THE COMMON CORE BOOSTER ARCHITECTURE AS BASIS FOR A COST EFFICIENT EUROPEAN NEXT GENERATION LAUNCH VEHICLE

S. Larch, P. Perczynski, Dr. O. Kunz
MT Aerospace AG, Augsburg, Germany

R. Ernst
OHB System AG, Bremen, Germany

Summary

In an internal R&D study a variety of concepts for a next generation launcher (NGL) were investigated with a special focus on minimal life cycle cost (LCC). The comprehensive experience of the involved companies in the development and production of tanks and structural elements for different launcher programs was an important asset for these investigations.

Cost estimations were performed on basis of Transcost 7.3 [1], internal tools and in house data bases. For the comparison of different concepts a payload manifest was established and extrapolated to a service life time of 20 years. Preliminary trajectory analyses were performed by ASTOS for a proposed common core booster (CCB) launch vehicle family that evolved as the lowest cost approach.

This CCB launch vehicle family was further investigated with regard to production aspects and detailed technical solutions like a modular interstage adapter for axial load bearing. Additional approaches for further cost savings, especially for production and operations, were considered.

1. POTENTIAL REQUIREMENTS FOR A NEXT GENERATION LAUNCHER

For this in house study, basic requirements were used which differ in some points from the current NGL requirements used within the FLPP program (e.g. the payload range). These slightly different requirements were established to allow a new and unbiased look on launcher concepts that are not covered by current NGL proposals.

The basic requirements within this study are:

- The NGL should include a fleet of vehicles that cover the payload range from 3t to 10t to GTO as currently partly provided by the Ariane 5 and the Soyuz launcher. Additionally it should close the gap between those current launchers with intermediate steps. A replacement of also the Vega launcher seems not to be feasible.
- The NGL should be able to launch all commercial and institutional satellites and probes in single payload launches. Dual satellite launches should be possible if required.
- The NGL should allow the reduction of the number of stages to be produced. Today eight different rocket stages are in serial production for Soyuz and Ariane 5 with very limited synergies.
- The ability to launch large ATV-class exploration payloads to LEO should be maintained.
- A maximum axial load factor of 4 g should not be exceeded.
- All variants of the NGL should use the same production, test and launch infrastructure.
- The stages of the NGL should share, where ever possible, common components like tank domes, structural parts, electronics, fluidic components, sensors etc…

2. THE INTERNAL SYSTEMS STUDY

The main driver during all phases of the study and for all decisions made is the minimization of the launcher family's life cycle cost. This summarizes all the cost factors, occurring during the life time of the launcher project and consists mainly of the following fractions:

- Development cost for engines and stages (non recurring).
- Production cost for the required number of stages during the operational life time (recurring).
- Operational cost for the launchers (recurring).

The NGL general requirements mentioned in chapter 1 cannot be fulfilled by a single launcher. Therefore the systems study favored - from the beginning - a family of launch vehicles. The following strategies to form a launch vehicle family with different payload performances were taken into account:

- The "Building Block" strategy, consisting of a variety of different stages that can be combined to form a fleet of launch vehicles with a wide payload range:

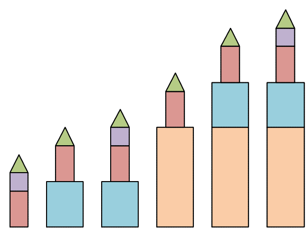


FIGURE1: Schematic of the "Building Block" strategy

- The "Upper Stage" strategy, by using different upper stages on a common lower stage or a combination of lower stages (see figure 2).

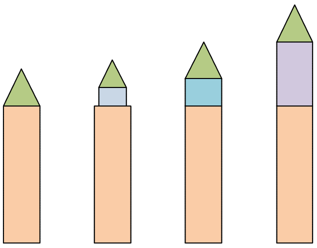


FIGURE 2: Schematic of the "Upper Stage" strategy

- The "Strap-on-Booster" strategy, using a common launch vehicle with a different number of solid or liquid strap-on-boosters:

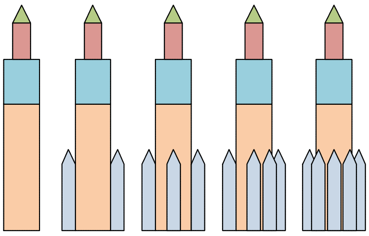


FIGURE 3: Schematic of the "Strap-on-Booster" strategy

- The "Common Core Booster" strategy, using a bundle of identical modules as lower stage and a common upper stage:

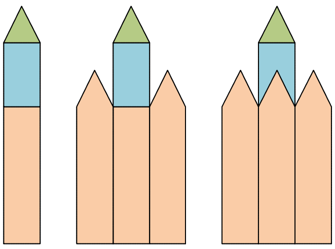


FIGURE 4: The "Common Core Booster" strategy

The "Building Block" strategy was rejected early in the study because the high number of different stages that are necessary cannot be cost effective at today's relatively low launch rates. The "Upper stage" strategy was rejected because of its limited payload bandwidth.

2.1. Cost comparison

For the remaining strategies, the following four concepts were developed to cover the payload range between 3000 kg GTO up to 10000 kg GTO:

A) A family of launch vehicles consisting of five different versions: a two stage core vehicle, surrounded by 0, 2, 4, 6 or 8 liquid strap on boosters.

B) A family of launch vehicles consisting of five different versions: a two stage core vehicle surrounded by 0, 2, 4 or 6 liquid strap on boosters and a 3 core CCB vehicle.

C) A family of launch vehicles consisting of five different versions: a two stage core vehicle surrounded by 0, 2, 4 or 6 solid strap on boosters and a 3 core CCB vehicle.

D) A Family of launchers, consisting of three vehicles with one, two or three CCB's in the first stage and a common upper stage

Preliminary drawings for these concepts, with indication of the GTO payload capacity, are shown in figure 5.

