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Liquid rocket engine test facility engineering challenges

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Abstract

Liquid rocket engines for launch vehicles and space crafts as well as their subsystems need to be verified and qualified during hot-runs. A high test cadence combined with a flexible test team helps to reduce the cost for test verification during development/qualification as well as during acceptance testing for production. Test facility intelligence allows to test subsystems in the same manner as during complete engine system tests and will therefore reduce development time and cost.

This paper gives an overview of the maturing of test engineering know how for rocket engine test stands as well as high altitude test stands for small propulsion thrusters at EADS-ST in Ottobrunn and Lampoldshausen and is split into two parts:

- Part 1 gives a historical overview of the EADS-ST test stands at Ottobrunn and Lampoldshausen since the beginning of Rocket propulsion activities in the 1960s.
- Part 2 gives an overview of the actual test capabilities and the test engineering know-how for test stand construction/adaptation and their use during running programs.

Examples of actual realised facility concepts are given to demonstrate cost saving potential for test programs in both cases for development/qualification issues as well as for production purposes.

1. Introduction

Test facilities are an indispensable element for the development and acceptance of space systems/subsystems and components. Hot-test facilities especially with environment simulation (e.g., altitude simulation) are very unique and are specifically designed to their needs.

In Germany rocket propulsion developments were started during the 1950s in Ottobrunn near Munich. Beginning in the 1960s developments of attitude control engines and thruster for space crafts were started in Lampoldshausen. In addition to these two plants with test facilities and test capabilities, a third centre with test facilities operated by ERNO in Trauen was built up for the development of the ELDO Launcher (Europa III).

In the frame of the consolidation of the different Space Propulsion activities within Dasa (Daimler-Benz Aerospace) in the 1990s as well as the creation of EADS-Space, all test activities were concentrated to the Lampoldshausen site, concluded in 2000.

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Main reasons for this concentration to one test site were:

- One EADS-ST test-centre in Germany.
- One EADS-ST Test and Engineering Team at one location.
- Multi-use of the three EADS test fields in Lampoldshausen instead of 10 facilities.
- Experts with test engineering know how for development and production programs at one location.
- Synergy effects for test facility modification/maintenance and field support together with DLR.

In addition, cost aspects, especially for test conductions have to be reduced. Therefore, the facility and test requirements have been changed by:

- Using more intelligence in the design and features of the facility (e.g., several test objectives to be tested during one hot-firing test).
- Use of test data for computer simulations as code calibration and therefore reduction of the total number of needed tests.
- Multi-function of test specialists with the main goal to reduce the test team size.
- Computer aided test set-up, firing sequencing and on-line documentation.

Fig. 1. Building-up of P 59 with safety walls.

Fig. 2. Integration of the HM7 Engine with NE in the vacuum capsule with thrust measurement rig.

2. Historical overview

2.1. Ottobrunn

A complete overview of all technologies created since the mid of the 1950s is given by Hopmann in [1]. Within this chapter the focus was set on technologies and know how generated in the frame of the Ariane cyrogenic developments at P 59 and air-breathing propulsion [2,3].

The start of the ARIANE 1 programme and the contract for the development of the HM7-A thrust chamber called for a new facility complex. The erection of the P 59 Test facility was the first high-pressure thrust chamber facility in Europe with a storage level of 800 bars. This high pressure gas was needed to feed the 400 bar LH2 and LOX vacuum insulated run-tanks. For this facility also a special valve test facility was erected in order to test the facility valves in advance to their integration into the test bench (Fig. 1).

Within the HM7 thrust chamber development the integral combustion chamber design based on cooper liner with galvanic Ni technology for the outer shell and the technology to manufacture a dump-cooled nozzle designed on welded rectangular tubes was created. This technology was used for third stage Ariane 4 (HM7-B) nozzle extension (NE) and is in used for the ESCA Engine (HM7B) as well as for the Vulcain1 (Ariane 5 GS-Version) and for the Vulcain 2 (NE).

For the development of the HM7 NE, tests with a self sustained supersonic diffuser were performed. The ignition was performed under sea-level conditions. After reaching the steady state level a surrounding vacuum pressure of 15 mbar was achieved, which allows the verification of the NE behaviour as well as a thrust level measurement under altitude conditions (Fig. 2).

For the start up and shut down, the NE was fixed with a clamping device. A high pressure flow with GN2 during shut down prevents the shock wave reflow into the supersonic diffuser which could destroy the NE (Fig. 3).

With this technology the determination of the vac-Isp with an accuracy of 0.9% of the total measurement line was possible. The NE was qualified under off-design

Fig. 3. Test of the HM7 B third stage thrust chamber under altitude conditions.

