IAC-11-D2.3.4

VENUS - CONCEPTUAL DESIGN FOR VEGA NEW UPPER STAGE

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With the first launch of VEGA approaching, the European launch vehicle family will soon be completed. VEGA aims at transporting small research- and earth observation satellites to Low Earth Orbit (LEO).

Ongoing investigations show the opportunity for a performance improvement of the launcher to cope with the market demand for evolution in P/L mass. Therefore, studies to enhance the capabilities of the launch vehicle were started.

The German Space Administration (DLR) has funded the VENUS (VEGA New Upper Stage) studies on behalf of the German Federal Ministry of Economics and Technology with Astrium Space Transportation as Prime Contractor and the DLR institute for Space Launcher Systems Analysis (SART) as subcontractor, in order to identify and assess the potential of increasing the upper stage performance. The second slice of the study, the so-called VENUS-2 study (support code FKZ50RL0910), was started in July 2009 and has been finalized mid 2011. VENUS-2 aims at investigating possible evolutions of the VEGA-launcher upper stage. In particular, conceptual lay-outs for new storable propellant upper stages have been investigated including engines.

The VENUS-2 study is divided into three study phases. Phase 1 work was focused on conceiving and analysing different new upper stage architectural concept candidates and selecting reference concepts on the basis of trade-offs and by optimization of overall launcher P/L performance. After this phase the main parameters were frozen. Phase 2 focuses on the Conceptual Design during which dedicated stage mechanical designs and trade offs were conducted, as well as thermal studies on the thermal behaviour of the stages, lay-outs of the functional propulsion systems, propellant and helium budgets on the basis of more detailed analyses, needed electrical interfaces between upper stage and avionics equipment, trade-offs for the separation systems, dedicated designs for the engines AESTUS-2 and BERTA, resulting mass budgets, and adapted launcher performance characteristics in order to update the maximum payload mass. Further, in Phase 3 development logics and plans were established.

In parallel to the study work experimental demonstration on new injector concepts addressing the BERTA engine have been conducted.

I. INTRODUCTION

Background

The VEGA launcher (Figure 1), currently in its final phase of qualification, is a 4-stage single-body vehicle consisting of three solid-rocket motor (SRM) stages (P80, Zefiro-23 and Zefiro-9A) and a liquid-propulsion (UDMH/NTO) upper stage (Attitude Vernier Upper Module, AVUM), with the following main characteristics [1]:

- Height 30 m
- Diameter 3 m
- Liftoff mass 137 tons
- Payload mass 1500 kg (700 km circular polar orbit)

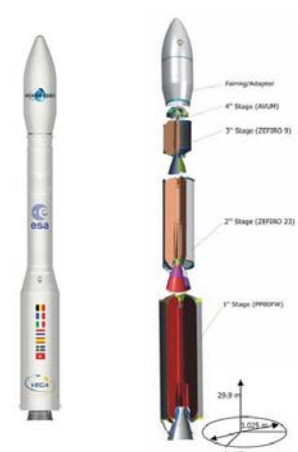


Figure 1: VEGA launcher [1]

Together with Europe's heavy-lift launcher Ariane 5, and the Russian medium-lift launcher Soyuz, VEGA will extend Europe's space-port launcher family with a small launcher which is meant for easy, quick and cheap access to space for small satellites. The first launch is planned for 2011.

However, current investigations show that beyond 2014 a performance improvement of the VEGA launcher is needed in order to be compliant with the evolution demands in P/L mass.

The increase of VEGA launcher payload (P/L) capabilities could be obtained through the use of stages with increased thrust level. Especially the replacement of the 3rd (Z9A solid stage) and 4th (AVUM liquid stage) stages by a new single, more powerful upper stage seems to be very attractive. In order to validate this statement and to quantify the performance increase a German national-study called VENUS (VEGA New Upper Stage) was initiated and funded by the DLR Space Administration with Astrium Space Transportation as Prime Contractor and the DLR institute for Space Launcher Systems Analysis (SART) as subcontractor. The first VENUS study was started in July 2007 and was finalized in November 2008 [2].

Facing interesting results, especially w.r.t. upper stage concepts fed by storable propellants, a second study slice VENUS 2 was initiated.

Scope

The VENUS-2 study comprises the investigation of new upper stage concepts for the VEGA launch vehicle, either in 3-stage or in 4-stage launcher configuration:

- The 3-stage launcher configuration is a VEGA Evolution launcher using the P100 first stage and either a Z30, Z35 or Z40 second stage plus a completely new storable propellant upper stage as third stage with the AESTUS 2 pump-fed engine.
- The 4-stage launcher configuration consists of a P100 first stage, Z23 second stage and Z9A third stage. The fourth stage is equipped with a new low-thrust pressure-fed engine BERTA.

Objectives

The overall main objectives of the VENUS-2 study were to:

- Select the most promising upper stage concept;
- Increase overall payload performance;
- Set-up the development plan for the roadmap to the first qualification flight.

Approach

The VENUS-2 main objectives divide the study into its main three study phases:

- Phase 1 - Conceptual architecture investigation and selection. In this phase initial requirements, parametric ranges and assumptions were defined, various stage architectures were investigated and its parametric influence on driving performance parameters defined. The parametric iteration process towards the main parameter definition (propellant mass, chamber pressure, mass flow rate, mixture ratio, etc.) has been conducted in the DLR Concurrent Engineering Facility in Bremen in order to increase the robustness of the concept consolidation process and to speed it up.
- Phase 2 - Conceptual design. With the most driving and sizing parameters being fixed, in this phase a detailed conceptual lay-out has been conducted. Afterwards, the resulting characteristics were used to update the final payload performance.
- Phase 3 - Development plan, detailing stage and engine related activities.