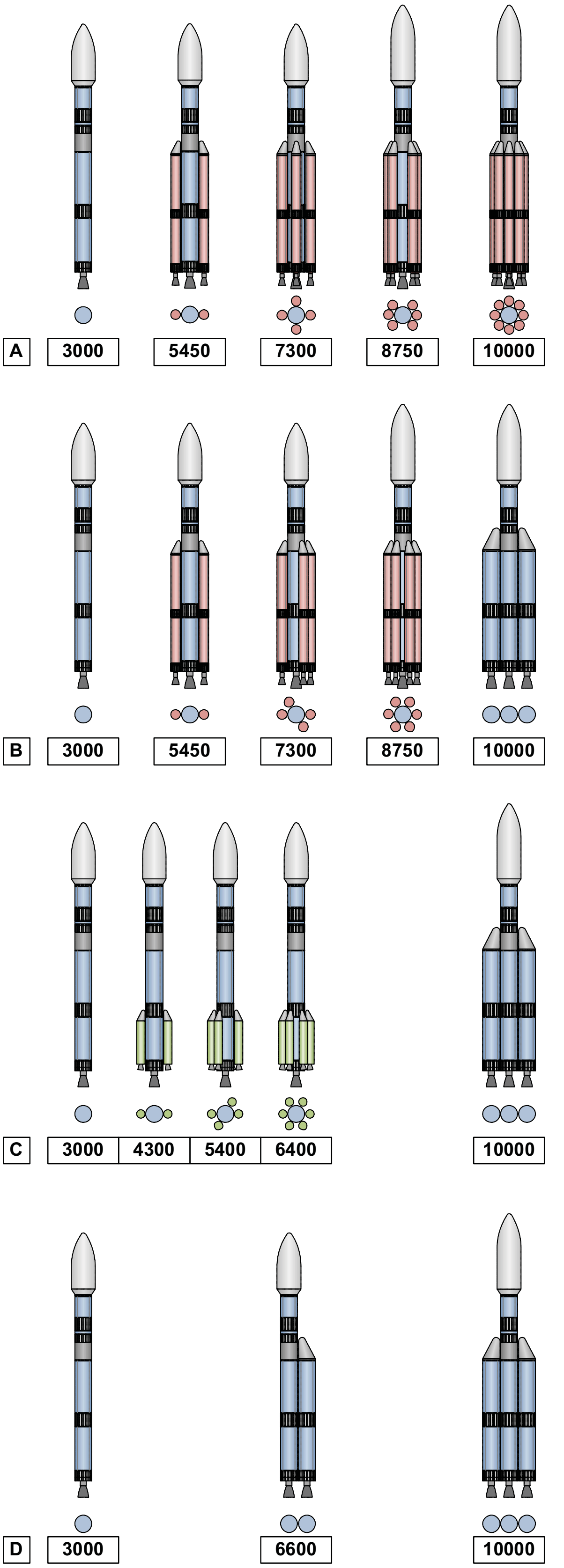


FIGURE 5: Concepts for cost comparison

The core stages of those four concepts use LOX / methane as fuel combination as do the liquid strap on boosters of concepts A) and B). All upper stages are based on the LOX / hydrogen Vinci engine.

Life cycle cost analyses were performed for those concepts, based on a common payload manifest issued by the OHB group (see figure 6) and extrapolated to a potential launcher service life time of 20 years.

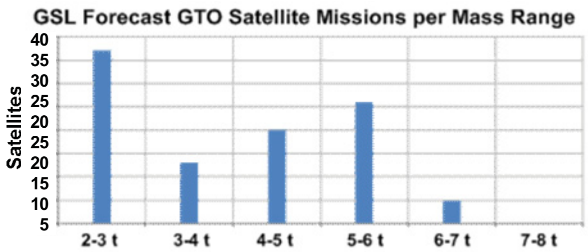


FIGURE 6: Satellite launch manifest

The life cycle costs include development costs, serial production costs for engines and stages and operational costs. These calculations were made mainly on basis of the Transcost 7.3 [1] model and were complemented by estimates based on in house data bases and experience. The launchers life cycle cost were based on a life time of 20 years to allow a reasonable comparison.

The cost calculations were made with the assumption that all satellites are launched as single payloads, even though the proposed launcher family allows multiple payload launches with a SYLDA-derived adapter (see also chapter 4.4).

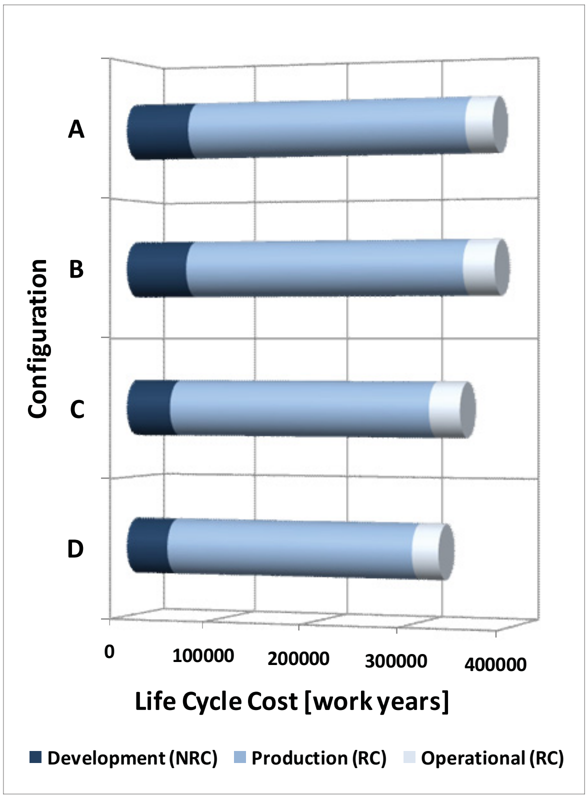


FIGURE 7: LCC comparison for launcher concepts

Figure 7 shows the calculated life cycle cost (in work years) for the launcher family concepts mentioned afore.

The LCC comparison shows lowest cost for the pure CCB concept (D) without any strap-on-boosters. The cost for the solid strap-on-booster concept (C) is slightly higher while the concepts with liquid strap-on-boosters (A & B) show considerably higher LCC. The pure CCB-concept (D) was chosen for further refinement.

