Advanced Launcher Options under Constraints of Synergy, Commonality and Affordability

Martin Sippel, Etienne Dumont, Vanessa Clark, Aaron Koch, Emmanuelle David, Nicole Garbers, Chiara Manfletti
Martin.Sippel@dlr.de Tel. +49-421-244201145
Space Launcher Systems Analysis (SART), DLR, Bremen, Germany
Birte Höck, Gunter Geiss
MT Aerospace AG, Augsburg, Germany

This paper addresses technical options to increase synergies between European launchers of different size. This approach should help to further improve cost competiveness though keeping the capability of serving a broad range of missions.

Various combinations of stage, engine, and motor hardware exist which can be evolved or modernized to form a small to medium-size launcher. The potential future launcher options usually are an arrangement of solid and cryogenic propellant stages but with different selection for the main stages and usually a cryogenic liquid propellant upper stage with VINCI engine.

DLR's launcher analysis is focusing its research on a few promising development lines. The paper provides an overview on recent results of these activities and presents the promises and constraints of all investigated launcher configurations. Their growth potential is assessed and relative NRC and RC are presented.

Nomenclature

D	Drag	N
I_{sp}	(mass) specific Impulse	s (N s / kg)
L	Lift	N
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

CAD	Computer Aided Design
CE	Concurrent Engineering
CEF	Concurrent Engineering Facility at DLR
EAP	Etage d'Accélération à Poudre (of Ariane 5)
EPS	Étage à Propergols Stockables (of Ariane 5)
GLOW	Gross Lift-Off Mass
GTO	Geostationary Transfer Orbit
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LOX	Liquid Oxygen
MEO	Medium Earth Orbit
MEOP	Maximum Expected Operating Pressure
MR	Mixture Ratio
MTO	Medium Transfer Orbit
NPSP	Net Positive Suction Pressure
NRC	Non Recurring Cost
RC	Recurring Cost
SI	structural index
SRM	Solid Rocket Motor
SSO	Sun Synchronous Orbit
TSTO	Two-Stage To Orbit
VEGA	Vettore Europeo di Generazione Avanzata
cog	center of gravity

1 INTRODUCTION

Currently, Europe is operating three largely different launchers at the Kourou spaceport: Vega, Soyuz and Ariane 5. The next evolutionary step, still under development, is the Ariane 5 MEa which should be operational before the end of the decade. Continuous improvements of the launch vehicles and services are necessary in the future in order to be competitive and technologically attractive.

While re-organization of the industrial infrastructure could be an important factor, increasing technical synergies between European launchers of different size should help to further improve cost competiveness though keeping the capability of serving a broad range of missions. This approach should reduce development cost, but even more importantly, to raise production numbers of components and thus decrease manu-facturing cost and enhance quality.

An interesting, relatively simple two-stage to orbit launch vehicle (TSTO) concept has been studied by DLR's Space Launcher Systems Analysis (SART) department since several years [1] making use of synergies by implementing stage or component hardware already existing or under development. The studied TSTO configurations, which easily exceeded Vega's performance, nevertheless, revealed the need for improvement in booster performance to reach approximately 3000 kg of GTO payload. The first stage, based on a single segment grain propellant and a carbonepoxy filament wound monolithic motor case, grew up to 175 tons of propellant [2].

Various other combinations of stage, engine, and motor hardware exist which can be evolved or modernized to form a small to medium-size launcher. These potential future launcher options typically are an arrangement of solid and cryogenic propellant stages but with different selection for the main stages and usually with a cryogenic liquid propellant upper stage using the VINCI engine.

2 STUDY APPROACH AND REQUIREMENTS

In an early phase starting in October 2013, using a systematic approach small to medium-size launcher options were identified and preliminarily sized [4]. In February 2014 these launcher configurations have been further investigated together with alternative designs in a concurrent engineering workshop held in the Concurrent Engineering Facility (CEF) at DLR Bremen. The aim of the workshop was to quickly investigate different launcher concepts with respect to their performance and cost.

During the early phase investigations (section 3), the stage mass estimations are based on the structural index (SI) trends of known stages. Calculated propulsion data sets of liquid engines and solid motors are generated if they do not yet exist. A dedicated aerodynamic drag estimation of each lift-off configuration using engineering methods and subsequently trajectory optimizations are used to obtain the payload performance. An iterative approach is used for the stage propellant loading or motor thrust level in order to fulfil the target performance.

The most promising launcher configurations are afterwards modelled in the second loop (section 4) in a more sophisticated preliminary design. The work includes update of propulsion data sets if necessary, a first CAD model, a component mass breakdown with some major items like tanks or interstages structurally pre-sized, aerodynamic drag, trajectory optimization and flight controllability assessment. As manufacturing synergies are the major driver, not only the medium-size launcher is investigated but also the impact of potential new or resized stages for Vega and Ariane 5ME.