II. VEGA REFERENCE CONFIGURATION

In order to assess the payload performance improvements brought by the different considered configurations, the performance of the Vega launcher were calculated first with the DLR launcher performance tool TOSCA for the reference orbit: 700x700 km polar orbit (Table 1).

VEGA Configuration	P/L Mass [kg]
P80/Z23/Z9/AVUM	1518
P80/Z23/Z9A/AVUM	1563
P100/Z23/Z9A/AVUM	1720

Table 1: TOSCA results of VEGA reference configurations (700x700 km polar orbit)

The 1518 kg P/L mass for the P80/Z23/Z9/AVUM configuration is very close to the specified 1500 kg [1]. Therefore, these results can be used later on for comparison with the new VENUS-2 configurations.

In order to assess the gain in payload performance resulting from the new storable upper stage designed in this study, the performance of a hypothetic improved version of Vega with the P100 solid rocket motor as first stage has been estimated too.

III. PHASE 1 - VENUS 2 ARCHITECTURE

In this phase different architectures were defined, investigated and selections were performed. A distinction has been made between a 4-stage launcher configuration (exchanging the AVUM upper stage with a VENUS), and even changing to a 3-stage launcher configuration (replacing the 3rd and 4th stage by VENUS and enlarging the 2nd stage). The specific trade-offs that were performed on the architectures are treated in the following.

Propellant

Since for the 3-stage launcher configuration the turbopump engine AESTUS 2 [3] is specified, the MMH/NTO propellant combination was fixed.

For the 4-stage launcher configuration a trade-off has been conducted concerning the storable fuel to be used together with the NTO (N2O4) oxidizer. The study has been accomplished using an Analytical Hierarchy Process taking into account technical and programmatic aspects at engine, stage and launcher level against the background of the expected thrust range of 2-8kN and taking into account regenerative and film cooling within a pressure-fed engine cycle. The strong Astrium MMH heritage has also been taken into account in the trade-off. Further, hydrazine was knocked out because its monergolic dissociation characteristics would impose significant design risks in a regeneratively cooled engine, but has been kept in the trade-off for completeness. In order of trade-off ranking the propellants were:

- MMH (best option),
- UDMH,
- Hydrazine,
- AZ50 (50% Hydrazine, 50% UDMH)

Therefore, also for the 4-stage configuration the MMH/NTO combination has been chosen.

Engine

For the 3-stage launcher configuration the already demonstrated turbopump-fed AESTUS 2 engine [3] is foreseen and for the 4-stage launcher configuration a new pressure-fed engine, called BERTA (Bi-Ergol Raum-Transport Antrieb), is to be conceived.

AESTUS 2 Engine Architecture

The turbopump-driven 55kN AESTUS-2 engine - a result of a joint technology demonstration of Astrium and P&W Rocketdyne - can be considered a technological derivative of the AESTUS engine, the latter propelling the Ariane 5 EPS upper stage during GS and ES missions. Also the more powerful 60kN DBRD-II engine (predecessor of the AESTUS 2 demonstrator) has been considered, but was discarded because the higher thrust could not compensate the higher engine mass and lower specific impulse, and resulted therefore in decreased payload performance.

Therefore, the reference conditions set for the AESTUS II are:

- Thrust 55.03kN
- Chamber pressure 60 bar
- Engine mixture ratio 2.09 (optimal Isp)

The only remaining variable on the AESTUS-2 engine was the nozzle geometry (area ratio, length factor). A weighted scoring model, containing

- Payload gain,
- Rigidity,
- Induced structural loads,
- Heat soak back,
- Manufacturing,
- Geometrical envelope provided by stage,

has been established, which confirmed the current Aestus-2 reference nozzle geometry to be the optimal solution for our launcher configuration as well.

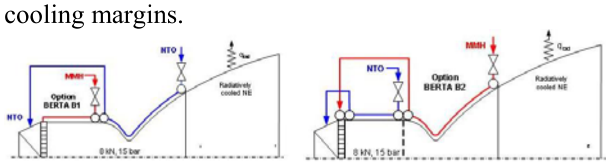
BERTA Engine Architecture

For the 4-stage launcher configuration a new engine named BERTA had to be conceived, as no engine is existing today in Europe in the required thrust class.

Many different configurations were considered for the BERTA engine in the concurrent engineering session with various values of:

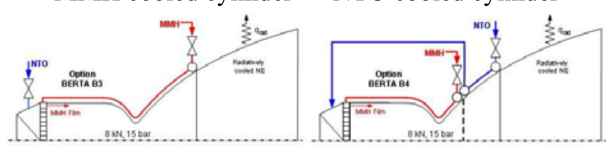
- Thrust 2 - 16 kN,
- Chamber pressure 8 - 15 bar,
- Nozzle lengths / expansion ratios,
- Engine mixture ratio 2.0 - 2.1,
- Engine mass 15-67 kg

Fine-tuning of the mixture ratio was foreseen for phase 2. Further, a preliminary study on cooling concepts was performed, in order to prove the feasibility of the combustion chamber in general. Four different combustion chamber cooling concepts have been investigated (Figure 2) and the general cooling capability of the different configurations under consideration coulde be shown, still providing sufficient cooling margins.



B1) NTO cooled throat MMH cooled cylinder

B2) MMH cooled throat NTO cooled cylinder



B3) Purely MMH cooled Additional film cooling

B4) NTO cooled div. part cyl. & throat MMH cooled

Figure 2: BERTA cooling concepts

This was the basis for detailed cooling-concept analyses in phase 2.

