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60 YEARS DLR LAMPOLDSHAUSEN – THE EUROPEAN RESEARCH AND TEST SITE FOR CHEMICAL SPACE PROPULSION SYSTEMS

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The DLR site at Lampoldshausen, which employs some 230 staff, was founded in 1959 by space pioneer Professor Eugen Sänger to act as a test site for liquid rocket engines. The site went into operation in 1962.
In January 2002 the DLR facility at Lampoldshausen, which is home to all research activities and experiments relating to rocket test facilities, was officially named the Institute of Space Propulsion.

The Institute's ongoing research work focuses on fundamental research into the combustion processes in liquid rocket engines and air-breathing engines for future space transport systems. The Institute is also concerned with the use of ceramic fiber materials in rocket combustion chambers and the development and application of laser measurement processes for high-temperature gas flows. One of DLR's key roles in Lampoldshausen is to plan, build, manage and operate test facilities for space propulsion systems on behalf of the European Space Agency (ESA) and in collaboration with the European space industry. DLR has built up a level of expertise in the development and operation of altitude simulation systems for upper-stage propulsion systems that is unique in Europe.

As part of the Ariane 6 program, for example DLR Lampoldshausen was tasked with the development and qualification testing for the upper-stage propulsion system Vinci® using the P4.1 altitude simulation test bench, as well as the Vulcain 2.1® main stage engine using the P5 test bench. The DLR Lampoldshausen was also responsible for developing and erecting the European upper stage test facility P5.2, on which the ULPM of the Ariane 6 will be tested prior to the maiden flight of Ariane 6.

1. HISTORICAL BACKGROUND [1]

1.1. A Test Site for Liquid Rocket Propulsion

In the afternoon of the 24th August 1962 a sudden noise echoed through the forests nearby the village of Lampoldshausen in southern Germany. The unnatural sound could still be heard some kilometers away and was the first of many to follow. That day the first hot-fire test was successfully conducted at the newly erected test site.

On 08th July 1954 the “Forschungsinstitut für Physik der Strahlantriebe (FPS)” (research institute for physics of jet propulsion) was found by Eugen Sänger and his wife Irene with the headquarters at Stuttgart airport. Tasks of the FPS included lectures at the university, fundamental research and contract works for the industry like Porsche, General Electric, Fiat as well as several defense industry companies. During the first years experiments on ramjet engines, hotwater-rockets and electrothermal propulsion systems and furthermore on Sängers idea of a reusable spaceglider were conducted. But testing possibilities were limited at the airport. In fact, no larger rocket engines could be tested. The need for a larger test site with modern equipment got obvious. In December 1957, Sänger therefore encouraged the search for a new test location.

With the geophysical year, 1957/58, public discussions about military and civil space usage, satellites and space transportation began. The same year the Soviet Union brought the first satellite – Sputnik 1 – into orbit and shocked the world. Developments for space transportation and launchers became urgent topics.
During the selection process a lot of criteria needed to be fulfilled for a suitable test location. As branch office of the FPS, it should be in reach of Stuttgart. Good transport connections and at the same time remote from habituated areas, solid ground and sufficient water supply to fulfil all cooling purposes, no nature reserve area and many more. More than 30 potential locations throughout Baden-Württemberg were examined. Sänger

was assisted by Wolfgang Pilz, Wilhelm Dollhopf, the later head of the institute, and a team of engineers.

Fig. 1. Notes from the selection process for the Test Site

On 18th July 1959 the “Ministerium für Ernäherung, Landwirtschaft und Forsten (BMEL)” (Federal Ministry of Food and Agriculture) approved the test site “Im Langen Grund” with its 35 hectares in the Hardthäuser Forest, 18 kilometers away from Heilbronn. DLR’s test site Lampoldshausen was found.

With the villager’s acceptance for the new test site for liquid propulsion and rocket engines construction works began.

Drilling of a 72 m deep fountain (also supplying Lampoldshausen), electrical transmission lines and infrastructure, buildings, propellants storages and two testbeds – P1 and P2 – belonged to the first construction stage in the southern part of the site.

Testbed P1 was planned for small engines, thrusters and development engines and propellant research. Testbed P2 was designed for larger engines in vertical position, especially for the main stage of the Pilz-rocket using storable propellants.

Fig. 2. Images of Test Site Lampoldshausen during phase one construction works

In the summer of 1962 the first test campaign was conducted at testbed P1 with water- and film-cooled combustion chambers with a thrust of four kilonewton to investigate materials and propellants. Furthermore, the “Forschungsinstitut für Chemische Raketenantriebe” (Research institute for chemical rocket propulsion) is formed.

