To all professionals engaged in design and production of the European satellite generation for the IRIS² – Constellation:

Introduction to the ADEO Deorbit Sail

(100% Sustainable Space, 100% European, 100% SME)

Generic Product Proposal for IRIS²

This document is to give an overview of the ADEO modules which are applicable for the IRIS² constellation:

- ADEO deorbits satellites by using a deployable sail, which decelerates the satellite by the drag of the upper atmosphere.
- The ADEO mass is much less than that of propulsion needed for the same deorbiting process.
- ADEO can deploy autonomously, if requested, when the satellite is out of order.
- ADEO comes with TRL-level 9, proven flight heritage, and unparalleled competitiveness that guarantees unique economic advantages. It was developed under ESA contract according to all ECSS requirements and consequently fully qualified.
- ADEO stands like nothing else for all three top priorities for IRIS² of the European Commission: sustainability, original European technology, innovation made by SME.

The ADEO-modules are briefly presented and described, hidden advantages are listed, frequently asked questions are answered. A general price indication for whom it may concern in your company as participant in the IRIS²-consortium is amended.

Product:	ADEO	
Document:	Generic Product Proposal for IRIS², issue 1, 07.06.2023	
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1. ADEO Range of Applications

ADEO is able to deorbit any S/C up to 1.500 kg from altitudes up to 900 km. The deorbit time depends on the selected sail size; the bigger the sail, the higher the drag in the atmosphere and the faster the deorbit. The ADEO sail area and interface is completely adjustable to any satellite design and mission (w.r.t. satellite mass, orbital altitude and solar activity). This provides different operational applications:

- Very low LEO (up to 300 km):
  ADEO is selected as single and primary deorbit solution. A small sail size is sufficient to deorbit very quickly.
- Normal LEO (300 km – 900 km):
  ADEO is selected as single and primary deorbit solution. A typical sail size needed is 7 m^2 – 15 m^2 for satellite masses between 200 kg and 500 kg.
- High LEO (900 km – 2000 km):
  ADEO is combined with any active propulsion system in order to deorbit initially with propulsion and upon reaching a lower altitude to deorbit with the ADEO dragsail system. Also here, the mass needed for deorbiting is much less than using propulsion only. This option provides also a high operational flexibility: It can be decided on the spot if the satellite's lifetime shall be extended by the remaining propulsion, as the sail can do the job from 900 km downwards.

ADEO Application Area

- ADEO as Backup-Parachute:
  ADEO can optionally be equipped with a small electronic module, which is able to absolutely reliably react autonomously in case of any satellite failure and deploys the sail via a “watch dog”. By this, compliance to deorbit regulations can be obtained.
- In orbit servicing with ADEO Service Satellite:
  The Service-Satellite accommodates several ADEO modules; it approaches the client-satellite of the customer and attaches one suitable ADEO to the client-satellite with its robotic arm. ADEO opens its sail remotely and does the job deorbiting the client-satellite, while the Service Satellite flies to the next client.

As an option, a specific device can be integrated which determines deorbit path data in order to support collision warning. Further assistance services for collision avoidance are available through our partners.

In order to underline the low mass advantage of ADEO in comparison with active propulsion, the following example is given:

Deorbit (until burn) of a 500 kg satellite <u>from a 550 km to 350 km</u> orbit:		
ADEO-M: 3.5 kg (net mass)	**vs.**	**Propulsion: 19.5 kg** (pure propulsion mass @Isp = 300s)

ADEO has been developed as solution for complying with new regulations on debris avoidance, such as the ones of the American FCC, the European STM and Zero-Debris Initiative limiting presence in orbit after EOL to 5 years until re-entering.

Contributor to several ESA, European and National – Debris Avoidance and CleanSpace Commites and Associations:

CleanSpace Initiative & Zero Debris Policy


ESOC Space Safety Programs

European Space Traffic Management


German BDI NewSpace Initiative – sustainable astronautics

2. The ADEO Product Family

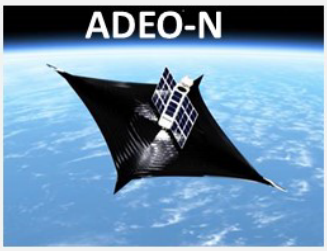
All ADEO family members work according to the same procedure:

Deployment after mission time

Deceleration until dense atmosphere

Burn of satellite in dense area

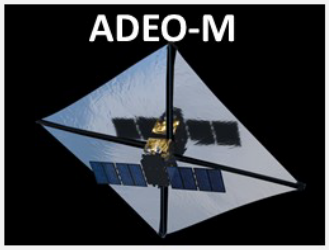
Suitable for IRIS² spacecraft are the versions ADEO-N and ADEO-M, depending on the mission- & satellite- parameter:



Application Satellites:
1 - 250 kg

Sail Sizes:
nominal: 5 m²
+/- 2 m²

Characteristics:
mass: 0.8 kg
size: 10x10x10 cm³



Application Satellites:
100 - 700 kg

Sail Sizes (tbc):
nominal: 15 m²
+/- 5 m²

Characteristics (tbc):
mass: 3.5 kg
size: diam. 20 cm
height 25 cm

ADEO-N and ADEO-M main characteristics and suitable satellite masses

Following bullets list material- and performance-data of ADEO-N and ADEO-M:

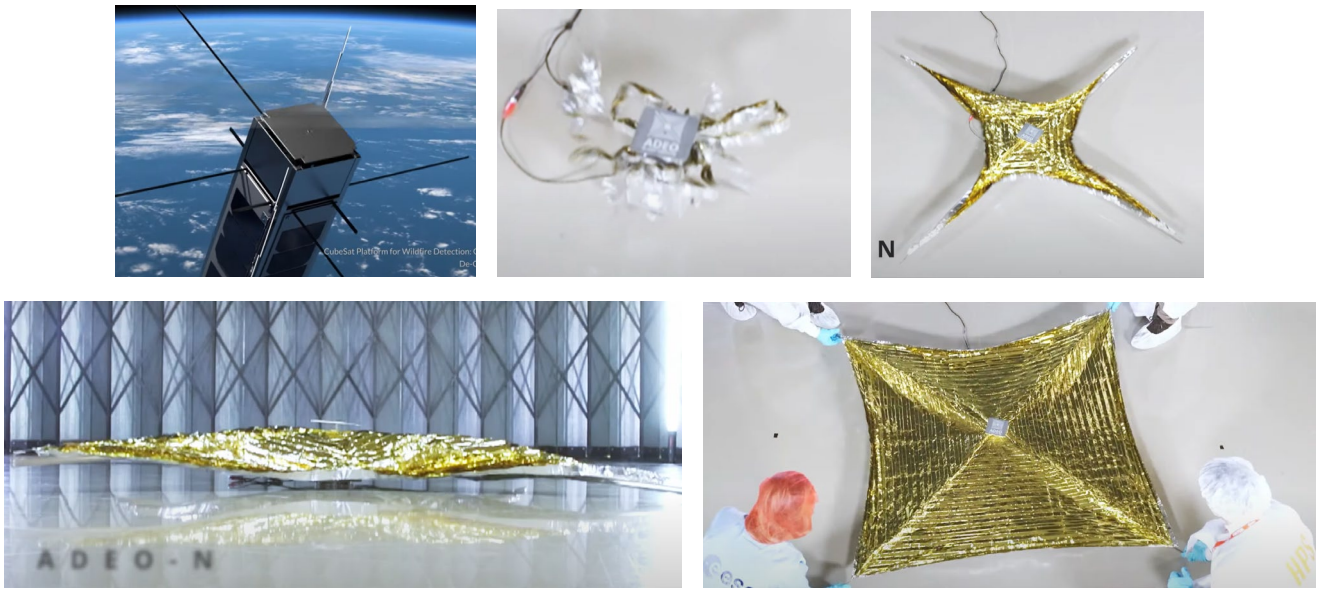
Deployment activation:	via pyro cutter
Activation signal:	by satellite, as baseline (via ADEO's watch dog as option)
Deployment principle:	spring based
Deployable boom material:	thin steel (-N) and titanium (-M) bistable blades
Sail material:	- either thin Kapton-based foil (aluminium coated), - or, for IRIS2 soon available: non-reflective material (complying with the requirement "not disturbing astronomers", even lowering reflection of satellite.
Mechanical interface:	4 screws ADEO-N; 8 screws ADEO-M
Electrical interface:	2 wires ADEO-N; 4 wires ADEO-M

In the ANNEX of this Document (Chapter 8), exemplary the Data Sheet of ADEO-N is attached with detailed interface data and qualification loads.

In order to complete information w.r.t. quality:

- ✓ ADEO development within ESA contracts and ECSS standards
- ✓ Usage of qualified and certified products (e.g. with CoC, CoA) and associated processes
- ✓ Quality and Product Assurance following EN9100 and ESA documentation (e.g., DML, DPL, DCL, etc.)
- ✓ Usage of high-level EEE & COTS components iterated with ESA (e.g., radiation, long term storage).

