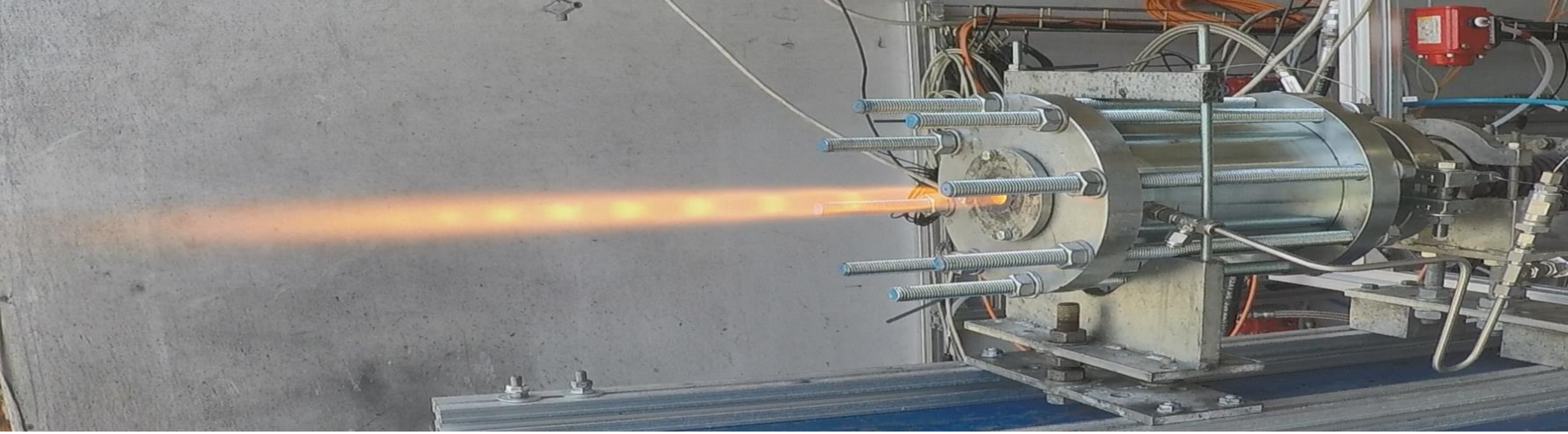

Enrico Paccagnella

13 September 2018

Development and Testing of a Small Hybrid Rocket Motor for Space Applications

Università degli Studi di Padova

Centro di Ateneo di Studi e Attività Spaziali "Giuseppe Colombo"

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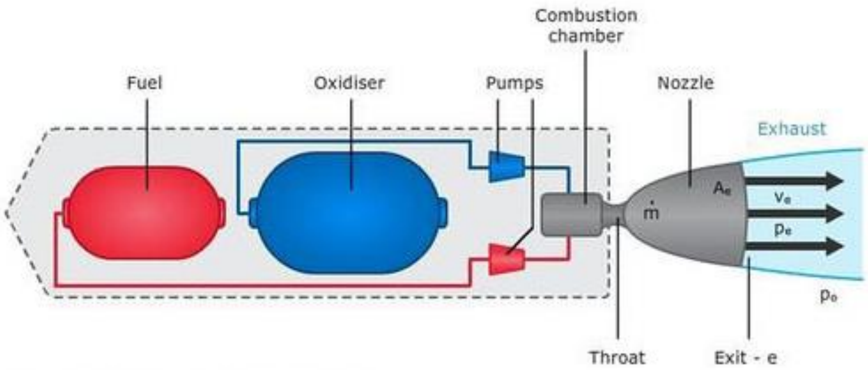
CISAS G. COLOMBO

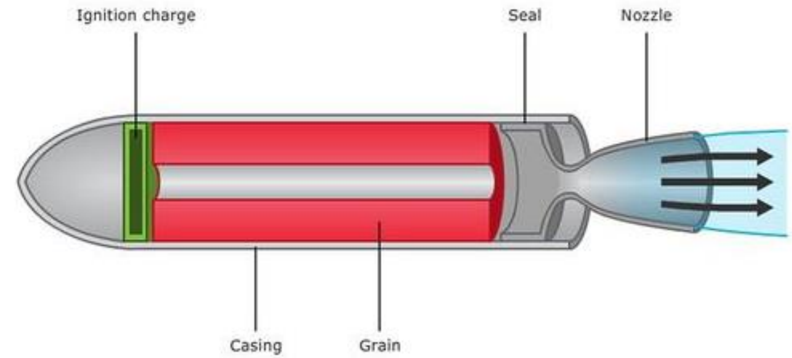
Outline

1. Introduction to HRMs
2. Applications of small HRMs
3. Numerical investigation
4. Experimental activity
5. Conclusions

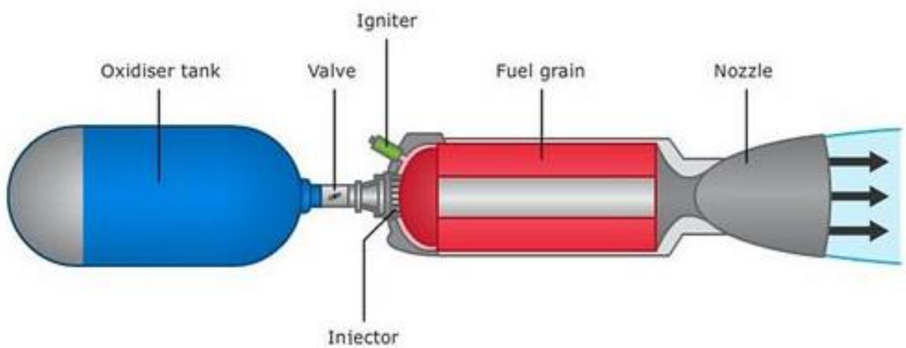
Introduction to HRMs (1/5)



