ENABLING TECHNOLOGIES FOR THE NEXT GENERATION REIGNITABLE CRYOGENIC UPPER STAGE

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OVERVIEW

This paper describes the identification of needed and enabling technologies for next generation launcher cryogenic upper stages, which will have to accomplish characteristic missions using multiple ignitions of the main engine and the performance of non-propulsive coasting phases in the low gravity periods in between. A survey of the market, customer needs and competitors' capabilities followed by a definition of reference mission scenarios and requirements result in the identification of the critical functions and technology needs. Using both product tree and functional analysis methodologies, a list of critical aspects and the related enabling technology needs are presented, including the potential future industrial partners or subcontractors for a proposed technology maturation and demonstration phase. As an outlook, an overview is given on existing and future studies on national and European scope that are directly linked with this activity.

1. INTRODUCTION

The European Expandable Launcher family Ariane with its latest offspring - the fully cryogenic Ariane 5 ECA - is regularly and successfully carrying satellites into orbit, with missions into Geostationary Transfer Orbit (GTO) being the largest portion of today's commercial satellite market. However, future market demands with respect to mission flexibility (e.g. higher perigee GTO+ or insertion into Low/Medium Earth Orbit), but also with respect to increasing satellite complexity and mass will require design evolutions especially for the Upper Stage of the launcher. Here, the primary focus is to achieve a high payload performance coupled with the ability of multiple engine ignitions after successive non-propulsive coasting phases.

For future cryogenic upper stages, several mission scenarios have been discussed in the past, with mission durations ranging up to 18 hours in total, whereas today a typical mission duration for the existing European cryogenic upper stage is in the order of 60 minutes.

For such extended mission timelines, the following technologies play a dominant role:

- Propellant management (one of the main drivers, since the main engine needs to be restarted, requiring proper conditioning and preparation of the propellant / propulsion system)
- Thermal conditioning and housekeeping
- Electrical Power system
- Flight control
- Operation/design optimisation

When comparing these needs for expendable and for reusable launch systems (ELV / RLV), it seems that a many of the mission requirements and constraints will be quite similar for the respective versatile upper stage (for all flight phases except the ascent from ground with the primary stage and lower composites as main “reusable” elements of the launcher). Some induced requirements are therefore derived from these advanced concepts, as for example the need to perform horizontal starts.

To determine the mentioned main functional requirements and critical technological needs, the following logic is applied:

- Market analysis and assessment of future ELV needs
- Comparison with RLV requirements
- Development of a Conceptual Stage Design and Architecture Baseline, using both Ariane 5 and foreign launch vehicle as references
- Functional Analysis in comparison with an analysis of a typical product tree

The resulting list of technologies seen as mandatory or helpful to realise an efficient and capable next generation versatile cryogenic upper stage is used to identify potential partners for cooperation.

Finally, as the work presented here is a starting point and input to broader activities, an overview and outlook on existing and future European programmes dedicated to either Upper Stage Technology or Upper Stage Concepts is given.

2. IDENTIFICATION OF NEEDS

Starting from the determination of customer mission needs and mission constraints a typical reference mission is defined which is than used as a basis for the evaluation of the concept. The reference mission could be ‘unphysical’ in the sense that for generation of a wider and more robust boundary envelope a superpositioning of different mission needs can be made. In case of any conflict/contradiction, always the more driving and severe parameter will be chosen. In the following paragraphs, requirements for ELV and RLV are treated separately at the beginning. As the ELV needs are more evolved, these are analysed first.

2.1. Future Mission Needs ELV

When looking to the European launcher logbook and the foreseen satellite missions in the coming decade (see FIG 1), the following conclusions can be drawn:

- Main market for today's launch systems is clearly the GEO market either via a GTO (geo stationary transfer orbit) or direct GEO injection (less frequent). GTO is the classical trajectory for the main portion of today's satellites, even though Russia (and also the US Air Force) are using direct GEO insertion for most of their military GEO satellites.
- Commercial customers dominate the total number of world wide launches (appr. 50% of all launches),
- Approximately 33% of all missions are for non commercial or institutional purposes (including the 5% to Deep Space).

