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# LOX/HTPB/AlH3 Hybrid Propulsion for Launch Vehicle Boosters

M.Calabro[1],
max.calabro@freesurf.fr
The Inner Arch, Villennes, France

## Abstract

One of the most interesting fuels for propulsion is aluminum Hydride, AlH3, commonly known as alane. Alane has historically represented a great challenge. To day this product could become available on the market, partly characterized for propulsion and usable for propellant with an aluminum coating [R1] from an US source or from Russia where it was used as raw material for SRM propellant.

A first and safe step would be to use alane in a hybrid formulation for a civilian launch vehicle

An optimization of the formulation from the Isv and density standpoint, would lead to the following choice for the formulations:

- 35% AlH3, 10% HTPB, 55% NTO equivalent density 1,37 Isvth for Σ20= 347s
- 35% AlH3, 15% HTPB, 50% LOX equivalent density 1,18 Isvth for Σ20= 363s leading in this case to a roughly 25s increase versus LOX/HTPB

This last formulation is more powerful and "green" (non toxic) so it will be selected for study.
Nevertheless, the use of NTO would allow smaller motors (higher density)
This paper will present its interest with two cases of use:

- the replacement of the Ariane 5 boosters
- as first stage of a small launcher (the LLV1 launcher)

It will show that- *with constraints of lay-out*- this hybrid solution lead to improved performances

## Introduction

Except for very peculiar military applications where velocity tailoring (shape versus time and amplitude) is mandatory, Hybrid propulsion is met by a lack of interest due not only to the fact that Hybrid is not a pure liquid nor a pure solid but also that for a conventional use such as booster propulsion, its interest was marginal from the standpoint of cost as well as from the standpoint of performances. Moreover the very low combustion rate of the usual formulations leads to the use of complex wagon wheel grain configurations.
So a prerequisite is to be competitive in terms of performances and easy to use in a booster i.e; to have a burning rate close or higher than 7 mm/s.
In some early European tests [R6], hybrids used an liquid oxidizer with a fuel grain i.e. a binder and a fuel (amine, boron hydride?), it resulted in some applications burning rate higher than 1mm/s.
The idea is to follow this way considering one of the most interesting fuels for propulsion: Aluminum Hydride, AlH3, commonly known as Alane. Alane has historically represented a great challenge. To day this product could become available on the market, partly characterized for propulsion and usable for propellant with an aluminum coating [R1] from an US source or from Russia where it was used as raw material for military SRMs
A propellant with Alane may increase roughly the Isv of 25s versus the LOX/HTPB (Isvth for Σ20= 363s); note that addition of conventional aluminum does not increase the Isv nor significantly the burning rate.
Some sources indicate that a propellant using Alane will show an increased burning rate [R8].

Compatibility tests of Alane with R45M and GAP (Glycidyl Azide Polymer) were very encouraging [R1]
Recently, the possibility of using a mixture GAP/HTPB has been considered (GAP is today studied to improve solid propellant formulations) with a liquid oxidizer. Such a hybrid formulation may have a regression rate close to 10 mm/s

Nevertheless a propellant where HTPB and LOx remain the major materials has to be looked at. It is the reason why in Europe, combustion programs are proposed to agencies to characterize the effect of Alane in different configuration/type of propellant.

The aim of this paper is only to remind the interest at system level of using Alane taking as example, or the replacement of the Ariane 5 boosters, or the replacement of first stage of a small launcher (the LLV1 launcher)

1- AIAA Associate Fellow
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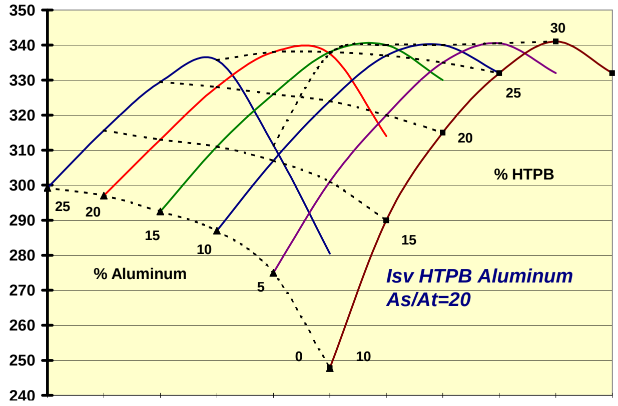
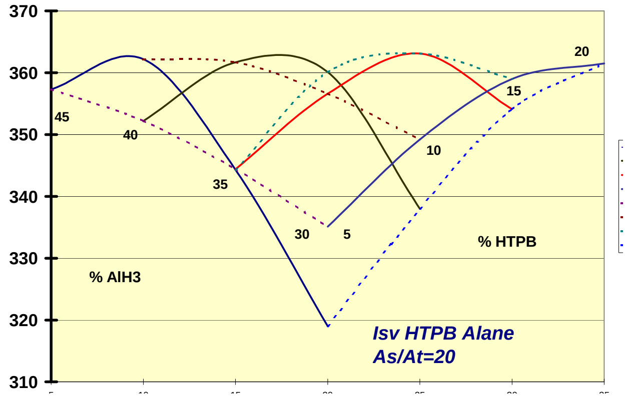
## The choice of the Formulation