Liquid rocket motors



Solid rocket motors



Hybrid rocket motors

Introduction to HRMs (2/5)

Hybrid motors advantages:

- Simplicity
- Reliability
- Safety
- Low cost
- Start, stop, restart
- Thrust control
- Environmental friendliness

Hybrid motors issues:

- Low regression rate
- Fuel residuals
- Low volumetric loading
- Combustion inefficiency
- Mixture ratio shift

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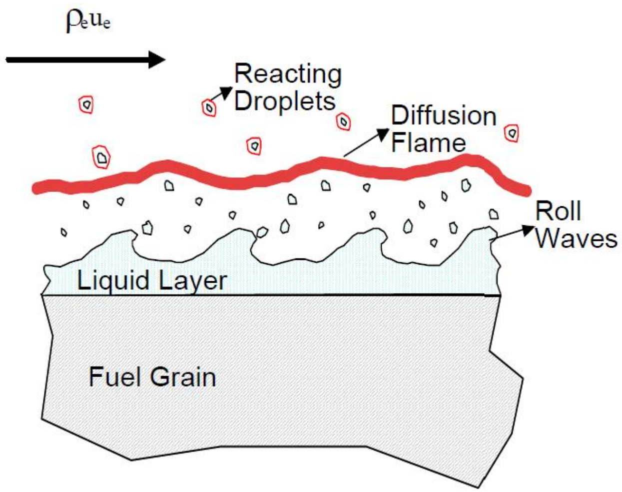
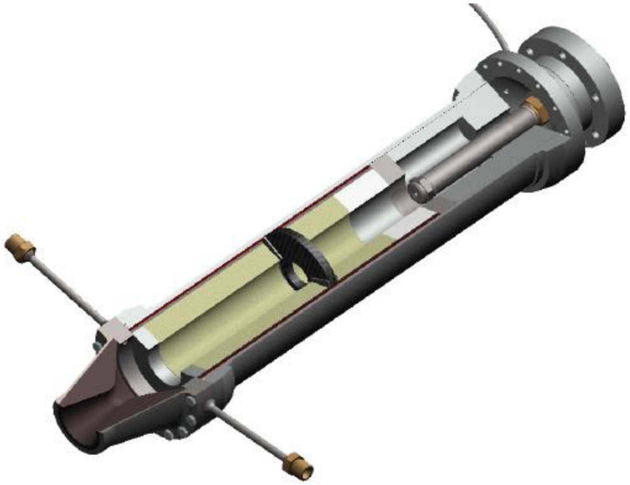
Possible solutions to increase low regression rate and low combustion efficiency:

- Solid fuel additives
- Liquefying solid fuels
- Diaphragms
- Nonconventional injector designs





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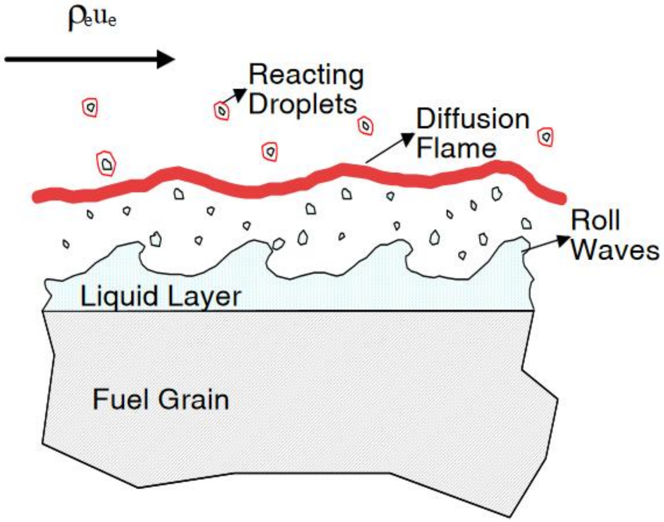
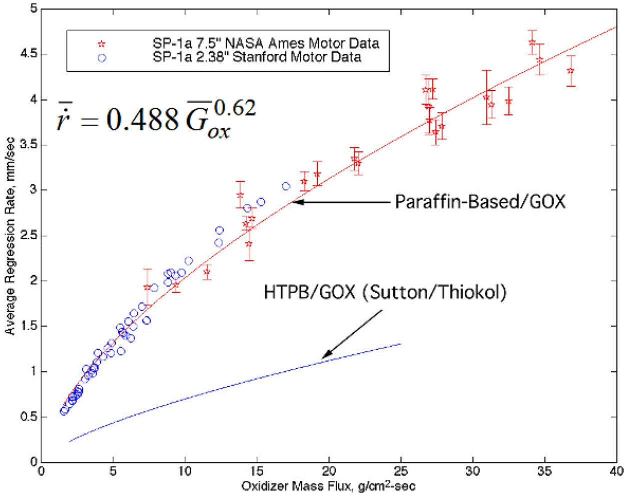
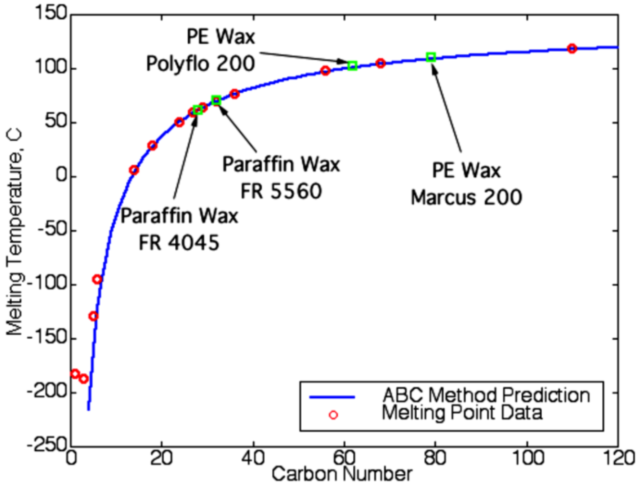
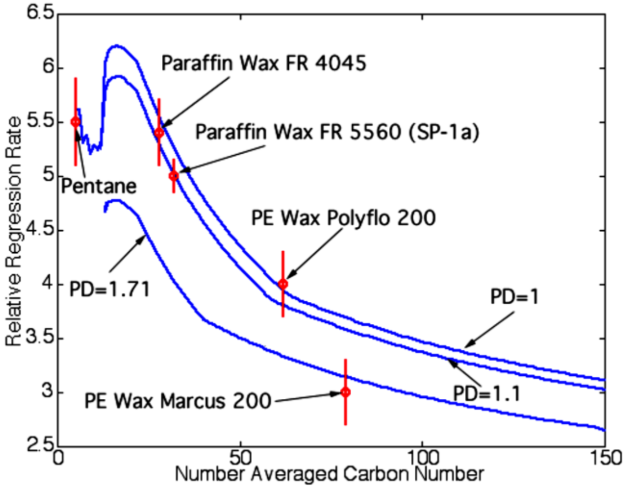
Entrainment





