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Investigations of Future Expendable Launcher Options

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The paper summarizes recent system study results on future European expendable launcher options investigated by DLR-SART.
In the first part two variants of storable propellant upper segments are presented which could be used as a future evolvement of the small Vega launcher. The lower composite consisting of upgraded P100 and Z40 motors is assumed to be derived from Vega.
An advanced small TSTO rocket with a payload capability in the range of 1500 kg in higher energy orbits and up to 3000 kg supported by additional strap-on boosters is further under study. The first stage consists of a high pressure solid motor with a fiber casing while the upper stage is using cryogenic propellants. Synergies with other ongoing European development programs are to be exploited.
The so called NGL should serve a broad payload class range from 3 to 8 tons in GTO reference orbit by a flexible arrangement of stages and strap-on boosters. The recent SART work focused on two and three-stage vehicles with cryogenic and solid propellants.
The paper presents the promises and constraints of all investigated future launcher configurations.

Nomenclature

D	Drag	N
I_{sp}	(mass) specific Impulse	s (N s / kg)
M	Mach-number	-
T	Thrust	N
W	weight	N
g	gravity acceleration	m/s^2
m	mass	kg
q	dynamic pressure	Pa
v	velocity	m/s
α	angle of attack	-
γ	flight path angle	-

Subscripts, Abbreviations

AP	Ammonium Perchlorate
AVUM	Attitude and Vernier Upper Module (of VEGA)
CAD	Computer Aided Design
ELV	Expendable Launch Vehicle
GLOW	Gross Lift-Off Mass
GNC	Guidance, Navigation, Control
GTO	Geostationary Transfer Orbit
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
NGL	Next/New Generation Launcher
SI	Structural Index (m_{dry} / $m_{propellant}$)
SRM	Solid Rocket Motor
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
cog	center of gravity
sep	separation

1 INTRODUCTION

Two new launchers, Soyuz and Vega, are scheduled to enter operation in the coming months at the Kourou spaceport, increasing the range of missions able to be launched by Western Europe. Nevertheless, continuous improvement of the launch vehicles is necessary in the future which requires starting such investigations already today.

DLR's launcher analysis group SART is focusing its research on a few promising development lines. Some concepts have been studied jointly with industry; other investigations are carried-out independently by internal DLR funding.

A DLR space agency funded study called VENUS is looking at future upgrades of Vega. This analysis is now focusing on three and four stage configurations based on solid rocket motors for the lower stages and on different storable liquid propellant upper stages.

Another interesting, simpler concept is currently studied by SART, namely a two-stage to orbit launch vehicle (TSTO) making use of synergies by implementing stage or component hardware already existing or under development. This approach should reduce development cost, but even more importantly, promises to raise production numbers of components and thus decrease manufacturing cost and enhance quality. The studied TSTO configurations, which aim for a performance range in-between Vega and Ariane 5, are all based on a solid rocket motor for the first stage and a cryogenic liquid propellant upper stage with VINCI engine currently under development for Ariane 5 ME.

Under the terms “NGL” and “Ariane 6” a still somehow nebulous future medium lift launcher configuration is investigated in Europe within ESA’s FLPP research program and in France by CNES and industrial contractors. This launcher with a potential GTO payload capability range between 2 and 8 tons has also been independently investigated by DLR-SART and preliminary results are presented here.

All presented payload performance data consider the de-orbitation of the upper stage after final injection in order to avoid their uncontrolled reentry or the generation of new space debris.

Note that all presented launcher concepts are under investigation to obtain a better understanding of future ELV options. Study results should support Germany’s preparations of the European ministerial council 2012. For none of the launchers, even the most promising ones, is a development decision currently implicated.

2 VENUS II

The small launcher VEGA with an advanced solid propellant first stage, P80, will become operational soon. VEGA consists of three solid rocket motors and a small liquid propulsion module for precise orbit injection called AVUM. Germany is not participating in this launcher development project.

Already in 2007 DLR and Astrium started looking into a potential upper stage evolvement and performance upgrade of the VEGA launcher in a study called VENUS (references [1] through [4]). A second iteration of VENUS has been initiated in July 2009 which ran through June 2011 and focused on options for storable liquid upper stages in a small launcher.