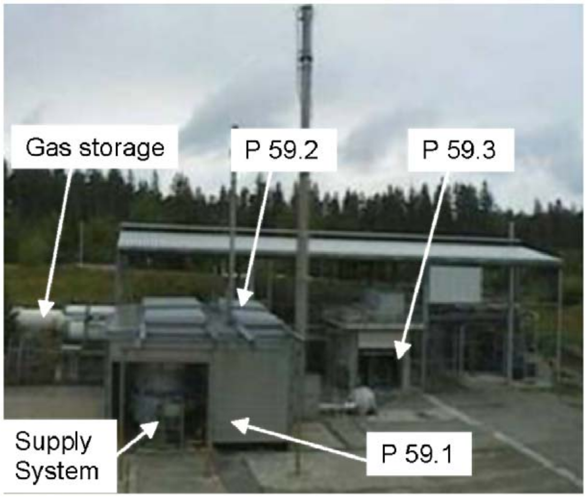

Fig. 4. P 59 test complex; status 2000.

conditions and allows a TC mixture ratio of max. 5.8 (nominal 5.0) corresponding to a temperature of 1000 K at nozzle end.

In the frame of the Vulcain development of the Ariane 5, the test facility complex P 59 was modified and extended with two additional test- cells; one for subscale thrust chamber tests (P 59.1), one for gas-generator tests (P 59.2), one for LOX-TP (P 59.3) tests with and without gas-generator (cold gas drive) (Fig. 4).

Tests were performed on all three test cells with different test teams. Control-loops for start-up, steady state as well as for special tests like cavitation limits, overspeed tests, etc. were performed. Therefore special facility control valves with hydraulic actuation were developed with an industrial partner. In addition specific tools for test predictions as well as for safety reasons were created. The development tests of the Vulcain 2 TP LOX for the Ariane 5E were performed on P 59.3 and

Table 1
Main LH2/LOX & LOX/JP-1 developments at Ottobrunn

	P 111 LOX/JP 1	Bord-1 LOX/LH2	HM7 TC LOX/LH2
Development period	1956–1967	1967–1968	1976–1982
Chamber pressure (nom.)	85 bar	210 bar	35 bar
Mixture ratio (nom.)	2.7	6.0	5.69
Operational range			
Chamber pressure in bar	4.9–49	38.5–282	30–43
Thurst in kN mixture ratio	2.1–4.0	23.5–180	60–78
		4–8	4.0–5.8
Combustion efficiency	97.2%	97.5%	98.7%
Injector	Coax	Multi-coax	90 el- coax

Fig. 5. Air-breathing facility F3.

concluded in 2000. Especially cavitation limits as well as overdrive tests were performed under hot-gas-drive conditions (with gas generator) and in cold-gas drive conditions (using GH2 HP gas as working medium for the turbine). After finalisation of the test programme the facility was dismantled and all equipments were transferred to the P 3.2 test complex at Lampoldshausen.

Table 1 shows an overview of the main developments performed at Ottobrunn [2,4,5]. Especially the patented Bord-1 thrust chamber technology is in used for the Space-Shuttle main engine.

2.1.1. Air-breathing propulsion

For the Sänger vehicle an air-breathing propulsion system with entrance speed up to Mach 7 was developed at the end of the 1980s. Based on the available facility technologies hydrogen feed system as well as the entrance temperature and speed conditions were simulated by the facility using N_2O in the vitiator. The design of the vitiator allows adjusting of the different conditions in the Mach range 3.5–6.8 (Fig. 5).

The investigation of a unique nozzle shape-form was under leadership of MTU for the design and the coating of the NE. The determination of the heat-transfer of the NE, especially in the edges of the NE calls

Fig. 6. NE of the Sänger engine under hot-firing conditions.

for measurement of the exhaust temperature. These were successfully performed by an optical temperature measurement devices based on laser-technique, a special–development for such unique investigations [6–8] (Fig. 6).

2.2. Lampoldshausen

2.2.1. Attitude control systems

In 1963 a small team from Ottobrunn started the development of the ELDO 400 N attitude control system based on $AZ50/N_2O_4$. AZ50 a mixture of $UDMH/N_2H_4$ was used in the beginning due to the fact that MMH was not available at that time as fuel. In order to decrease the freezing temperature of N_2H_4, the fuel was mixed with UDMH (50%/50%).

The first test facility was simply designed in order to start the investigations soon (Fig. 7).

For the understanding of the combustion flow and film-build-up-process, special "Plexiglas-Chambers" were used (Fig. 8) and observed with high speed camera.

For the determination of the Thrust-level under vacuum conditions, EADS-ST (former MBB) developed in cooperation with DLR (former DFVLR) the first high altitude test facility with an ejector pump vacuum system in Germany. The work share covers for DLR the responsibility of the altitude conditions and therefore the ejector-system and for EADS-ST the complete design and lay-out of the feed-system including the thrust measurement device. In common teams the tests were performed. DLR was responsible to provide the vacuum conditions, EADS-ST for the conduction of the hot-run. The ejector system of the P 1.5 test facility was fed by

Fig. 7. Sea-level tests of the 400 N engine as well as the 400 N engine with regenerative cooled throat-area.