Thermomechanical properties





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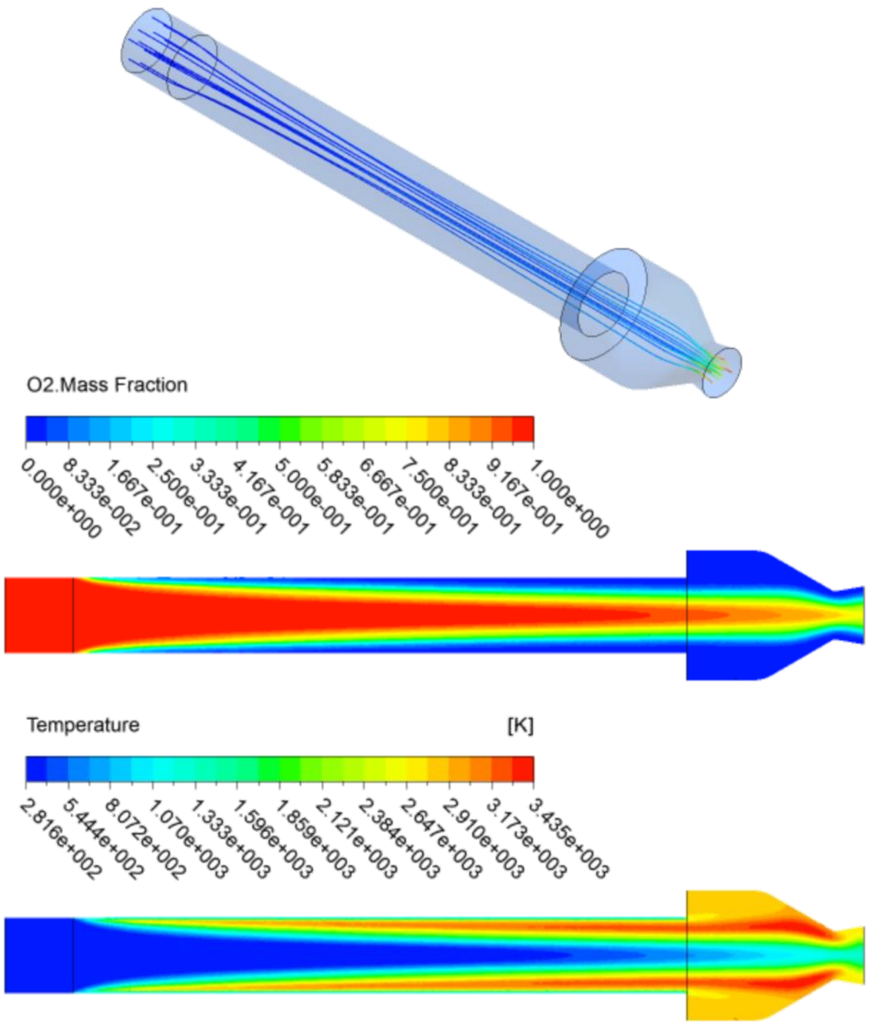
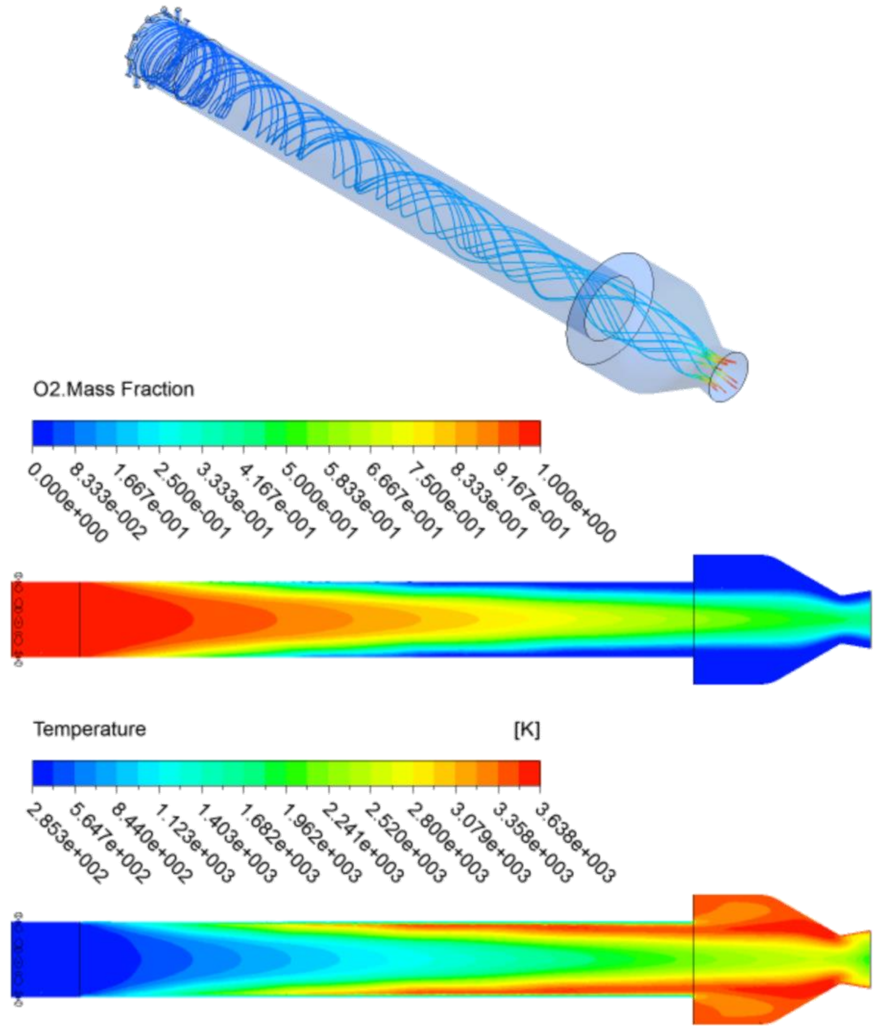
Axial injection