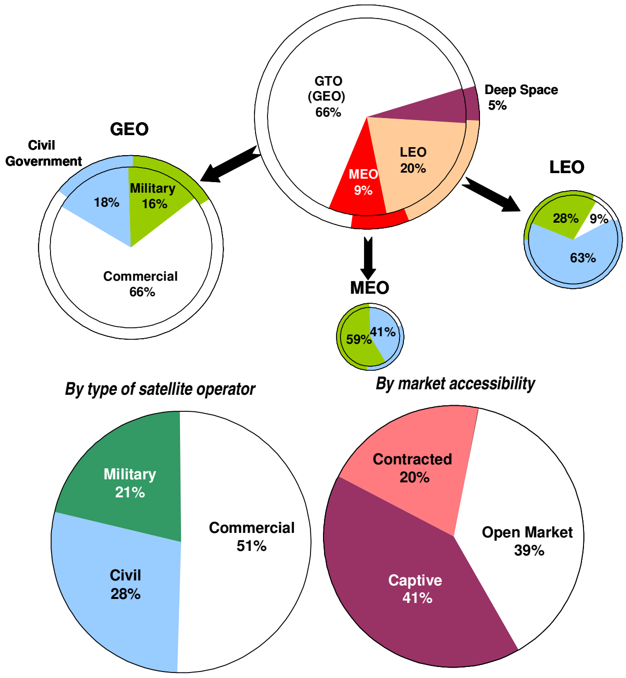

FIG 1. Breakdown of the 2002-2011 launch market by orbit, by client, by satellite operator and by accessibility [1]

2.1.1. Commercial Market

Analyses on future market demands are generated by Arianespace / Euroconsult ([3], mainly for commercial needs), in the US there are COMSTAC (Commercial Space Transportation Advisory Committee), the FAA/AST (Federal Aviation Administration's Associate Administrator for Commercial Space Transportation, [4]) and the USAF (National Launch Forecast incorporating civil and military launches, but only for the US, [7]). According to these most recent informations, the future commercial market is anticipated to be dominated by

- Telecommunication applications (as High Definition TeleVision, audio and video data, telephony, internet broadband data transmission) on Geo-synchronous Earth Orbits with an expected market volume of 70% of the overall market
- The Arianespace/Euroconsult market forecast ([3], [6]) indicates a slight increase of satellite mass even beyond the 6 tons class (such as AAS SPACEBUS 4000C or EADS ASTRIUM EUROSTAR 3000 Heavy)
- For the replacement of existing satellites (altogether 181 launched during the peak period of 1994-2000), fewer large satellites will be used to serve larger markets. This is mainly due to gains in transponder capacity, data compression and number of TV channels broadcast per satellite. As a result, it is likely that a typical 7 to 8 tons - 70kW GEO- class communications satellite in 2012 will have the capabilities of 6 to 8 satellites of today, and be capable of serving simultaneously several millions of users.
- Customers ask for increased payload mass by reducing mass of the satellite apogee propulsion [3]. Therefore, in the next decade the demand for missions with higher transfer orbit perigee (like GTO/GTO+) will be strengthened, or even be extended to the requirement of a Direct-GEO insertion (where re-ignition of the upper stage is a must).

2.1.2. Institutional Needs and Non-GTO missions

Customers for the so-called institutional missions are the European Union, ESA, European national governments or organisations and other public entities. As described in [1], [2], [4], and [5], most potential missions here are non-GTO and cover a wide range of orbits, from Low Earth Orbits (LEO) and medium Earth Orbits (MEO), to more "exotic" orbits such as to Moon, Mars or beyond. Due to limited access to non-European institutional markets and due to international competition in Europe, the annual European institutional satellite implementation rate is expected to be limited to a maximum of five in the next 10 years. Earth Departure Missions (EDM; such as non-crewed cargo missions to Moon or Mars) will be even less frequent. Some increase might be expected due to an emerging interest of national governments, non-profit organizations and companies into near Earth orbits (Galileo, GNSS, Artemis, SART, Envisat, Metop…).

Although these institutional missions are far fewer in numbers, they also ask for "versatility" in the launcher upper section due to non-GTO orbits.

2.2. Comparison between ELV and RLV

Re-usable launch vehicles were studied intensively in the past, including technology development as well as demonstration on ground and by experimental vehicles. In the US, examples are DC-XA, X-34, X-33 and X-38, as well as private initiatives such as Kistler, Eclipse, Pathfinder, VentureStar or Falcon SLV. In Europe, ESA started the Future European Space Transportation Investigations Programme (FESTIP) in 1994 with the objective of defining the requirements, comparing vehicle concepts and preparing the enabling technology for a new generation of reusable launchers. In parallel CNES initiated studies for investigation of a successor of the Ariane 5 around 2020, called Ariane 6 [8]. During the last ministry council no positive decision was made for starting a development of an RLV within the next years. Apart from the fact that any Next Generation Launcher (NGL) development will most likely not start before 2015, the decision is today not made whether this NGL is an ELV or RLV. In any case, the development start of the RLV option is not expected before 2020.