Both design loops are concluded by a parametric cost estimation (NRC and RC) and final evaluation with potential development roadmap. The operational cost assessment is not only performed for the new launch vehicle but also takes into account the impact on the launcher family including Ariane 5 and Vega.

2.1 Technical Requirements

Mission and high-level design requirements for a medium class, Soyuz from Kourou replacement option are summarized in Table 1.

The new launcher should also have the capability of serving SSO and MEO/MTO missions.

Active de-orbiting of the upper stage after payload injection is required for all investigated launchers. Instead of detailed analyses of the deorbiting process, a mass margin of 500 kg is assumed for this activity. The policy for selection of suitable stage dry mass margin distinguishes between existing or slightly adapted stages with 0%, SI-derived masses of new stages also at 0% and pre-designed new stages with a margin between 5% and 10% on estimated component masses.

Table 1: Mission and technical high level requirements

Reference mission	
Launch place	CSG, Kourou
Reference orbit	GTO
Apogee	35 786 km
Perigee	250 km
Inclination	6°
Payload range	**3.5 t ± 0.2 t**

The diameter of all newly designed stages is assumed to be either 4.1 m or 5.4 m due to the existing heritage in Europe of Ariane 5 and Soyuz ST with those diameters. Choosing the same diameter reduces the tooling costs. In case several engines are located in the first stage an additional skirt may be necessary to cover all the engines.

3 EARLY PHASE CE-STUDY

During the CE-workshop, preliminary calculations of the concepts listed in Table 2 were performed. Even more concepts had been proposed, but due to time-constraints the less promising ones were not treated. The launcher type acronyms reflect the stage's fuel type as commonly used in Europe: H= hydrogen, P= solid, C= methane, K= kerosene.

Table 2: Launcher concepts investigated in the CE-workshop [5]

Launcher designation	Launcher type
HH_2V2	HH
HH_3V2	HH
HH_2V3	HH
P+HH_V2	P+HH
"TSTO common engine" Hydrogen	HH
"TSTO common engine" Methane	CC
"TSTO common engine" Kerosene	KK
"Mini A6" PPH: 3P88P88H23	PPH
PPH: 2P125P125H23	PPH
"A5/2": P240, P80, H28 Vinci	PPH
"A5/2": P250, P120, H26 Vinci	PPH
P240 (composite), P80, HXX Vinci	PPH

During the CE workshop a structural index (SI) and especially for solid rocket motors, an inert mass ratio was used. The structural index as utilized by DLR-SART in this study is defined as the stage's dry mass without engines divided by the complete loaded propellant mass which includes the propellants for nominal ascent flight, the reaction control system, the reserve, residual and those for engine transient startup/-shutdown.

An example of typical SI behavior as function of nominal ascent propellant loading is shown for cryogenic LOX-LH2 upper stages in Figure 1. Data for the trendline is collected from the dry masses of existing stages or former studies with a sufficient level of detail in stage design and analysis. Similar curves have been generated for stages of different size and – even more important – of different propellant type. In case of the methane propellant curves are interpolated between trendlines generated for existing LOX-RP and LOX-LH2 stages because up to now not a single LOX-LCH4-stage has ever been built or flown.

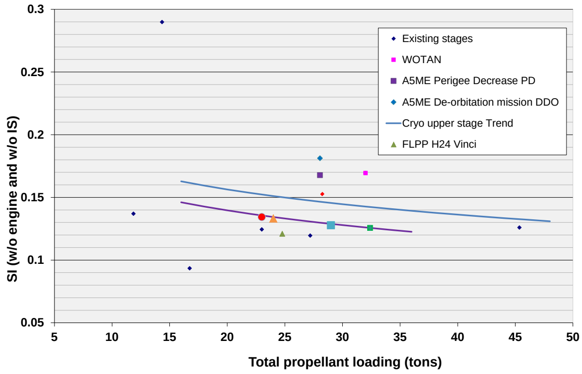

Figure 1: LOX/LH2 structural index evolution for various propellant loadings of the upper stages

The TSTO concepts with a common engine type on both stages require a clustering of this engine on the lower stage. This approach is similar to the 3-stage Ariane 4, however even more so to the Falcon 9 launcher of SpaceX, which also utilizes a TSTO architecture. None of the currently available liquid rocket engines in Europe is, however, suitable for this design. Therefore, a new, medium-size engine needs to be developed which in that case also might use alternative propellant combinations like LOX-methane or LOX-RP. The obvious drawback of the TSTO concepts is their significantly limited synergy to existing Ariane and Vega hardware.

3.1 Overview on major results

Nearly all configurations reach the desired payload performance of around 3.5 tons in GTO as sufficient flexibility in the stage design is available. The RC per flight estimation shows a significantly larger range than the payload performance [5].

In order to select the more promising options for more detailed analysis, pros and cons of the configuration were listed and examined. Those configurations requiring the most development, i.e. the TSTO configurations are discarded, as these do not make use of existing stages and engines. Finally, three configurations, which offer the highest number of synergies, were selected for a more detailed and updated pre-design and subsequent technical and cost assessment.