1.2. On the way to a European Launcher - ELDO

The same year, Europe agreed to found the European Launcher Development Organisation (ELDO) to realize and build an independent European space launch system with Germany being responsible for the engine of the third stage “Astris” of the “Europa” rocket.

Fig. 3. Test Facility P2 after construction in 1963

To fulfil this task the institute was commissioned to set up a European high altitude test center in collaboration with the industry. To achieve this goal the site was extended by test facilities P3 and P4 at which tests under atmospheric as well as high-altitude conditions could be done.

Fig. 4. Dedication of newly erected Test Facility P3

Fig. 5. P4 during a hot-fire vacuum test of "Astris"

Besides upper stage testing and development works for ELDO, fundamental research was intensified in Lampoldshausen on highly energetic propellants containing lithium or fluorine, which at that time, were seen as propellants of the future. Therefore, test facilities P6 and M11 were erected in the mid-sixties.

Tests for the European launcher began immediately after construction works were finished 1973.

Fig. 6. 3rd stage engine of the "Europa" rocket "Astris"

With the Europa-programme ending, test site Lampoldshausen slipped into a crisis, since nearly full capacity of the institute was focused on this program. Way out could be made with the help of the modern and unique test capabilities the site offered combined with skilled and experienced workers and engineers and excellent industry partnerships. The field of research broadened and research on annular combustion chambers, blue-burning fuel oil combustors and hydrogen/oxygen-steam-generators for power plants was conducted.

Anyway, rocket testing never stopped. Since the beginning of the seventies, development and qualification tests for a commercial launcher from OTRAG (Orbital Transport- und Raketen-Aktiengesellschaft) took place at the test site. OTRAG CEO Lutz Kayser planned to place a cheap and independent launcher on the market by bundling simple and series-produced engines. In particular, development works for propellant tank pressurization by in tank combustion and rocket steering, which was realized by throttling individual engines, were developed by Lampoldshausen engineers.

Fig. 7. OTRAG rocket hot-fire test at P2.2

1.3. The Ariane program: A success story, but not without mistakes

Already in 1973 plans for future European launchers began and lessons learned from ELDO proofed helpful. In 1974, ELDO and ESRO (European Space Research Organisation) were combined to form the "European Space Agency (ESA)". In 1975 the cornerstone for the European test center for liquid rocket propulsion was laid by signing the Ariane-program. The federal republic of Germany contributed by delivering the second stage of Ariane, the turbopumps for the Viking-engines and thrust chambers and propellants valves for the HM-7 upper stage engines.

Development tests of the Viking engines under atmospheric and subatmospheric pressures and flight qualification of the complete second stage of Ariane was conducted at test site Lampoldshausen on the P4 test facility. Once again, infrastructural modification works were needed. Besides general safety modifications, test facility P4.1 was equipped with a reinforced thrust frame for the higher thrusts of the Viking engines compared to Astris, new propellants tanks that equaled the flight-tanks were installed.

Fig. 8. Ariane Stage integration

At test facility P4.2 a new high-altitude simulation system was installed, consisting of a new vacuum chamber, new ejectors and diffusor and new rocket steam generators. The first hot-fire tests at P4.2 took place in 1976 with a Viking-3 engine and later that year with a Viking-4 engine. Afterwards, the second stage of the Ariane launcher was tested at P4.1. During 1978 development tests were finished and a year later also qualification tests for the Viking-4 engine under high-altitude conditions and for the Ariane second stage under atmospheric tests successfully ended.

Maiden flight for Ariane from the European Space Port in Kourou was set for 15th December 1979 but was delayed to 24th December 1979. Christmas Eve 1979 Ariane lifted-off and brought a 1.6 ton payload successfully into a 218 kilometer orbit.

Fig. 9. Ariane 1 lift-off in Kourou

Disillusion set in with an engine failure during the second launch caused by acoustic instabilities. Troubleshooting was done at Lampoldshausen and the anomaly was reproduced during a hot-fire test at P4.2 leading to destruction of engine's the thrust chamber and set the test facility on fire. Modifications to the propellant mixture and the injector heads proofed helpful but instabilities could never be disregarded. Therefore decision was made to pretests every engine planned for an Ariane-launcher. These preflight-test runs were done at test site Lampoldshausen and later also in Vernon. The plan payed out and from the third launch in 1981on Ariane became a success with its commercial marketer Arianespace.

Fig. 10. Viking failures at Test Facility P4.2

Continuing development work was carried out at Lampoldshausen test center to adapt to an increase of Ariane payload. Ariane 2 was designed for heavy-payload missions, Ariane 3 for dual-payload options with medium mass. The Viking engine was modified and UH25 was chosen as new fuel. Viking-2B developed a sea-level thrust of 643 kN. Exclusively for Ariane 3 development 35 injector qualification tests were conducted between 1980 and 1984 in Lampoldshausen as well as 2 tests under high-altitude conditions.

