

# Test facilities for VINCI®

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**Abstract** With the replacement of the current upper-stage ESC-A of the Ariane 5 launcher by an enhanced cryogenic upper-stage, ESA's Ariane 5 Midterm Evolution (A5-ME) program aims to raise the launcher's payload capacity in geostationary transfer orbit from 10 to 12 tons, an increase of 20 %. Increasing the in-orbit delivery capability of the A5-ME launcher requires a versatile, high-performance, evolved cryogenic upper-stage engine suitable for delivering multiple payloads to all kinds of orbits, ranging from low earth orbit to geostationary transfer orbit with increased perigee. In order to meet these requirements the re-ignitable liquid oxygen/liquid hydrogen expander cycle engine VINCI® currently under development is designated to power the future upper stage, featuring a design performance of 180 kN of thrust and 464 s of specific impulse. Since 2010 development tests for the VINCI® engine have been conducted at the test benches P3.2 and P4.1 at DLR test site in Lampoldshausen under the ESA A5-ME program. For the VINCI® combustion chamber development the P3.2 test facility is used, which is the only European thrust chamber test facility. Originally erected for the development of the thrust chamber of the Vulcain engine, in 2003 the test facility was modified that today it is able to simulate vacuum conditions for the ignition and startup of the VINCI® combustion chamber. To maintain the test operations under vacuum conditions over an entire mission life of the VINCI® engine, including

re-ignition following long and short coasting phases, between 2000 and 2005 the test facility P4.1 was completely rebuilt into a new high-altitude simulation facility. During the past two P4.1 test campaigns in 2010 and 2011 a series of important milestones were reached in the development of the VINCI® engine. In preparation for future activities within the frame of ESA's A5-ME program DLR has already started the engineering of a stage test facility for the prospective upper stage. The new test facility P5.2 is to perform the qualification of the anticipated upper stage with the VINCI® engine. In the past year DLR has started the design phase for these modifications. The main design drivers are the test configuration and operation domain described in the test request.

**Keywords** Ariane 5 Midterm Evolution (A5-ME) program · High-performance cryogenic upper-stage engine · Re-ignitable liquid oxygen/liquid hydrogen expander cycle rocket engine · Test Facilities · DLR Lampoldshausen

## Abbreviations

A5-ME	Ariane 5 Midterm Evolution
CdCF	Cahier des charges fonctionnelles—functional requirements document
CGRS	Cold gas reaction control system
EBS	Equipment bay structure
EGSE	Electric ground support equipment
EPC	Étage principal cryotechnique—cryogenic main stage
ESC	Étage supérieur cryotechnique—cryogenic upper stage
GTO	Geostationary transfer orbit
GTO+	Geostationary transfer orbit with increased perigee
HGRS	Hot gas reaction control system

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ISS	Inter stage skirt
JAVE	Jupe avant équipée—equipped front skirt
LEO	Low earth orbit
LSCR	Launch system concept review
LSPDR	Launch system preliminary design review
M	Mise au point—run-in firing test
MCC	Measurement, command and control system
MR	Maquette remplissage—fill-in mock-up
NA	Not applicable
NE	Nozzle extension
OBC	On-board computer
PDR	Preliminary design review
CDR	Critical design review
Q	Qualification (firing test)
SCAR	Système de contrôle d'attitude et roulis—roll and attitude control system
SCATE	Système de contrôle, d'attitude et de tassement d'ergols—control, attitude and propellant settling system
SEL	Système électrique et logiciel
SSD	Supersonic diffuser
TBC	To be clarified
U/S	Upper stage
W/O	Without

## 1 Introduction

At present and in the near future Lampoldshausen is dedicated to supporting Europe's Ariane 5 ME program [1]: the development of the new upper stage with the 180 kN, re-ignitable engine VINCI<sup>®</sup>. This engine is tested on the P4.1 test bed. High-altitude testing represents a major core competence in Lampoldshausen.

For risk mitigation the rocket propulsion systems have to be qualified close to the operational conditions and flight loads. The verification of the functional parameters of the operation and the performance is necessary for the prediction of the mission parameters. Special demands are imposed by the flight environmental conditions, the ground operations and the mission requirements.

With its engineering and operations departments on the one hand and the research departments on the other hand, the Institute of Space Propulsion is a unique place which delivers results from the early stages of a development project all the way to qualification of the final product: a qualified rocket engine.

In this context, the P3.2 facility for combustion chamber testing and P4.1 for high-altitude testing are presented. Furthermore, basics for the new P5.2 facility for stage

testing are summarized also. A status report of the results is included.