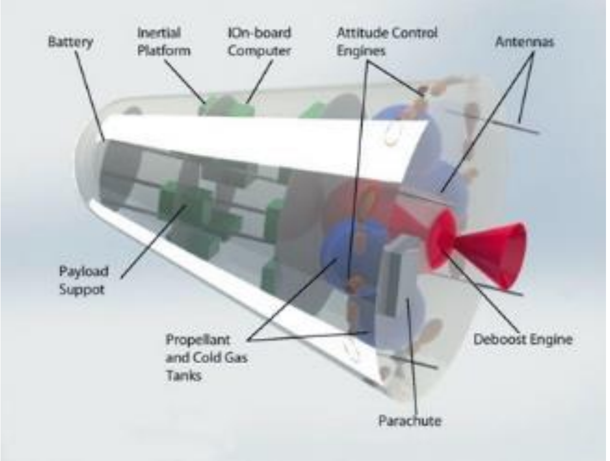
Swirl injection



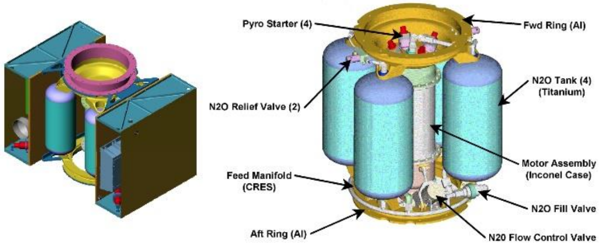
Applications of small HRMs

Sounding rockets

Deorbiting systems



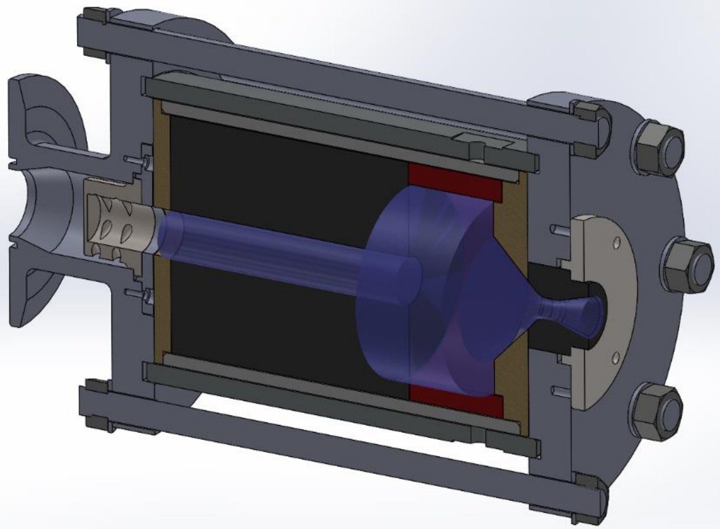
Orbit raising and reentry maneuvering systems

