Articulated Booms Large Ultrastable Deployable Structures (ABDS)

TRP Study (July 2016 - February 2019)

ABDS-HPS-RP-0400, issue 1, Executive Summary

(ESA/ESTEC Contract N° 4000118112/16/NL/BJ)

Prime Contractor:

HPS GmbH (DE)

Subcontractors / Major External Services

RSG - RUAG Space Germany (former HTS GmbH) (DE), INVENT GmbH (DE), INEGI- Instituto de Engenharia Mecânica e Gestão Industrial (PT), DLR Bremen (DE), VTT Technical Research Centre of Finland Ltd. (FI), OHB System (DE)

Background and Objective of the Activity

Large deployable articulated boom structures can be considered as a key technology for large deployable reflector applications. Within the ESA funded activity, ABDS (Articulated Boom – Large Ultrastable Structures), the focus is put on the development, manufacturing and experimental characterization of an articulated deployable boom system suitable for LDR applications from 6–12 m reflector diameter with the goal to reach TRL 5 at the end of the activity. To achieve this goal a 6.1 m deployed length demonstrator model has been developed, manufactured and extensively tested under representative environmental conditions.

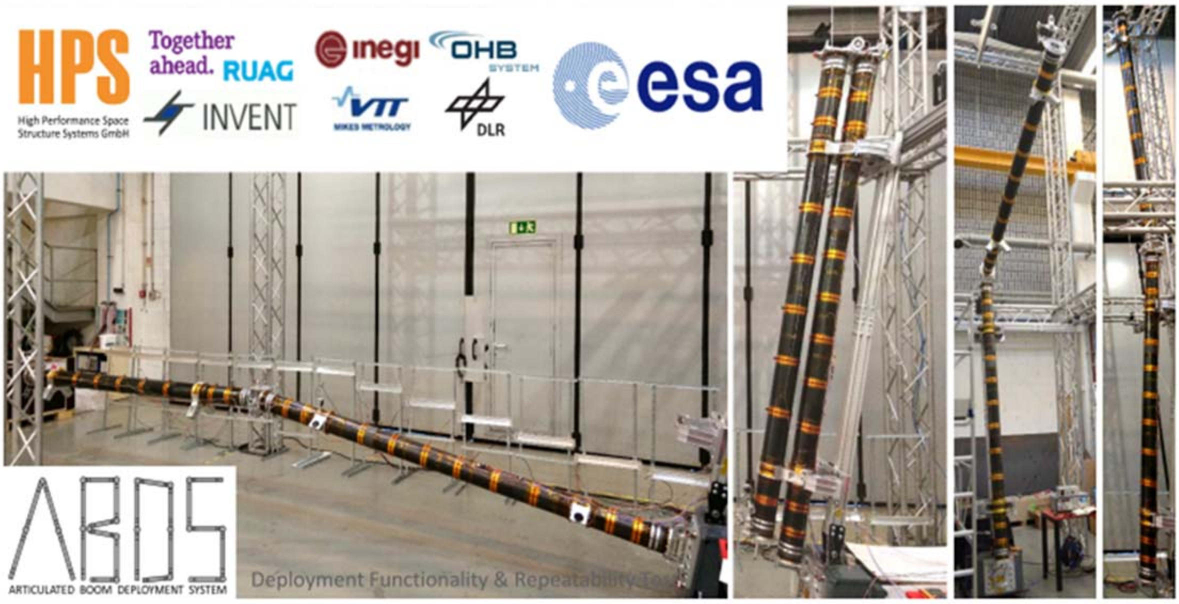

Figure 1: ABDS Demonstrator Model in different configurations from stowed to deployed

Industrial Team

The industrial team with the main tasks of each member is shown in the following figure.