The following pictures show the deployment sequence of ADEO-N:



Deployment Sequence ADEO-N (snapshots of a movie)

3. Deorbit Examples

We are providing - as service - deorbit prediction analysis for any request. This might be interesting in order to compare the analysis performed by yourself (typically they match quite well with almost all customers). What we would need as input from you are:

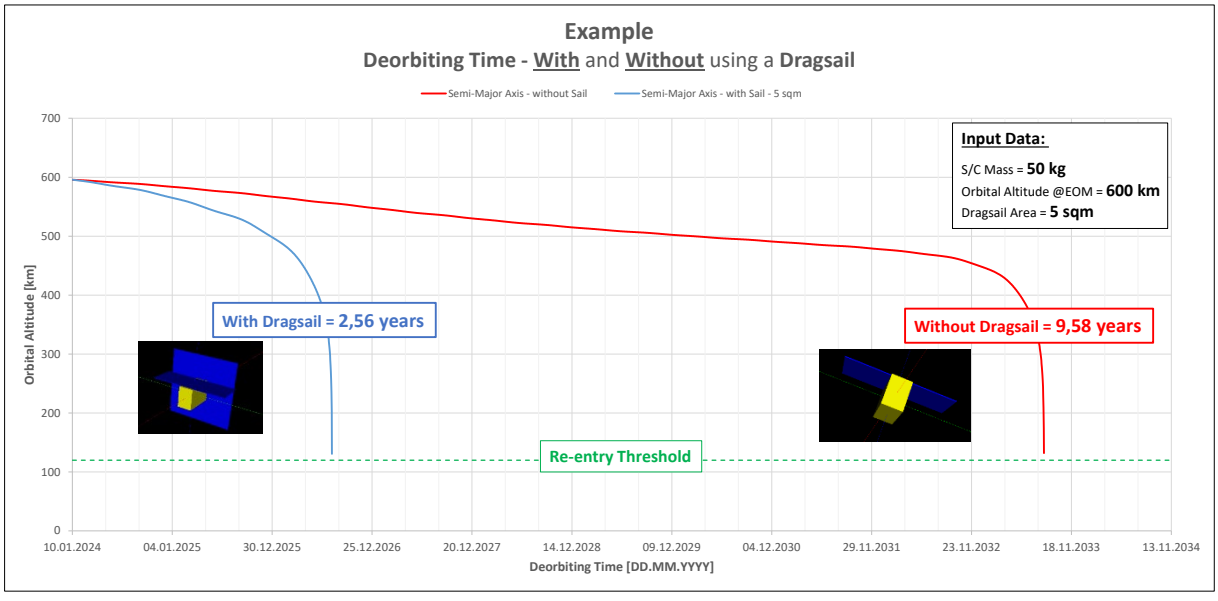
- Satellite mass (after mission)
- Orbit parameter of starting orbit
- Potential launch date (in order to consider solar activities)
- Area of deployed solar arrays, if present

In order to optimise the sail size, we would need also your

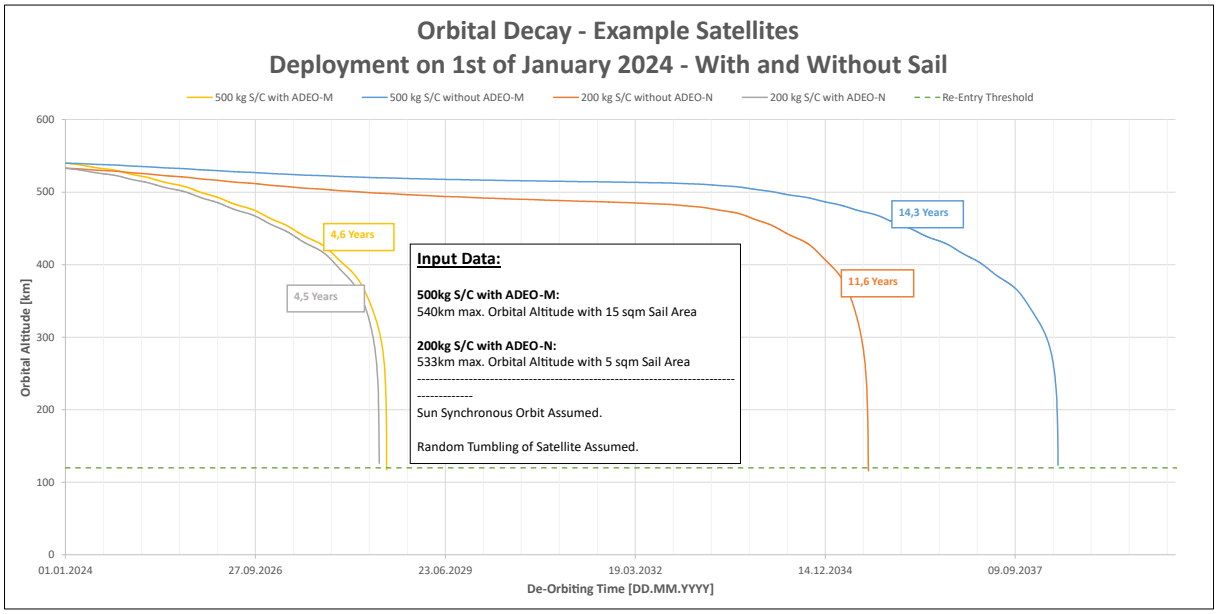
- desired target deorbit time.