2.2. CCB fuel type

In a next step, the appropriate fuel combination for the CCB stage was evaluated. For each of the following fuel combinations, a preliminary design for the entire family of four launchers was elaborated, and the payload performance calculated:

- LOX / hydrogen
- LOX / kerosene
- LOX / methane

The cost estimates were then performed in the same way as mentioned above. Transcost [1] provides cost estimate relationships (CER's) only for cryogenic LH2-stages and "conventional" stages. As no large LOX / methane engine was ever designed, it cannot be clearly decided if the cost for such a stage will be closer to the hydrogen or the conventional CER's. For the calculations within this study the methane version was treated as a "conventional" fuel combination, still the above mentioned uncertainty must be kept in mind. The cost calculation results are summarized in figure 8 with the above mentioned uncertainty indicated in red.

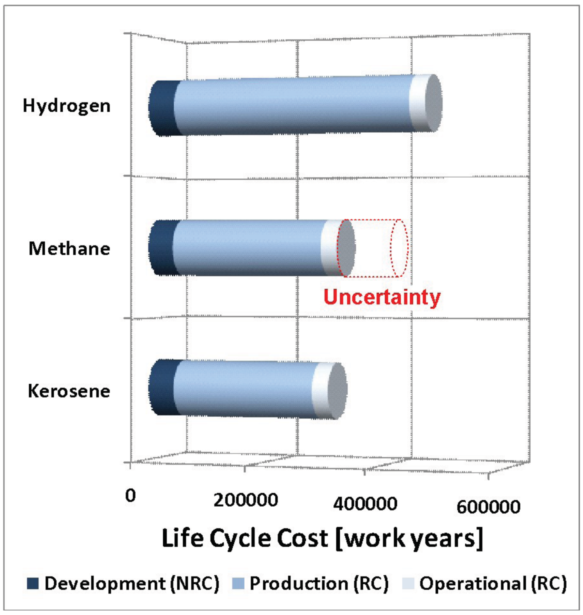


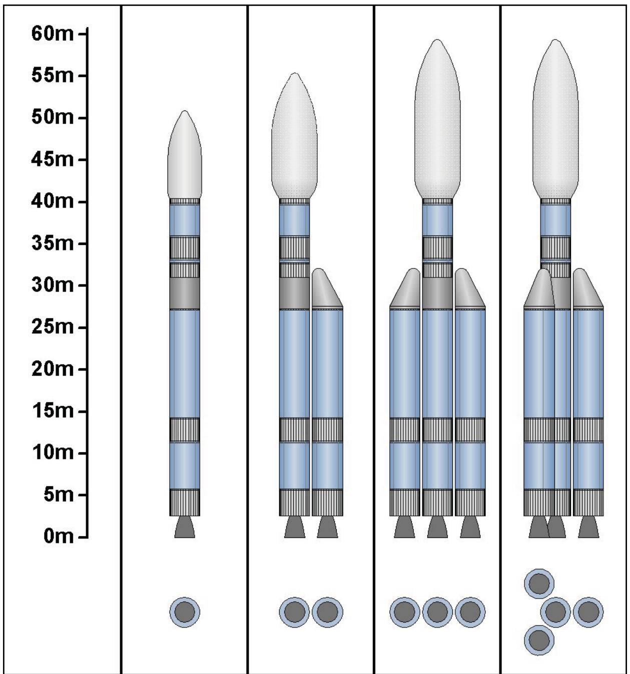
FIGURE 8: Life cycle cost comparison for fuel type

It is obvious that a LOX / hydrogen CCB would lead to considerably higher cost than a LOX / kerosene fueled stage. As no reliable statement can be made for the LOX / methane combination, the LOX / kerosene alternative was chosen as baseline for the further investigation. Nevertheless other fuel combination could be envisaged in future investigations.

3. THE PROPOSED NEXT GENERATION LAUNCHER FAMILY

Based on the tradeoffs mentioned before, a next generation launcher family was established as a baseline for further investigations. Due to the uncertainty for methane stage cost estimates the CCB fuel was changed to LOX / kerosene. To better fit the needs derived from the payload manifest the GTO payload of the single core launcher was reduced to 2900 kg and a fourth vehicle, with four CCB's in the lower compartment, was added to the family to extend the upper end of the payload range.

The proposed NGL family consists of four launch vehicles, based on the common core booster concept. They use either 1,2,3 or 4 CCB stages in the lower compartment, completed by a common cryogenic upper stage, based on the existing Vinci expander cycle engine. The launcher family covers a payload range from ca. 3t up to 11t GTO and can also launch any institutional payload to all kinds of orbits and to interplanetary trajectories. LEO payloads of more than 25t can be delivered to an ISS orbit by the largest launcher version. The presented launch vehicle family, shown in figure 9, would be able to replace both, the Soyuz and the Ariane 5 launchers. For small payloads, the Vega launch system will stay in service.



GLOW [t]	279	524	774	1020
GTO [kg]	2900	5400	9100	11200
LEO [kg]	7900	12300	21300	26300

FIGURE 9: The next generation CCB launcher family

The main task of the CCB family will be the launch of commercial payloads to GTO. With the re-ignitable upper stage, practically all kinds of orbits and trajectories can be reached. For the commercial market the launchers can offer single payload launches to give the customer a maximum of schedule flexibility and independence from a partner payload. On the other side, all vehicles of the family can provide dual launches for customers who set more value on cost savings than on flexibility.

By maintaining a continuous serial production and the intermediate storage of some stages at the Kourou spaceport the system can also provide short term launch service e.g. within a few weeks after incoming order. Such a "launch on demand" option could be a crucial factor for future market success.

3.1. The single core CCB launcher

The smallest member of the launcher family, consisting of only one CCB and the upper stage, has a payload capacity comparable to the existing Soyuz launch vehicle. It can launch all commercial GTO payloads up to a launch mass of 2900kg and LEO payloads up to a mass of 7900kg. The limiting boundaries are the acceleration load limit of 4g and an initial thrust to weight ratio at liftoff of at least 1.25.