Fig. 8. Glas-chamber test of the swirl-injector system.

nitric acid (HNO_3) and N_2O_4. With this facility 400 N engines up to an expansion ratio of 220 were developed and qualified. In the following production phase 100 engines were flight acceptance tested with the P 1.5 facility (Fig. 9).

After the stop of the ELDO programme, beginning of the 1970s, the team in Lampoldshausen focused on satellite propulsion system. The first satellite equipped with a pure bi-propellant propulsion system in Europe was Symphonie, launched in 1978. Two different feed systems were used ($AZ50/N_2O_4$) for the apogee-boost motor 400 N (Fig. 10; developed in the ELDO Programme) and a second system using MMH/N_2O_4 for the so called hot-gas-system. In total seven thrusters of the new 10 N thruster were integrated in the system (Fig. 11).

Fig. 9. P 1.5 high altitude test facility up to 400 N.

Fig. 10. Apogee boost system for Symphonie.

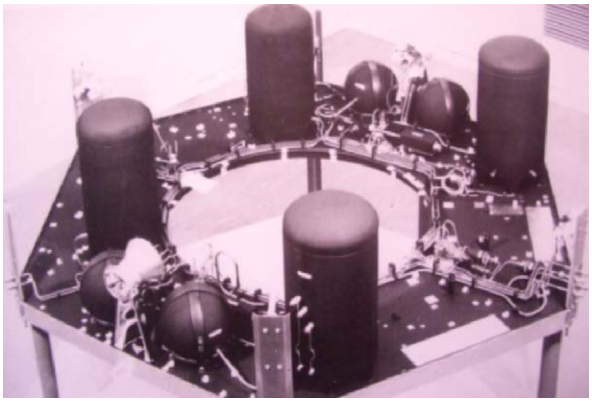

Fig. 11. Hot-gas-system symphonie satellite.

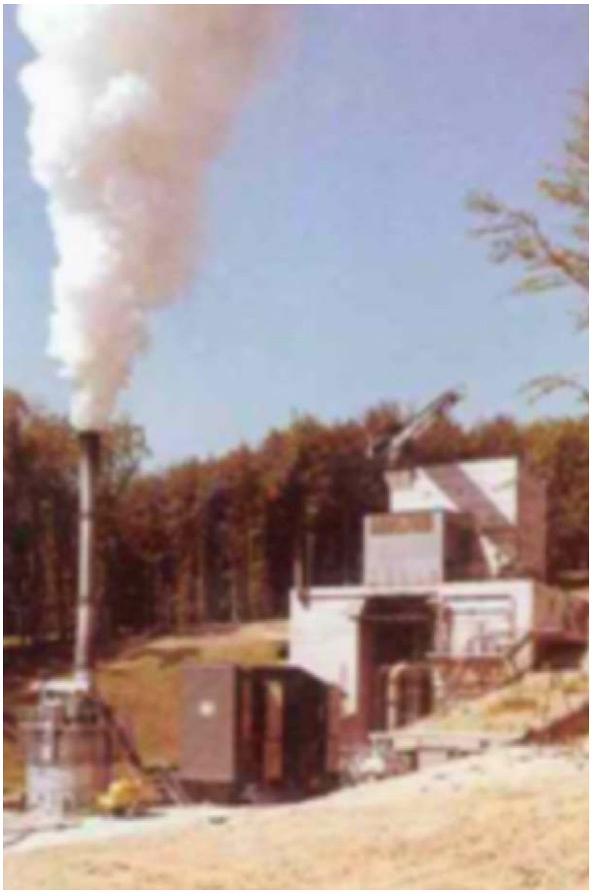

Fig. 12. High altitude P 3.1 test facility with running steam ejector.

For the qualification of the complete propulsion system under vacuum conditions the well proven work share between EADS-ST and DLR was applied for the adaptation of the ELDO P 3.1 test facility. This facility was originally built-up in the ELDO program, designed by EADS-ST and used for ignition tests under simulated altitude conditions of the ARTIS stage main engine, a 23.5 kN AZ $50/N_2O_4$ Engine (Fig. 12).

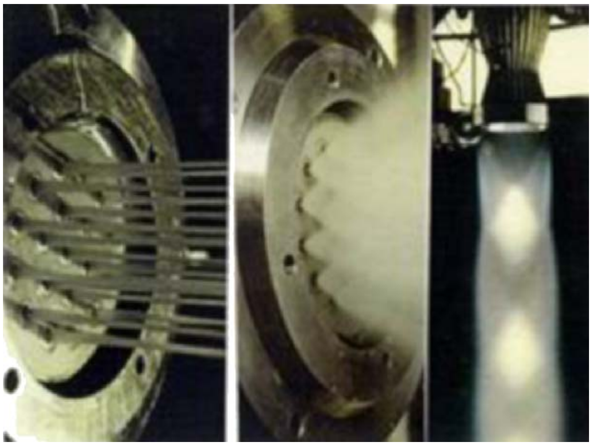

Fig. 13. Water-flow tests of oxidiser and fuel; hot firing subscale tests with water cooled TC.

