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THE ASTRIS KICKSTAGE PROPULSION SYSTEM DEVELOPMENT STATUS & OUTLOOK

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ABSTRACT

The ASTRIS KickStage will provide the Ariane 6 Launch System with even further enhanced mission performances, an enlarged mission portfolio and associated missions flexibility and versatility.

By these elements the Ariane 6 Launch System shall be enabled to attract an even bigger market share within the commercial and scientific payloads domain to further increase the Ariane 6 launch and production rate. This, to foster further industrialization and recurring cost optimization.

Therefore the KickStage development project is part of ESA's Competitiveness Improvement Programme (CIP) and is one of the key projects in ArianeGroup on the way to Ariane 6 full recurring production.

The given paper will provide an overview of the development status of the Propulsion System of the ASTRIS KickStage as well as the next development steps and global programme outlook

KEYWORDS: Ariane 6, KickStage, ASTRIS, HERA, EPS, Propulsion System, Storable Propellants, MON, MMH, SPE, BERTA, PCA, Pressure Regulation

1. INTRODUCTION

The perimeter of target missions for ASTRIS as part of the Ariane 6 launch system is ranging from multi-plane constellation spacecraft deployment missions up to scientific earth escape missions with a KickStage on-orbit mission duration lasting up to several days. The target maiden launch date of the first ASTRIS KickStage is set to be in late 2024 to meet the need of the HERA mission to the Asteroid Didymos (see Fig.1).

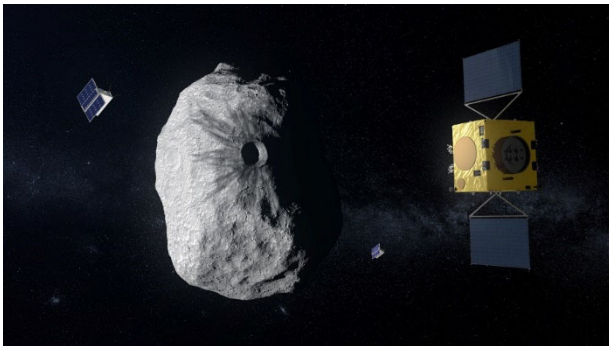

Figure 1. HERA Mission to Didymos © ESA

Due to the aspects stated above, the ASTRIS KickStage as well as its Propulsion System is required to be of high performance, of low recurring production cost and, maybe most important, of short development duration (and therefore low development effort, risk & cost) to allow for the 2024 launch date. Therefore the propulsion system is relying on heritage technology and an only limited ASTRIS oriented product development.

One key element for the ASTRIS propulsion system is the 5kN-class main engine, called BERTA, which has been matured already within ESA's Future Launchers Preparatory Programme (FLPP). BERTA is based on the technology heritage of the AESTUS Engine of the former A5 EPS stage. Most of the other propulsion equipment and concepts are based on Components-off-the-Shelf (COTS) or adapted COTS, e.g. again from A5 EPS as well as from ATV or from satellite propulsion systems.

2. ASTRIS GOALS, OBJECTIVES & MISSION

The ASTRIS KickStage development project is pursuing multiple goals and objectives elaborated in the subsequent paragraphs.

2.1. Project Goals & Objectives

Mission related Objectives

- Enhancing the Ariane 6 launch capabilities further by enabling new types of missions and performances even beyond the Ariane 6 portfolio
- Serving institutional and also commercial mission scenarios
- Attracting therefore new customers and/or expanding the market share in the commercial missions domain
- Enabling “exotic” mission types, such as HERA, and providing even further growth potential to “go beyond” and
- Providing an additional element to guarantee Europe’s independent and broad access to space

Cost related Objectives

- By enlarging the market share for the Ariane 6 launcher, aiming at an increasing production cadence, a further recurring cost optimization for the overall launcher is targeted.
- The recurring cost for the ASTRIS KickStage shall be kept to a minimum by e.g. embarking “new space” solutions.
- The development cost shall be minimized by adopting “new space “ solutions and their development approaches in some areas and relying on heritage and COTS in others, especially in the propulsion sector.

These cost objectives must incorporate a well-balanced risks and opportunities management and are the driver for design solution choices and associated trade-offs as presented later-on in this paper regarding the Pressure Control Assembly (PCA) architecture selection.

Development Approach Objectives

- Adopting and embarking “new space“ solutions and companies to foster a prosperous interaction of “new and old” space economy within this launcher application
- Performing in parallel the development of the main engine, the propulsion system as well as the overall stage and system
- Taking therefore the challenge of an extremely condensed schedule for the overall development to be executed in less than four years (from initiation of Phase B up to Maiden Flight),
- to meet on one side the HERA mission need as well as the time-to-market for the targeted commercial missions and in the end
- to allow to cope with the available development budget and therefore to limit the overall development cost

2.2. ASTRIS Missions Portfolio

The following missions are defined as reference missions for sizing the ASTRIS system:

1. Multi SSO/LEO

The upper stage of the launcher will deliver the first payload in a 300 km polar orbit. The rest of the payloads will be raised by the ASTRIS KickStage by 300 km first to 600 km altitude with an inclination change of 5°. Here a second payload will be released, after which the third payload will be raised again by the ASTRIS KickStage by another 300 km with another inclination change of 5° (now to 900 km altitude). All payloads account for an overall mass of 4.5t.

2. GTO-GEO

The upper stage of the launcher itself will deliver the first payload in a GTO with 250 km perigee altitude, 35486 km apogee altitude. The ASTRIS KickStage is located between the launch vehicle adapter and the second payload in the lower compartment of the payload fairing (see Fig. 2). The ASTRIS KickStage will raise its up to 3t heavy payload to GEO (35486 x 35486 km, 0° inclination) including the needed inclination change.

