# Thermal Control of the Cryogenic Upper Stage of Ariane 6

Rick Burow[1], Daniel Just,[2] Anna Adamczyk[3], Cord Jagels[4], Alexander Milke[5], Christian Wendt[6], Helge Kneistler[7]
*ArianeGroup GmbH, Bremen, Germany, D-28199*

**The Upper Liquid Propulsion Module (ULPM) is the upper stage of the new Ariane 6 currently under development. Utilizing a re-ignitable engine, it provides full flexibility for costumers serving LEO, SSO, MEO, GTO and Earth escape missions. This wide range of missions poses several challenges for the thermal control of the stage. Long coasting phases of several hours require innovative strategies for propellant management and insulation concepts to keep the cryogenic LH2 and LOX in the desired conditions. High-temperature insulations have to deal with aerothermal loads during atmospheric flight and the heat radiation coming from the radiative-cooled engine nozzle. Electrical equipment has to be protected from the temperature extremes and maintained in ambient temperature range. This paper gives an overview of the thermal control system and the associated thermal simulations of the ULPM.**

## Nomenclature

| | | |
|---|---|---|
| A6 | = | Ariane 6 |
| APU | = | Auxiliary Power Unit |
| AVMS | = | Avionic Main System |
| AVSS | = | Avionic Support Structure |
| CFD | = | Computational Fluid Dynamics |
| CTLO | = | Combined Test Loading Campaign |
| DLS | = | Dual Launch Structure |
| DLR | = | Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center) |
| EPS | = | Étage à Propergol Stockable |
| ESA | = | European Space Agency |
| ESATAN | = | European Space Agency Thermal Analysis Network |
| ESC-A | = | Étage Supérieur Cryotechnique Type A – cryogenic upper stage type A (Ariane 5) |
| ESR | = | Equipped Solid Rocket |
| ETI | = | External Thermal Insulation |
| GEO | = | Geostationary Earth Orbit |
| GMM | = | Geometrical Mathematical Model |
| GTO | = | Geostationary Transfer Orbit |
| GTO+ | = | extended Geosynchronous Transfer Orbit |
| ITS | = | Inter Tank Structure |
| H2 | = | Hydrogen |
| He | = | Helium |
| HFT | = | Hot Firing Test |
| HPHV | = | High Pressure Helium Vessel |
| LEO | = | Low Earth Orbit |
| LH2 | = | Liquid Hydrogen |

[1] Thermal Engineer, Thermal Department, Rick.Burow@ariane.group
[2] Thermal Engineer, Thermal Department, Daniel.Just@ariane.group
[3] Thermal Engineer, Thermal Department, Anna.Adamczyk@ariane.group
[4] Thermal Engineer, Thermal Department, Cord.Jagels@ariane.group
[5] Thermal Engineer, Thermal Department, Alexander.Milke@ariane.group
[6] Thermal Expert, Thermal Department, Christian.Wendt@ariane.group
[7] Team Leader Thermal System Development, Thermal Department, Helge.Kneistler@ariane.group

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|---|---|---|
| LLPM | = | Lower Liquid Propulsion Module |
| LOX | = | Liquid Oxygen |
| LVA | = | Launch Vehicle Adapter |
| MEO | = | Medium Earth Orbit |
| MLI | = | Multi Layer Insulation |
| O2 | = | Oxygen |
| TMM | = | Thermal Mathematical Model |
| RCS | = | Reaction Control System |
| ULPM | = | Upper Liquid Propulsion Module |
| ViTF | = | VINCI Thrust Frame |

## I. Introduction

IN the year 2014, empowered by the Ministerial Conference, the European Space Agency ESA initiated the development of Ariane 6, the newest version of the European launch vehicle series. The development of Ariane 6 was contracted to an European industrial consortium headed by ArianeGroup as prime contractor.

Ariane 6 will continue the success of its predecessors Ariane 1-5 for providing reliable transportation capabilities for international satellite providers. Furthermore it provides greater flexibility to enable a much wider range of missions. This flexibility is being ensured on the one hand by a choice of two or four solid rocket booster on the lower stage to adapt the launch vehicle to the payload mass. On the other hand a new cryogenic upper stage, called upper liquid propulsion module (ULPM) with a re-ignitable engine allows a servicing of many different multiple satellites mission scenarios. Those missions are ranging from low Earth and sun synchronous orbits (LEO, SSO) via medium Earth orbits (MEO) up to so-called GTO/GTO+-missions.

The environmental constraints imposed by those missions, combined with the use of cryogenic propellants and the requirements for ensuring multiple ignitions of the main engine imply challenging tasks for the thermal control subsystem. In the following, an introducing overview is given of the Ariane 6 design with focus on the ULPM and about its mission versatility with the resulting thermal impacts. The thermal subsystem development approach in the context of the stage development logic with the links to external subcontractor activities as well as to supporting activities for other subsystems is presented in principle.