A comprehensive overview on the results of VENUS II is presented in [5]. This study considers in particular a 3-stage and a 4-stage configuration based on solid rocket motors for the lower stages and different storable liquid propellant upper stages. DLR has been involved in the preliminary sizing of the launchers, organization of concurrent engineering design sessions run in DLR’s Concurrent Engineering Facility (CEF) in Bremen, and all performance and trajectory optimization. Astrium, as prime contractor, has been responsible for the propulsion system definition and conceptual design and the upper stages’ mechanical and functional architecture.

Both small launcher configurations investigated in VENUS II use the P100 solid motor as the first stage which is a derivative of the P80 of Vega with increased propellant loading. The three stage vehicle (sketch in Figure 1) further consists of a new second stage called Z40 which is a proposed evolution of the Z23 motor of Vega. It is characterized by increased fuel mass of almost 40 tons and a longer combustion time in comparison to Z23. The storable propellant upper stage with the proposed turbopump fed MMH-N2O4 engine AESTUS 2 (Table 1) has been slightly redefined in VENUS II compared to similar launcher arrangements studied in the first loop of VENUS (see [2, 3]!). Various fuel tank layouts all with optimal 5400 kg propellant loading have been explored in preliminary sizing. From a comprehensive trade-off the spherical conical type turned out to be the one with lowest structural weight to be placed inside a long cylindrical interstage. A sphere of 2.19 m diameter is intersected by a cone containing the N2O4 with the MMH in the remaining sphere-section volume. This innovative design allows for a highly efficient structure because short cylinder elements with relatively heavy dome connections can be avoided. However, processes for a cost efficient manufacturing and quality assurance of this design could become challenging.

The payload performance of the VENUS II 3-stage launcher in a polar orbit could reach about 2200 kg and 3100 kg into an ISS-LEO inclined 51.6 degrees. These values are several hundred kilograms above what is to be expected for Vega. With its GLOW between 162.4 and 163.2 Mg the payload fraction is in the range 1.35% to 1.9%.

Table 1: Characteristic calculated performance data of small launcher upper stage engine options

		AESTUS 2	**BERTA**
vacuum thrust	kN	55	8
vacuum spec. impulse	s	336.4	321.3
chamber pressure	bar	60	15
ENGINE SIZE			
total engine length	m	2.171	1.194
nozzle exit diameter	m	1.361	0.65
nozzle expansion ratio	-	280	ca. 110

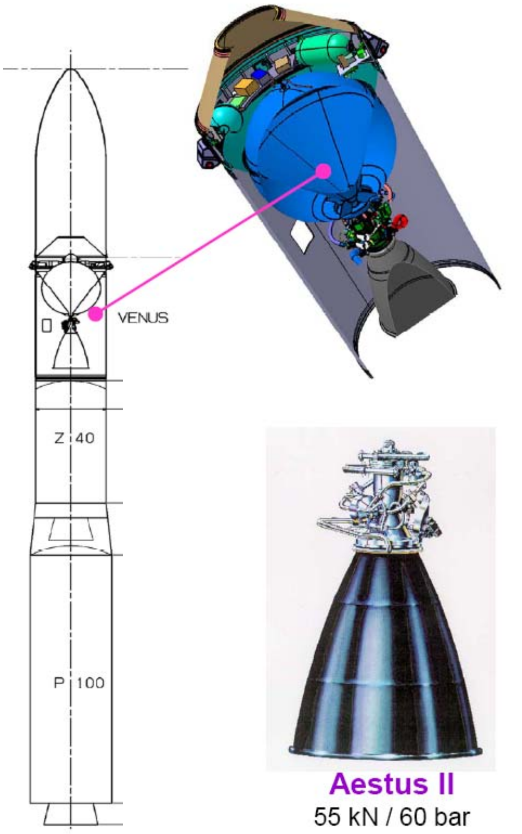

Figure 1: Sketch of VENUS II three-stage launcher configuration with Aestus II engine in upper stage

The VENUS 4-stage configuration shown in Figure 2 resembles more the shape and architecture of Vega. Three solid motors (P100+Z23+Z9A) are completed by a storable liquid propellant upper stage intended to replace the current AVUM. Investigations on a suitable engine which does not yet exist in Europe have been performed with several trade-offs on the thrust level, chamber pressure, and combustion chamber cooling concept [5]. The selected pressure-fed engine should achieve 8 kN of thrust and has been dubbed BERTA (see data in Table 1).

