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ARIANE 6 – TANKS & STRUCTURES FOR THE NEW EUROPEAN LAUNCHER

J. Merino, A. Patzelt, A. Steinacher, M. Windisch, G. Heinrich, R. Forster, C. Bauer
MT Aerospace AG, Germany

Abstract

In the frame of the Ariane 6 Program, MT Aerospace AG (MTA) is responsible for the design, analysis, test and qualification as well as for later series production of metallic bare tanks, tank components and structures of the new heavy European launcher. Due to increased launch rate and ambitious performance and cost requirements, new manufacturing processes and automated assembly technologies are key topics within the running development program using a design-to-manufacturing and a design-to-cost approach.

During the last decade, MTA has developed and successfully demonstrated its competences focusing on aluminium lithium technology and friction stir welding (FSW) together with their related damage mechanics. These competences have turned into sound heritage and will now be applied for the realization of the new generation launcher Ariane 6, which will include FSW applied to all aluminium tank structures, shot peen forming performed on domes and cylinder segments made of aluminium lithium and automated riveting for the assembly of the structures.

The paper describes the present design configuration for the Upper Liquid Propulsion Module (ULPM), the Lower Liquid Propulsion Module (LLPM) and the metallic skirts of the equipped solid rocket motor, together with the engineering, technology development and industrialization activities in order to deliver the products with the required performance, on time and within the costs limitations. These designs are entering the manufacturing releases of the first development and qualification models.

Keywords

Ariane 6, heavy launcher, bare tanks, structures, shot peen forming, FSW, aluminium lithium, manufacturing

1. INTRODUCTION

MTA is dedicated to contribute to provide Europe with a self-sustainable, efficient launch system, which is competitive on the commercial market and serves the needs of ESA member states. The responsibility of MTA comprises the metallic bare tanks and the metallic structures with thermal protection by the latter.

The cost efficiency of a future Ariane 6 launch system [1] depends largely on two main conditions: a design that is focused on efficient manufacturing concepts, and an industrial organisation that is built on the expertise of suppliers that are part of the design team from the beginning.

The engineering, technology and industrial solutions presented in this paper have been created by our teams, supported by leading engineering experts based on best practices. Over the last decade, MTA has worked with the support of ESA, DLR and the Bavarian Government investigating efficient design solutions, which will enable the use of advanced, highly automated manufacturing technologies, for both composite and metallic solutions. This paper concentrates in the latter ones.

1.1. General Ariane 6 aspects

The Ariane 6 Program is led by Ariane Group and intends to develop a family of launchers: Ariane 62, primarily for institutional launches; and Ariane 64, primarily for commercial (multiple) launches. Modularity and flexibility are key features of the Ariane 6 configurations. The commonality with other European launchers has been present in the project since the beginning. Examples are the VINCI re-ignitable engine from A5 ME Upper Stage, the main stage experience from Ariane 5 ECA and the new Solid Rocket Motor from VEGA C. The maximum production rate is 12 shipset per year.

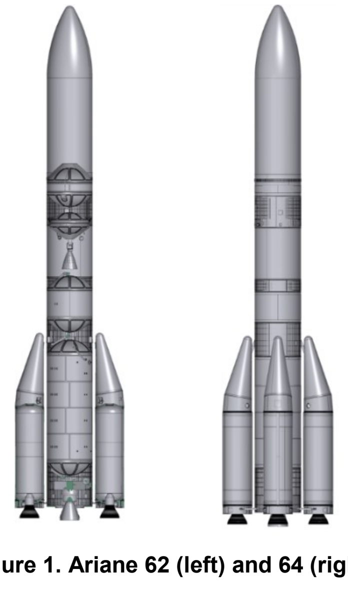

Figure 1. Ariane 62 (left) and 64 (right)

The boundary conditions, under which Ariane 6 is envisioned, represent a series of main challenges influencing the whole development and qualification of the components:

- Ambitious schedule until maiden flight in 2020
- Limited development time & NRC budget
- Matching of competitive launch price targets (RC)
- Enhanced performance objectives
- Increased accountability of industry including transfer of risk and associated financial exposure
- Smooth transition from Ariane 5 to Ariane 6

1.2. MTA Perimeter

The main MTA contribution to Ariane 6 comprises the development and production of:

- ULPM bare tanks
- LLPM bare tank components
- Structures
  - ULPM Intertank Structure (ITS)
  - LLPM ITS
  - Equipped Solid Rocket Motor (ESR) Forward Skirt
  - ESR Rear Skirt
  - Vulcain Aft Bay
  - VINCI Heat Shield
- Solid Rocket Motor (SRM) with a 50% workshare

Within this paper, only metallic tanks and structures are presented. The milestone reflecting the present status of the Project is Preliminary Design Review (PDR), equivalent to a Preliminary Design Review.

