Launch Assist System

Dumitru Popescu | Teodor Diaconu

ARCA

January 14th, 2020, Issue 2.0

This document will be constantly updated during the test program.

Content

Track changes

Version	Date	Modified sections
1.0	May 1st, 2019	Initial issue
2.0	January 14th, 2020	The whole document was revised.

1. Introduction

The companies involved in the space business are making efforts to reduce the launch cost, and their efforts are directed mainly to improve technologies that are decades old. They push the envelope to gain a few more seconds of specific impulse by increasing the chamber pressure, or using slightly better propellants like methane instead of kerosene, or to densify the propellants by cooling them.

ARCA made similar efforts by creating a single stage rocket supported by an innovative aerospike engine.

The reusability, another trend in today's rocket development, did not deliver the trumped cost reduction of orbital launches yet, and the prices remain high. Why is this? Because after each flight the vehicles need extensive checking and refurbishing leading to long turnaround time.

Apparently, no effort was enough to make spaceflight significantly affordable. For us it was clear that all these efforts were doing nothing more than to improve the performance of decades old technologies. In addition, with each new improvement, sometimes the overall cost is becoming even higher.

In the case of current technology, "making it better" was leading to increased complexity, hence higher cost.

It was clear that small steps towards innovation were not the answer to spaceflight cost reduction, and the answer-needed will come from a radically different approach.

Therefore, we started by asking ourselves four fundamental questions:

<u>1. Why are rocket launches expensive?</u>

Rocket launches are expensive because the vehicles themselves and the fabrication and launch operations are complex. Complexity leads to high costs.

<u>2. Why are rocket systems complex?</u>

Because their propellants are volatile, explosive, corrosive, toxic, carcinogenic, polluting, cryogenic, exhibit high burning temperatures and pressures in the engine. All these characteristics are leading to the necessity to have complex machinery, fabrication processes and operations, extreme safety measures, in order to be able to handle the extreme propellants parameters.

<u>3. How can we avoid rocket's complexity?</u>

Since we identified the propellants as the root cause of rockets high cost, it was clear for us that incremental evolutions are definitely not helping towards the creation of a truly cost-effective rocket system. We knew that some radical changes were needed to get a significant cost reduction and these meant only one thing: eliminate, or at least significantly reduce the use of volatile, explosive, corrosive, toxic, carcinogenic, polluting, cryogenic propellants.

<u>4. What potential propellant has completely different properties than the current ones?</u>

As much as it might seem a very bold approach, we looked at the cheapest, cleanest and easily available liquid: water, and we looked at ways to work with it. And after thousands of hours we spent on the topic, analyzing various options, we concluded that the only option that has a potential at this point is an electro rocket in which the water is heated and produces thrust from evaporation accelerating the water vapor in a convergent-divergent nozzle.

Therefore, we identified the root cause of rocket launches high cost: the propellants. They are not generating high costs by themselves, but by their nature and associated measures of complex fabrication and operations. Water completely avoids these.

On top of everything, water as propellant does not lead only to an unprecedentedly cost effective vehicle to build and launch, but it came with two other great features: no pollution and unprecedented safety. The idea of a hot water rocket engine is not new. Robert Truax who actually experimented with hot water rocket engines proposed it also in the 70's.

Another effort was done by the University of Berlin, which also experimented with hot water rockets and their results were published through the European Space Agency.

As far as we know, the University was the first one to propose the hot water rocket as a booster for orbital vehicles.

Both predecessors lacked the proper funding as well as the better technology we have today in terms of composite materials, and batteries.

Extensive tests were done at ARCA since July 2018 to develop a water-based rocket engine, and here is how the system works:

The rocket tank is filled with regular water mixed with benign phase destabilizers, used in the food industry. The water from the tank is electrically heated to temperatures of hundreds of degrees in a process that lasts for hours. Then the water is injected into the engine where a phase change occurs from liquid to vapors. In the engine, a further heating occurs. A second electric heating phase takes place in the engine using high discharge LiPo batteries, the same type of batteries used by ARCA to power the cutting-edge ArcaBoard.

Even for our team an inherent question arose: how can we use a rocket that offers only around 50 - 60 seconds of specific impulse? Because this by itself can't give the necessary performance for an orbital flight, and not even for a suborbital flight. We were literally struggling to find an option to work with a rocket with such low performance. Because when you look at current rockets and see specific impulses that are around four times higher, the first instinctual reaction is to quit the idea thinking: this isn't going to work. But the tremendous advantages offered by the water in terms of cost, safety and lack of pollution was what kept us pushing and come back to it over and over again, to find an option to work with this system.

But then we looked at the Space Shuttle and Ariane 5's SRBs that are indeed low performance rockets by themselves compared with the vehicle's main engines from the core stages.

Their impulse is lower than their main engines and the propellant mass to empty mass ratio is very low, but the thrust to weight ratio is very high, as we can see from the Table 1.

Table 1

Characteristic	Space Shuttle SRB	Ariane 5 SRB	LAS 100
Empty mass [kg]	91,000	38,000	5,000
Propellant mass [kg]	500,000	240,000	45,000
Launch mass [kg]	591,000	278,000	50,000
Thrust [kgf]	1,271,000	510,000	100,000
Propellant mass/empty mass ratio	5.5	6.3	9
Thrust/weight ratio	2.15	1.89	2

It was clear that what matters for boosters is the thrust/weight ratio, while the specific impulse is of secondary importance. As long as the thrust to weight ratio is higher than the first stages', the booster will fulfill its duty to contribute to the vehicle's acceleration during ascent, regardless of the booster's impulse. Also, the higher the acceleration at start, the better the flight performance of the orbital vehicle and LAS was designed with this feature in mind.

With this conclusion well structured, the team started to perform simulations to see what is the impact of the use of a water booster having a low impulse on orbital vehicle's performance.

We named it the Launch Assist System (LAS).

At impulses in the range of 50-60 sec, the engine's performance is lower compared with the ones using classic propellants, but we found it ideal from many points of view to assist the launch of current rockets.

The Launch Assist System (LAS) is a lifting vehicle, designed to boost the orbital vehicle's performance, using hot water as propellant, safe and clean, allowing a major cost reduction of orbital launches. Built in the corresponding size for the lifted payload, it can transport any orbital rocket to altitudes of around 3,000m and speeds of around Mach 2.

It was concluded that LAS can be used both as booster as well as a first stage for an orbital rocket, providing a boost of their payload weight with up to 30%, or make the current rockets use 25% less polluting propellant.

As we can see from an example analyzed below in the document, a Falcon 9 rocket using the LAS technology could use only 6-7 Merlin D engines instead of 9 for the first stage.

LAS is built in two types, expandable and reusable, each type with its own variant, ranging from thrusts of 25-7,000 tf.

Currently, the engines and tanks used at take-off, are the largest and inherently the most expensive parts of a rocket launcher. A vehicle designed around the LAS concept can replace the need of current classic boosters, or work in conjunction with them, or even work as a first stage of a vehicle.

For instance, ARCA's Haas 2CA SSTO rocket can boost its payload from 100 kg to 600 kg using LAS as first stage.

Or, for the same payload of 100 kg, the Haas 2CA rocket will reduce its polluting propellant mass from 16 tons to only 6 tons, with a launch cost of $1 million. As a comparison, Rocket Lab is launching similar payloads in the highly complex Electron rocket for $5,9 millions/launch.

ARCA is currently testing an expendable 25 tons of thrust rocket that will be followed by a larger reusable vehicle. The reusable, aerospike engine LAS is scheduled for launch in April 2020 to prove the technology in flight.

LAS also opens the way to create heavy lifting reusable vehicles.

Due to the benign nature of water, the recovery and preflight inspection becomes a simple and fast process.

By eliminating the need of extreme safety measures and complex fabrication technologies and operations required by explosive and toxic propellants at take-off, we think that we finally found a way to make space access clean, safe and affordable.

We aim for the next months to demonstrate that the Launch Assist System is the most cost effective, ecological and safe rocket vehicle ever created.

2. Program history

In July 2018 ARCA opened the electric, water-based rocket engine research program. The effort was aiming at the creation of an unprecedented cost effective, safe and clean rocket.

It was clear for the team that the proposed system was packing a series of innovation that made it a very risky endeavor. However, the potential benefits hugely outweigh the risks.

ARCA performed extensive computation and tests of this concept on a 100 kgf rated installation.

At the time, ARCA was also developing an aerospike rocket engine for the hydrogen peroxide monopropellant Demonstrator 3 rocket.

As we identified the most suitable application for the new propulsion system, the team named it Launch Assist System, or LAS.