A similar upper stage spherical-conical tank architecture as for the 3-stage vehicle has been selected but with 1700 kg MMH/N2O4 propellant instead of 580 kg UDMH/N2O4 in AVUM. The calculated structural index of this L1.7, however, is unfavorably impacted by its smaller size and the increased tank pressure of 26.5 bar and thus less promising than the SI of the larger L5.4 of the 3-stage vehicle.

The optimized payload performance is above 1700 kg for the polar mission and approximately 2400 kg into an ISS-like orbit. This corresponds to a potential payload gain of roughly about 100 kg compared to a similar, hypothetical P100-based 4-stage launcher but using the existing AVUM. The GLOW is about 10 tons below the three-stage VENUS vehicle (152.8 Mg to 153.5 Mg) resulting in a modest payload fraction between 1.1% and 1.56%.

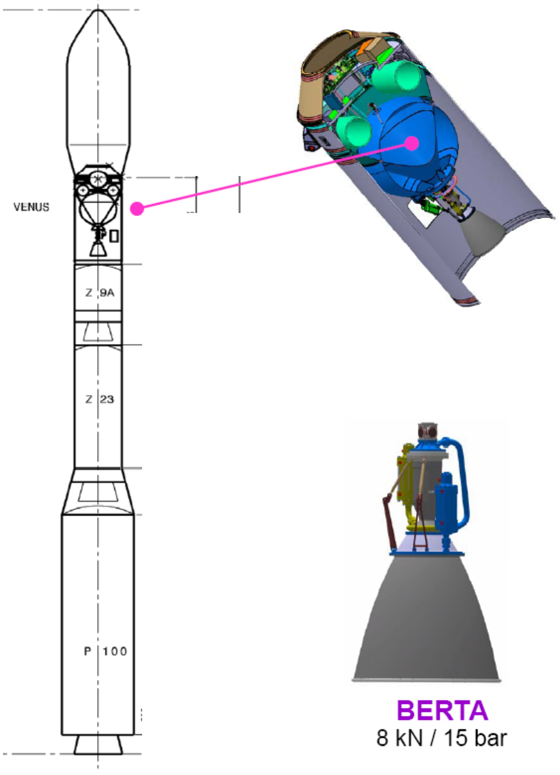

Figure 2: Sketch of VENUS II four-stage launcher configuration with BERTA engine in upper stage

All investigated VENUS II configurations are not capable of any significant payload delivery to high energy orbits like GTO or MTO. Therefore, those missions have not been considered in the study.

3 ADVANCED SMALL TSTO LAUNCHER

The need for a performance upgrade of VEGA and the simplification of the overall lay-out combined with a reduction in the total number of stages has been the major driver in the study of an advanced small expendable TSTO launcher. Six different liquid engine options with three different propellant combinations have been analyzed by SART. One major result published in [1, 2, 3] is the strong interest in a combination of a solid first stage and a cryogenic upper stage. This small TSTO has the additional advantage of being very compact and having the shortest length of all investigated versions presented in [1, 4].

The preliminary design and more detailed investigation of such an advanced small TSTO was initiated at DLR early in 2010. An important requirement to be considered for this launcher is the implementation of European launcher hardware already existing or under development. This approach should allow for reducing development cost, but even more importantly, to raise production numbers of components and thus decrease manufacturing cost and enhance quality. The main propulsion system should include the advanced, expander cycle VINCI upper stage rocket engine ([13], data in Table 4) currently under development for Ariane 5 ME [10]. Some parts of the propellant feed and tank pressurization system, as well as substructures and equipment of this large upper stage might also be used again on the smaller TSTO. However, such dual application of similar components on different launchers is not always easy to be realized. One aim of this study is to identify potential design synergies for advanced cryogenic stages to be later critically analyzed for their feasibility.

3.1 Evolution of small TSTO configurations

Version “F” of VENUS, as investigated in 2007, intended to replace the current VEGA’S Z23 solid 2nd stage, Z9A solid 3rd stage, and the AVUM 4th stage by a single new cryogenic (LOX/LH2) propellant stage equipped with a 180 kN VINCI engine [1]. For the VENUS F TSTO version, the optimum upper stage fuel mass had been found to be around 16000 kg. 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. Payload capacity in the polar VEGA orbit could reach almost 2600 kg [1].

A future increase in the size of VEGA’s first stage P80 is already under discussion before its inaugural flight. The propellant loading, for which a thrust law has been calculated but not yet tested, could reach almost 100 tons (P100) for the first stage motor. A VENUS F TSTO, taking into account more powerful first stages like P100, was already proposed in references 2 and 3.

