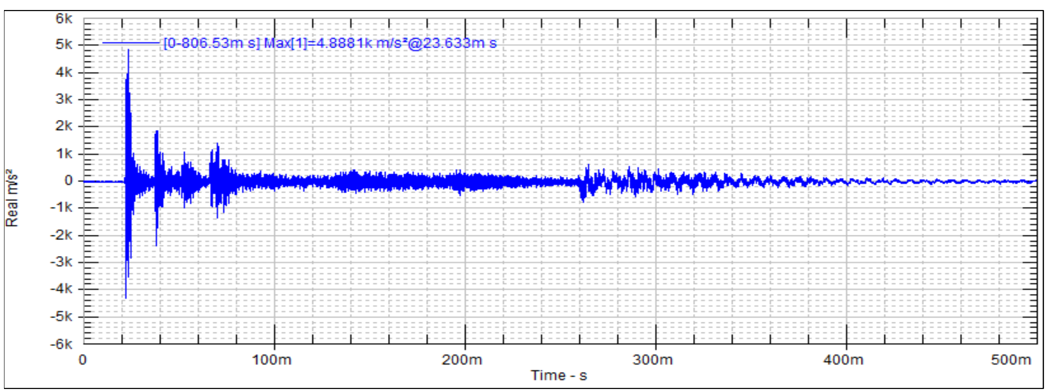
ADEO demonstrator in climate chamber

Environmental Test 2/3: Mechanism Test at HOT TVAC Conditions

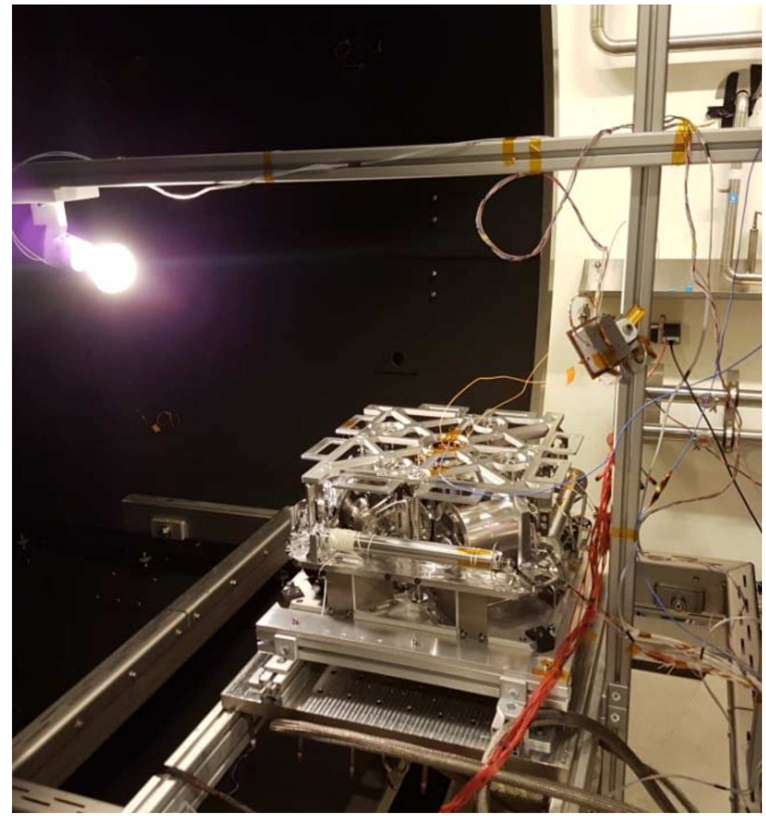
- **Temperature: +40°C, TVAC**



Temperature and vacuum profile before, after and during test



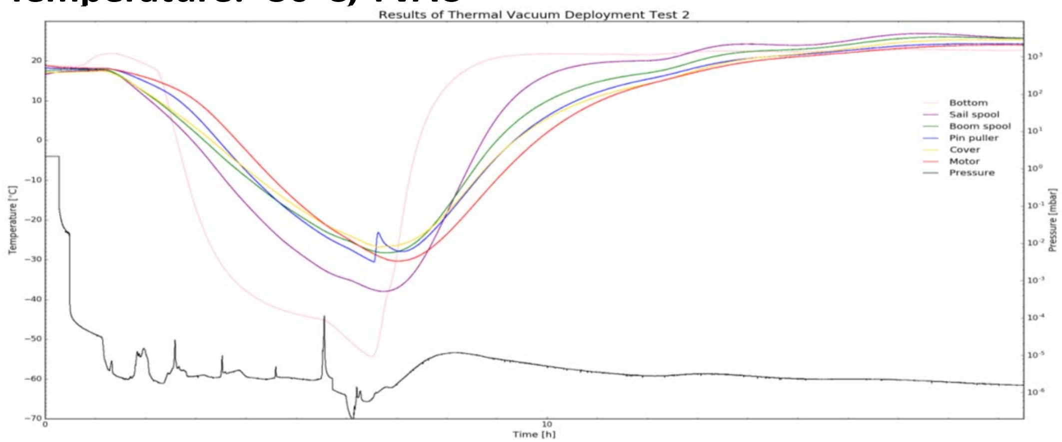
Acceleration measurement at HDRM activation