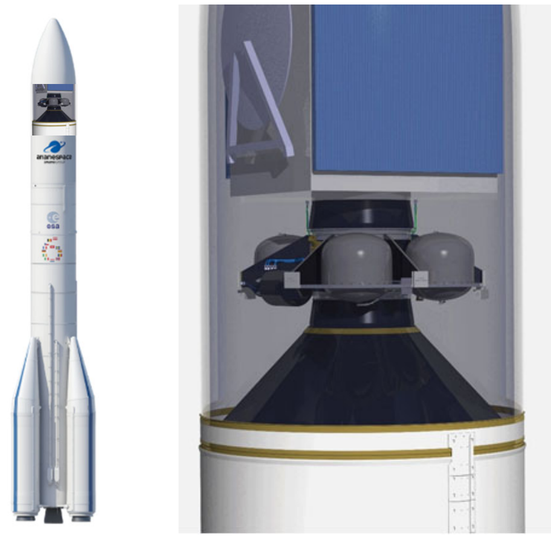

Figure 2. Ariane 6 / ASTRIS Configuration

3. <u>Earth Escape</u>
The upper stage of the launcher in single-launch configuration will deliver the KickStage with its payload in a 200 x 43450 km orbit at an inclination of 35°. From this elliptical orbit the KickStage will raise the orbit and make the necessary manoeuvres to reach the Earth-escape trajectory with Δv_∞ of 6.0 km/s. The payload mass is about 1300 kg. This mission is representative for the HERA mission case.

4. <u>GTO/LTO – ASTRIS Growth Potential</u>
An assessment of the design impacts on the "baseline" KickStage for encompassing a growth-potential mission will be performed. For this mission the upper stage of the launcher will deliver the KickStage and its payloads into GTO. Afterwards the "growth potential" KickStage shall release a set of three payloads of 1000 kg each by providing impulsive Δv's of 1.55 km/s and 2x 0.7 km/s.

The overall mission duration for this mission portfolio is up to two days for the reference missions and up to 15 days for growth potential missions.

In addition to these reference missions, additional ones of interest have been selected and defined to further expand on the commercial market, e.g. targeting the satellite constellation deployments (see Fig. 3).

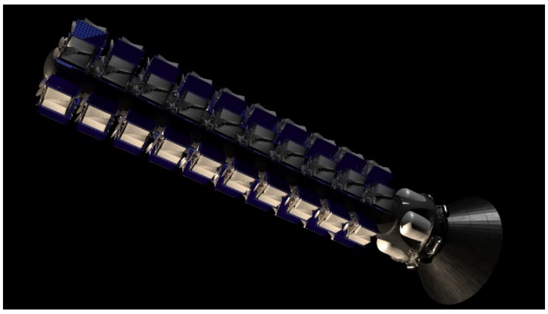

Figure 3. ASTRIS Constellation Deployment Mission

3. ASTRIS DESIGN OVERVIEW

The ASTRIS KickStage vehicle general design overview at its Preliminary Design Review (PDR) is shown in Fig. 4 from a top and bottom perspective.

The maximum diameter of the stage is about 4.5m and the height is limited to about 1.8m only and even about 1.1m only for the height of the central cylinder. This flat design is chosen to maximise the payload accommodation capacity in the Ariane 6 fairing / payload compartment.

The main structure, with its central cylinder, is completed by the externally attached "butterfly" structures supporting mainly the propellant tanks and the engine cross, providing the main engine interface.

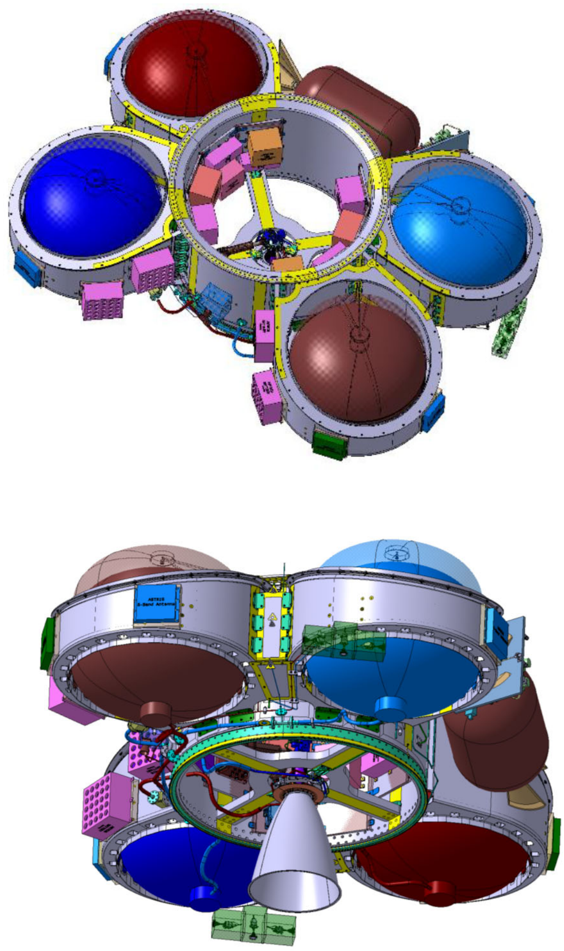

Figure 4. ASTRIS KickStage Design Overview

Additionally, the following subsystems and equipment are located mainly on or within the central cylinder and butterfly structure:

- The overall vehicle Avionics System, incl. the On-Board Computer, Data Handling System, Telemetry, Tracking & Tele-Command System, GNC Equipment, Electrical Power System, Payloads Management Unit, Valve Drive Electronics,…

- The Thrust Vector Control System with its Actuators to gimbal the Main Engine

- A distributed Thermal Control System, incl. e.g. electrical heaters and insulations, such as Multi-Layer-Insulation, e.g. encapsulating most of the vehicle (not shown in Fig.4).