Three different optimum upper stage propellant loadings on top of P100, corresponding to three different possible structural index evolutions have been calculated; each for its maximum payload into the VEGA reference orbit. The range of interesting propellant mass has been found to be between 14000 kg and 19000 kg. A preliminary stage architecture design has been started for 14, 17, and 20 tons LOX-LH2 mass and with two different tank configurations for each of them [6]. A separate tank architecture, as shown in Figure 3, has been regarded together with a common bulkhead design.

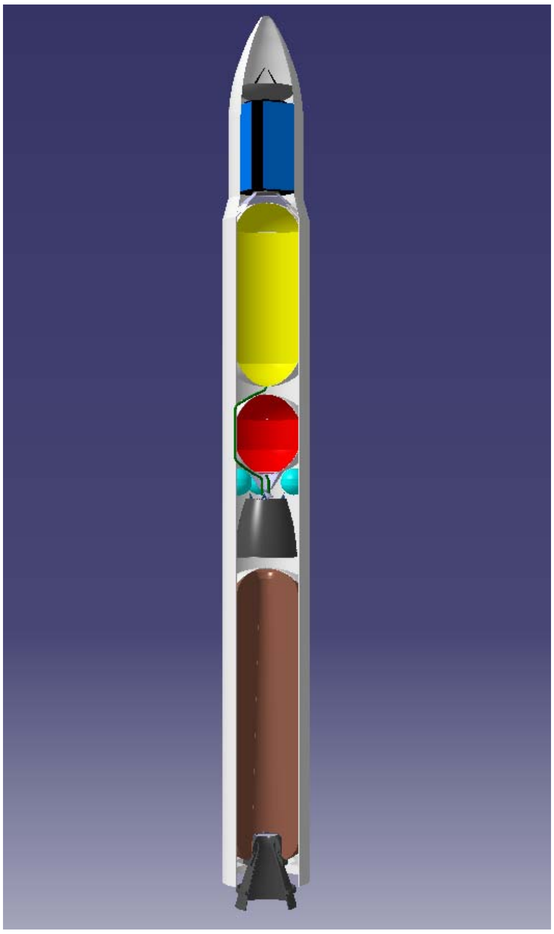

Figure 3: Preliminary architecture of advanced small launcher TSTO with H17 upper stage on top of P100 [6]

All investigated launchers are very compact and are in the same range of length as the current VEGA. The cryogenic stage's outer diameter is kept at the same value as the P100 motor beneath. The faring is reused from VEGA but might also be enlarged to a 3 m external diameter. Separated payload masses for different orbits have been calculated and data are provided in Table 2. The polar and the ISS mission are calculated with two engine burns while MTO and GTO are reached by direct injection single burn of the upper stage.

Table 2: Preliminary calculated payload performances of TSTO P100+H17 configuration [6]

	polar	ISS	MTO	GTO
Orbit para-meters	700 km, 90°	300 km, 51.6°	250 km x 23616 km, 56°	250 km x 35943 km, 5.4°
separat. payload	3074 kg	4122 kg	991 kg	947 kg
GLO mass	133008 kg	133960 kg	130806 kg	130756 kg
Payload fraction	0.0231	0.0308	0.0076	0.0072

The maximum static axial acceleration levels during the P100 burn time have been found to be between 6.8 and 7.4 g depending on the payload mass. These values have been assessed as unacceptably high for the payload environment. Actually, the situation with the proposed P100 is even more critical than with the P80 profile [1] because of an increased thrust level at the end of burning.

A potentially interesting market for an advanced small TSTO with a cryogenic upper stage could be the deployment of small satellites into high energy orbits which will not be possible by VEGA. The single deployment of future Galileo replacement satellites could be of considerable interest. However, an MTO performance of less than 1000 kg is insufficient because each satellite has to be accompanied by an apogee motor for circularization.

Both critical points indicated that P100, as currently proposed, is not well suited for the acceleration of a relatively light-weight cryogenic upper stage. Thus, different motors with increased total impulse have been investigated in the continuation of DLR-SART's TSTO study.

3.2 TSTO with increased performance

Despite the promising performance compared to other concepts of the potential VEGA evolution [6], the next investigation step of the advanced small TSTO focused on an escalated payload range between 1.5 and 3 tons into high energy orbits. The first stage should be newly designed with a single segment grain propellant and a carbon-epoxy filament wound monolithic motor case, similar to the current Vega P80FW and still keep its diameter of 3 m. The considered more powerful motors have originally been planned to contain up to approximately 140 tons of solid propellant. It was however then found that higher propellant mass had to be considered in order to reach the target payload. Solid strap-on boosters should allow reaching the upper performance target range.