Main emphasis is laid on the description of the overall upper stage thermal control concept and its organizational challenges, on three selected examples:

1) The thermal control of the electronic equipment is essential and challenging for long mission durations such as e.g. GTO/GTO+-mission. This is shown in chapter IV subsection D for the avionic support structure.
2) The data exchange between the upper stage thermal subsystem and its subcontractors and vice versa is essential for such a project with many subcontractors involved. It is worth mentioning that a reduced thermal mathematical model of the VINCI-engine is provided by the engine responsible, which can be implemented in the thermal system model as a sub-model.
3) The development of an appropriate cryogenic propellant management strategy in the tanks during the ballistic phases is one of the most important tasks in the development of the A6 ULPM. This is an inseparable part of the thermal control concept. The ground and ballistic phase thermal control for the cryogenic propellants is outlined in chapter IV subsection E.

## II. The Ariane 6 launch vehicle

The new European launch vehicle Ariane 6 combines the reliable and proven technology base of Ariane 5 and VEGA with new system and technology approaches. It consists of 4 main parts:

1) 2 or 4 equipped solid rockets (ESR), based on the first stage P120C of the small VEGA launch vehicle to adapt to a payload mass of 6 to 11 tons to GTO
2) A lower liquid propulsion module (LLPM) with liquid hydrogen LH2 and liquid oxygen LOX utilizing the Vulcain 2.1 engine, which is based on the Vulcain 2 of Ariane 5
3) An upper liquid propulsion module (ULPM) also with LH2 and LOX and the re-ignitable VINCI engine, originally developed for Ariane 5ME [5].
4) A payload compartment, consisting of the launch vehicle adapter (LVA), a dual launch structure (DLS) and the fairing

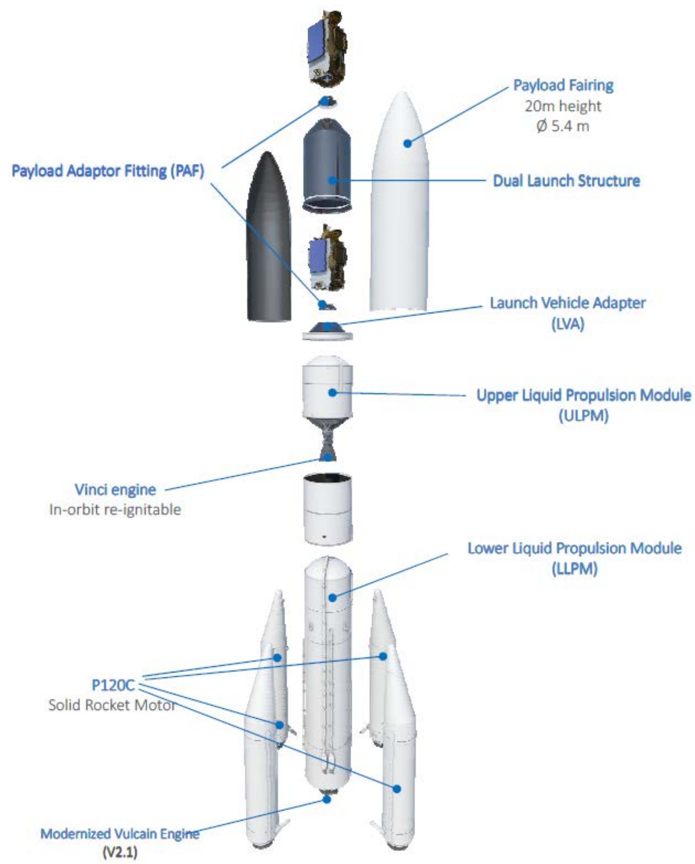


**Figure II-1: Ariane 6 launch vehicle configuration [6]**

In contrast to its predecessor it uses the horizontal integration scheme and payload integration on the launch pad. Newly introduced technologies are for example the use of friction-stir-welding of the propellant tanks, 3D-printed parts for the engine and a spray-on-insulation for the outer surfaces of the launcher.

## III. The ULPM of Ariane 6

### A. Configuration of the ULPM

The cryogenic upper stage of A6, as shown in Figure III-1, comprises the following main structures:

1) The two main tanks for liquid hydrogen (LH2) and liquid oxygen (LOX)
2) The Inter Tank Structure (ITS)
3) The VINCI engine, capable of multiple re-ignitions
4) The VINCI Thrust Frame (ViTF)
5) The Avionic Support Structure (AvSS)