In addition to this, the system is completed by secondary support structures, harness, additional sensors,…

The overall Propulsion System is described in more detail in the following section.

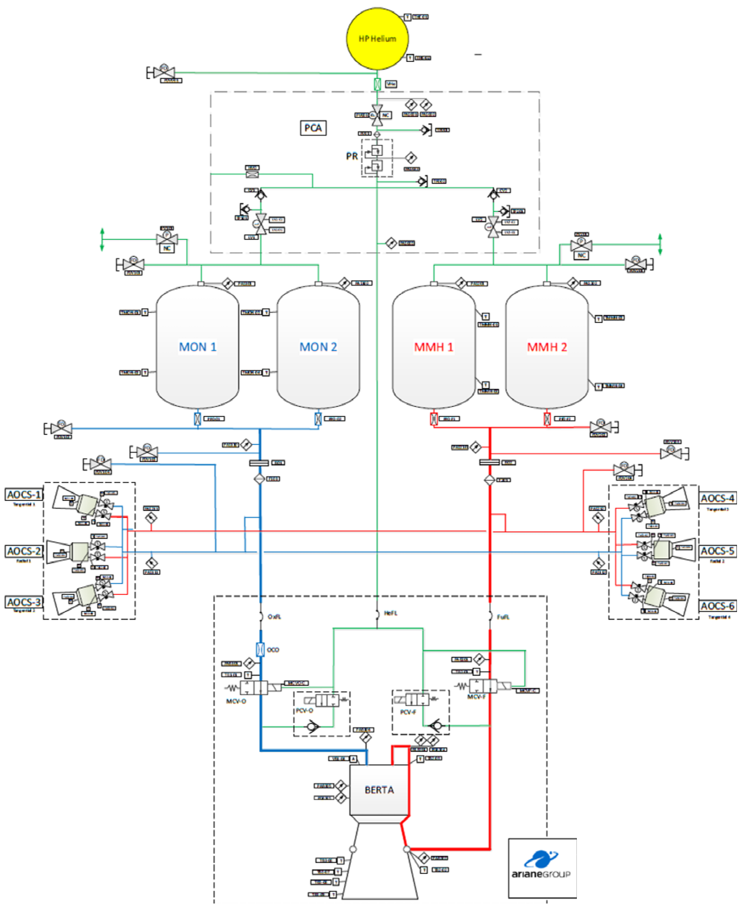

Figure 5. ASTRIS Propulsion System Flow Schematic

4. PROPULSION SYSTEM DEFINITION AND DESIGN STATUS

This paragraph describes the overall design and definition and operational scenario of the ASTRIS Propulsion System.

4.1. Flow Schematic & Main Elements

The flow schematic of the ASTRIS Propulsion System is depicted in Fig. 5.

The Propulsion System and its main elements can be characterized and described as follows:

- storable bi-propellants based system using MON and MMH

- pressure fed-main engine (4.2 kN nominal thrust) with gimballing for pitch/yaw control

- unified propulsion system featuring in addition six AOCS thrusters (10 N nominal thrust) for roll control during main engine boost and 3-axis control during coasting/ballistic phases

- Single He High Pressure (He HP) Storage Tank (≈ 260l / 400bar)

- Pressure Control Assembly with common (MON-MMH) pressurization featuring a
  - mechanical Pressure Regulator,
  - He HP Isolation PyroValve
  - Check Valve / Latch Valve Combination for each propellant side to ensure vapour isolation and pressure control / blow-down capabilities
  - Dedicated He supply line for the main engine to ensure
    - the commanding of the main engine feed valves (being He pressure assisted)
    - the He supply for the purge valves of the main engine

- 2x2 Propellant Tanks, which can be chosen according to mission needs with a volume between 700l and 860l
- The propellant tanks feature a dedicated Propellant Management Device (PMD) to allow for adequate propellant feed for AOCS thrusters during coasting phases as well as main engine (re-)ignition.

- Parallel depletion of the propellant tanks is ensured by proper design of the system as well as dedicated parallel flow equipment

- Downstream propellant isolation during ground phase is realized using Burst Discs
- Passivation at the end of mission is ensured by two passivation PyroValves
- He and Propellant Filters
- Fill & Drain Valves (FDVs) & Test Ports
- Pressure & Temperature Sensors
- High & low pressure Helium and pressurization lines as well as propellant feed lines, associated secondary lines and needed junction elements for lines interconnections

4.2. Operational Scenario

The operational scenario for the ASTRIS propulsion system is as follows:

1. After additional and repeated acceptance and check-out tests at the spaceport in Kourou the propellants will be loaded in the spacecraft preparation facility
2. The section downstream of the burst disks will be pressurized with Helium to 1-1.5 bar
3. The propellant tanks will be pressurized by Helium to a level of about 5-6 bar
4. The He tank will be loaded/pressurized to a level of about 400 bar
5. The KickStage will be assembled with the payloads as part of the payload stack and then encapsulated under the A6 fairing
6. In the launch zone building the payload stack will be mated with the rest of the A6 launcher
7. Execution of launch chronology, lift-off, A6 booster and main stage flight phases during which the KickStage (propulsion system) is in stand-by
8. During the A6 upper stage flight the ASTRIS propulsion system will be primed in the following manner:

   a. PCA latch valves are commanded open
   b. PCA He HP isolation pyrovalve is fired

   By this the Helium flow towards the propellant tanks will be established and will pre-pressurize the tanks from the pad pressure to a level of about up to 20bar.