4 PROMISING MEDIUM-SIZE LAUNCHER OPTIONS

Three configurations of the early phase study are selected for a more detailed and updated pre-design and subsequent technical and cost assessment. All are 3-stage vehicles with the lower composite using solid motors, as with this architecture major commonalities with the existing European operational launchers Ariane 5 and Vega can be identified.

All versions are to use the existing Soyuz ST fairing and a cryogenic upper stage with 4.1 m diameter. The fairing and payload attachment should not be changed with respect to the currently operational version and, thus, is not described here. The next section explains the upper stage architecture options and their intended commonalities with the new Ariane 5 MEa stage.

4.1 Cryogenic upper stage with commonalities to Ariane 5 MEa

All regarded stages are using the Vinci expander cycle engine with 180 kN thrust which will be operated for the first time on Ariane 5 MEa.

During the early phase investigations (described in section 3), the upper stage loading was optimized for GTO missions to be between 21 and 24 tons for the various configurations that are retained for consideration in the second iteration loop. An upper stage with a loading of 23 tons is selected for all these vehicles. Actually for each of these launchers, the payload performance deviation from the optimum value to the performance with an upper stage loading of 23 tons is limited to a few kilograms. This result is easily explained by the similar total impulse of all launcher types' lower composite.

The cryogenic LOX-LH2 upper stage is proposed to be designed to utilize as many commonalities from the Ariane 5 MEa upper stage as practicable. Subsystem-, as well as structural elements should be taken from the MEa-stage, providing that these are suitable considering the reduced diameter and stage propellant loading. The structural elements from the Ariane 5 MEa upper stage that might be used are the engine thrust frame and the LOX tank aft dome. The diameters of these components are smaller than the Ariane 5 stage diameter of 5.4 m, and would fit well into a stage with a 4.1 meter diameter. The pressurization lines and propellant feedlines, including valves and attachments, might also be retained, however shortened to fit with the reduced tank length and diameter.

Newly required stage structural elements consist of the cryogenic LOX and LH2 tanks; excluding the existing LOX tank aft dome. Two configurations have been studied: a common bulkhead tank configuration, wherein the LOX tank front dome is also utilized as the LH2 tank lower dome; and a configuration using separated tanks. The LH2 tank is incorporated above the LOX tank in both instances. The two configurations are shown in Figure 2.

New helium storage vessels are likely to be designed. Although the predicted required helium mass is not found significantly reduced from the Ariane 5 MEa upper stage, the 831 mm diameter spherical vessels could hardly be accommodated on the engine thrust frame with significant clearance to the un-deployed Vinci engine nozzle, or to the attached interstage. The chosen storage vessels are each 220 l, with a mass of 58 kg (including brackets) and a radius of 640 mm for MEOP 400 bar. These tanks have been scaled from the EPS 300 l vessels. The ST-configuration would allow the accommodation of the pressure vessels in the intertank structure (Figure 2).

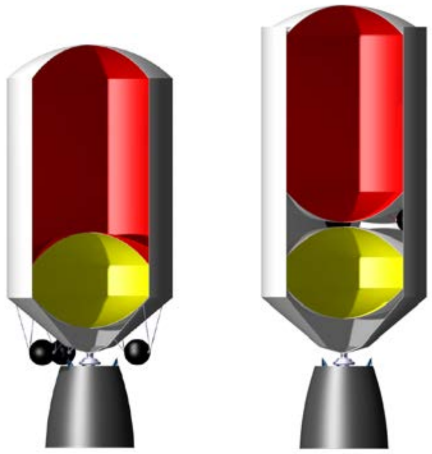

Figure 2: Sketch of common bulkhead (CB, left) and separated tank (ST, right) cryogenic upper stages with major commonalities to Ariane 5 MEa

A new interstage to the lower composite is composed of a 1700 mm cylindrical section and a 3000 mm conical section, to accommodate the Vinci engine and connect to the lower SRM stage.

The use of the Vinci engine already places constraints on the system including feedline diameter, and propellant management and conditioning. In order to satisfy this need and to enable the use of common functional propulsion system components, nearly all operational aspects of the Ariane 5 MEa upper stage are to be re-used. Functional propulsion system aspects should be retained or, where applicable, scaled, from the Ariane 5 MEa stage; including the pressure domain; engine performance transients; tank residuals; propellant boil-off and propellant reserves.

An Ariane 5MEa mission profile involving payload release into GTO and a coasting phase followed by the Vinci engine re-ignition for de-orbitation has also been selected as the basis of this new launcher's system functional aspects. The de-orbitation using the Vinci engine operating with a mass flow rate of 19.8 kg/s and 90 kN was assumed from the selected Ariane 5 MEa mission profile. It has been found that the total mass due to increased pressurant gas needs, boost propellant and engine restart propellant correlated to the previous assumption of 500 kg for the de-orbitation, as stated in section 2.1.

