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Study Trade-Offs on Future European Expendable Launchers

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The paper describes latest results of recent activities in Germany in the technical assessment of future European launcher architecture. In a joint effort of DLR-SART with German launcher industry a next generation upper-medium class expendable TSTO and options for new liquid fuel upper stages for the small VEGA-launcher are addressed.
The WOTAN study has investigated fully cryogenic launchers as well as those with a combination of solid and cryogenic stages, fulfilling a requirement of at least 5000 kg single payload into GTO. With this study finished, final performance data as well as critical technical and programmatic issues are presented.
The VENUS research on potential new VEGA upper stages is focused on storable and on Vinci-based cryogenic propulsion and includes not only the VEGA solid propellant lower composite, but also its potential more powerful future upgrade. The challenges in achieving a considerable performance gain compared to VEGA are revealed.

Subscripts, Abbreviations

I_{sp}	(mass) specific Impulse	s (N s / kg)
M	Mach-number	-
T	Thrust	N
W	weight	N
m	mass	kg
q	dynamic pressure	Pa
α	angle of attack	-
ε	expansion ratio	-

AP	Ammonium Perchlorate
AVUM	Attitude and Vernier Module
CAD	Computer Aided Design
ELV	Expendable Launch Vehicle
GLOW	Gross Lift-Off Mass
GNC	Guidance, Navigation, Control
HTPB	Hydroxyl Terminated Poly Butadiene
ISS	International Space Station
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LOX	Liquid Oxygen
MEOP	Maximum Expected Operating Pressure
MMH	Monomethyl Hydrazine
MR	Mixture Ratio
MTO	Medium Transfer Orbit
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
SSO	Sun Synchronous Orbit
TRL	Technology Readiness Level
TSTO	Two Stage to Orbit
VEGA	Vettore Europeo di Generazione Avanzata
VENUS	**VE**GA **N**ew **U**pper **S**tage
WOTAN	**W**irtschaftlichkeitsuntersuchungen für **O**rbital-**T**ransportlösungen von **A**riane **N**achfolgeträgern (Economic Assessment of Orbital Transportation Options of Ariane-Succeeding Launchers)
cog	center of gravity
sep	separation

1 Introduction

The system activities in Germany on the future European launcher options during the last almost three years focus on a next generation upper-medium class expendable TSTO and options for new liquid fuel upper stages for the small VEGA-launcher. Two DLR-agency funded studies support the investigations of these subjects [4]: WOTAN on the next generation launchers and VENUS on potential new VEGA upper stages. Beyond that effort technology preparation and maturation activities for re-ignitable cryogenic upper stages are under way [5]. All work is performed as a joint effort of DLR with German launcher companies EADS astrium and MT Aerospace.

Advanced upper-stage technologies are one of the primary German investigation areas. These technologies could not only be applied to the above mentioned TSTO but also to a potential upgrade of the Vega small launcher. A broad range of small launcher upper stages have been investigated in VENUS spanning storable as well as different cryogenic propellants. The system investigations in VENUS are not only based on the VEGA solid propellant lower composite currently under final development, but also on its potential more powerful future upgrade.

Note that all presented launcher concepts have been under investigation to obtain a better understanding of future ELV options. Study results supported Germany's preparations of the European ministerial council 2008. For none of the launchers, even the most promising ones, currently a development decision is implicated.

2 WOTAN: Next Generation Expendable Medium-Lift TSTO Options

Subject of the WOTAN study [1] were options for next generation expendable TSTO launchers fully based on European technology. Its major programmatic goals are to foster ELV system expertise in Germany and to promote cooperation and collaboration of German key industrialists and DLR-launcher systems analysis group (SART). The main technical objectives of WOTAN have been:

- Perform a pre-design for two pre-selected, promising ELV configurations
- Assess operational constraints
- Establish a parametric cost assessment
- Cost-benchmark with existing launchers

The WOTAN launcher architecture study has been run from November 2006 until July 2008 with a total budget of 1.6 Million €, investigating expendable fully cryogenic (LOX/LH2) TSTO name-coded "K" and solid 1st stage / cryogenic 2nd stage TSTO combinations name-coded "F". The possibility to increase GTO and LEO performance by means of added solid Strap-On-Boosters is highlighted by an additional "+"-sign.

2.1 Study Logic, Constraints, and Margin Policy

The GTO-launch from the European Space-Port of Kourou (French Guyana) is defined as the reference mission with the requirement of a minimum single payload injection of 5 metric tons. This mission obligates the size of the two core stages. Afterwards, these are kept fixed and the propellant loading of the 6 solid-Strap-On-Boosters is defined in order to reach the augmented-performance aiming at 8 metric tons in GTO.

The maximum diameter of the stages (and the fairing) has been fixed at 5.4 m in order to allow the re-use of Ariane 5 manufacturing and procurement assets. The needed under-fairing volume for the payload is similar to AR5 for a single launch, so the same fairing volume and shape has been used (same class of payload, similar aerodynamics).

A general payload performance margin of 200 kg to the reference geostationary transfer orbits is assumed, calculated engine I_{sp} are reduced by approximately 1 % and solid motor I_{sp} by 5 s. Further a small mass margin depending on the used technology is added. Overall, this margin policy can be understood as relatively conservative, allowing a good confidence in the vehicles' simulated performances.