The following graphs show exemplarily some deorbit curves for three different mission scenarios:

a) 50 kg satellite mass, starting orbit: 600 km, sail size: 5 m^2 (ADEO-N with 1 kg mass)
b) 200 kg satellite mass, starting orbit: 533 km, sail size: 5 m^2 (ADEO-N with 1 kg mass)
c) 500 kg satellite mass, starting orbit: 540 km, sail size: 5 m^2 (ADEO-M with 3.5 kg mass)



Example a) with: 50 kg satellite mass, starting orbit: 600 km, sail size: 5 m^2 (ADEO-N with 1 kg mass)



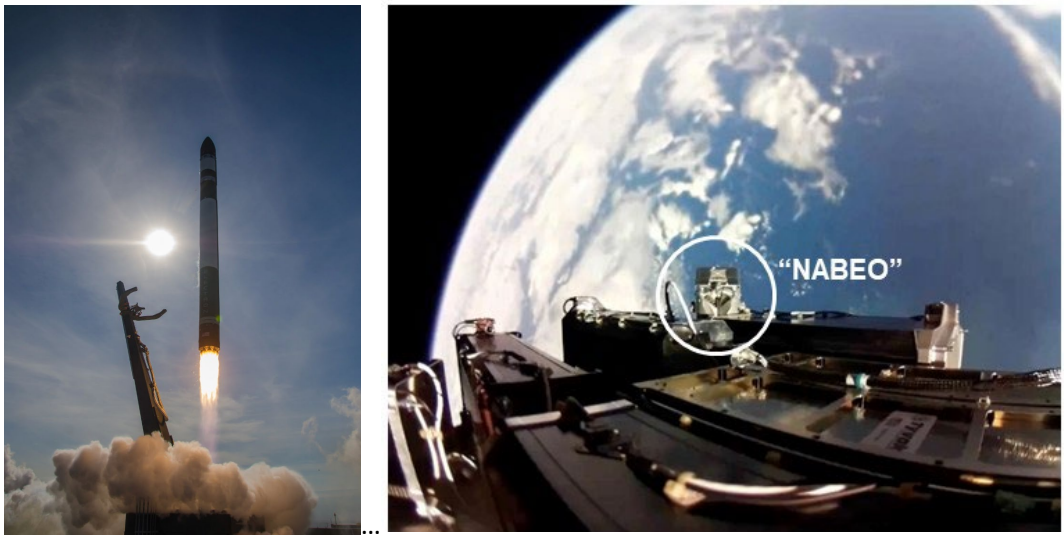
Examples with:

b) orange/grey: 200 kg satellite mass, starting orbit: 533 km, sail size: 5 m^2 (ADEO-N with 1 kg mass)

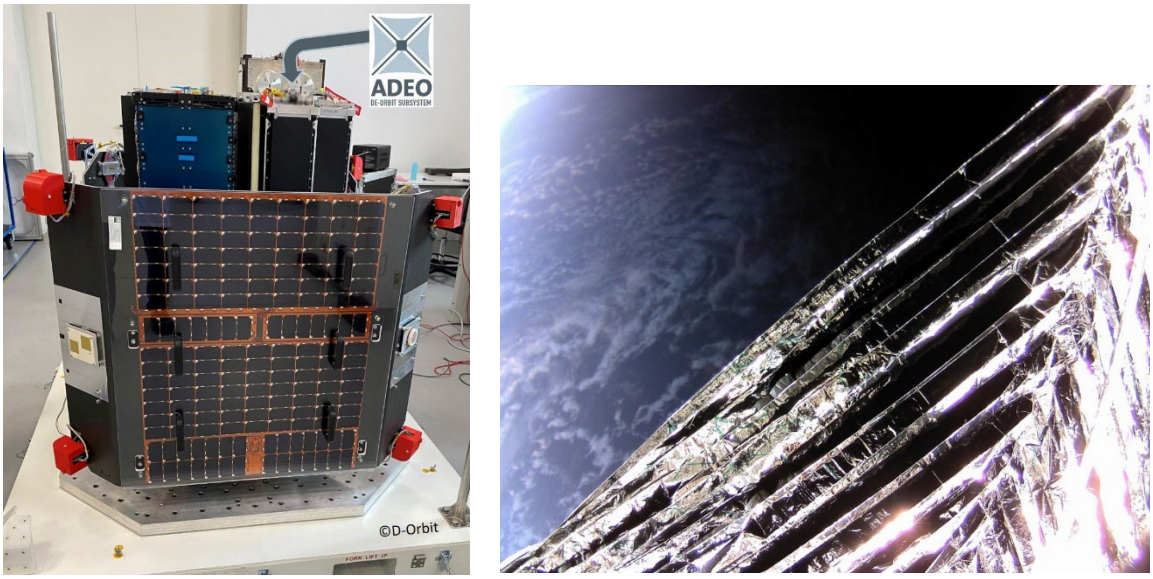
c) blue/yellow: 500 kg satellite mass, starting orbit: 540 km, sail size: 15 m^2 (ADEO-M with 3.5 kg mass)