All different configurations studied during these sizing steps are described in [7]. For three selected types of first stage (P120, P150 and P160) preliminary launcher architectures have been defined, as shown in Figure 4. Versions with two P30 strap-on boosters are also considered which deliver the loads for the preliminary structural sizing of the major components. Both separate and common bulkhead tanks have been considered, and the later architecture was chosen preliminarily as the reference, as it shows a sizeable advantage in term of payload performance in direct injection missions like GTO without long ballistic phases.

The thrust histories of the first stage and that of the boosters have been chosen to keep the maximum dynamic pressure and the maximum acceleration at an acceptable level. Three optimum staging combinations have been selected P120+H24, P150+H26 and P160+H26. Two newly defined P30 strap-on boosters can be added to all of them. Their calculated payload performances to GTO are listed in Table 3.

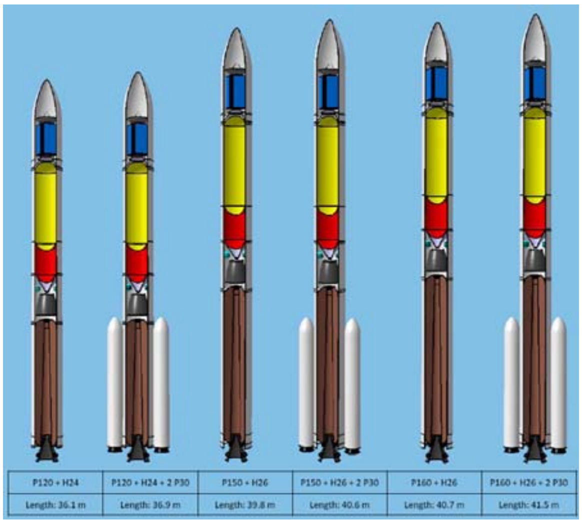

Figure 4: Preliminary architecture of advanced small launcher TSTO with P120 to P160 and H24 to H26 upper stage [7]

Table 3: Preliminary calculated payload performances of advanced TSTO configurations to GTO [7]

	P120+H24	**P150+H26**	**P160+H26**
separat. payload	891 kg	1376 kg	1598 kg
GLO mass	162010 kg	197440 kg	208450 kg
Payload fraction	0.0055	0.0070	0.0077
as above	**+ 2 P30**	**+ 2 P30**	**+ 2 P30**
separat. payload	2031	2588	2792
GLO mass	229598	265120	276110
Payload fraction	0.0088	0.0098	0.0101

Different concepts to realize the upper stage de-orbit maneuver after payload delivery have been assessed. It has been found that using the VINCI engine, for this maneuver, is probably not advantageous in spite of the high specific impulse. Indeed the engine pre-conditioning and the start-up require a relatively large amount of propellant without providing a propulsive impulse. A technical solution based on cold gas thrusters using the gaseous hydrogen present in the upper stage could be interesting but cannot compete with a small solid rocket de-orbit motor kit [7], even if the propellant composition avoids metal powders like aluminum in order not to release solid reaction particles and hence creating new space debris. The solid motor kit de-orbiting option is selected as the baseline for calculating the TSTO performances of this section.

The obtained results for the increased size TSTO are promising because the largest version is approaching the payload target. Maximum accelerations are kept at 5 g or below even for the boosted versions. However, in some cases with boosters the maximum dynamic pressure is relatively high reaching 70 kPa [7]. Further, all launch vehicles are quite long (up to 42 m) which may become challenging for vehicle controllability. An increase of the diameter from 3 m to 3.5 m would allow for reducing the total length of the launcher and also facilitate the design and the fabrication of the first stage. This will however have an impact on the performance due to the increased cross section and on the structural index.

3.3 Latest TSTO evolution

Based on the above findings, work on the latest step in the advanced small TSTO definition has recently been initiated. The diameter of both stages will be enlarged to 3.5 m or even slightly beyond. Propellant loading might further increase to match the 1.5 to 3 tons GTO payload range target forced by a growth in estimated upper stage mass. Different thrust law options are currently investigated to find the best solution taking into account performance and load constraints. The strap-on boosters might be reduced in size but with an increased number. Although the performance impact is slightly negative, this approach allows for better mission flexibility. If some of the strap-ons are ignited in flight, more complex thrust profiles become possible which could not be realized with a single motor grain.