Computations where made on the following propellant types: HTPB/AL/LOx and HTPB/Alane/LOx




With Alane




Adding Aluminum is without any interest from the stand point of Specific impulse that decrease slowly when the aluminum percentage increase. A potential increased apparent density of about 10% is without interest from a system point of view, the only potential advantage could be a higher burning rate when using Aluminum nano particles

So, addition of Alane appears as the only solution to increase together:

- The specific impulse by about 23 seconds
- The density of 15%
- The burning rate , this point has to be verified and to be studied

An additional advantage will be to lower the erosion of the throat comparatively to LOx/HTPB

The optimum for the LOx seems always close to 50%, the specific impulse remains close to the maximum in the ranges 30-45% Alane/20-15% of binder

For the following, the chosen formulation will be 40% of Alane, 12% of HTPB and 48% of LOx

The Theoretical specific impulse for an area ratio of 20 is 363.6s

## The choice of the grain geometry

The grain initial shape will depends of the burning rate that today is unknown. The aim is to obtain a burning rate high enough to use a tapered star grain; so, the main assumption is an expected burning rate close to 7mm/s

Nevertheless, it could be useful to implement radial slots in the middle and in the rear part of the grain, not to have a greater initialsurface, but to create turbulent zones to improve the combustion efficiency and avoid creation of vortices with a long grain (Parietal Vortex Shedding) and so, to reduce the risk of low frequency oscillations.

## Technical choices

The SRB will have 3 main parts:

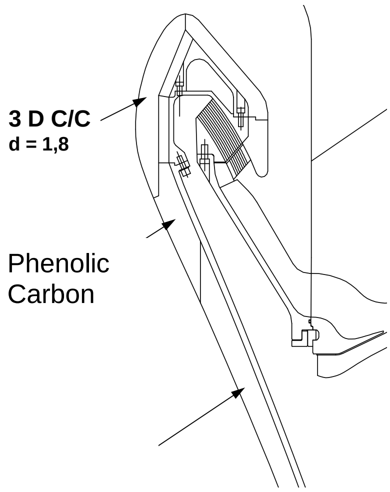
- A solid motor containing the fuel HTPB/Alane
- A Lox tank and its pressurization system
- A Turbopump

*The solid part:*

The part containing the solid grain is made as a solid booster with a composite case wound with and intermediate modulus carbon fiber (IM7/T800 or equivalent composite/ Al 7010 polar bosses / wound EPDM Internal Insulation)

Note that this insulation could be considered as a propellant with a low burning rate

The nozzle is conventional with a Flexible joint, a Carbon/carbon ITE (see figure)



*The LOx Tank:*
The LOx tank is made of 2219 Aluminum Alloy.
The upper dome is of an ellipsoidal shape; a partly reversed lower dome allows a more compact lay-out: the LOx lower dome is parallel to dome of the solid tank and realized wi sandwich aluminum/rigid foam insulat epoxy.
On the cylindrical part and the upper d insulation is assumed to be rigid expa polyurethane foam (Klegecell, density 31 kg/m³) with eventually additional MLI (Multi-Layer Insulation) on the domes
The foam thickness will be roughly15 mm, both for the external and the intertank insulation.
For the pressurization system (internal pressure 0.35 MPa), 2 solutions can be envisaged:

- The LOx tank is pressurized by helium, helium is stored in external composite high pressure bottles. This conventional solution is bulky.
- The LOx Tank is self-pressurized: LOx is taken at the turbopump exit, evaporated an heated by an exchanger located at the turbine entrance. This system is more complex but avoids the implementation, in the Ariane 5 case- of 4 bottles of 0.9 meter of diameter containing 80 kg of Helium

In both case the first pressurization is made by the GSE by Helium.

*The Turbopump*:
A pump (efficiency 0.65) increases the LOx pressure (Injection pressure 10 MPa)
The turbopump (efficiency 0.60) will be driven directly by a mixture of combustion gases and oxygen; Oxygen is injected to lower the temperature of the gases to 1000K (derivation on the injection duct) .If such a solution is considered as too risky, the implementation of a special tank for a coolant fluid can be done (water or a fuel like ethanol)
The gases are jettisoned by non propulsive venting nozzles.
The turbopump is between the tanks, on the external side.
It is started by the Ground Support Equipment (cold gas bleeding)

## Ariane 5 application

The maximum length of the booster is 28.70m(the length is increased by DIAS removal and a new lay-out of the aft skirt) and the maximum diameter is 3.09 m [R7]