## 2 VINCI<sup>®</sup> engine

The VINCI<sup>®</sup> engine is developed by Snecma (Safran group). Its architecture is characterized by four sophisticated features [2]:

- Full expander cycle

Unlike traditional pump-fed cryogenic engines, the VINCI<sup>®</sup> expander cycle engine does not need a gas generator to drive the two turbo-pumps for both of its propellants, liquid hydrogen (LH<sub>2</sub>) and liquid oxygen (LOX). Instead, hydrogen, which is also used as the engine coolant, after leaving the combustion chamber's regenerative cooling circuit, is fed to the turbines that drive the propellant pumps. Downstream of the turbines the hydrogen is injected into the combustion chamber. In this closed engine cycle the enthalpy gain of the hydrogen flow, achieved by the heat transfer from the hot combustion gas flow to the coolant flow through the chamber's high aspect ratio cooling channels, is exploited to provide the turbine power.

- High-performance LH<sub>2</sub> and LOX turbo-pumps

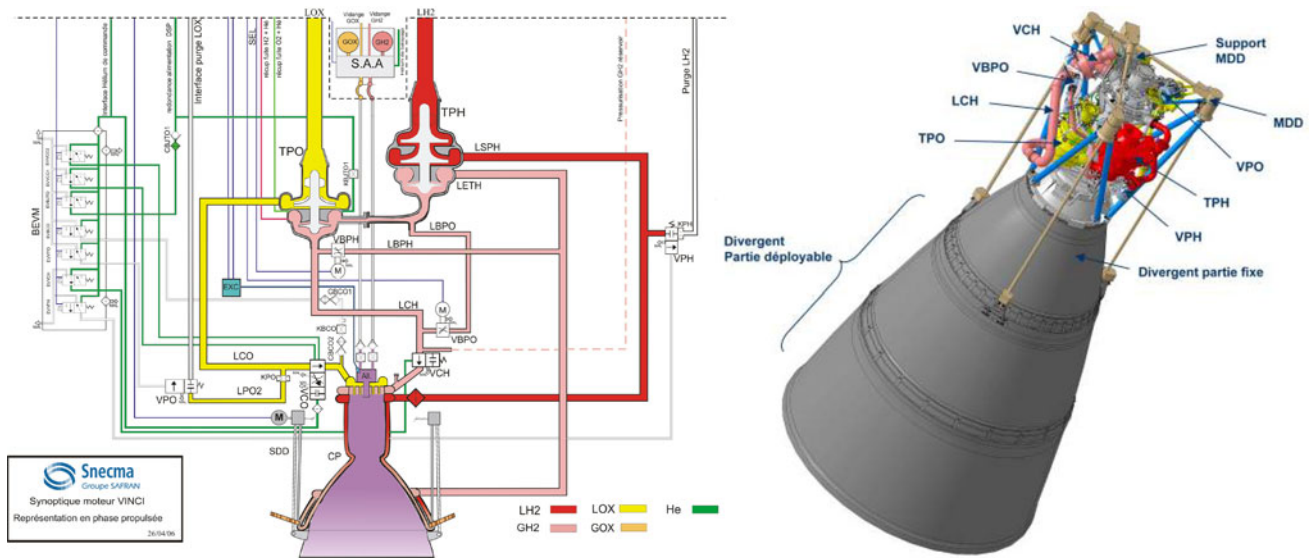
The engine has two separate turbo-pumps mounted close to one another in a "power pack" kit. Turbines are set "in serial", and a set of two by-pass valves adjusts their flow rates as shown on Fig. 1. This set allows tuning the engine operating point, in terms of thrust (VBPH) and mixture ratio (VBPO). Both turbo-pumps have integral inducers, which lead to low NPSP with the objective to avoid the use of boost pump.

- Re-ignition system

A H<sub>2</sub>/O<sub>2</sub> gas fed torch, electrically initiated by a spark system, is used for engine ignition. This igniter is fed by gaseous oxygen and hydrogen contained in high-pressure bottles operating in a blow down mode, allowing multiple engine ignitions during the stage's flight which are necessary for re-start capability.

- Deployable composite nozzle

The nozzle is composed of a fixed part attached to the combustion chamber and a deployable part stowed around the upper part of the engine during the first stage flight. After stage separation the extendable nozzle is deployed into its operational position illustrated in Fig. 1. This allows the use of a large area ratio nozzle extension for maximum engine efficiency with minimum stage length, interstage skirt length and associated mass saving. Both the



**Fig. 1** VINCI® engine flow scheme (*left*) and mock-up (*right*), courtesy of SAFRAN

fixed and extendable nozzle sections are made from a ceramic material and supplied by Herakles.

### 2.1 Reference operation point

The VINCI® engine is designed to operate in a domain centered on a nominal thrust equal to 180 kN and the mixture range 5.7/5.9.

