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LunaNova kick stage: an overview of the system propulsion trade-offs

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Abstract

In the last decade, the boom of commercial space has irrevocably propelled the space sector into a new era. These new times come along with a whole new portfolio of missions and services to deliver. ArianeGroup, willing to embrace this vision, has been working to enhance the future European launcher capabilities by studying and developing new space transportation services and logistics. Among these lasts, kick stages play a significant role in providing multi-injection capabilities and in-space services such as communications relay or towing. Under the ESA Future Launcher Preparatory Programme (FLPP), ArianeGroup is carrying out a Phase 0/A study to advance this new generation of in-orbit vehicles, i.e. the LunaNova study. This paper provides a product description of the envisioned LunaNova family to later focus on the performed propulsion system trade-offs. More specifically, an overview of the pressurisation system and propellant selection is provided. The paper concludes by discussing the selected alternatives, which will be then integrated into the preliminary system architecture.

Keywords: (kick stage, propulsion, e-pumps, green propellants)

Nomenclature

O/F	Mixture Ratio	-
P	Power	W
Δp	Pressure rise	Pa
$\dot{m}$	Mass flow rate	kg/s
ρ	Density	kg/m^3
η_p	Pump efficiency	-
δ_p	Power density	W/kg
δ_e	Energy density	Wh/kg
m	Mass	kg

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η_p	Pump efficiency	-
H_2O_2	Hydrogen Peroxide	
Isp	Specific Impulse	s

Acronyms and Abbreviations

A6	Ariane 6 launcher
AG	ArianeGroup
AOCS	Attitude & Orbit Control System
e-pumps	Electric pump-fed pressurisation system
ESA	European Space Agency
FLPP	Future Launchers Preparatory Programme
GEO	Geostationary Orbit
GNC	Guidance, Navigation and Control
H/W	Hardware
HTP	High Test Hydrogen Peroxide
LEO	Low Earth Orbit
LLO	Low Lunar Orbit
LN	LunaNova Kick Stage
MBSE	Model-Based Systems Engineering
MEOP	Maximum Expected Operating Pressure
NRC	Non-Recurrent Cost
NRHO	Near Rectilinear Halo Orbit
RC	Recurrent Cost
S/S	Subsystem

1. Introduction

The emergence and later establishment of commercial space activities, the so-called new space, has imposed new dynamics and challenges on the space transportation industry. Multi-injection capabilities and in-orbit services will become key features for any launcher provider in the upcoming decades.

To answer these needs, the ESA Future Launchers Preparatory Programme (FLPP) carries out system studies to enhance European launcher capacities. Among others, these related studies undertake the challenges associated with the new LEO, GEO and cis-lunar space logistics needs [1].

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Under this frame, ArianeGroup Bremen is carrying out a phase 0/A study to promote the development of a new European kick stage generation. The product, named LunaNova, is considered an addition to the baseline launch services to extend the mission opportunities.

Kick stages are space vehicles designed to provide the last-mile delivery after dedicated, rideshare or piggyback launches. This versatility is a key enabler for the efficient deployment of multiple-plane constellations or the accurate injection of payloads from different operators within one launch. Moreover, they can enhance payload deployment beyond Earth orbit, promoting cis-lunar commercial ecosystem and deep space exploration missions.

The space market can additionally benefit from kick stages thanks to in-orbit operations such as communications relay, towing or active debris removal.

Thanks to this potential, both well-established launcher providers and younger startup companies are already developing (or planning to) kick stages to include these last-mile flight services in their portfolios.

Among the well-established actors, ArianeGroup Bremen is developing ASTRIS, the Ariane 6 kick stage, whose maiden flight is expected this decade. It will be marketed as an add-on to Ariane 6's standard launch service and will interface directly with the payload [2].
ASTRIS will increase the A6 services portfolio by allowing complex orbital transfers and taking over some propulsion capabilities otherwise delegated to the payload. ESA's Hera spacecraft, a planetary defence mission to the Didymos asteroid system, is planned as its first mission. Closer to Earth, it will also provide flexibility by enabling LEO multi-orbit multi-payload deployment [2].
Regarding the propulsion system, ASTRIS will be powered by the BERTA engine, a mid-size storable-propellant engine currently under development at ArianeGroup Ottobrunn [2].

On the other hand, NZ-US launcher manufacturer Rocket Lab offers a kick stage tailored for their Electron small satellite launcher. It relies on the Curie engine, an in-house manufactured propulsion system capable of multiple re-ignition and a cold gas reaction control system for precise attitude manoeuvres [3].

Finally, startups such as Rocket Factory Augsburg (RFA) also include kick stages into their development strategy. This case involves the so-called orbital stage, which aims to accurately deliver different payloads from LEO to GEO [4].

Coming back to the LunaNova study, this paper will cover the following topics:

- LunaNova services
- LunaNova product overview
- LunaNova propulsion trade-offs
- Summary

2. LunaNova services

LunaNova (LN) kick stage aims to extend the launcher capabilities further by providing the flexibility required to target additional mission scenarios. From the operational perspective, LunaNova shall enable the following services:

TO-ORBIT MISSIONS	High versatile Earth missions
	Lunar missions
IN-SPACE SERVICES	Active debris removal
	Towing
	Communications relay

Table 1: LunaNova services

2.1 TO-ORBIT MISSIONS

2.1.1 Highly versatile Earth missions

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LunaNova shall provide one or multiple payloads with precise orbital injection. High versatile and complex mission scenarios can be pursued since payloads belonging to different operators can be delivered to different destination orbits within a single launch.