At the end of September 2018, we decided to use the LAS technology in combination with the aerospike engine also under development at ARCA and replace the hydrogen peroxide considered as monopropellant for the Demonstrator 3 aerospike engine. It was however clear for us that we need first to understand the new propulsion system and run tests on a larger classic engine, before implementing it on an aerospike engine.

At the same time, the LAS 25D (D-Demonstrator) program was opened with the objective to test a 25tf thrust rated engine, as the 100kgf thrust rated installation had limitations in gathering enough data for the new propulsion system.

For the LAS 25D ARCA used as many stock parts as possible already found in our inventory, such as the valves and molds for the propellant tank. ARCA's test stand, rated at 40tf was also chosen to accommodate the large test article.

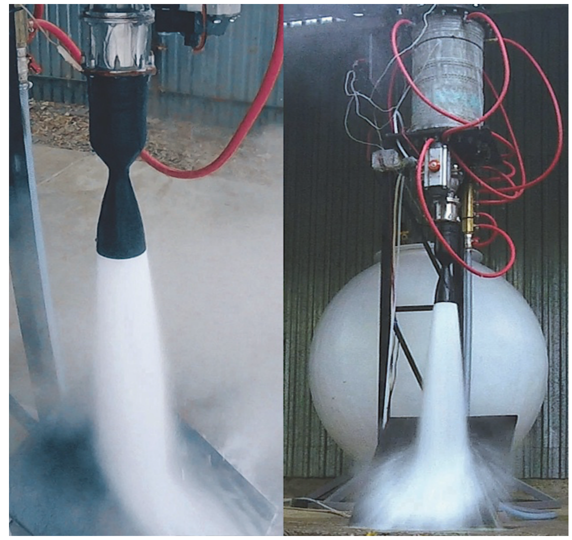

Fig. 1 - The 100 kgf, LAS technology test installation.

Fig. 2 - The 1,000 kgf Demonstrator 3 linear aerospike rocket engine.

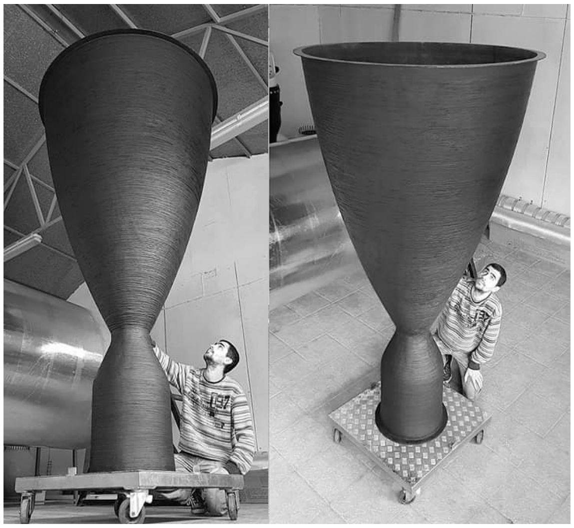

Fig. 3 - The 25,000 kgf LAS engine.

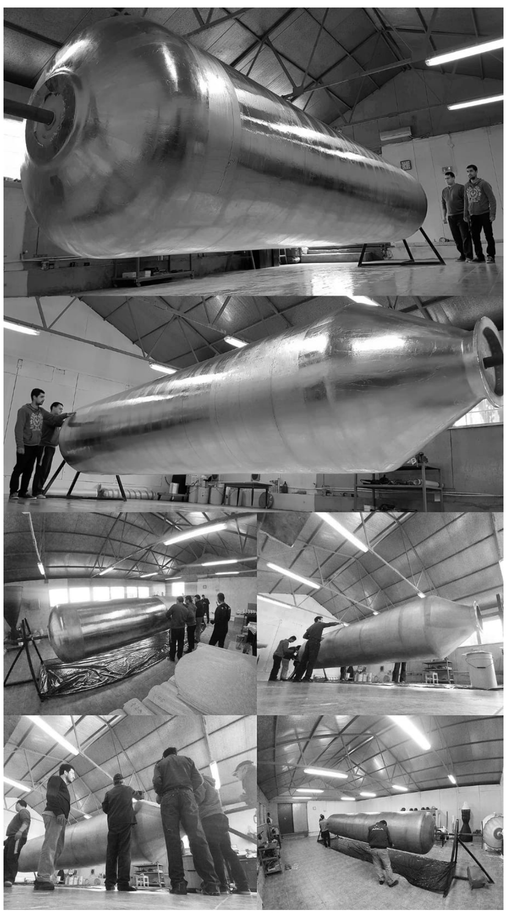

Fig. 4 - The LAS tank under fabrication at ARCA.

Fig. 5 – LAS 25D engine on the test stand.

The LAS 25D composite engine was casted at ARCA at the end of October 2018.

Fig. 6 – The LAS 25D test article on the test stand.

LAS 25D is using a 1.2m diameter composites tank that was casted at ARCA at the beginning of November 2018 using the Haas 2C's rocket molds.

The first fit check of LAS 25D on the test stand was performed on December 28th, 2018, followed by the complete test article integration on February 21st, 2019.

The avionics integration was finalized at the beginning of April 2019.

Fig. 7 – LAS 25D avionics integration.

On April 21st, 2019 the LAS 25D was tested for the first time. After the first test firing the composites tank was damaged due to a human error in following the post-test procedures. The engine's main valves were closed after the test and the hot vapors were enclosed inside. Once cooled, the tank's internal pressure dropped below atmospheric pressure and the tank imploded damaging the structure. A stainless steel tank was used instead for the following tests, but the composites tanks will still be used in the future for the LAS system.

In 2019 ARCA fired the LAS 25D, several times using both classic and aerospike engine configurations, demonstrating the engines predicted performances.

Fig. 8 – LAS 25D during its first and second test firing.

On December 20th, 2019 ARCA fired for the first time the LAS 25D aerospike engine. A direct test comparison between the aerospike and the classic engine was performed, the team obtaining extremely valuable data. Further tests are scheduled for 2020.

ARCA intends to invite representatives of space agencies and industry leaders to attend at least one of the tests to demonstrate the LAS technology, sometimes in 2020.

Fig. 9 – The aerospike engine and the classic bell-shape nozzle engine on the test stand.

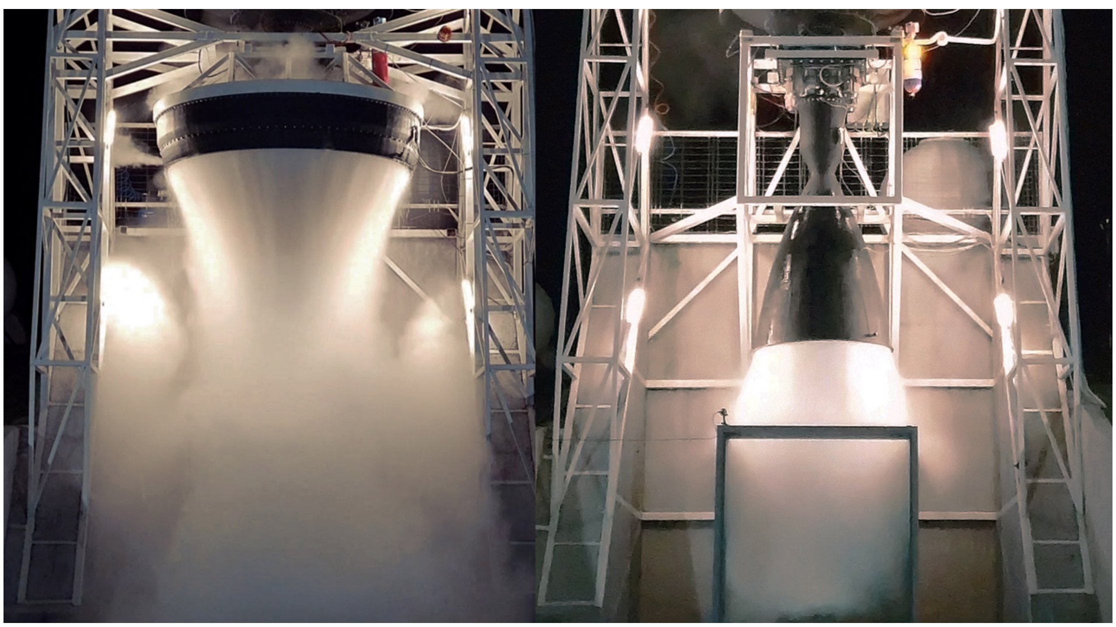

Fig. 10 – The aerospike engine and the classic bell-shape nozzle engine during tests.

In February 2019 ARCA started the study of a reusable LAS vehicle using an aerospike engine, with VTOL capability, that will serve as a fast turnaround shuttle. Considering the propellant's benign nature, the reusability was seen as a very tempting option. The reusable LAS will lift the rockets to around 3,000m and Mach 2 and then land on the launch pad, be refueled and perform a new mission in 24 hours.