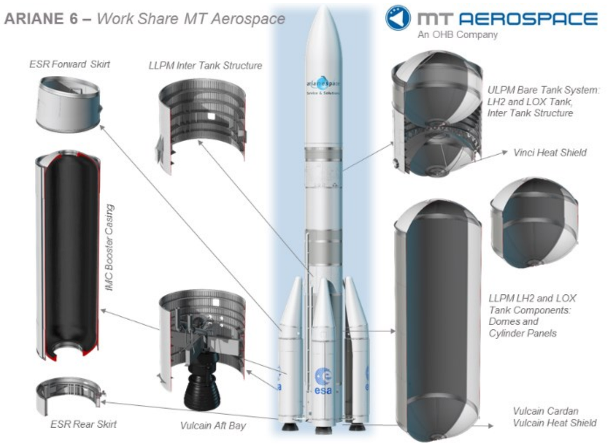

Figure 2. Overview MTA perimeter by Ariane 6

2. ENGINEERING

2.1. Present design configuration

2.1.1. ULPM Tanks

The current design the ULPM bare tanks and ITS is shown in Figure 3.

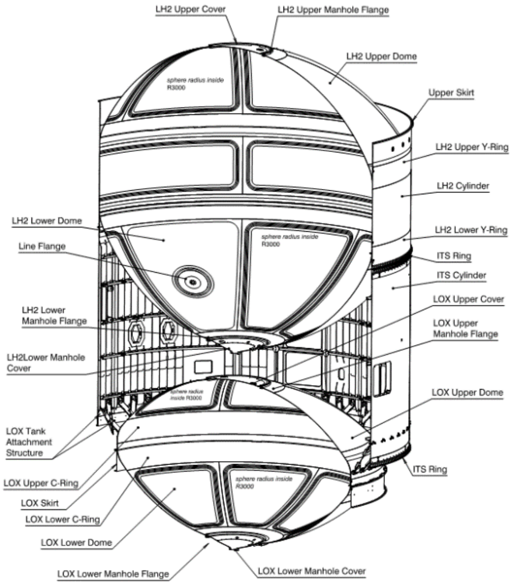

Figure 3. Overview of ULPM bare tanks and ITS

The ULPM bare tanks main features are:

- LH2 tank and LOX tank to store and provide liquid propellant and transfer loads from and to adjacent structures
- Mechanical I/F to
  - ULPM ITS for both tanks, LOX tank via X-/Y-shaped LOX attachment structure segments
  - Launch vehicle adapter (LVA): LH2 tank
  - Engine thrust Frame (ETF): LOX tank
  - Additional: fluid and pressure lines and other equipment
- Delivered tanks consist of:
  - Cylindrical parts
  - Upper and lower bulkheads
  - Note: cylindrical section for LOX tank is small and thus, integrated in the bulkhead. As a result, no separate cylinder is included
- All parts consist of aluminium alloys and all connections are friction stir welded, with the exception of the interface LOX lower C-Ring to lower skirt
  - AA2195: cylinder and dome segments
  - AA2219: Y-rings, manhole cover, and manhole flanges
- Other delivered main parts are the manhole covers, which are fixed with a bolted connection to manhole flanges. The final assembly will be done by the customer.

The LH2 tank withstands cryogenic temperatures in the range from 20 K to Room Temperature (RT). The LOX tank withstands cryogenic temperatures in the range from 90 K to RT. Both tanks material are compatible with their correspondent environment.

2.1.2. ULPM ITS

The main functions of the structure are the transfer of the loads from the interstage structure (IFS) and LOX tank to the LH2 tank, the accomplishment of the needed mechanical connections and the provision of the interfaces for the equipment (electronic boxes, cable ducts, lines, electrical I/F…) of the ULPM.

The ULPM ITS main design configuration aspects are:

- Bare structure comprising:
  - Face ring to IFS
  - Face ring to LH2 tank
  - LOX attachment to LOX tank
  - Outer skin including cut outs for access and lines which is split in axial direction into 8 x 45° panel segments, stiffened by frames and integral stringers
  - Splice sheets
  - I/F plates
  - Avionic and special kits brackets for technological flights
- Access doors
- Thermal protection, which is applied on the thermally loaded faces, presently not needed

The panel material is AA7XXX with 8 segments, shot peen formed, joined using riveted technology. The LOX tank attachments (LTA) are made of titanium alloy, due to thermal requirements.

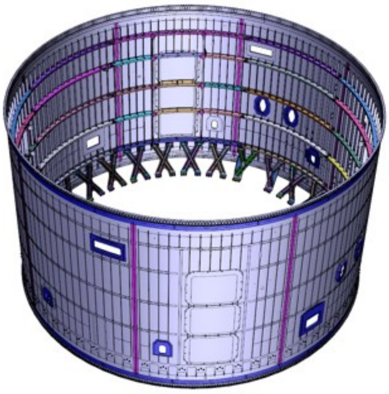

Figure 4. Overview of ULPM ITS

2.1.3. LLPM Tank Components

The current design of the LLPM bare tank components is shown in Figure 5. MTA delivers bare tank components (bulkheads and cylinder panels) to the customer. The customer is Design Definition Authority of the LLPM Bare Tanks and responsible for cylinder weld sizing and the qualification of the finalized LLPM Bare Tanks.

The components consist of

- LH2 and LOX Bulkheads and single cylinder segments. Final welding of BT will be performed by customer.
- Mechanical I/F between
  - Vulcain Aft Bay and LH2 bare tank
  - LLPM Intertank structure (ITS) and both tanks
  - LLPM Interface structure (IFS) and LOX tank
  - Additional interfaces: fluid and pressure lines and other equipment
- Accompanying parts: manhole covers: bolt connection to manhole flanges (final assembly: by customer)

All parts consist of aluminium alloys and all connections are friction stir welded with material AA2195 for the dome segments and AA2219 for cylinder segments, Y-rings, manhole cover and manhole flanges.