Main subject of the modification was the installation of a turntable with 120 RPM in the vacuum cell of the facility. Two main test campaigns were performed, one for the qualification of the 400 N AZ50/N_2O_4 engine in up-side down position with the original symphony feed system and a second campaign with the complete “hot-gas-feedsystem” including the seven Thrusters. EADS-ST was responsible for the complete feed system including special measurements like the test table; DLR was responsible for the vacuum level by using a much more complex ejector system based on the same propellants as used for the P 1.5 vacuum facility (Fig. 12).

The Symphonie project with the responsibility for the propulsion System at EADS-ST (former MBB) was the start of developments and manufacturing of propulsion systems and components for satellite propulsion systems. The EADS-ST heritage book of satellite propulsion systems and components operating in space is given in [9].

2.2.2. Launcher Propulsion

Since the beginning of the 1980s, studies of the new Ariane Launcher (Ariane 5) have been initiated. In 1985 EADS-ST was selected to develop the HM60 Thrust Chamber for the Vulcain 1 Engine. In addition, the development of the Aestus upper-stage engine was contracted to EADS-ST. For both developments, specific facilities were needed.

Aestus-upper-stage engine development. The development started with a subscale engine in the thrust class of 4.5 kN. These tests were performed at the facility P 1 with a water cooled combustion chamber due to the low MMH mass flow and the potential risk of MMH boiling and/or decomposition in the cooling channels (Fig. 13).

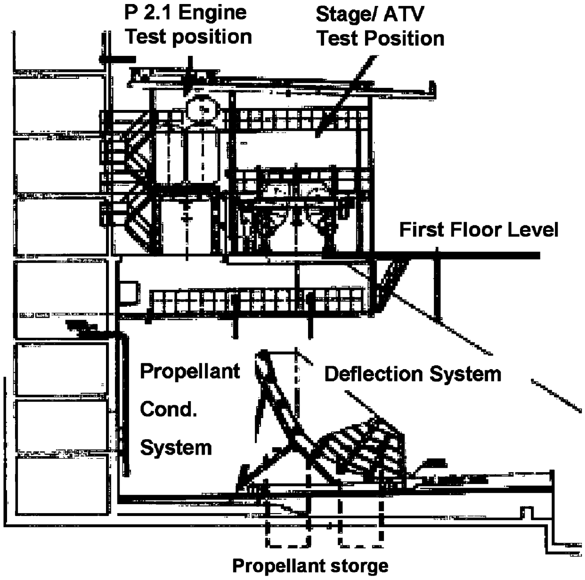

Fig. 14. Side view of the P 2 facility.

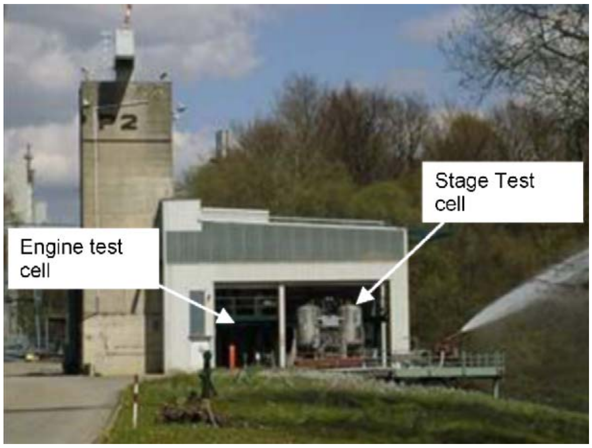

Fig. 15. P 2 Test complex with the two test cells.

The fullscale investigation of the injector and the combustion chamber were performed under seal-level conditions at the P 2 facility [10].

The steel structure of the facility is designed for a thrust-load of 100 kN. Two test cells were constructed in the P 2; one test cell for engine development, one test cell for the stage testing, both under sea-level conditions (Figs. 14 and 15).

The main data of the P 2 facility capabilities are given in Table 2. With this capability full run duration lifetime tests were performed.

Due to the toxicity of the used propellants the concrete ground plate is designed as a bathtub directly connected with the central neutralisation facility. This

Table 2
P 2 capabilities

	LP storage bar 15	Run tank engine test cell	Run tank stage test cell
N_2O_4	3000 ltr.	350 ltr.–60 bar 200 ltr.–120 bar	6300 ltr.–40 bar
MMH	3000 ltr.	350 ltr.–60 bar 200 ltr.–120 bar	4700 ltr.–40 bar

measure prevents ground contamination. Additional safety equipments were installed, also for the detection of very small quantities of propellant leakages.