4 "NGL"

Under the term "NGL" a still somehow nebulous future medium lift launcher configuration is investigated in Europe. ESA is managing since a couple of years the FLPP research program focusing system studies on expendable launchers [8]. In France 82.5 million € have been allocated as the first tranche of a 250 million € programme to carrying out preparatory work linked to the post-Ariane-5 next-generation launcher there called Ariane 6 [9].

According to ESA [8] the "mission requirements for the NGL ask for a single P/L launch system with a high degree of versatility in terms of P/L performance but also in terms of different orbits that shall be served and with reduced Total Cost of Ownership (TCO) […]. Accordingly, the required performance range currently required for the NGL, expressed in terms of P/L mass delivered in standard GTO, starts at 3t followed by an intermediate performance of around 5t and a maximum performance not greater than 8t in GTO. The […] NGL shall be capable of performing missions into a variety of other orbits such as MEO, GEO, LEO and SSO".

The primary intention of all "NGL" system study work performed at DLR has been in establishing an independent model for the assessment of payload performance and critical design issues of such vehicles. These results will support the programmatic decision process and should help in the system assessment of new technologies and improve future launcher designs. Completing the development of Ariane 5 ME [10] as the next evolution step of this launcher has priority over starting new large development programs. Other interesting options than "NGL" for the future launcher evolution exist [11, 12] which should be further investigated and subsequently evaluated for a potential realization after the successful development completion of Ariane 5 ME.

The recent SART work focused on two and three-stage vehicles with cryogenic and solid propellants. A broad payload class range from 3 to 8 tons in GTO reference orbit should be served by a flexible arrangement of stages and strap-on boosters. DLR-SART is convinced that a combination of HTPB-AP-based solids and LOX-LH2 cryogenic liquids with considerable industrial expertise in Europe allows fulfilling a large range of missions with significant growth potential. Currently, no other propellant like hydrocarbon is offering such major advantages that the cost and risk of developing propulsion systems for new fuels could be justified. Therefore, the (at least for Europe) more exotic propellant options have not been included in the analyses.

Hence, one common element of all "NGL" regarded here is a cryogenic upper stage propelled by the VINCI expander cycle engine currently under development for Ariane 5 ME [13]. Engine data as used for all investigated cryogenic upper stages are listed in Table 4. For active de-orbiting of all NGL upper stages after payload delivery the VINCI engine is assumed to be used. The necessary engine pre-conditioning has an adverse effect on payload performance and potentially small solid motor kits might improve the situation (compare section 3.2!). The NGL de-orbiting choice is similar to the current Ariane 5 ME baseline but decreases performance compared to the latest TSTO variants of sections 3.2 and 3.3.

Table 4: Characteristic performance data of VINCI upper stage engine

vacuum thrust	kN	180
vacuum spec. impulse	s	464
chamber pressure	bar	62
ENGINE SIZE		
total engine length	m	4.2
nozzle exit diameter	m	2.18
nozzle expansion ratio	-	243

4.1 Three-stage PPH configuration

The three-stage PPH configuration tries to avoid the expensive development of new high-thrust liquid rocket engines. Further, it should take advantage of synergies with other European programmes. The first stage is the largest carbon-epoxy filament wound monolithic motor currently considered in Europe: a P180 with a diameter of 3.7 m. The second stage is the P88 motor used as first stage on VEGA (there named P80 FW) with an increased nozzle expansion for high altitudes, giving a vacuum Isp of 285 s. On the top of it comes a cryogenic upper stage, H31, propelled by the VINCI engine. The fairing diameter has been set to 4.3 m to provide sufficient volume for the payload.

The thrust law of the not yet existing P180 has been optimized to get the highest payload and keep the maximum acceleration under 4.5 g and the maximum dynamic pressure below 50 kPa. This is achieved due to a fast combustion time of no more than 80 s. Preliminary estimations show that such a launcher would be able to inject almost 1870 kg in a GTO for a GLO mass of 338650 kg giving a payload fraction of 0.55%. Versions with strap-on boosters have been considered as well, but due to the short firing time of the first stage, the design of a booster thrust law providing an acceptable maximum dynamic pressure and acceleration level is difficult. Without any restrictions in maximum dynamic pressure and maximum axial acceleration, payloads up to 5.6 tons could theoretically be injected into GTO with the help of 6 P30 boosters.