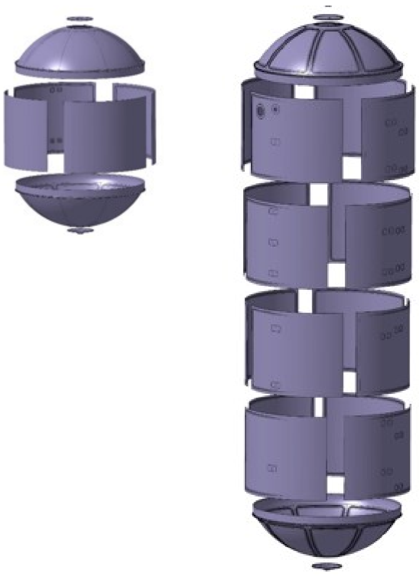

Figure 5. Overview of LLPM Tank Components and ITS

2.1.4. LLPM ITS

The LLPM-ITS is composed of

- Bare structure comprising of
  - Face ring to LH2 tank
  - Face ring to LOX tank
  - Outer skin including cut outs for access and lines which is split in axial direction into 8 x 45° panel segments, stiffened by frames and ribs, stringers and girders.
  - Back up structure for the introduction of the ESR loads
  - Splice sheets
  - Boosters load introduction fittings (2 or 4 ESR fittings, depending on launcher configuration)
- Access doors
- ESR fitting cover
- Thermal protection which is applied on the thermally loaded faces with material PROSIAL 2000

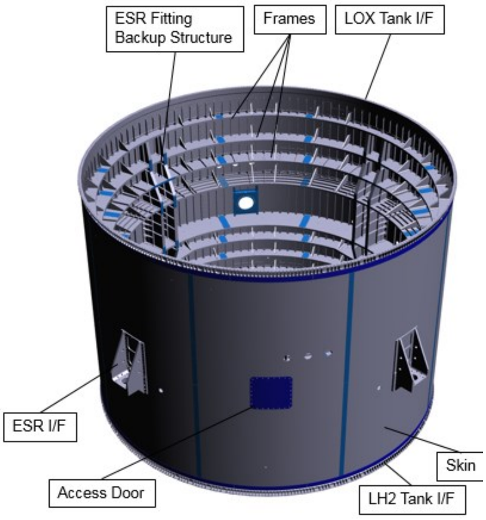

Figure 6. Overview LLPM ITS

The panel material is AA7XXX with 8 segments, shot peen formed, joined using riveted technology. The I/F rings are made of AA7XX, forged and turned. The ESR fittings and backup structures are machined in AA7XXX.

2.1.5. ESR Forward Skirt

The ESR Forward Skirt consist of:

- Basic structure
  - Solid Rocket Motor (SRM) I/F Ring
  - Cone Ring
  - Outer skin split into four skin panel segments
  - Distancing rocket support structure
  - Reinforcing profiles and splice sheets
- Access door
- Equipment brackets
- Distancing rocket fairings
- Thermal protection Prosial 2000
- Major Interfaces to Solid Rocket Motor (SRM) and Cone. Minor I/F to: Distancing rocket, distancing rocket fairing, equipment, access door

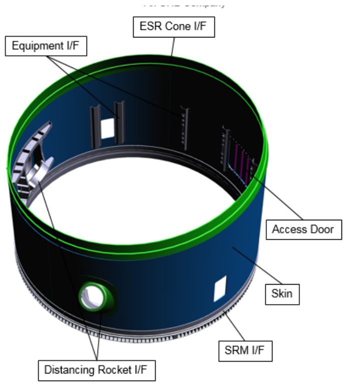

Figure 7. Overview ESR Forward Skirt

The panel material is AA7XXX with 4 segments, shot peen formed, joined using riveted technology. The interface rings are made of AA7XXX, forged and turned. The distancing Rocket adapter is machined also in AA7XXX.

2.1.6. ESR Rear Skirt

The ESR Rear Skirt consist of:

- Bare structure
  - SRM I/F Ring
  - Upper Frame
  - Lower Frame
  - Outer skin (split in four segments) including cut outs for access doors, electrical plates
  - Rod fittings
  - Ribs and splices
  - Various Attachment and Reinforcing Parts
- Access doors
- Thermal protection, which is applied on the thermally loaded faces.

The structure sees a maximum temperature of 373 K. The panel material is AA7XXX with 4 segments, shot peen formed, joined using riveted technology. The I/F rings are made of AA7XXX, forged and turned. The distancing Rocket adapter is machined in AA7XXX.

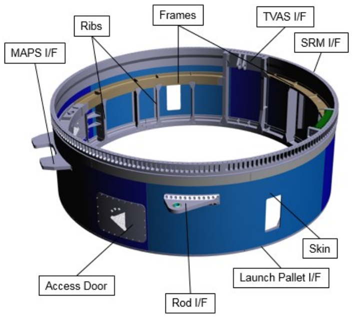

Figure 8. Overview ESR Rear Skirt

2.1.7. Vulcain Aft Bay

MTA participates in the development of the Vulcain Aft Bay (VuAB) by providing the skirt panels of the cylindrical barrel. Due to synergies with other lightweight structures (e.g. engineering, processes), an effective development can be ensured. The principle function of the VuAB skirt panels is to provide the support and load transfer for the propulsion system of the mains stage including interfaces for supporting equipment. The next figure illustrates the MTA workshare of the VuAB. The panels include integral stiffeners in axial direction with riveted frame segments and local reinforcements around large cut-outs. The panels are made from high strength aluminium alloy AA7XXX.