The first stage engine will launch at full thrust until the load limit of 4g is reached. Then the engine will be throttled down to 85% thrust until this limit is reached again. Then the engine is throttled to 50% of nominal thrust until depletion of fuel. After staging the upper stage engine is ignited for a 630s burn at full thrust until the final GTO orbit is reached. After deployment of the payloads the launcher's primary mission, except for passivation of the upper stage, is finished. A summary of the CCB thrust sequence and thrust / weight ratio during a typical GTO mission is shown in the following figure:

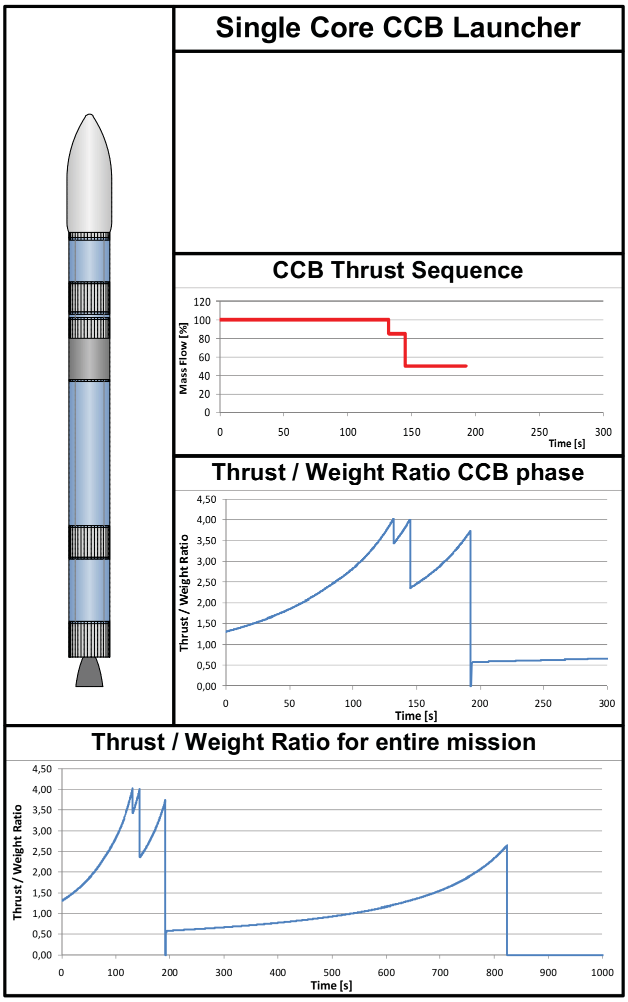


FIGURE 10: The single core CCB launcher

3.2. The double core CCB launcher

This member of the launcher family, consisting of two CCB's and the upper stage, has a payload capacity between the existing Soyuz and Ariane 5 launch vehicles. It can launch commercial GTO payloads up to a launch mass of 5400kg and LEO payloads up to a mass of 12300kg.

The launcher starts with the center CCB at full thrust and the side CCB at 85%, resulting in an exactly vertical lift off. Approx. 10s after liftoff the side CCB is throttled up to 100% thrust to minimize the launchers overall gravity loss. To reduce lateral loads on the launcher during max Q transition the side CCB is throttled down again to 80% thrust as soon as the dynamic pressure reaches 10kPa to reduce the angle of attack to almost 0°. This maximum allowable dynamic pressure was arbitrarily chosen for the first trajectory calculations.

Up to now, the center CCB has consumed more propellant than the side CCB. Therefore the center CCB will be throttled down to 50% thrust after the max Q transition phase is completed and the dynamic pressure is again below 10kPa. At the same time the side CCB will be throttled up again to 100% thrust. During this flight phase the side CCB will overhaul the center CCB in fuel consumption. The maximum angle of attack of about 4.8° and the maximum lateral load factor of about 0.34g occur near the end of this phase.

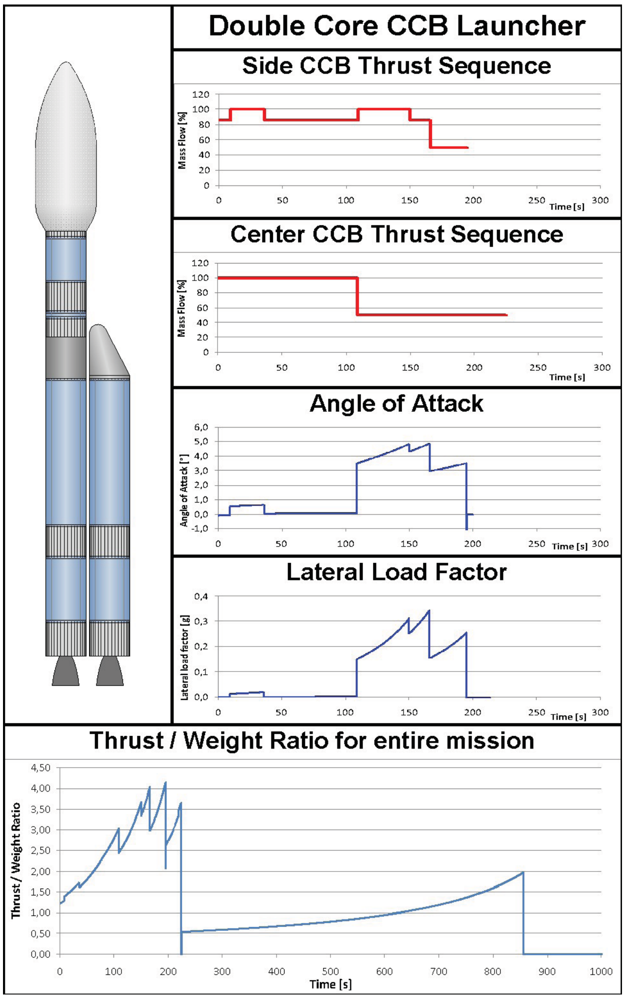


FIGURE 11: The double core CCB launcher

At the moment, the vehicle's acceleration reaches the maximum of 4g, the side CCB will also be throttled down to 50% stepwise to keep flight loads within the desired limit of 4g and the angle of attack below 5°. The fuel of the side CCB is consumed about 40s prior to the center CCB. The side CCB is jettisoned and the center CCB continues its flight at 50% thrust until its fuel is also exhausted. Then the upper stage takes over. Thrust sequence and resulting AoA, lateral load factor and thrust to weight ratio during mission time are summarized in figure 11.