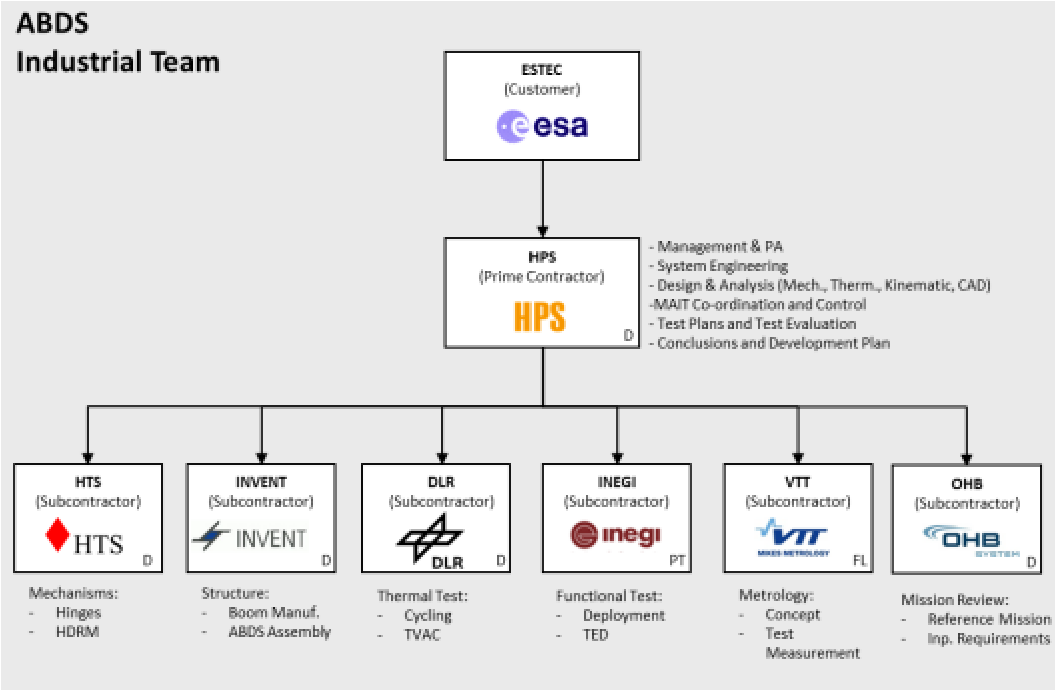

Figure 2: ABDS Industrial Team

* note: HTS has changed during the ABDS contract to RUAG Space Germany (RSG)

Study Logic

Definition of reference mission scenarios and related requirements

A review on potential applications of an articulated boom concept is performed resulting in the definition of a reference flight mission. Based on that, a comprehensive set on requirements was elaborated as an input to the structural design and analysis phase. Wherever possible the requirements have been defined such that a wide range of possible applications or missions can be satisfied. Finally, a demonstrator model has been derived representing the key elements of a potential flight model.

Structural design and analysis on components and system level

A demonstrator representing a deployable boom system has been design and analysed on boom system and component level. The design is driven by the pointing accuracy under extreme thermal conditions together with sufficient stiffness properties in deployed configuration and constraints resulting from available accommodation.

The most important design driving aspects are:

- thermoelastic stability under extreme thermal conditions
- deployed configuration stiffness properties
- accommodation constraints
- deployment actuation concept
- scalability and modularity of the architecture.

Demonstrator Manufacturing

Suitable manufacturing technologies and processes have been identified ensuring a successful manufacturing not only of the Demonstrator model but also possible future Boom assemblies of different dimensions. For the CFRP tube manufacturing, filament winding, a well known process at INVENT with lots of heritage and high TRL has been selected and successfully applied to the ABDS tube manufacturing.

Breadboard Level and Demonstrator Test methodologies & GSE design

In parallel to the design and analysis activities additional developments have been made regarding proper testing methodologies and related test GSE designs. Especially the large size of the demonstrator model required well designed and characterized gravity offloading systems for deployment, accuracy (including thermal distortions) and stiffness measurements. Before the demonstrator test campaign several critical items have been identified being subject to breadboard testing. These items were the deployment mechanism and the metal to CFRP joint design. All knowledge gained throughout the breadboard test campaign has been finally included into the demonstrator design process.

Design

Overall System Design

In the following table the key design requirements identified for the overall system design are summarized. These requirements can be seen as excerpt of a full set of requirements identified throughout the first phase of the activity also taking into account requirements coming from a S/C and operational point of view.