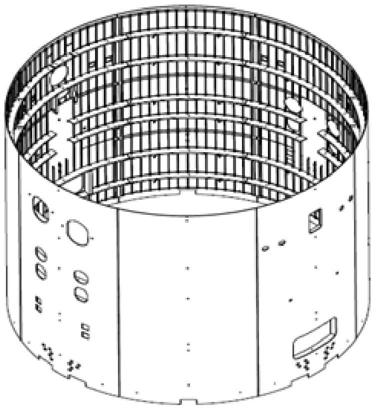

Figure 9. Overview VuAB

2.2. Development Logic

The Ariane 6 development roadmap is mainly driven by:

- Concurrent engineering approach: significant parallelization of product definition, process development and procurement of J&T
- Implementation of a Production pull logic: hardware delivery dates define need dates and product definition
- Handling of launcher maturity and corresponding inputs, e.g. customer specifications, load environment and interface definition with individual Design Key Points (DKPs) with customer and with internal Manufacturing Readiness Reviews (MRRs)

In order to navigate and advance in this roadmap, a series of development and qualification models have been planned to address the MTA and Ariane Group needs. The heritage of Ariane 5 by MTA has influenced strongly the selection of the configuration of some of these models.

The TRL assessment and methodology is performed acc. to ISO 16290 [2]. A summary of MTA heritage and identification of development needs was done in early 2015 and the next development steps were identified. For every relevant technology, e.g. forming, welding, inspection and material qualification, a roadmap has been defined with the identification of corresponding breadboards for TRL 5, demonstrators for TRL 6 and contribution to qualification models.

2.3. Trade-offs

Until PDR, a series project phases have contributed to the present selected technologies and concepts: former Ariane 6 configuration (PPH), Phase A, Phase B (present PDR loop). During the Ariane 6 phases starting in 2015, a series of trade-offs have been performed. The general assessment parameters are recurrent costs, non-recurrent costs, performance and schedule. These parameters are adapted for the different trade-offs and extended if relevant.

Some of the trade-offs were performed within dedicated Working Groups together with the customer.

The main trade-offs performed are:

- Launcher and stage configuration studies
- Sandwich Common Bulkhead for the ULPM
- Dome geometries
- Material selection
- LOX Tank attachment concept structure and material
- Cylinder material and segmentation
- Interface ULPM LOX Tank to Engine Thrust Frame
- ULPM LH2 Tank Pressurization Line Interface
- Position on ITS height of ESR Attachment
- Dome forming process
- Cylinder panels forming process
- Main Launcher Interface Working Group activities
- Frame design
- Cylinder panel segmentation and stiffening

The results of these studies are implemented in the present configurations of the product shown in §2.1. The partial results have been subject of value analysis with respect to the general assessment parameters.

2.4. Technical Specification

Based on customer requirement specifications for each product, a compliance status has been produced and the customer inputs consolidated. Then, MTA has established its own Technical Specification (ST), Verification Plan (PVE) and Justification File (DJ). The ST describes the products engineered by MTA. The different varication tasks in order to ensure the performance of the tanks and the structures are registered in the PVE. Finally, the DJ summarizes the main results of the design & analysis loops, describing how every requirement is demonstrated.

2.5. Structural Analysis

2.5.1. Mathematical Models

For the tanks products, mainly two type of models are established, i.e. dFEM (detailed FEM model) and sFEM (system FEM model). The former represents the minimal wall thickness for strength evaluation and the nominal wall thickness for linear buckling evaluation. The latter represents the nominal wall thickness for global stiffness, mass and inertia behaviour.

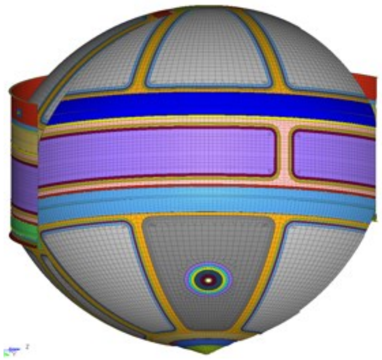

Figure 10. ULPM Tank sFEM (system FEM model)

For the structures, mainly only one type of detailed model is established for all evaluations.

2.5.2. Dimensioning Load Cases

Based on semi-automated tools and engineering judgement a working number of dimensioning load cases have been defined for all relevant ground phases (transport, integration, empty and filled tanks) and flight phases (lift off, ESR flight phases Qmax and γmax, LLPM flight and ULPM Flight). The following load types were considered:

- General loads, including pressure loads
- Inertial loads
- Enforced displacements induced by adjacent structures
- Aerodynamic and cavity pressure
- Build stresses (internal loads from manufacturing) and mounting fluxes
- Thermal loads
- Local loads (e.g. from equipment and line inertia)

2.5.3. Strength Analysis

The pre- and post-processing activities are done using Hyperworks 13.0 and the solver is NASTRAN 2013.1.1 64-Bit.