However, as it can be seen in TAB 1, top level functional requirements for ELV and RLV are qualitatively similar in most parts (especially after separation from the launch vehicle first stage), resulting in similar technological needs. Therefore, any candidate technology investigated is also regarded in the sense of maximising commonality with ELV upper stage needs.

NGLV Requirements		ELV US	ELV PS	RLV US	RLV PS
Reusability	Health Monitoring	–	–	–	X
	Repair	–	–	X	X
	Affordable Maintenance	–	–	–	X
	Robustness and durability for cyclic loads	–	–	X	X
High-Perfo. Up Lift Capability / Perfor-mance	System Mass	X	X	X	X
	Flexible manoeuvres	X	–	X	X
	Small Residuals	X	X	X	X
	Optimised in flight operations	X	X	X	X
	High performance main propulsion system with high ISP and high thrust	X	X	X	X
Versatility/ Mission Flexibility	Missions flexibility (e.g. Under loading)	X	–	X	X
	Long ballistic flight phases	X	–	X	X
	Re-ignitability of main propulsion system	X	–	X	(X)

TAB 1. Typical top level requirements and level of importance for ELV and RLV systems (US = Upper stage. PS = Primary stage)

As a reference scenario for an RLV mission in this study, the Hopper concept is used (FIG 2). Investigated in the ESA FESTIP and the German ASTRA programme, the winged Hopper RLV carries an upper stage inside a cargo bay. It uses cryogenic rocket propulsion, horizontal take-off and horizontal landing, accelerating the upper composite to sub-orbital separation conditions. After ejection of the orbit insertion stage into a transfer orbit above atmosphere, it automatically executes a re-entry and descent. Following separation the orbit insertion upper stage accelerates the payload further into its desired injection orbit (FIG 3). The performance target was defined as to deliver 7t into GTO and about 13t into LEO orbits with an upper stage derived from the Ariane 5 ESC-B upper stage configuration and adapted to the specific needs and constraints.

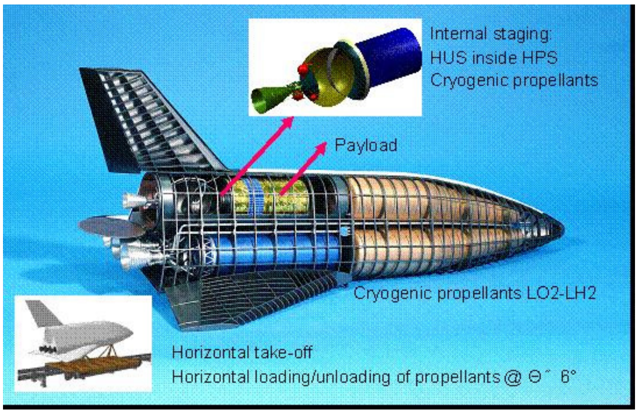

FIG 2. Hopper RLV Concept

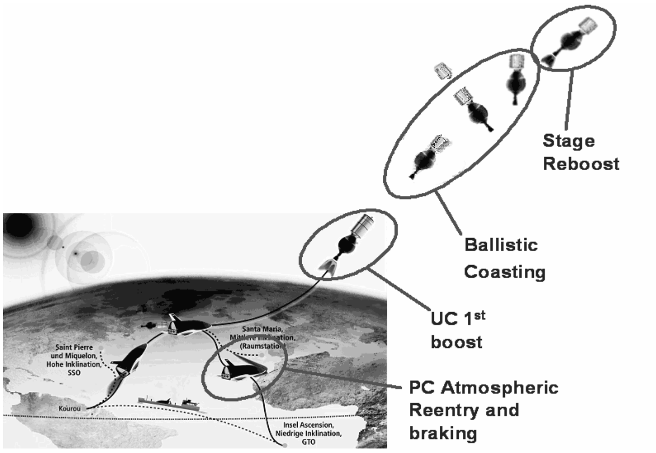

FIG 3. Hopper Mission Characteristics

2.3. Synthesis of Mission Scenarios – Design Reference Missions (DRM)

The idea of a DRM is to limit the amount of effort for investigations into different mission parameters by focusing on a sufficiently representative reference instead. During ESC-B development, detailed studies were made in the scope of the AMARANTE and SYCOMORE working groups. With respect to the specific orbit/ascent conditions of the direct/near GEO missions it can be concluded that