4. Heritage

After the extensive development mostly in the frame of ESA-activities such as within the GSTP-Programme, but also in German national, as well as Bavarian local co-funding programs, TRL9 was achieved for the ADEO-N version. For ADEO-M (a derivate of ADEO-N), TRL6/7 will be reached in Q4/2023. ADEO-L (most probably not applicable for IRIS^2 satellites) will reach TRL8 by 12/2023 and have its first launch in 2024 onboard an IOD/IOV-mission funded by the European Commission.



ADEO-N1 (called "NABEO"), launched in 2018 on ELECTRON (left), stowed in-orbit on the upper stage (right), pictures by RocketLab.

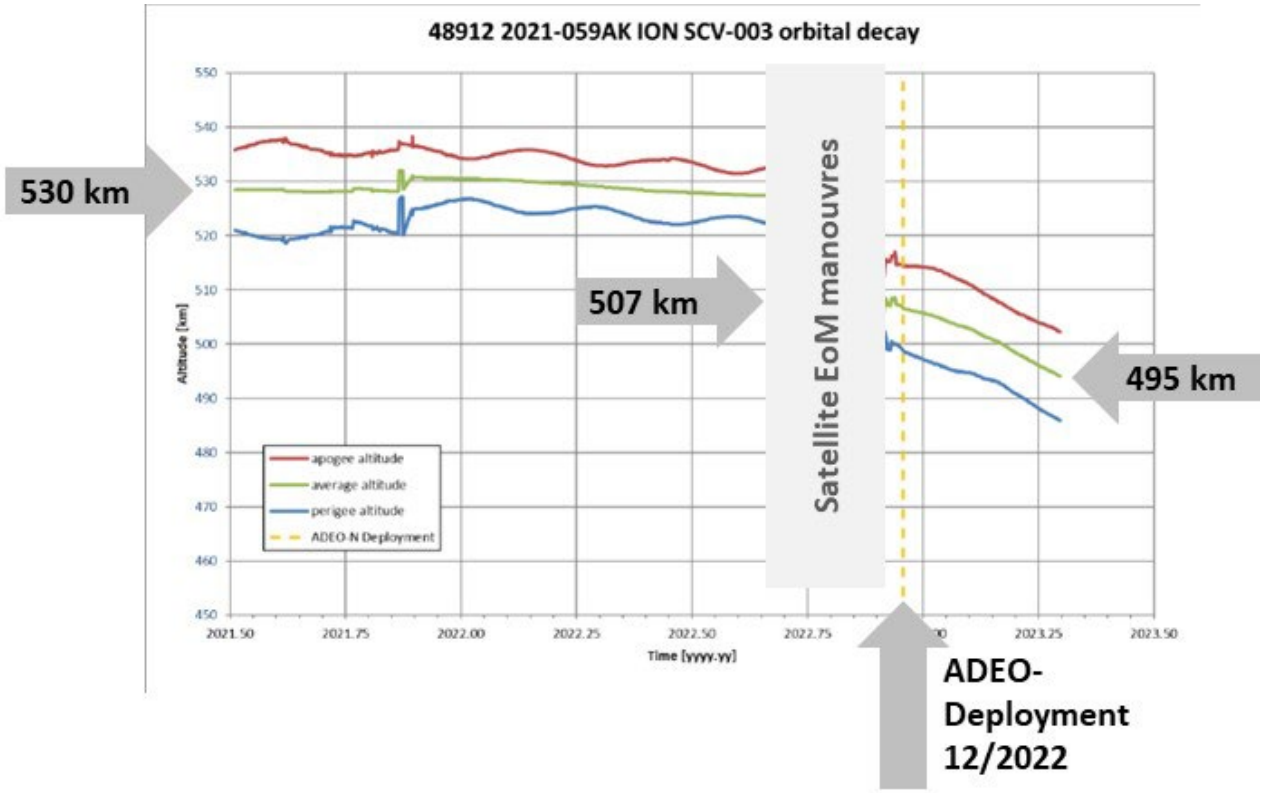


ADEO-N2 (called "Show me your Wings"), integrated inside ION-satellite carrier (left), launched in orbit mid 2021 on FALCON-9, deployed in orbit (right) 12/2022 (pictures by D-Orbit)