2.1.2 Lunar missions

Following the same philosophy, LunaNova shall deliver one or several payloads into one or multiple Lunar orbits, namely LLO and NRHO orbits. Cis-lunar activities and deep exploration missions will directly benefit from these new capabilities.

2.2 IN-SPACE INNOVATIVE SERVICES

2.2.1 Debris removal service

Debris removal involves capturing and placing a target into either a de-orbiting trajectory or graveyard orbit. Figure 1 provides an example of LunaNova active debris removal mission profile.

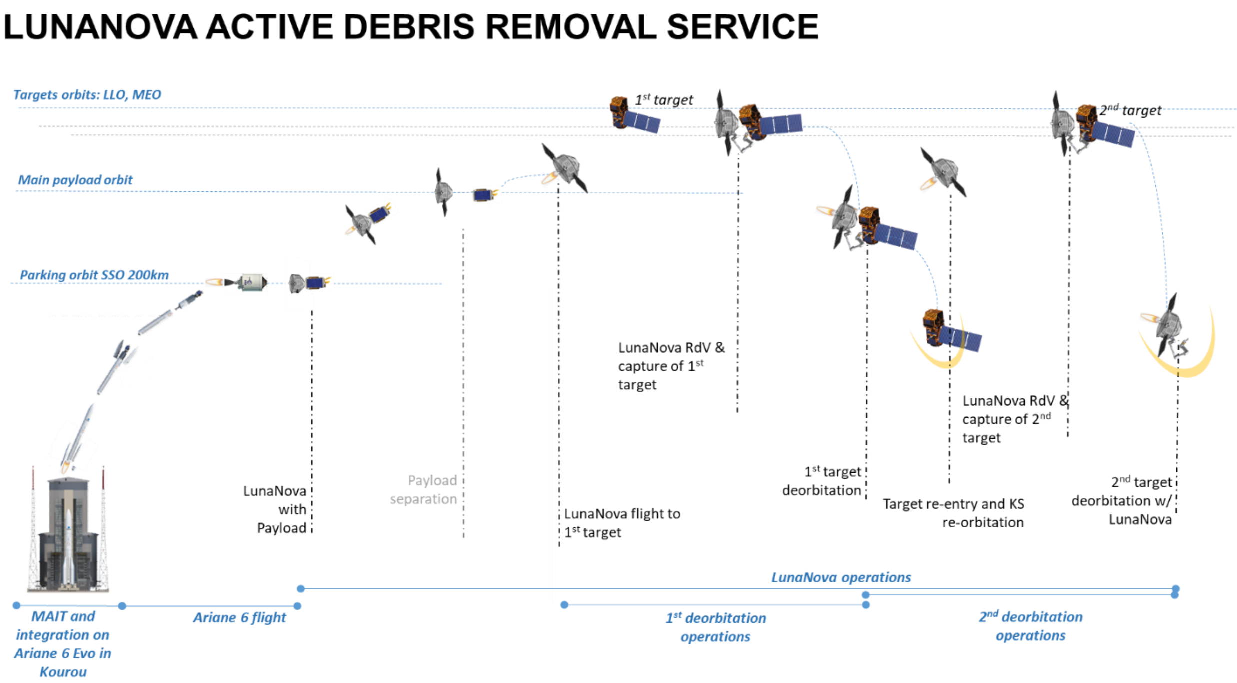

Figure 1: LN Active Debris Removal Service

As seen in the Figure, LunaNova is foreseen to perform several de-orbiting missions consecutively.

2.2.2 Towing service

Similar to debris removal, this service consists of capturing a target (in this case, a collaborative target) and transferring it into a new orbit. Figure 2 depicts one possible mission scenario with two towing services.

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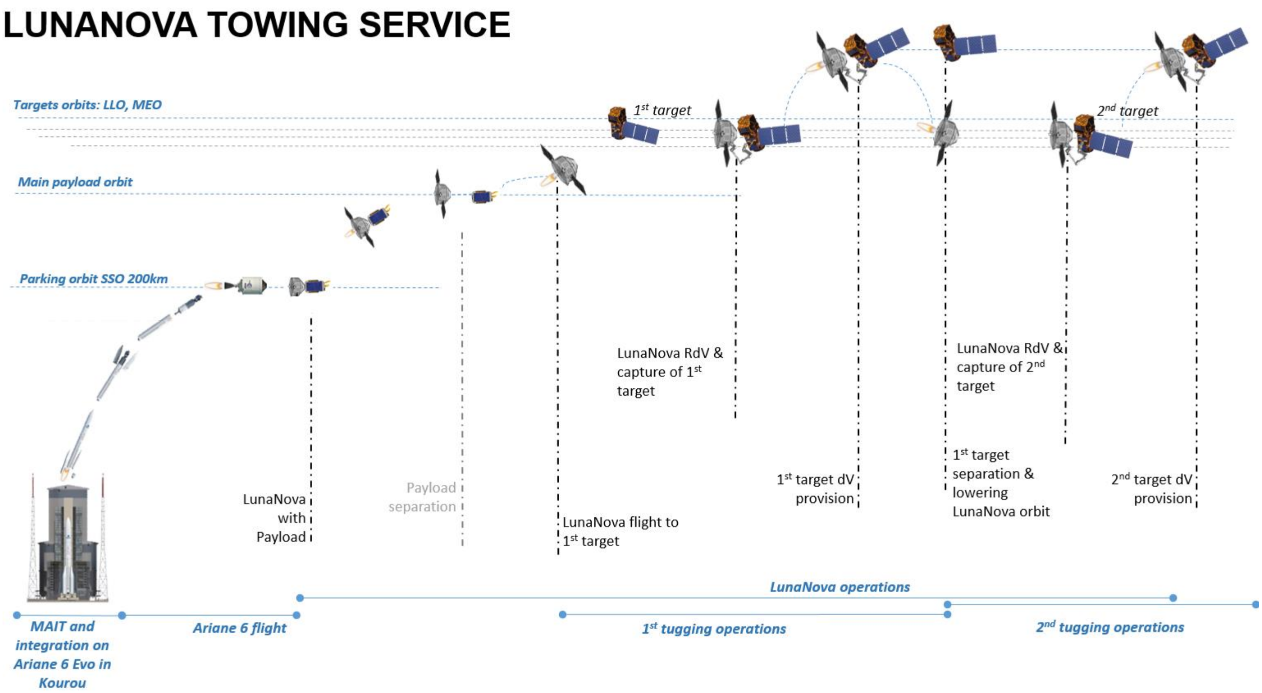