Fig. 11. Ariane 2, Ariane 3 and Ariane 4

The striking successor became Ariane 4 with its dual-payload option and its possibilities to adapt to different payloads. Besides the Viking-5C engines the biggest innovation was the Viking-6 engine for the PAL (liquid propellant booster). The PAL was hot-fire tested and qualified on test facility P4.1.

Fig. 12. Integration and test of a PAL at P4

1.4. Ariane 5 – a brand new launcher

In 1987 the Ariane 5 program was decided as a successor for the Ariane 4 launcher.

The fifth version of Ariane was planned as heavy-lift, low-cost launcher to secure Europe's independent access to space and to continue the commercial success of Ariane 4. Furthermore, other reasons supported the realization of a heavy-lift vehicle. One of them was the space glider "Hermes", for which also a lot of research work was conducted at test complex M11, and second, for the planned ESA-space station "Columbus" and third, satellites grew in mass and heavy-lift vehicle was necessary.

Fig. 13. Ariane 5 ES on launch pad

Major modifications were made at the Lampoldshausen test site to meet the new demands. Measurement, diagnostics and controls of the test facilities were modernized and construction of test facility P5 for the new mainstage engine Vulcain® was initiated. Additionally, the European Research and Development Test Facility P8 was designed and erected for development works in liquid propulsion systems together with industry partners. In contrast to the engines before, Vulcain® used cryogenic propellants, liquid hydrogen and liquid oxygen respectively, and the whole propellant infrastructure needed to be also established.

Fig. 14. Control Room of P5

The upper stage engine AESTUS (Ariane Engine for Storage Upper Stages) uses MMH and NTO as propellants. Initial development works were carried out at P2 and later on at modified P4.2 at high altitude conditions. Meanwhile, test facility P3 was modified and a second test position was installed, the so-called P3.2, to conduct Vulcain® combustion chamber tests. After 2 years of erection, P5 was finished in 1990. The first Vulcain® hot-fire test took place in October 1990, even over a month before the facility was officially dedicated on 27th November. The following years several test campaigns for development and qualification of the engine were conducted at P5.

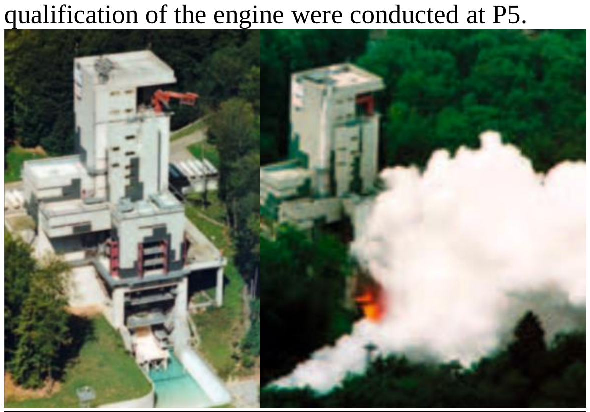

Fig. 15. Test Facility P5; Vulcain® hotfire test at P5

However, the maiden flight of Ariane 5 failed and the launcher self-destroyed after 37 seconds on 4th of June 1996 due to a software problem. Another problem occurred during the 10th launch of Ariane 5 in 2001due to a failure of the upper stage engine. Specific test activities were initiated at P4.2 to investigate on the ignition process of AESTUS. By using mechanical vacuum pumps, the most relevant ignition processes were evaluated and delta-qualification of AESTUS could be reached. Since then flight qualification is carried out for AESTUS upper stage engines at P4.2 by DLR Lampoldshausen.

In 1995 ESA decided to modify the Vulcain® engine to the so called Vulcain 2® to adapt to a performance-increased launcher version called Ariane 5 ECA. The development of this engine was in a large part carried out at the test facility P5 at DLR, which has been modified and adapted to the need of the Vulcain 2® engine 2. Again a first-flight failure occurred. Investigations came to the conclusion that a mechanical failure of the nozzle extension was the origin of the failure. Following that the P5 test facility was adapted to perform specific tests with the Vulcain 2® engine. A "Load Simulation Device (LSD)" developed by Snecma and DLR, which could simulate mechanical loads onto the nozzle, taking into account the surrounding vacuum conditions. Finally the requalification of Vulcain 2® was accomplished and Ariane 5 launched again with a now very reliable Vulcain 2® mainstage engine. In autumn 2003 the third successful launch in a row was carried out and the turnaround was reached. On 12th February 2005 an Ariane 5 ECA lifted-off again, this time successful with the satellites "XTAR-EUR" and "Maqsat-B2". The ECA-setup is the most powerful version of Ariane 5, still in operation today with more than 100 successful launches.