In the launcher definition process it is tried to use as few liquid engines as possible, while on the other side remaining in a high-thrust range accessible with reasonable technological extension from current and past European high-thrust liquid engines. That drove to the initial choice of a twin-engine 1st stage for the "K" configurations and a single engine 2nd stage for both "K" and "F" configurations (see [5]). For the full cryogenic version, 3 different technologies for first stage high-thrust engines had been initially considered, in relation with their expected production cost [3].

The WOTAN-study has been subdivided into four subsequent phases including two iterative launcher sizing loops. Previous study results have been presented in [4], [5]. In a first step SART performed an iterative pre-design and sizing of engines, solid motors and launchers based on similar assumptions. Preliminary data, documented in [3], allowed a down selection on a few most promising configurations. Different cycle complexities of high thrust liquid rocket engines and large solid motors in the first stage were looked upon. The K1-type launcher with 'low-cost' gas-generator cycle engine has been eliminated early from further WOTAN investigations due to its outsize dimensions.

The next step of already more detailed sizing analysis has been performed for the K2 Vulcain-type gas-generator cycle engine, different variants of the K3 high performance staged combustion cycle engine, and two different versions of the solid motor first stage. The launcher sizes are iteratively found in combination of mass estimation and trajectory simulation. [4]

2.2 Propulsion system data

All engines in WOTAN had been preliminarily sized in a close iteration between launcher dimensioning and engine cycle analyses at DLR-SART [3]. The mass flow is determined by the minimum lift-off T/W-requirement of 1.3. A preliminary engine component sizing and mass estimation including the definition of more detailed engine architecture is afterwards performed by EADS astrium.

A detailed propulsion system description of the WOTAN ELV is provided in [5]. This paragraph gives a brief overview.

The K3's cryogenic first stage engine is of staged combustion type with an engine mixture ratio of 6.7. A throttling requirement of more than 30 % in a 'step-function' (see [3, 6, 7]!) is new for large European engines. A cryogenic staged combustion engine with a vacuum thrust of almost 2700 kN is beyond every such engine type ever developed (SSME with 2280 kN is the largest yet) and therefore has to be assessed as very critical for realization.

A single Vinci with 180 kN vacuum thrust is the baseline engine for the upper stages. This advanced expander cycle rocket engine is currently under development. Note that Vinci is the largest engine of this cycle ever built. However, 180 kN thrust is not fully sufficient to propel the heavy upper stage of a large TSTO with a payload requirement of 5 ton in GTO. A double engine solution as used in some Centaur stages is assessed as too complex to be integrated and too costly. Therefore, for launchers with lower performance solid first stages a need exists to raise upper stage propellant loading and hence available thrust. The expander cycle is thought difficult to be enlarged beyond its current size because the chamber wall surface required for the heat transfer does not increase at the same rate as the mass flow. Therefore, DLR-SART defined a generic gas generator engine with 500 kN thrust and a nozzle extension mechanism similar to Vinci. A first impression of the lay-out is presented in [5].

The solid motor characteristics for the very large first stage for WOTAN F and for the strap-on boosters have been defined by DLR-SART and EADS according to launcher requirements and trajectory constraints. The propellant grain is based on the established HTPB – AP combination and the average combustion pressure is about 90 bars with nozzle expansion ratio at 15. An average vacuum I_{sp} of 283 s without margin is calculated for the large first stage motors. The strap-on's I_{sp} is lower by 3 s due to their reduced nozzle expansion ratio and to take into account the slight outboard inclination of the fixed nozzles. The main stage propellant loading of almost 600 tons is far beyond the current Ariane 5 EAPs and even larger than the Shuttle's SRB.

2.3 Stages Pre-concept and Structural Sizing

The final architecture studies and structural optimization have been performed by EADS astrium with the support of MT Aerospace. These analyses were restricted to the K3-46 6.7 fully cryogenic launcher and to the improved F2 configuration with P596 and H68.

In order to assess the structural dry mass via a pre-sizing, general flight loads have been computed by mean of a simplified pre-project approach. Additionally, a functional general architecture of stages has been established for allowing a pre-sizing when necessary for main sub-systems mass estimates or mass allocation and to propulsion function realization. It concerns typically:

- Functional stage propulsion system conceptual architecture, and flow schematics.
- Propellant loading need, and residual estimate (including thermal).
- Tanks volume need.
- Simplified pressure allocation pre-sizing.
- Pressurization system concept and pressurization-fluid need.

2.3.1 Fully-cryogenic version “K3”

The final configuration, essentially driven by the needed propellant mass, is presented in Figure 1. The aft-skirt and engine bay structure from the first loop [4], capable of attaching 6 SRB, is kept almost unchanged.

The LOX/LH2 first stage concept is built around the following major sub-systems:

- LOX and LH2 tanks with common bulkhead, and external feed-lines
- Liquid Helium supercritical storage for LOX tank pressurization (heater in each engine) – AR5 1st stage technology currently available, and in production - and regenerative heated GH2 (each engine combustion chamber) for LH2 tank pressurization.
- Engine gimballing by a pair of hydraulic actuators each (pitch and yaw), and GH2 roll-control thrusters
- Redundant electrical system for critical functions, batteries on-board for 1st stage flight needs.
- Strap-On-Boosters mechanical connections on the engine-bay (6 boosters, for having reduced length)
- Classical thermal insulation concept (similar to AR5 cryogenic stages), due to the short flight time and large fluid thermal inertia.