Stage

The main performance measure on the stage is the structural index. Various concepts were considered. The main varying driving parameters are the propellant loading and the tank pressure. Since for the 3-stage configuration the engine characteristics are fixed and a target structural index has been set, a first optimum on propellant loading and tank pressure could be given with launcher performance calculations. Therefore, the trade-off for the 3-stage configuration mainly concerns the tank concept definition. For the 4-stage configuration, the optimal propellant loading and tank pressure cannot be fixed because thrust and chamber pressure is part of the optimisation.

With this propellant loading, tank concepts could be pre-sized using the dimensioning load cases (wind loads, accelerations, tank pressure loads).

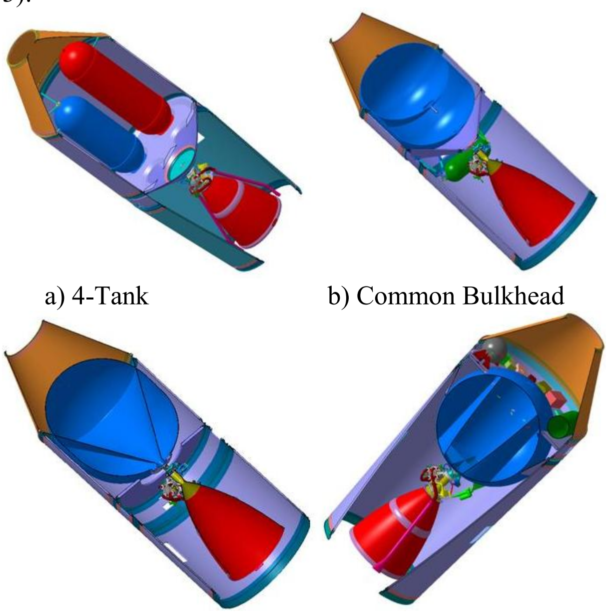
For attitude control the VEGA RACS foreseen for VEGA has shown to be the better option over a unified propulsion system after a technical/programmatic trade-off.

3-Stage VENUS 2 Concepts

First assessments lead to the following reference value for the optimal ascent propellant and tank pressure:

- Ascent propellant 5.4t
- Tank ullage pressure 5.5/6 bar

Four different architectures were considered (Figure 3):



a) 4-Tank b) Common Bulkhead

c) Spherical/Conical d) Annular/Cylindrical

Figure 3: Phase 1 VENUS Architectures for 3-stage configuration

Because a 4-tank configuration would generally result in unrealistically high stage mass and volume for the current propellant mass, it has already been discarded before the CE session. For the CB the following has been evaluated before the CE session: different stage diameters, dome geometries, and tank diameters and the fact whether the tank should be a structural part or not. For the CB concept two different stage diameters were considered and for the A/C only one (same diameter as the S/C concept). Therefore, the following tank-architectures were considered for the CE session (depending on 2nd stage):

- Common Bulkhead (CB) ∅2.2/2.6m (non-structural) SI 15.8-17.0%
- Spherical/Conical (S/C) ∅2.6m SI 13.7-13.9%
- Annular/Cylindrical (A/C) ∅2.6m SI 14.0-14.6%

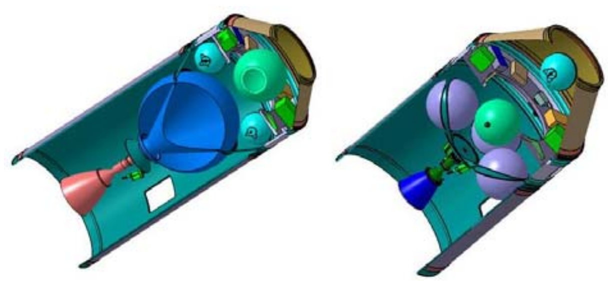
4-Stage VENUS 2 Concepts

First assessments using structural index dependencies and BERTA thrust and chamber-pressure ranges, lead to the following ranges of ascent propellant and tank pressure:

- Ascent propellant 1.1-2.2t
- Tank ullage pressure 18-26 bar

Taking into account the results from the 3-stage concepts and the fact that propellant masses are lower, two concepts were considered promising (Figure 4):

- 4-tank ∅2m SI 56-70%
- Spherical/Conical (S/C) ∅2m SI 22-83%



a) Spherical/Conical b) 4-Tank

Figure 4: Phase 1 VENUS Architectures for 4-stage configuration

The 4-tank concept might be promising for small propellant masses. For higher propellant masses again stage mass and volume becomes unrealistically high.

Because this VEGA Evolution concept still consists of 4 stages but is heavier than the current VEGA launcher, it was assumed that one VEGA RACS bladder tank would not be sufficient, and therefore two were foreseen.

Lower Stage Options

For the 4-stage configurations there are no options concerning the lower stages, only the VEGA evolution configuration for AVUM is considered: P100/Z23/Z9A. For the 3-stage configuration it is different. The first stage is again P100 (100t propellant). For the second stage Z30 (30t propellant, ∅2.2m), Z35 (∅2.6m), and Z40 (∅2.6m) have been considered. However, before the CE session it became clear that Z40 would deliver the highest P/L mass anyway. Z30 would remain as a check because the diameter is different. Therefore, the following second stages were considered

- Z30, and
- Z40 (baseline)

VENUS 2 Architectural Trade-Off

Even though performance is a main driver, other criteria were considered as well using a weighted scoring model. The following criteria were assessed for the VENUS configuration trade-off:

- Payload mass
- Manufacturability
- Integration (on stage level)
- Testing
- Propellant sloshing
- Propellant settling
- System / subsystem / component complexity
- Dynamic behaviour / payload answer
- Equipment accommodation
- Versatility
- Maturity / TRL
- Design robustness / flexibility
- Industrialization efforts
- Stability / controllability
- Acceptance efforts