Figure 2: LN Towing Service

2.2.3 Communications relay service

Communication between "System A" and "System B" shall be enabled via the LunaNova vehicle. Systems A and B could be either ground stations, spacecrafts, satellites or any other type of vehicle. Figure 3 shows the different actors involved in the service.

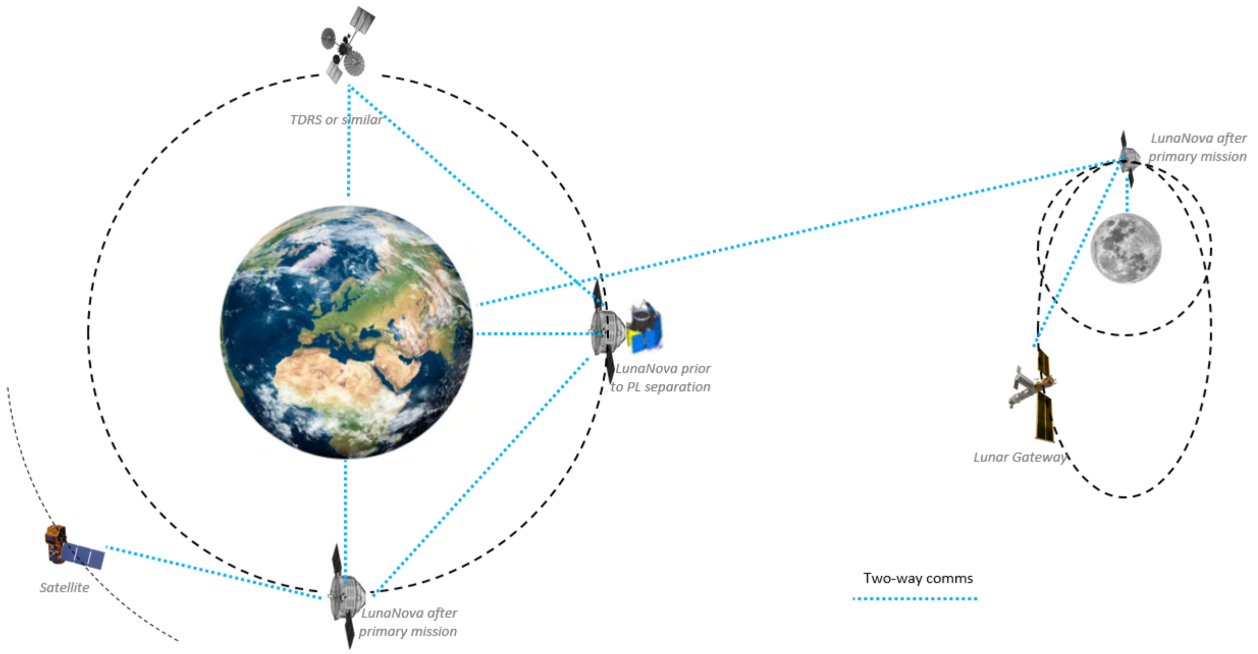

Figure 3: LN Communications Relay Service

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Figure 3 shows communication relay services being performed at both Earth and Lunar orbits. Particularly, enabling this kind of service in cis-lunar orbits would be highly beneficial to the development of a lunar commercial environment.

2.3 KITS APPROACH

LN system design will allow combining two or more services within a single flight. To accomplish this goal, a modular design philosophy has been adopted. Depending on the mission scenario, LN vehicle will be equipped with one of the following kit configurations:

Scenario	Final orbit	To- orbit service	ADR/Towing KIT	TC/Comms relay KIT
1	Earth/Moon Full to-orbit service launch	Maximum mass P/L	✗	✗
2	Earth/ Moon	High mass P/L	✗	✓
3	Earth/Moon Full services	Low to medium mass P/L	✓	✓
4	Earth/Moon Full in-orbit services launch	✗	✓	✓

Table 2: KITS configuration

3. Product overview

The mission scenarios described in Section 2 determine the system architecture. Moreover, LunaNova design shall rely on innovative technologies to lower production and operational costs while improving competitiveness and commercial appeal. Additive manufacturing and next-gen avionics have been already identified as potential technologies within the LN study. Their potential to enhance the system performance and reliability as well as to provide mass and cost reduction is being assessed through dedicated trade-offs. In parallel, the preliminary system architecture's definition is supported by applying Model-Based System Engineering tools (MBSE), namely the Arcadia methodology. Figure 4 depicts the Arcadia working principle.

