THE ADEO PASSIVE DE-ORBIT SUBSYSTEM: REFERENCE MISSION SELECTION AND PRELIMINARY DESIGN OF PROTO FLIGHT MODEL

Clean Space Industrial Days 2018


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1. Avoiding Space Debris for a Clean Space

Current Space Environment:
› Space debris in orbit increases since beginning of space flight
› LEO, MEO, GEO full of space debris

Europe for a Clean Space:
› International guidelines enforce disappearance 25 years after end of mission
› ESA is pushing, as global leader, for a „Clean Space“. (Ref: Space Debris Legislation: ESA/ADMIN/IPOL(2014)2)

Technical Solutions:
› Many variants under discussion and development:
  · Rocket engine for de-orbiting
  · Dragsails
  · Tethers
The „ADEO“ Solution

ADEO-Application Area:

› passive solution:
  · using rest-atmosphere to decelerate
  · augmentation of drag-area by a deployed sail.
› Applicable to LEO-orbit: up to 750 km (perigee)
› For all satellites cleared for uncontrolled de-orbit

ADEO „Family“:

› ADEO-L (Large for satellites between 100 and <1.500 kg)
› ADEO-N (Nano for cubesats and larger: 1 – 100 kg)
› ADEO-M (Medium class: overlapping L- and N-class).
2. Previous Activities

The ADEO-1 Project (2014-2017)

Project Team

› ESA: Customer
› HPS Germany: Prime, system engin., design & analysis, S/S AIT
› DLR Bremen/Braunschweig: boom and sail technology
› HTS: sail development and mechanisms
› ETAMAX: debris modelling & stabilisation techniques

Programmatics:

› GSTP-Program
› SME driven
› Parallel activity („DEPLOYABLE MEMBRANE“):
   sail development, primed by HTS
Preliminary De-orbiting Analysis

Key Specifications:
- 1.000 kg satellite
- 650 km orbit altitude
- De-orbiting within max. 25 years
  ⇒ 25 m² drag area.

Simulation:
- 2014 start solar activity
  ⇒ above 700 km solar pressure is dominant.
ADEO Demonstrator

- Complete subsystem with flight representative mechanisms and components
- Designed for 25 m² drag sail area with 4 sails, but demonstrator testing with 1 sail segment only
- Deployment via 4 CFRP booms, but demonstrator testing with 2 booms only
ADEO Demonstrator Test Campaign

Test as you fly approach:

<table>
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<tr>
<th>Launch:</th>
<th>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).</th>
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<td>In-Orbit Storage:</td>
<td>The temperature change of an orbiting space craft was mimicked via thermal cycling test.</td>
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<td>Deployment:</td>
<td>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)</td>
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<td>De-Orbit:</td>
<td>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.</td>
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Sail Critical Testing
(as part of DEPLOYABLE MEMBRANE Study (HTS prime, HPS & DLR sub))

Environmental survivability

- Vibration, thermal cycling, rapid decompression, full sail deployment
- Impact and Crack Propagation
- ATOX & UV radiation

Folding of sail segment

Deployment of sail segment
Deployment Test: Full Ambient Deployment (after vibration, TC & TVAC)

Full deployment successful: Demonstrator Test Campaign sucessful, raising TRL of ADEO to 5/6.
2.2. ADDA ADEO De-Risk Dynamical (De-Orbit) Analysis
The ADEO De-Risk Activity

Project Team
› ESA: Customer
› HPS Germany: Prime, Reference Mission Review
› ASTOS Solutions:
  · Dynamic analysis
  · De-orbit & stability assessments and analysis

Programmatics:
› GSTP-Program
› SME driven
› Duration: 05/2017 – 08/2017.
Conclusions of ADEO De-Risk Activity ADDA

1. The drag sail shortens the post mission life time significantly: e.g. 97% faster de-orbit time with a 25m² 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°).

3. Sail angles of 0° are fully acceptable for meeting de-orbit requirements without GNC.

4. 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 x 10⁻⁴ Nm will not be exceeded over the de-orbit time (assuming worst case conditions).

5. 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.
3. Current Activities

3.1 ADEO(2) (2018-2020): Towards a flight ready dragsail PFM
ADEO2 (ESA GSTP activity) - Objective

The objective of this activity is to:

• define a reference mission for a passive de-orbiting sub-system (ADEO) for a LEO S/C

• define requirements for the ADEO subsystem to be flown with this reference mission

• Based on this mission and requirements, to flow down the requirements to an IOD.

• Based on the IOD requirements, a PFM shall be designed, developed, manufactured and fully qualified.

The refurbished (after all environmental tests) PFM is the final deliverable which can then be directly used for an IOD in a follow-up activity.

The de-orbit subsystem shall be built using the technologies developed in the previous ESA GSTP developments. Electronics for an autonomous deployment shall be flight standard. An on-board camera for a possible future IOD mission shall be included in the subsystem design (it shall not be a new development) and it must be possible to download the pictures. Mechanical and ground support equipment (GSE) for the verification of the de-orbit subsystem shall be designed and manufactured.
Teaming

ADEO2: Prototype and Qualification of a De-orbiting Subsystem (Issue 1, 04.04.2018)

HPS (SME, D)
- (Project Mgmt, System Engineering, S/S Design, S/S Analysis, Internal (IF, S/S Assembly, MLJ, Test Coordination, Lead PA))

SME, D
- (Stability & De-orbit analysis)

SME, D
- (Debris Modelling & Re-entry Analysis)

SME, D
- (Sail Engineering, Boom Design & Manufact., PFM Testing)

SME, D
- (Sail Manufacturing, Mechanism input, HIRM)

SME, D
- (Boom Assessment Industrial POV)

SME, D
- (Deployment Electronics and EGSE)