   During this pre-pressurization the burst disks will rupture at a defined Δp. Propellants priming will be executed against the downstream Helium to limit the waterhammer induced.
9. After having reached the pre-pressurization threshold the latch valves will be commanded closed. The propellant tanks ullage temperatures and pressures will be allowed to settle for a certain duration.
10. Afterwards a second pressurization will be executed to achieve propellant tank pressures defined for the main engine ignition domain. When this domain is reached the latch valves will again be closed.
11. After separation and sufficient distancing from the launcher upper stage, the ASTRIS main engine will be ignited by a sequence of purge and main feed valves activations.
12. In case of a longer coasting phase upfront a first main engine boost, the AOCS thrusters might be used for minor manoeuvres and 3-axis attitude control purposes.
13. With the main engine ignition completed the latch valves will be commanded open again to allow the pressure regulator to control the propellant tanks pressure during the steady state boost.
14. AOCS thrusters activation might occur during main engine boost for roll control purposes.
15. At the end of the main engine boost the latch valves will be closed and the system will work in a blow-down mode to reduce tank pressures typically for about 2-2.5 bar, before the main engine is shut down and purged.
16. In the subsequent ballistic phase, the AOCS thrusters will be used for minor manoeuvres and 3-axis attitude control incl. potential payload release sequences.
17. Prior to a subsequent additional main engine boost, a re-pressurization will be executed similar to the second pressurization above to again reach the main engine ignition domain.
18. Afterwards the a.m. steps will be repeated for all boosts until the mission is completed, all payloads have been released, and the KickStage is put on its final orbit / trajectory.
19. At the end of the mission, the propulsion system passivation will be executed by subsequently firing the two passivation pyrovalves and therefore releasing the residual propellants and helium with the latch valves being open.

4.3. Mission & Performance Analysis

A first propulsion system performance analysis has been performed for the different reference missions for the main phases of concern. This was aiming

- to assist the definition, characterization and validation of the preliminary design and its behaviour,
- to support the necessary design choices as well as
- to support the requirements declination and
- to contribute to the overall KickStage budgets and performances, i.e.
- to verify some of the main mission requirements.

This propulsion system performance analysis has been performed with the help of the simulation software ECOSIM and its ESPSS libraries. Fig. 6 displays the model established for this analysis.

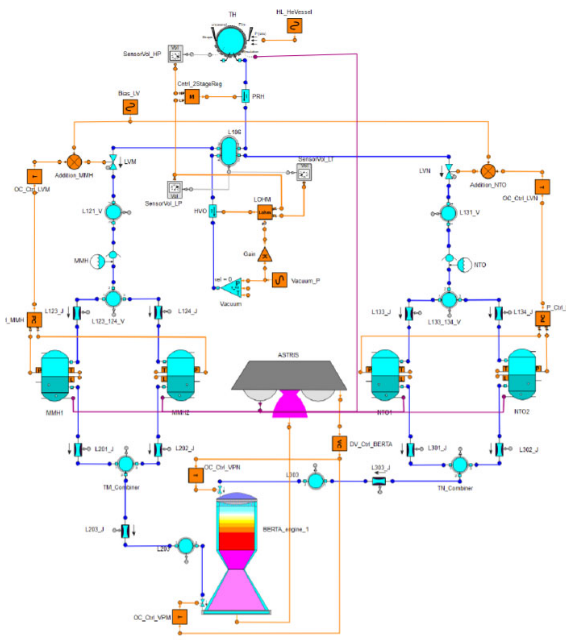

Figure 6. ASTRIS EcosimPro Propulsion Model

Relevant mission, environmental, design definition and operational inputs and parameters were collected and/or elaborated to allow for the different mission analyses.

Sample results are shown in fig. 7 to fig. 9 giving an example for the initial pressurization during the A6 upper stage flight phase, the propellant tanks pressure evolution during the two boost GTO-GEO mission and the resulting BERTA main engine mass flows and thrust performances for this mission case.

These analysis results demonstrate that the propulsion system with its definition and operational scenario is able to meet the mission and performance requirements and expectations (at this still early phase of the project).