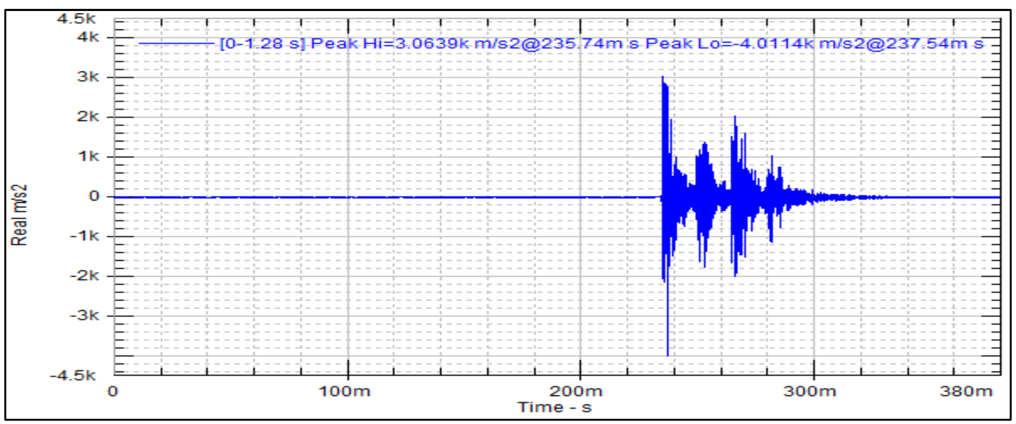
ADEO demonstrator in TVAC chamber

Environmental Test 3/3: Mechanism Test at COLD TVAC Conditions

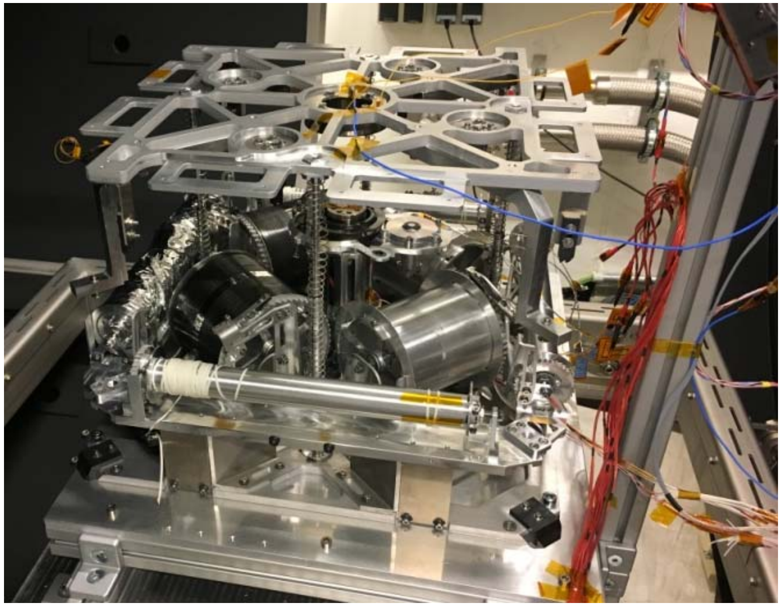
- **Temperature: -30°C, TVAC**



Temperature and vacuum profile before, after and during test



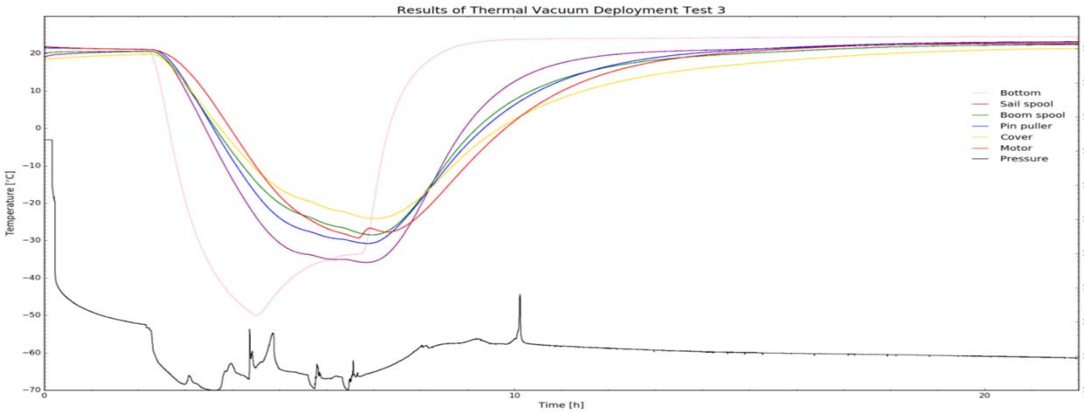
Acceleration measurement at HDRM activation



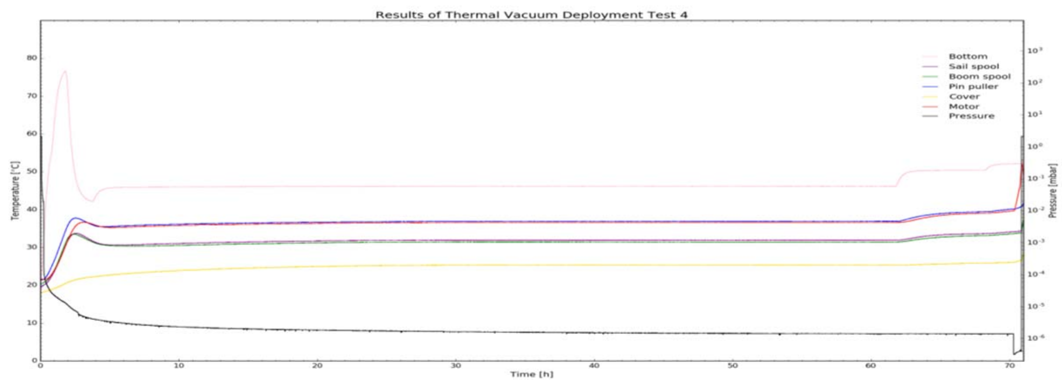
ADEO demonstrator with released cover in TVAC chamber