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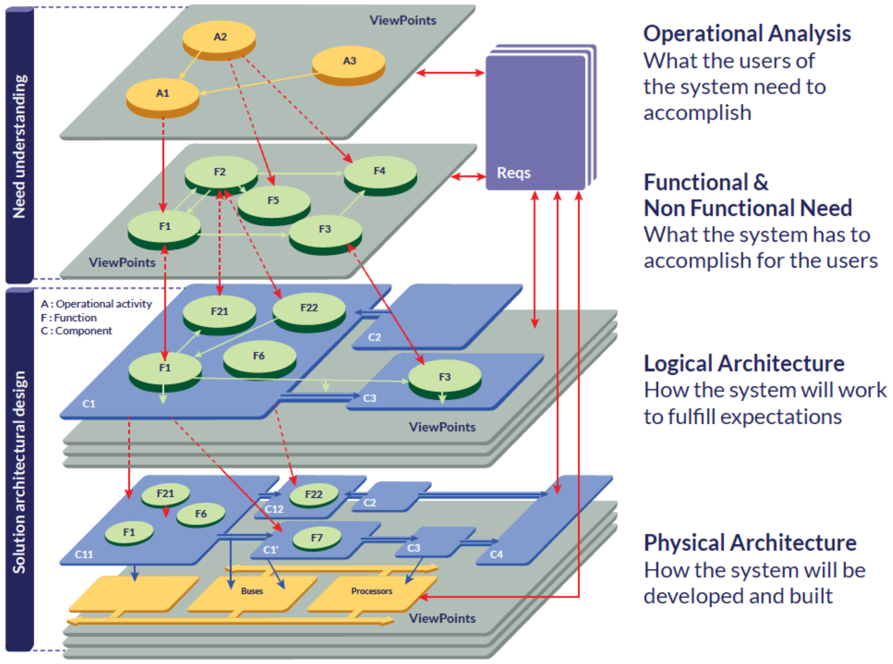

Figure 4: Arcadia working principle

The Arcadia methodology is conceived to ensure consistency between the operational analyses, in charge of expressing the customer's and user's needs, and the system definition and design. The utilisation of the functional analysis to trace and link the high-level needs to the low-level design guarantees the compliance of the final design with the customer's requirements and properly tracks any changes.

The yellow top items in Figure 4 represent the operational elements used to define the customer's needs. The blue and yellow bottom items are, respectively, subsystems and components elements. Finally, in green, the functional analysis is depicted.

3.1 Propulsion subsystem overview

Regarding the propulsive subsystem, storable green propellants, new tank configurations and innovative pressurisation systems have been identified as potential technologies.

As already discussed, the implementation of a light kick stage can be a decisive asset for enhancing the launcher's versatility towards the completion of more complex Earth-orbit profiles and new beyond-Earth scenarios. Storable propellants present advantages in these cases with respect to their cryogenic counterparts' since the longer mission durations can be hardly compliant with the stringent thermal control constraints of cryogenic propellants.
LunaNova propulsion capabilities will take advantage of a new green storable engine currently under development within the FLPP framework.

In addition to their improved sustainability, the easier handling of green propellants may lower ground operational costs. In general, the implementation of green propellant is not a short-term cost-efficient solution but has the potential to prove efficient in the long run, especially with the foreseen sunset date of using hydrazine for space applications. Green propellants can already bring several advantages, such as higher density, translating into a reduction of propellant tank sizing, and higher flexibility. Hydrogen peroxide indeed brings the following perks and cons at system level when compared to hydrazine and its derivatives:

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ADVANTAGES	DISADVANTAGES
High maturity	Lower performance than hydrazine at same operational conditions
High density	Material compatibility
Multimode configuration	

Table 3: Hydrogen peroxide advantages and disadvantages

Finally, the utilisation of e-pumps can also bring performance advantages in terms of mass reduction when compared to pressure-fed systems.

The use of pumps can lead to a decrease in the propellant tank MEOP pressure and, consequently, a reduction in tank and pressurant gas masses. Both together result in significant mass savings that can increase the payload capability and the system delta-v capabilities. On the other side, the simplicity and maturity of pressure fed systems can bring advantages in terms of reliability and costs. E-pumps low maturity level implies substantial non-recurrent costs that cannot be neglected when the two pressurisation technologies are compared.

Table 4 sums up e-pumps main advantages and disadvantages with respect to pressure fed systems.

ADVANTAGES	DISADVANTAGES
Tank mass reduction	Higher development costs
Pressurant gas mass reduction	Lower reliability

Table 4: Electric pump feeding advantages and disadvantages

In conclusion, both technologies have advantages and disadvantages that need to be carefully weighed before selecting them to be part of our system. Following this objective, Section 4 presents two of the trade-offs already accomplished in LunaNova: the first one regards the oxidiser selection, while the second focuses on the pressurisation system.

4. Lunanova propulsion trade-offs

As noted in Section 3, some trade-off analyses were required in order to define the LunaNova system preliminary architecture.

Before going through them, it is important to highlight that a cost-oriented approach was applied in both cases, based on the impact of specific key parameters of each technology. From the propellant point of view, after selecting HTP as LunaNova baseline oxidiser, different analyses were accomplished to assess its optimal concentration. In the case of electric pump feeding, an estimate of the different masses for each pressurisation system was carried out. Moreover, the perspective of relevant engineering disciplines was also included in the study.

Due to the early stage of the project, the degree of uncertainty in the calculations is still high. Even though margins and reasonable assumptions were adopted, mass and costs are to be intended as preliminary estimations to investigate the benefits of implementing such technologies. The accuracy of the calculations will be improved in the subsequent phases of the project.