- GTO/GTO+ mission definition seems sufficiently representative for direct GEO (last boost for direct GEO: about 50 to 60s instead of 26 to 30s for GTO/GTO+ with 180kN VINCI like engine).
- For Sun Synchronous Orbit (SSO), the upper stage under-loading can be very similar to LEO/ATV, whereas the constraints, boost duration and propellant consumption for the last boost (de-orbitation) are expected to be close to that of the LEO/ATV. Thus the A5ECB LEO/ATV scenario is chosen as representative for all Near Earth Exploration missions and SSO.
- More than 90% of the previous Lunar Transfer Missions are based on a launch into a circular LEO with an altitude of 250 to 300 km for the preparation and proper injection into the transfer orbit (number of boosts for the upper stage can be in the order of 2 to 4). As the transfer itself is then to be done by another

(transfer) stage the LEO/ATV scenario can be used as sufficiently representative for LTO (and most Earth departure mission not relying on a single long boost for which the standard GTO is proposed to be used instead).

In conclusion the SYCOMORE mission scenario definitions can be used as representative for the identified missions:

- A5ECB GTO/GTO+ scenario is representative for Direct GEO, Super GEO and sub GEO,
- A5ECB LEO/ATV scenario covers the SSO, NEE Orbits and Lunar Mission Scenarios,
- A5ECB GTO is representative for future GTO and single boost Earth departure,
- A5ECB MEO missions are assumed to be covered by the other mission scenarios.

The data created during SYCOMORE is therefore used to build a dimensioning envelope for preliminary sizing and sensitivity analysis. The governing mission conditions identified during Sycomore are

- The ascent flight profiles, environmental loads and trajectory characteristics (e.g. propellant under-loading and thermal loads during ascent),
- Specific governing versatile mission conditions apart from the ascent loads, such as:
  - Number of re-ignitions (e.g. for pressurisation needs, consumption of fluid for propellant conditioning and chill down, liquid levels, sloshing suppression and geysering)
  - Minimum duration of boosts (e.g. ratio of transient/steady state engine operating phases for stable burn conditions, liquid levels prior to the boost)
  - Minimum and maximum in orbit coasting duration (e.g. for boil-off losses and time for propellant conditioning, propulsive needs for propellant retention and settling, exposure time to harsh natural environment)

3. SYNTHESIS OF THE CONCEPTUAL STAGE DESIGN AND ARCHITECTURE BASELINE (CSAB)

The definition of a generic Conceptual Stage Design and Architecture Baseline (CSAB) – similar to the DRM described in the previous paragraph – decouples the identification of technologies from a given single reference concept, acting as a kind of typical envelope. Therefore, technology needs applicable for this CSAB will also be applicable to a wide range of existing and future upper stages for both expendable and reusable vehicles.

To arrive at such a CSAB, background information was collected from a multitude of launch vehicles, either operational or defined in feasibility or pre-development studies:

- **Ariane 5 pre-Development and Evolution Studies**
  During the pre-development of the versatile cryogenic stage ESC-B, an industrial team lead by CNES was founded, the so-called Amarante working group. This group investigated many different configurations of new upper stage concepts and architectures. FIG 4 shows the final selected configuration in comparison with the operational ESC-A Ariane Upper Stage. Main features are:
  - Diameter: 5,4 m
  - Nominal propellant mass: 28 tons
  - Re-ignitable VINCI engine with extendable nozzle (thrust: 180kN)
  - Common bulkhead between LOX and LH2 tanks

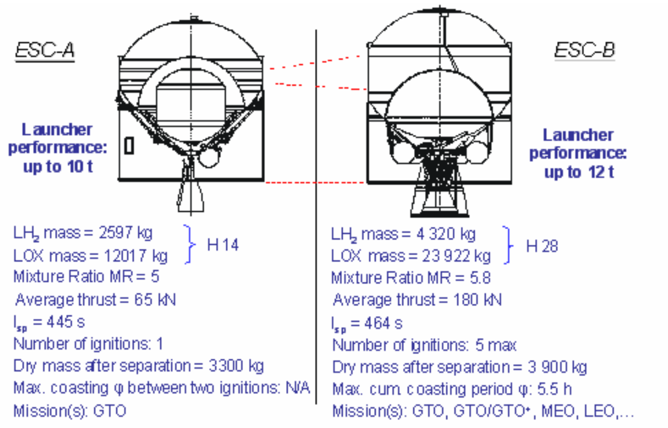

FIG 4. Comparison between Ariane 5 ESC-A and ESC-B Cryogenic Upper Stage.