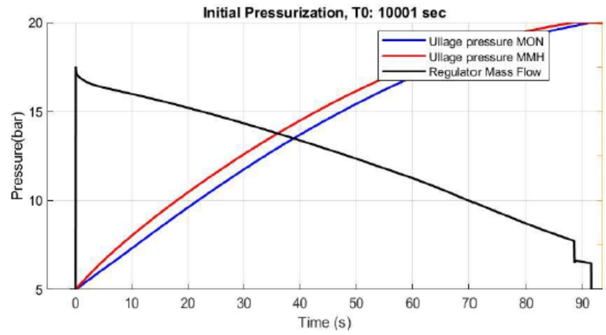

Figure 7. Initial Propellant Tanks Pressurization

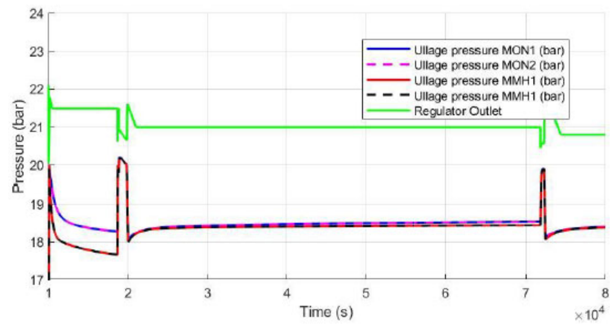

Figure 8. GTO-GEO Propellant Tank Pressures

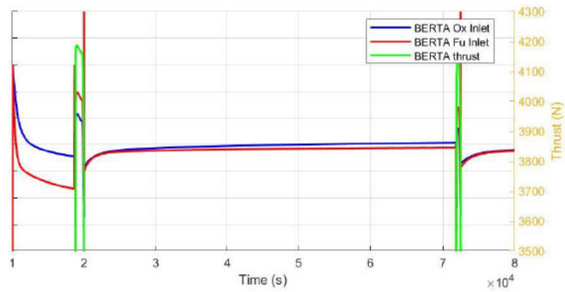

Figure 9. GTO-GEO - BERTA Performances

The results also contribute to the definition of the operational domains of the main engine as e.g. given by the resulting interface pressure domain as shown in Fig. 10.

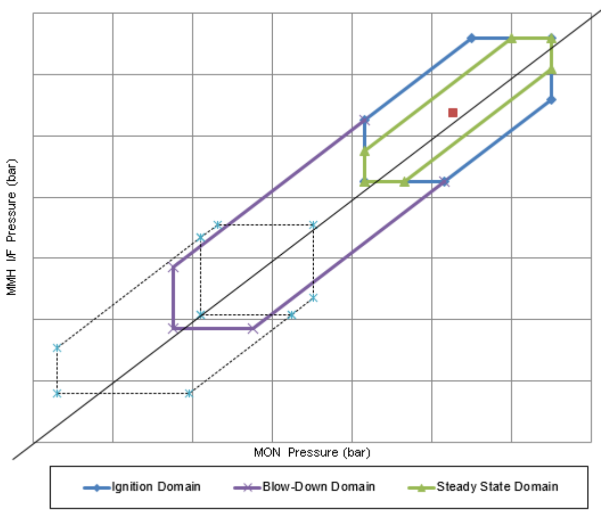

Figure 10. BERTA Pressure Domains

5. BERTA ENGINE DEVELOPMENT STATUS

An outline of the BERTA Flight Model (FM) design and its main components is given in fig. 11.

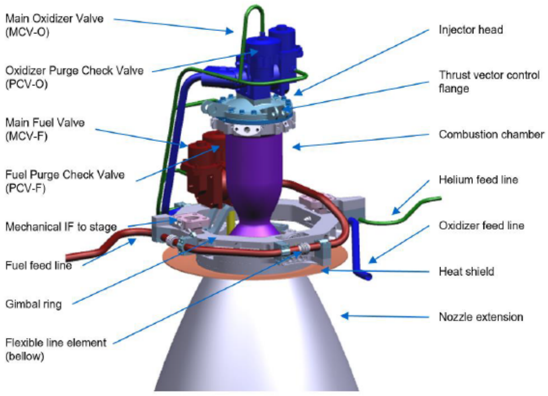

Figure 11. BERTA Design & Main Components

The BERTA design & development is widely based on the heritage and experience gathered from the A5 EPS AESTUS engine development, production and flight evaluations and, not to forget, lessons learnt through occurred problems and anomalies.

The BERTA engine technology and concept definition has been matured by ArianeGroup within the frame of ESA's Future Launcher Preparatory Program (FLPP) including hot firing tests for verification of the chosen main design solutions. The ASTRIS programme worked in close collaboration with FLPP to take advantage of the existing test model: A very early Hot Firing Test (HFT) could be performed in the frame of FLPP, using the Pre-Development Model #1 (PDM1) to de-risk the ASTRIS programme.

A specific challenge to this small-scale engine, in comparison to AESTUS, is the management of thrust chamber cooling and associated stability of the engine operation within its overall operational domain.

Resulting from the FLPP analysis and tests it has been decided to base the thrust chamber design on a fuel regenerative cooling concept. The feasibility of this concept was confirmed for the ASTRIS foreseen operational domain by the PDM1 test campaign executed at end of Q2 2021 and will be validated by the PDM2 test campaign in Q2 of 2022.

The engine / thrust chamber model configuration chosen for the PDM1 campaign is representative to study the main aspects and objectives foreseen within the given development step, i.e. feasibility demonstration for the cooling concept as well as validation of stability aspects.

The PDM1 configuration is shown in fig. 12 also in comparison to the upcoming PDM2 test article / campaign.

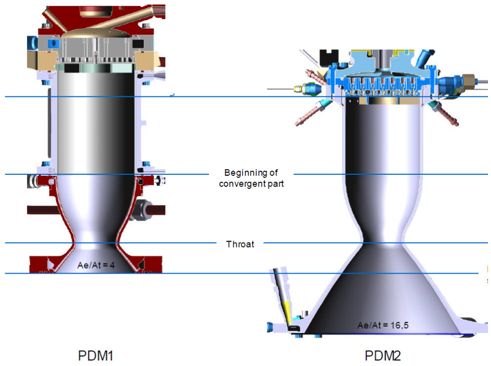

Figure 12. BERTA PDM1 & PDM2 Configurations

An impression of the PDM1 HFT at DLR Lampoldshausen is presented in fig. 13

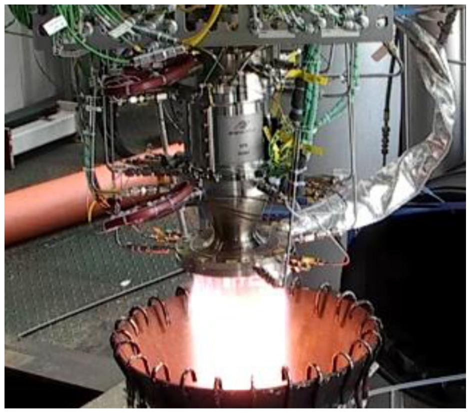

Figure 13. PDM1 Hot Firing Test – Courtesy: DLR

The tests evaluation revealed the capability of the engine in terms of cooling and stability within the foreseen operational domain but also provided some indications of potential limits regarding these aspects as illustrated by the green line and blue area in fig. 14.