4.1 Oxidiser concentration trade-off

One of the trade-offs regarding the LunaNova propulsion system was to decide on whether to keep the same toxic propellant combination as ASTRIS or target a green propellant alternative. In the frame of the FLPP program, implementing a green option was recommended.

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Moreover, since the FLPP green storable propulsion project is already exploring some H_2O_2/Hydrocarbon propellant combinations, choosing hydrogen peroxide as oxidiser seemed a logical follow-up.

Indeed, hydrogen peroxide stands as one of the favourite candidates to replace hydrazine-based propellants, especially for low to medium thrust applications. It brings many perks, such as reduced toxicity and higher density impulse than hydrazine combinations. Its multi-mode functionality, allowing it to be used either in monopropellant or bipropellant systems, also increases the system versatility. On the other hand, H_2O_2 has some downsides, such as low performance, incompatibility with Titanium and high decomposition rates in certain conditions. However, despite its rather low performance as monopropellant, it can reach promising performance when combined with a hydrocarbon fuel. Above all, the main advantage of hydrogen peroxide over other green alternatives is its high maturity.

For rocket propulsion applications, hydrogen peroxide is used at very high concentrations. Highly concentrated hydrogen peroxide referred to as HTP (High-Grade Peroxide), should be at least 70% concentrated by weight with a regulation on concentrations and impurity levels. HTP is commercially available in aqueous solution at concentrations up to 99% by weight. However, while the production process is well-rounded for concentrations up to 87.5%, optimisations are still ongoing for higher concentrations, resulting in a significant price difference. Indeed, price figures gathered from production companies showed that 98% HTP is four up to five times as 87.5% HTP. Since most of the bipropellant systems using HTP/Hydrocarbon combinations have high oxidiser-to-fuel mixture ratios, most of the propellant mass needed for the kick stage will be covered by HTP. Therefore, the price difference between the two HTP-concentrations could lead to a substantial cost impact. However, while lower concentrated HTP comes at a lower price, it also comes with weaker performance, namely a lower specific impulse, which results in a payload mass penalty. With this in mind, a trade-off based on cost and performance is performed between the two following oxidiser concentrations:

- 87.5% HTP
- 98% HTP

4.1.1 Hypotheses relevant for the trade-off

A simple analysis performed with the open-source Rocket Propulsion Analysis (RPA) tool for a HTP/Hydrocarbon combination shows, in Figure 5, that the I_{sp} increases almost linearly with the HTP concentration. After applying an internal performance factor, the difference in specific impulse between the two HTP concentrations has been estimated to be 30 s. This performance gap directly impacts the payload mass the kick stage can carry and is evaluated in the next section.

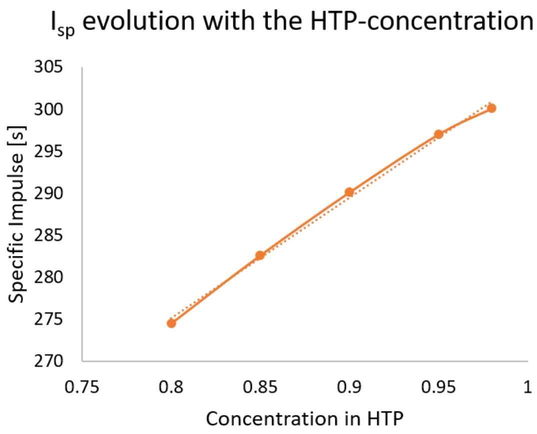

Figure 5: Evolution of the specific impulse with the concentration in hydrogen peroxide

4.1.2 System engineering perspective

From a system engineering perspective, a first point to observe is the density difference between the two HTP concentrations. Indeed, as reported in Table 5, 87.5% HTP is slightly less dense (4%) than 98% HTP and would

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therefore require a larger tank volume. Moreover, as the concentration in oxidiser decreases, the mixture ratio for the HTP/hydrocarbon combination would increase, resulting in a larger oxidiser mass.

	Density [kg/m^3]
98% H_2O_2	1437
87.5% H_2O_2	1379

Table 5: HTP densities with respect to the concentration in H_2O_2

The decrease in performance, shown in Figure 5, from 98% to 87.5% HTP directly translates into a lower payload mass capacity. This mass penalty has been evaluated for each future mission foreseen for the LunaNova system and weighted with respect to the occurrence of each mission per year. The total weighted mass penalty is, in this way, estimated to 250 kg per year. The impact is shown in terms of payload mass fraction in Table 6 for missions performed either with the A62 or A64 launchers.

	Lunar Orbits	Earth Orbits					
Mission Orbit		SSO	A62 GEO	A64 GEO	A62 MEO	A64 MEO	A64 GEO
Percentage of Payload Mass Penalty [%]	6.1	1.1	6.3	5.7	6.0	5.6	5.0

Table 6: Payload mass penalty for LunaNova future missions due to the performance loss from 98% to 87.5% HTP

ArianeGroup internally computed the LN payload mass for performing the Earth and Lunar missions reported in Table 6. As the overall 250 kg payload mass penalty per year, associated with the 30s loss in performance from 98% to 87.5% HTP, is a weighted average, Table 6 reports this loss, in percentage, of the payload mass capacity for each mission. Results show that the impact in payload capacity is generally lower for the A64 configuration targeting Earth orbits. Overall, for most missions, the payload mass penalty represents between 5 and 6.3% of the kick stage payload capacity.

The SSO mission is a special case. Indeed, as this mission is intended for low orbits, few propellant mass is needed, leaving space for an important payload mass capacity. Hence, the mass penalty impact is much lower for SSO missions.