- **Foreign Launch Vehicle Upper Stage Characteristics**
  An overview on the most important examined foreign launchers is given in TAB 2. Length, diameter, propellant mass and thrust vary significantly, whereas the ISP is in the range of 450s, indicating an LH2 / LOX fed engine. Examples for systems that have mission profiles and overall needs of performance and capabilities most similar to the envisaged new upper stage are Atlas V or Delta IV.

- **Other Concepts and Architectures**
  Other concepts that were examined include the Delta IV Heavy and highly versatile Evolution Option for Earth Departure, the Potential Future Atlas Evolution for long term Missions (so-called ICES), linear aerospikes, solar thermal upper stages or the Hopper Upper Stage. The last configuration has been studied intensively in Europe and is supposed to use components of the Ariane 5 ESC-B evolution, such as the VINCI engine and Subsystem equipments

Launcher	L (m)	D (m)	Prop. Mass (kg)	Thrust (kN)	ISP (s)	Status
ANGARA	8,6	4,1	19800	73,6	461	Planned
ATLAS ILAS	10	3,0	16780	198,4	450,5	Operational
ATLAS IIIA	10,5	3,0	16930	99,2	450,5	Operational
ATLAS V-4				99,2	450,5	Operational
ATLAS V-5	11,7	3,0	20830	99,2	450,5	Operational
DELTA IV-M	12	4,0	20400	110	462,4	Operational
DELTA IV-H	13,7	5,1	27200	110	462,4	In Development

Launcher	L (m)	D (m)	Prop. Mass (kg)	Thrust (kN)	ISP (s)	Status
HII A	9	4,0	16600	137,0	447	Operational
LM3B	12,4	3	18190	157	440	Operational
TITAN IV	9	4,3	20950	146	444	Operational

TAB 2. Overview on foreign launcher upper stages main data

Summarising all above mentioned data, some major similarities between the concepts can be detected:

- Usage of cryogenic propellants as the most critical load case for storage, propellant management etc.
- Common bulkhead between LOX and LH2 (except Delta 4, for example) as the most critical load case for tanks, insulation, etc.

Differences like diameter, length, or propellant mass play a minor role with respect to the selection of critical technologies.

Since the Ariane 5 ESC-B concept is very representative for the critical aspects and is also very well known from extensive studies in the past, it was decided to use the associated concept definitions as baseline for the CSAB. This includes main propulsion system, geometrical and mechanical interfaces, launch environment subsystems and ground interfaces. TAB 3 shows some of the main parameters and their possible variations that are used to deduct the technology needs. The “corridor” of the parameter variations was chosen to take into account main “versatility” requirements (re-ignition and prolonged non-propelled coasting). Some representative concept architectures are given in FIG 5.

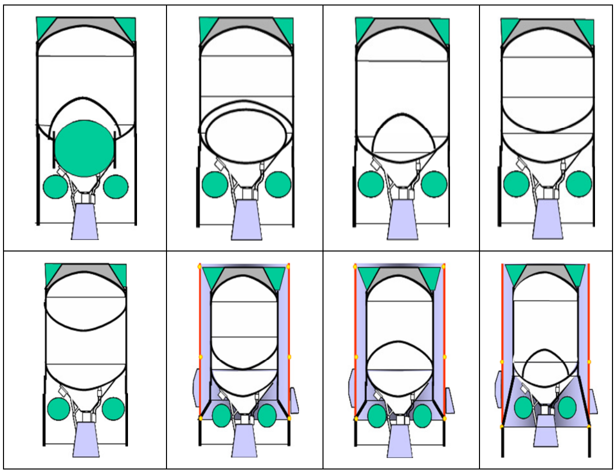

FIG 5. Reference concept architectures (examples)