The overall dimensions of the final WOTAN K3 concept are:

Total Length (short fairing, GTO):	**66.6 m**
Total Length (Long fairing, ISS):	**70.7 m**
Launcher diameter:	**5.4 m**

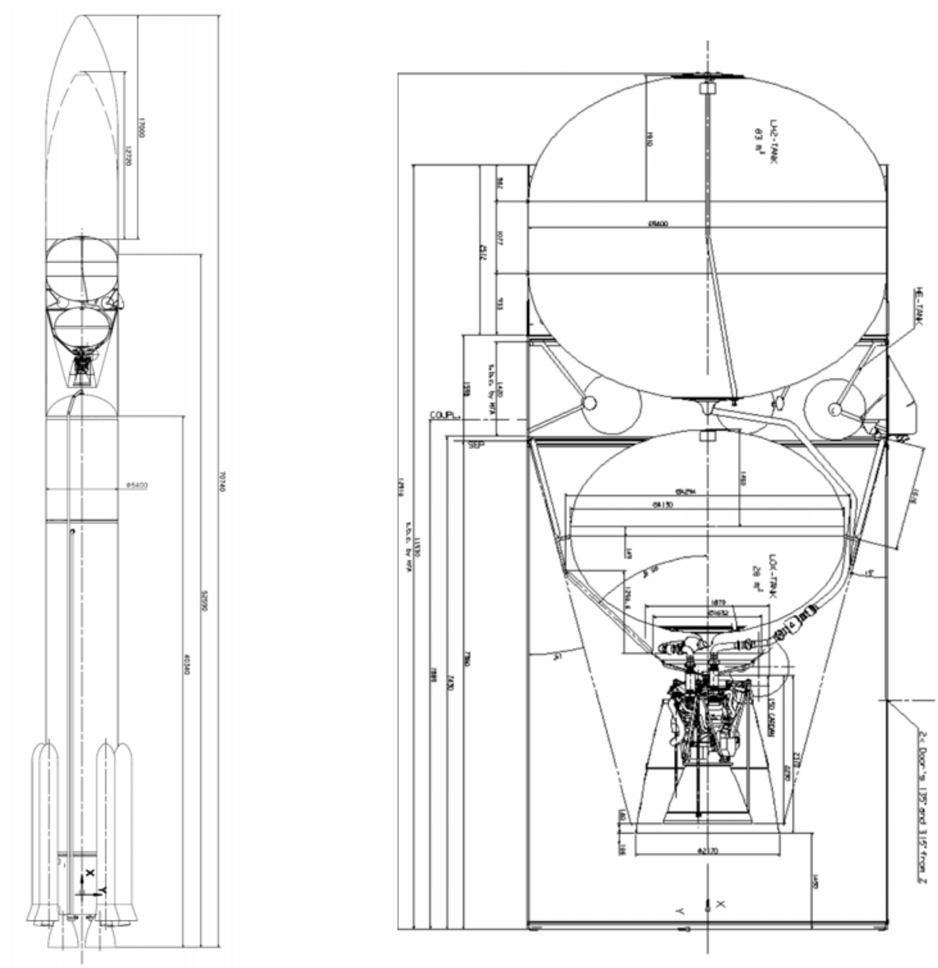

Figure 1: WOTAN “K”3+ conceptual architecture (left) and of 2nd stage H32 (right, enlarged)

The lay-out of the first stage engine-bay has been based on advanced material. The minimum weight to fulfill strength and stability demands is 1980 kg with CFRP [5]. The CFRP-structure is extremely lightweight with respect to the high loads.

The upper-stage concept has taken benefit of the previous studies made for extending mission capabilities of European launchers, and for introducing the Vinci expander cycle in an improved AR5 cryogenic upper-stage. A conceptual geometrical architecture of the resized WOTAN stage is shown in Figure 1.

The LOX/LH2 second stage concept is built around the following major sub-systems:

- Separate LOX and LH2 tanks
- Single engine mounted on a thrust-frame, which also accommodates fluid equipment
- Engine gimballing by a pair of hydraulic actuators each (pitch and yaw), and GH2 roll-control thrusters
- High-pressure (400 bar) ambient temperature Helium storage for LOX tank pressurization, and regenerative heated GH2 (engine combustion chamber) for LH2 tank pressurization.
- Redundant electrical system for critical functions, batteries on-board for 2nd stage and payload-separation flight phase needs.
- Classical thermal insulation concept (similar to AR5 cryogenic stages) for GTO reference mission
- Specific additional equipment (thermal insulation, propellant settling system) as kits for “versatile” missions

2.3.2 Solid 1st stage / cryogenic 2nd stage version “F2”

The diameter of the first stage solid motor has been restricted at 4.6 m in order to remain comparable with other heavy solid motor pre-project studies made in France [2]. For the upper-stage a diameter of 5.4 m has been retained (same as for the fairing). The WOTAN “F” launcher’s latest concept definition is presented in Figure 2.