2. PRESENT [2,3,4]

Since 1973, the institute has been supporting programs relating to the European launcher Ariane, which is being developed under the aegis of the European Space Agency (ESA). In 2002, the DLR institution, which now accommodates all research and rocket engine testing activities, was renamed as Institute of Space Propulsion.

The institute handles research, technology, development, and experimental activities of every kind at a single location. The present headcount at the Lampoldshausen site is 320 plus approximately 300 personnel from ArianeGroup GmbH, who has rented facilities from DLR on site.

Today the testing capability at DLR Lampoldshausen ranges from specimens with a few hundred Newton up to 1300 kN. It is possible to test engine components, as well as complete rocket engines or even stages. Furthermore testing in all stages of technology readiness level is possible.

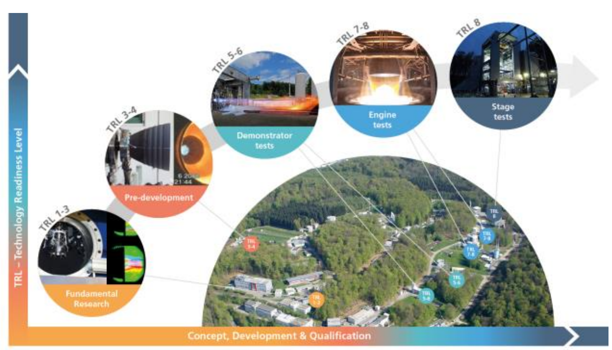

Fig. 16. Testing Capability at DLR Lampoldshausen

Fig. 17. DLR Site Lampoldshausen today [2]

2.1. Test facility P1.0 – altitude simulation

P1.0 is the smallest test facility in the Test Facility Department of DLR, used for tests under altitude conditions. Small propulsion systems with a thrust of up to 600 N and the so-called storable propellants mono-methyl hydrazine (MMH) and dinitrogen tetroxide (N_2O_4) are tested here. The steam generator, used to drive the altitude simulation system is operated with alcohol and liquid oxygen.

Fig. 18. Test Facility P1.0

2.2. Test facility P2 – ground tests

The test facility P2 dates back to the founding period of the site, as does test complex P1.

It is today a test facility where engines and components using storable propellants can be tested. The maximum thrust range is about 100 kN. The P2 is a DLR test facility which offers an expandable infrastructure and is mainly used for development testing.

Fig. 19. Test Facility P2

2.3. Test facility P3 – component tests

Test facility P3.2 was erected in the period between 1987 and1989 as a high pressure test bench for thrust chamber tests. Since 1989 it was used to carry out development tests for the thrust chamber of the Vulcain® engine. After adaptation of the test facility, development tests were also executed with the thrust chamber of the cryogen upper stage engine Vinci®. In 2015, the testing facility was again modified for the new propellant combination of liquid oxygen and methane. A demonstrator thrust chamber developed and manufactured by ArianeGroup was then successfully tested at P3 by DLR. The next modification step gave the possibility to test under an ESA FLPP program a new thrust chamber concept (ETID – Expander Technology Integrated Demonstrator). The thrust chamber was developed and manufactured by ArianeGroup. The P3 is an ESA test facility, managed and operated by DLR. It has to be noted that all above given testing possibilities are still kept and the facility can be retrofitted for each configuration and test need.

Fig. 20. Test Facility P3.2 during a methane development thrust chamber hotrun

2.4. Test facility P4 – altitude simulation

Test facility P4 comprises two test positions, namely P4.1 and P4.2. Both facilities were subject to several modifications after their first time usage to comply with the requirements of various development programs. In today's expansion stage P4.1 and P4.2 are used for testing under altitude conditions of rocket upper stage engine. Both test positions offer the additional possibility to carry out tests under sea level conditions. The AESTUS engine for the Ariane 5is tested on P4.2. AESTUS uses storable propellants. The cryogenic upper stage engine Vinci® for Ariane 6 is tested on P4.1.

Both altitude simulation systems are driven by a common steam generator plant. This is able to supply up to 260 kg/s steam using DLR own developed rocket steam generators which have liquid oxygen and ethanol as propellants.

The P4 is an ESA test facility, managed and operated by DLR.

Fig. 21. P4 Steam Generator system and Test Facility P4

2.5. Test facility P5 – ground tests

Test facility P5 was built between April 1988 and July 1990. In the period from 1990 to 1996, development tests for the Vulcain® engine of the cryogen main stage for the European launcher Ariane 5 were carried out here. Acceptance campaigns were run on P5 between 1996 and 1998.