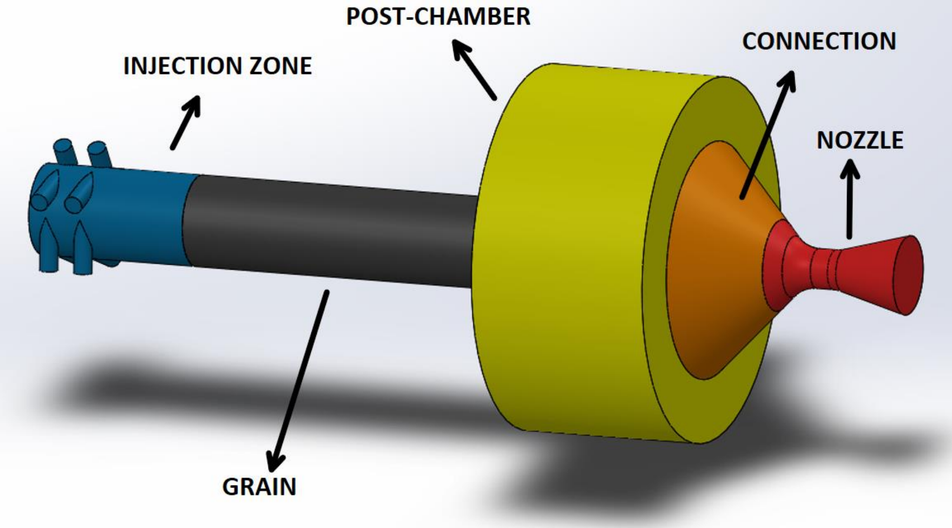


Maneuverable adapter rings

Main objectives of the investigation:

- Support the design of the small scale HRM
- Quantify the combustion efficiency varying the injection
- Assess the effect of the post chamber length
- Estimate the decay of the swirl along the motor axis
- Determine the wall heat flux to the thermal protections

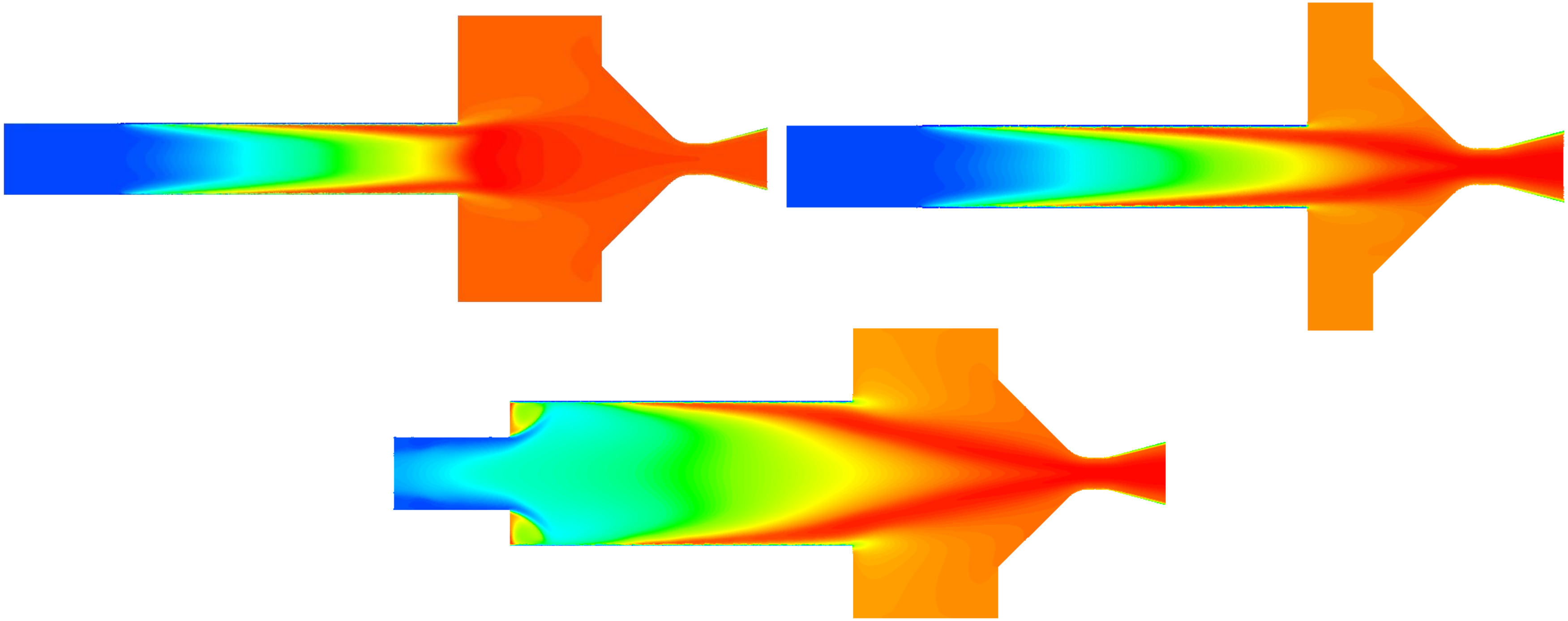




Numerical investigation (2/4)

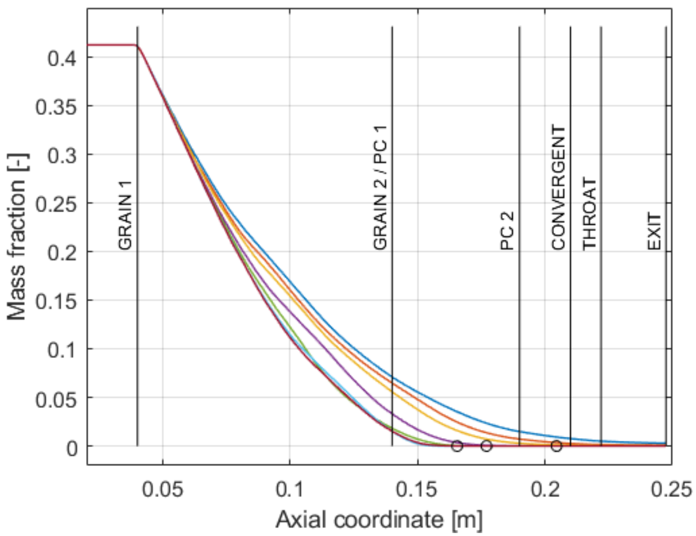
Several configurations analyzed:

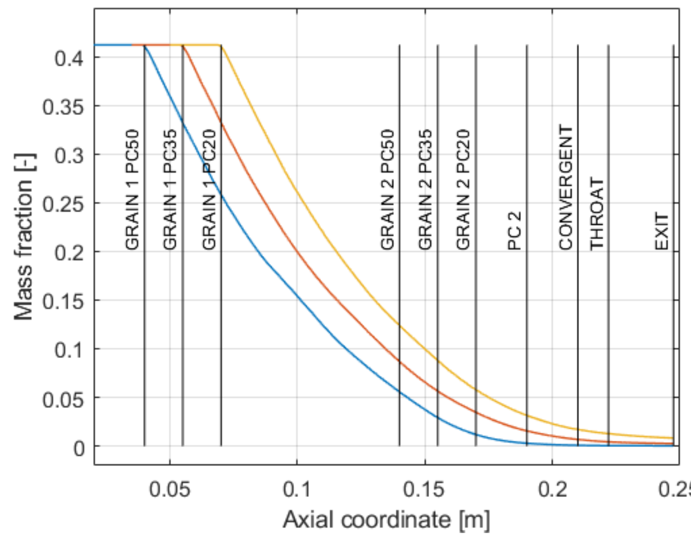
- Different injection intensities
- Different post chamber lengths
- Different grain internal diameters



Results of the numerical simulations:

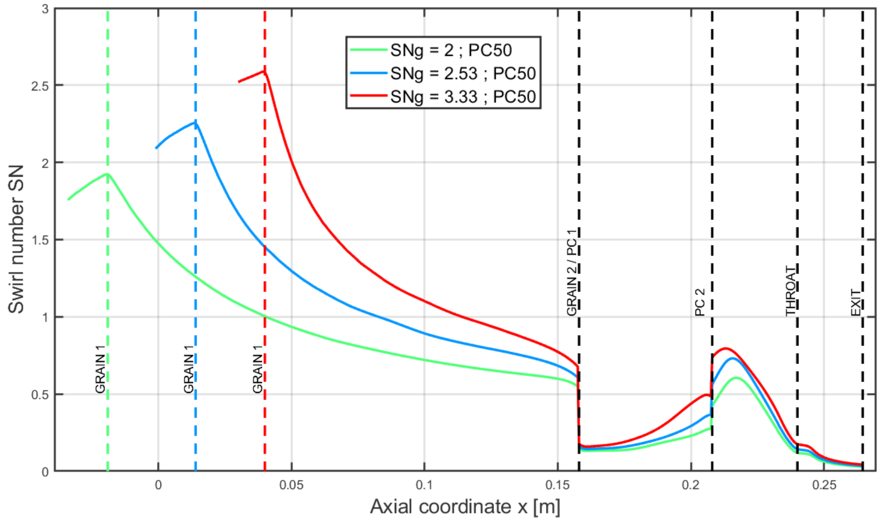
- All the configurations achieved high efficiency η > 95 %
- The oxidizer mass fraction is almost zero when the mass flow reaches the end of the post chamber
- A longer post chamber results in higher efficiency
- The wall heat flux increases with the intensity of the injection



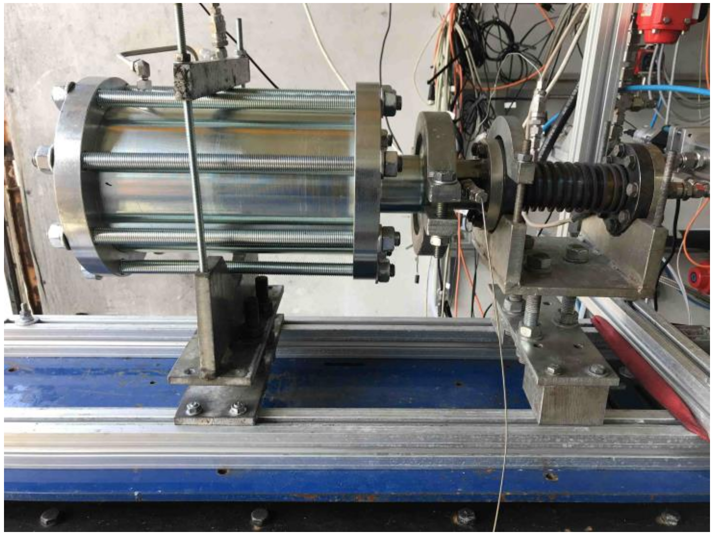


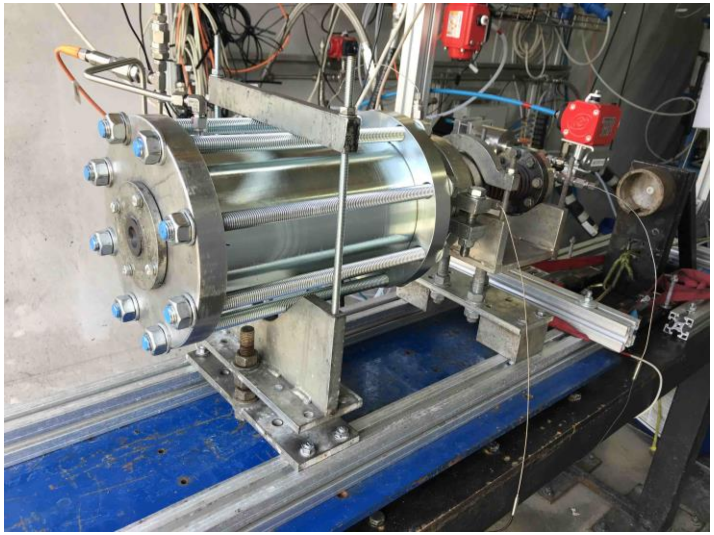
Phenomenon of swirl decay in the combustion chamber:

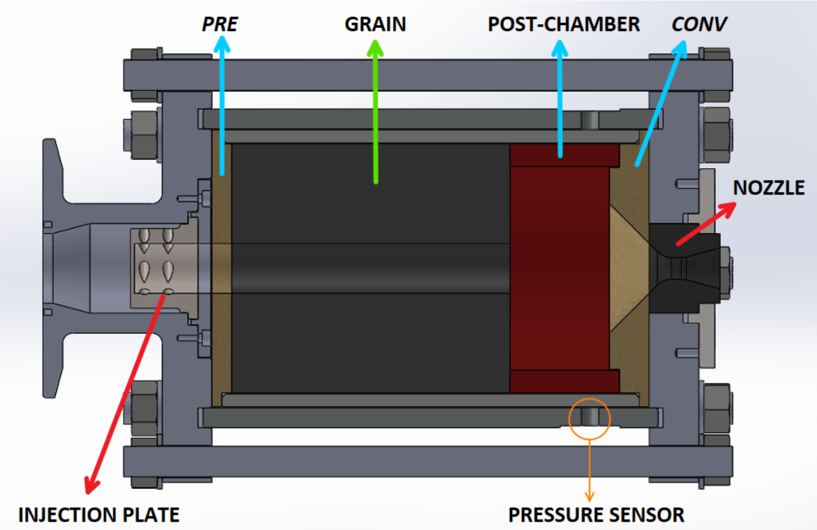
- Caused by the wall friction between the hot gases and the internal surfaces
- Cause by the addition of the gaseous fuel blowing from the grain port area
- Caused by the huge increase of temperature (and thus velocity) of the gases due to the combustion process

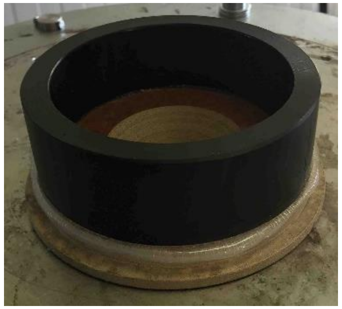


Experimental activity (1/5)









Experimental activity (2/5)

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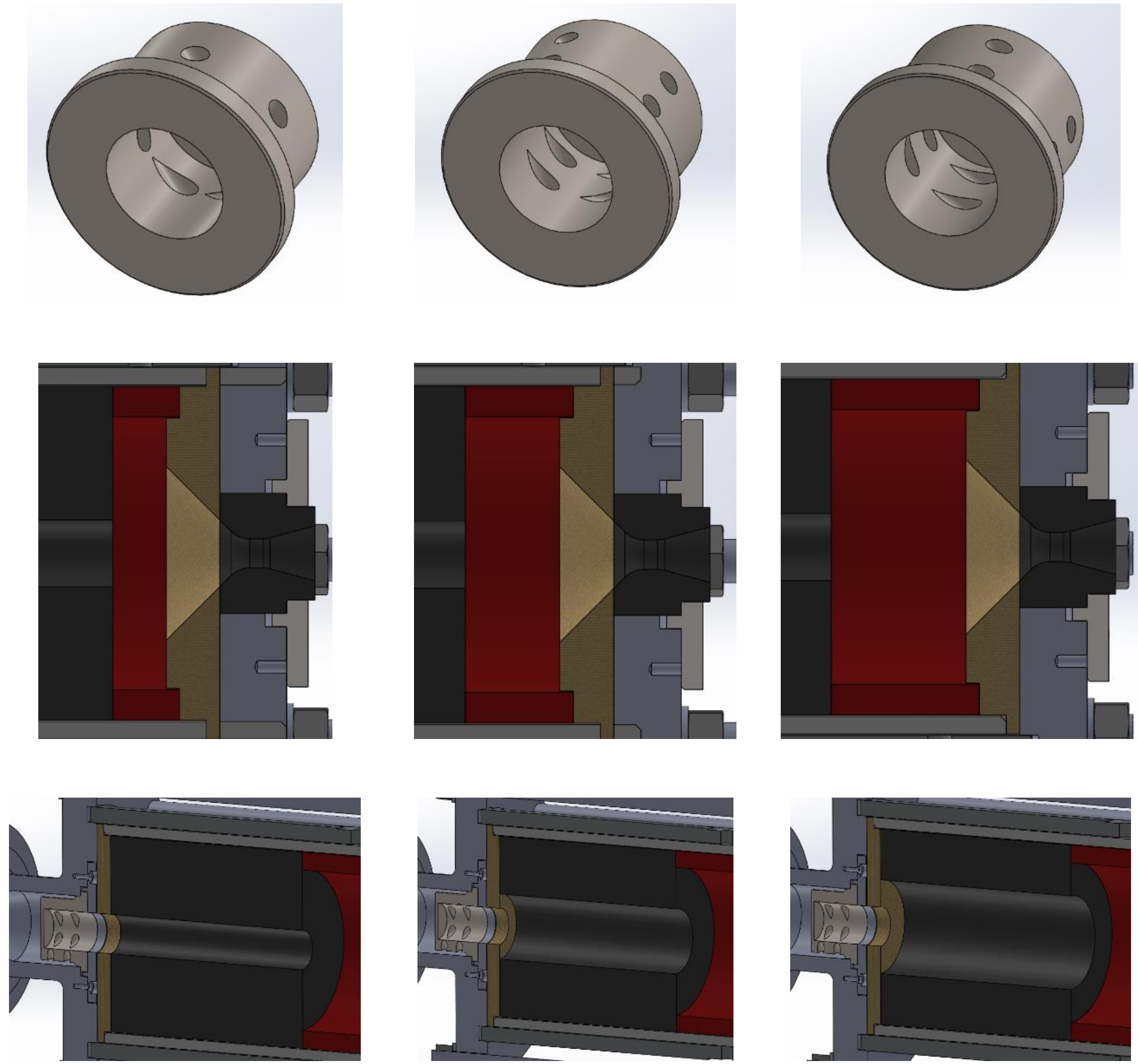
#	SN_g [-]	L_{pc} [mm]	D_p [mm]
1	2	20	25
2	2	50	25
3	2	50	43.5
4	2	50	56
5	2.53	20	25
6	2.53	35	25
7	2.53	50	25
8	2.53	50	46.5
9	2.53	50	61
10	3.33	20	25
11	3.33	35	25
12	3.33	50	25
13	3.33	50	50
14	3.33	50	66.5