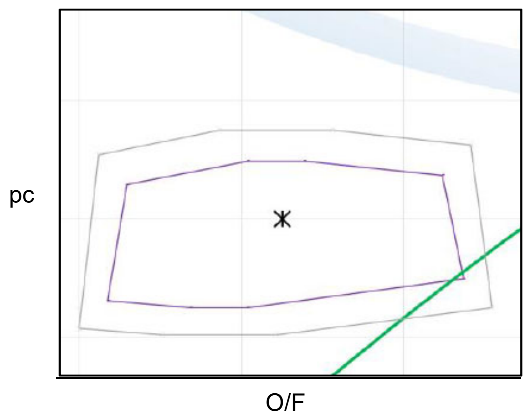

Figure 14. PDM1 Tests - Cooling and Stability Results

To anticipate these potential limit indications the stage propulsion and engine engineering teams are working in close cooperation to adjust the operational domains and the engine robustness to mitigate any of the associated potential remaining risks. This robustness demonstration will be one of the core elements and objectives of the upcoming PDM2 HFT campaign.

6. PRESSURE CONTROL ASSEMBLY ARCHITECTURE CHOICE

6.1. Background

One of the core questions in the early development phases of the ASTRIS KickStage propulsion system development was the selection of the pressure control technology, the concept and its architecture, incl. the subsequent impacts of this choice on the overall propulsion system and on the KickStage system level, in terms of performances and programmatic aspects.

For this reason an extensive trade-off has been performed in the early Phase B, which was concluded in early Q3 2021 at the System Requirements Review (SRR), to determine the best solution in view of the ASTRIS project needs and constraints.

6.2. Rules of the Trade-Off

As agreed for the project, trade-offs and the associated selections shall be based on the subsequent governing equation Eq. 1:

$$RPE = RP - \mathbf{X}\,\frac{M€}{\%}\cdot Rel. + \mathbf{Y}\,\frac{M€}{t}\cdot Mass + \mathbf{Z}\,\cdot NRP \qquad \text{Eq. 1}$$

This means, options shall be compared (mainly) on the basis of a Recurring Price Equivalent (RPE), which is a combination of the Recurring Price (RP), the ASTRIS Mission Reliability (Rel., factorized by X), the Mass of the solution (factorized by Y) and the Non-Recurring Price/Effort (NRP, factorized by Z) associated to the development cost of this solution.

Additional solutions discriminating aspects (e.g. development risks) were also considered in the trade-off and were, where possible, implemented in the a.m. governing equation.

6.3. Trade Options

As a starting point the different options for the PCA technology, the resulting architectures, possible equipment candidates, including ongoing developments, have been identified, elaborated and analysed in view of the ASTRIS and PCA functional, operational and performance requirements, incl. general feasibility within the project technical and programmatic perimeter, and especially regarding the a.m. trade-off criteria.

Regarding this step of the trade, the large experience from different projects (e.g. EPS, ATV, MPCV, Satellite Propulsion Systems, Ariane 6) and sites within (and even outside) of ArianeGroup were of large benefit to complete the picture upon the options and provide elements for their assessments and analyses.

The following main Architecture / Technology Options and sub-options were defined for the trade-off, also illustrated in Fig. 15:

1. <u>Mechanical Pressure Regulator Architectures:</u>
   based on
   - former (adapted) EPS Pressure Regulator
   - Satellite Propulsion System Regulators (as adapted COTS or new development)
   - US Equipment
2. <u>Hybrid Pressure Regulator Architectures:</u>
   based on an
   - Automotive Equipment solution (CNG technology)
3. <u>Electric Pressure Regulator Architectures:</u>
   based on
   - Bang-Bang Solenoid Valves
   - Motorized Valve
   - Piezo-Electrical Valves

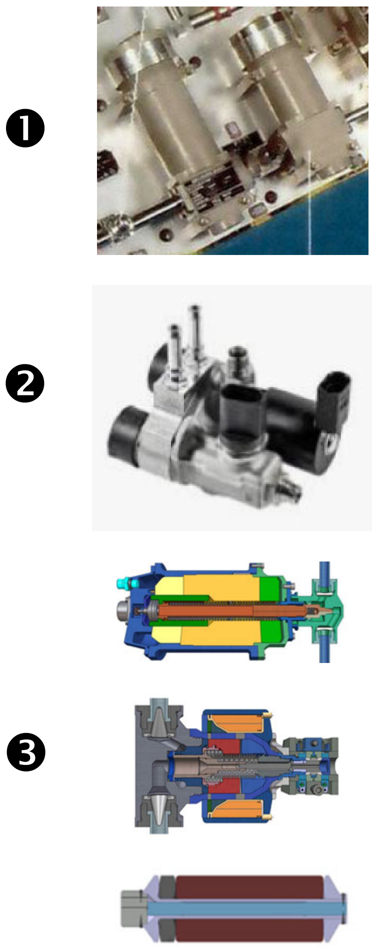

Figure 15. PCA Trade-Off Technology Options (examples)

6.4. Trade-Off Execution & Prel. Conclusions

Based on these technologies PCA architectures were defined in line with the ASTRIS needs.