General launcher concept data of the final configuration are:

Total Length (short fairing, GTO)	**56.3 m**
Total Length (Long fairing, ISS)	**60.6 m**
Launcher diameter (lower section)	**4.6 m**
Launcher diameter (upper section)	**5.4 m**

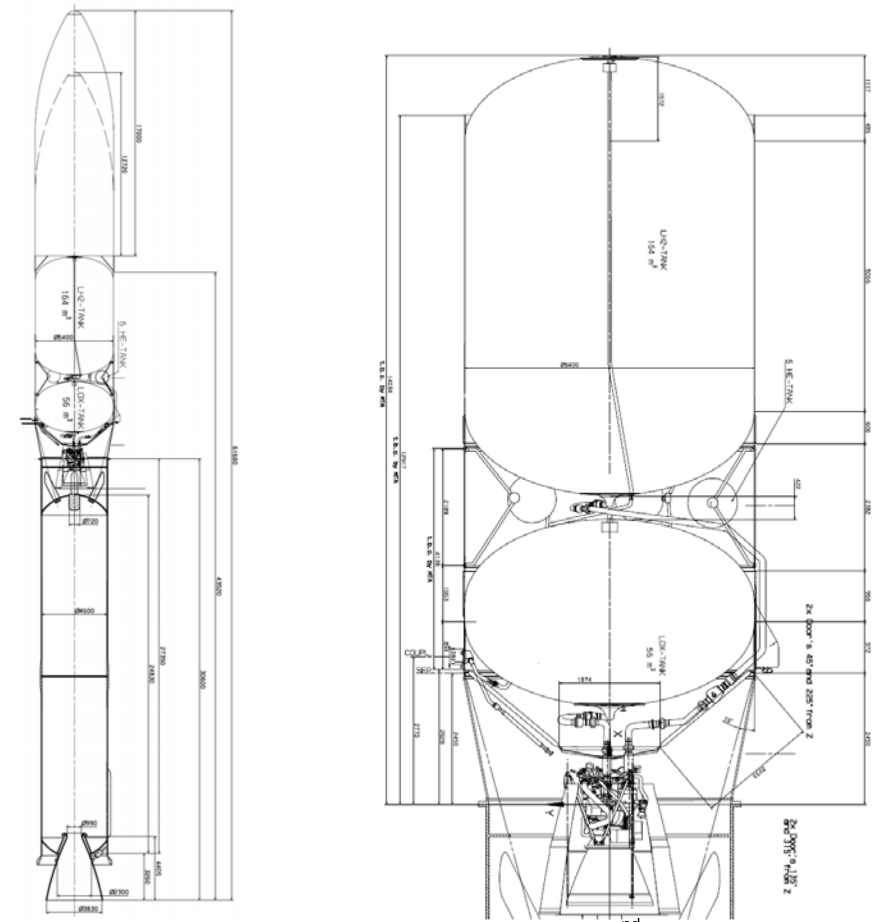

Figure 2: WOTAN “F”2 conceptual architecture (left) and of 2nd stage H68 (right, enlarged)

The solid propellant heavy first stage concept is built around the following major sub-systems:

- Composite motor casing, in 2 segments using high performance T800 fiber.
- Propellant grain of new generation, allowing large mass and large geometry casting. Profile and grain structure adapted for limiting the maximum acceleration (compare [2]).
- Flexible nozzle gimballing by a pair of hydraulic actuators (pitch and yaw), and hot gas (hydrazine as reference) roll-control thrusters.
- Redundant electrical system for critical functions, batteries on-board for 1st stage flight needs.
- 6 Strap-On-Boosters with mechanical connections on the aft skirt and a forward position close to the motor casing segmentation interface.
- Special residual thrust-neutralization device for the separation phase [4]. The TRL of this new concept for space launchers is low. Separation or braking rockets might be a potential fall-back replacement of this device.

The cryogenic upper stage including its functional architecture is similar to the “K3” version presented in the previous paragraph 2.3.1, but both tanks with 5.4 m diameter due to the larger amount of propellant (see Figure 2).

2.4 System and Performance Synthesis

The simulation of the launcher control system of the long K3-configuration in a critical gust and wind condition has been analyzed [5, 8]. The calculations proof the principal feasibility within typical actuator constraints. The amplification factors of the control algorithms should be adaptable due to the flight configuration.

The performance calculations of the WOTAN K3 and F2 TSTO launchers in their final configurations represent separated payload masses as theoretical maximum performances, not taking into account any additional upper-stage fuel for de-orbiting. The TSTOs are not constrained by their lower-stage impact points, if launched from Kourou.

The WOTAN data obtained at the end of the study considerably exceed the original payload requirements. A second iteration loop including a resizing of the stages and a structural optimization was quite successful insofar as the reference values are now well beyond the initial goal. Figure 3 shows that GTO payloads of K3 and F2 still come quite close, with a performance edge for F2+ due its more powerful upper stage.

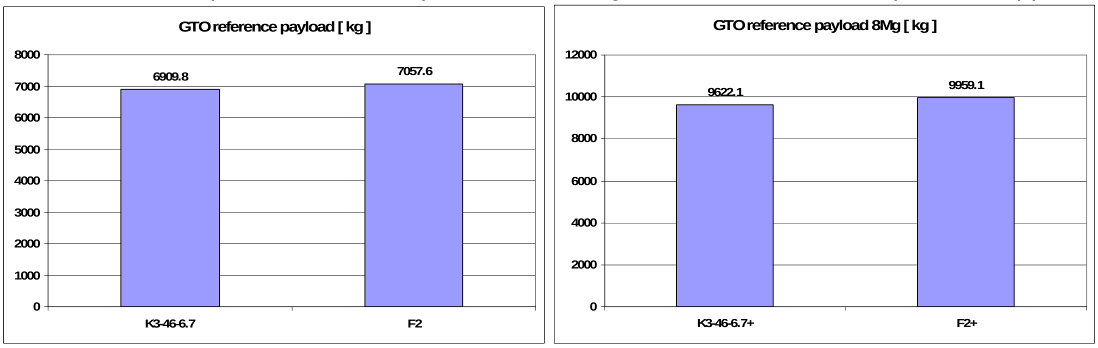

Figure 3: Separated payload mass of WOTAN launchers for GTO mission

Further, it is interesting to compare the required GLOW presented in Figure 4 which is approximately twice for F2 due to its lower average I_{sp}.