4.1.3 Cost engineering perspective

The mass penalty highlighted in Table 6 has a direct cost repercussion, and this impact has been computed and weighted for each mission to reach an average price estimation. The results show that the overall cost associated with the payload mass penalty is more than four times more expensive than the save in oxidiser cost. Indeed, 87.5% HTP is less expensive than 98% HTP but is also less performant. The cost impact of this performance loss is by far too expensive and is not compensated by any other factor. The decision is therefore made to choose 98% HTP as oxidiser for the LunaNova system.

4.1 Pressurisation system trade-off

The two pressurisation systems considered for this trade-off are:

- Pressure- fed system
- Electric pump-fed systems or e-pumps

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While the last ones may reduce the system's dry mass, pressure fed systems have the advantage of being a well-established and reliable solution. The following sections present the different aspects of the trade-off, from hypotheses to results and perspectives from the different engineering disciplines.

4.1.1 Hypotheses relevant for the trade-off

Table 7 shows the initial hypotheses for the trade-off.

Maximum boost time (s)	6 500
Minimum coasting time (s)	30 000
Oxidiser	98% HTP
Fuel	Kerosene

Table 7: Assumptions

The first two values in Table 7, i.e., boost and coasting time, strongly influence the batteries and solar panel sizing. To note that these assumptions are highly conservative since both situations are auto exclusive; the need for full battery recharge is associated with a complete battery depletion over the first firing and, therefore, a significant propellant consumption. A limited amount of propellant would be available at this point for this second burn, and hence, there would be no need for full battery capacity. In other words, this implies that both power storage and generation will be dimensioned for the most critical conditions, i.e. maximum boost and minimum coasting times.

The assumption was taken to cope with the following:

- Early-stage CONOPS
- Low heritage and uncertainties in e-pumps figures of merit

Both systems were weighed under the same conditions, i.e. thrust level and specific impulse were considered equal for both configurations. Based on these inputs, oxidiser and fuel mass flow rates were calculated.

Regarding tank pressures, the implementation of e-pumps allows a significant reduction of the MEOP while maintaining the same chamber pressure, as shown in Table 8.

	Pressure fed	**E-pumps**
MEOP (bar)	20	5

Table 8: MEOP tanks

Finally, the e-pump specifications were gathered through consultation with different sources and a literature review [5, 6, 7, 8, 9] and for all cases, conservative values were selected.

Pump power was calculated according to the following equation:

$$P = \frac{\Delta P \dot{m}}{\eta_p \rho} \qquad (1)$$

where P (W) is the pump required by the pump, Δp (Pa) is the pressure increase that needs to be delivered, $\dot{m}$ (kg/s) is the propellant mass flow rate, η_p is the pump efficiency, ρ (kg/m^3) is the propellant density.

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Equivalently, the rest of the consumptions are calculated based on the electric motor, controller, and battery efficiencies. Solar power generation is also determined via the same method.

With the help of power and energy density, battery masses are calculated:

$$\delta_p = \frac{P}{m} \qquad (2)$$

$$\delta_e = \frac{E}{m} \qquad (3)$$

where δ_p (W/kg) and δ_e (Wh/kg) are the component power and energy density, respectively, and m (kg) is the mass.

4.1.2 System engineering perspective

Any dry mass savings can be directly correlated to an increase in payload capacity. Therefore, the selection of the pressurisation system has a remarkable impact at system level.

Calculations showed that approximately one-third of mass reduction could be achieved by using e-pumps rather than the constant gas pressurised system configuration. This is mainly driven by the linear decrease in tank mass with pressure.

Figure 6 and Figure 7 depict the mass distribution for each configuration.

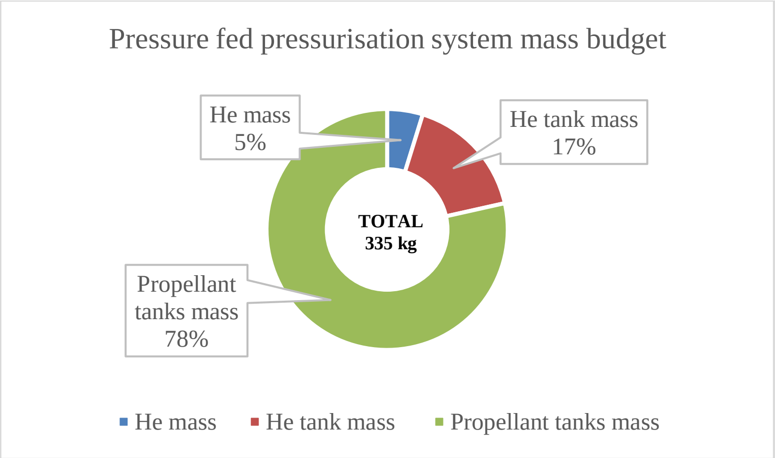

Figure 6: Pressure fed system mass distribution

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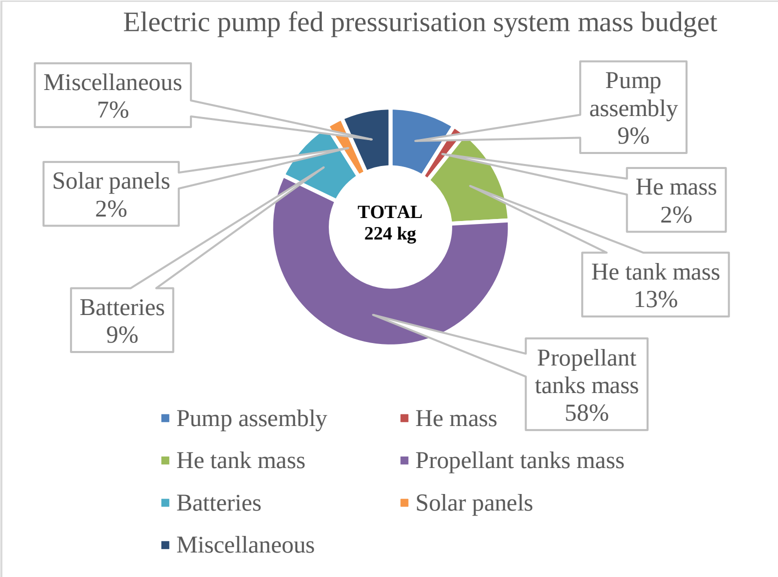

Figure 7: E-pumps mass distribution

Where miscellaneous in Figure 7 accounts for e-pumps additional components for thermal management, and extra avionics.