3-Stage Trade-Off

The remaining options were the Common Bulkhead (CB), Spherical/Conical (S/C), or Annular/Cylindrical (A/C) configuration for VENUS 2 on top of either Z30 or Z40. The following payload performances were found for these 6 options (see Figure 5):

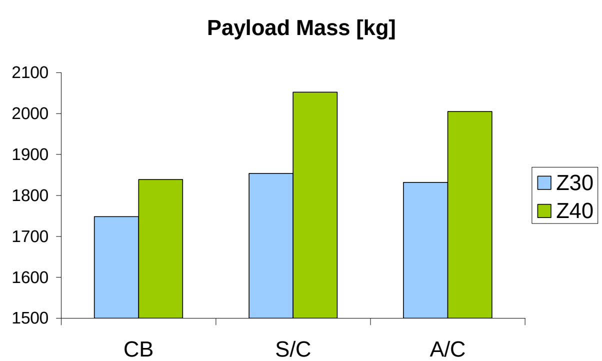


Figure 5: Phase 1 P/L mass performance results for the 3-stage launcher configurations

It can clearly be seen that on the performance stand point of view the Spherical/Conical configuration for VENUS would be the best option on top of the Z40 stage.

The Z40 motor gives much better performances than the Z30 motor. However the preliminary thrust history used for Z40 lead to high acceleration levels. This is not seen as critical as the thrust law of Z40 can be adapted during the geometrical design of the grain. Therefore, on the basis of payload performance Z40 has been selected. The result of the assessment between the VENUS configurations is presented in Figure 6:

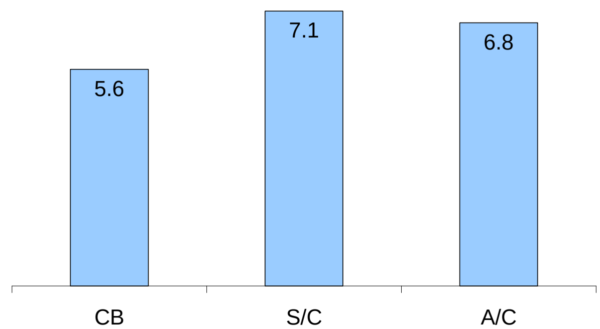


Figure 6: Phase 1 trade-off results for the 3-stage launcher configurations (2nd stage: Z40)

Therefore, again the spherical/conical configuration reaches the highest score, mainly because of the highest payload performance.

The reference conditions were subject of specific sensitivity investigations for the S/C architecture:

- Thrust - Increasing the thrust level above the nominal level of 55.03 kN would only give marginal increase in payload mass and has therefore been abandoned.
- Mixture ratio - It has been confirmed that the mixture ratio for optimal specific impulse also results in the optimal payload mass. The mixture ratio remains therefore 2.09.

4-Stage Trade-Off

The options considered were the 4-tank configuration and the spherical/conical tank configuration. Using the stage structural index dependencies of both configurations and the BERTA engine mass dependencies, the optimal propellant loading and P/L mass was defined by launcher trajectory and performance analyses. These preliminary curves are presented in Figure 7 as the preliminary optimums.

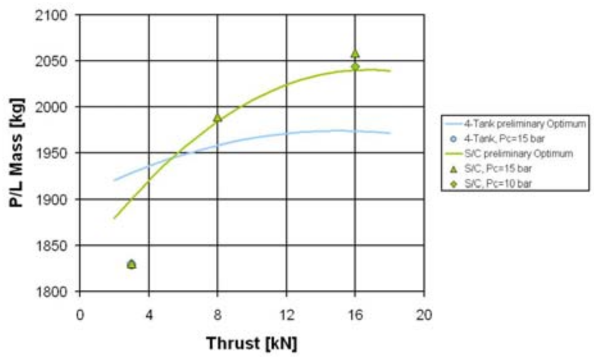


Figure 7: Phase 1 trade-off results for the 3-stage launcher configurations (2nd stage: Z40)

These preliminary results were used in the CE session to define 5 configurations, which were investigated in more detail:

- 4-tank, 3kN, Pc=15 bar
- Spherical/Conical tank, 3kN, Pc=15 bar
- Spherical/Conical tank, 8kN, Pc=15 bar
- Spherical/Conical tank, 16kN, Pc=15 bar
- Spherical/Conical tank, 16kN, Pc=10 bar

The optimal performance was expected to be 8-16kN. For this range, the 4-tank configuration is not feasible anymore, because the corresponding optimal propellant loading gets to high. Therefore, the 8-16kN thrusts were taken for the S/C configuration together with the 3kN (both configurations) for completeness.

It can clearly be seen that indeed the interesting thrust range is 8-16kN for which only the spherical/conical tank is feasible. Therefore, a more detailed trade-off on the concept was unnecessary. The spherical/conical tank has been chosen for phase 2.

A specific trade-off on the engine chamber pressure revealed overall payload performance benefits for the higher 15 bar chamber pressure, as the Isp gain was found to overcompensate associated tank mass penalties. Therefore, 15 bar was selected for the phase 2 detailed studies.

The highest P/L performance was found for 16kN. However, for reasons of commonality with other potential usage in future launcher-, in-orbit and exploration missions, the thrust has been limited to 8kN for phase 2. This corresponds to an optimal ascent propellant mass of 1.7t.

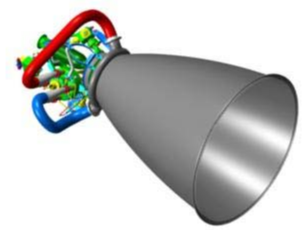
IV. PHASE 2 - VENUS 2 CONCEPTUAL DESIGN

In the previous phase the overall architectures were chosen and the main parameters set. In phase 2 a detailed conceptual design has been elaborated with more local optimisations and trade-offs. Afterwards, the resulting characteristics were used to update the final payload performance.