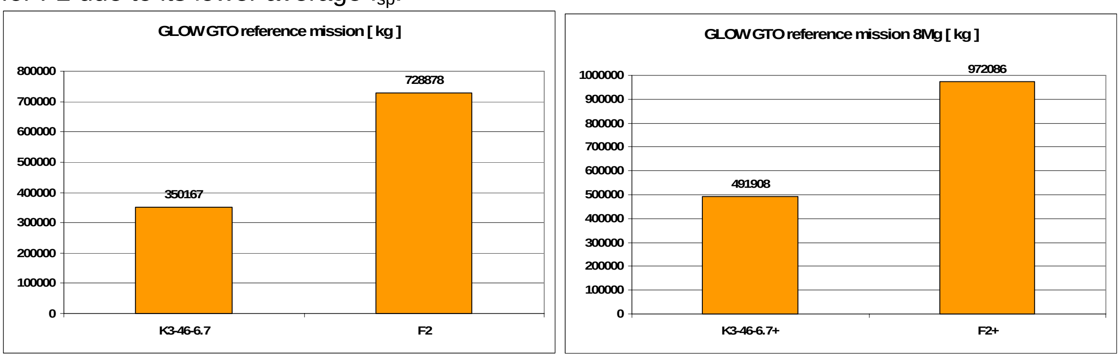

Figure 4: GLOW of WOTAN launchers for GTO missions (bottom with strap-on boosters)

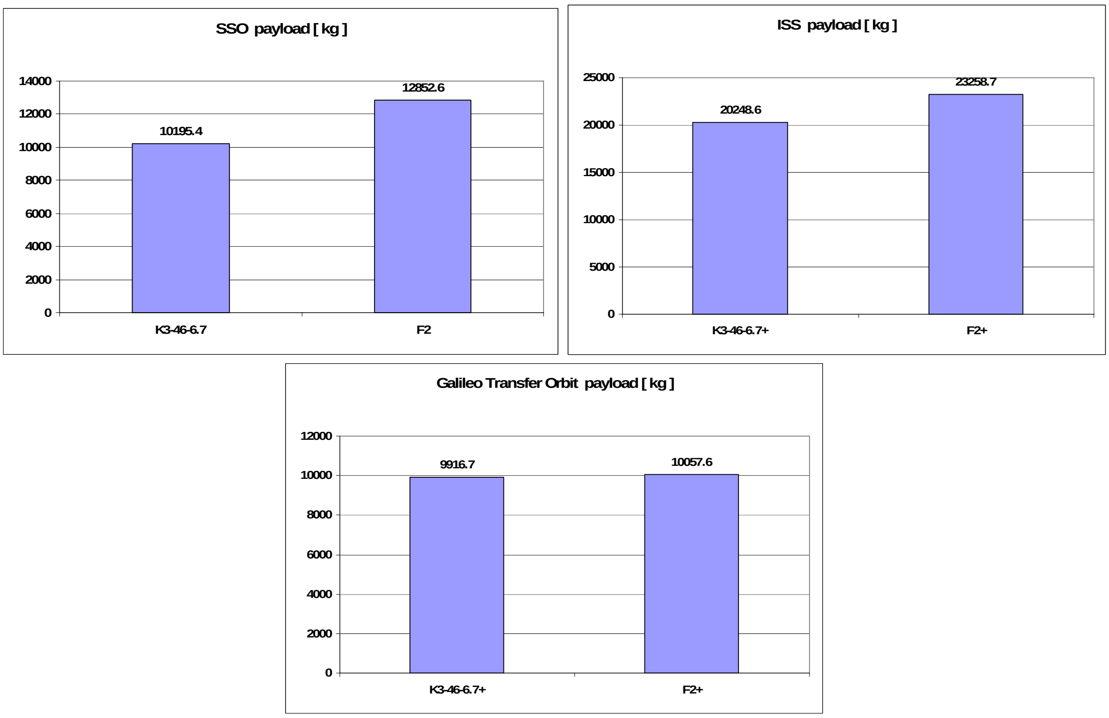

Figure 5: Separated payload mass of WOTAN launchers for secondary SSO, ISS and Galileo missions

Regarding the secondary missions, F2 shows notably better performance in a comparison of achieved payloads in the LEO-missions for ISS re-supply and to polar SSO then K3 (see Figure 5), while the high-energy Galileo orbit payload is almost the same. All investigated types are able to deliver heavy platforms into SSO without strap-on boosters. The resized K3 and F2 are both able to at least match the current Ariane 5 ES performance in case of the flight to the ISS.

3 VENUS: Small Launcher Evolution Options

Currently, the small launcher VEGA with its advanced solid propellant first stage P80 is under development in Europe. VEGA consists of three solid rocket motors and a small liquid propulsion module for precise orbit injection called AVUM. Germany is not participating state in this launcher development project.