3.3. The triple core CCB launcher

With a GTO payload of 9100kg the triple core CCB vehicle covers the payload capacity of the current Ariane 5 ECA. It can launch either two payloads of medium size or one very large payload at one time.

For liftoff all three engines will work on 100% thrust level. To save fuel for the later flight phases, the center CCB's engine will be throttled down to 50% thrust after ca. 30s. By reaching an acceleration load of 4g, the side CCB's are also throttled stepwise to 50% thrust to stay within the 4g limit.

After jettison of the two side CCB's the center CCB can be throttled up again to 85% for a certain time to reduce gravity loss during that flight phase, but an additional throttling back to 50% will be necessary to stay below the limit of 4g (see flight data summary in figure 12).

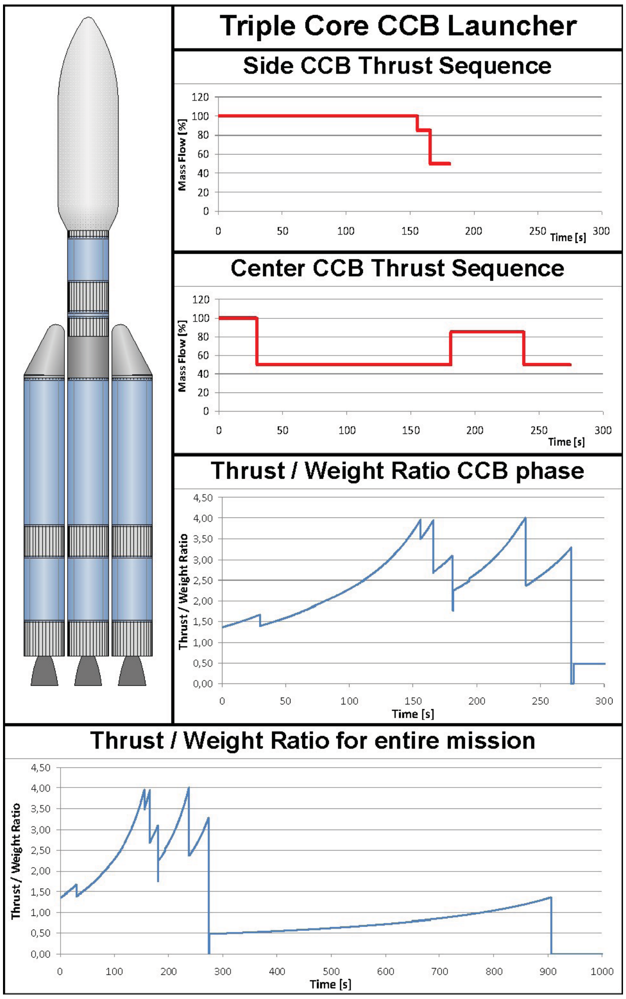


FIGURE 12: The triple core CCB launcher

3.4. The quadruple core CCB launcher

The largest member of the launcher family consists of four CCB's, one center CCB surrounded by three side CCB's in a 120° spacing. With its GTO payload of more than 12 tons it is able to lift even the largest current communication satellites in a dual mission, if required, but the most likely application area of this launcher is the transportation of large LEO payloads like space station elements or resupply missions of an evolved ATV with an increased payload mass of more than 25 tons.

The three side CCB's will work at maximum thrust for liftoff while the center CCB can be throttled to 85% from the beginning to save its fuel for the later flight phases. Similar to the three core vehicle the engine of the center CCB will be throttled down to 50% after ca. 50s into the flight. When the 4g load limit is reached, the stepwise throttling of the side CCB's thrust will be performed similar to the three core launcher. After the three side CCB's are jettisoned, the thrust of the remaining center CCB will be throttled up again to 85% to reduce gravity loss effects. The last throttling maneuver will again reduce the acceleration load to fit the 4g load limit. The relevant flight data are shown in figure 13.

A preliminary CAD drawing of the quadruple core launcher is shown on the last page of this paper.

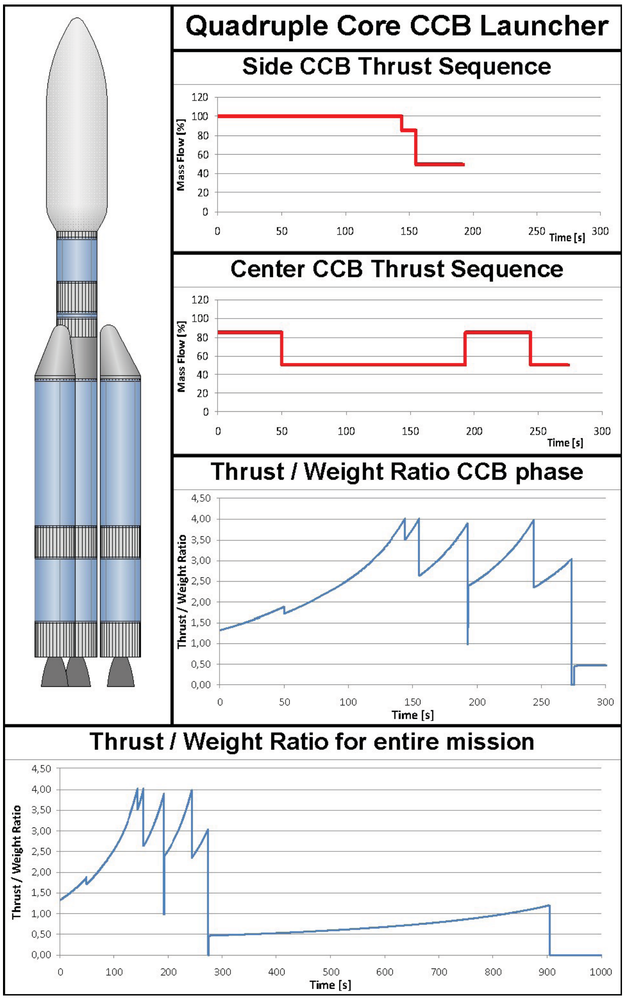


FIGURE 13: The quadruple core CCB launcher

4. THE LAUNCHER COMPONENTS

4.1. The CCB stage

The main element of the launcher concept is the common core booster (CCB) itself. It is used to form the lower compartment of all vehicles of the launcher family.