Parameter	Nom/Ref.	Opt.1 / Max.	Opt.2 / Min.
Stage diameter [m]	5.4 (Ariane 5)	4 (≈Ariane 4 H10)	≈3 (VEGA PW80, LYRA)
Propellant loading [kg]	28000	~22000	
Propellant tank position [-]	LOX aft, LH2 front of the stage	LOX in front, LH2 in aft of the stage	
Main Engine [-]	VINCI, Expander Cycle (ISP 464s, Mixture Ratio MR = 5.8)		
Propellants [-]	LH2/LOX	Optionally for sensitivity check: LCH4/LOX	
Attitude Control System [--]	Hot gas reaction control system (propellants tbd.)	cold gas from propellant ullage (eventually heated for enthalpy rise)	
Propellant Management [-]	(Cooled) Liquid Acquisition Device	+ Start Basket / Tank + Phase separator at gas port	
Common Bulkhead Thermal Design	Internal wetted insulation on LH2 compartment side	Evacuated sandwich common bulkhead	

TAB 3. Overview of CSAB main parameters

4. ANALYSIS OF NEEDED TECHNOLOGIES

Two independent methods can be used for the identification of needed enabling technologies: Analysis of the upper stage product tree or functional phase by phase analysis of the mission. Here, both approaches are applied independently to crosscheck the results afterwards.

4.1. Analysis of the Product Tree

Using the product breakdown of the baselined CSAB, the following critical technological areas can be identified (TAB 4):

Main propulsion system (incl. engine, turbo pumps, engine propulsive equipment, etc.)
• Igniters
Propellant storage tank
• Liquid Acquisition devices (liquid port) • Phase separation devices (gas port) • Heat flux reduction via Y-rings • Advanced metallic tank alloys • Cryogenic composite tank materials (with/without liner) and associated tests • New tank dome shapes • Affordable evacuated metallic bulkhead and vacuum panels

• Outer Thermal Tank Insulation (low degradation thermal optical properties) • Inner Thermal Tank Insulation (LH2 compatible) • Sensors for mass gauge (under low g) • Propellant conditioning (fluid destratification/mixing, propellant temperature conditioning, propellant debubbling and phase separation) • Micro gravity pressure control
Stage pressurisation system
• Gas generator • Super critical helium storage • Helium bubbler • Hydrogen pressurisation of LOX tank
Thermal Insulation and thermal control system
• Stage versatile insulation kits • Radiative heat flux protection
Feeding system
• Boost Pump • Internal (LOX/LH2) compatible feed lines (bellows) • Void fraction and liquid quality measurement • Start basket • Cryogenic composite lines • Pump driven liquid circulation for feed line cooling and to guarantee mono-phasic conditions • Vapour cooled feed lines (double walled/vacuum jacket) • Engine Chill Down
Main structures (ETF, VEB, Intertank structures)
• Spin table • P/L damping mechanism • Fairing damping adapter • Syntactic metallic material /metallic foam composite • Advanced joints composite/metal
Attitude control system and propellant settling
• Cryogenic reaction control system • Compatible green propellant RCS • Gas generator • Pulsed mode and continuous operating modes • Throttle variability
Avionics System
• High bandwidth/high speed data management system • Enhanced tracking system (using GPS) • Enhanced telemetry/communication system (TDRSS/Artemis)
Power Supply System
• Li Ion batteries • Fuel cell cold startable diaphragm • Solar Power Generator
Electrical System
• Low power consumption valves and regulators • Advanced Health Management System
Actuators
• Power booster and amplifier
Ground I/F
• Loading/Deloading of densified or slush propellants

TAB 4. Critical technologies according to product tree analysis

4.2. Functional Analysis

For the Functional Analysis, operations and phenomena during typical versatile mission phases are analysed first to identify and assess potential risks and problems during flight. The following phases are studied:

- Ground Phase
- Primary Composite until booster separation
- Primary Composite propelled flight after booster separation
- Separation U/S from launcher
- CSAB boost
- Engine shut down
- Payload Separation Phase(s) after boost
- Long duration coasting phase(s)
- Preparatory phase(s) prior boost (inclusive propellant settling and propellant reconditioning)
- CSAB reboost
- De-Orbitation

In a second step the functional tree necessary to operate the stage is established and mapped to above mentioned mission phases for critical phenomena and operations.

As a result the following critical functional needs have been identified. For each critical function and phenomena a formulation of a top level functional need is derived which is foreseen to be given as top level statement and requirement in the following technology conceptual analysis loop. The initial list of roughly 86 functional needs derived form the analysis is synthesised and condensed to 21 top level functional sections as given hereafter.