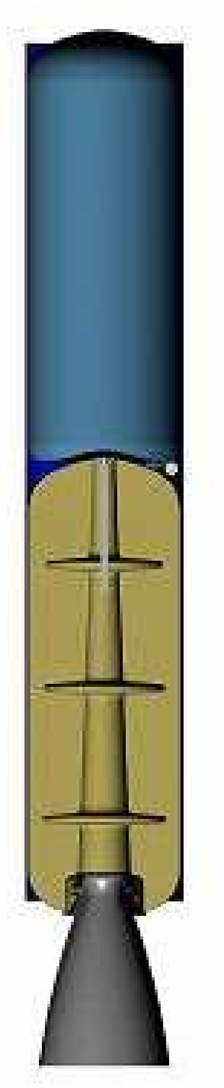
General characteristics:

| | |
|---|---|
| Max Diameter : | 3.09 m |
| Exit diameter | 2.98 m |
| Motor length | 28,70 m |
| Pmax | 8.5 MPa |
| Pmean | 6.8 MPa |
| Pmax/Pmean | 1.24 |
| Burning time | 125 s |
| Throat diameter | 733 |
| Ae/At | 15.5 |
| Isvth | 353.7s |

The mass breakdown with the above dimensions and technological assumptions will be (in tons):

| | | |
|---|---|---|
| Lox Tank: | 1.220 | |
| Turbopump: | 0.250 | |
| Inter tank: | 0.500 | |
| Gaseous res. | 0.850 | |
| Solid tank | 3.650 | |
| Internal Ins.: | 0.850 | |
| Nozzle : | 3.600 | |
| Misc. | 0.250 (injection/ignition/ducts) | |
| Sub Total: | | 11.000 |
| Stage masses | | 7.200 |
| Total | | 18.200 |

So the comparison with Ariane 5 is as follows:



| | Current MPS | Hybrid MPS |
|---|---|---|
| Mp | 237.7 | 210.0 |
| Mi | 30.8 | 18.3 |
| Isv | 275.3 | 327.3 |
| $A_e$ | 6.99 | 6.99 |
| Tb | 128 | 125 |
| Pmax | 6.1 | 8.5 |

The order of magnitude of the performance increase would be of roughly 2 tons for the Ariane 5-EPS version

This comparison is not fully representative:

- The Ariane 5 booster uses old technologies (metallic case,..)
- But there are layout constraints.

This point penalizes hybrid solutions that have larger dimensions than SRMs.

So, a comparison with a modern SRM was made, on the basis of the same propellant mass (49 tons): the inert will be comparable but the specific impulse (335s instead of 280s) will be greater of 55 seconds

The results are as follows:

| | 49t SRM | 49t Hybrid |
|---|---|---|
| Solid | | 2980 |
| Lox Tank | | 300 |
| Gaseous res. | | 200 |
| Interstage | | 125 |
| Turbopump, inject, misc | | 150 |
| Motor Mass | 3705 | 3755 |
| Stage mass | 675 | 675 |
| End of mission Mass | 4380 kg | 4430 kg |

So, the end of mission mass will be comparable but the specific impulse (335s instead of 280s) will be greater of roughly 55 seconds. It would result a dramatic increase of the performances of a small launcher (more than 50%)

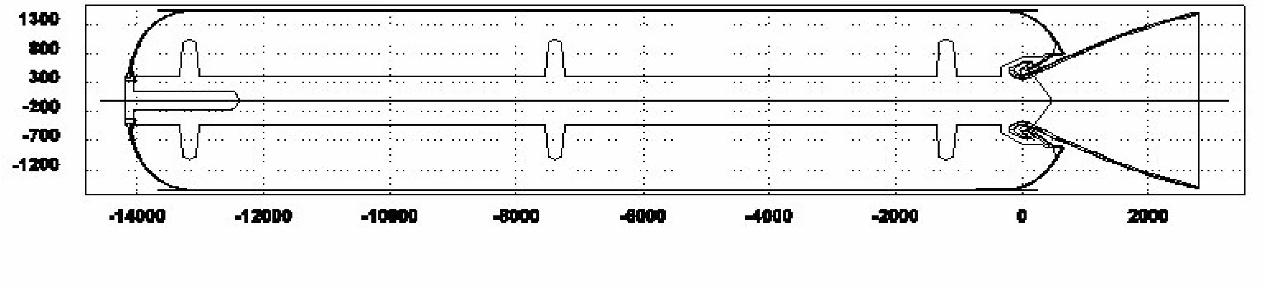
## CONCLUSION

The potential solution to improve the performances of hybrids seems to be to load the HTPB grain with a very energetic fuel such as Alane. Aside the dramatic increase on the specific impulse, it may result a better behavior of the nozzle versus erosion and versus pressure oscillations. Hybrid solutions could become very competitive with new solutions under study such as low cost LOx/Methane boosters

But, first a demonstration of its feasibility has to be done. The influence of the percentage of Alane on the regression rate has to be determined. It is the reason why experimental works have been proposed in collaboration with SME to the European Space Agency

**Acknowledgments** to Mr Fabrice .Martin for his help

**Hy 210 View of the solid grain**



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