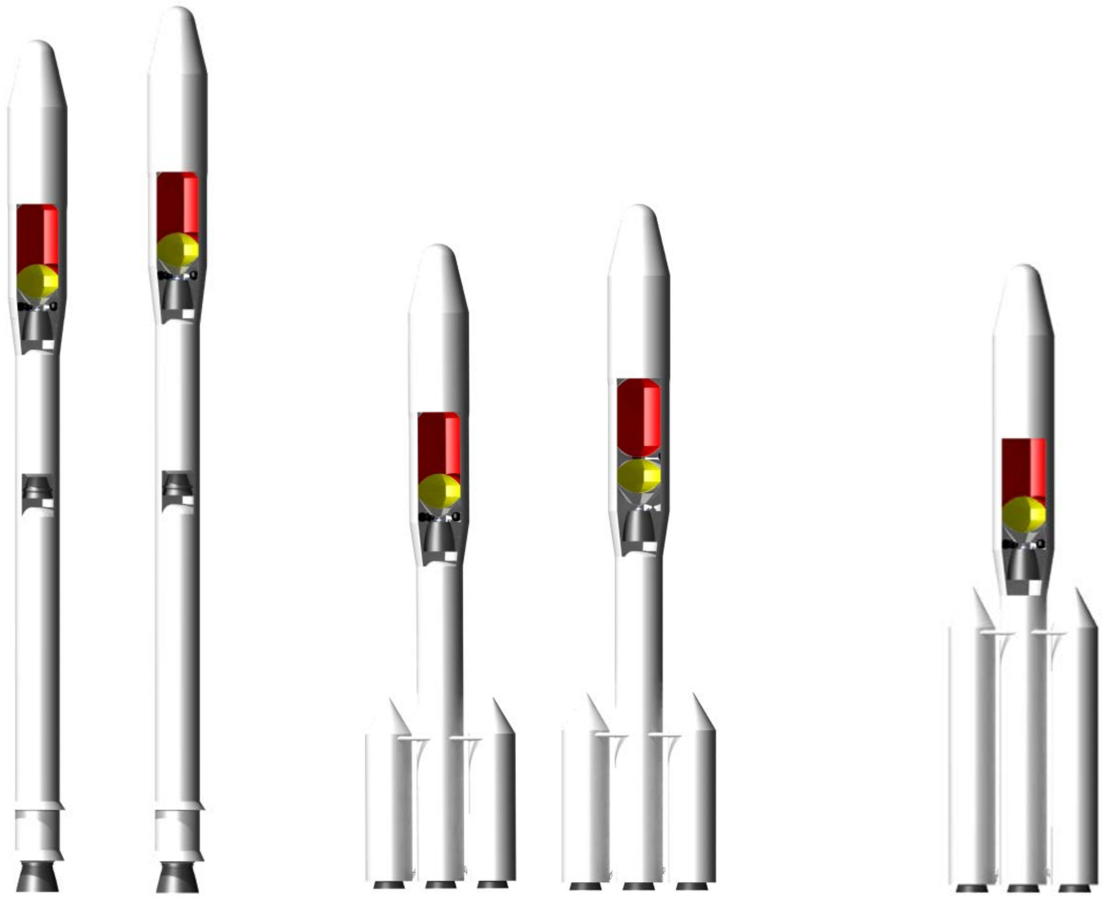

Figure 3: Sketches of different medium size launcher options with cuts to show upper stages, from left to right P250+P80+H23, P250+P105+H23, 3P80+P80+H23CB, 3P80+P80+H23ST, 2P120+P120+H23CB

Table 3: Geometrical data of different medium size launcher options

	P250+P80+H23CB	P250+P105+H23CB	3P80+P80+H23CB	3P80+P80+H23ST	2P120+P120+H23CB
overall length [m]	60.0	61.0	44.00	45.1	41.2
overall width [m]	4.11	4.11	10.1	10.1	9.75

The main commonalities with the AR5 MEa upper stage are with the engine, propulsion system, subsystems and a few structural elements. Despite the fact that the H23 is a new stage, the many similarities to the Ariane 5 would allow for assembly, integration and test at the same site. Thus, increased manufacturing flexibility could be permitted at reduced production cost.

4.2 PPH – P250+P80/P105+H23

A concept already proposed in the early 2000s, has been studied anew based on the latest available data. A new high-performance solid motor is generated by upgrading the Ariane 5 EAP.

4.2.1 Overall architecture

This PPH configuration consists of three independent propulsive blocks. The first stage is a P250 derived from the current Ariane 5 EAP. The second stage is based on the first stage of the Vega launch vehicle: either the operational P80FW or an evolution of this stage, the P105. The third and upper stage is the already described cryogenic H23. The baseline requirement is that the P250 and the P105 are designed to be used in their primary role as an evolution of Ariane 5 ME, and respectively of Vega. The application of these advanced motors in small- to medium-class launchers is to be understood as their second role, and thus should not be the main driver of an optimization process.