Fig. 22. Integration of a Vulcain 2.1® engine at P5

Following the adaptation of the test facility P5, development test were carried out from 1999 to 2004 for the enhanced Vulcain 2® engine of Ariane 5. The P5 was then adapted in 2017 to the Vulcain 2.1® engine of the Ariane 6 launcher. The development and qualification testing of this engine took successfully place at P5 in 2018 and 2019.

The P5 is an ESA test facility, managed and operated by DLR.

Fig. 23. Exhaust gas and cooling water clouds during a P5 hot-fire test

2.6. Test facility P5.2

The European upper stage test facility P5.2 has been developed by DLR Lampoldshausen and erected at the site since 2014. It will allow testing the cryogenic ULPM (Upper Liquide Propulsion Module) of the Ariane 6 under sea-level conditions. The test facility is able to test the complete upper stage in its original configuration. Failure tests as well as limit tests will be carried out in 2020 at the facility. Furthermore, processes and procedures which will be applicable for the newly developed and erected launch pad ELA4 in Kourou will be done and verified at P5.2 in

Lampoldshausen. Currently the reception phase is running in order to prove the full functionality of the facility with respect to the specification of the ULPM.

The P5.2 is an ESA test facility, managed and operated by DLR.

Fig. 24. European Upper Stage Test Facility P5.2

2.7. *Test facility P8*

In 1992 the business partners SEP (today: ArianeGroup SAS), DASA (today: ArianeGroup GmbH), CNES and DLR set up a European co-operation project on hydrogen/ oxygen high-pressure combustion, and P8 was erected as European Research and Development test facility for this purpose. The facility is composed of two test cells with a 100-day/year availability for experiments.. A third test position, the so called P8.3 is designed and currently under erection. The overall P8 test facility will be even more flexible as today, usable for engine as well as component testing in the frame of research and development programs. Different cryogenic propellant combinations will be available. The P8 is a DLR test facility.

Fig. 25. European Technology and Development Test Facility P8

Fig. 26. Control Room of P8

2.8. *Test facility P6*

Test facility P6 is a research and development test facility, using propellants like hydrogen, oxygen, gaseous and liquid methane or LNG for rocket applications to meet the environmental boundary conditions of today's rocket engines. Test facility P6.1 completes the portfolio to P8 in sight of lower mass-flows and feed pressures. During design of P6.1 a focus was laid on optical accessibility of the engine and the combustion process itself.

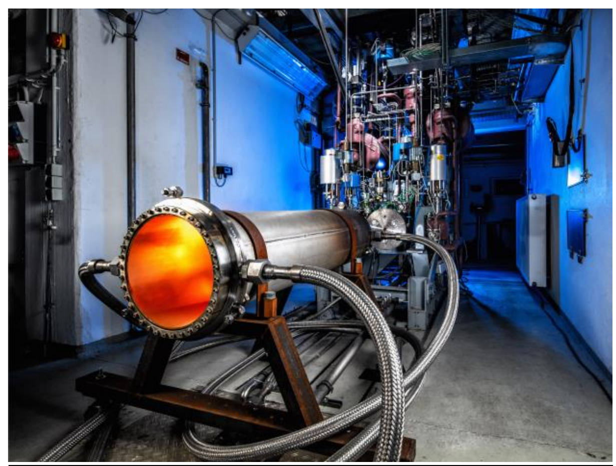

Fig. 27. Test Specimen at Test Facility P6.1

2.9. *Test facility M3* [5]

The test field M3 offers a high number of experiments and tests at small scale with many different configurations. The field is set up of three test positions with different areas of research: M3.1, M3.3 and M3.5. Propellant ignition, injection and spray atomization are main research topics and are highly relevant for rocket combustion.

Test positon M3.1 is used for examination of injection processes of cryogenic propellants into the combustion chamber. Ignition, e.g. laser ignition, combustion phenomena or material analysis can also be investigated.

Test position M3.3 and M3.5 deal with the investigation of phase flows of cryogenic fluids, as these could appear in valves, injector heads or during injection into the combustion chamber.