In April 2020 ARCA scheduled the first test flight of LAS 25DA (DA-Demonstrator Aerospike).

3. How LAS works?

3.1 LAS description

Regardless of its version (expendable or reusable), a LAS vehicle is made of a composite materials propellant tank, a feed system, an engine, the electric heating system and avionics. The water from the tank is electrically heated to up to 250°C. At engine start, the water is injected into the engine's chamber through the feed system where transforms partially from liquid to vapors. A further heating phase takes place in the engine (only for the reusable LAS version), using the power generated by the high discharge LiPo batteries. These water vapors are accelerated through the engine's nozzle to supersonic speeds creating thrust.
The expendable LAS will be used mostly as strap-on boosters for third party vehicles upon request, while the reusable version of LAS will be used exclusively by ARCA and third parties in conjunction with their own vehicles.

<u>The tank</u>

The propellant tank is made out of composite materials. ARCA has extensive experience with composite materials tanks fabrication. All our previous rockets used composite tanks never recording a single fail.
For LAS however a special challenge arose from the fact that the propellant needs to be heated at around 250°C and the regular composites are susceptible to ruptures at these temperatures. Since the fibers are not posing special challenges of usage at these temperatures, the only challenge was to select the proper resin.

Fig. 11 – Haas 2C composites tank, during ultimate load tests at ARCA. The same type of tank is used for LAS 25D.

Tests were performed on various tanks to find the right type of resin able to withstand the relatively high temperatures required for the stored propellant.
The tanks are made of two separate layers. An internal thermal liner over wrapped in glass fiber fabric/filament and epoxy resin. The thermal liner's acts as a thermal insulator that is protecting the outer mechanical layers from overheating, keeping the external temperature below 140°C. While it features the same fabrication technology, the tanks for the expendable version of LAS has a high length to diameter ratio, while the tanks for the reusable version has a smaller length to diameter ratio.

This is due to the fact that the reusable version needs to accommodate a large diameter aerospike engine, while keeping the center of gravity as low as possible and a wide base for increased stability during the landing phase.

Fig. 12 – The LAS 25D composites tank, is transported to the test stand (left). The tank is lifted on the test stand (right).

After the first LAS 25D test firing the team performed an operation that damaged the composite tank built for the LAS 25D. The main valves were closed immediately after the test enclosing inside the atmosphere made of hot water vapors. When the water vapors condensed, the internal pressure dropped compared with the outside pressure. With the tank composite walls still relatively hot and softened, the tank imploded at the middle section. The team had three options at that point: to attempt repair the damaged composite tank, to fabricate a new composite tank, or to use an already existing stainless-steel tank. The first option was considered of high risk, the second one time consuming, therefore the third option was retained. Due to the higher conductivity of stainless steel compared with the composites, the stainless-steel tank was covered with an insulation to shorten the heating process by reducing the heat loss.

Fig. 13 – Stainless steel tank on the left and the composite tank on the right. Same engine and feed system.

A new composite tank will be fabricated at ARCA for the LAS 25R VTOL vehicle.

<u>Pressurization system</u>

Differently than the classic rockets, the LAS tank doesn't need a dedicated pressurization system. So, the high-pressure bottles, pumps, conduits and valves are completely eliminated. The pressurization is achieved when the water is heated. It generates vapors that are keeping the tank's internal pressure at a value

corresponding to the boiling temperature, preventing the water to boil. As an example, when the temperature is reaching 200°C the tank pressure is 16 bars.
LAS is using benign phase destabilizers that are amplifying the evaporation process in the engine. These destabilizers are also impurities in the water and they are modifying evaporation point of water. The nature of phase destabilizers and corresponding pressure vs temperature is kept proprietary by ARCA.
Once the engine starts, the water level drops increasing the tank's empty volume. Therefore, the pressure tends to decrease. However, the hot water will start to evaporate due to pressure decrease. The evaporation is not fast enough to fully compensate for the tank increase of empty volume. However, the simulations that also took into consideration the increase of acceleration of the vehicle and therefore the increase of the liquid static pressure indicated that a pressure drop is desired to keep an overall acceleration of the vehicle in the acceptable limits for the airframe. To conclude, the decrease of pressure on vehicle's performance is negligible. The simulations are indicating a low loss of speed of 5% and low increase of altitude of around 8%, compared with a simulated tank with a constant pressure.

<u>The feed system</u>

The LAS feed system, regardless if it is the expendable or reusable version is of a rupture disk type, placed between the tank and the engine, while the engine is fixed, bolted directly on the tank. Beside the rupture disk, the reusable version will have eight controllable flow valves for attitude control and power descent and landing, mounted directly on the engine. The valves are of the same type as the ones used for the LAS 25D test article. The rupture disk is the suitable option, since high temperature and large propellant flows are required. For preliminary ground tests of LAS 25D, four ball valves were used.

Fig. 14 - The valves used for the first phase of LAS 25D tests.

The same type of valves will also be used for the expendable LAS in conjunction with verniers for the attitude and trajectory control.
For the LAS 25D final tests, the current valves mounted on the engine will be replaced with the rupture disk.
The valves are pneumatically actuated and feature proportional flow control that works in conjunction with the engine's controller and vehicle's flight computer and stabilization system.

Fig. 15 - The valves mounted on the tank and engine for the LAS 25D test article.

<u>The engine</u>

The expendable LAS uses a bell-shaped nozzle engine, while the reusable LAS uses a toroidal aerospike engine. The expendable LAS needs to be simple to fabricate in large volumes and at a lowest possible cost, while the reusable version is focused more on higher performance.

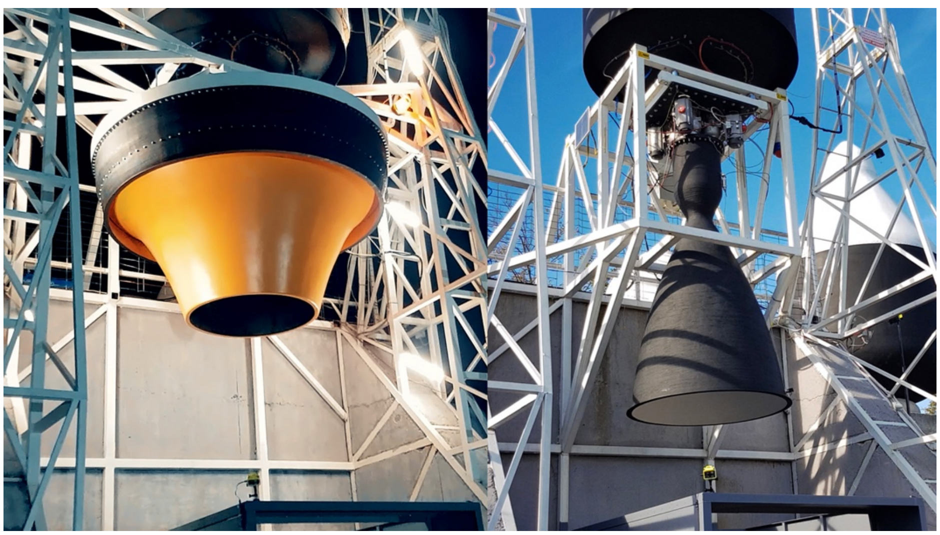

Fig. 16 - The LAS 25D aerospike and classic bell-shaped nozzle engine.

An aerospike engine offers a higher specific impulse, but at the same time is made of more parts and the associated cost is higher. Also, the aerospike engine will have a second phase heating system for the water, a system not present on the expendable version of LAS. Both engine versions are made of lightweight composite materials. For the ground tests the bell-shaped nozzle engine of expendable LAS is also fully reusable, requiring virtually no maintenance due to propellant benign nature.

ARCA tested initially the classic engine and then the aerospike engine on the same stand, using the same tank, same feed system, same pressures, same sensors, allowing us to further find unprecedented answers regarding the direct comparison between the two engine configurations.