To derive the strength justification for the different components of the ULPM Tanks, FEM results of the LH2 bare tank and LOX bare tank are analysed. The respective models consider minimal wall thickness. The model is mainly meshed with shell elements. Only the Y-Rings of (LH2 tank) and the C-Rings (LOX tank), as well as the connected welds, are modelled with solid elements.

For the analysis, the relevant adjacent structures are incorporated. Different preselected load cases are analysed to define the global dimensioning load case (GDLC) for each component. The temperature loads were applied for the tanks as boundary conditions.

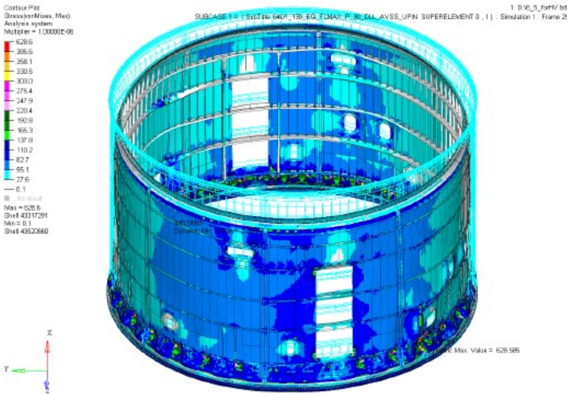

Figure 11. U-ITS Deform./vMisesStress Plot

2.5.4. Buckling Analysis

For the verification of the buckling modes, mainly due to axial and hoop stresses, a detailed linear stability analysis has been done for all the products. The solver is the SOL 105 from NASTRAN 2013.1.1 64-Bit.

For the current stability analysis, the KDF approach according to NASA SP 8007 is selected. As this approach is partly conservative for further performance improvement and margin recovery of the products, the use of non-linear analysis methods (e.g. collapse analysis) could be used. This procedure has been discussed during co-engineering sessions in terms of harmonisation of the analysis methods in the A6 program.

2.5.5. DTA

The critical crack size will be evaluated either by LEFM in the case of linear material behaviour or by the FAD (R6, SINTAP, FITNET) approach for elastic plastic conditions. The latest at MTA available versions of the following program will be used: ESACRACK (NASGRO), IWM Verb.

The damage tolerance analysis demonstrates the compliance to the fracture control requirements for flight hardware. The following approach is applied:

1) Structural screening for identification of Potential Fracture Critical Items
2) Selection of the applicable damage tolerance design principle for each item (safe life/fail-safe)
3) Analysis
    a) Safe life: it is demonstrated that flaws, cracks or crack-like defects, which are assumed to be in the component at the end of the manufacturing process, will not lead to catastrophic or critical failure by initiation or propagation.
    b) Fail-safe: it is demonstrated that a structure has redundancy to ensure that failure of one structural element does not cause general failure of the entire structure during the remaining lifetime.

The safe life approach is implemented as follows:

1) Critical crack size analysis due to static load
2) Crack growth analysis of an initial crack with a size equal to the non-destructive inspection limit.
3) The final crack size is compared to the critical crack size. Safe-life is demonstrated if the final crack size is smaller than the critical crack size

2.6. Thermal Analysis

2.6.1. Mathematical Models

Thermal models are established for the Structures products, not for the Tanks products.

As an example, for the ULPM ITS thermal analysis, different thermal mathematical models have been established.

For the determination of basic thermal characteristics, a ULPM 1/8 Model has been established that represents in a simplified way the ULPM ITS represents typical panel design in terms of the material thickness distribution and the material assignment to the individual components, in particular the LTA.

For computing the temperature response of the complete ULPM ITS as well as for verifying the results that have been obtained from the 1/8 Model, a model spanning the complete circumference of the ULPM ITS is established. This full model follows the same modelling approach of using predominantly shell elements (except interface rings and Thermal Protection) and in particular, the modelling of the LTA. The 3D model thereby allows deriving results that are more accurate.

2.6.2. Analysis

Thermal analysis are performed for the different Structures products using the solver P/Thermal from MSC Software.

By the U-ITS, the Hot Case, the Cold Case and the Maximum Heat Flux Case (MHF). The Hot Case is responsible for the assessment of the maximum temperature gradient on the LTA. This case is already mapped on the structural model for the most mechanically loaded timeframes. The maximum heat flux case is responsible for the assessment of the temperature gradient on the structure. Based on higher margins of safety in this region, the MHF case was not considered critical.

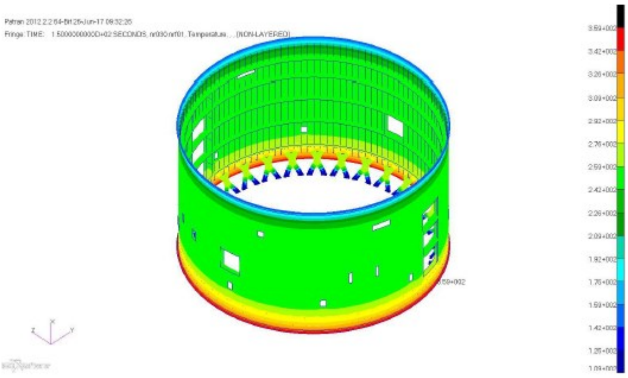

Figure 12. Temperature Distribution on the metallic parts

The hot case is the main driver behind the dimensioning of additional thermal protection on the outer surface of the ULPM in the form of PROSIAL 2000. The analysis has shown that no additional thermal protection is need. All metallic components have temperatures under the specified limit of 90 °C. The maximum heat flux case was analysed with respect to the allowable heat fluxes through the LOX and LH2 interfaces. The fulfilment of the given maximum heat flux requirements is extremely challenging.