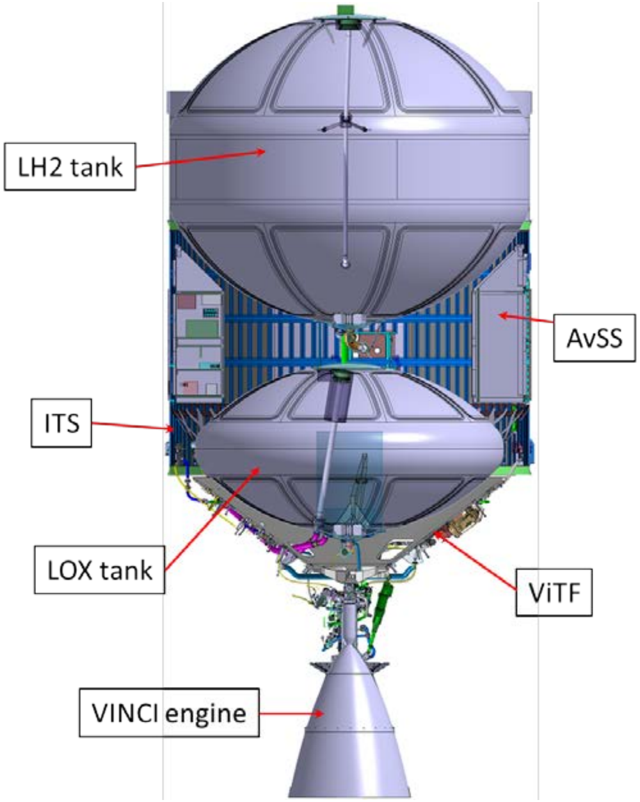


**Figure III-1: Configuration of A6 ULPM**

The main tanks are designed for a maximum loading mass of approximately 5 t LH2 and 26 t LOX. The two tanks are connected via the ITS. The VINCI engine conducts its forces via the ViTF into the ULPM. The cone-shaped ViTF is equipped with fluid control equipment (FCE), electric equipment, the Auxiliary Power Unit (APU) and two high pressure helium vessels (HPHV). The majority of the Avionic Main System (AVMS) such as navigation computers are located in the AvSS between the two propellant tanks. On top of the ULPM sits the Launch Vehicle Adapter (LVA), this provides connection of the payload (P/L) to the launch vehicle. The LVA serves furthermore as connection point for the fairing and the dual launch structure (DLS). LVA, DLS and fairing are not shown in Figure III-1.

### B. Mission Scenarios

As already mentioned above, Ariane 6 shall be capable to deliver spacecraft's into various orbits. At present, missions into low and medium earth orbits (LEO, MEO) that require multiple boost phases are executed by the Ariane 5ES version using the EPS upper stage with storable propellants. Single and dual launch missions into geosynchronous transfer orbit (GTO) are performed on Ariane 5 ECA version with its cryogenic upper stage ESC-A. Further missions, such as the delivery of payload into the extended geosynchronous transfer orbit (GTO+) are currently not covered by the Ariane 5 launcher family. The new launcher Ariane 6 with its cryogenic upper stage shall be capable of deliveries into LEO, SSO, MEO, GTO, GTO+ and earth escape trajectories.

1) LEO, SSO missions: Ariane 6 would deliver (multiple) payload into a low earth or sun synchronous orbit. The ULPM will be de-orbited at the end of the mission. Such missions require multiple boost phases. Short ballistic phases and significant propellant movement are further characteristics.
2) MEO mission: This mission is required for delivery of the Galileo satellites for the European Navigation System. It comprises of two boost phases, one for injection into a transfer orbit and one for circularization into MEO. Both boost phases are separated by a ballistic phase of several hours duration.
3) GTO mission: The present Ariane 5 ECA classical mission of (multiple) payload delivery into the GTO will also be covered by Ariane 6. Compared to the current ESC-A mission sequence a de-orbitation manoeuvre will be conducted at the end of the mission.

4) GTO/GTO+: This dual payload mission combines two different strategies to reach the geosynchronous orbit. First, the delivery of the upper payload into the GTO, where the apogee-boost is required to be conducted by the payload itself. Second, a delivery of the lower payload into the extended geosynchronous transfer orbit GTO+, with a perigee-lifting boost phase operated by the ULPM. Hence, the delivery into GTO+ requires a second boost phase of the ULPM after a ballistic flight phase of several hours duration
5) Earth escape trajectory: Required by space probes and scientific missions to send them onto their trajectory outside of the earths gravitational field. This mission profile is normally conducted as a mono-boost sequence.