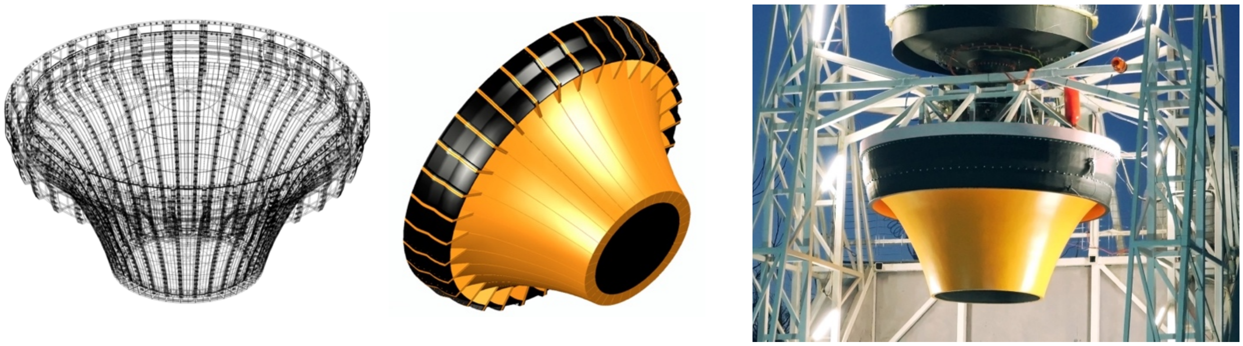

Fig. 17 - The aerospike engine for the reusable LAS.

For the first aerospike test, we were able to draw an initial conclusion that the aerospikes are indeed better than the bell shaped nozzle engines at sea level, and not by a little, but by a large margin, as follows:

Table 2

Parameter for the test	Classic engine	Aerospike engine
LAS 25D dry weight (kg)	748	1025
Engine dry weight (kg)	48	184
Test pressure (barg)	5	4.2
Average Isp (s)	17	20
Thrust (tf)	2.1	2.4

For the first test we didn't want to push the test installation too far, and for the following tests we will increase the work parameters until we will reach a specific impulse in the range of 60s. We can see that the aerospike had a 15% higher specific impulse but a question arises: From where this increase of specific impulse? ARCA have some hypothesis, but until we are not going to perform further tests and be sure, we don't want to publicly conclude at this point. We expect that this percentage to get even higher as the test pressure increases as the push effect of engine exhaust on the central plug will increase.

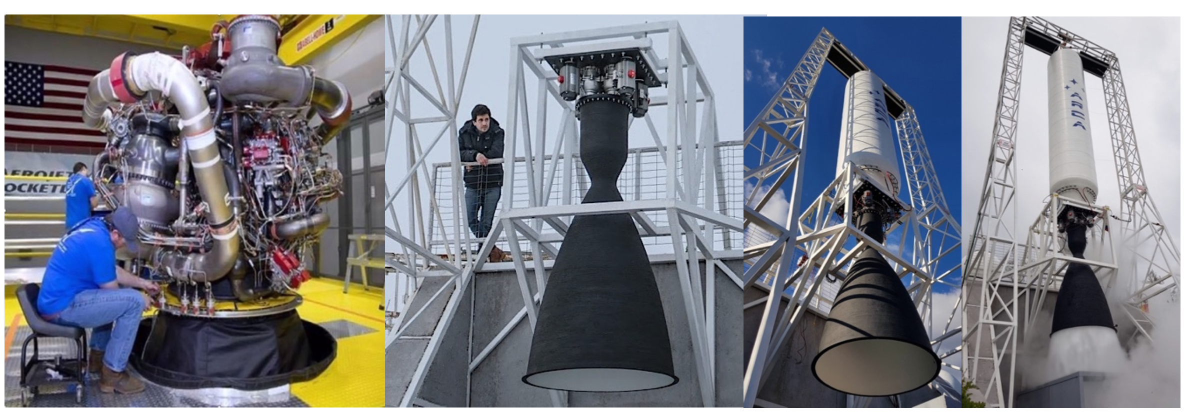

Fig. 18 – High complexity is one of the defining features of current rocket engines (left photo).
ARCA's philosophy is based on extreme simplicity rather than high performance (right photos).

<u>Avionics, attitude and guidance control</u>

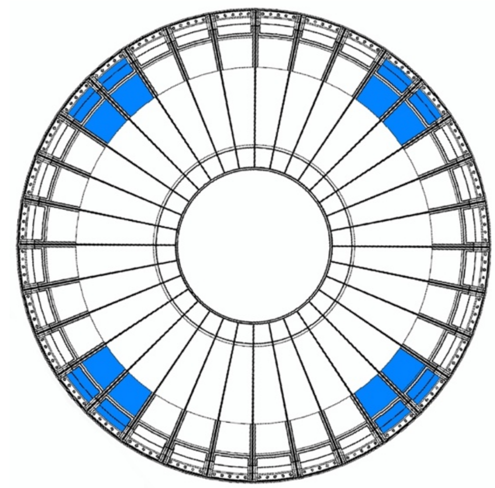

Fig. 19 - The arrangement of thrust chambers that allows the reusable LAS to perform attitude and trajectory control.

The LAS attitude and guidance system allows the rocket vehicle to fly stabilized on a desired trajectory during the ascent phase (both the expendable and reusable versions) and during the descent and landing phase (only the reusable version of LAS).

In the case of expendable LAS, eight RCS's are ensuring the attitude and guidance control. Four are used for pitch and yaw control, while the smaller remaining four are used for roll control.

In the case of the reusable LAS, the attitude and guidance control are achieved through eight chambers out of 32 of the aerospike engine (Thrust Vectoring Control), for pitch and yaw and through four verniers for roll control. While 24 chambers are receiving a constant flow of propellant during ascent, the flow is modulated by eight ball valves in the case of the remaining 8 chambers..

The control of the output thrust level is achieved by varying the pressure in each chamber, thus providing thrust vectoring. The input commands to the engine are sent from the engine controller changing the chamber's pressure amplitude.

During the descent phase only the 8 above mentioned chambers will be fueled and will run providing the necessary thrust.

The LAS flight avionics will use the same parts already integrated on the LAS 25D test article.

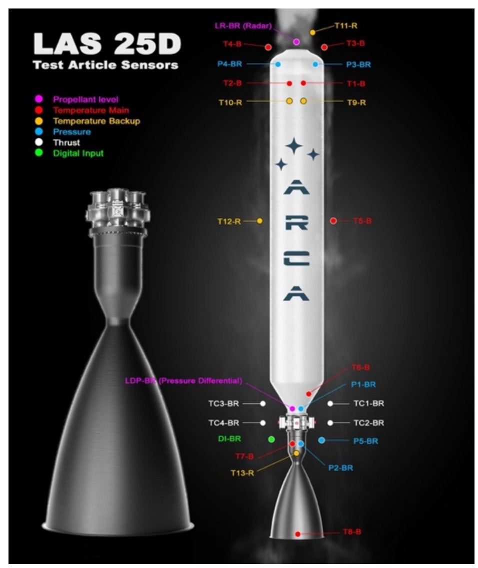

Fig. 20 – The sensors position on LAS 25D test article.

<u>The heating system</u>

The heating system of LAS is made of two segments. The one from the tank and the one from the engine. While the expendable LAS has only the tank heating segment, the reusable LAS has an extra heating segment in the engine.

The water from the tank is heated before launch using resistors connected to an external power supply. For LAS 25D for instance the team used 100kW of power to heat the water. The external power supply can come from solar/wind sources.

Once water injected into the engine, it starts to partially evaporate. The evaporation is amplified by phase destabilizers and in the case of reusable LAS by the second heating system placed in the engine.

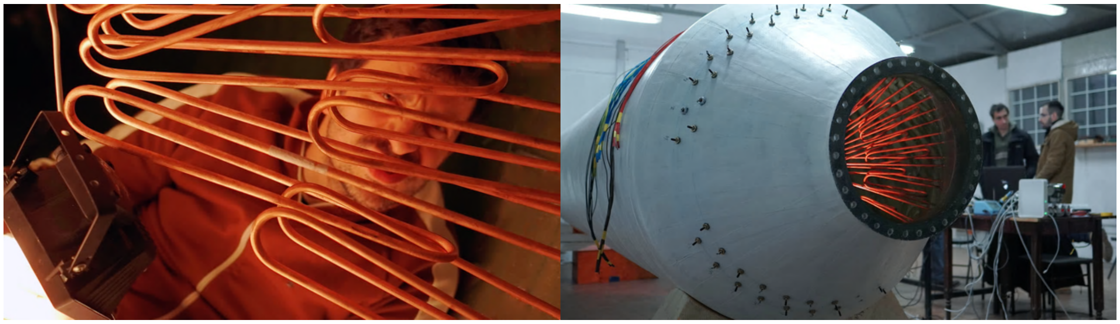

Fig. 21 - The LAS 25D tank resistors during integration.

This engine heating system is powered by high discharge (90C) LiPo batteries, the same as the ones used by ARCA to power the 700kW cutting edge ArcaBoard.

In the case of LAS 25R, the engine heating system generates 21MW/s of electricity during the whole flight, which is more than what a small nuclear reactor generates.

Fig. 22 – The resistors are mounted on the LAS 25D tank (left).
LiPo batteries used for the ArcaBoard will be used for the reusable LAS (right).