2.7. Development and Qualification Models

A variety of hardware models are planned to feed the development and qualification tests. These models represents the needs of both MTA, e.g. some manufacturing models (MM) and qualification models (QEM) and the customer needs, e.g. Hot Firing Test Model (HFM). In some cases, the configuration of such models is driven by schedule and are not full representative of the correspondent flight models (FM).

2.8. Qualification Tests

During the development phase, the QEM and some of the MM models will be used to conduct a variety of tests for the manufacturing processes, validation of the analytical models and to prepare the final qualification. These series of test can include burst pressure tests and static tests to verify the design against the load environment provided. Qualification by similarity is in consideration by the LLPM bulkhead.

3. TECHNOLOGY DEVELOPMENT

The development of the selected technologies in the frame of Ariane 6 is categorised in:

- Forming Processes
  - Shot Peen Forming selected for all segments/panels
  - Materials: AA7XXX (structure panels), AA2219 (cylinder segment), AA2195 (dome segments, cylinder segments)
- Welding processes
  - FSW used for all welds.
  - Two types: retractable and fixed pin
- Material Qualification
- Inspection
- Automation in riveting technology

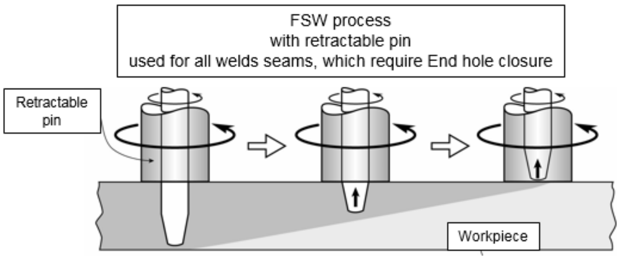

Figure 13. FSW process

3.1. Forming

Based on a performed trade-off considering state of the art forming processes (e.g. break forming, age creep forming etc.), the shoot peen forming has been chosen as baseline forming process for all cylindrical panels of the structures and propellant tanks within the A6 development. The main advantages are:

- Flexibility regarding wall thickness distribution and local reinforcements of different panel geometry
- Flexibility regarding panel curvature and global dimensions
- Potential of high automatization

By Shot Peen Forming, several demonstrators have been performed representative for all relevant geometries. This comprises the successful manufacturing and NDI results with sufficient material properties. The dome segments can be formed down to a thinnest field area of 1.4 mm. The segments are formed for dome diameters of 5.4 and 4.6 m. One of the segments has the special feature of a weld area for a pressurization line flange. A TRL 6 has been reached for all configurations.

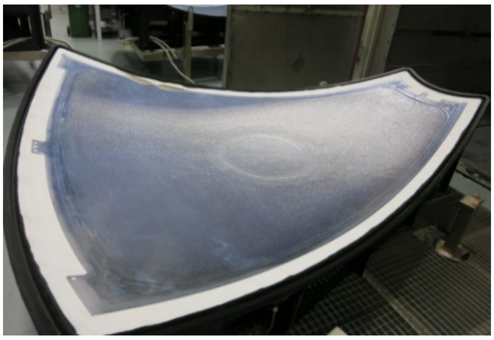

Figure 14. Ø5.4m ULPM LH2 dome segment

The Tank cylinder panels: breadboards have been manufactured in a reduced size (45°, reduced height) with all interfaces and testing the thinnest and the thickest field area thickness. A TRL 6 is reached for all configurations.

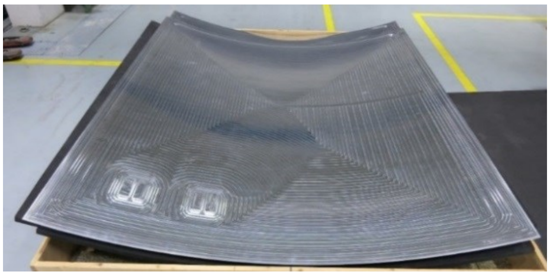

Figure 15. LLPM LH2 Cylinder Panel (AA2219, thinnest field)

For the Structure panels, tests with reduced and full sizes with relevant wall thickness have been performed in stiffened and unstiffened configurations for AA7XXX and AA7XXX. TRL 6 is reached for all relevant stiffened structure segments (ITS / VUAB) and for unstiffened structures (ESR).