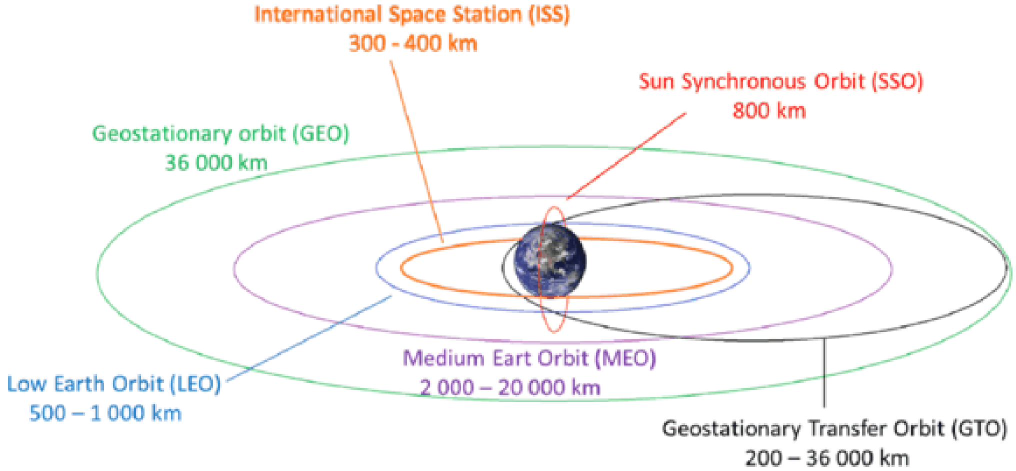


**Figure III-2: Mission scenarios for Ariane 6 [1]**

### C. Development Process of the Thermal Control of the ULPM

As the main driver for development the defined High Level requirements are a driving environmental aspect. Breakdown into different level of product requirements are major tasks in development. In order to be compliant to defined requirements all families of requirement needs to be treated. In a first step responsibilities needs to be defined. Components of the ULPM are sub-contracted to supplier who is in charge of providing the capable product design, not only including the thermal aspects. Those suppliers rely on well written environment specifications. This process is iterative and needs constant exchange between launcher responsible and supplier.

To estimate the impact of product/components evolution on the overall system behaviour the changes needs to be implemented into the thermal system model as well. The improved status of thermal model allows justifying and checking the established specification based more mature design status (Figure III-3).

When the development and design process is succeeded the product/components design and specification can be validated with tests. Those tests are on components level, assembly level and on complete launcher level.

The main criteria's in Ariane 6 ULPM development are Performance aspects which directly impacts the payload capacity (mission dependent). It is important to state that not only structural mass (tanks mass, equipment mass, support structures …) is driving this value. As well the functional performance (propellant budget) takes over a considerable part. Financially the costs of the launcher production itself are of high interest but as well the development costs needs to be improved. The European industrial setup of the launcher production substantially contributes to the competitiveness of the Ariane 6.

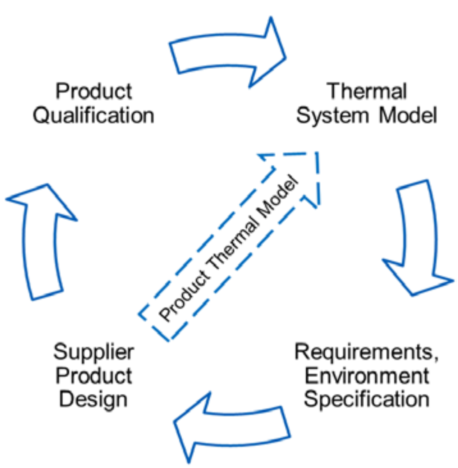


**Figure III-3: Simplified Schematic of Product/Component Development Process**

## IV. Thermal Control on the ULPM of Ariane 6

### A. Requirements to the Thermal Control System

The Thermal Control System has different types of design drivers (e.g. temperature limits), which needs to be ensured for different types of equipment or structure at every mission time. However, the limits may vary during different mission phases (ground, ascent or flight). Also other aspects, such as performance may define the major requirements for the thermal control system, since the high heat fluxes into the tank lead to the propellant losses due to boil-off. Considering all of the design drivers the thermal measures need to be defined, however one measure at the same time may positively influence the thermal environment for equipment and negatively for other. Furthermore, the wide operational and environmental temperature range (Figure IV-1) makes the system vital for the overall ULPM system. Some of them are shortly explained below.

1) Physical limits or design criteria:
   The thermal control system needs to comply all off the individual as overall ULPM system requirements. This is applicable for every structural part, equipment and consumables (e.g. LH2, LOX, and Helium).
2) Heat fluxes limits into tanks
   The overall thermal concept is dealing with an optimization of several parameters. Major task are the provision of propellant friendly conditions. Reduction Propellant Boil-off in ballistic phase needs to be treated as well as the minimum need of evaporated cold gas for RCS.
3) External thermal loads:
   These loads occur at all mission phases and include e.g. sun fluxes and convection to the external environment on ground or space environment during the flight phase. During the ascent phase occur heat fluxes caused by the friction between the air and the launcher, especially on and around the protuberances (external mounted equipment). This external equipment need to be protected by additional structure (e.g. thermal insulated covers).
4) Ice formation on cold tank walls
   The thermal design for an optimized propellant thermal budget may lead to other drawbacks. An important topic is the risk of ice on external parts of the launcher. The avoidance of ice is an added value in terms mass reduction in risk minimization.

### B. Measures of Thermal Control

In order to satisfy the requirements mentioned above, the thermal control system of A6 uses certain types of measures, which are described here. These measures are dimensioned with the help of the Thermal Analysis and are validated by tests (see chapter IV and V, respectively).

*1. Positioning:*

Components such as most electronic instruments with operating temperatures in a rather narrow range around room temperature are preferably positioned not in the direct proximity of cryogenic tanks. From the other hand, accommodation of highly dissipative units near to the passive components requiring heating may help to maintain the temperatures of both instruments within desired temperature limits.

*2. Mountings and interfaces*

Thermal fillers are suitable to improve the thermal coupling at selected interfaces, whereas thermal washers are used to reduce the thermal coupling.

*3. Conditioning of equipment:*

In the A6 ULPM internal cavity helium conditioning is foreseen in order to avoid humidity and for leak dilution, i.e. to provide an inert gas atmosphere. Moreover, the helium venting helps to condition the equipment in this cavity.