One major axis of the engine maturity demonstration program is the assessment of the re-start capability under near-vacuum condition. This function leads to place a strong focus on the igniter, the thermal control of the engine and the behavior of propellants in vacuum. The engine hot firing tests are performed at DLR P4.1 test facility. In complement to the engine testing, sub-system testing, such as full-scale combustion chamber tests, has been performed at the DLR P3.2 test facility, that just as the P4.1 test facility is located at the test site in Lampoldshausen, to carry out activities for system modeling and improvement of the design concept [3, 4].

## 3 VINCI® combustion chamber tests at P3.2 test facility

For detailed investigations into individual components, dynamic and thermal testing of the full-scale sub-systems has been conducted at P3.2.

In 2010 a dedicated combustion chamber test campaign has been performed to provide detailed knowledge of the regenerative cooling circuit temperatures and flow conditions as well as of wall heat fluxes and wall temperatures [5]. The tests have been accompanied by exhaustive CFD

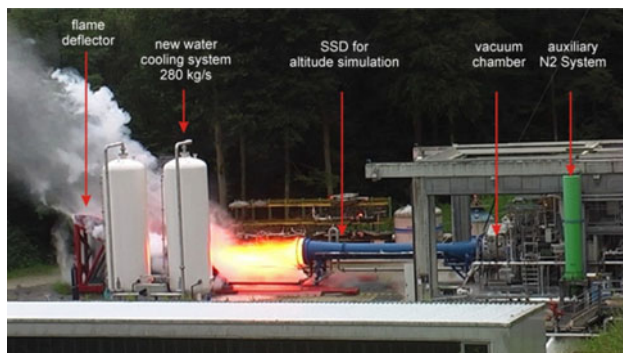
modeling for an in-depth characterization of the hydrogen expander cycle combustion chamber.

### 3.1 Test bench modifications

The P3.2 is a high-pressure thrust chamber test bench that was originally erected for the development of the thrust chamber of the Vulcain engine. It was designed for providing the Vulcain thrust chamber with the necessary propellants at the required injection pressures. In the recent years the test facility P3.2 was modified to develop the thrust chamber of the VINCI® engine that uses the same propellants LH<sub>2</sub> and LOX as the Vulcain engine. For the VINCI® engine they are supplied to the combustion chamber at about 230 bars (LH<sub>2</sub>) 80 bars (LOX), enabling test operations at more than 10 tons of thrust for up to about 60 s at the P3.2.

The propellant supply system consists of vacuum-insulated run tanks with corresponding feed lines and a pressurisation system. Volumes and pressures amount to 4.5 m<sup>3</sup> at 350 bars for the oxygen tank and 12 m<sup>3</sup> at 400 bars for the hydrogen tank. The vacuum-insulated feed lines to the combustion chamber in the test cell are also rated for these pressure ranges.

The required flow rate and injection pressure are achieved by pressurising these run tanks with gaseous hydrogen or gaseous nitrogen. The pressure is adjusted by a control computer. The pressurising gas is taken from high-pressure bottles each of which holds 15 m<sup>3</sup> and can be charged up to 800 bars from the central gas supply. The propellant storage tanks are located at the test facility itself and can be directly re-filled by tanker trucks. The available capacities are 30 m<sup>3</sup> for LH<sub>2</sub> and 30 m<sup>3</sup> for LOX. The run



**Fig. 2** VINCI® thrust chamber test with P3.2 configuration for full altitude simulation (courtesy astrium)

tanks are filled from these storage tanks via transfer pipes by means of low-level pressurization of the storage tanks [6].

The test cell of P3.2 is erected behind a solid concrete wall to protect the supply systems. The test cell accommodates the interfaces for supply lines to the combustion chamber together with the thrust stand for the horizontal installation of the combustion chamber. At the outlet a vacuum chamber, an ejector and an exhaust jet guiding system are installed. The vacuum and exhaust system are cooled with water which is supplied from a water tower located directly adjacent to the P3.2 test cell.

After completion of the modifications of the P3.2 test facility, today it is able to simulate vacuum conditions for the ignition and start-up of the VINCI® thrust chamber. The vacuum system is closed during ignition by a cover which is designed to be blown away when the start-up pressure of the thrust chamber reaches a certain level. Then an ejector keeps the conditions in the vacuum chamber at a level of about 200 mbar for the remainder of the hot fire test.

During the 2010 test campaign 16 hot firing tests have been successfully performed at the P3.2 test bench, improving the understanding and the mastering of the VINCI® thrust chamber behavior. Figure 2 shows a snapshot from a video recorded in one of these tests.

#### 4 VINCI® engine tests at P4.1 test facility

In the M3 and M4 VINCI® engine test campaigns which took place in 2010 and 2011, for the first time tests with the new extendable composite nozzle were performed, including its complete deployment. The first hot fire testing of the complete deployed nozzle extension was successfully performed with the nozzle withstanding temperatures of more than 1,600 °C. Additionally, the VINCI® engine was re-ignited successfully under vacuum

conditions subsequent to the simulation of long and short coasting phases.