Engine

AESTUS 2 Engine Conceptual Design

Because the AESTUS 2 nominal configuration has proven to be the optimal solution for the current launcher configuration as well, the engine conceptual design work was limited to the investigation and definition of the stage / engine interfaces. The engine main data are summarized in Table 2.



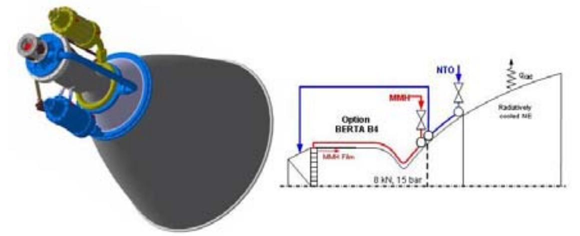
Engine Type	Pump-fed
Engine Cycle	Gas-Generator/ TEG injection
Propellant	MMH/NTO
Vacuum Thrust	55.03 kN
Isp vacuum	336.4 s
Nozzle Area Ratio	280
Chamber Pressure	60 bar
Engine Mixture Ratio	2.09
Mass Flow Rate	16.68 kg/s
Design Life	2500 s 20 starts
Restart Capability	5
Mass	≤139 kg
Length	2171 mm
Diameter	1361 mm

Table 2: AESTUS 2 engine characteristics.

BERTA Engine Conceptual Design

The four cooling concepts (Figure 2), preliminarily assessed in phase 1, were elaborated more in detail in phase 2. The nozzle extension is radiatively cooled. The axial position of the interface between combustion chamber and nozzle extension has been defined ensuring sufficient limits to nozzle material temperature limits. Except for B3 (MMH cooling), all concepts use both the fuel and oxidizer as coolant. This B3 concept, applied on AESTUS and AESTUS 2, would need extra cooling, which would be provided by the injection of an MMH film. A trade-off using technical and programmatic criteria was conducted, after which concept B4 (NTO cooled divergent part; cylinder & throat MMH cooled) was selected.

The final engine main data are summarized in Table 3.

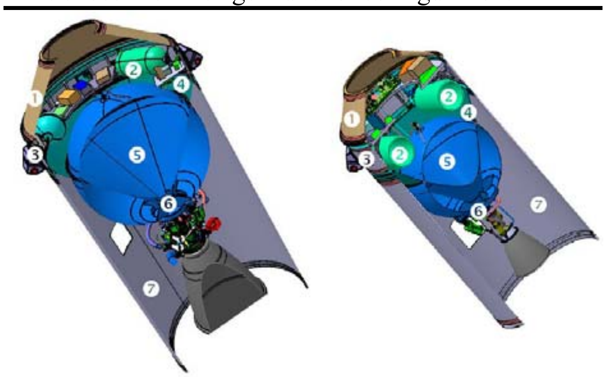


Engine Type	Pressure-fed
Propellant	MMH/NTO
Vacuum Thrust	8.09 kN
Isp vacuum	321.3 s
Nozzle Area Ratio	~ 110
Chamber Pressure	15.0 bar
Engine Mixture Ratio	2.0
Mass Flow Rate	2.567 kg/s
Mass	30.2 kg
Length	1193.6 mm
Diameter	649.0 mm

Table 3: BERTA engine characteristics.

Primary Structures

For both the 3-stage and 4-stage launcher configuration the spherical/conical tank architecture prevailed. Main objective of the mechanical studies on was to perform a trade-off on different design solutions for the main structural elements (primary structures) of this concept, namely: Intermediate Skirt (IMS), Conical Tank Attachment Ring (CTAR) and the Tank (including the tank-outlet concept). Moreover, these and the rest of the primary structures have been optimised for minimizing stage mass while keeping margins with the applied loads. The primary structures are presented in Figure 8. The trade-offs are presented separately, where:
❸ : chosen for 3-stage launcher configuration;
❹ : chosen for 4-stage launcher configuration.

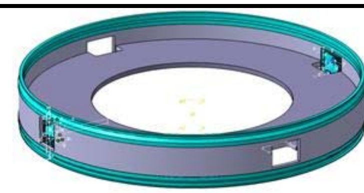


VENUS L5.4 for 3-stage VEGA Evolution	VENUS L1.7 for 4-stage VEGA Evolution

❶Payload Adapter, ❷ Helium Tanks, ❸Intermediate Skirt (IMS), ❹Conical Tank Attachment Ring (CTAR), ❺Spherical/Conical Tank, ❻Integrated Engine Thrust Frame, ❼ Inter-Stage Skirt (ISS)

Figure 8: VENUS primary structures.

Intermediate Skirt (IMS)



❸ + ❹ Sandwich Composite Cylinder	Metallic Cylinder (grid-stiffened ring integrally milled)

Figure 9: Intermediate skirt (IMS) trade-off.

For the IMS the following trade-off candidates were assessed: Sandwich Composite Cylinder and Metallic Cylinder (grid-stiffened ring integrally milled), see Figure 9. The CFRP Sandwich with IM7/8552 carbon fibre skins and HC-3-16 honeycomb core has been chosen after the trade-off, mainly because of mass-reduction and stiffness reasons. Further studies may only lead to an optimization procedure for the rings

Conical Tank Attachment Ring (CTAR)

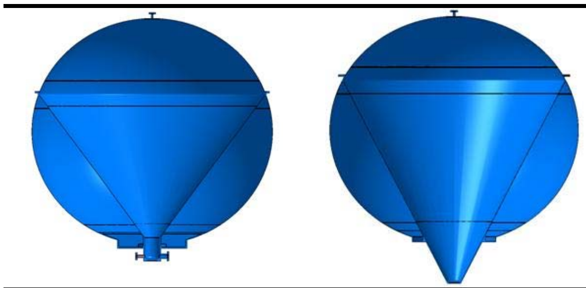
❹ Non-stiffened metallic structure	❸ CFRP monolithic laminate

Figure 10: Conical Tank-Attachment Ring (CTAR) trade-off.