Let's consider LAS 25R. Adding an extra energy of 21MW/s, from 5A, 90C LiPo batteries (840MW total available), it will increase the vehicle's weight with 970kg. Considering the aerospike engine's specific impulse of 60 sec, (an increase of 10 seconds from the 50s of the bell-shaped nozzle engine), we will get an increased evaporation process of engine's specific impulse with 7s, to 67s. This doesn't sound like a major increase; however, the simulations indicate a flight performance improvement in spite of added weight. Furthermore, the batteries are needed to heat the aerospike's eight chambers used for attitude and trajectory control and for descent and landing.

The batteries will not deplete completely during the vehicle's 20s ascent, but only half of their total capacity. Therefore, there will be enough energy remaining for the descent and landing phase. Due to the fact that all 21MW/s available will be diverted to heat the 8 chambers during descend and landing, we will have on these 8 chambers the whole amount of heat we had in all 32 aerospike chambers together during ascent. This means that in those 8 chambers, during descent and landing we will have a rather remarkable impulse of no less than 94s, matching the hydrogen peroxide 70% concentration used as monopropellant.

3.2 LAS flight profile

LAS works in conjunction with an upper stage or a core stage (in the case of LAS used as strap on boosters). The water from the LAS tank is heated and when the desired temperature is achieved, the vehicle is launched.

Expendable LAS

In the case of LAS used as strap-on booster, the vehicle can start both the LAS plus the core stage, or LAS alone, depending on the vehicle's configuration. In the case of LAS used as first stage, the only engine working at start will be the LAS one.
After the launch the vehicle will climb and accelerate to altitudes of around 3,000m and speeds of Mach 1.2, and this performance will be achieved during of around 20 seconds of engine run.
After the LAS tank depletion and engine stop, the upper stage will continue the flight to reach orbit. LAS, it will fall on the sea, being destroyed at impact.

Reusable LAS

In the case of reusable LAS, the water engine will be the only one fired at start and the upper stage will start after the LAS tank depletion.
After the launch the vehicle will climb and accelerate to altitudes of around 3,000m and speeds of Mach 1.5, and this performance will be achieved during of around 23 seconds of engine run.
After the LAS main tank depletion and engine stop, the upper stage will continue the flight to reach orbit.
LAS, it will start the powered descent to the ground under 8 chambers out of 32 from the aerospike engine.
The vehicle will land and be prepared for the upper stage integration and batteries recharge.
The team aims to a very fast return to flight of the vehicle, of around 24 hours, since the recovery takes place from altitudes that pose no thermal and mechanical challenges and the LAS engine run at low pressures and temperatures.

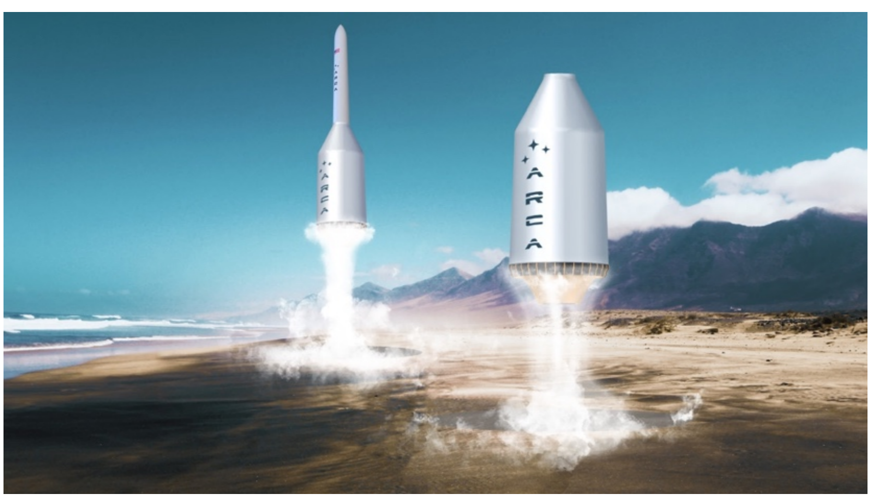

Fig. 23 – CGI render of reusable LAS.

4. Characteristics and performance

The proposed LAS vehicles have the following technical characteristics and performance:

Table 2

Characteristic	LAS 25D	LAS 25R	LAS 200E*	LAS 500E*	LAS 500R	LAS 7000R
Application	Test bed	Haas 2CA Mini	Intended for Vulcan class rockets.	Intended for Ariane 62 class rockets.	- Haas 3 - Intended for Vega class rockets.	Haas Heavy
Propellant	98% water + 2% benign, clean phase destabilizers;					
Engine type	Bell nozzle	Toroidal aerospike	Bell nozzle	Bell nozzle	Toroidal aerospike	Toroidal aerospike
Reusable	N/A	Yes	No	No	Yes	Yes
Diameter (m)	1.2	2.4	2.4	3.4	6	12
Length (m)*	9.2	6	28	44	18	36
Empty mass (t)	1.8	2.4	6.8	19.4	42	390
Water mass (t)	8	9	80	200	200	2,800
Tank pressure (bar)	28	40	40	40	40	40
Engine thrust sea level (tf)	25	25	200	500	500	7,000
Specific impulse (s)	50	67	50	50	67	67
Engine run time (s)	16	23	20	19	26	25
Max. altitude with payload (m)	N/A	3,000	N/A	N/A	3,100	3,600
Max. velocity with payload (km/h)	N/A	1,400	N/A	N/A	1,200	1,400
Max. altitude no payload (m)	N/A	13,600	27,000	27,000	23,300	50,000
Max. velocity no payload (km/h)	N/A	2,100	3,700	4,600	2,700	4,600
Payload mass (t)	N/A	4	N/A	N/A	95	1085

* It will be developed only if clear orders exist. There's ARCA's intention to propose LAS to third parties that are developing the rocket vehicles that will be mentioned in this document. No discussions with third parties were initiated as of now.

The expendable LAS uses a classic bell-shaped engine, while the reusable LAS uses an aerospike engine. Both have their advantages. While the expendable LAS is more suitable to be used as a strap-on booster due to the small diameter, the reusable LAS is more suitable as a first stage. Due to the small diameter of the expendable version, it's difficult to accommodate an aeropspike engine, while the expendable version needs an aerospike engine that offers the possibility of thrust vectoring control without gimbaling the engine. The engine of the expendable version has a higher impulse due to the aerospike solution and the second phase of propellant heating in the engine. However, the production cost difference between the two is rather significant.

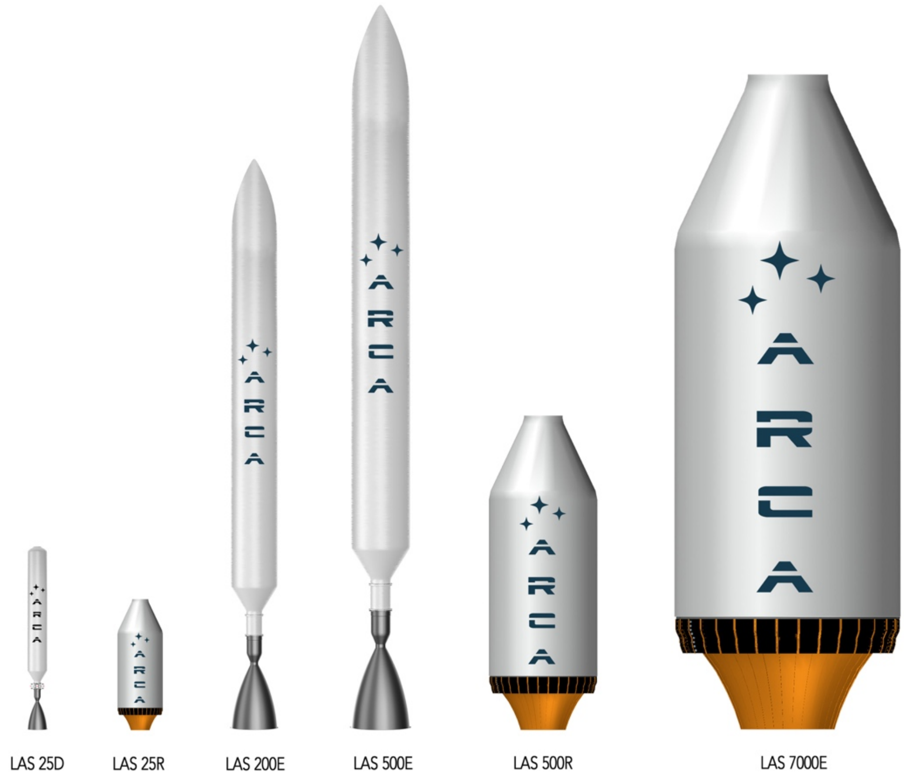

Fig. 24 – The versions of LAS currently under tests or construction preparation at ARCA.