However, the need for a performance upgrade of VEGA in the next decade has already been identified. A simplification of the overall lay-out combined with a reduction in the total number of stages and the introduction of a larger liquid propellant upper stage could be an interesting configuration. Several options of different propellant combinations and engines have been under assessment in the German VENUS study. This work is another joint DLR-SART EADS astrium effort for which most recently a second step VENUS 2 has been kicked-off. This paper presents the final results obtained up to the end of 2008.

3.1 Study Logic, Constraints, and Margin Policy

The first VENUS study has been initiated in mid 2007 and has been running in 3 phases until the end of 2008. The approach is quite different to WOTAN because upper stages should be adapted for VEGA's already existing lower composite instead of starting a blank sheet of paper design. In the first step SART analyzed 6 different liquid engine options and found the optimum performance for each stage into the VEGA polar reference orbit. Based on these data, astrium established preliminary upper stage architectures including mass balances for some of the initially most-promising-looking configurations.

Early in the VENUS study it became clear that a potential new liquid upper stage would probably not be mounted on the already qualified P80 and Z23 but on newly upgraded stages P100 and e.g. Z40. The work has therefore been reoriented towards two other configurations from the previous VENUS investigations. One of them is cryogenic, the other one with storable propellants. However, the changes on the lower composites' performance required a new liquid stage propellant loading optimization.

Trajectory and performance analysis for almost all of the upper stage configurations is made, targeting the VEGA reference mission, a final circular orbit with an altitude of 700 km and an inclination of 90°. After injection in a transfer orbit and succeeding ballistic phase an apogee circularization maneuver takes place.

In the trajectory analyses, an additional margin of 5 s on the specific impulse is taken into account for the cryogenic Vinci and 4 s for AESTUS 2.

3.2 Configurations with P80 (+ Z23)

The different upper stages investigated differ in propellant type and engine. Below all the versions initially investigated are briefly recalled. Each version has been sized for its optimum propellant loading to the reference orbit. Further the performances for typical LEO and GTO missions have been calculated. Complementary data on e.g. the engines is found in [4], [5].

3.2.1 VENUS version "A"

Version "A" has been intended replacing the current Vega Z9 solid 3rd stage and the AVUM 4th stage by a single new storable propellant stage equipped with Ariane 5's AESTUS engine. The configuration is severely restricted by the low 27.8 kN thrust of the AESTUS. Payload capacity has been found considerably below that expected for VEGA. Thus, this configuration is not interesting as VEGA's future upgrade and is no longer considered for more detailed investigations.

3.2.2 VENUS version "B"

Version "B" intends replacing the current Vega Z9 solid 3rd stage and the AVUM 4th stage by a single new storable propellant stage equipped with a potential future AESTUS 2 engine. The AESTUS 2 is a proposed upgrade of the AESTUS engine with turbopumps and multiple ignition capability. A new European power pack and gas generator would have still to be developed for the AESTUS 2. (See [5] on preliminary data!).

Upper stage propellant loading optimization results in an optimum fuel mass of around 8000 kg [4]. On this basis the stage architecture has been defined by EADS astrium. The nominal engine mixture ration is assumed at 1.9. A slightly increased mixture ratio would deliver better I_{sp} performance but 1.9 is still the AESTUS 2 baseline because the Pathfinder thrust chamber tests had been performed with a corresponding mixture ratio [11]. The theoretical optimum performance is expected for an engine mixture ratio of about 2.2. The calculated tank volume needed for the N_2O_4 tank is 4.4 m^3 and for the MMH tank 3.85 m^3. The design choice of the tank configuration is a common bulkhead with the N_2O_4 in the forward position. The thermal insulation should be foam insulation removable from the stage outer structure on ground.

The VENUS so called "B80" or L8 conceptual architecture is shown in Figure 6. The L8 is the only detailed stage architecture so far designed in VENUS for the P80 first stage. Mass estimation values including propellant residuals and hence performance data are thus expected to be the most reliable. Payload capacity is limited to 1610 kg; no more than a slight improvement compared to VEGA.

3.2.3 VENUS version "C"

Version "C" has been intended replacing the current Vega Z9 solid 3rd stage and the AVUM 4th stage by a single new cryogenic (LOX/LH2) propellant stage equipped with the 180 kN Vinci engine. Analyses show that the optimum loading is around 16000 kg fuel. Payload might reach an impressive 3560 kg [4] assuming simplified stage mass estimation. However, the large upper stage propellant mass and low density of LH2 causes the size of the upper stage and therefore total launcher length to become very long. This could lead to problems regarding high bending moments. In addition the upper stage diameter is larger than the diameter of the Z23 2nd stage. This is unavoidable because of the large nozzle diameter of the Vinci engine. Potential problems of such a configuration could be aerodynamic buffeting, vehicle control and difficult stage integration [4]. Thus, VENUS C has been reoriented towards an upper stage with shortened Vinci nozzle mounted on an increased diameter Z40 motor. (See paragraph 3.3.2!)

3.2.4 VENUS version "D"

Version "D" has been intended replacing the current Vega Z9 solid 3rd stage and the AVUM 4th stage by a single new cryogenic (LOX/LH2) propellant stage equipped with adapted expander-cycle cryogenic engines: 100 kN and 60 kN vacuum thrust [4]. The expansion ratios are limited to 200, to fit in any case within the diameter of the Z23 second stage.

The VENUS D 60 kN version has a payload maximum of 2760 kg, whereas the 100 kN version has a capacity of about 3200 kg [4] assuming simplified stage mass estimation. In these two cases the launcher again becomes quite long and this could lead to problems regarding high bending moments or control issues. Another problem of VENUS D is that a complete new thrust chamber would have to be developed, making this option less attractive and investigations on the D version have not been continued.