The nominal ION-mission with ADEO-N2 onboard is finished. For investigation purposes, the orbit data are still acquired via different channels (via satellite AOCS & telemetry, as well as ground observations). The following figure proves already now the deorbit-effectivity introduced by the ADEO-sail (green line below):

- Deorbit without sail: 3 km within 10 months.
- Deorbit with sail: 12 km within 7 months (escalated: 17 km within 10 months).

In general, the deorbit time with a deployed sail can be assumed to be 6 to 10 times quicker than without sail, with a mass penalty (ADEO-mass) of 1.0 kg (ADEO-N) to 3.5 kg (ADEO-M).



5. Programmatic Aspects

Geographical Aspects -> DE + RO

ADEO has been developed in Germany, in a long years collaboration between industry and R&D, funded by agencies and own company funding. Since 2020 HPS-Germany's affiliate in Romania contributes to the production of the ADEO-Modules. Especially within series production, this German-Romanian collaboration leads to very cost-effective prices for the customers.

ADEO modules for IRIS^2 will therefore have a return to

- Germany (80-90 %, tbd): HPS GmbH is contractor to the IRIS^2 consortium member
- Romania (10-20 %, tbd): HPS S.R.L. is subcontractor to HPS GmbH (which might improve any georeturn expectations at ESA and any geographical diversity at European Commission).

Industry Group -> SME

HPS GmbH, Germany, as well as HPS S.R.L., Romania are both SME. Some qualification tests (in case of required delta-developments) and acceptance tests (recurring modules) are contracted to Non-SME, but via "External Services".

ADEO modules for IRIS^2 will therefore have a return to

- SME: 100 %.

Development Activities

The ADEO standard versions are a "Product" with defined interfaces and outer geometries, different sail sizes.

We are open to any adaptations for the implementation on-board IRIS^2, e.g., in the frame of the ESA-part of IRIS^2 Programme. This could be:

- Mechanical interfaces
- Launch load verification via analysis & test
- Thermal load verification via analysis & test
- Mass optimisation of any thermal hardware needed
- Autonomous deployment electronics (adaptation to S/C electronic needs)
- Potentially required redundancy-functions
- Integration of an automatic orbit determination device (together with our Italian Start-up partner)

On service-level, the following activities can be performed:

- Deorbit predictions to optimize the ADEO sail size and associated characteristics
- Integration support
- Collision avoidance prediction (together with e.g., our German Start-up-partner)

Series Production

All ADEO Versions are designed taking into account a cost-effective series production following a standard configuration to allow for efficient production and logistics. For each constellation it should be evaluated together with the Customer, if possible, design adaptations are worth the effort.

Series production for ADEO-N will be started soon. Series production initiation for ADEO-M modules is planned for 01/2024.