The restricted performance of this launcher, which remains well below the requirement of 3 to 8 tons in GTO, can be explained by the high gravity losses during the firing of P88 which has been developed as a first stage motor. Modifications of the thrust law show that a slightly higher payload performance could be reached; however, then requiring a new motor different to the first stage of VEGA. Another staging and increased loading could probably improve the situation in terms of payload performances but then new motor and casing sizes would have to be developed. Currently investigations on the PPH are not continued at DLR-SART.

4.2 Two-stage HH configurations

A straight forward and maybe the most affordable way of getting a new fully cryogenic two-stage-to-orbit launch vehicle is reusing existing engine hardware. The Vulcain 2 is the most powerful rocket engine under production in Europe. As the main propulsion system operational in Ariane 5's core stage EPC, the engine delivers up to 1350 kN thrust in vacuum. The Vulcain 2 is optimized for its application in the Ariane 5 architecture with two large solid boosters necessary for acceleration of all launcher variants. Following the flexibility requirement of NGL some adaptations will be required. At least two engines will be needed to power the first stage if the size of the boosters is to be reduced compared to Ariane 5's EAP or if they are completely eliminated.

In order to arrange 2 engines below the first stage, the expansion ratio has been reduced to 48.5 with only minor impact on vacuum thrust and Isp (Table 5). Further reducing the nozzle expansion ratio would allow for raising sea-level thrust while decreasing vacuum performance. A potential lower limit for shortening the Vulcain 2 nozzle without completely changing the layout is at $\varepsilon=32$ because at this value the regenerative cooling circuit ends.

Both engine variants have been investigated in HH-launcher configuration pre-designs. In a vehicle that should address the NGL payload range no viable version is found without booster support. Even in case of the shortest nozzle and some propellant de-loading in the first stage, lift-off acceleration is poor and no payload could be delivered to high energy orbits. Using two P80 motors as strap-on boosters would allow delivery of more than 5.4 tons into GTO in a H170+H23 launcher configuration. Best performance with the same number of boosters is reached with H240+H25 configuration at almost 6.5 t. Throttling of the Vulcain 2 engines is never required during these missions. Replacing the P80 by smaller strap-on boosters would allow for reduced payload performance while additional boosters could approach the intended 8 t GTO performance.

Table 5: Calculated characteristic performance data of adapted cryogenic first stage engine Vulcain 2 (gg cycle) with reduced nozzle expansion

sea level thrust	kN	1114	1038.5
vacuum thrust	kN	1313	1340
sea level spec. impulse	s	355	330.9
vacuum spec. impulse	s	418.4	427
chamber pressure	bar	117	117
total engine mass flow	kg/s	320	320
total engine mixture ratio	-	6.05	6.05
nozzle exit pressure	bar	0.368	0.215
ENGINE SIZE ESTIMATION			
total engine length	m	2.7	3,2
nozzle exit diameter	m	1.58	1.95
nozzle expansion ratio	-	**32**	**48.5**

Although a significant amount of payload can be delivered within acceptable load constraints, all Vulcain 2 based variants of NGL require a multitude of systems and propulsion components for the fulfillment of the required payload range. Therefore, this NGL launcher system is technically feasible but not overly attractive concerning operational cost and system reliability.

In another approach the design of the fully cryogenic two-stage-to-orbit launch vehicle has been built around new high-thrust first stage engines. In order to reduce complexity with fewer strap-ons, the TSTO should be capable of lift-off without boosters in the reference mission. Under this condition a single first stage engine of reasonable size is not sufficient. The first stage is propelled by two new large gas generator engines based on Vulcain 2 technologies. The characteristics of this engine which has to be throttleable by up to 40% are presented in Table 6.

Table 6: Calculated characteristic performance data of new large gg-cycle cryogenic first stage engine

sea level thrust	kN	1900
vacuum thrust	kN	2238
sea level spec. impulse	s	355.2
vacuum spec. impulse	s	418.4
chamber pressure	bar	117
total engine mass flow	kg/s	545.5
total engine mixture ratio	-	6.05
nozzle exit pressure	bar	0.37
ENGINE SIZE ESTIMATION		
total engine length	m	3.46
nozzle exit diameter	m	2.25
nozzle expansion ratio	-	32

The goal of the staging optimization has been to keep the gross lift-off mass small while using a maximum of two first stage engines, also of minimum size. The eventually selected staging is a H220-H23. It was estimated that the launcher in the reference version will be able to inject about 3760 kg into GTO for a GLO mass of 286120 kg. Up to six P30 boosters can be added (Figure 5) to inject 7860 kg into GTO, bringing the GLO mass at 490490 kg. In every case the maximum acceleration is kept below 45 m/s² due to throttling. The boosted version is however flying with a high maximum dynamic pressure (65.3 kPa), which may potentially lead to controllability problems.