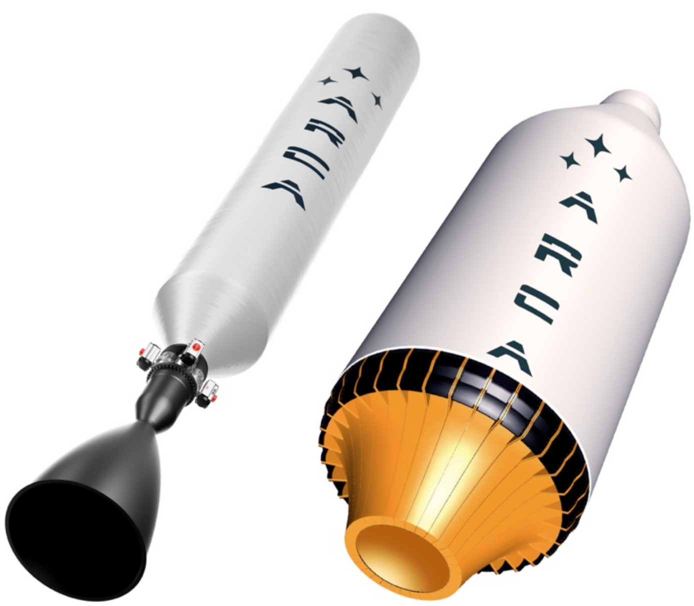

Fig. 25 – 3D views of LAS 25D and LAS 25R.

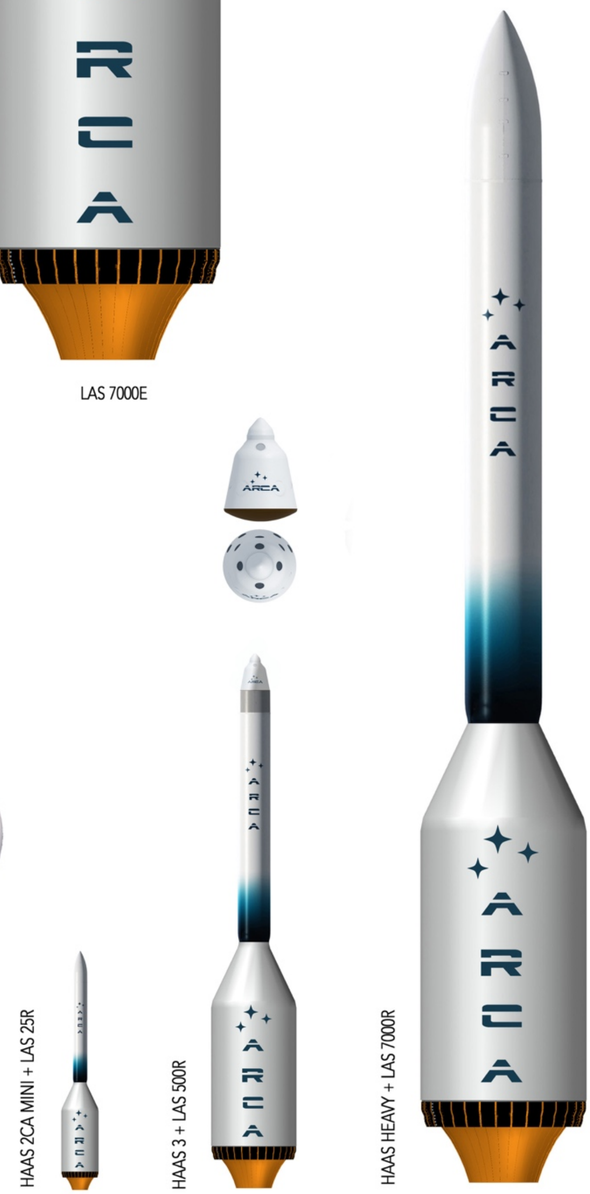

Fig. 26 – ARCA's vehicles based on the LAS technology.

5. ARCA's development plan for the LAS technology

ARCA plans to use only the reusable LAS, while both the reusable and expendable LAS will be offered to third parties upon request.

We are currently developing the Haas 2CA Mini, that works in conjunction with LAS 25R, for payloads of 40kg to LEO.

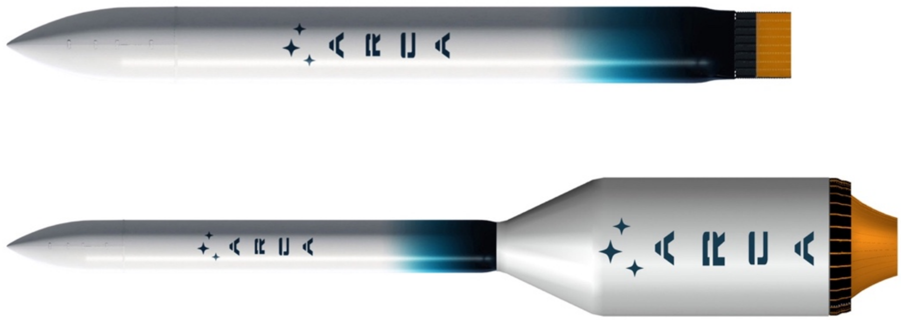

Fig. 27 – Haas 2CA will reduce its polluting propellant from 16 to 4t using LAS.

Haas 2CA Mini + LAS 25R will serve also as a technology demonstrator for Haas 3 + LAS 500R and at a later date for Haas Heavy + LAS 7000R, although we aim to make this vehicle a viable candidate on the small satellites market.

Without considering potential orders from third parties for the LAS technology, ARCA will continue with the ground tests of LAS 25D towards the middle of 2020, and will start the construction of LAS 25R with the first flight test scheduled for April 2019.

The below table shows the vehicles that ARCA is developing to work in conjunction with the LAS technology:

Table3

Vehicle	LAS diameter [m]	Rocket diameter [m]	Vehicle total length [m]	Vehicle total mass [t]	LAS thrust [tf]	Rocket thrust [tf]	Payload to LEO [t]
Haas 2CA Mini + LAS 25R	2.4	0.8	14	15.4	25	6.3	0.04
Haas 3 + LAS 500R	6	3.4	42	320	500	140	3
Haas Heavy + LAS 7000R	12	6	82	4,010	7,000	1,240	60

We will also continue with the development of Haas 2CA Mini that is working in conjunction with LAS 25R. The first flight of Haas 2CA Mini + LAS 25R should be expected for 2021, when we should also expect the start of commercial services for small payloads of 100kg to LEO.

The development of Haas 3 + LAS 500R with capabilities of 3000kg to LEO should start in 2022 with the first flight expected in 2024, followed by the launch of commercial services in 2024.

The start of construction of Haas Heavy + LAS 7000 should be expected in 2025 with the LAS 7000 VTOL flights performed in the same year and the complete vehicle first flight around 2027.