Eleven firing tests were performed with the M3 engine in 2010 and six with the M4 engine in 2011. The entire test duration during the campaign with the M3 VINCI® engine totalled to 6,286 s which is equivalent to nine flight durations. During both test campaigns in the 2010–2011 period the following main objectives have been demonstrated [5, 7]:

- to cover the operating domain with margin tests beyond the flight domain, e.g. first tests with engine throttling down to 30 kN
- to operate at inlet thermodynamic conditions representative of the future upper stage, e.g. operations with sub-cooled LOX
- to test design modifications of sub-systems as, e.g. fuel turbo-pump, turbine by-pass valves, thrust chamber, etc., which provide increased performance and reliability

In July 2012 the M4R VINCI® engine campaign has started [7]. In this ongoing test campaign the necessary engine operations to be compliant with the Ariane 5 Mid-term Evolution (A5-ME) requirements will be tested:

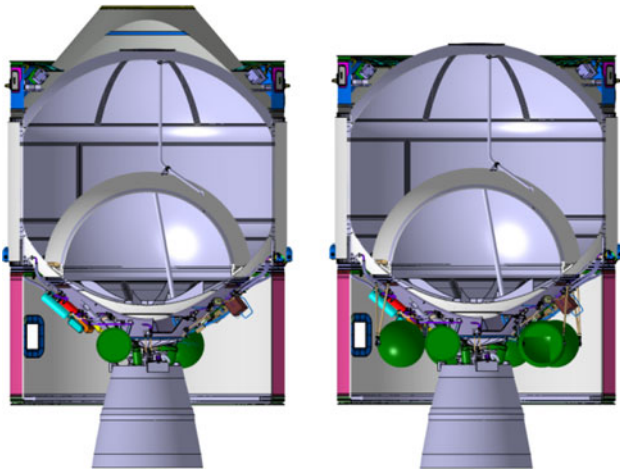
- operation at reduced thrust level (130 kN)
- operation under idle mode, i.e. with out (w/o) rotation of the turbo-pumps, for de-orbitation

#### 5 Stage tests at P5.2 test facility

For the purpose of stage level testing of the complete new upper stage (U/S) including firing stage tests with the VINCI® engine the infra-structure of the P5 test facility is designated to be extended for the erection of a new test facility, the so-called P5.2. The mission of the test bench is to ensure the development and the qualification tests of the U/S equipped with the VINCI® engine and the ground umbilical (electrical, fluidic). This section presents the necessary requirements which the test bench will have to meet to fulfill this mission. Figure 8 in the “Appendix” shows the design of the new U/S in several configurations that are dimensioned according to the type of mission: the geostationary transfer orbit (GTO) mission with and without direct de-orbiting, the low earth orbit (LEO) mission (ATV to inter stage skirt, ISS) and the GTO/geostationary transfer orbit with increased perigee (GTO+) mission.

##### 5.1 A5-ME U/S configuration

During the launch system concept review (LSCR) and launch system preliminary design review (LSPDR) the so-



**Fig. 3** New cryogenic upper stage for both GTO and LEO missions (courtesy astrium)

called B5-H28 configuration of the new U/S (see Fig. 3) has been confirmed as the reference configuration, featuring a propellant tank with a common bulkhead.

## 5.2 Test scenario

The A5-ME U/S test logic is associated to maquette remplissage—fill-in mock-up (MR), Mise au point—run-in firing test (M) and Qualification (firing test) (Q) tests as follows:

- performance of a MR test campaign mainly dedicated to the tank and thermal topics and integrating additional test objectives w/o hot firing
- performance of M and Q test campaigns mainly dedicated to the validation and qualification of the U/S with hot firing

The MR campaign comprises two test configurations:

- Configuration 1: ground and EPC flight phase
- U/S including Jupe avant équipée—equipped front skirt (JAVE), ISS and cold EPC dome
- Configuration 2: U/S ballistic flight (coasting) phase w/o engine firing
- U/S after stage separation with nozzle extension (NE) for deployment in cold condition

The M and Q campaigns include only one test configuration:

- U/S flight phase with engine firing
- U/S after stage separation w/o NE for operating in hot-firing conditions

The general logic of the tests is depicted in Table 3 in the “Appendix”.

The baseline for the test monitoring in the MR, M and Q campaigns, at least for all test configurations in which the flight phases of the U/S are simulated, consists in using the on-board computer (OBC). Especially during the flight phases with the U/S operating in hot-firing conditions, i.e. in the M and Q campaigns, the on-board avionics shall be used to activate and control the VINCI® engine firing sequences.