The trade-off on the CTAR design was between non-stiffened metallic structure and CFRP monolithic laminate. The CFRP monolithic laminate is the lighter solution and provides more stiffness. The metallic structure is however easier in manufacturing, less complex and cheaper. Because for the 3-stage launcher configuration the difference in mass was significant the monolithic laminate was chosen. For the 4-stage launcher configuration, the mass reduction would be marginal and therefore the metallic structure was chosen.

Tank Outlet Concept

For the tank outlet concept the following trade-off candidates were assessed: internal disk-shaped outlet and long conical outlet (see Figure 11).



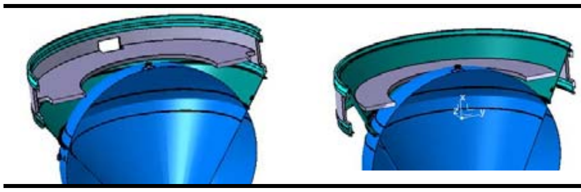
❸ + ❹ Internal Disk-Shaped Outlet	Long Conical Outlet

Figure 11: Tank outlet concept trade-off.

The trade-off showed that the internal disk-shaped outlet is the more interesting option, because of mass, manufacturing, test, and integration reasons.

IMS/CTAR Interface

For the interface between CTAR and IMS two options were assessed: interface either at the IMS lower ring or at the upper ring, see Figure 12.



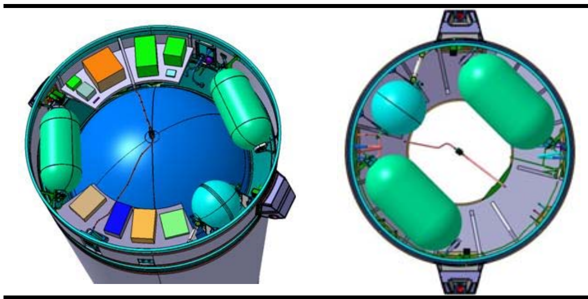
❸ + ❹ IMS Lower-Ring Attachment	IMS Upper-Ring Attachment

Figure 12: IMS/CTAR interface trade-off.

The main difference is that the upper ring attachment would decrease the ISS length, but the interface would be between four structures (CTAR, fairing, payload adaptor, IMS) instead of three (CTAR, ISS, IMS), resulting in higher complexity and needed local reinforcements. All together, the payload performance would be lower for the upper ring attachment. Therefore, the lower-ring attachment has been chosen for 3- and 4-stage launcher configuration.

Helium Tanks

For the helium needs assessments have been made regarding the optimal configurations. Both for the 3- and 4-stage launcher configuration, one tank would lead to higher local loads and therefore heavier structures in comparison with helium distributed over 2 tanks. For the smaller 4-stage launcher configuration, the single tank would not even fit near the IMS wall and would have to be placed in the middle (Figure 4a) leading to a heavy structure. The resulting double helium tank configurations are presented in Figure 13.

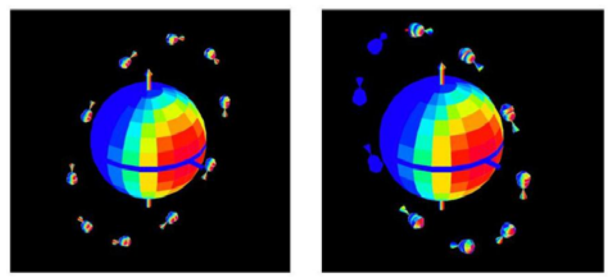


❸ stage launcher configuration L5.4	❹ stage launcher configuration L1.7

Figure 13: Helium tanks configurations.

Thermal Hardware

Thermal analyses have been conducted in order to define the needed amount of insulation and prove that the stage operates within its thermal requirements at all time.



a) hot case orbit b) cold case orbit

Figure 14: Hot and cold case analyses

Thermal protection on tank, P/L adapter and avionics was required to satisfy the thermal requirements.

Propulsion System

As defined in phase 1, the propulsion system consists of a stand-alone Attitude Control (ACS) and a Main Propulsion Systems (MPS): fill & drain system, the feeding & purge system, pressurisation system and conditioning system.

The objective of the functional studies on the propulsion systems were to re-assess the functional budgets like propellant, helium, pressure and hydrazine (RACS) budget on the basis of the ECOSIM FPS models of both stages.

Propellant Budget

The initial functional budget assessments performed in phase 1 for sizing the propellant tank were giving enough margins to account for the potentially increased propellant needed for performance reserves, residuals, de-orbiting propellant, transients, etc. The propellant/oxidizer tank volume could therefore be maintained.

Helium Budget

In comparison with the phase 1 assessments, the helium demands from engine side (AESTUS 2 and BERTA) were increased, based on the fact that the Maximum Design Pressure (MDP) is not changed compared to phase 1 results, which meant an increase in helium tank volumes. As already stated in the Primary Structures' section, the helium budget has been distributed over two tanks for both configurations.

Pressure Budget

The calculations showed that the pressure losses in the lines are in line with the phase 1 results, complying with maximal ullage tank pressures and the required interface pressures to the engine. However, for the 4-stage launcher configuration (pressure-fed) it has proven to be very difficult to comply with the maximal differential pressure between the MMH and NTO tank compartments during the pressurisation phase. Therefore, in order to get similar pressurisation slopes for both compartments at different propellant loadings, it seems necessary to equip the propulsion system with two pressure regulators in case of the 4-stage launcher configuration.