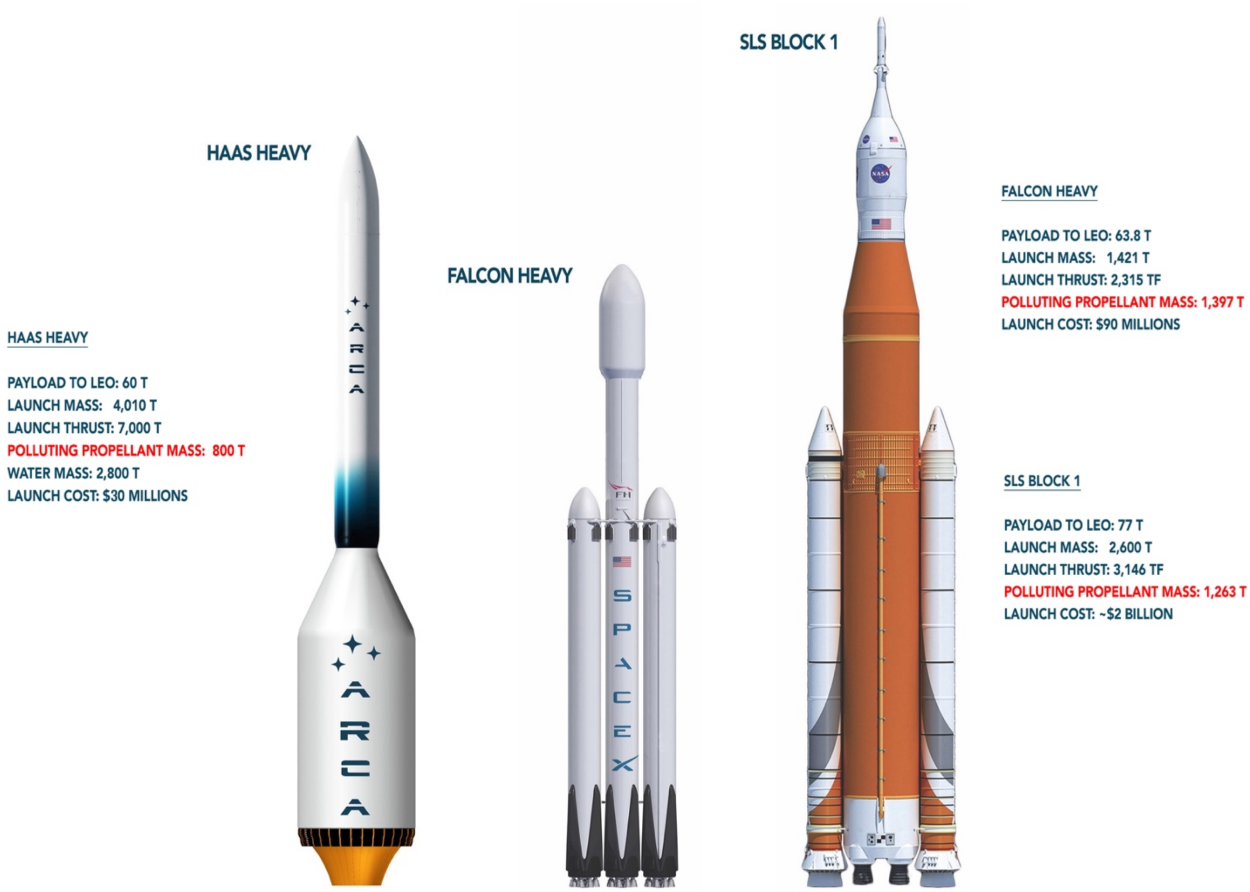

Fig. 28 – Haas Heavy + LAS 7000R compared with Falcon Heavy and SLS Block 1.

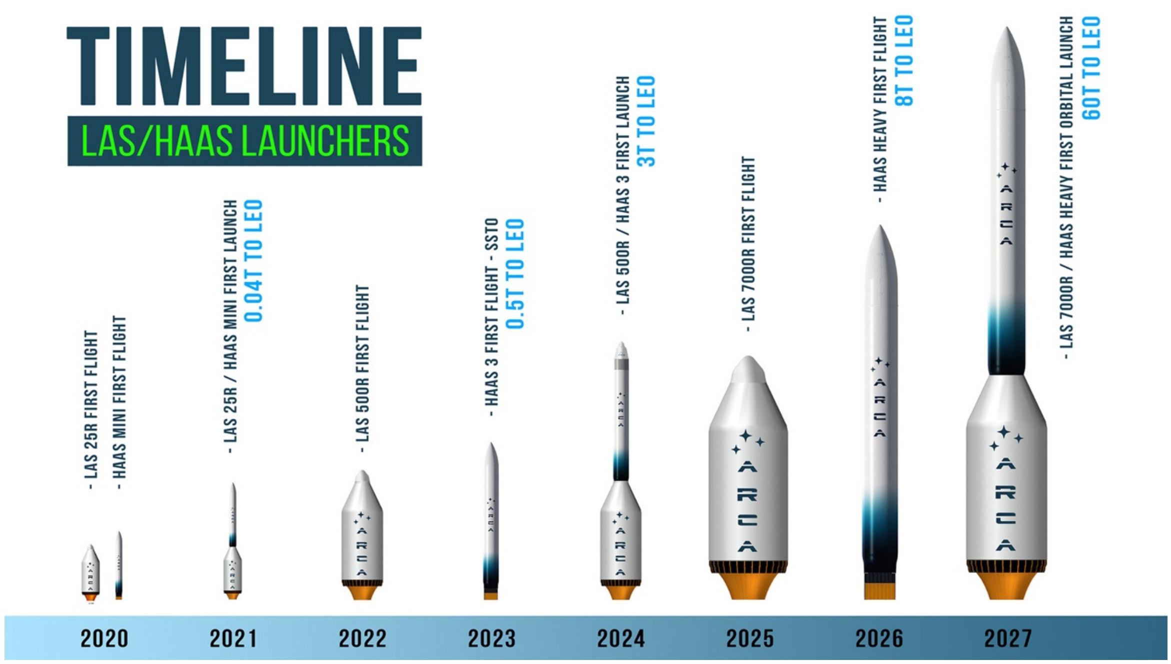

Fig. 29 – The LAS / Haas program timeline.

6. Uniqueness and benefits

Orbital flight

The current technology uses Solid Rocket Boosters (SRB) or Liquid Rocket Boosters (LRB). These are high performance, high cost, unsafe and polluting pieces of hardware. Furthermore, they are even generating toxic gases (especially the SRBs). These pieces of hardware are making a significant portion of the cost of an orbital rocket launcher. A careful analysis shows that LAS could be a viable candidate to work beside or even completely replace these. LAS is a lower performance rocket and the reduction in performance came with the cost of reducing the rocket's payload at half, while offering a cost reduction of around 60% and at virtually no pollution and increased safety.

Regarding ARCA's Haas 2CA SSTO rocket, this vehicle was designed with the capability to put 100kg into LEO in a single stage, for a take-off mass of 16,000 kg. The use of a 9,000kg of water for LAS 25R booster would offer a reduction of mass of the Haas 2CA rocket from 16t to 4t, while keeping the payload capability. Another example is also related to the Haas 2CA rocket. Adding a 40t LAS 200E booster to the existing configuration would increase the payload capability of the rocket from 100 kg to 700 kg, using just the benign, extremely cost-effective hot water booster.

Fig. 30 – ARCA's Haas 2CA, linear aerospike rocket.

Suborbital flight

There are currently very few large suborbital rockets and those existing are mainly made for space tourism. One of the most capable and well known is New Shepard. This rocket works with a mixture of liquid oxygen and hydrogen. This combination, while very efficient, it's also volatile and expensive to build and operate. The use of a hot water rocket plus a small hot engine upper stage would offer the same performance at a fraction of the cost and at a much-improved safety.

For space tourism, there's no better candidate, from the safety point of view than water as propellant.

7. The proposed use of LAS for current launchers

Case study I: Enhanced payload capability

By using LAS, the current rocket could enhance their payload capabilities as we can see in the analyzed cases of Atlas V 500 and Falcon 9 rockets. Depending on the rocket vehicle, LAS strapped on the vehicle's airframe at take-off could lead to payload capability increase that ranges from 20-30% (Table 5).

Case Study II: Reduce first stage polluting propellant load

By using LAS, the current rockets first stages could reduce the polluting propellant load and the size of their first stage, while retaining the same payload mass (Table 6). Depending on the rocket vehicle, the use of LAS could lead to a reduction of first stage's propellant in the range of 25%. This is leading to a reduction of tank length and therefore a reduced airframe weight. In the case of multiple engines vehicle, like the Falcon 9, a reduced number of engines could be considered.

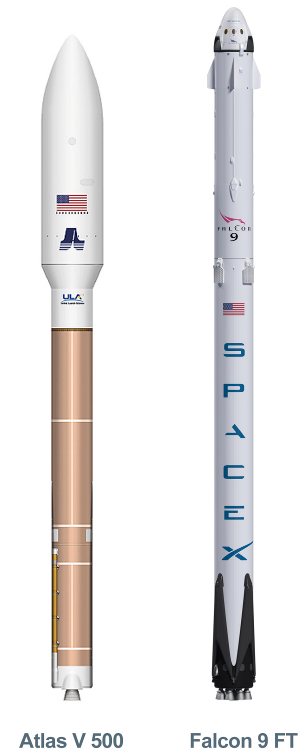

Fig 31 - Atlas V 500 and Falcon 9 FT rockets analyzed in combination with the LAS technology.

Table 5

	Current vehicle specifications			Upgraded vehicle with the LAS technology					
Vehicle	Total launch weight [t]	Launch thrust [tf]	Payload [t]	LAS Version Used	Number of LAS Units	Launch weight [t]	Launch thrust [tf]	Enhanced Payload [t]	Increase of payload [%]
Atlas V 500	329	390	8.1	LAS 50E	4	421	590	11.6	31
Falcon 9 FT	549	855	22	LAS 200E	2	723	1255	28.5	24

Table 6

	Current Vehicle Specifications			Upgraded vehicle with the LAS technology						
Vehicle	Total Launch weight [t]	Launch thrust [tf]	Payload [t]	LAS Version Used	Number of LAS units	Take-off Weight [t]	Take-off Thrust [tf]	Polluting propellant reduced weight [t]	Polluting propellant reduced weight [%]	Payload [t]
Atlas V 500	329	390	8.1	LAS 50E	4	359	590	70	24.6	8.1
Falcon 9 FT	549	855	22	LAS 200E	2	623	1255	100	25.6	22

Case Study III: Replace current toxic, polluting boosters

The expensive current boosters are usually using solid propellants that are a source of toxic byproducts. LAS can dramatically reduce the cost, while keeping the environment clean, as we can see in the analyzed cases of Vulcan, Ariane 62 and Delta 4 Medium+ rockets. Depending from case to case, LAS could replace the expensive size solid rocket boosters that are using propellants generating toxic byproducts (Table 7).