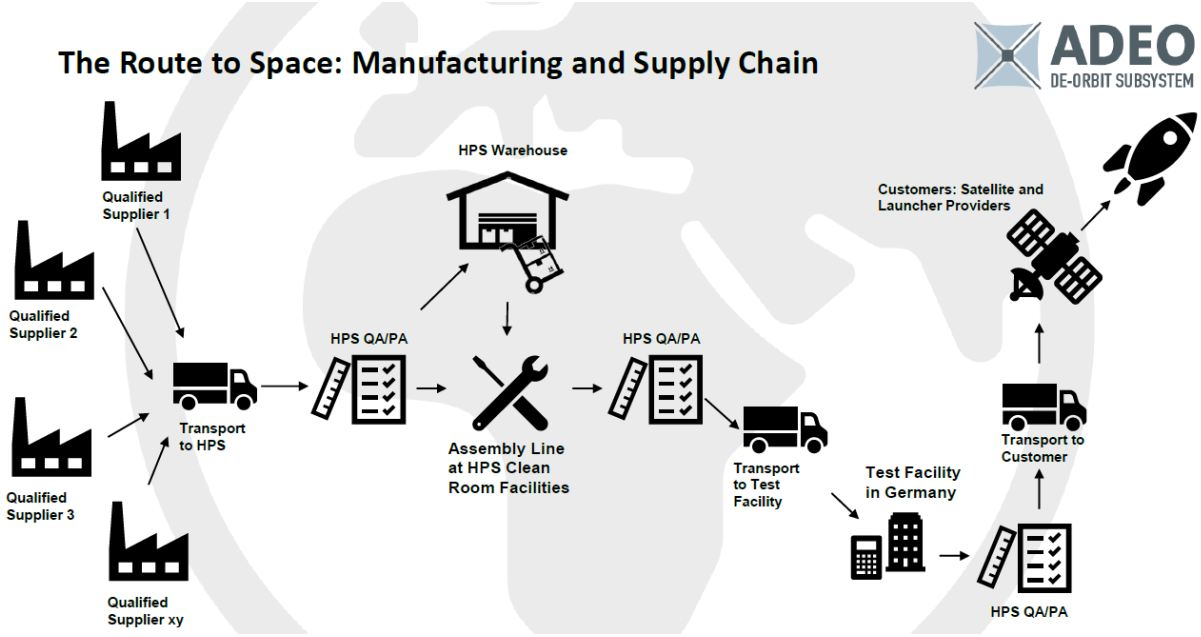
The production of all various metal non-metal parts is allocated at partner companies specialised in their areas. This is performed under strict internal supply chain management processes. Incoming inspections are taking place via HPS-internal QA-staff. Subassemblies are assembled in house in Germany and Romania, both in clean environment (ISO8). An example is the time-consuming sail folding and sail interface bonding, performed in Romania. Final assembly is performed by HPS Germany, followed by functional acceptance tests.

No criticality has been identified in our supply chain and our capacity could answer to any constellation need. Associated assembly-halls and clean rooms at HPS:

- HPS-Germany
  - several assembly rooms and laboratories
  - 100 m^2 clean room
  - 350 m^2 clean room (from end 2023 on)
- HPS-Romania:
  - 350 m^2 assembly areas with clean rooms.

The verification-approach of each model is selected by the Customer. It can be done by taking samples of a lot, or by each unit.

Lead time can be assumed between 3 and 6 months for the first 1 to 10 units. Then, for series production, a production rate of 1 Unit per day is assumed for IRIS2. The capacity will have a rate of 2 Units per day from 2024 on.



ADEO series production cycle; risk management at each step performed, EN9100 application

ADEO manufacturing and supply chain; pre-assembly and final assembly in own HPS facilities

Sustainability – ZeroDebris Initiative – Space Traffic Management

ADEO on board means to have a “Clean Green Mission”. Arguments for ADEO are:

▪ 100% clean deorbiting by air drag ▪ No propulsion-exhaust-plume in space just for decelerating ▪ Less mass to be transported into space, less propellant-exhaust on launcher side ▪ Empty tanks before sail deployment reduce risk of explosion and catastrophic debris production (with or without being hit by another satellite) ▪ In case of malfunction of satellite, no junk remains in space	

A view into the future: it is already now discussed that in case of a satellite remaining in space due to malfunction, the satellite operator has the duty to remove the satellite actively via in-orbit-servicing spacecraft. This removal will have cost far beyond 3-5 Mio. Euro per satellite. ADEO-module cost plus respective launch cost of an ADEO will be many factors less.

Insurance

First talks to insurance companies show, that a potential necessary insurance for having actively removed a spacecraft will be quite expensive. The insurance fee will be much less when embarking ADEO as fail safe parachute.

6. Synthesis on ADEO Advantages

Advantage Nº 1: Flight heritage + TRL 9

Advantage Nº 2: One of a kind: Deorbit in < 5 down to < 2 years

Advantage Nº 3: Price beats any competition

Advantage Nº 4: Minimum mass without comparison

Advantage Nº 5: Reliable reentry

Advantage Nº 6: Serial production by HPS

Advantage Nº 7: Comprehensive range of models

Advantage Nº 8: Autonomous reentry with silent sat

Advantage Nº 9: Non reflective sail surface (astronomy) and surface adaptable to your need

Advantage Nº 10: One of a kind: Transparent sails available

Advantage Nº 11: Added value as fail-safe backup

Advantage Nº 12: Clear attitude determination

Advantage Nº 13: Simple Interfaces just mechanical

Advantage Nº 14: Easy mechanical deployment

Advantage Nº 15: Smallest possible volume ever

Advantage Nº 16: Supporting operator´s flexibility

Advantage Nº 17: Zero propulsion descent extending Sat lifetime, propulsion budget optimization

Advantage Nº 18: Low weight + small volume

Advantage Nº 19: For CubeSats: Installation into all canisters possible

Advantage Nº 20: ESA ECSS qualified

Advantage Nº 21: Available as comprehensive carefree package.