According to the concept, the CCB has to fulfill two roles:

- As center CCB it forms the backbone of the launch vehicle. It has to transfer all lateral loads that occur during TVC maneuvers to the upper compartment. It is topped by the interstage adapter that is composed of different panels to accommodate to the different number of side CCB's
- As side CCB it is fixed to the center CCB by struts at the aft end that allow transmission of all lateral loads to the center CCB. The side CCB is topped by a structure that transmits the longitudinal loads from the side CCB to the interstage adapter. An additional nosecone provides aerodynamic protection during flight.

Despite the different roles the CCB has to fulfill, a vital characteristic of the launcher concept is the fact that all CCB's are completely identical and are not designated to their role in the launch vehicle at manufacturing. This provides the latitude to decide whether the CCB is used as center or side CCB until the final integration of the vehicle at the launch site. This represents a key factor for a cost effective serial production of CCB's and is in contrast to existing CCB vehicles like the Delta IV which uses different designs for central, right, and left CCBs.

The CCB is composed of the following four main components as shown in figure 14:

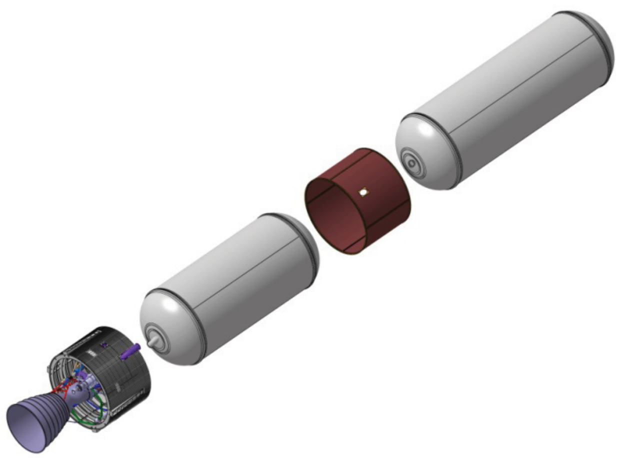


FIGURE 14: Components of the CCB stage

- The propulsion section, consisting of the main engine, propulsion subsystems, thrust structure, TVC equipment, launch pad connection structure, ground couplings for fuel and oxidizer tanking and joints for CCB connection struts. Pitch and jaw control during CCB flight is provided by engine tilting via TVC actuators while roll control is provided by TVC of side CCB's or tilting of the gas generator exhaust ducts during single CCB flight phases.
- The fuel tank, with its two spin formed domes, two Y-rings and four cylinder panels shows the simplest possible configuration of such a tank.

- The intertank structure that connects the two tanks is a simple barrel structure except for a cut-out for the fuel feed line. It could be manufactured as a CFRP-sandwich structure. Two ring flanges at the ends of the barrel structure will provide interfaces to the tanks.
- The metallic part of the LOX tank is identical to the fuel tank except for the cylinder length. Different internal equipment like slosh baffles and external insulation differentiate the two tanks but for cost reduction it should be aimed to use identical parts for both tanks wherever its feasible, e.g. domes, Y-rings etc.

Additional secondary components are:

- The LOX feed line, routed alongside the exterior of the fuel tank to avoid fuel tank penetration
- Tank pressurization lines
- Cable ducts
- Electrical and telemetry equipment

The CCB architecture is aimed for simplicity and easy manufacturing as cost efficiency is more important for the lower stage than extremely low weight. A common bulkhead architecture for the CCB's tank system should be carefully traded during subsequent design loops, but should only be introduced if significant cost savings can be obtained.

The propulsion system of the CCB consists of the main engine, the propulsion subsystems (lines, valves, helium tanks, etc.), ground couplings for fuel and oxidizer tanking, feed lines and thrust vector control actuators.

The main engine architectural philosophy is based on the low cost approach that was applied to the RS-68 engine of the Delta 4 launcher [2], the Viking-H study [3] by SNECMA or NASA's FASTRAC engine [4]. These approach uses a simple gas generator cycle, a moderate combustion pressure (< 100 bar), film cooled combustion chambers and /or ablative cooled nozzles.

The technical data of the CCB stage and the main engine, used for the performance calculations, are summarized in the table below:

Gross lift off weight (w/o interstage)	**239300 kg**
Inert weight (incl. residuals)	**19140 kg**
Usable fuel weight	**220160 kg**
Ratio of oxidizer and fuel	**2.8**
Isp at sea level	**2651 Ns/kg**
Thrust at sea level	**3500 kN**
Isp in vacuum	**2975 Ns/kg**
Thrust in vacuum	**3927 kN**
Combustion pressure	**80 bar**
Expansion area ratio	**1:16**
Engine mass flow (at 100%)	**1320 kg/s**

TABLE 1: Technical data for the CCB stage

4.2. The upper stage

For the upper stage, the already existing VINCI engine was chosen as is. With its thrust of 180 kN it fits to the CCB launch system. It is assumed that all commercial GTO missions launching from the Guyana Space Center do not need multiple ignitions of the upper stage. As these missions represent the majority of expected missions of the CCB launcher, it could make sense to offer the baseline upper stage without the capability of restart and longer coast phases if this leads to cost reduction. For missions that require restart and coasting capability the upper stage can then be converted into a versatile configuration with additional RCS propellant, enhanced insulation and higher helium capacity.

Some synergies can be used by adopting parts of the stage's subsystems from the A5ME upper stage project, e.g. helium tanks, RCS system, fill and drain couplings, valves etc…

For cost effectiveness the diameter of the upper stage (3,6m) was taken over from the CCB to ensure maximum commonality between both stages and allow use of the same production facilities. It should be aspired to use identical parts of the CCB as much as possible like tank domes and Y-rings.