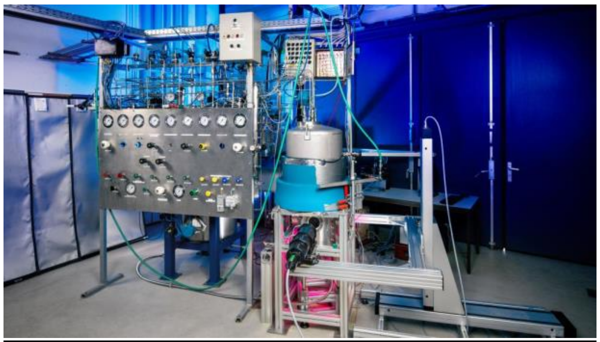

Fig. 28. Test position M3.3 at Test Field M3

2.10. Test Complex M11 [6]

Test Complex M11 and the associated physical-chemical laboratory investigate green and advanced propellants for orbital and satellite propulsion systems as well as supersonic and hypersonic combustion for Ram- and SCRamjet engines. To fulfil this task, specific propellants and propellants combinations are investigated in coldflow and hotfire tests under atmospheric and vacuum conditions.

Typical propellants to be tested are monopropellants, bipropellants, hypergolics as well as gel propellants or hybrid propellants for smallsat launchers. The close connection between the laboratory and the testfield allows for short turnaround times, simple propellant and residue analysis, examination or synthesis respectively production.

Besides the combustion and performance investigation also all other subsystems comprising a satellite propulsion system can be tested and investigated. This includes for example valves, piping, tanks, pressure regulators, combustion chamber materials, thermal, physical and chemical material analysis, etc.

M11 consists of five testbeds, each with a particular field of research. Thrust range at Test Complex M11 ranges from 1 N up to 10 kN.

Fig. 29. Test Complex M11 [7]

2.11. Test facility M51 [3]

The research priorities of the Structural Analysis Group are thermo-mechanical analysis, material behaviour under cyclic load changes, hydrogen embrittlement and the impact of reducing and oxidating flows on material properties. Thermo-mechanical fatigue is investigated on a test bench (TMF test bench, Training and Model Forecast) where cyclical loads with representative heat flows of up to 20 MW/m^2 can be simulated under controlled conditions. Our aim is to optimise and conceive models to describe failure processes and anticipate life cycles.

2.12. Supply Systems

2.12.1. Liquid Hydrogen fuel storage

The liquid hydrogen depot is supplying the test facilities P4.1 and P5 as well as P5.2 with liquid hydrogen. The storage consists of a vacuum-isolated main storage tank with a usable inner volume of 270 m³ and a vacuum-isolated pilot tank with a usable inner volume of 55 m³. There are connection options to discharge tank trucks as well as the necessary pressurizing and safety systems.

1.1.1. Liquid Oxygen fuel storage

The liquid oxygen depot is supplying the test facilities P4.1, P5 and P5.2 with liquid oxygen. It consists of a vacuum-isolated storage tank with 210 m³ volume, two connections for tank trucks, the necessary pressurising system, as well as safety installations.

1.1.2. Production plant for GH_2

DLR is producing in a specific facility GH_2 by evaporation of Liquide Hydrogen. The GH_2 is compressed to different needed pressure levels, maximum up to 800 bar. The GH_2 is then distributed to all test facilities on site using hydrogen as propellant.

1.1.3. Production plant for GN_2

The operation of the test facilities and their dedicated supply systems requires a sufficient supply with gaseous nitrogen in different pressure stages. To cover this need the test facilities are fed from the upper area of the test site where the compressor unit D22 GN_2 is based. The GN_2 is produced from liquid nitrogen by evaporation and compression to the needed pressure stages. This GN_2 is then distributed to all test facilities onsite using fixed transfer lines.

The existing GN_2 production in D22 has been recently enhanced by another production station, the so called D57A, which is used for P5.2 operation with ULPM of Ariane 6 only.

Fig. 30. D57A GN2 Production for P5.2.

1.1.4. Production plant for GHe

The operation of the test facilities and their dedicated supply systems requires a sufficient supply with gaseous helium in different pressure stages. To cover this need the test facilities are fed from the upper area of the test site where a connection point for Helium tank systems or trailers is present. A compressor has been added recently in order to secure the specific supply for P5.2 during ULPM Ariane 6 testing.

1.1.5. Cooling water supply

Test facilities P4, P5 and P5.2 are supplied with cooling water from the elevated tanks N33, N63 and N63A. The main supply is there for the high altitude simulation system of P4.1, which needs a supply of about 5 500 l/s. While P5 evaporates a high amount of cooling water during a hot-firing test, the cooling water from P4.1 and P4.2 is collected in underground water basins. This cooling water is transferred back to the elevated cooling water tanks and re-cooled as needed in the test facilities. The water towers N33 and N63 have a maximum volume of 1 000 m³ each, N63A can absorb up to 4 000 m³ of cooling water.

All these supply facilities are operated from a specific command building using a dedicated command system.

All these supply facilities are ESA facilities, managed and operated by DLR.