Two examples corresponding to a.m. options 1 & 2 are given in Fig. 16 and 17 below.

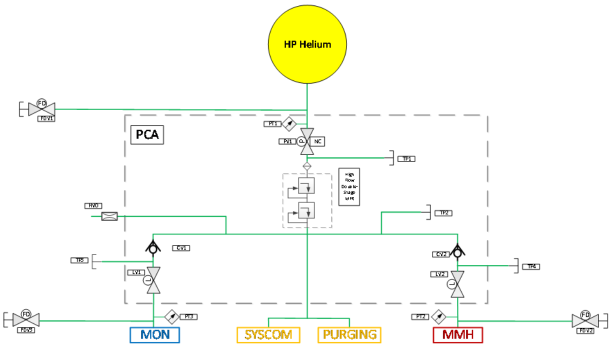

Figure 16. PCA Mechanical PR Architecture Option

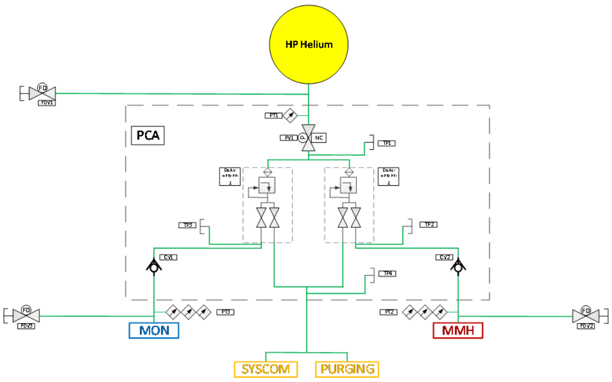

Figure 17. PCA Hybrid PR Architecture Option

The architecture definitions and subsequent analyses were performed for all pressure regulator technology options and sub-options/architectures to allow for the comparison by the RPE criterion and additional aspects collected aside.

This included also the identification, definition and evaluation of different complementary PCA equipment, as shown in the schematics above.

The assessment was performed on PCA level and on overall pressurization system level incl. the Helium tank (as shown in Fig. 16/17 with the results given in Fig. 18). And as well on the overall ASTRIS KickStage level e.g. especially for the electrical architectures having a non-negligible impact upon the KickStage avionics.

To support the trade-off some suppliers were contacted in the frame of Request for Information (RFI) loops to consolidate and back-up the trade assessments by the ArianeGroup team, especially in view of programmatic aspects.

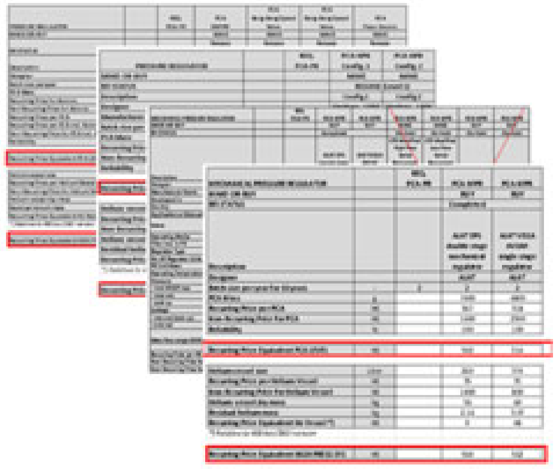

Figure 18. PCA Architecture Options Evaluations

The following conclusions could be drawn from these evaluations:

- All electrical pressure regulator options have been dropped from the options list in view of the ASTRIS development schedule, development cost and associated risks - and for some of the sub-options also wrt the evaluated performance parameters (esp. mass & recurring cost).

- Solutions with (new) developments featuring satellite propulsion regulators or US components scored also low on programmatic aspects as schedule and risk, and were therefore discarded.

- The re-activation of the former EPS regulator and its technical adaption to ASTRIS needs proved to be more realistic, in contrast to initial assumptions, in view of ASTRIS programmatic constraints.

- The hybrid pressure regulator concept, based on an automotive equipment, was also considered of high interest, able to “compete” with the EPS based heritage solution. Therefore, and also in view of the “new space solutions and suppliers” project objective, it has been retained for the subsequent trade-off refinement.

6.5. Trade-Off Refinement & Final Choice

The remaining two options (and some sub-options) were analysed in more detail from a technical, costs, schedule, as well as risks and opportunities perspective. The interaction with relevant suppliers was intensified: With their input the trade-off assessment gained credibility and at the same time, the suppliers got ready to onboard the project.

This trade refinement led to the following conclusion: Even if the hybrid concept was analysed to be slightly more competitive than the EPS heritage solution in terms of RPE, the heritage and technology maturity clearly outweighed this due to the given project constraints.

ASTRIS schedule analysis showed that the pressure regulator choice, its development and (delta) qualification is on the critical path for the overall development. The remaining risks with the EPS solution are judged acceptable.

Therefore the final trade-off conclusion and selection was to base the PCA architecture on a mechanical pressure regulator using the Ariane 5 EPS pressure regulator adapted to ASTRIS needs.

This equipment and respective delta-development will be provided and performed by Air Liquide Advance Technologies, e.g. also supplying the pressure regulator for the Ariane 6 upper stage.

The resulting PCA architecture is shown as an extract of the flow schematic in Fig. 19.