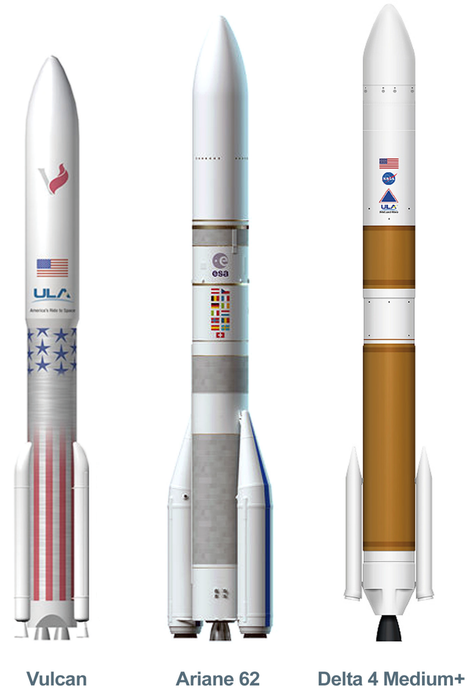

Fig 29 – Vulcan, Ariane 62 and Delta 4 Medium rockets analyzed in combination with the LAS technology.

Table 7

	Current Vehicle Specifications			LAS Upgraded Vehicle				
Vehicle	Total launch weight [t]	Boosters total thrust [tf]	Payload [t]	LAS Version Used	Number of LAS Units	Total launch weight [t]	LAS total thrust [tf]	Payload [t]
Vulcan + 2 GEM63XL	523	374	17.8	LAS 500E	2	523	1,000	17.8
Ariane 62	530	1,000	10.35	LAS 500E	2	530	1,000	10.35
Delta 4 Medium+	325	169	12	LAS 200E	2	325	400	12

8. The use of LAS technology for deep space exploration

There are plans from space agencies and companies to use the resources from other planets to produce the rocket propellants onsite in support for spaceships sent from Earth.

For instance, there are plans to obtain methane from CO_2 and liquid oxygen from water through electrolysis and then liquefaction, on Mars. These are indeed possible, but involves additional equipment and effort. On the other hand, icy water is abundantly found in the Solar System, on the asteroids, Moon, Mars, Europa, Enceladus, Titan, etc. A LAS technology vehicle will just require to put ice in the tank. The ice will be melt in the tank using the onboard resistors. In this way, LAS could become a good choice for a deep space exploration vehicle since its propellant is abundantly found through the Solar System.

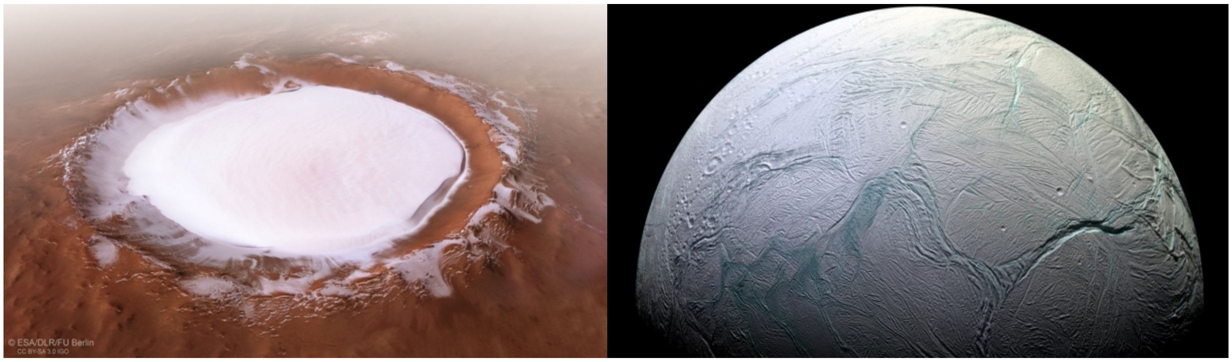

Fig. 32 – Icy water on Mars (left). Europa, Jupiter's satellite has a water ocean under the thick icy surface (right).

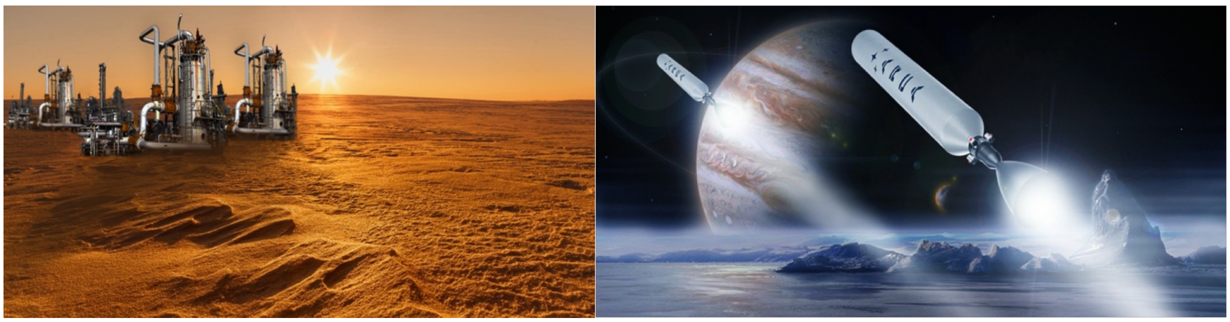

Fig. 33 – Space and companies are proposing to obtain the rocket propellant in situ on Mars from water and CO_2 using extraction facilities (left). LAS technology requires water to fly (right).

9. LAS price

Custom made LAS models could be considered upon request.

LAS will be operated by both ARCA as well as third parties upon request. The following prices are subject to change during the development program:

Table 8

	LAS 25R	LAS 200E	LAS 500E	LAS 500R	LAS 7000R
LAS cost, sold to third parties [millions]:	1	2	4	6	20

Table 9

	Haas 2CA Mini + LAS 25R	Haas 3 + LAS 500R	Haas Heavy + LAS 7000R
Payload to LEO [t]	0.04	3	60
Cost/launch operated by ARCA [millions]	0.8	3.6	30
Cost/kg	20,000	1,200	500

The LAS product is offered for sale with no restriction only in the United States and European Union. Purchasers from other countries should contact us directly to exchange more information, at: contact@arcaspace.com. ARCA reserves the right not to sell the LAS technology in certain countries.

10. Conclusions

- The Launch Assist System (LAS) could be used to boost an orbital rocket payload with up to 30%, in an unprecedentedly clean, safe and affordable way;
- LAS could reduce an orbital rocket's required quantity of polluting propellant with around 25%, while keeping the payload capability;
- LAS can replace the current solid boosters that are using toxic, carcinogenic propellants;
- ARCA is going to use LAS 25R as a first stage for the Haas 2CA Mini, a 4-ton rocket able to put 40kg to LEO;
- Based on the LAS technology, ARCA is going to develop a heavy launcher able to put 60 tons into LEO;
- The LAS technology is going to be offered to third parties to work in conjunction with their own launch vehicles;
- LAS is unprecedentedly safe, since it is using 98% water and benign phased destabilizers instead of chemicals which are "inherently unsafe";
- The use of LAS avoids accident risks related to the use of toxic and polluting chemicals for propellants in chemical plants;
- LAS opens the way to the creation of a new generation of cleaner launch vehicle, tailored to have LAS as first stage or booster, leading to a cost reduction of orbital launches in the range of five fold;
- LAS opens the way to the creation of planetary exploration vehicles that will use water abundantly found through the solar system.
- Like in the case of electric cars, an electric water-based rocket is less efficient than the ones using polluting propellants, but it's a stepping stone on which the industry can build a new generation of clean, safe, affordable launch vehicles. ARCA will continue its R&D efforts to improve the system;
- ARCA will organize an open house event at the middle of 2019 to allow the space agencies and industry representatives to attend a LAS test to familiarize with the technology.

Fig. 34 – Haas 2CA Mini + LAS 25R.

https://youtu.be/WKHI5VXisEc

https://youtu.be/zV8j08mCBEs

https://youtu.be/WnrTrsRskp8