During the period of 1990 till 1994, several hundreds of ignitions were performed for performance mapping as well as for HF investigations. Special test adaptations with GHe ingestion and integration of pyrotechnical shock generators in the combustion chamber were performed for the determination of the damping behaviour against HF of the engine.

The test of nozzle extension verification was performed at the P 4 facility under responsibility of DLR. This high attitude test facility with a vacuum level of 5 mbar allows the full verification of the Aestus engine.

In addition to the hot-firing activities, the design and qualification of ground support equipments to be used on launch pads was tested and qualified by the engineering and test team at Lampoldshausen (Fig. 16).

Vulcain 1 Development. For the development of the Vulcain 1 thrust chamber it was impossible to extend the available facility (P 59-OTN); [11,2,12]. Therefore, it was decided to build a new fullscale thrust chamber facility close to the P 3.1 facility in Lampoldshausen. The P 3 facility was not more in use since the finalisation of the Symphonie program. The Engineering know-how and experience of cyrogenic facilities from OTN was used. In cooperation with the subcontractor Thyssen-Krupp (former UHDE) the high mass flow valves were designed and tested in a special valve test bench at OTN. The lay-out of the feed system from run-tanks (fix-point-1 at tank-outlet) to the main shut-off valve (fix-point 2) was performed under the constraint of contraction resulting from the 20 K cold hydrogen. The piping-system is therefore working like a "spring", self-compensating the contraction forces (Overview P3 area Fig. 17).

During the period of 1988 till 1993 in total 280 hot firing tests were performed on six different hardware's. The test specimen was installed in horizontal position. The flame deflector then changes the orientation of the exhaust steam in order to prevent damages of the surroundings (Fig. 18) (Table 3).

Fig. 16. Test of GSP equipment.

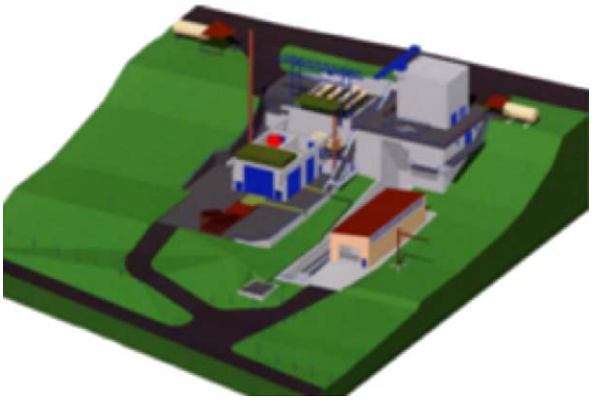

Fig. 17. Test complex P 3.

3. Today's status of hot firing test facilities at Lampoldshausen

Fig. 19 shows the overview of the current test complexes at the DLR/EADS-ST-area in Lampoldshausen.

Today EADS-ST and the DLR are operating different kinds of test facilities for storable and cryogenic propulsion systems on component and engine level. The whole area contains offices, scientific laboratories, workshops, propellant storage as well as environmen-

Fig. 18. Top view of P 3.2 with LH2/LOX compartments and the test cell.

Table 3
P 3.2 thrust chamber facility capabilities

	Gas storage 800 bar	Run tank 400 bar	Storage at 10 bar
H_2	$30\,m^3$	$12\,m^3$ LH2	$50\,m^3$ LH2
OX	$27\,m^3$	$4.5\,m^3$ LOX	$30\,m^3$ LOX

tal protection facilities. The small thrusters for satellites up to 500 N be tested under vacuum condition at the test *complex P1*.

The DLR *facility P 2* equipped with ESA installations is operated by EADS-ST and dedicated to upper stage engine and propulsion system tests. Today at the first test position, the Aestus-engine (upper stage ARIANE5) as well as RS 72/Aestus II and at the second test position the EPS stage and the ATV propulsion system are qualified and pre-accepted under sea level conditions.

ESA's high pressure cryogenic thrust chamber test *facility P 3* is operated by EADS-ST. Today the development of the new cryogenic upper stage (ESC-B) engine for ARIANE5-VINCI is supported by tests of the TC under vacuum condition during ignition.

The ESA test *facility P 4*, operated by DLR, supports steady state vacuum tests for the upper stage engines for ARIANE5. At P 4.2 qualification and acceptance hot runs of the AESTUS engine including nozzle extension were carried out. At P 4.1 the modification for VINCI engine vacuum tests was finalised by mid 2004.

The ESA test *facility P 5* (brother facility to the PF 50 facility in Vernon, France) operated by DLR, is the second main engine test facility in Europe for ARIANE5. Hot runs are performed under sea level conditions.