Table 1: Key Design Requirements

Deployed Dimension	The design shall be suitable to different deployed lengths of L = 3m to 12m.
Modularity & Scalability	The design shall be modular and scalable as much as possible to achieve the above mentioned lengths by scaling of individual building blocks (arm segments) or variation of number of elements.

Deployed accuracy / repeatability	The deployed configuration accuracy / repeatability shall be better than L (deployed length) x 10-4.
Thermoelastic stability	The thermoelastic stability of the boom tip shall be better than L (deployed length) x 10-4.
Accommodation Envelope	As an available accommodation envelope a S/C with the dimensions of 1.6m x 1.2x x 3m inside a 2.6 m usable fairing diameter (e.g. VEGA – C) is considered.
Overall system mass	< 9 kg/m

The overall Arm design is presented in the following figure with its major building blocks.

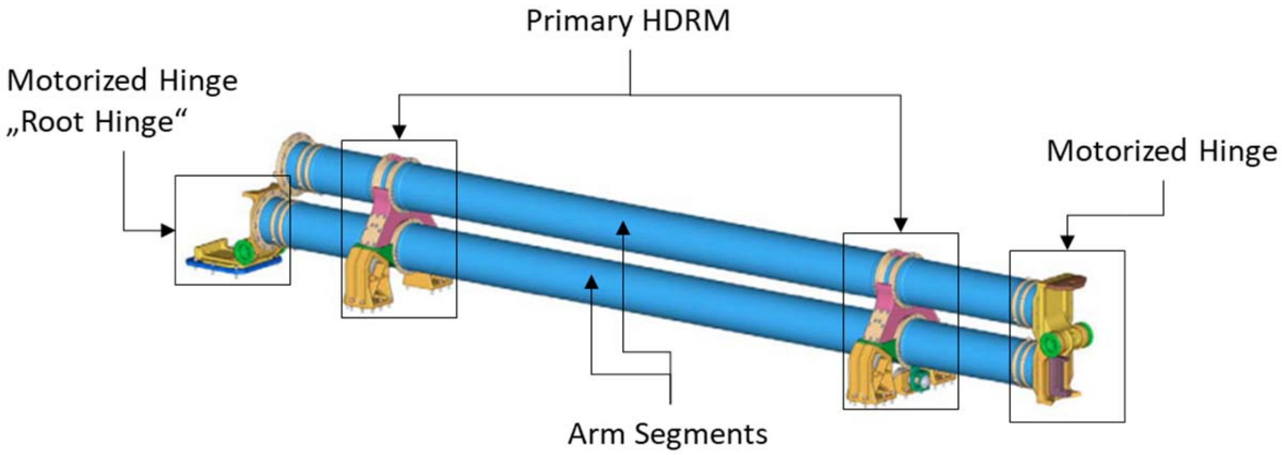

Figure 3: ABDS overall Arm Design with major Building Blocks.

Deployment Mechanism Design

The deployment mechanisms have been developed by Ruag Space Germany (former HTS). The principle design is based on a motorized (by stepper motor) hinge with a mechanical end – stop and latching system providing a mechanical latching in fully deployed configuration. The deployed angle respectively latching position can be adapted by a simple exchange of the so called hard – stop allowing the design to be easily adapted to a wide range of different deployment angles.