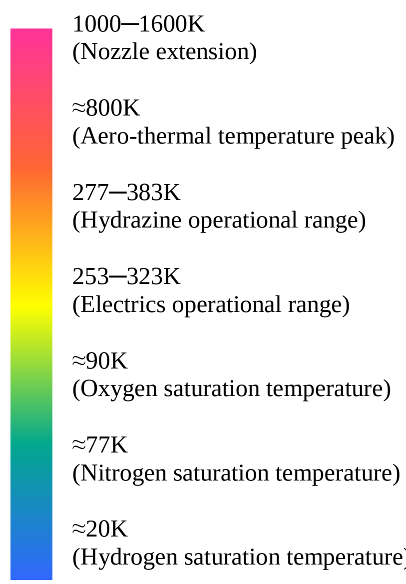


**Figure IV-1: Temperature range on A6 ULPM**

*4. Thermal protection:*

In order to prevent the nitrogen from liquefaction at the cold surfaces of the LH2, the walls must be insulated. Closed cell foams prevent the nitrogen from direct contact with cold structures. Hence, closed cell foams are the appropriate choice for the cold LH2 tank structure insulation. On its external surfaces, during ascent, the A6 launcher experiences high temperatures due to atmospheric friction. The application of ablative materials to surfaces with strong aerodynamic turbulence helps reducing the thermal loads towards the structure, as some of the energy is consumed and exported by the depreciation of the material. Local plume emitted by hot or cold gas thrusters of the attitude control system frequently charges the adjacent materials with heat fluxes, especially during long ballistic phases. Multi-layer insulations (MLI) are employed to efficiently reduce the radiative heat exchange.

*5. Electrical heaters:*

Electrical heaters are a common measure for equipment temperature regulation, especially for the systems and units exposed for cold environment. For A6 ULPM, since during the launch preparation on ground electrical power is ensured by the external interface, electrical heating is an accessible solution for thermal control of critical structures and instruments. However, as no electricity will be generated during flight but the necessary electric power will be distributed by batteries, the limitation of the use of electrical heaters is indeed a performance issue.

*6. Thermal surface finishes:*

Paints or chemical surface treatments as well as enlarged surfaces (e.g. by ribs) are suitable to lower or increase the heat transfer. High-temperature resistant coatings can protect lower lying materials. Optical coatings are used on A6 to reduce the absorptance of solar and infrared fluxes.

In the following, the thermal control for A6 is illustrated on selected areas, where the described measures for thermal control are applied.

### C. Liquid Propellants Thermal Control

Concerning the liquid propellants, both LH2 and LOX temperatures are required to fit a certain range (minimum and maximum temperature) prior to ignition and re-ignitions, in order to guarantee the operability of the VINCI engine. Moreover, tank-filling is a complex process and depends amongst other aspects on the heat fluxes entering the tanks on ground, whereas during flight the boil-off mass needs to be limited (compare points 1, 2 and 3 in subsection A). The thermal control of the upper stage has to ensure the compliance to the requirements using mostly conditioning, the use of appropriate materials and liquid propellant positioning (compare points 1, 3 and 4 in subsection B).

To minimize the incoming heat flux from the sun and to block the very high fluxes coming from the radiation cooled engine nozzle, the ViTF is covered with a tent consisting of several layers of MLI with a cover fabric to withstand temperatures of several hundred degrees Celsius.

The external cylinder of the LH2 tank will not be exposed to the high heat fluxes of the engine, but has to be protected from ice formation of the moisture in the air and the aerothermal loads during the ascent through the atmosphere. For this purpose closed cell foam, called ETI (External Thermal Insulation) is sprayed on the external surface. It is a new development from ArianeGroup Bremen with improved thermal properties and allows a faster application during manufacturing process.

**Figure IV-2: LH2 tank sprayed with ETI on cylindrical part [2]**

### D. Thermal Control on AvSS / AVMS

Avionic equipment has to be maintained within specified temperature range in order to ensure their operational performance during the whole mission.

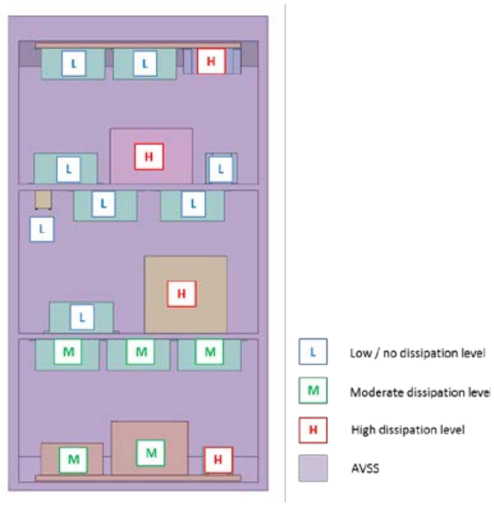


**Figure IV-3: Positioning of Avionic equipment**

As already mentioned in Chapter III most of the avionic equipment is positioned within AVSS. Its main function is to provide a moderate thermal environment through separating avionics from the cold environment on the ground and during the flight as well as storage and dispersion of the internally dissipated heat during flight.