1.1.6. Waste water treatment

The DLR site at Lampoldshausen operates a large-scale water treatment plant. Contaminated sewage water coming in from test facilities using storable propellants is treated in this neutralization plant and can subsequently be channeled out into the environment fulfilling the legally prescribed regulations. This plant was extensively modernized in the past years. The plant consists of two parts using different concepts. The first and older part incorporates systems applying the so-called catalytic wet hydrogen peroxide oxidation (H_2O_2) and ultraviolet light as well as the so-called ammonia stripping. The physical extraction by blowing down ammonium provides a balance between ammonium (NH_4+) and ammonia (NH_3). A balance shift in favor of the gaseous and water-soluble ammonia commences once the pH value of 9 is exceeded. When a pH value of 11.5 is achieved, the nitrogen has been transformed into ammonia at 100 %. The pH value is gradually set to 10 as caustic soda is added to ensure a rapid mass transfer. The ammonia is feed into a circulation system and then transferred to gas phase via a trickle tray tower for stripping. The stripped air, now charged with ammonia, is circulated by fans, injected into a sulphuric washer and cleaned. Ammonium sulphate remains as a by-product $(NH_4)_2SO_4$. The benefits of this application are on one hand the highest possible waste water quality (considering the extremely varying organic sewage water agents), secondly no sewage water salting, thirdly, low susceptibility to failure thanks to simple reactor technology, fourthly, low consumption of human and economic resources and least: easy expandability.

In recent time a second system was added as a pilot system, the so-called SOWARLA (SOlare WAsserReinigung Lampoldshausen - Solar Water Treatment Lampoldshausen). Here the waste water is cleansed using a photocatalytic process. The waste water is laced with a catalysator and an oxidizer and afterwards pumped through the solar receivers. The water is exposed to the sun as long as needed to ensure the decontamination. After a final check the water can then either be re-used or discharged into the environment. This method saves up to 90% energy compared to the old system.

Fig. 31. SOWARLA waste water treatment

3. FUTURE

3.1. *H_2Orizon* [8,9]

DLR's Lampoldshausen site, which lies 50 kilometres north of Stuttgart, is currently creating another element of the energy future. The Institute of Space Propulsion in Lampoldshausen is one of Europe's largest consumers of hydrogen and is situated next to what is currently the biggest wind park in Baden-Württemberg. Taking this infrastructure as their starting point, the DLR Institute of Space Propulsion and ZEAG Energie AG are currently working together to create a hydrogen-based, networked energy system. This will see the energy, transport and space industries coupled on a megawatt scale.

The plant concept of the H2Orizon project consists of two main components. One is renewable hydrogen production based on wind energy. The polymer electrolyte membrane electrolysis (PEM electrolysis for short) system has a power input of around one megawatt and is directly connected to the Harthäuser Wald wind farm. Hydrogen is processed, compressed and pumped directly into special transport vehicles, known as tube trailers, for distribution. H2Orizon will also be used to construct a new plant to supply the DLR site with heat and electricity. The two gas-engine cogeneration units with a total output of 1.6 MW (thermal) and 1.4 MW (electric) will also be directly connected to the hydrogen production plant, as well as the conventional natural gas supply.

The DLR Institute of Space Propulsion is bringing its knowledge as Europe's largest consumer of hydrogen to bear on the H2Orizon project and is drawing upon the highly developed expertise of the whole of DLR, where the study of hydrogen links the felds of aerospace, aeronautics, energy, transport and security. ZEAG Energie AG is the world's longest-established three-phase supplier. As such, it knows the energy sector and is familiar with the challenges of operating renewable energy plants and power grids, as well as the conditions for successful participation in the energy market.

The infrastructure and expertise of the two project participants will be made available to potential industrial partners – especially small and medium-sized enterprises – and scientific institutions from January 2019, and will be known as the 'H2Orizon Test Field'. In creating the H2Orizon Test Field, DLR and ZEAG are aiming to enable new hydrogen-related technological and conceptual solutions to be researched, developed, demonstrated and validated at the DLR site in Lampoldshausen.