## 5.3 Test facility configuration

The basis configuration of the test facility for the stage level testing of the A5-ME U/S including tests with ignition/firing of the VINCI® engine is

- sea level test bench:
- 1st VINCI® ignition under vacuum conditions (<60 mbar)
- VINCI® re-ignitions and steady-state firing at sea level conditions
- Purge lines will be under vacuum condition during engine chill-down phase (200 mbar during 30 min)
- Cold gas reaction control system (CGRS) exhaust will be in vacuum condition (200 mbar for 3 h 40 min)

At sea level conditions, the thermal impact of the nozzle radiation on the U/S (e.g. heat flux input on the propellant tanks, the He vessels, etc.) is not representative with respect to the thermal status of the VINCI® engine for re-ignition at flight conditions. Instead, the nozzle radiation under vacuum will be measured during VINCI® tests at the P4.1 test facility. Thus, the stage tests at P5.2 test facility serve for the validation of the thermal model with respect to the thermal influence on stage components.

The CGRS and the Hot Gas Reaction System (HGRS) are sub-systems of the Système de contrôle, d’attitude et de tassement d’ergols, Attitude Control and Propellant Settling System (SCATE) that serves to perform the cryogenic propellant management. While for the HGRS a new green rocket propulsion system with H<sub>2</sub>O<sub>2</sub> as monopropellant is investigated [7], the CGRS is derived from the existing Système de contrôle d’attitude et roulis—roll and attitude control system (SCAR) presently used for ESC-A. At the P5.2 test facility no firing testing of the HGRS is foreseen. Test objectives are limited to the thermal control concept and validation of the thermal model. The validation of the CGRS is foreseen as a passenger test during steady-state firing of the VINCI® engine. The objective is to validate the impact on the engine and on the H<sub>2</sub> pressurization system when the CGRS is active. This test objective has a great influence on the test facility design, since an own exhaust system is required to provide vacuum conditions for the CGRS.



#### 5.4 Test bench design

According to the upper stage life phases, tests objectives were defined and dispatched between the three test campaigns mentioned in Sect. 5.2. From these test objectives that are specified in the functional requirements document (Cahier des charges fonctionnelles, CdCF) a set of test bench functions was derived, representing the necessary support of the test facility to fulfill the test objectives, as, e.g. functions to withstand or to comply with the external interfaces and environment:

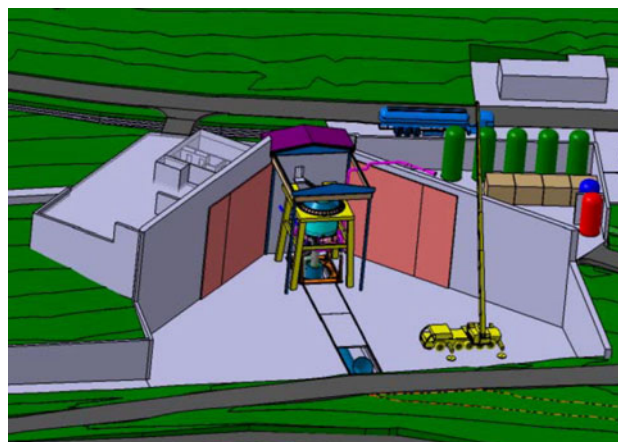
- Accommodation and keeping of test items
- Access, storage and handling of test items
- Ground interfaces
- Test items environment
- Power supply, Propellant supply and management
- Pressurant/conditioning/flushing fluid supply and management
- Exhaust fluid management
- Test run control and monitoring
- Data acquisition, treatment and recording
- Test safety management

Since the OBC shall be used for the test run control and monitoring (see Sect. 5.2) it controls the operation of the U/S on-board electrical system (Système électrique et logiciel, SEL). Astrium will develop the electric ground support equipment (EGSE) system which is the interface between the SEL and the test facility measurement, command and control system (MCC) system provided from DLR. The combination of the Astrium EGSE and the DLR MCC is required for the following:

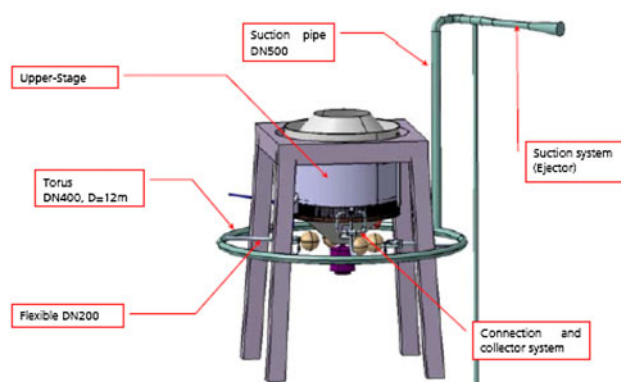
- Ground power provision and on-board batteries replacement
- Avionics MIL 1553 bus control, avionics equipments commanding, thrust vector control
- Software loading to and configuration of on-board electrical equipments
- Data acquisition and archiving of standard on-board sensors

The acceptance tests of the EGSE are to be conducted at Astrium Bremen, using a mock-up of the U/S SEL for the electrical and mechanical validations during stage integration. After its successful pre-validation in the stage tests at the P5.2 test facility, potentially further use of the ESGE be made at the Ariane 5 launch pad ELA3 at the Centre Spatial Guyanais (CSG).