This launcher requires development of an advanced version of Ariane 5's EAP, a new cryogenic upper stage to be derived of the Ariane 5 ME, and optional development of a new enlarged SRM based on P80.

4.2.1.1 P250 motor

According to reference 6, it would be possible to upgrade the current Ariane 5 EAP by increasing the propellant loading to 250 tons with the same external geometry and developing a new two-segments casing out of carbon fibres. A two-segments casing for two large segment solid propellant grain elements of about 125 Mg each is compatible with the existing casting capabilities in Kourou.

Large CFRP casings for monolithic single segment solid motors have successfully been manufactured in Europe and are flown with the Vega small launcher. A dual-segment casing configuration combining CFRP and metallic structural elements is a technical challenge.

Due to the request for lower weight and lower cost of a next generation launcher, MT Aerospace (MTA) is developing methods for design and cost efficient manufacturing of solid rocket motor (SRM) casings made of carbon fiber reinforced plastics [9]. Several research and development projects have been established. Based on this heritage, a segmented strap-on booster demonstrator has been designed and afterwards been manufactured using a thermoplastic automated fiber placement process. The demonstrator shown in Figure 4 measures a diameter of 1.3 m and a length of 4 m, and will be burst tested by the end of 2014.

Within another ESA research project a monolithic SRM casing with a diameter of 3.5 m and 6 m in length is already designed and is also foreseen to be built and burst tested. The manufacturing technology for this demonstrator is based on a dry winding and fiber placement process with a subsequent resin infusion.

Figure 4: Segmented strap-on booster demonstrator of 1.3 m Ø made of carbon fiber reinforced thermoplastics

The maximum chamber pressure of the new motor is planned to be limited at about 100 bars, which corresponds to the current state-of the art for carbon fibre casing SRM. Keeping the overall geometric dimensions of today's Ariane 5 EAP booster casings unchanged, MTA performed a mass estimation for a segmented SRM casing. Assuming the maximum expected operating pressure (MEOP) at 100 bar, a mass of 10.3 t has been calculated for the pressure vessel consisting of 2 segments. In comparison the estimated mass of a monolithic case would be approximately 9 ton. Both metallic polar bosses are included in this mass, however, internal and external thermal protection is not considered. For the dimensioning of the pressure vessel, a safety factor of 1.5 against burst has been used. Additionally, a strain limitation at maximum static pressure has been considered.

A new, low-torque nozzle, which would allow using an electromechanical thrust vector control, is also considered. The mass of the nozzle has been assessed based on published data of the current EAP nozzle type D [7], and the proposed P2010 nozzle [6]. In addition, the influence of the reduction of the throat diameter has been taken into account.

The thrust law of the new P250 has been designed so that an Ariane 5 ME equipped with the P250 solid rocket booster (from here referred to as Ariane 5 ME+) would encounter similar levels of dynamic pressure and acceleration as Ariane 5 ME in its current design. The nozzle expansion ratio has been optimized to increase the performance of Ariane 5 ME+ and under restrictions of the nozzle exit diameter, an expansion ratio of 17 has been selected. The main characteristics of the current P240 and proposed advanced P250 are given in Table 4.

Table 4: Main Characteristics of P240 and P250

	Current P240 EAP	Advanced P250
Casing	Tri-segment steel	Bi-segment carbon fibre
Inert mass [Mg]	34.8	24.4
Propellant mass [Mg]	240	250
Pcc max [bar]	69	100
Throat diameter [m]	0.9	0.72
Expansion ratio [-]	11	17
Isp s.l./vac. [s]	255.3/274.6	257.8/284

4.2.1.2 P80FW/P105

For the second stage two options have been considered, namely an unmodified P80FW and a P105 derived from P80. The P105 is under consideration for use in an evolution of Vega, henceforth referred to as Vega+, else called Vega E(volution). The P105, which is filled in with 105 tons of HTPB, has the same diameter as the P80FW: 3 m, but is 1.8 m longer [8]. The maximum combustion chamber pressure has been set at 100 bar (i.e. 13 bars more than P80FW). In order to take into account the higher thrust level, increased internal pressure level, and higher bending loads (due to the longer stage) of P105 compared to P80FW, a slightly larger structural index has been considered. It corresponds to a larger wall thickness, which allows stiffening the rocket. This is beneficial for the controllability of such a long and slender launcher.

The P105 thrust law has been designed to maximize the performance of the advanced medium launch vehicle while keeping the loads for a Vega+ in the same range as for the current Vega. The expansion ratio has been set to 18, as for an even larger expansion ratio the gain in specific impulse brings only a relatively small increase in performance, when the growth of the nozzle mass is considered. The main characteristics of the current P80FW and P105 are compared in Table 5.