Two separate tanks are preliminary proposed for the propellants as a common bulkhead for a LOX/LH_2 stage is considered a major cost driver, but nevertheless such a common bulkhead configuration should be investigated and carefully traded for potential RC cost reduction. Its impact on the system level costs (potentially smaller CCB required) should also be fully evaluated. An advantage of the separate tank configuration is that the helium tanks for LH_2-tank pressurization could be arranged in the available space between the main tanks as can be seen in the following Drawing:

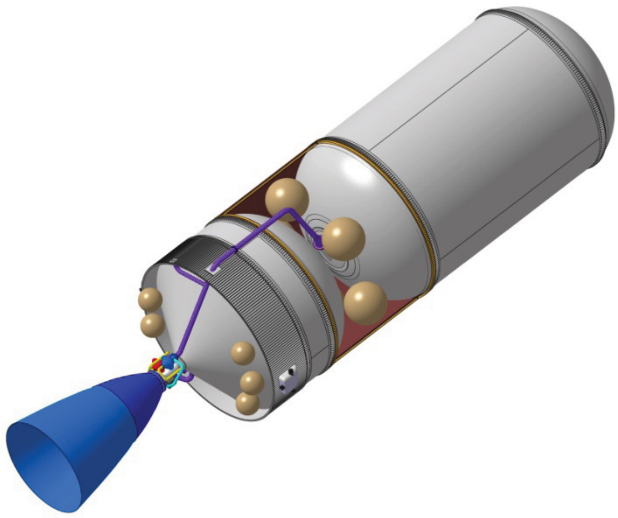


FIGURE 15: Concept for the upper stage

A secondary RCS propulsion system, e.g. based on hydrazine monopropellant thrusters, provides maneuver capability for payload release and stage passivation. Its components can probably be transferred from the A5ME project.

An inert mass (including propellant residuals) of 3715kg was assumed for the stage representing 13% of its gross liftoff mass. The stage's length is approximately 12.6m with undeployed engine nozzle.

Gross lift off weight (w/o interstage)	**28600 kg**
Inert weight (incl. residuals)	**3715 kg**
Usable fuel weight	**24885 kg**
Ratio of oxidizer and fuel	**5.8**
Isp in vacuum	**4562 Ns/kg**
Thrust in vacuum	**180 kN**
Combustion pressure	**60 bar**
Expansion area ratio	**1:240**
Engine mass flow (at 100%)	**39.5 kg/s**

TABLE 2: Technical data for the upper stage

As another subsystem, all the flight electronics are placed in the upper stage. As this is the only upper stage used for the complete launcher family, a separate vehicle equipment bay (VEB) structure is not necessary.

4.3. The interstage adapter

The interstage adapter acts as the central load bearing system for the multiple CCB versions. Similar to Ariane 5's front skirt all the axial loads of the side CCB's are mitigated trough the interstage adapter.

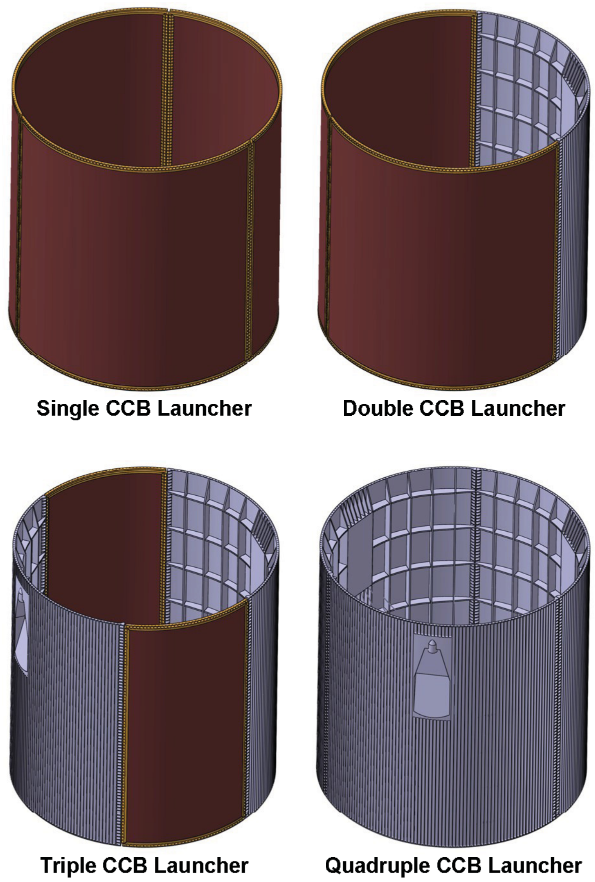


FIGURE 16: The modular interstage adapter

To accommodate the different number of side CCB's (0 – 3) a modular interstage adapter could be envisioned. To form the barrel shaped structure, three different panels are necessary: a 120° panel, a 60° panel and a 120° panel with side CCB connector. With these three elements the interstage adapters for all launcher versions can be built as shown in figure 16.

In a further trade study this modular approach should be traded against a solution with dedicated monobloc interstages to ascertain if this concept is feasible and more economic.

4.4. Payload fairings and multiple launch adapters

For the CCB launcher family a variety of payload fairings should be available. A fairing of 3.6 or 4m diameter can be used specially for small scientific satellites or probes. At least two fairings of 5.4m diameter with different lengths should be available to keep a certain compatibility with Ariane 5 (see figure 17).

The standard Ariane 5 bolted interface for payload adapters of 2624mm diameter should also be used on the CCB launcher family to be compatible to all payload adapters in use today.

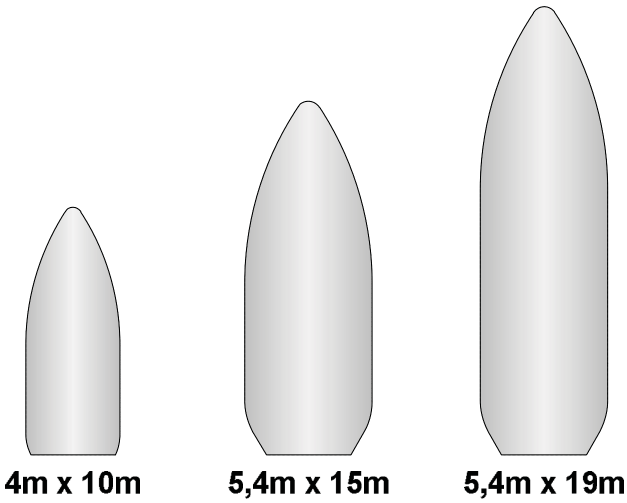


FIGURE 17: Different payload fairings

A SYLDA-derived dual launch adapter should also be available at different length:

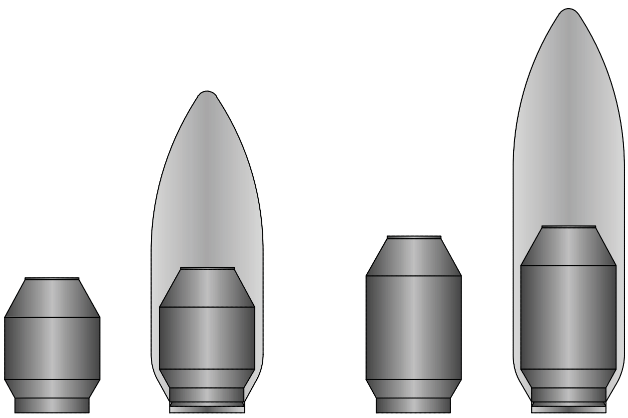


FIGURE 18: Dual launch adapters

5. INDUSTRIALIZATION AND LOGISTICS

The careful planning of the manufacturing flow for the launcher is a key factor for cost effectiveness. To reach a competitive cost situation for any NGL vehicle, independent of its design and configuration, it is mandatory to concentrate the main manufacturing and integration efforts at a minimum number of sites.

Therefore a single integration site for both, the CCB and the upper stage, together with the tank manufacturing is proposed to reduce transportation efforts. Assuming an annual production cadence of 25–30 CCB's and 12–15 upper stages the introduction of intermittent assembly lines for the two stages should be considered. The propulsion sections of the stages should be pre-manufactured at the engine manufacturer's premises and delivered as an assembled and tested unit to the integration site.

A possible layout for a serial manufacturing plant is shown in figure 19.

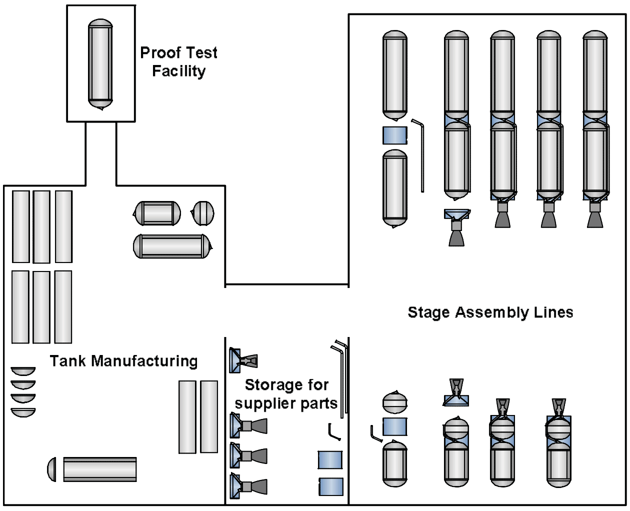


FIGURE 19: Possible layout for a manufacturing plant

A vital requirement for future launch vehicle systems will be short term availability of launch services for the customer. Higher flexibility and short term availability could be the most significant features for competiveness in the future.

The launcher stages should be shipped to the launch site by sea transportation using the existing ships on a regular basis (e.g. four times a year), but all components of the CCB launcher can also be air transported by existing standard AN-124 or Airbus Beluga airplanes. In case a stage is quickly needed at the launch site the air transportation can provide a suitable solution.

To allow short term launch on demand service of the CCB vehicle, a certain amount of stages (e.g. at least 3 CCB's and one upper stage) should be held in intermediate storage at the Kourou launch site at any time as indicated in figure 20.

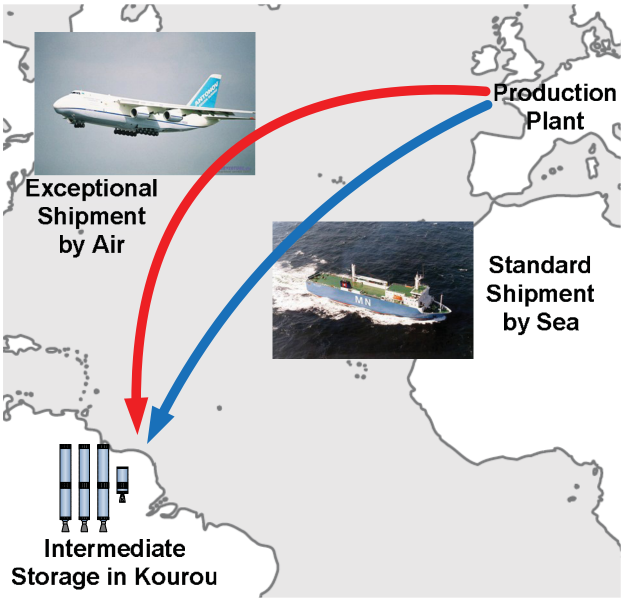


FIGURE 20: Stage transportation to Kourou

6. CONCLUSION AND FURTHER STEPS

During an internal R&D study a variety of next generation launch vehicle concepts were calculated and compared w.r.t. minimized life cycle cost. As a result a pure common core booster concept without additional strap on boosters showed lowest cost and was used as a baseline concept for further refinement.

A launcher family of four vehicles, covering a payload range between 3t and 11t to GTO, was established as a potential future launch system.

Some considerations were made to technical detail solutions as well as to manufacturing and logistics aspects to reduce cost and enhance flexibility and availability.

This basic study is limited to rough performance and cost calculations based on preliminary mass assumptions. Further investigations must address at least the following points:

- Detailed trajectory analysis for all launchers
- Optimal sizing of stages
- Detailed life cycle cost estimates
- Detailed flight analysis of asymmetric two core launcher
- Identification of dimensioning flight load cases
- Detailed structural layout (tanks, structures etc.)
- Establishment of mass breakdowns
- Evaluation of CCB propulsion alternatives (kerosene vs. methane)
- Preliminary layout of CCB propulsion system
- Mass and cost estimates for CCB propulsion system

To perform these tasks, external funding, e.g. in the frame of FLPP system studies, is essential. Also the involvement of an experienced engine manufacturer is necessary.

7. REFERENCES

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