4.1.3 Operational engineering perspective

From the operational perspective, a decrease in the He tank MEOP pressure could lead to significant cost savings due to the following reasons:

- The relaxation of safety procedures
- The decrease in operational time required to pressurise the tanks

Hence, the lower e-pump propellant tank pressure does not only translate into direct mass savings but also into lower operational costs. As seen in Figure 7, the He mass required for the e-pump configuration is four times lower than for the pressure fed. This mass reduction could leverage the increase in pressurant gas volume associated with the lower tank pressures, and therefore, the mentioned cost savings can be targeted.

4.1.4 Propulsion engineering perspective

The propellant tank MEOP pressure reduction might also bring some advantages from the propulsion engineering perspective.

Due to its lower operating pressure, part of the propulsion sub-system down to the e-pumps could be pressurised on ground, meaning the e-pump configuration would not require an extra in-flight pressurisation step. This would allow improving failure detection on ground, eventually increasing system reliability and streamlining acceptance test procedures.

On the other hand, throttleability could also take advantage of the e-pump configuration. Regarding this fact, one possible approach could be to throttle the engine by tailoring the electric motor rpm, enabled with little to no impact on the engine definition itself.

Finally, late performance adaptations from the nominal operating point could be envisioned for systems using e-pumps since higher chamber pressures can be achieved with a smaller system impact.

4.1.5 Cost engineering perspective

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Finally, as stated at the beginning of Section 4, the trade-off was performed with a cost-oriented approach. Hence, the decision on what technology to select was triggered by the presumable higher value that each technology could provide, based on the performed assessments. Table 9 presents the analysed recurrent costs (RC).

Description	**Remark**
Operating costs	Impact due to the possibility of lowering the He tank MEOP
Delta RC for propulsion S/S	Due to part of the system running at lower MEOP
RC for e-pumps H/W	
Delta RC for Tanks	Due to the fact that they use different He masses
Delta RC for GNC/AOCS	
Delta RC solar arrays	Note that the trade-off is highly sensitive to solar array cost; could be significantly reduced in the near future due to new technology (e.g. perovskites)
Delta RC avionics uncertainty	Specific electronics for e-pumps
Performance improvement due to delta mass	Due to the fact that any system mass savings can be correlated with an increase in the payload capacity and, therefore, in the revenues per flight See Figure 7 for mass breakdown

Table 9: Analysed recurrent costs

On the other hand, the non-recurrent costs (NRC) taken into consideration are:

Description	**Remark**
Development costs for e-pump	Up to TRL 9
Delta development costs for engine	Regarding impact due to different "startup" transient

Table 10:Analysed non-recurrent costs

Quantitatively, this preliminary cost assessment shows that, in the case of LN, e-pumps could trade more favourably than their pressure-fed counterparts when costs and performance improvements in the form of mass savings are

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considered. This mass reduction translates into a bigger payload capacity, resulting in greater average revenue per flight. The main reason for this better performance is the lighter tanks enabled by the e-pump configuration. Figure 8 depicts the estimated revenues and costs per flight.

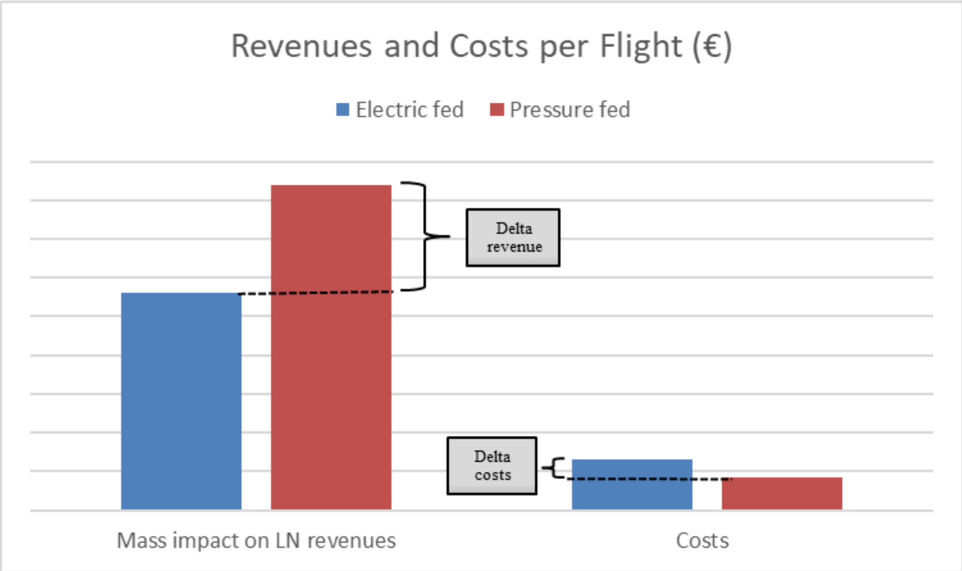

Figure 8: Revenues and costs per flight

As seen in the first column of Figure 8, the implementation of e-pumps can increase the LN revenue per flight. The magnitude of this increase is proportional to the one-third mass reduction achieved when adopting them, as stated in Section 4.1.2.