In co-operation between DLR, CNES, SNECMA and EADS-ST, the European research and technology test *facility P 8* was erected for the purpose of studying high pressure combustion of hydrogen and oxygen. DLR operates the P 8 (Table 4).

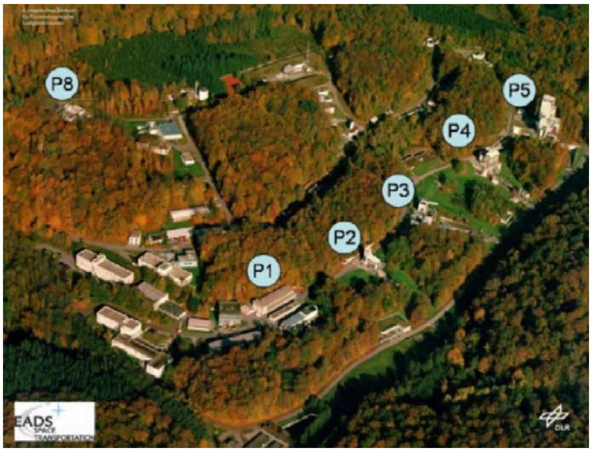

Fig. 19. European test center for Space Propulsion.

4. Test facility engineering know how

Today test facilities for liquid rocket engines, subsystems or components has to fulfil in addition modern requirements like

- tight modification schedule and costs,
- high flexibility for different test purposes,
- harmonised technical environment to balance program and resource loads,
- quality norm DIN EN ISO9100:2003,
- environment norm DIN EN ISO140001:1996.

ESAs policy is to have a competitive industries for Space Propulsion subsystem and components as well as for the ARIANE launcher. The demands of today's market conditions forces flexible facility technologies in addition to flexible resources/manpower.

Taking these challenges into account EADS-ST has built-up a modern strategy of test facility engineering and operation.

This new approach was implemented during the refurbishment of the test complex P 1 which is in use for hot firing tests of satellite propulsion thrusters for production and development purposes.

Examples of how to fulfil these new requirements are given for the pure commercial market realised at the test complex P 1 and for the launcher propulsion activities for P 3.

Test complex P 1. A detailed overview of the P 1 test complex is given in [13]. In the frame of upgrading to the actual needs three new test cells were constructed.

Table 4
Main data Lampoldshausen facilities

	P 1	P 2	P 3	P 4	P 5	P 8
Application	Thruster/apogee engines	Launcher upper stages	Thrust chambers	Upper stage engines	Core stage engine	Research & Technology
Thurst level	0.5–600 N	0.4–100 kN	3–1500 kN	15–300 kN	1500 kN	1–10 kN
Propellants	Bi-prop/monoprop	Bi-prop	LH2/LOX	Bi-Prop LH2/LOX	LH2/LOX	LH2/LOX
Vacuum	X			X		
Sea level		X	X	X	X	X
No testcells	6	2	1	2	1	2
Use	EADS-ST DLR	EADS-ST	EADS-ST	DLR	DLR	DLR

Fig. 20. Test facility test cells for satellite propulsion thrusters.

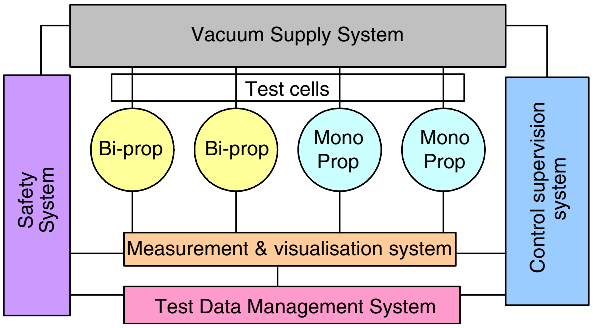

Fig. 21. General facility lay-out.

In the past, the test cells were designed for development test, with a high flexibility for adaptation changes to very unique test requirements. Today, two twin test cells, for bi-propellant testing of up to 30 N (P1.2, P1.3) and for monopropellant Thrusters (up to 400 N, SCA-Level) were designed, constructed and accepted for pure production purposes (Fig. 20).

The construction of these new test cells were performed in the period 2000 up to 2003 in parallel to the actual test programme. For all new test cells a harmonised measurement-control-sequencing system (MCS) was designed and installed in cooperation with a subcontractor (Fig. 21).