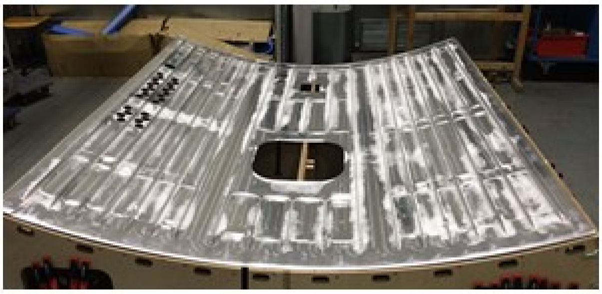

Figure 16. ULPM ITS Skin Panel Y (full scale)

3.2. Welding Processes

The performed program can be condensed in the following points:

- Flat and curved plate trials for parameter definition
- Demonstrators for TRL6
    - for flange welds (RPT)
    - for RPT circumferential welds
- for meridional welds (dome, C-FSW)
- for longitudinal welds (cylinder, C-FSW)

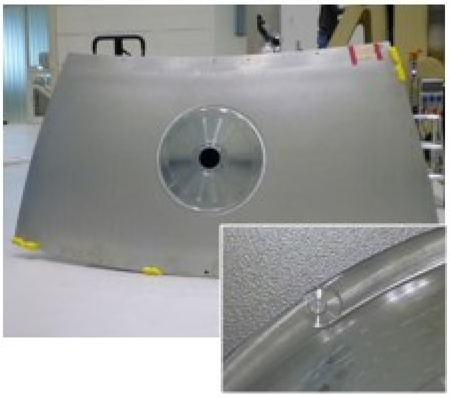

Figure 17. Flange weld (RPT)

Figure 18. Meridional R = 3000 mm (dome, C-FSW), Longitudinal/axial (cylinder, C-FSW) (Material from forming demonstrators)

3.3. Material Qualification

The material qualification activities are planned for the upcoming phase of the project. The maturation has already started for some applications, e.g. by AA2195 shot peened, AA2219 shot peened and AA7XXX shot peened. Material qualification activities that will be performed directly in the next Phase are related to the AA2219 rolled rings, AA 2219 forged parts for tank lower covers, AA7XXX rolled rings and AA7XXX forged parts.

3.4. Inspection processes

Currently MTA uses Penetrant Inspection (PT) inspection process on peen formed segments. The intention is to replace it in the Ariane 6 Project in order to achieve an automatization with no need of etching. A feasibility study has been performed at external suppliers to demonstrate three major topics, i.e.

- Ability to achieve the required sensitivity despite the rough surface of the peened material
- Ability to find defects introduced before peening
- Ability to find defects in the „grooves“ of the transition area between peened surface and thicker weld area

The selected methods used for inspection regarding peculiarities and surface crack are penetrant inspection, eddy current inspection and ultrasonic inspection. All goals could be achieved thus demonstrating TRL6 and the industrialisation is in progress.

4. INDUSTRIALIZATION

4.1. Objectives

The main tasks and objectives of the industrialization activities are condensed in:

- Reduction of manufacturing lead times (compared to Ariane 5)
- Reduction of Recurring Cost (compared to Ariane 5)
- Achieve a production cadence of 11 shipsets per year in 2021. The maximum capacity is envisioned to 12 shipsets per year
- Manage a transition phase with an Ariane 5 ramp-down vs. an Ariane 6 ramp-up, by developing the manpower and skills according to production rate and verifying the production areas

4.2. Approach

The industrialization approach includes five main steps, occurring both in series and in parallel.

- Design
    - Definition of components
    - Number of parts
- Process & Technology
    - Process Definition
    - Material flow analysis
    - Manpower analysis
- Value Stream
    - Process analysis & optimization
    - Site, supplier and contractor selection
- Means of production
    - Floor space analysis
    - Building selection
    - Definition and selection of machines, J&T
- Realization
    - Procurement and installation of machines, J&T
    - Refurbishment of existing buildings
    - New buildings

By the definition of the processes, investigations of feasibility and manufacturing possibilities were made mainly via trade-offs. An end-to-end optimisation for the entire supply change management has been performed including material part flow and ensuring commonality in the means and processes. Lean production principles are applied using e.g. one-piece flow for the main components of the products (pull principle), push principle for sub-components and multiple machine operation.

The Industry 4.0 is one of the main supports of the industrialization. A Manufacturing Execution System (MES) is implemented in order to facilitate a networked production. The tracing and tracking of parts is done by RFID for internal production and transport logistics. The logistics are optimized by warehouse management system (LVS). This approach is coordinated with the implementation of a new

Product Lifecycle Management (PLM). The selected system is the Siemens Teamcenter, where a Collaborative Product Data Management is ensured from Product Design Data to Product as-built Data. All these items will turned the MTA Ariane 6 manufacturing activities to occur in a de facto digital factory.

Design-to-Manufacturing & Assembly activities based on A5 lessons learned sessions are periodically scheduled. Value Stream Mapping (VSM) is used with the aim to eliminate waste, identify bottlenecks and optimize production cycles. The main KPIs are the lead-time and the lead-time index (value added time / total). An industrialization lean development is adopted with a monitoring of the Manufacturing Readiness Level (MRL). The industrialization schedule is permanently updated to be able to track the critical path and examine work around solutions in case of delays or new customer needs.

4.3. Jigs & Tools and Facilities

A new series of tooling, machines and facilities have been engineered at MTA together with its suppliers. In the next figure, the welding bench for the domes (Augsburg) is depicted, including a turntable, clamping device (M1), clamping device (M2.x) and FSW gantry.