Hydrazine Budget

Taking into account the attitude control demands for VEGA, translating them into the VENUS2 missions, and calculating the hydrazine consumption, showed that the current VEGA RACS system, equipped with two thruster cluster assemblies (Figure 15) and only one bladder tank (VEGA configuration), satisfies the mission needs. In phase 1 for the 4-stage launcher configuration it was expected that 2 tanks would be necessary, but the 2nd bladder tank could be omitted.

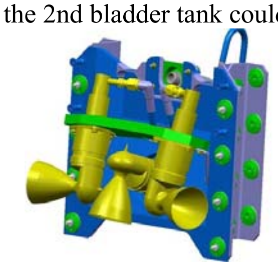
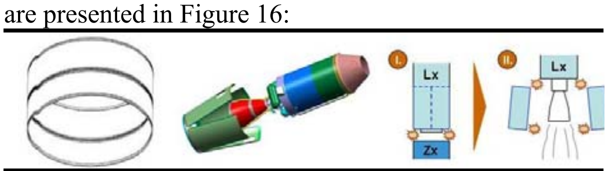


Figure 15: VEGA RACS thruster cluster assembly

Separation System

Trade-offs on technical and programmatic issues have been performed for the separation systems. 3 opening configurations with corresponding selections are presented in Figure 16:



❹ Cylindrical Petal ❸ Fairing-type

Figure 16: Separation-system opening configurations.

Further, for the following distancing systems were considered (with corresponding selection):

- Pusher elements
- RACS (❹) or Acceleration Rockets
- Combination of pusher elements and RACS (❸) or AR.

Electrical System

The performed electrical studies describe the needed electrical interfaces (Figure 17) and their properties between the VENUS 2 upper stage configuration and the avionics equipment, derived from the AVUM (Attitude and Vernier Upper Module) upper stage.

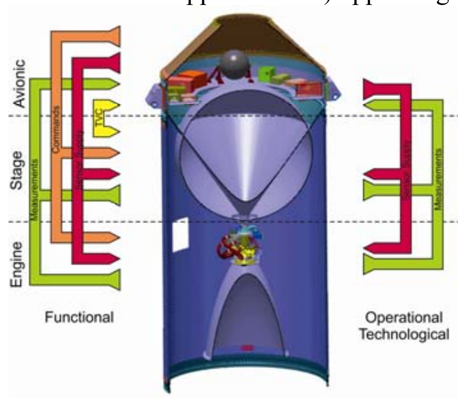


Figure 17: Electrical interfaces between avionics and stage

The electrical system of the VENUS 2 upper stage is derived from the Ariane 5 EPS upper stage, with modifications concerning the engine. The main characteristics of the system are:

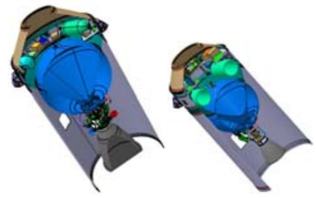
- Centralised On-Board Computer (OBC)
- Non-redundant system concerning the avionic boxes (like AVUM), but redundant functional chains

Different chain types have to be taken into account, which mainly differ in their importance:

- *Functional chains* are directly influenced by the flight program, or they are input to the flight program. These chains are redundant
- *Operational chains* are measurements which are broadcasted to earth stations for further investigations
- *Technological measurements* will also be sent to ground, but this kind of signals is just used for qualification flights

VENUS 2 Properties

After the phase 2 trade-offs, the final VENUS-2 configurations were frozen. The general properties are given in the following Table 4.

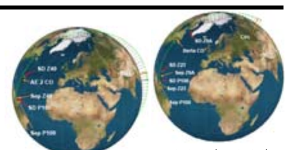


VEGA New Upper Stage (VENUS)	L5.4	L1.7
Length* [m]	5.1	3.9
Diameter [m]	2.6	1.9
Prop. Tank Vol. [m³]	5.5	1.8
Propellant	MMH/NTO	
Dry Mass** [kg]	978.7	864.5
Main Propulsion System	AESTUS 2 (pump-fed)	BERTA (pres-fed)
Thrust [kN]	55.03	8.09
Isp [s]	336.4	321.3
Mass flow rate [kg/s]	16.68	2.567
Engine mixture ratio	2.09	2.0
Attitude Control System	RACS (N2H4/GN2)	
Pressurisation	GHe	
ISS 2/3 Mass [kg]	335.4	121.0
Fairing Mass [kg]	579.1	562.2
Fairing Length [m]	7.9	

Table 4: VENUS 2 properties. (* incl. ISS; ** incl. MPS, ACS, P/L cone, avionics, clampband)

Launcher Performance Analysis

Using the properties of the VENUS 2 stages and the data of the lower stages provided by ESA, the optimal trajectories were calculated with the 3D ASTOS tool. The mission profiles and the resulting characteristics for the reference 700x700km polar orbits are presented in Table 5 [4]:



VEGA Evolution configuration	P100/Z40/ VENUS L5.4	P100/Z23/ Z9A/ VENUS L1.7
Mission Profile		
Separation P100 [s]	110.0	108.5
Separation 2nd stage [s]	203.4	187.8
Separation Fairing [s]	218.4	204.7
Separation 3rd stage [s]	-	302.7
VENUS 1st ignition [s]	220.0	314.7
VENUS 1st extinction [s]	534.8	925.4
VENUS 2nd ignition [s]	2809.8	2157.4
VENUS 2nd extinction [s]	2819.0	2208.9
Mission characteristics		
Max. acceleration [g]	6.6	4.4
Payload Mass [kg]	2350	1821

Table 5: Ref. ASTOS mission (polar 700x700km)

Moreover, these missions have also been optimised using the much faster TOSCA tool. Then, these results can better be compared with the 2D TOSCA calculation performed for the nominal VEGA configuration (P80/Z23/Z9A/AVUM) and the VEGA Evolution with AVUM (P100/Z23/Z9A/AVUM), presented in Table 1. The comparison is graphically presented in Figure 18.