1) To perform accurate and efficient loading / deloading (mainly loading of liquid propellant into main propellant tanks, but also filling of pressurant gas or other consumables)
2) To limit material degradation / deformation (deformation or degradation of the performance of a functional or structural element, e.g. outer thermal insulation by wind loads or common bulkhead thermal insulation by chilling shock due to propellant loading)
3) To establish accurate fluid conditions in tanks/lines (thermodynamic conditions of the liquid propellants and of the gas-vapour mixture in the tank ullage; it concerns temperature, pressure and density, but also two phase flow conditions, contents of bubble or diluted gases in the bulk liquid or liquid flow and the amount of droplets in the ullage of a tank)
4) To provide efficient and accurate measurement (physical and technical measurements such as temperature, pressure, attitude, power current/voltage)
5) To predict fluid behaviour accurately and efficiently (capability/ability to predict thermodynamic and fluid dynamic states of on-board liquids and gases)
6) To withstand environmental conditions (external loads during the mission, like wind, solar radiation, Earth Albedo, Earth shadow, humidity, acceleration, vacuum, particle radiation, X-rays etc.)
7) To perform efficient & accurate engine equipment temperature conditioning (mainly chill down of engine equipment to appropriate conditions, but also heating in case engine equipment gets too cold)
8) To perform efficient venting and purging (provision of gases to internal cavities including tanks and rejection of gases/vapour from internal cavities to the outside)
9) To perform efficient & accurate tank pressure control/pressurisation (control and stabilisation of tank pressure at a given set point)

10) To limit the heat exchange with the propellant in tanks/lines (parasitic heat entrance into the propellant tanks and feed lines)
11) To provide the P/L comfort box (protection of payload from dimensioning environmental or launcher induced loads)
12) To contribute to stage operations/design optimisation (reduction of mass, power, residuals, non propulsive propellant mass, losses, leaks etc.)
13) To limit induced loads and perturbations (by propulsive means like attitude control or by launcher operation such as stage separation shock, liquid sloshing in tank, etc.)
14) To eliminate void fraction/bubbles and gas efficiently and accurately from the liquid (avoidance / elimination of gas or vapour content from liquid bulk or flow, for diluted gases as well as physical void fractions like non-wetted outlet)
15) To provide accurately directed and sufficient acceleration (need for sufficient acceleration for propellant positioning, filling of cavities or predictability of thermodynamic phenomena)
16) To control upper composite attitude/roll motion (the upper stage SCATE function for attitude and roll control, without the need for propellant settling)
17) To limit electrical power consumption (relevant for long duration missions, e.g. GTO/GTO+)
18) To provide sufficient power for operations (generation/storage of power for long duration missions with high energy consumption at end of mission)
19) To provide Thrust Vector Control (orientation of the main engine thrust to control and optimize flight path of the launcher)
20) To perform efficient communication to ground (data ground link to provide information for later recovery activities or nominal post-flight evaluation)
21) To perform efficient data management (reduction /compression of data, transfer and optimization of the measured parameter during flight for both functional and operational measurement).

When comparing the results from the product tree analysis with those from the functional analysis, the latter gives more extensive information for ground/in-flight operations, needs for behaviour predictability, principle unknowns of the fluid behaviour and coupled/competitive effects. However, it is obvious from the above list that the same or at least very similar technologies will finally be required to fulfill the identified functions, therefore consolidating the identified technology needs.

4.3. Potential Industrial Partners

For a proposed maturation and demonstration phase of the technological needs identified in the previous paragraphs, industrial partners or subcontractors are needed. According to the know-how available in Europe, TAB 5 finally gives an overview on the potential partners for the various topics.

Enabling Technologies	**Partners /SubCo**
Inner Cryogenic Thermal Insulation	
Internal Insulation	CSP, Airliquide, Others
Evacuated Common Bulkhead	Alenia, MTA
Cryogenic Reaction Control	
H2/O2 Thrusters Technology	OTN, LAM, AirLiq., APP
Green Propellant Alternative	APP, TNO
PMD	
Liquid Acquisition Device and start basket	AL, IBE, Astrium
Phase Separation Device (and Bubbler)	Astrium, AL
Sloshing Suppression Device (and Baffles)	Anaylsis tbc.
Anti Wetting Device	Astrium, ZARM
Liquid Destratification Device	AL, Astrium
S/W Tools	
EUCES	IE, EA, Cenaero
Simplified System Simulation/Perfo. Analysis & Opt. Tool	IE, Astrium, Cenaero, TUE
Coupled Analysis (FCS, POGO, etc.)	Astrium, SNECMA
Outer CRYO Thermal Insulation	
Re-enforced Composite Material	CSP, AL others
Versatile Kit	Austrian Aerospace, IBE
Smart Sensors	
Mass gauging/mg Liquid Position	Tbc AL
Liquid Quality	TBC MAGNA
Press. System Elements	
Amplifier	others
Gas Generator	TNO, Bradford, others
SSHEL Storage	AirLiquide
Power Generation & Storage	
Li-Ion Batteries	SAFT
Solar Generator	Tbc
TVC Booster	SABCA
Operations	
Chill Down	SNECMA
T-Conditioning	Astrium, AL
Data Management and Ground Communication	
Digital avionic and OBC	Astriu, Saab
GPS Simulator	Astrium
Relay satellite communication	Astrium
Structures	
Internal Feed lines (LOX/LH2) & torsion free	MAGNA, Idrosapiens, AL
Active Payload Adapter	CASA, Astrium
Full Composite Stage	CASA; Dutch Aerospace, Alenia, EIRE
Sandwich common bulkheads configs.	MTA, Alenia, AirLiquide
Al-Lithium Tanks	MTA, Alenia
Spin table P/L adapter and propulsive dispenser	Tbd.
Metallic foam Composites	MTA, others