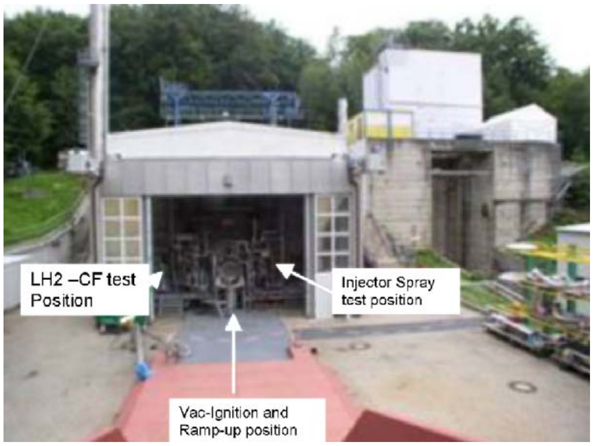

Fig. 22. Front-view of the test cell P 3.2 with the different test positions.

The concept contains a common control and supervision system which handles the manual and automatic functioning of the vacuum supply system as well as the individual feed systems of the vacuum test cells.

All measured data together with the digital documentation (log-books) are managed by a state-of-art measurement and visualization system. The safety parameters are monitored by an overall safety system. For data treatment the test results are transferred to a central test data management system. The maintenance of the system will be performed online via internal link by the industrial subcontractor.

Test complex P 3. In 2000 ESA/CNES decided to run-up and modify the P 3.2 Test facility for development tests of the Vinci thrust chamber (Fig. 22).

Three different types of test were required:

- Injector spray-test with LN2.
- LH2-Cold-Flow tests of the regenerative part of combustion chamber.
- Ignition and ramp-up tests; the ignition shall be performed by 60 mbar ambient pressure.

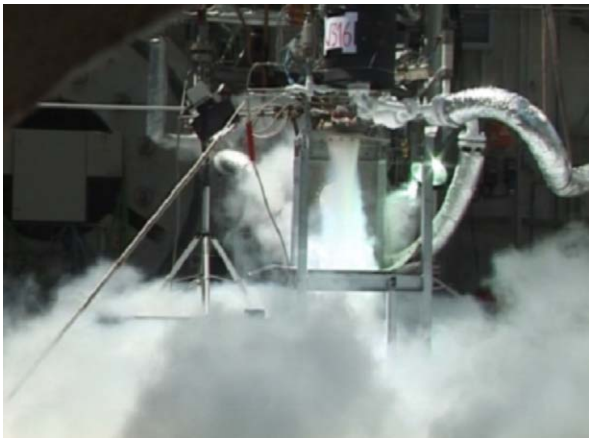

Fig. 23. Injector spray test with LN2.

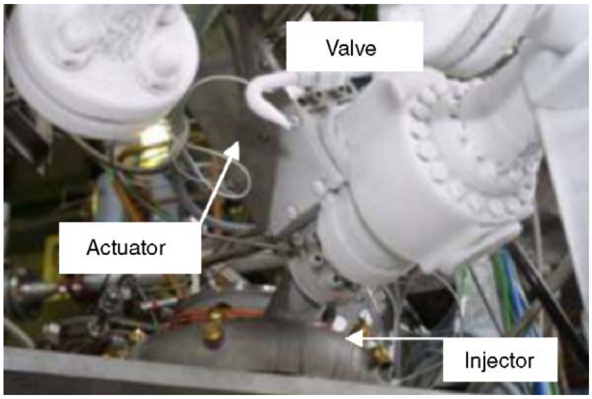

Fig. 24. EADS-ST motor driven valve used for test purposes.

A re-set to operational conditions as well as a detailed inspection was necessary. The run-in of the 30 m^3 low pressure (10 bar) LOX storage tank with LN2 was combined with the LN2 spray tests for budgetary reasons.

Inspector spray tests. In order to optimise the ignition sequence the spray pattern was observed via high-speed-video-cam. This allows the visual detection of the first flowing elements. The tests were performed in different directions, down stream flow (as shown in Fig. 23), horizontal flow as well as horizontal with 180° turned entrance flange, in order to understand the gravity impact of the creation of the build-up flow pattern.

The original thrust chamber valves were not available at that time. In order to simulate the required opening characteristics the engineering team adapted the R&D funded EADS-ST motor driven valve with an off-the shelf linear electrical actuator. In total 5000 cycles in cold and ambient conditions were performed, without damages. The opening of the valve is computer controlled, in order to fulfil the opening characteristic (Fig. 24).

LH2-Cold-flow tests of the regenerative part of combustion chamber. The objective to identify the heat flux into the hydrogen-flow is necessary to adjust the engine start-up, because the complete combustion chamber has ambient temperature at the beginning. The challenge was to measure the flow at the end of the cooling circuit of the combustion chamber (Fig. 25).

With the help of the available motor driven valve the back pressure was adjusted to simulate the correct pressure and flow in the cooling circuit. In addition a heat exchanger was installed to warm-up the specimen. This was necessary to reduce the warming- up time of the CC in between test. The flow determination was performed by a mass flow measurement based on heat-wire technology. The mass flow measurement was performed in one-phase flow (gas). Therefore the flow was heated up prior measurement (Fig. 26).

Fig. 25. Test set-up of Vinci CC for LH2 Flow tests.