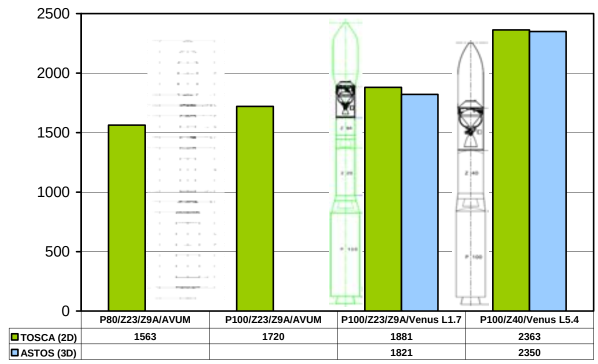


Figure 18: Payload performances of VEGA, VEGA Evolution AVUM, and VEGA Evolution VENUS L1.7 and L5.4.

The 4-stage VENUS launcher configuration shows a 161kg improvement in comparison with AVUM (Evolution) and the 3-stage VENUS launcher configuration even a 643kg P/L performance gain according to the TOSCA calculations.

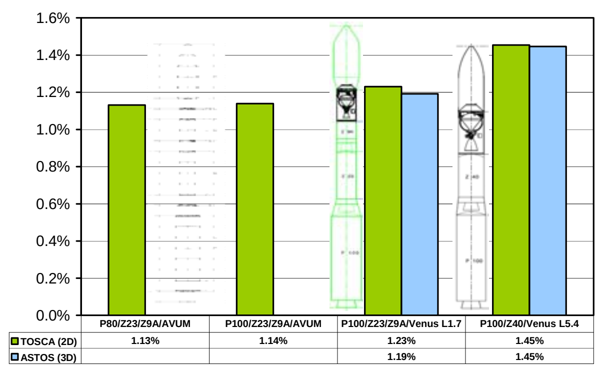


Figure 19: Payload fraction for VEGA, VEGA Evolution AVUM, and VEGA Evolution VENUS L1.7 and L5.4.

In order to give a fair comparison between the different launcher configurations it is better to compare the payload fraction, being the payload mass over GLOW (Gross Lift-Off Weight), see Figure 19. It is clear that increasing the first stage size does increase the performance but not the efficiency (1.13% to 1.14%). Then, exchanging the AVUM with VENUS L1.7 increases the P/L performance again and now also the efficiency (P/L fraction) from 1.14% to 1.23%. Further, by replacing the 3rd and 4th stage by the even more efficient (pump-fed) and much bigger VENUS L5.4, the payload-fraction rise is considerable 1.23% to 1.45%.

In this phase of development it is hard to predict the final masses. The masses presented here are nominal (best-guess) masses. Nevertheless, contingencies have been taken into account and for sizing, project margins as well. In order to account for the uncertainties on the P/L performance at the end of a potential development, a thorough dedicated uncertainty investigation has been conducted taking into account the individual sensitivities of the main driving parameters on the payload mass. The overall uncertainty resulted in ~±4% of the predicted nominal performance value for both, the 3-stage and 4-stage configuration.

V. TECHNOLOGY TESTING

In addition to the study work, complementary investigations on suitable high performing injector designs to be applied to the new BERTA engine have been requested by the customer. In that frame three new types of single injection elements to be used in a later multi-element arrangement have been conceived, based on the heritage and injection principles of existing Astrium engines in the medium and small thrust classes. A fourth injector has been scaled down from Aestus engine to be used as a reference

After hydraulic characterization including spray visualization (using H_2O) on a test stand operated at the University of Applied Sciences, Munich, Germany, the various injectors have been subjected to hot fire testing on single element level at the Astrium P2 test facility at Lampoldshausen, Germany. Figure 20 displays the test specimen comprising the injector with single element adapter, a combustor cylinder made up from silica glass for flame visualization and a combustor throat section fabricated from copper.

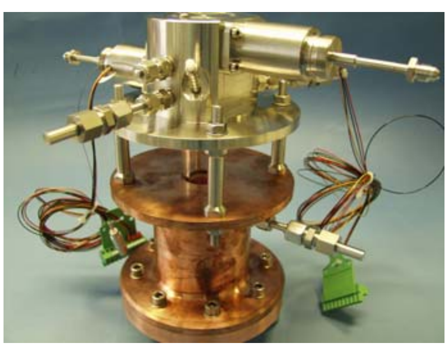


Figure 20: BERTA Single Element Hot Fire Test

Out of the four investigated injector types, three candidates showed excellent results mainly in terms of combustion efficiency and combustion roughness with reference to former AESTUS reference testing. For two of those promising candidates even design optimization potential has been identified, which has been proposed for the currently ongoing FLPP 2.2 Storable Program on a 5 kN full scale demonstrator.

VI. CONCLUSION

This study proves that a considerable payload performance increase (+800kg) to 2350kg is possible by incorporating German upper stage technologies (VENUS) into a potential VEGA Evolution launcher, improving the launcher efficiency considerably: Payload fraction would increase from 1.13% to 1.45%.

The BERTA technology demonstration testing on several adapted and novel single injection element concepts, revealed promising results. For superior candidates dedicated design optimizations have been proposed

VII. REFERENCES

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