Column 2 shows the total costs per flight by configuration, including the RC and NRC as defined in Table 9 and Table 10. NRC per flight are defined by assuming 6 flights per year over a 10 years depreciation period [1].

As expected, the total costs of e-pumps are higher than the pressure fed configuration. However, as explained in Section 4.1.3, e-pumps estimated RC substantially benefits from the decrease of pressure inside the pressurant gas tank. On the other hand, the development costs associated with their lower maturity level result in a significant NRC increase.

Overall though, the potential delta revenues of e-pumps turn out to be approximately 5 times bigger than their delta costs with respect to pressure fed systems. Moreover, it is also interesting to point out that if e-pumps were selected, their development costs would be partially covered by LN programme, and a new competitive product would be available within AG portfolio.

It is important to note that, regardless of the rough cost estimation typical of these preliminary phases of the project, an additional safety margin was also included to account for other expenses not properly quantified in this study. What was meaningful for the trade-off was mainly to account for the differences in performance and costs to, eventually, be confident in picking one technology over the other. More accurate revenues and cost studies will be carried out in the next steps of the project.

Summary

The study presented in this paper, namely the LunaNova study, aims to enhance the European launcher competitiveness by extending the range of services provided and opening up new mission opportunities. This increase in flexibility will enhance European capabilities to target more complex mission scenarios.

In particular, LN cis-lunar operations could represent an interesting opportunity to consolidate European participation in the emerging lunar commercial activities as well as to boost deep exploration missions.

Preliminary system design is being carried out by:

- The application of MBSE tools

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- The definition of dedicated trade-offs

The conclusions drawn from the two trade-offs presented in this paper are specified in the following lines:

- **Propellant selection trade-off**

While 87.5% HTP is four up to five times cheaper as 98% HTP, it is also less performant by 30s in I_{sp}, meaning that the kick stage can carry less payload. This payload mass penalty has been evaluated as 250 kg per average flight in a year. When combined with the foreseen price per kg for the future LunaNova missions, this loss represents more than four times the savings that would have been made in terms of propellant cost. The decision to go for the highest HTP concentration has therefore been made.

- **Pressurisation system trade-off**

Preliminary estimations on the subsystem mass budget concluded that about one-third of the dry mass could be spared by switching from pressure fed to e-pumps, mainly driven by the lighter e-pumps tank configuration.
Moreover, significant e-pumps RC cost savings were also identified due to the opportunity to reduce the pressurising gas tank MEOP.
On the other hand, estimations of LN revenues and costs per flight revealed a potential for e-pumps, thanks to the improvement in performance related to the previously mentioned mass savings. Regarding costs, their low maturity level results in higher development costs.
This trade-off concluded in favour of e-pumps since their increase in revenues was estimated to be 5 times the increase in costs when compared to the pressure-fed version. Consequently, e-pumps were selected as LN baseline pressurisation system. Additionally, their development within this programme could grant AG with a new product within its portfolio.

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References

[1] ESA HQ, «STorable Extension for Versatility and Exploration (STEVE),» ESA-STS-FLP-SOW-2019-0010, 2019.

[2] ESA , «Ariane 6 targets new missions with Astris kick stage,» 13 July 2021. [En ligne]. Available: https://www.esa.int/Enabling_Support/Space_Transportation/Ariane/Ariane_6_targets_new_missions_with_Astris_kick_stage.. [Accès le 19 April 2022].

[3] Rocket Lab, «The Kick Stage: Responsible Orbital Deployment,» [En ligne]. Available: https://www.rocketlabusa.com/updates/the-kick-stage-responsible-orbital-deployment/. [Accès le 19 April 2022].

[4] Rocket Factory Augsburg (RFA), [En ligne]. Available: https://www.rfa.space/launcher/. [Accès le 19 April 2022].

[5] G. Waxenegger-Wilfing, J. Deeken et R. Henrique dos Santos Hanhn, «Studies on Electic Pump-Fed Liquid Rocket Engines for Micro-Launcher,» chez *Space Propulsion* , Seville , 2018.

[6] H. Kwak et S. Kwon, «Performance assessment of electrically driven pump-fed LOX/kerosene cycle rocket engine: Comparison with gas generator cycle,» *Aerospace Science and Technology* , vol. 77, 2018.

[7] P. Pavlov Rachov, H. Tacca et D. Lentini, «Electric Feed Systems for Liquid-Propellant Rockets,» *Journal of Propulsion and Power,* vol. 29, n° %15, pp. 1171-1180, 2013.

[8] N. Soldà et D. Lentini, «Opportunities for a Liquid Rocket Feed System based on electric pumps,» *Journal of propulsion and power,* n° %124, pp. 1340-1346, 2008.

DOI: 10.13009/EUCASS2022-7482

[9] L. Ordonez Valles, U. Apel, M. Tajmar et P. Weuta, «Comparison between a 400N electric pump fed hydrogen peroxide/ethanol thruster and the MMH/NTO legacy systems,» chez *International Astronautical Congress*, Dubai , 2021.

[10] L. Ordonez Valles et L. Blondel Canepari, «Green propellants and electric pump feeding system: challenges and opportunities of using these technologies for future kick stages,» chez *AIDAA* , Pisa, 2021.