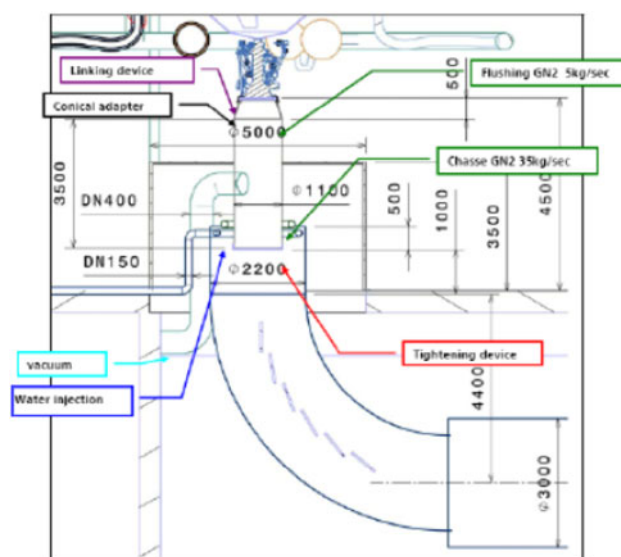
With regard to the aforementioned functions as the main design drivers of the test bench a preliminary design study has been elaborated for the preliminary design review (PDR), which was held at the end of 2011. Figure 4 shows a CAD drawing of the P5.2 test facility.



**Fig. 4** 3-D drawing of the U/S integration in the P5.2 test facility [8]



**Fig. 5** Exhaust system for the CGRS [8]



**Fig. 6** Exhaust system for the VINCI® engine [8]

This design concept includes two exhaust systems: one for the CGRS (see Fig. 5) and one for the VINCI® engine (see Fig. 6).

The new P5.2 test bench is located between the existing test facilities P5 and P6. The P5.2 building has a width of 14 m and a height of 32 m of which 20 m are above and 12 m below the ground. The bench location enables to recover some important functions from the P5 infrastructure. Thus, the P5.2 test bench will be an extension of the test facility P5 to reuse existing equipment as in particular:

- Cryogenic, gase and water supply from dedicated LOX/LH<sub>2</sub> tanks and gas/water storage capacities at P5
- Central Measurement, Command and Control (MCC) system located at P5 control room and its associated systems (cabling, main computer, ...)

In order to protect the surrounding P5 installations against the impact of blast waves originating from the P5.2 the DLR performed safety studies. These studies make the assumption that the yield of a LH<sub>2</sub>/LOX reaction is 20 % (called 20 % TNT equivalent method). Its results justify the P5.2 location at 100 m from the P5, where the blast wave pressure will be around 100 mbar. No protections are considered yet for the test facility P6 inside the 100-m blast wave radius around the P5.2. Figure 7 shows the test bench location which was selected as the best compromise considering the safety requirements and the space available at the DLR test site in Lampoldshausen.

### 5.5 Test operation domain

The P5.2 test facility has to cover the whole operation domain of the A5-ME U/S. In order to provide the aspired versatility of A5-ME its U/S shall be capable to deliver payloads not only in GTO but also in GTO+. Therefore, the stage's operation domain is divided into the GTO flight domain and the GTO extreme domain. In order to provide the mission flexibility for delivering multiple payloads to all kinds of orbits the thrust of the VINCI® engine must be adjustable over a wide range. Therefore, the VINCI® shall

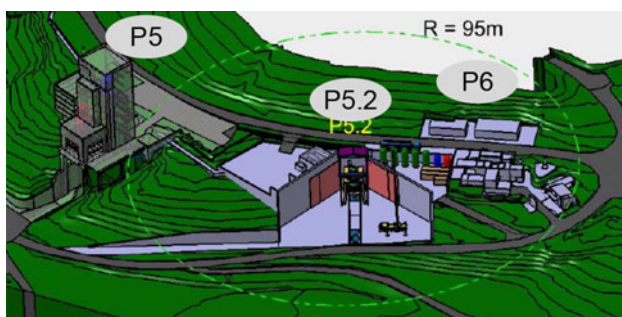


Fig. 7 Test bench location [8]

be operated at 100 % thrust (180 kN) and in a reduced thrust domain (see Table 3).

In order to optimize the performance of the U/S with respect to de-orbitation the operation of the VINCI® engine under idle mode is under investigation, extending the operation domain that needs to be covered by the test facility, to the lowest possible margin.