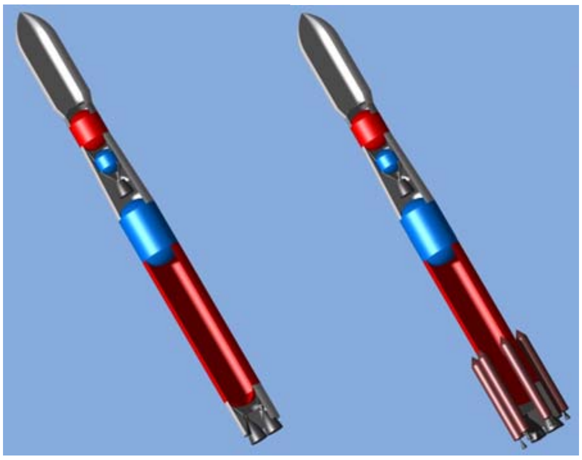

Figure 5: Preliminary architecture of HH-launcher configuration with 1900 kN GG engines in reference (left) and boosted lay-out (right) [14]

This full cryogenic HH-launcher seems to be currently more attractive than the PPH solution as it better matches with the requirements of what is commonly called NGL or Ariane 6. But a critical point could be the development of a new very large cryogenic gas generator cycle engine which has to be 70% larger than the Vulcain 2 and beyond that should be throttleable by up to 40%.

5 CONCLUSION

This paper describes some of the most recent activities in Germany in the technical assessment of future European expendable launcher architectures.

The first section summarizes major system aspects of the VENUS II study on potential future VEGA upgrades. This investigation performed together with Astrium focused on the conceptual design of storable propellant upper stages with gas generator cycle and pressure-fed engines. Different stage architectures have been investigated and an unconventional spherical-conical tank arrangement is preferred. A payload mass increase in polar missions of several hundred kilograms compared to VEGA seems to be achievable.

In its second part, the paper gives an overview on the progress made in the preliminary design of small TSTO launchers. All investigated options include a new cryogenic fuel upper stage with VINCI engine with technical synergies to Ariane 5 ME. The range of suitable solid first stages goes from the P100, a future advanced derivative of the already existing P80FW, to larger new single segment motors technically still based on Europe's experience with VEGA. The investigation directs to an increased payload performance range up to approximately 3 tons in GTO through means of several strap-on boosters. The new TSTO configurations' payload performances are promising and well adapted to LEO needs without boosters and also in high energy orbits like MTO and GTO using boosters. However, the needs of a new motor with increased total impulse will of course impact the overall development budget.

DLR-SART has independently started system study work on large “NGL”-options with the primary intention in establishing an independent model for the assessment of payload performance and critical design issues of such vehicles. The recent SART work focused on two and three-stage vehicles with cryogenic and solid propellants. A broad payload class range from 3 to 8 tons in GTO reference orbit should be served by a flexible arrangement of stages and strap-on boosters.

A relatively small three-stage NGL-vehicle PPH with two solid motors shows restricted performance without strap-on boosters not exceeding 2 tons in GTO. Adding these boosters theoretically allows significantly increasing the payload mass, however, without being capable of serving the full intended range from 3 to 8 tons. Further, staging characteristics and mechanical loads of this boosted version could become critical.

The alternative investigated NGL design option is an HH-configuration with fully cryogenic main and upper stage supported by solid strap-ons. Based on the operational Vulcain 2 engine the flexible launcher concept is feasible if all configurations are supported by solid boosters. However, this approach makes the concept complex and potentially expensive to operate. The development of a new large cryogenic gas generator cycle engine with up to 1900 kN sea-level thrust simplifies the launcher architecture and allows addressing the full payload range with only adding one type of booster. On the downside a challenging engine development with deep throttling capability will be required.

Other interesting options than “NGL” exist for the future launcher evolution of Europe which should be further investigated and subsequently evaluated for a potential realization after the successful development completion of Ariane 5 ME.

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