Table 5: Main Characteristics of P80FW and P105

	P80FW	P105
Casing	Monolithic carbon fibre	
Inert mass [Mg]	8.4	10.2
Propellant mass [Mg]	87.7	105.2
Pcc max [bar]	87	100
Throat diameter [m]	0.5	0.5
Expansion ratio [-]	16	18
Isp s.l./vac. [s]	250/279.6	256.5/284.4

The two configurations with different second stage motors are shown in the left of Figure 3; geometric data are listed in Table 3.

4.2.2 Commonalities to Ariane 5 ME and Vega

Besides the commonalities with the ME upper stage, the solid motors on the lower composite are foreseen to be used on the two other operational launchers Vega and Ariane 5 without major modifications. Increased yearly production rates should allow for better manufacturing capacity utilization resulting in cost reductions. The advanced P250 and P105 will, furthermore, bring better future performance to Ariane 5 ME and Vega.

Using the P250 as replacement of the current EAP in a future evolution of Ariane 5 ME would allow, according to early analyses, increasing the ME performance to GTO (180 km x 35786 km, 6°) by slightly more than 2.5 tons. This additional performance would strongly ease the pairing of the satellite on Ariane 5 because two large satellites could be launched together. Electric satellite might be launched much closer to their final orbit reducing the transfer times and hence delay before the start of their operation. The gross lift off mass is increased no more than 4 tons compared to Ariane 5 ME while the external geometry of the launcher is unchanged limiting the adaptations required to introduce this upgraded launcher. The maximum acceleration in flight is increased by 0.5 g and the maximum dynamic pressure by 0.5 kPa. Note that using a two segment motor could reduce the combustion instabilities compared to a three segment motor. Therefore, the dynamic vibration level at payload interface should be lower such that the increased maximum static acceleration level could become acceptable.

For Vega it is proposed to replace the first stage P80FW with P105. The performance on the reference LEO 700 km x 700 km, 90° is increased by about 450 kg, whereas the maximum acceleration decreases by about 0.3 g and the maximum dynamic pressure increases by 2 kPa.

4.2.3 System Assessment and Performance

A preliminary structural sizing has been completed, based on the loads encountered for the P250-P105-H23 on its ascent trajectory. Afterwards an analysis of the controllability of the long and slender launcher has been performed. When the interstages are sized only based on the main load cases, the launcher is at the limit of its controllability. Therefore, it has been decided in the early design assessment to further stiffen some elements such as the interstages to guarantee good launcher controllability during the whole flight. The payload performance of the launcher is therefore slightly decreased.

The trajectory optimisation has been performed for the GTO with 250 km x 35786 km, 6°. The performance and main characteristics of the ascent trajectory for the two considered configurations are shown in Table 6. It can be seen that both, the version with P80FW and the one with P105, can inject around the target of 3.5 tons followed by active de-orbiting of the upper stage.

Table 6: Performance and main characteristics of A6S with P80FW and P105

	P250+P80FW+H23	P250+P105+H23
P/L GTO [kg]	3408	3586
GLO mass [Mg]	409.4	429.1
q_max [kPa]	32.5	32.6
acc_max [g]	4.9	4.6

4.3 PPH – 3P80+P80+H23

4.3.1 Overall architecture

Similar to the Ariane 6 PPH "Multi-P linear" launcher as proposed in 2013 [9], this configuration utilizes a number of identical SRMs as its lower and middle stages, topped with cryogenic LOX-LH2 upper stage powered by the Vinci engine. This stage is the new cryogenic upper stage with Ariane 5 MEa commonalities, outlined in section 4.1.

The first and second stages are based on the existing P80FW; the SRM currently utilized as the first stage of the Vega launch vehicle. Contrary to the name, the propellant loading of this motor is in fact 88 tons. A summary of its characteristics are given in Table 5.

The first stage is composed of three parallel P80FWs, with the central booster ignited after the side SRMs following a 10 second delay. This approach has already been proposed for the Ariane 6 PPH "Multi-P linear" to assure controllability under worst case conditions [9]. The side SRMs of the lower stage are coupled with the core through fasteners and load carriers situated on the skirts, the forward shrouds of the side motors, and on the central interstage. Once the first stage side motors and core are expended, all three motors (including the central booster) are separated concurrently through a single separation point on the interstage.

Two options have been investigated for the cryogenic upper stage; namely the common bulkhead and separated tank stages, each with a 23 ton propellant loading, as described in section 4.1. The total length of the vehicle is estimated to around 44 - 46 meters for the common bulkhead and separated tank configurations, respectively. The two configurations are shown in in the center of Figure 3; geometric data are listed in Table 3.

This launcher requires limited development with only the cryogenic upper stage to be derived of the Ariane 5 ME.

4.3.2 Commonalities to Ariane 5 ME and Vega

This launcher has high synergies with Vega, through its re-use of the P80FW. Additionally, the upper stage also exploits synergies with Ariane 5ME. These synergies would enable common production facilities and infrastructure, strengthening both programs and reducing development costs.