### 5.6 Test bench requirements

In the CdCF a group of requirements is defined, including

- General requirements, e.g. bench geometry, test rig, test sequence and duration, fluid storages, etc.
- Operational requirements, e.g. availability, test frequency, reduced thrust, etc.
- Interface requirements, e.g. mechanical, fluid and electrical interfaces
- Hardware environment, e.g. atmospheric, thermal and electromagnetic environment, vacuum simulation, etc.
- Adjacent structures, e.g. the EPC LOX bulkhead
- Control and measurements, e.g. transducer type, number of measurement chains, sampling rate, acquisition system, etc.

For instance, the geometry of the bench shall be compatible with the hardware length, which is given in the drawings in the CdCF. On the respective drawings also the mechanical interface of the device used for the self-supporting of the stage can be located, which must be ensured by the bench. For the ground tests the interface will be the lower flange of the JAVE. For the hot firing tests the interface will be either the upper flange of the equipment bay structure (EBS) or the lower flange of the lower skirt (see Fig. 8 in the “Appendix”).

The fluid interfaces (I/F) are given in the flow scheme of the U/S that is also provided in the CdCF. They include the fill and drain coupling plates for O<sub>2</sub> and for H<sub>2</sub> as well as the respective purging connectors for both fluids. The functions of this hardware are, e.g.

- to fill and to degas the LOX tank and the LH<sub>2</sub> tank
- to pressurize both propellant tanks with ground helium
- to evacuate the engine fluids during chill down and to evacuate the tank degassing
- to manage tank pressure in case on coupling plate failure or emergency deloading

In the CdCF the fluid conditions at all fluid interfaces are defined by a set of temperature, pressure and mass flow rate criteria. As an example, the criteria for the tank filling are given in Tables 1 and 2.

The bench shall control the interface pressure during the phases of loading (at an accuracy of  $\pm 0.2$  bar) and also the interface temperature, which will have to be maintained

**Table 1** Filling of the LOX tank

Criteria of filling	Requirement
Filling temperature range (K)	$T < 92$
Filling pressure range (bar)	$1 < P < 5$
Filling mass flow range (l/s)	$0.5 < Q < 6.0^a$

<sup>a</sup> In relation to the height of liquid in the tank or to the instant of loading, the mass flow rate evolves; so the bench shall allow to change instantaneously the mass flow rate over a wide range

**Table 2** Filling of the LH<sub>2</sub> tank

Criteria of filling	Requirement
Filling temperature range (K)	$20 < T < 21$
Filling pressure range (bar)	$1 < P < 5$
Filling mass flow range (l/s)	$1 < Q < 15^a$

<sup>a</sup> In relation to the height of liquid in the tank or to the instant of loading, the mass flow rate evolves; so the bench shall allow to change instantaneously the mass flow rate over a wide range

during the loading in a range of  $\pm 0.5$  K on the LOX and  $\pm 0.2$  K on the LH<sub>2</sub> side, respectively.

Further fluid interfaces have to be provided for the HGRS and for the CGRS of the SCATE as well as for the umbilical to the EBS and the EPC dome. For the installation validation of the test facility different mock-ups of certain stage components will be used. The DLR will build wooden mock-ups of the structures bearing the mechanical and fluid interfaces.

The bench's compatibility to the requested reduced thrust domain from 50 to 200 kN is presently being investigated in a dedicated DLR study to decide about the use and the design of a supersonic diffuser (SSD). Thus, the performance of the P5.2 test bench with respect to the engine operating domain tested in the M and Q campaigns is yet to be clarified (TBC). On the other hand, regarding its performance with respect to the control and measurement

capabilities, Table 4 in the "Appendix" gives a first overview of the amount of channels needed for the M/Q campaigns, even so their type, number and sampling rate might evolve during the U/S development. The measurements were counted taking into account forecasts from stage and engine equipment.

## 6 Summary, conclusion and outlook

All requirements for the erection of the P5.2 test facility were cleared to proceed with the critical design review (CDR) phase. The CDR will be completed by summer 2013 to assure the availability of the bench in 2015.

The P5 and the P5.2 will have major equipments in common (MCC, LOX and LH<sub>2</sub> tanks, etc.). The operations on these two benches will have to be diligently managed to avoid unexpected interactions from a bench towards the other. Concerning the P5 MCC specific tools have to be developed to check the status of the test bench after a configuration change (P5 → P5.2 or P5.2 → P5).