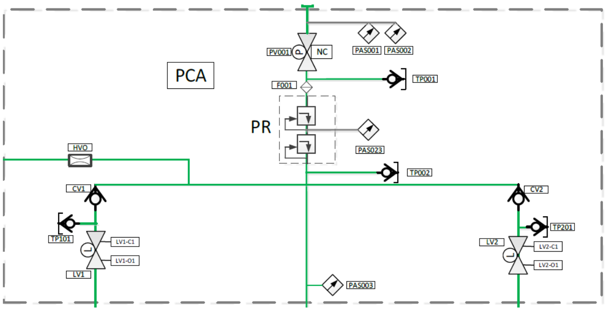

Figure 19. PCA selected Architecture

7. OTHER PROPULSION EQUIPMENT

The other propulsion equipment have been mainly selected in the six month prior to the ASTRIS System PDR (held at end of Q1 2022).

The main items are (see also Fig. 20):

- The main engine valves will be specifically designed and developed for BERTA by SAB
- The AOCS thrusters will be the S10-13 type from ArianeGroup using a single-seat flow control valve from MOOG US, i.e. a close-to-COTS equipment
- The PCA latch valves will also be supplied by MOOG US as COTS equipment
- The PCA check valve will be (based on) the former ATV PCA check valves as COTS equipment
- The He high pressure tank will be specifically developed for the ASTRIS application by PEAK
- The propellant tanks are based on the ArianeGroup OST 22 tank family, adapted for the ASTRIS application
- The propellant tank internal PMD will be specifically designed and developed for the ASTRIS needs (ArianeGroup internal development)
- The pyrovalves and fill & drain valves will be taken from the ArianeGroup satellite products portfolio as COTS components
- The burst disk will be taken from ArianeGroup EPS heritage, adapted to the ASTRIS pressure definitions
- Sensors will be chosen from A5 and A6 COTS catalogue components
- Pressurant and propellant lines will be based on Titanium tubing for most parts of the system

Figure 20. Some selected Propulsion Equipment

8. ASTRIS KICKSTAGE - GLOBAL DEVELOPMENT LOGIC & SCHEDULE

8.1. Stage - Propulsion System - Main Engine Current Development Status & Interactions

A major challenge is the strong link and parallel development of the main engine, the propulsion system and the overall KickStage. This means that the main engine & stage development logic and schedule have to deviate from the usual logic and the risks have to be carefully mastered.

The engine was matured in the frame of ESA’s FLPP and was embarking the ASTRIS project based on the PDM1 tests. In parallel the KickStage development was starting and gathering in speed to pass its System Requirements Review (SRR) in mid 2021.

Subsequently and based on the evaluation of the PDM1 test results, the BERTA engine passed its PDR in Q4 2021. This was linked to the need to freeze the design of the first engine Development Model (DM) in view of its manufacturing schedule.

In parallel, preparations for the PDM2 test campaign started to further mature the flight design. Inputs were refined, interacting with the stage propulsion team, for definition and analysis, e.g. based on above presented PCA definition, mission and performance analysis and resulting engine operational domains.

In addition, both - engine and stage propulsion system teams - were also starting and executing their relevant equipment developments and or / COTS selections, within the same phase, when also consolidating the system set of requirements towards the ASTRIS System PDR held at the end of Q1 2022.

8.2. Next Development Steps

For all selected COTS items, Equipment Qualification Status Reviews (EQSRs) will be performed to refine the need for delta verification and qualification of these items in view of the ASTRIS application.

Based on the PDM2 test results and System PDR conclusion the engine development will enter a complementary PDR as risk mitigation to secure the design of the main engine Development and Qualification Models (DMs & QMs), also embarking the other engine items such as valves, gimbal and nozzle extension, which were not yet part of the PDM definition.

On stage and propulsion level a proto-flight model approach is targeted, which foresees mainly a mechanical test campaign and a hot firing test campaign before converting the stage into its final FM1 configuration.

These test campaigns will be executed in the course of Q2-Q4 2023 after the ASTRIS System CDR which is scheduled at the end of 2022.

Propulsion system equipment will be qualified in parallel mostly on equipment basis, either on a.m. EQSR approach or following a standard development cycle for the specifically developed items.

The PCA is foreseen for verification and qualification on its level to verify the proper interaction of the different components (with a PCA DM) as early as possible and to fill any potential gaps for the individual equipment qualification by a dedicated PCA QM.

The core validation of the overall propulsion system will be the Stage Hot Firing Test campaign which will embark all relevant elements of the propulsion system and also of the overall KickStage in case of stage/propulsion system interactions of interest.

This Stage Hot Firing Test will use the QM1 main engine and will also perform some main engine verifications needed to contribute to and complete the overall engine qualification.

All this will be cumulating in several Qualification Reviews (QR) on different items and levels up to the final Ground Qualification Review (G-QR) of the ASTRIS system in 2024 with the preparation of the Flight Model #1 performed in parallel and the foreseen HERA mission maiden flight at the end of 2024.

9. SUMMARY & CONCLUSION

The ASTRIS KickStage will be a valuable asset for the Ariane 6 Launch System to enable an even larger coverage of customer interests in terms of spacecraft and mission scenarios as well as associated performance needs. This will further foster the success of the Ariane 6 in terms of market share, industrialization potential and therefore cost efficiency of the launcher.

This will be achieved by an ASTRIS KickStage and Propulsion System development focused on development schedule, and therefore development effort & cost, also keeping recurring cost and development risks as low as possible, especially using and relying on the broad heritage of ArianeGroup, and its project partners, products, the related technology and competences as well as using synergies of other programmes such as Ariane 6 itself or past & current satellite propulsion products and projects.

This approach and the ambition and engagement of the overall development team, within ESA, ArianeGroup, as well as its multiple project partners involved, will enable the ASTRIS maiden flight, to meet the need of the HERA mission, targeted for the end of 2024, and the subsequent exploitation phase for the benefit of commercial and scientific payloads, missions and customers.