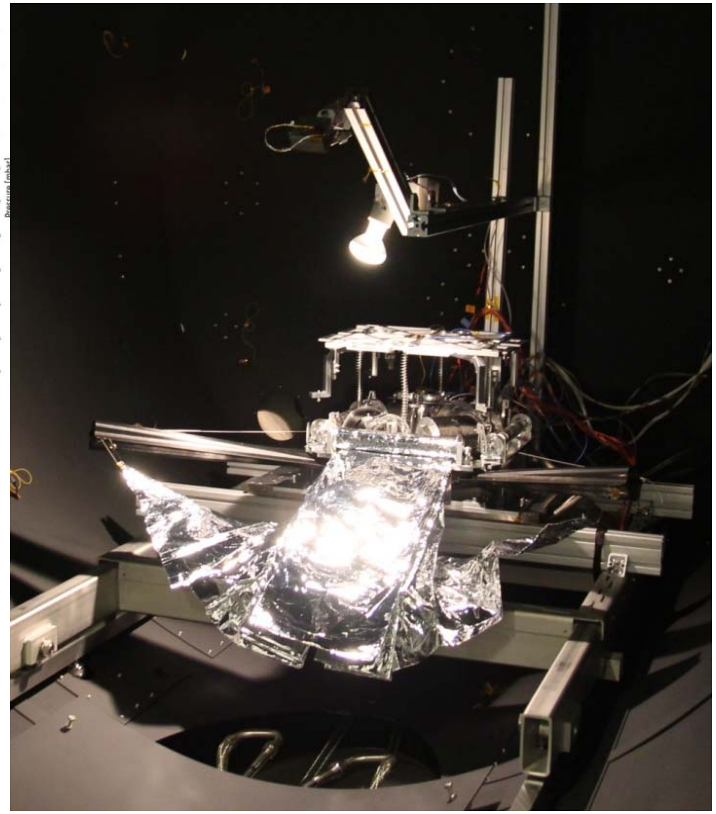
Deployment Test 1/2: Partial Deployment in HOT and COLD TVAC