Several tests at different entrance and temperature conditions were performed for the design of the engine start-up sequence (“to-high-performance”- during start-up of the turbines due to high-flow-performance of the “warmed-up” hydrogen). The flow of the LH2 is in combustion flow direction (Fig. 26).

Ignition tests under vacuum conditions and ramp-up tests. A trade-off was performed of different concepts to ensure the vacuum during ignition. The selected solution is based on:

- thrust-chamber mounted outside the vacuum capsule,
- capsule closed by a simple lid (bumped-boiler head),

Fig. 26. Heat-wire-measurement, prior to the system the motor driven valve with battleship-actuator.

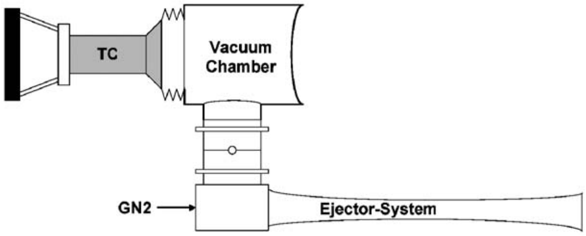

Fig. 27. Vacuum concept.

- GN2-ejector fed by HP GN2 shall ensure the vacuum,
- installation in the centre of the test-cell (originally HM 60 test position).

The selected concept is given in the following (Fig. 27).

This concept allows in addition the observation of the hardware during the test. During test preparation, the capsule will be closed by the simple designed lid. Feedline pre-cooling as well as temperature and pressure condition will be adjusted by the automatic sequence and control loops. Prior to the opening of the main TC valves (Fig. 24), the GN2 ejector starts. A "clap-valve" between the ejector-system and the capsule will be opened and the vac. Pressure is present in the capsule as well as in the TC up to the main TC valves.

During the hot-firing, the pressure in the capsule will reach ambient conditions and the lid will move and open the capsule for test continuation under sea level conditions (Fig. 28).

A comparison between predicted vacuum pressure in zero-flow conditions and with mass flows resulting from pre-H2-Flow, purging, etc. prior to the ignition were performed and the predicted data from the engineering phase were confirmed by tests results.

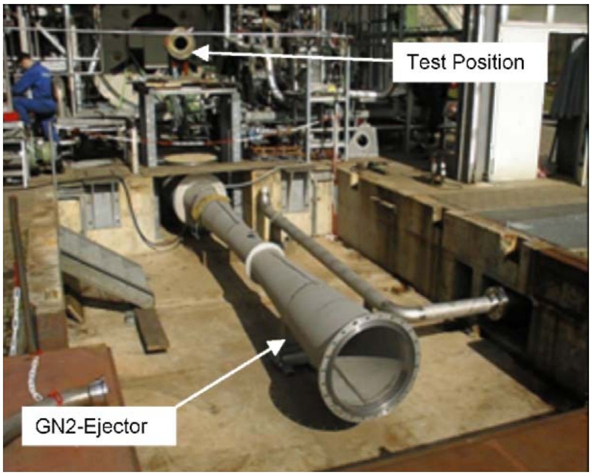

Fig. 28. GN2-Ejector arrangement.

Fig. 29. Hot firing of the Vinci thrust chamber.

Beginning with pure ignition tests the chamber pressure was successively increased up to nom. operational conditions.

Fig. 29 shows the Vinci TC in hot-firing conditions during start up.

5. Conclusion and outlook

An overview of hot-test facility know how is presented at the EADS-ST location in Lampoldshausen. With the decision of EADS to concentrate all hot-firing activities at one location, synergy effects were used to increase the competitiveness for both the commercial market as well as the launcher propulsion agency market. The engineering and test team at Lampoldshausen has demonstrated with adequate engineering solutions on one hand, the fulfilment of the test requirements on the other hand to stay within the very limited budget. In addition, cost savings were gained due to the flexible arrangement of the complete test team.

Next steps will be to use the generated know-how especially in MCR Systems for the launcher propulsion complexes P 2 and P 3 in order to come at the end for all test complexes to a harmonized system.

For future planned development programs the test site Lampoldshausen is well prepared. In the area of the P 3 complex all major subsystems of the P 59 test facility from OTN are integral parts of the test area. With simple adaptations HM7 Engine/thrust-chamber test could be performed in order to use as much as possible the stage propellant residuals. In addition the P 59.3 TPLOX test-facility subsystems are available and could be re-installed e.g. Ariane 5 follow on programmes.

Components and subsystems of the F3 Air-breathing facility are also located at the P 3 area in Lampoldshausen, and could be re-installed in the case of set up a development program based on air breathing propulsion for Launch vehicles in Europe.

Especially the P 2 test facility complex shows a high potential to be adapted for LOX/hydrocarbon investigations. The safety and neutralisation systems will prevent high investments for Europe.

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