Advantage N° 22: Georeturn optimization with Romania activities

Advantage N° 23: Inclusion of innovative SME.

7. General Price Indication

The standard ADEO-modules are offered via price list:

Standard Package	**Units**	**Price Indication [EURO] (without VAT)**
ADEO-N ▪ Modul with 5 m^2 sail size ▪ Storage and Transportation Box ▪ Documentation: ICD, CoC, DMPL	1 10 100	62.000 EUR 540.000 EUR 4.600.000 EUR
ADEO-M ▪ Modul with 15 m^2 sail size ▪ Storage and Transportation Box ▪ Documentation: ICD, CoC, DMPL	1 10 100	96.000 EUR 830.000 EUR 6.800.000 EUR

In case of need for design changes for an optimisation to a specific IRIS2 platform, e.g. **in the frame of the ESA-development part**, we estimate an effort of between

500.000 EUR and 2.500.000 EUR (excl. VAT)

The following options can be requested, as examples. Prices after iteration with the IRIS^2 Customer:

Verification Options	
A	TVAC Test with partial deployment of one unit
B	Vibration Test @ Acceptance Level
C	Functional deployment tests
Hardware Options	
I	Standard MLI (depending on mission profile just before deployment)
II	Autonomous Functionally if satellite fails
III	Attachment of a device for reentry path monitoring
Service Options	
1	Further Documentation (according e.g. ECSS)
2	Collision Avoidance Service
2	Reentry path data transmission

8. ANNEX: ADEO-N Data Sheet as Example

HPS
High Performance Space Structure Systems GmbH

Data Sheet

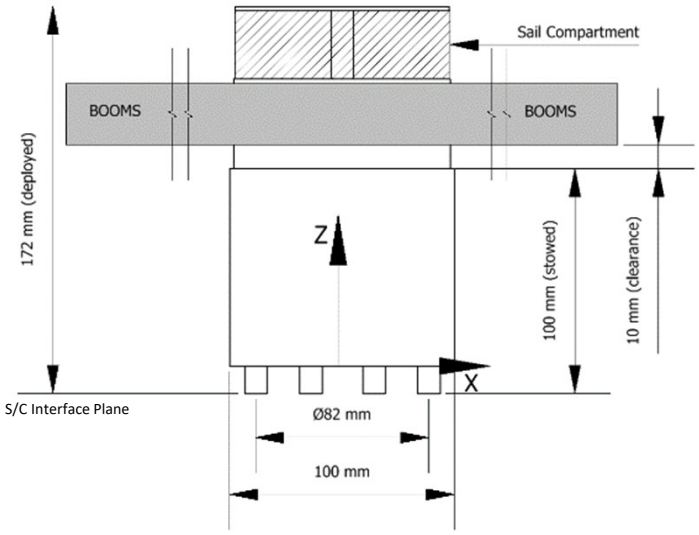
Deorbit Module ADEO-N 1.1

Application Area	
Recommended Spacecraft Mass	1 kg up to 250 kg
Orbit Height	200 km up to 900 km

ADEO-N deployed demonstration model with sail size 3.6 m²

Technical Data	
Technology Readiness Level	TRL 9
Export Regulations	ITAR-free
Module Mass (depending on sail size)	0.8 kg (± 10%)
Module Size (stowed)	10 cm x 10 cm x 10 cm
Sail Area (adaptable to customer needs)	2 m² up to 5 m²
Center of Gravity (rel. to ground plane)	0 mm x 0 mm x 38 mm (stowed) 0 mm x 0 mm x 83 mm (deployed)
Moment of Inertia [kg mm²] (rel. to CoG)	Ixx 105,932 Iyy 105,933 Izz 210,964
1st Eigenfrequency	242 Hz
Mechanical Interface	4 x M5 (at diam. 82 mm)
Deployment Principle	Spring-based
Activation System	Pyro Cutter
Electrical Interface (without connectors)	2 wires (0.9 mm each)
Electrical Power	12 V @ 1 A, 10 msec
Autonomous Functionality (deployment, when satellite out of operation)	As option, on request

Qualification Loads		
Quasistatic	Lat. ± 15 g	Ax. ± 15 g
Sine	5 Hz	1.875 g
	45 Hz	1.875 g
	50 Hz	3.750 g
	100 Hz	3.750 g
Random	20 Hz	0.026 g²/Hz
(14.1 gms)	50 Hz	0.160 g²/Hz
	800 Hz	0.160 g²/Hz
	2000 Hz	0.026 g²/Hz



June 2023

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Homepage Flyer

Homepage:

ADEO Deorbit Dragsail:

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