Thermal control system of the Avionics inside AVSS is a combination of the active and passive thermal control methods, listed in Chapter IV, sec B.

The basic thermal control measure is the layout of the electronic boxes (see Figure IV-3). Highly dissipative components are placed in the direct perimeter of the passive or low dissipative instruments. It allows to transfer the dispersed energy to the non-dissipative equipment and therefore reduce their temperature decrease while limiting the temperature increase of highly dissipative electronics.

Avionics are situated on the plates made of the aluminum alloy, connected to the main structure, what allows to remove the dissipated energy through conduction. Conductive interfaces between the containers and panels structure are individually adjusted to the performance of each device. Highly dissipative electronics are well thermally coupled to the structure by application of thermal fillers enhancing the contact between two attached surfaces. Some of the equipment have to be thermaly separated from the mounting structure due to their highly restricted operational conditions. Thermal de-coupling is ensured by application of low conductive washers (see Figure IV-4) and baseplates as well as limitation of the contact area.

A neutral environment and constant temperature inside the equipment compartments before lift-off is additionally ensured by helium venting on ground. The whole bay is globally conditioned and the heat is exchanged through convection.

Radiative heat exchange is a second heat transfer mechanism which allows to maintain the units below specified maximal temperature limits during flight. AVSS is made of composite structure characterized by high infrared emissivity. It allows to collect heat radiated by high-dissipative units, covered with the black paint and then to radiate it to the surroundings by the highly emissive outer surface during flight. At the same time, non-dissipative units are covered with rather reflective coatings like Surtec650V in order to limit their heat loss during flight.

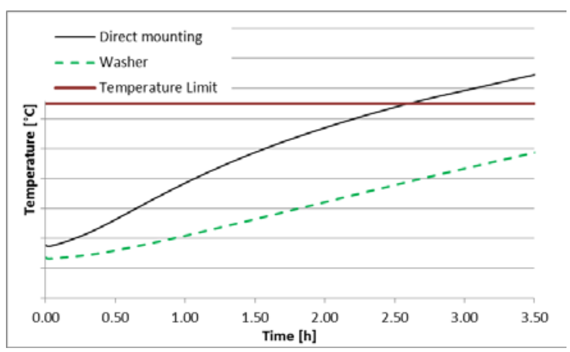


**Figure IV-4: Influence of low conductive washer, applied on conductive interface - comparison of temperatures calculated for single avionic unit**

### E. VINCI Engine Thermal Control

VINCI is the first European rocket engine using the expander cycle in combination with cryogenic propellant. Whereby liquid hydrogen is used for cooling the combustion chamber while expanding by absorbing energy and driving the turbopumps. Afterwards it is injected gaseous in the combustion chamber. The main advantages of this technique are efficiency, simplicity and robustness (no gas generator is needed) and high performance. The capability to restart five times and a performance of 180kN of thrust and a specific impulse of 464s make VINCI extremely powerful and flexible likewise. An accurate thermal dimensioning of the engine is mandatory for assuring these features. Besides functioning tests in the DLR facilities in Lampoldshausen, a prediction of the engine's thermal performance has to be simulated for a wide range of mission scenarios and therefore different environmental conditions.

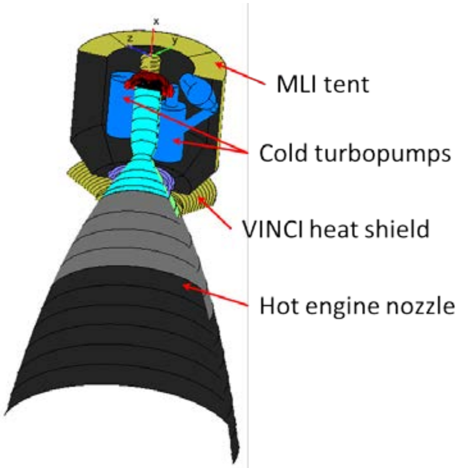


**Figure IV-5: VINCI engine thermal control**

The development of the VINCI engine is under the responsibility of ArianeGroup Vernon, where detailed thermal and functional computations are performed. For the exchange a reduced thermal model is integrated in the upper stage thermal model (cf. Figure IV-5), whereas a thermal environment of the stage's rear part is provided to ArianeGroup Vernon. Both engine thermal models feature the same main parts, but of course the reduced thermal model uses a simplified approach for the main fluid equipment modelling and the combustion chamber. Moreover, most of the engine equipment and lines are not represented in the reduced thermal model. Detailed and reduced models are correlated to each other.

The engine combines extremely cold (e.g. LH2 and LOX turbopumps) and extremely hot components (e.g. radiation cooled nozzle) in the smallest spaces. Due to the engine architecture a parting plane derives for both temperature areas. This plane is the mounting point for the VINCI heat shield, which serves as an optical barrier for the cold components against the heat radiation of the hot parts. Furthermore, a MLI tent is blocking the solar radiation to minimize the temperature increase of the turbopumps during ballistic phase. This reduces the amount of propellant required for chill-down of the pumps. On the other hand the MLI tent reduces the infrared radiation from the engine to the stage during engine operation.