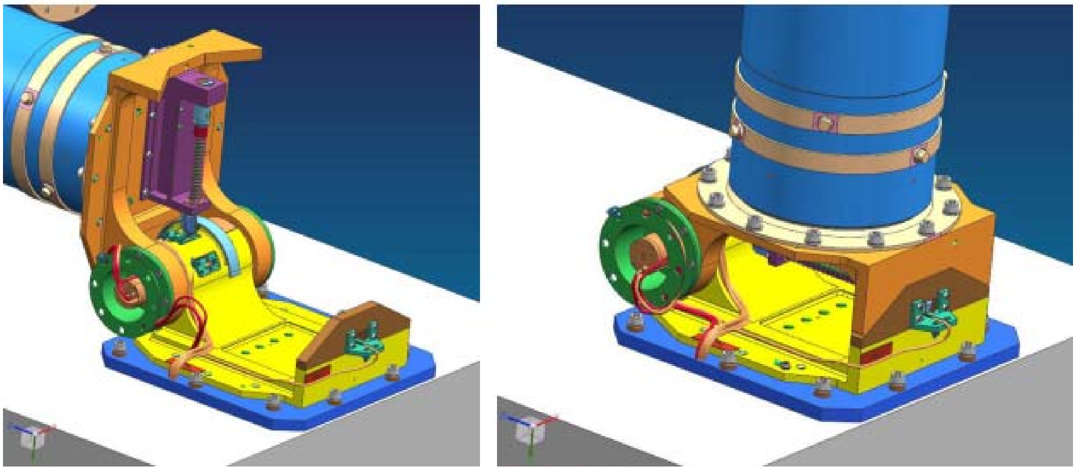

Figure 4: Deployment mechanism in stowed and deployed (latched) configuration developed by RUAG Space Germany

The design driving aspects for the mechanism development have been its deployed stiffness, functionality under extreme temperatures and high deployment accuracy. Throughout an extensive breadboard test campaign these key performance values of the mechanisms have been derived and are summarized below.

Table 2: Mechanism Key Performance Values

Repeatability in latched position (measured after 10 deployments)	<5*10-4 deg
Translational Stiffness	>1.5*107 N/m
Rotational Stiffness	>3.5*105 Nm/rad
Mass	3.60 kg
Operational temperature	-60° to +80°C

Hold – Down and Release Mechanism

The hold down and release mechanism (HDRM) is responsible to keep the boom in its stowed configuration and providing sufficiently stiff boundary conditions to meet the stowed configuration requirements on 1st Eigenfrequency. In addition the HDRM design has to be compatible with the deployment kinematics.

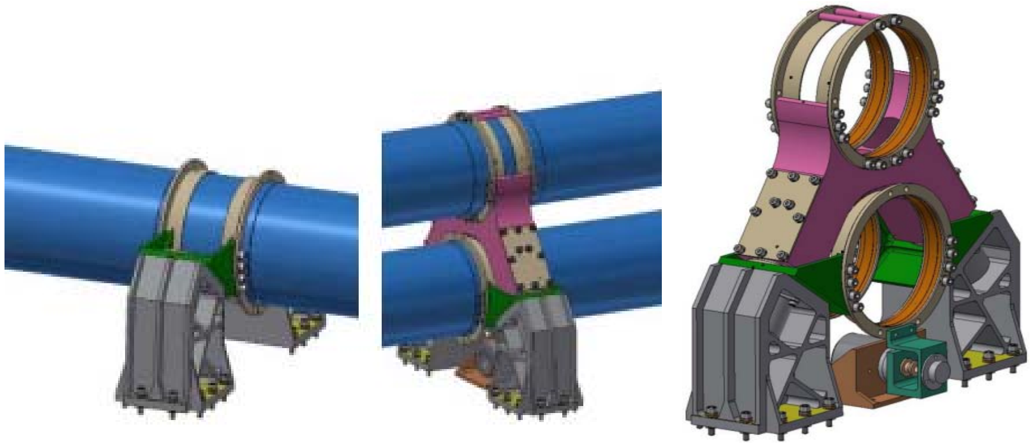

Figure 5: ABDS HDRM Assembly design

With the HDRM Design developed a scaling of the arm segments in diameter or change of deployment kinematics can be realized by minor design adaptations being a big advantage for a scalable and modular concept.

Arm Segment Design & Manufacturing

The main structural elements of the deployable boom are represented by the arm segments. These segments are made of CFRP being designed to an optimal compromise between stiffness and thermoelastic stability. Filament winding was identified to be the most suitable manufacturing process. Each CFRP segment is interfacing with one of the deployment mechanism via metallic End – Fittings. Taking into account the thermal environment and the thermoelastic incompatibility between metal and CFRP a design solution for the joining of these two elements was developed allowing a robust and reliable joining. The joining is mainly a combination of bonding and riveting. This design has been verified by breadboard test before realizing in the demonstrator model.