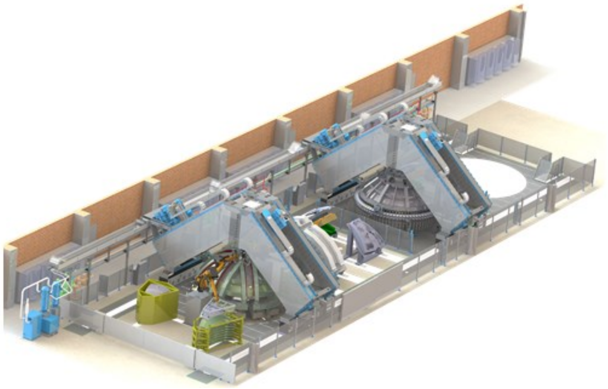

Figure 19. Overview Welding Bench Components

Means and buildings from previous projects are incorporated, e.g. A5 ME means and facility in Figure 23.

Figure 20. Welding Bench – Base machine S23

The following FSW machine will be placed in the welding bench presented in Figure 20.

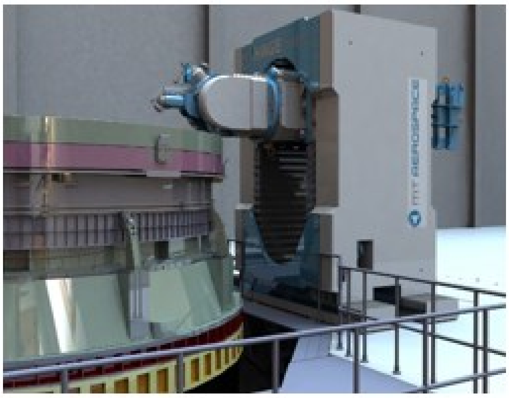

Figure 21. FSW Machine M3

For the Structures products, an assembly concept is also optimised for the facilities in Augsburg and shown in the next figure.

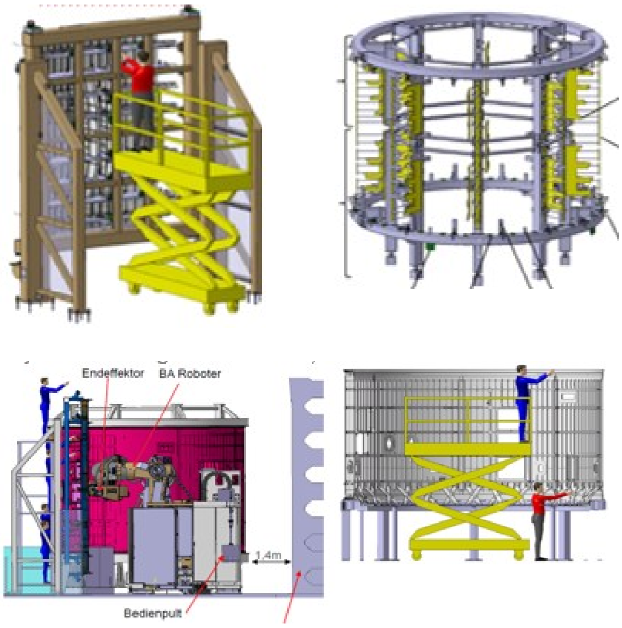

Figure 22. From top left the stations: (1) panel pre-assembly, (2) manual cylinder mounting, (3) cylinder riveting station and (4) Final Assembly ULPM, LLPM

Figure 23. MTA facilities in Bremen

5. MANAGEMENT & PRODUCT ASSURANCE

The governance of the project is done through Visual Management on program, project, engineering, manufacturing and quality disciplines. Weekly telecons, regular reporting and collocations and task forces are part of this governance.

Configuration Management is introduced to track and evaluate changes in the baseline. Risk & Opportunity Management is used for regular and systematic assessment of risks, opportunities and mitigation action by all team members. A dedicated risk manager coordinates all relevant activities with the support of a risk management commercial tool.

The project logic, development and schedule is based on a so called “Production Pull” approach, where taking as a starting point the delivery need dates for the Models according to the Statement of Work (SOW), a manufacturing plan is established to come up with the Manufacturing Readiness Reviews (MRR). The resulting dates of the MRR is driving the development schedule.

The Product Assurance domain comprises the RAMS, Quality Assurance and Supplier Quality management. A Quality Assurance Plan and a RAMS Plan are established according to SOW and the TRL logic is supervised [2].

6. CONCLUSION & OUTLOOK

The major review PDR has taken place in July 2017 aiming at the following objectives:

- Appraise, verify, endorse maturity of design solutions and performance data
- Prove maturity of process technologies and industrialisation concepts
- Evaluate, check, confirm progress and status of the design, qualification and production technologies and manufacturing readiness levels (TRL and MRL)
- Confirm tooling and facilities configurations and authorise production of models
- Consider the context of design, costs, schedule, and risks opportunities

The PDR Review has been passed successfully based on the configuration presented in this paper.

After the PDR Review, the next steps are:

- Consolidate the PDR results, Review Panel and customer recommendations in order to start the next loop pMG7
- Optimise the present design
- Performance of the engineering loop to face the upcoming MRRs for qualification and flight models
- Consolidate the customer inputs: interfaces, load environment and specifications
- Confirm and realise the technology development and industrialization activities and roadmaps
- Consolidate together with the customer the development logic and schedule

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8. REFERENCES

[1] Ariane 6 User’s Manual, Arianespace, Issue 0, Revision 0, May 2016.

[2] International Standard ISO 16290 – Space systems – Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment

Contact Email

Juan Merino, email: juan.merino@mt-aerospace.de