SME, D
- (Battery Design)

SME, D
- (Accom. Concepts to Satellites & Interfaces)

LSI, D
- (Accom. Concepts to Satellites & Interfaces)

QinetiQ
- (Satellite Accom. via ext. service)

R&D, D

RUAG, D
- (Development, Mechanism input, HIRM)

INVENT
- (Boom Assessment Industrial POV)

DSI
- (Deployment Electronics and EGSE)

ASP
- (Battery Design)

Electrical Parts (Motor, ...)
(ext. Service)

Mechanical Parts Manufact.
(ext. Service)

MLI Manufact.
(ext. Service)
Project Flow

Phase 1:
• Requirement Definition for Reference Mission and IOD (-> 10/18)
• Preliminary Design (->12/18)
• Breadboards and Confidence Life Tests (-> 04/19)
• Detailed Design (-> 10/19)

1 Month Gap (Kick-off Phase 2: 11/19)

Phase 2:
• Manufacturing/Assembly of PFM (-> 03/20)
• Testing of PFM (->06/20)
• Refurbishment of PFM (->08/20)
ADEO2: Main dimensions Preliminary Design

- **Stowed Configuration:**
  Stored in a box of 42 cm x 42 cm x 18 cm

- **Deployed Configuration:**
  25 m$^2$ drag sail area 5m x 5m

- Total mass of 8 kg
- First natural frequency = 140 Hz
ADEO2: Reference Mission Trade Off

Most interesting region for ADEO: 400-700km
Mass of applicable satellites: 100-500kg

Most promising as future missions: ALTIUS & PICE
Most promising as IOD/IOV: EC IOD/IOV call, RocketLab/Ecliptic Enterprises Hosted Payload Programme
Accommodation:
Satellite size 0.8m x 0.65m x 1.2 m
ADEO2: Main Requirements

› The ADEO subsystem shall be designed, build and tested for a S/C with a wet mass of 100-500 kg in an sun synchronous orbit with a starting altitude of 400-700 km.

› The ADEO subsystem shall de-orbit the S/C with re-entry taking place within 25 years.

› The ADEO subsystem shall be passively stabilized.

› The S/C plus ADEO subsystem shall not exceed the maximum allowable casualty risk upon re-entry.

› The ADEO subsystem shall be scalable and easily adaptable for multiple missions (generic interfaces).

› The mass of the ADEO subsystem shall be not greater than 5 % of reference mission S/C.

› The ADEO subsystem’s deployment shall be initiated by going through the subsystem internal deployment arming and deployment procedure (WATCHDOG and DEAD MAN SWITCH)

› ADEO shall be completely powered by the ADEO subsystem by a subsystem internal battery.
3.2 NABEO (ADEO-N): Launching onboard Rocket Lab’s #ItsBusinessTime
NABEO (ADEO-N): Overview

Summary:
› 2.5m² dragsail subsystem deployed out of 1U cube
› Subsystem applicable to nanosatellites (cube sats) up to perigee of 750km and a mass of 1-100kg
› Technology demonstrator to be launched and deployed onboard Rocket Lab’s #It’s Business Time in 2018
› Designed, built and tested in March - May 2018
› Delivered to Rocket Lab (Auckland, New Zealand) on 28.05.2018
The NABEO (ADEO-N) Project

**Stakeholders:**

› Launch Provider: RocketLab (USA/NZ)
› Hosted P/L program (by Ecliptic Enterprises)
› NABEO cube sat dragsail by HPS GmbH (DE)
  • Co-funding: Bavarian Ministry of Economics (DE)
  • Development partners:
    - Fraunhofer EMI (DE)
    - DLR Bremen (DE)

Onboard Camera: Ecliptic Enterprises (USA)

**Programmatics:**

› Offer for an IOV by RocketLab: April 2018
› 1st launch attempt: 23rd of June 2018 (weather delay)
› 2nd launch attempt: 27th of June 2018 (technical issue with rocket motor controller)
› Updated launch date: Beginning of November 2018
Meeting with RocketLab CEO Peter Beck in Auckland (NZ)
Electron 3 #ItsBusinessTime on Launch Pad with NABEO in payload fairing at launch pad in Mahia Peninsula (NZ)

Launch Beginning of November 2018, for launch and mission updates follow us on Twitter (@HPS_GmbH) and Facebook (@HighPerformanceSpace)

Picture Source: https://www.rocketlabusa.com/
NABEO(-2): Next Steps

Progress since June launch scrub:

› Revisiting of design and improvement of key components based on lessons learned during flight model test campaign and dedicated key components breadboard campaign in July/August 2018

› Simplification of parts to significantly decrease manufacturing costs, incorporation of ALM (3D printed) parts

› Manufacturing and assembly of NABEO2 (SN003, SN004 and SN005) finished, full qualification testing currently ongoing

Updated NABEO-2 properties

› Dragsail area: 2.5m²

› First Eigenfrequency: 400 Hz

› Mass: 834 g (incl. I/F plate)

› Stored volume: 10 cm x 10 cm x 8.7 cm (incl. I/F plate)
4. Conclusions
Conclusions

- Means to **de-orbit passively within 25 years**, no GNC required
- **Modular and scalable** subsystem:
  - ADEO-L (Large for satellites between 100 and <1,500 kg)
  - ADEO-N (**Nano** for cubesats and larger: 1 – 100 kg)
  - ADEO-M (Medium class: overlapping L- and N-class).
- Designed based on **requirements envelope** of applicable satellites (>30 mission analysed), **generic standard interfaces**

- **ADEO-M/L PFM** currently being designed for IOD in 2020/2021, commercial phase to start 2021/2020
- **ADEO-N IOD** to be carried out in **November 2018**, commercial phase to start in 2019.
Thank you for your attention!