## V. Thermal Analysis

As discussed above the Thermal Control System needs to guarantee that all of the requirements are fulfilled for each equipment as for the entire ULPM system. The design of an optimized Thermal Control System is an iterative process, since different parameters of each measure are interacting with other parameters of the other measures. In order to define and to optimize the thermal measures thermal analysis are used to predict the temperature range or heat fluxes of the structure, the equipment etc.

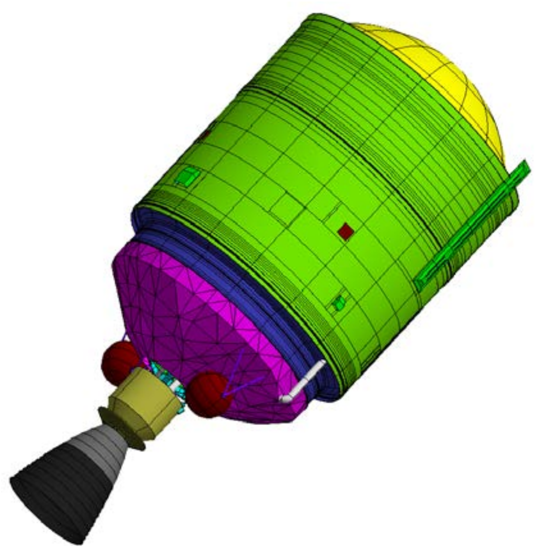

**Figure V-1: GMM of A6 ULPM in ESATAN-TMS [7]**

The Thermal Mathematical Model (TMM) of the ULPM uses the lumped parameter approach for modelling and is implemented using the ESATAN-TMS software. It has to include all aspects, which are influencing the thermal behaviour of the stage and its components. Those are among others:

- Conductive interfaces to the LLPM and LVA
- Convective and radiative environment on launch pad
- Aerothermal loads during ascent through the atmosphere
- Radiative environment in orbit (sun, earth, eclipse phase)
- Convective environment inside of the cavities of ULPM
- Filling / consumption of propellants
- Engine operations
- Activation and dissipation profiles of the equipment

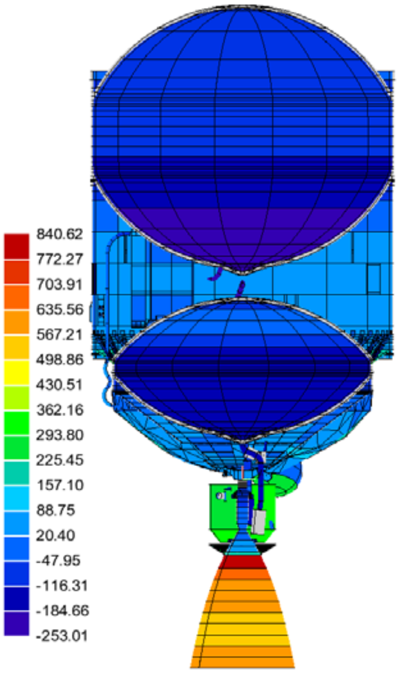


**Figure V-2: Temperature distribution of A6 ULPM (scale in °C, [7])**

Some of those points require input data from other simulations / calculations, for example the convective heat transfer, because the TMM enables only the calculation of radiative and conductive heat transfer. Since convective heat exchange has a significant influence on the overall thermal budget on ground, dedicated CFD analyses of the vented cavities are performed and their results are implemented into the ULPM TMM with the use of dedicated mathematical method (see [3]). It allows including the impact of free convection and increasing the accuracy of thermal budget prediction.

The thermal model (Example Figure V-1) is built up and refined during the Thermal Control System optimization process. The thermal analysis uses the defined scheme in order to represent the most critical cases which may occur during the mission:

1) For each equipment or group the most critical occurring hot and cold case need to be determined. It includes the external and/or possible internal environment parameters which lead to the possible hottest and coldest situation. This results in two predicted envelope temperature curves.

2) In case the results violate one of the allowable design limits the thermal concept need to be modified until all of the requirements are fulfilled. Also the possibility for optimization needs to be checked in order to safe mass and/or to reduce the complexity.

The thermal budget calculation is also used to design every kind of structure integrated on board of ULPM. The thermal analysis provides thermal environment, which is used for mechanical analysis at ArianeGroup or partners in order to ensure the mechanical stability.

Figure V-2 shows the temperature distribution of A6 ULPM shortly after engine cut off in a cross section view. The wide temperature range appearing on the stage is clearly visible.

## VI. Validation of Thermal Concept by Tests

Equipment, subsystem and system test results are taken into account for improvement and validation of the thermal design and thermal analysis results. The results of equipment and subsystem tests are used for the improvement of the thermal mathematical models by correlation. Those correlated models will be integrated in the upper stage thermal model in order to define and refine the thermal design of system and subsystems [4].