Experimental activity (3/5)

#	SN_g [-]	L_{pc} [mm]	D_p [mm]	O/F_g [-]	O/F_{tot} [-]	rr_g [mm/s]	rr_{pc} [mm/s]	Isp [s]	η [%]
1	2	20	25	5.75	4.82	0.86	0.79	216.26	99.03
2	2	50	25	6.09	4.00	0.84	0.79	210.17	98.68
3	2	50	43.5	6.09	4.50	0.53	0.42	206.09	95.08
4	2	50	56	5.93	4.44	0.46	0.40	205.13	95.11
5	2.53	20	25	7.10	5.54	0.78	0.71	216.17	96.80
6	2.53	35	25	8.20	5.76	0.75	0.68	215.76	96.55
7	2.53	50	25	7.03	4.48	0.81	0.76	215.85	99.60
8	2.53	50	46.5	7.14	4.90	0.52	0.46	189.79	87.45
9	2.53	50	61	6.32	4.46	0.43	0.38	208.47	96.43
10	3.33	20	25	6.62	5.34	0.91	0.88	215.25	96.63
11	3.33	35	25	6.64	4.88	0.95	0.83	212.13	96.35
12	3.33	50	25	6.26	4.10	0.94	0.90	208.07	97.51
13	3.33	50	50	6.42	4.19	0.58	0.49	207.15	96.61
14	3.33	50	66.5	6.41	4.24	0.49	0.38	203.13	94.74

Marxman regression rate law:

- Regression rate of the solid fuel grain $\dot{r} = aG^n$
- Oxidizer mass flux $G = \frac{\dot{m}_{ox}}{A_p}$
- Using the experimental results it is possible to calculate the values of *a* and *n*

SN_g	Injector	a	n
2	D5N10	0.068	0.522
2.53	D4.5N10	0.081	0.485
3.33	D5N6	0.103	0.471

- The value of *n* is almost 0.5 meaning that the fuel mass flow rate is approximately constant with the grain port diameter
- The value of *a* increases with the geometric swirl number

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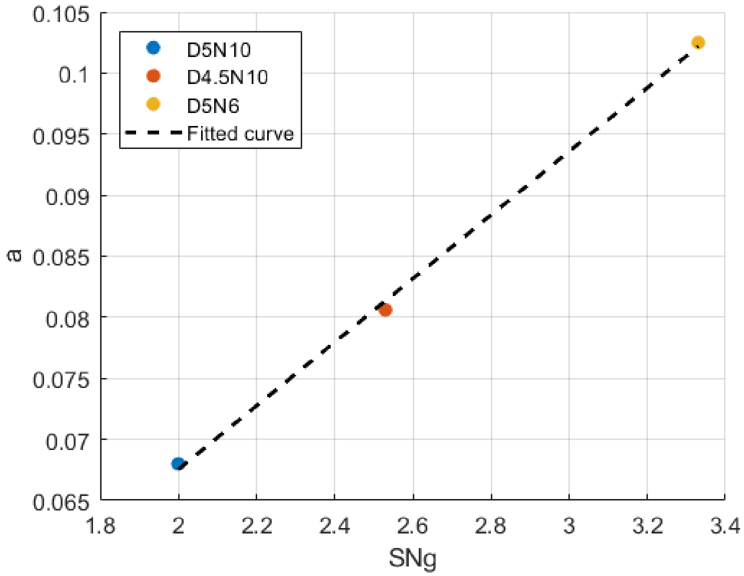
Relation between the geometric swirl number SN_g and the multiplicative coefficient a:

- An almost linear relation has been found (at least in the range of SN_g studied)
- The regression rate can be easily varied simply changing the injection plate



Conclusions

A HRM with swirl injection have been studied

Numerical investigation:

- All the configurations achieved high efficiency
- A longer post chamber results in higher efficiency but the difference is small
- A too high injection swirl intensity causes unacceptable wall heat fluxes to the thermal protections

Experimental activity:

- All the configurations achieved high efficiency, thus shorter post chambers are preferable because they have a lower influence on the global mixture ratio
- An almost linear relation between SN_g and a has been found, thus the regression rate can be easily changed during the design phase depending on the mission requirements

Thank you for your attention!

Any questions?