- **Cold Deployment at -30°C, TVAC:**



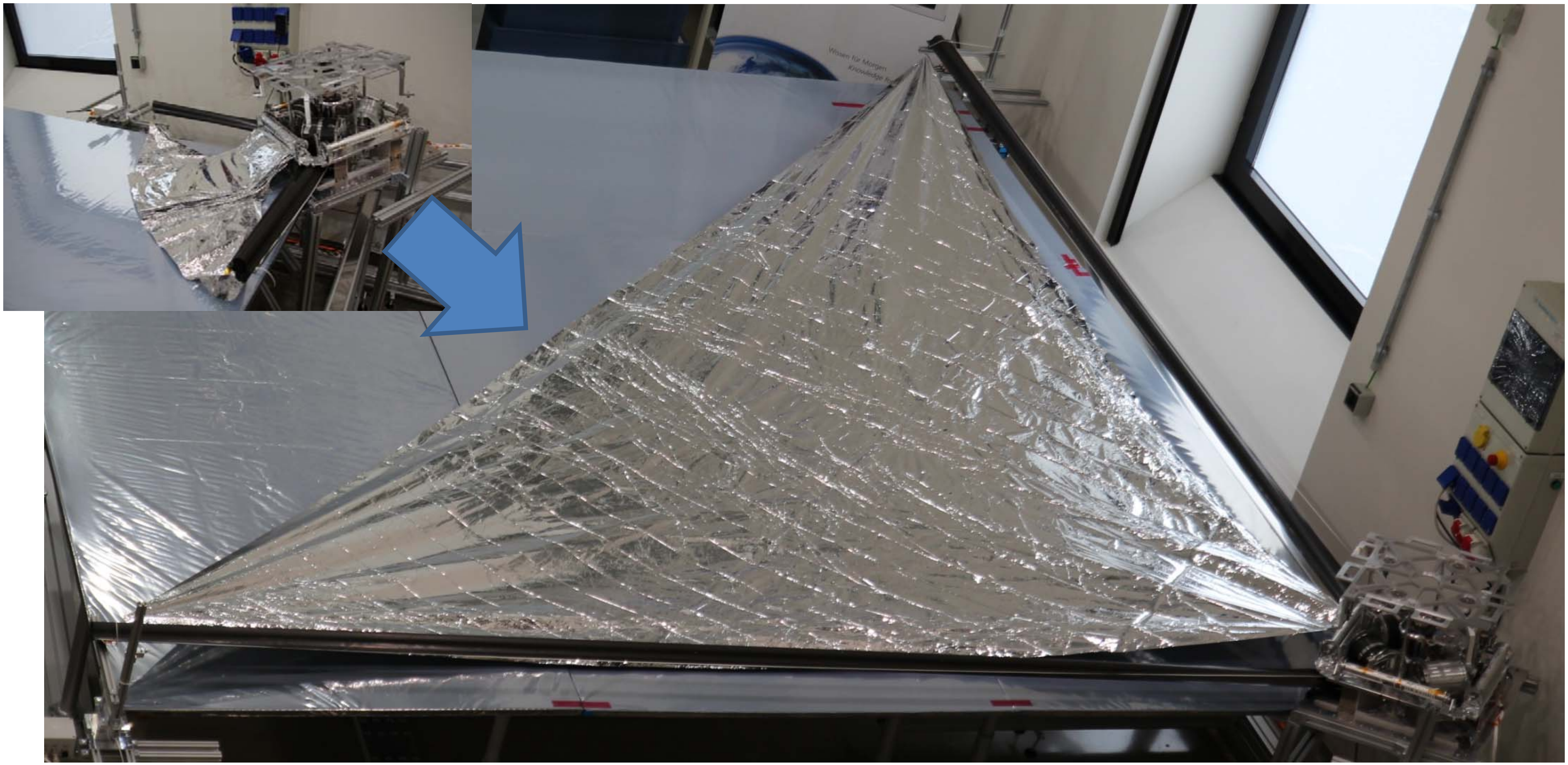
- **Hot Deployment at +40°C, TVAC:**





ADEO demonstrator partially deployed in TVAC chamber

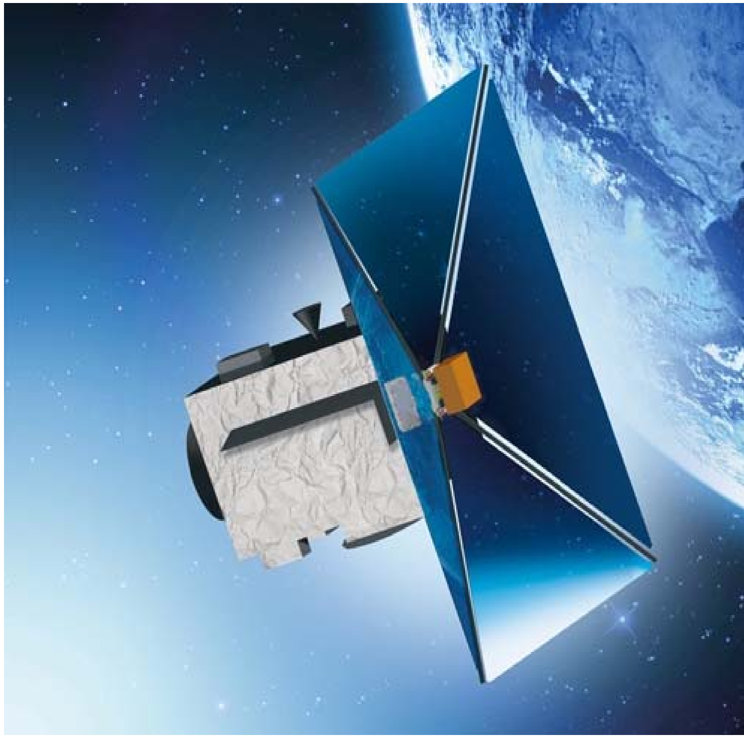
Deployment Test 2/2: Full Ambient Deployment



Full deployment successful: Demonstrator Test Campaign sucessful, raising TRL of ADEO to 5/6.

Conclusions

- **All technologies, parts and materials from European Companies**
- Means to **de-orbit passively within 25 years**, no GNC required
- **Modular and scalable** subsystem for satellites from 100 kg – >1500 kg (dragsail area from 2 m^2 to >200 m^2)
- **Adjustable pyramidal angle** from 0° (flat dragsail) to 60°
- **Lower mass compared to propellant** and engine mass required to de-orbit
- **Materials that can withstand >25 years de-orbiting time** (space debris impact, UV, ATOX and thermal cycling test campaign)
- **Verified by test for launch loads** (vibration and rapid decompression) **and orbital loads** (thermal cycling and deployment in hot and cold TVAC conditions) leading to TRL 5/6.
- **Next steps:**
  - **IOD preparation (until 2019), IOD (~2019/2020).**



Artist impression of 25m^2 ADEO dragsail attached on 1000 kg reference satellite

Thank you for your attention!

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