3.2.5 VENUS version "E"

Version "E" has been intended replacing the current Vega Z9 solid 3rd stage and the AVUM 4th stage by a single new LOX/CH4 (Methane) propellant stage equipped with an optimized expander-cycle cryogenic engine. The methane engine has been assumed with some similar parameters as the 100 kN LH2 engine [4].

The E version has a payload considerably above the storable AESTUS 2 variant B80; however, compared to its quite similar 100 kN LOX/LH2 counterpart performance is clearly much lower. Even the 60 kN LOX/LH2 powered upper stage achieves a higher payload. The length of the VENUS E launcher is only marginally shorter, and therefore does not offer a significant benefit [4, 9]. Investigations on this type have been stopped.

3.2.6 VENUS version "F"

Version "F" intends replacing the current Vega Z23 solid 2nd stage, Vega Z9 solid 3rd stage, and the AVUM 4th stage by a single new cryogenic (LOX/LH2) propellant stage equipped with a 180 kN Vinci engine. For the VENUS F TSTO version, the optimum upper stage fuel mass has been found around 16000 kg [4]. The F version has a relatively low lift off mass of below 120 tons, requiring an adjustment of the P80 end burn profile in order not to exceed 6 g axial acceleration. Such a tailored profile should be in full compliance with the technology required for the WOTAN solid first stages. Payload capacity is similar to VENUS D with 60 kN engine [4] but probably at lower cost.

The VENUS F TSTO launcher shows very interesting performance. The small TSTO has the additional advantage of being very compact and having the shortest length of all versions [4]. More detailed investigations are intended in the future, also taking into account more powerful first stages like P100.

3.3 Configurations with P100 + Z40

A future increase in the size of VEGA's first and second stages P80 and Z23 is already under discussion before its inaugural flight. The propellant grain loadings, as they have been calculated but not yet tested, could reach almost 100 tons (P100) for the first stage and almost 40 tons (Z40) for the second stage motor.

The optimum liquid upper stage propellant loadings of the so called B100 and C100 stages have been found by SART in combination of mass estimation and trajectory simulation [10].

3.3.1 Upper stage type B100

The AESTUS 2 (see section 3.2.2) is again selected as the B100's engine. The maximum payload is achievable with a propellant loading of about 6000 kg. The structural sizing and pre-design of EADS astrium delivered a short (Figure 6) but quite heavy upper stage with a structural index of 25.5 % [10]. As a result, the payload to the polar reference orbit is found at a poor 1450 kg, below that of the original VEGA and below VENUS B80. This is a sobering outcome, considering the more powerful P100 and Z40 solid motors in the first and second stage.

3.3.2 Upper stage type C100

The full size VINCI-engine has been found geometrically too large for VENUS C (see section 3.2.3 and [4]). The definition of the upper stage architecture of VENUS C100 is based on the removal of the lower two of VINCI's three nozzle segments A, B, C without changing the turbomachinery or the thrust chamber. Performance data of this engine variant is calculated at an I_{sp} of 452 s; further reduced by an additional margin of 4 s in the VENUS flight performance calculations. That approach is conservative because an engine variant including also half of the B nozzle segment is very much realistic and would considerably improve I_{sp} [5].

The maximum payload into a high energy MTO (e.g. delivery of Galileo replacement satellites) is achievable with a propellant loading of around 10000 kg, assuming structural indices in the range 16 % to 20 %. The structural sizing and pre-design of EADS astrium delivered a long (Figure 6) and heavier upper stage with a structural index of 29.7 % [10]. Therefore, no payload can be delivered into the intended MTO. However, this stage at least allows 1967 kg performance into VEGA's polar reference orbit. Therefore it is coming close to the target of 2000 kg which is not reachable by the storable B80 and B100 stages.