TAB 5. Potential European partners for technology maturation

5. SUMMARY AND PROGRAMMATIC OUTLOOK

This paper describes the identification of needed and enabling technologies for next generation cryogenic upper stages. Starting from the determination of customer mission needs and mission constraints, typical Design Reference Missions (DRM) are defined as an envelope for the evaluation of the selected concept. This concept is defined by the means of a generic Conceptual Stage Design and Architecture Baseline (CSAB) and decouples the identification of technologies from a given single reference concept. From here, the needed enabling technologies are identified, by both analysis of the upper stage product tree and by functional phase by phase analysis of the mission. Finally, the identified technologies are mapped against the industrial know-how in Europe to get an overview on future potential partners for technology maturation. Further details of the activities can be found in [9].

The study activities described in this paper were conducted using German National funding; they are a further step on the way to a new European Cryogenic Upper Stage. The results obtained are used as an input to more detailed and broader follow-up activities financed by ESA in the frame of the Future Launcher Preparatory Programme FLPP2.

CTECH - Ariane 5 Slice 10 Step 2

Completed in mid 2007, the CTECH study both detailed and enlarged the results, focusing on

- Technology Gaps and Needs
- Industrial Consultation
- Identifying Key Technology
- Detailed Technology conception
- Technology Priorities
- Industrial Organization
- Technology Maturation Master Schedule

CUST – Cryogenic Upper Stage Technologies

Currently under negotiation with ESA and NGL Company, the CUST activities will initiate the maturation of several high priority technologies to a Technology Readiness Level (TRL, [10]) of 6, which means that the respective technology will be tested on a system/subsystem model or demonstrated on a prototype in a relevant ground or space environment.

6. ACKNOWLEDGEMENT

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8. ACRONYMS

ATV	Automated Transfer Vehicle
A5ECB	Ariane 5 launch vehicle configuration using ESC-B cryogenic propellant upper stage
CNES	Centre National d'Études Spatiales
COMSTAC	Commercial Space Transportation Advisory Committee
CSAB	Conceptual Stage Design and Architecture Baseline
CUST	Cryogenic Upper Stage Technologies
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DRM	Design Reference Mission
EAP	Ariane 5 Solid Propellant Boosters
EDM	Earth Departure Mission
ELV	Expandable Launch Vehicle
EPC	Ariane 5 Cryogenic main Stage
ESA	European Space Agency
ESC-A	Ariane 5 Cryogenic Upper Stage, Version A
ESC-B	Ariane 5 Cryogenic Upper Stage, Version B
FAA/AST	Federal Aviation Administration's Associate Administrator for Commercial Space Transportation
FESTIP	Future European Space Transportation Investigations Programme
FLPP2	Future Launcher Preparatory Programme 2
GEO	Geostationary Orbit
GTO	Geostationary Transfer Orbit
ICES	Integrated Cryogenic Evolved Stage
ISP	Specific Impulse
LCH4	Liquid Methane
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LOX	Liquid Oxygen
LTO	Lunar Transfer Orbit
MEO	Medium Earth Orbit
MR	Mixture Ratio
PMD	Propellant Management Device
P/L	Payload
PS	Primary stage
RCS	Reaction Control System
RLV	Reusable Launch Vehicle
SCAR	Attitude and Roll Control System
SCATE	Attitude Control and Propellant Settling System
SSO	Sun Synchronous Orbit
TRL	Technology Readiness Level
US	United States / Upper Stage