4.3.3 Performance

A preliminary structural sizing has been performed for each upper stage design option using the loads encountered by the launcher during its ascent trajectory and on the launch pad.

A GTO trajectory with an apogee altitude of 35786 km and a perigee diameter of 250 km, as outlined in Table 1, has been optimized as the reference trajectory. The performance and main characteristics of the ascent trajectory for the common bulkhead and separated tank configurations are shown in Table 6. It can be seen that only the common bulkhead configuration is close to achieving the high level requirement of 3.5 ± 0.2 ton payload to GTO. The controllability of the launcher during ascent has been preliminarily assessed and no critical issues are found.

Table 7: Performance and main characteristics of 3P80+P80+H23

	3P80+P80+H23 CB	3P80+P80+H2 3 ST
P/L GTO [kg]	3186	2852
GLO mass [Mg]	421.5	421.7
q_max [kPa]	42.7	39.1
acc_max [g]	4.9	4.8

4.4 PPH – 2P120+P120+H23

The main driver of this launcher configuration is a further reduction in stage numbers and hence simplified operations at the launch site.

4.4.1 Overall architecture

Only two different stages are to be used: a common solid rocket motor and a cryogenic upper stage. In order to achieve the same payload mass range, the propellant loading of the solid motor has to be increased by approximately 35% compared to P80FW. In that case a similar total impulse of the lower composite as for the 3P80+P80+H23 is achievable. Latest information from AVIO within an ESA future launcher working group [11] indicate that a new P120 SRM is under consideration for use in an upgrade to the Vega E launcher and also suitable for a new vehicle, a so-called A6PPH EXPRESS. This P120 motor has another interesting application for the medium-class launch vehicle 2P120+P120+H23 described here.

The main characteristics of the proposed P120 are listed in Table 8. The total length of the vehicle is estimated to be around 41.5 meters for the common bulkhead configuration and hence, it is the shortest of all types. The configuration is shown in Figure 3 on the right; geometric data are listed in Table 3.

Table 8: Main Characteristics of P120

Casing	Monolithic carbon fibre
Inert mass [Mg]	10.2
Propellant mass [Mg]	123.7
Pcc max [bar]	93
Throat diameter [m]	0.58
Expansion ratio [-]	18
Isp s.l./vac. [s]	252.1/282.5

The two side-mounted P120 motors are ignited on ground while the core P120 actually forms the second stage. For reasons of worst-case controllability, this stage is already ignited 5 s prior to the outboard motors' burnout. The two side motors actually burn for more than 120 s, but are separated when the thrust law significantly drops off at 115 s. The central stage has been assumed to be ignited 110 s after lift-off. As the core stage should be ignited 5 s prior to the nominal separation of the outboard boosters, sufficient thrust is expected to be available to balance any non-symmetric thrust at the boosters burn-out.

4.4.2 Commonalities to Ariane 5 ME and Vega

This launcher exploits competencies, technologies and facilities from both the Vega and Ariane launcher families. It has high synergies with a future upgrade of Vega by using the P120. As for the preceding concepts, the upper stage also exploits synergies with Ariane 5 ME. These synergies, in additional to enabling common production tools, facilities and infrastructure, also strengthen both existing European launcher programs through performance upgrades. Finally, the development costs will be reduced as they will also be supported in part by future evolutionary Vega launcher development.

4.4.3 Performance

The performance of the 2P120+P120+H23 with common bulkhead (CB) architecture of the upper stage to a GTO has been assessed. The performance and main characteristics of the optimized ascent trajectory are shown in Table 9. It can be seen that the launcher is capable of the payload requirement of 3.5 ± 0.2 ton to GTO. The controllability of the launcher during ascent has been preliminarily assessed and no critical issues are found. The maximum static acceleration is marginally high and might require an adaptation of the thrust law if demanded by payload comfort.

Table 9: Performance and main characteristics of 2P120+P120+H23CB

P/L GTO [kg]	3399
GLO mass [Mg]	438.6
q_max [kPa]	21.0
acc_max [g]	5.4

5 EVALUATION AND COST ASSESSMENT

All investigated launcher configurations with common bulkhead upper stage architecture are at least close to the minimum payload requirement of 3.3 tons into GTO. The launcher with P80 in the lower composite remains at about 120 kg below this target, however still offers a performance improvement over the current Soyuz ST 2.1b. Additionally, this type's performance could be improved with the introduction of a more powerful solid motor like the P105 (see Table 5) as a potential growth option.

The development cost (NRC) (without potential ground infrastructure investment) is estimated for the different configurations as between 1.1 and 2.1 billion €; depen-ding on the required effort for new stages and overall system complexity. The P80-based configurations require the development of a cryogenic upper stage only and hence, the smallest investment. However, due to the fact that five independent stages are to be combined, the cost is penalized by additional system engineering effort. The highest development cost is linked to the P250+P105+H23 for which three new stages will be required. The solid motors of this concept are relatively large; however both have some heritage from the existing Ariane and Vega motors.