The results of Hot Firing Test (HFT) at the DLR P5.2 test side in Lampoldshausen (Germany) and Combined Test Loading Campaign (CTLO) in Kourou (French Guiana) will be considered in the qualification loop for thermal model correlation and validation for maiden flight (FM-1) prediction.

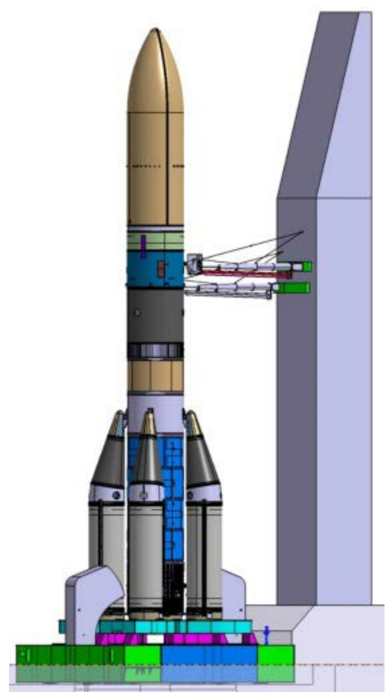

**Figure VI-3: CTLO**

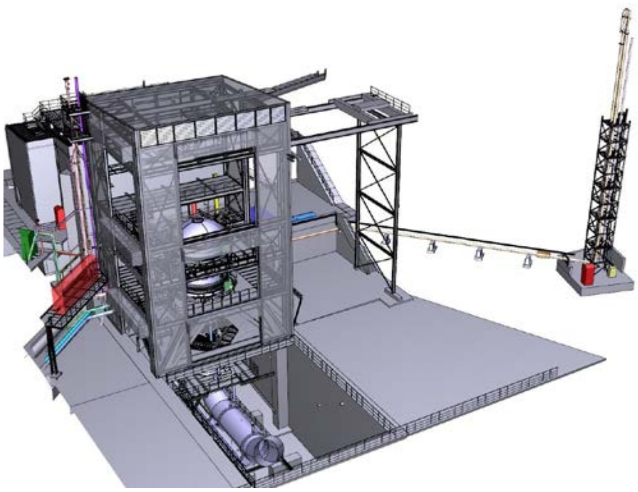

**Figure VI-1: P5.2 test stand with HFM**

The CTLO test will be performed in full representative launcher system configuration. It is foreseen to validate the operations of the Launcher on Ground during the chronology. The measured results will be used to validate the predicted heat fluxes and thermal behavior of main structures, conditioning- and insulation concepts for operational phases before lift-off.

The Hot Firing Test on the P5.2 in Lampoldshausen with the A6 ULPM Hot Firing model is foreseen to validate the functional propulsive components and fluid control sub-systems during flight phases. The measured thermal data will be used for validation of the predicted thermal behavior. The propulsive components and fluid control equipment observed as well during the test propulsive and propellant management phases.

By considering those test results for correlation and validation of the A6 ULPM TMM and its sub-systems allows continuous improvement of temperature and heat flux predictions. This allows to support the sub-systems with updates of thermal boundary conditions whereby the thermal concepts and sub-system design could be improved. The approach of validation and correlation with data from tests will decrease the uncertaintiy on predictions for ground- and flight phase and for the functional cases as well as for the worst hot and cold mission design cases.

## VII. Conclusion

The programme Ariane 6 has been presented and the key features of the newly developed ULPM have been outlined. Moreover, the development of the upper stage of Ariane 6 in terms of project phases, sub-contractors and subsystems has been shortly outlined in order to give an idea of the realization of this huge project.

The challenges towards the thermal control system, as a consequence to the mentioned key features, have been explained. These challenges have been expressed in terms of exigencies and requirements in a general manner.

Knowing these challenges, exigencies and requirements towards the thermal concept of the upper stage, the possible measures of thermal control have been shortly described.

The actual thermal concept is then a realization of the described measures, in order to fulfil the above mentioned requirements, dealing with the mentioned exigencies and challenges. Three examples have been given and described in a bit more detail: the "classical" thermal control of the avionic equipment, the cryogenic liquid propellants and the engine.

Finally an overview of the approaches for thermal analysis has been given, followed by a short description of the tests on ground for validation purposes.

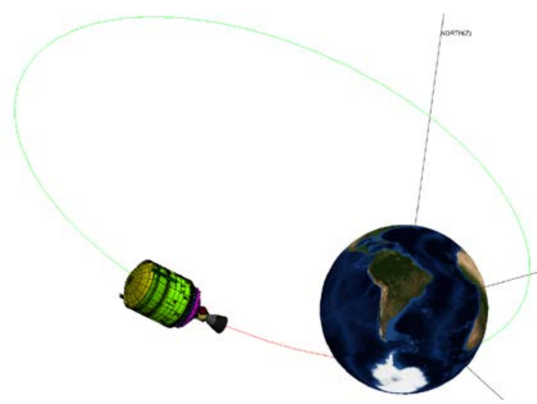

**Figure VII-1: ULPM GMM in GTO [7]**

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