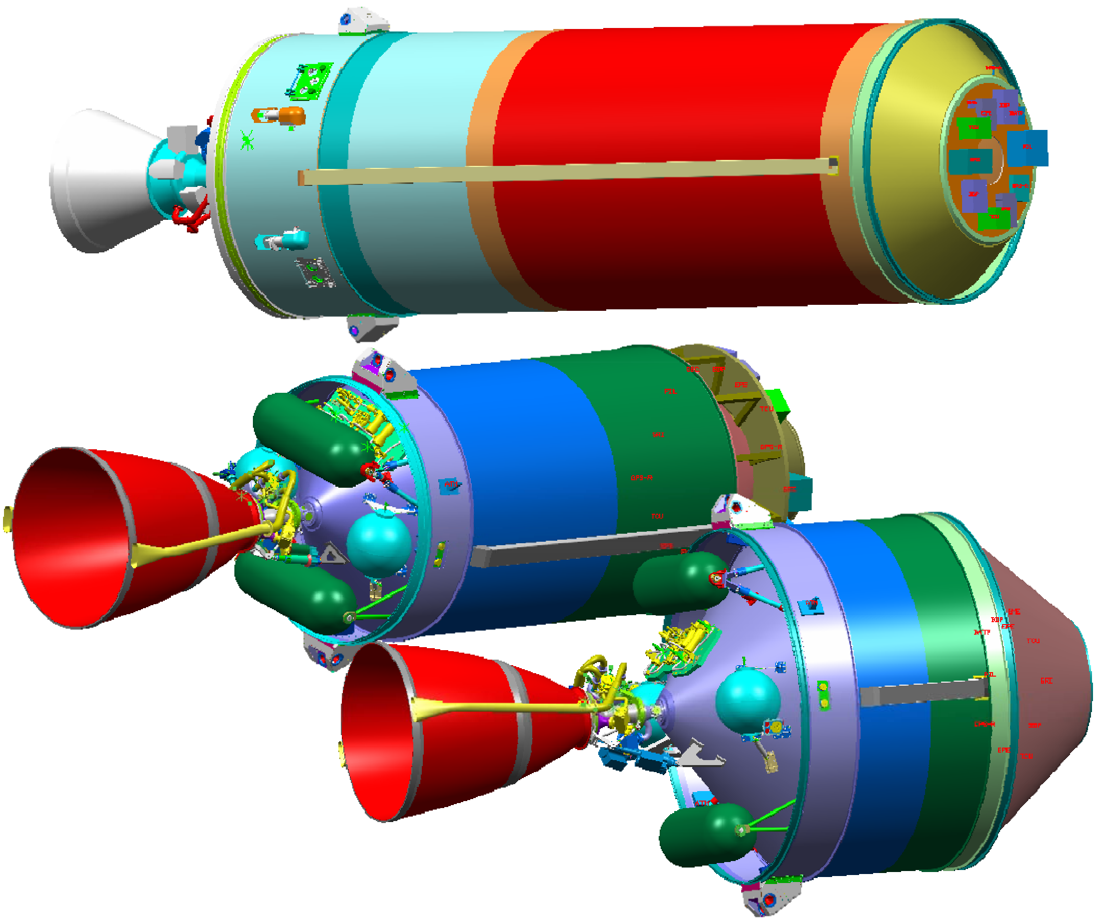

Figure 6: VENUS “C100”, “B80”, and “B100” (from top to bottom) conceptual architectures of VENUS upper stages defined by EADS astrium

3.4 System and Performance Synthesis

The primary intention of any future evolution on VEGA has been to assure a payload capability of at least 2000 kg in a polar orbit. The results of the VENUS study available up to now, based on a pre-design of the new upper stages, show that this target is hardly achievable with storable propellants. This outcome has been found for the existing lower composite with P80 + Z23 as well as for a potential P100 + Z40. These configurations’ performances are all relatively close to the VEGA baseline vehicle.

Trajectory simulations indicate that the proposed preliminary thrust law of the Z40 motor would have to be considerably adapted because currently the axial acceleration exceeds 6.8 g. Thus, currently the storable VENUS options are discouraging in payload performance and are not compatible with the required payload environment.

The cryogenic upper stages are more promising with respect to the payload performance to the polar orbit. However, they clearly miss the more demanding requirement of 2000 kg into an MTO. The VEGA launcher is obviously too small to support such missions, even with a significant upgrade of the lower stages.

Note that for all VENUS configurations the amount of fuel needed for stage deorbiting is not included, which – if to be considered – would further reduce the actual payload mass.

4 Conclusion

The paper describes some recent activities in Germany in the technical assessment of future European launcher architecture.

The first part gives an overview on the final results of a joint effort of DLR-SART with German launcher industry (EADS astrium and MT Aerospace) in the definition of a next generation upper-medium class expendable TSTO with an initial operational capability after 2020. This study called WOTAN has investigated fully cryogenic launchers as well as those with a combination of solid and cryogenic stages, fulfilling a requirement of 5000 kg single payload into GTO.

The study's later phases focused on staged combustion cycle propulsion as well as large solid motors in the first stages. Based on detailed analyses including stage pre-dimensioning, mass estimation, and iterative trajectory optimization to several orbital missions the conclusion can be drawn that a significant payload mass can be delivered to GTO by an expendable TSTO. However, mastering of advanced technologies for building very large and high performance solid motors or advanced cycle liquid engines will be essential to stay within acceptable size and hence cost targets for the launcher. The WOTAN design iterations confirmed again that a TSTO with potential strap-on boosters is probably more flexible but also much more sensitive to the availability of advanced technologies than a 2 ½ stage launcher like Ariane 5.

In its second part the paper describes options for new liquid fuel upper stages to be put on the lower composite of the future European small launcher VEGA or some of its proposed advanced derivatives. Versions with storable as well as cryogenic propellants are investigated in the VENUS study and most of them are sized for optimum performance to the VEGA polar reference orbit.

The technical, performance, and cost evaluations of the first round of upper stage investigations, all mounted on the P80 first stage, allowed a preliminary down selection. The storable propellant version with existing AESTUS, the LOX/LH2 stage with a new, smaller expander cycle engine, and a variant with a new methane engine are no longer considered in VENUS due to poor performance, high cost or significant technology risk.

Preliminary but detailed architectures have been designed by EADS for two stages with storable propellant using the potential AESTUS 2 engine and for a cryogenic stage with VINCI with fixed and shortened nozzle. All storable stages, even those based on a more powerful lower composite of P100 and Z40 solid motors fail to reach a considerable performance gain compared to VEGA. A new cryogenic upper stage delivers better results, however, clearly missing its more demanding requirement of 2000 kg into an MTO.

The recently started VENUS 2 study will mainly address options for a new Europeanized AVUM module on top of the Z9A third stage of VEGA. In addition to the stage architecture design and system analyses, trade-offs on the technology options of a new small storable engine will be investigated.

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Further updated information concerning the SART space transportation concepts is available at:
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