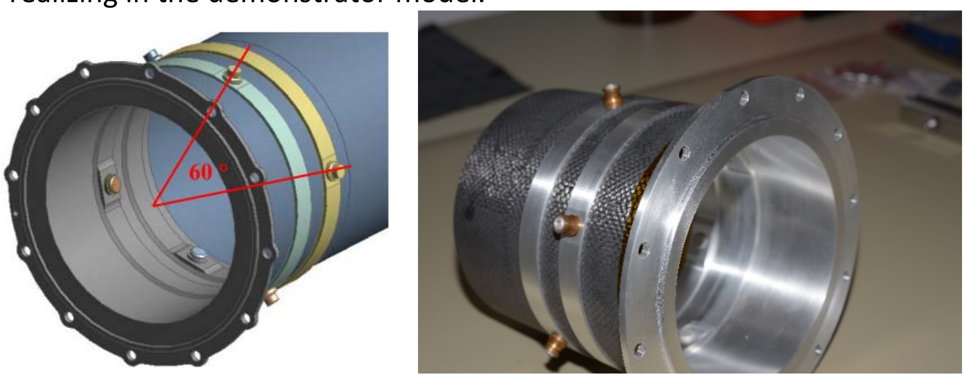

Figure 6: CFRP to Metal End – Fitting joining

Demonstrator Test Campaign

The ABDS demonstrator test campaign was including the following tests:

- TV cycling (±160°C) and TV deployment test (partial deployment at -60° & +80°)
- Vibration Test Campaign (sine, random)
- Deployment functionality and repeatability testing
- Thermoelastic distortion testing at ambient environment
- Component level shock tests (HDRM, deployment mechanism)

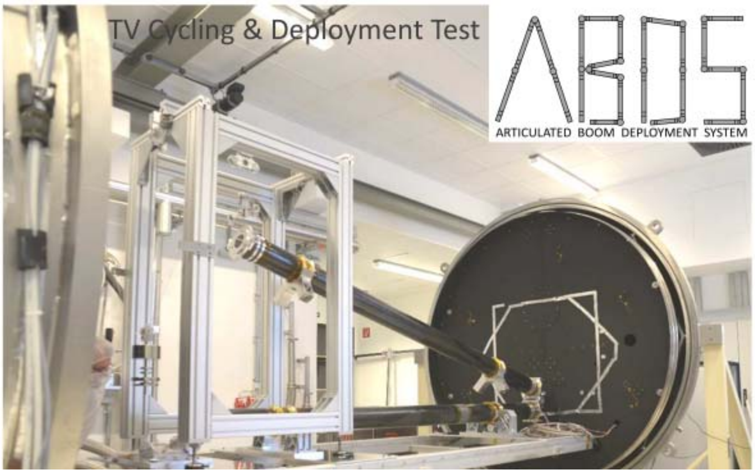

Figure 7: ABDS Demonstrator model prior to TV testing at DLR Bremen

Figure 8: ABDS Demonstrator model during vibration testing at ETS / ESTEC facilities

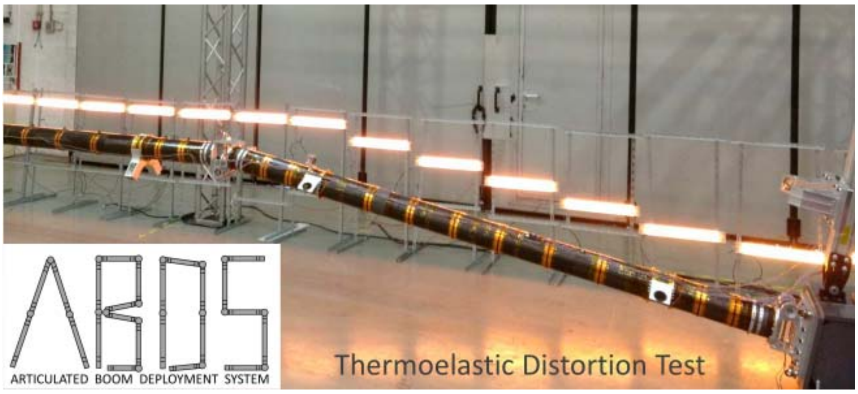

Figure 9: ABDS Demonstrator model during TED testing at INEGI

All test activities have been successfully performed and validated the performances predicted by simulation models.