In summary, the NRC of the investigated medium-size launchers is the highest when the new motors are also able to improve the performance of either Vega or Ariane 5. The P80-based configuration which has no impact on the Vega or Ariane 5 design requires the least development expense. Ground infrastructure invest-ments have not been assessed. In all cases at least adaptations to the existing infrastructure in Kourou on launch pads or tables are needed.

The medium-size launcher filling a gap between Vega and Ariane 5 ME will likely have a limited number of yearly launches. A moderate rate of three launches per year has been selected for the RC assessment of the different configurations. This value is compatible with the current Soyuz-flight-rate. Due to the production synergies with Ariane 5 ME and Vega, the cost estimation is more complex and needs to also take into account the production rate of these launchers. A realistic baseline of 6 Ariane 5 ME and an additional 2 Vega-flights per year has been used for the cost model. This scenario of 11 yearly launches is foreseen to be highly sustainable, as demonstrated by the past usage of the Kourou launch site for commercial and institutional missions. Making the further assumption that the new European launch vehicle will be operational in 2023, previously-produced hardware can be accounted for in the RC estimation.

In a similar way, an RC advantage through production synergies can be calculated for Vega and Ariane5 which is different for the three scenarios. For example, in case of the 3P80+P80+H23 the production rate of the P80 motor would rise by a factor of seven compared with the current situation where P80 is only used for Vega. The number of cryogenic Vinci engines built per year would increase for all configurations by 50%, related to the rate expected if Vinci would only be used in Ariane 5 ME.

The estimated cost for single-satellite-to-GTO-mission of all configurations is found to be attractive even under the restriction of no more than three launches per year. The maximum deviation is at about 10% from the maximum value of the P80 motor-based rocket (Figure 5).

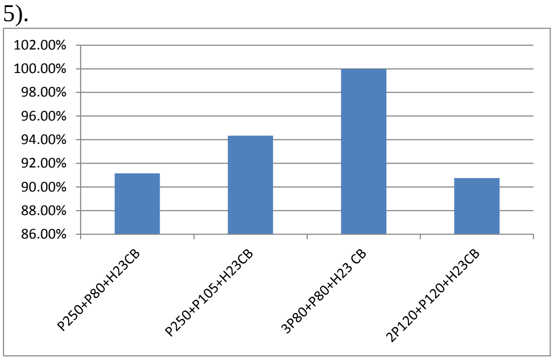

Figure 5: Relative comparison of recurring launch costs of small to medium-size launcher configurations

The two other options with new P250, P105, or P120 motors would achieve almost identical specific launch costs with a small advantage for the most powerful P250+P105+ H23 option.

Production synergies with Ariane 5 ME and Vega, could, moreover, create savings in the order of several million € per launch for these existing or soon-to-be-operational vehicles, due to the increased manufacturing cadence of stages and motors.

6 CONCLUSION

The paper describes some promising options for a small- to medium-size European launcher positioned between Vega and Ariane 5 ME which could serve in the future as replacement for today's Soyuz from Kourou. Major commonalities in stages or components with the existing European operational launchers are considered to keep the new vehicle affordable.

After an early phase study with more than ten different configurations, three of them have been selected for a more detailed pre-design including technical and cost assessment. All of these are three-stage vehicles with the lower composite using solid motors, the existing Soyuz ST fairing and a cryogenic upper stage with the Vinci engine.

The investigated launcher configurations with common bulkhead upper stage architecture achieve payload performances between 3.2 and 3.6 tons into GTO. Several design synergies with Ariane 5 ME and Vega have been identified for the cryogenic upper stage and solid motors. While an upper stage of 23 tons propellant loading fits well for all three different vehicle types, the lower composite could be composed of Vega's P80 FW motor or combinations of new solid motors, which would at the same time allow for an upgrade of Vega and Ariane 5 ME.

The development costs are estimated for the different configurations to be between 1.1 and 2.1 billion €; depending on the required effort for new stages and overall system complexity. The estimated recurring cost for the single-satellite-to-GTO-mission is found to be attractive for all investigated configurations, even under the restriction of no more than three launches per year. This result is only possible by exploiting technical and production synergies to Ariane 5 ME and Vega. The increased manufacturing cadence of stages and motors could moreover achieve significant savings for the existing or soon-to-be-operational launch vehicles.

A recommendation on which of the three small- to medium-size launcher configurations is to be selected for actual development predominantly depends on the strategic decisions for any Vega or Ariane 5 ME evolution. In any case, all proposed launcher options would dramatically increase technical synergies between European launchers of different size and hence establish a highly-flexible, strong-performing, and affordable launcher family.

7 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of Ms. Carola Bauer, Ms. Carina Ludwig, Mr. Alexander Kopp, Mr. Magni Johannsson, and Mr. Josef Klevanski to the preliminary design of the advanced future European launcher options.

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