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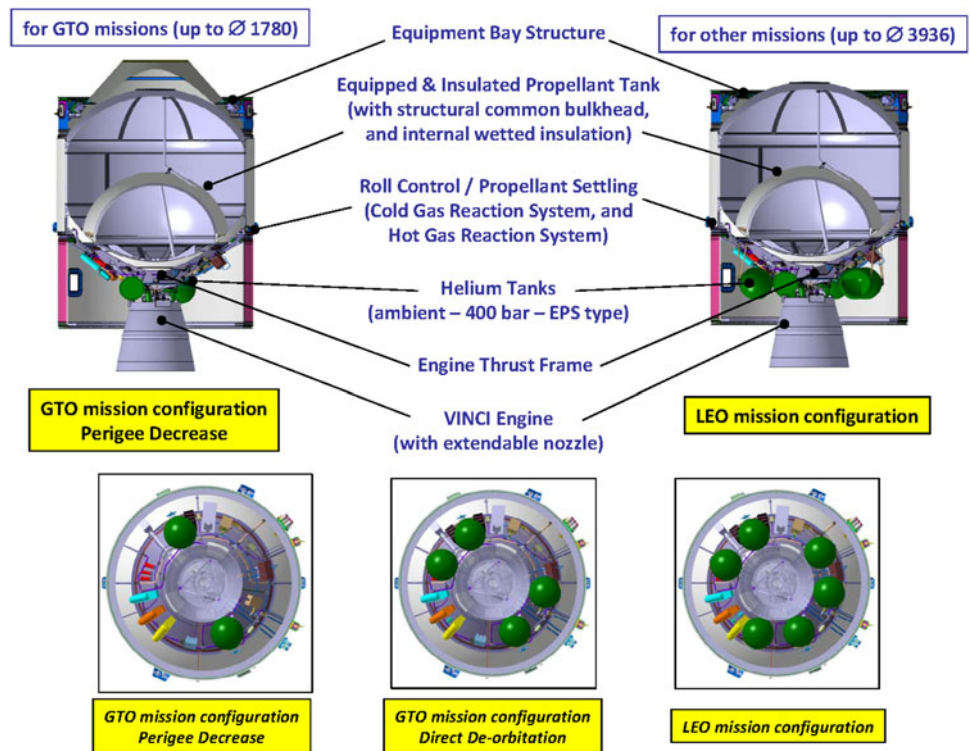
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## Appendix

See Fig. 8; Tables 3 and 4.



**Fig. 8** New U/S design for GTO and LEO mission configuration (courtesy astrium)



**Table 3** General test logic of the stage level tests for the U/S equipped with the VINCI® engine (courtesy astrium)

	MR		M		Q
Type of test	Development		Development		Qualification
Test bench configuration	Vertical		Vertical		Vertical
Test hardware configuration	Complete upper stage including ISS with JAVE and cold EPC dome	Complete upper stage after separation	Complete upper stage after separation		Complete upper stage after separation
Engine configuration	Engine with stowed nozzle	Engine with nozzle for deployment	Engine with no nozzle extension		Engine with no nozzle extension
Requirement for specific tooling	Closed EBS cavity	Anti-gravity tool <sup>a</sup>	Firing condition		Firing condition
Vacuum requests	No	No	VINCI® thrust chamber under vacuum for the 1st ignition Re-ignition under sea level conditions Vacuum in collecting lines (purge, discharge, CGRS)		VINCI® thrust chamber under vacuum for the 1st ignition Re-ignition under sea level conditions Vacuum in collecting lines (purge, discharge, CGRS)
Maximum duration with firing engine					
100 % thrust	NA	NA	800 s		800 s
Reduced thrust	NA	NA	Thrust domain 50–200 kN Duration TBC		Thrust domain 50–200 kN Duration TBC
Number of ignitions	NA	NA	3 TBC		3 TBC
Piloting with flight actuators	No	Yes TBC	Yes TBC		Yes TBC

<sup>a</sup> Anti-gravity tool is a specific device to allow nozzle extension deployment under 1 g condition (compensation of the nozzle weight)

**Table 4** List of control and measurements based on forecasts from stage and engine equipment (courtesy astrium)

Type of transducer	Number of measurements	Sampling HF/LF	Acquisition via	
			OBC	MCC
Stage Mechanics and POGO needs				
Vibration	~ 50 (triaxis)	>400 Hz		×
Dynamic pressure	~ 10	>400 Hz		×
Static pressure	~ 10	>10 Hz		×
Strain gauges	~ 20	tbd		×
Stage thermal needs				
Thermocouples	84	LF (1 Hz tbc)		×
Thermocouples	30	LF (1 Hz tbc)	×	
System thermal needs				
Thermocouples	205	LF (1 Hz tbc)		×
Thermocouples	25	LF (1 Hz tbc)	×	
Engine and FPS needs (excluding LOX and LH <sub>2</sub> reservoir)				
Pressure, thermos, strain gauge, valve status	37	tbd		×
Pressure, thermos, strain gauge, valve status	229	tbd	×	
Total	700			

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