Demonstrator Performance Summary

In the following table a summary of the most important performance values derived by the demonstrator test campaign are summarized.

Table 3: Demonstrator Performance Summary

Mass	44.2kg (7.24kg/m)
Length	6.1m
Deployed Stiffness	>1.7Hz
Stowed Stiffness	>140Hz
Thermoelastic Stability	Tip deflection <0.2mm (*)
Deployment Repeatability	Better ±0.28mm at boom tip

(*) analysed based on generic TED test results and correlated simulation models.

Possible Mission Scenarios

Based on the design concept developed and the main performance figures derived by analysis and testing from the demonstrator model several assessments have been made on possible mission scenarios where the ABDS boom concept could be applied. From a wide range of potential future missions two missions have been investigated more deeply. For the ROSE-L (L Band SAR) and CIMR (Radiometer) an architectural design has been elaborated for a complete large deployable antenna subsystem based on the ABDS boom concept together with the SCALABLE reflector architecture tailored to the main instrument requirements.

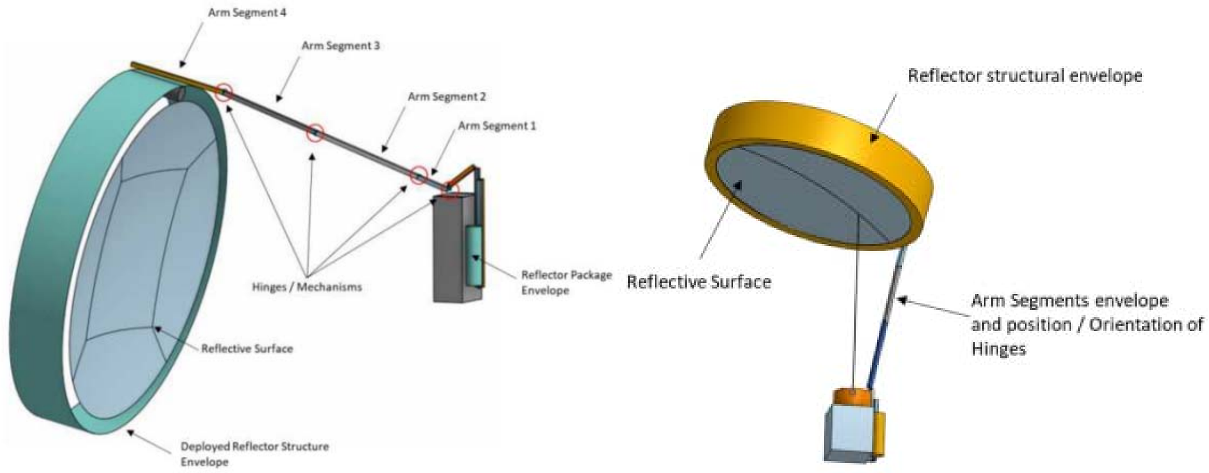

Figure 10: ROSE-L and CIMR LDRS architectures

For both mission scenarios feasible architectures have been identified with their key performance figures summarized in the following table.

Table 4: Key LDRS Performance Values for ROSE-L & CIMR architectures

	ROSE-L	**CIMR**
Reflector Diameter	12m	8m
Subsystem Mass (Reflector+Arm)	212 kg	130kg
1st Eigenfrequency deployed	0.25Hz	0.6Hz
RF Frequency	L-Band	L to Ka - Band

Summary & Conclusion

Within in ABDS activity the development of a European technology for a large deployable boom concept suitable for a wide range of LDR applications has been successfully demonstrated by design and validated by an extensive test campaign on breadboard and demonstrator level. Starting with a definition of potential mission scenarios together with the definition of key requirements a scalable and modular boom architecture has been designed, analyzed and manufactured on demonstrator level representing the major building blocks of the technology. The key performance figures have been successfully validated by a wide range of tests also allowing the correlation and validation of simulation tools established enabling a good prediction of the performances to be expected for different mission scenarios with adapted designs. Finally a European technology for large articulated deployable booms with a TRL of 5 has been achieved.

Munich, 18.02.2019