Fig. 32. H2Orizon project

3.2. Lumen [10]

The Liquid upper stage demonstrator engine (LUMEN) to be built at the German Aerospace Center will use the expander bleed cycle. The propellants for LUMEN will be liquid oxygen (LOX) and liquid methane or more specifically liquid natural gas (LNG). The demonstrator will provide a test bed for future component development as well as to enhance the understanding of the operation of the complete cycle. The cycle will feature two turbopumps in order to simplify the turbopump design, while on the same time allowing more freedom for a modular exchange of components. By this approach the DLR hopes to create point of contacts for interested parties to use the LUMEN demonstrator for turbopump component research on demonstrator level. In this paper we give an overview on the current development status of the turbopumps. The critical design phase (CDR) will be finished in early 2019 and the design of the components are discussed as they are close to be manufactured. Extensive CFD work has been done since the preliminary design phase in order to proof the reliable performance of the LOx and LNG pump. On the turbine side a full 3D simulation has been performed. The design of the housing for the oil lubricated off the shelf hybrid bearings as well as the design of the shaft has been completed. To ensure smooth operation of the turbopumps throughout the operational envelope of the LUMEN demonstrator, the critical frequencies of the turbopump rotor assembly have been determined and verified by FEM calculations. Finally we give an overview on the necessary future steps to put the turbopumps into service.

The LUMEN demonstrator will be tested on the P8.3 test position.

Fig. 33. P8 Test Facility and construction site of P8.3

3.3. Prometheus

By developing liquid oxygen (LOX)/methane technology, Europe is meeting the global requirements of the launcher market, as this fuel combination has huge potential for the development of cost-effective and reusable high-thrust rocket engines. The use of methane as rocket fuel has been investigated for decades, but LOX/methane propulsion has not been used in a launcher thus far.

As part of the Prometheus program, ArianeGroup is now developing a LOX/methane demonstrator engine with 1000 kN thrust, based on a concept by the French national space agency (CNES). In order to make this new engine cost-effective, new production processes are also being used, such as 3D printing. Since 2016, the program has been part of the European Space Agency's (ESA) Future Launchers Preparatory Program (FLPP).

The aim of the program is to test the Prometheus engine demonstrator under representative conditions on the P5 test facility at the DLR site in Lampoldshausen. Following the successful test campaign of a 60 t thrust chamber on the P3 component test facility in collaboration with ArianeGroup in 2016, this will be the second full-scale test of LOX/methane hardware on a large DLR test bench.

DLR Lampoldshausen has been conducting its own LOX/methane research since 2006. Furthermore, DLR has been collaborating with CNES since 2017 in order to support ArianeGroup's development of the Prometheus engine with accompanying research projects. It is also drawing on the experience gained from LUMEN, the DLR internal development project that began in 2016 with the aim of developing its own LOX/methane demonstrator in the 3 t thrust class.

In order to guarantee the success of the Prometheus engine tests at P5, DLR engineers are already preparing for the necessary adaptation and modification of the test facility. A new Methane supply system will be installed at the P5, making it possible to use different propellants in future on the facility. Further bench systems such as the electrical supply will be modernized, new command and control concepts will be established in interface to the demonstrator engine.

Fig. 34. Prometheus engine concept [11]

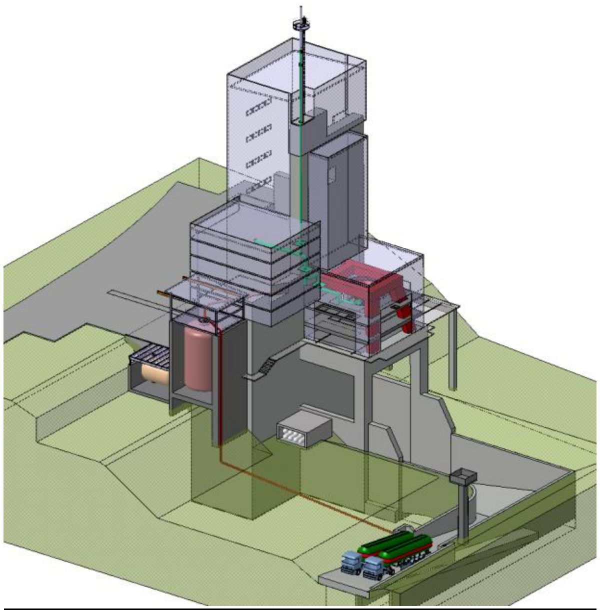

Fig. 35. Modification concept of the P5 to Methane capability

3.4. Lampoldshausen 2030

Not only is the testing capability enhanced at the DLR test site Lampoldshausen for future needs, but it is also foreseen to have a large scale modernization program in the next years. The test site will make a large step into the future, changing concepts and processes to even more efficient operations as of today.

The program is not only aiming to reduce operational costs but also to gain higher flexibility, perform higher testing cadencies and implement smart test infrastructures and support functions in operations.

Without DLR test site in Lampoldshausen the European launchers would not be able to deliver safe and reliable access to space. The site is unique in its capabilities and performance and it is indispensable for the European Space Transport.

DLR Lampoldshausen test site is ready for future challenges and opportunities while maintaining a huge and impressive heritage from 60 years of successful operation.

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