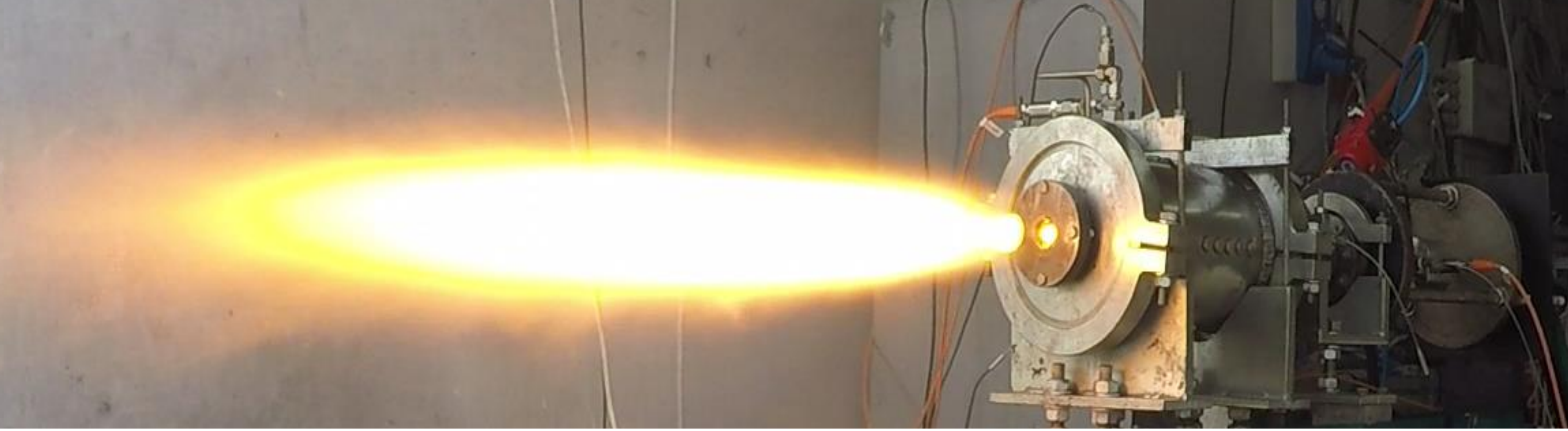

Enrico Paccagnella

22 September 2017

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”

UNIVERSITÀ DEGLI STUDI DI PADOVA

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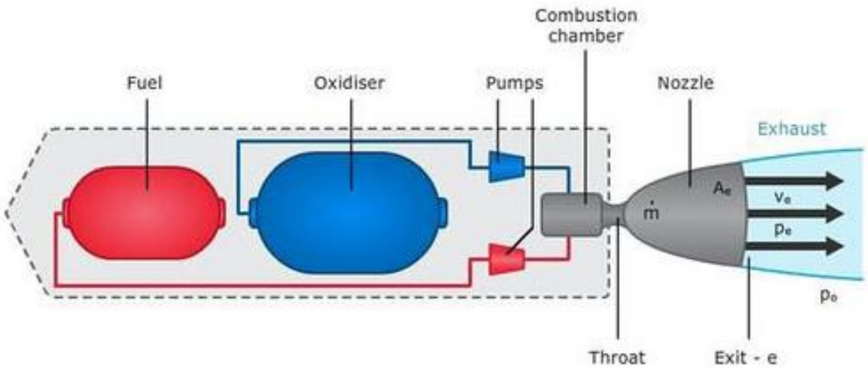
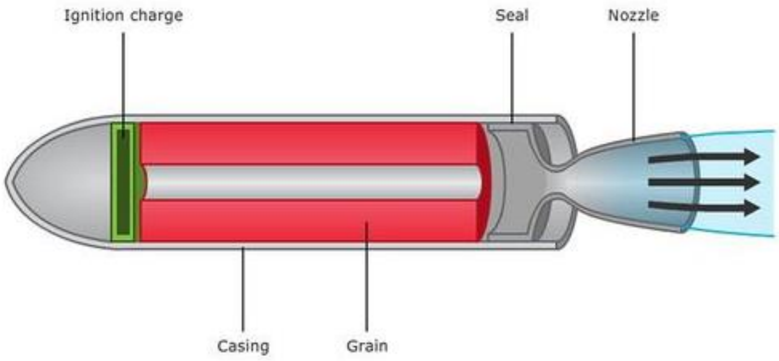
Outline

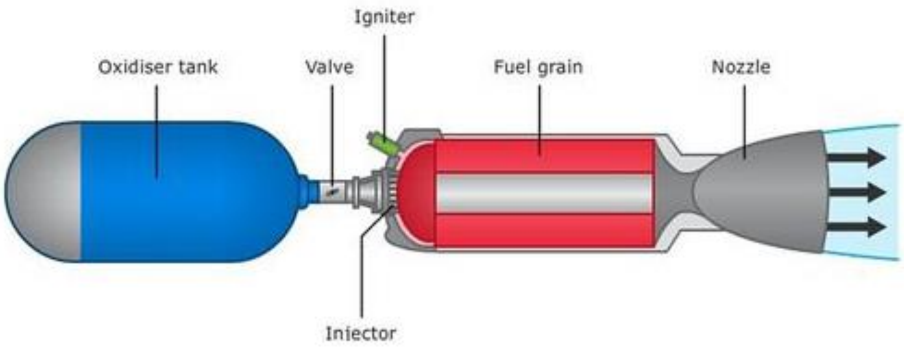
1. Introduction to HRMs
2. Applications of small HRMs
3. Mission envelope of HRMs
4. Long burn test of a lab-scale HRM
5. Conclusions



Liquid rocket motors



Solid rocket motors



Hybrid rocket motors

Introduction to HRMs (2/4)

Hybrid motors advantages:

- Simplicity
- Reliability
- Safety
- 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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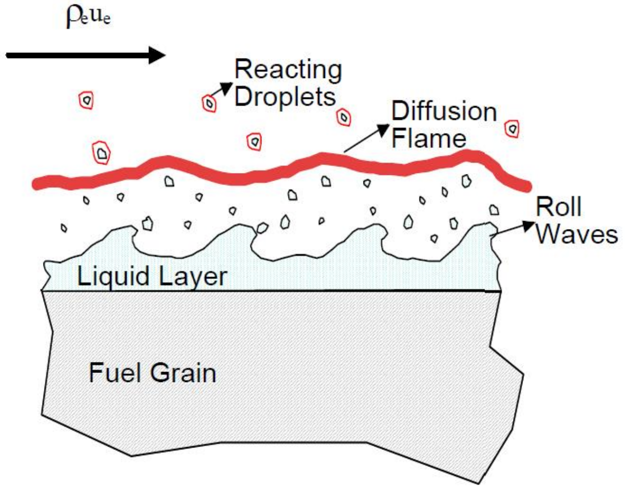
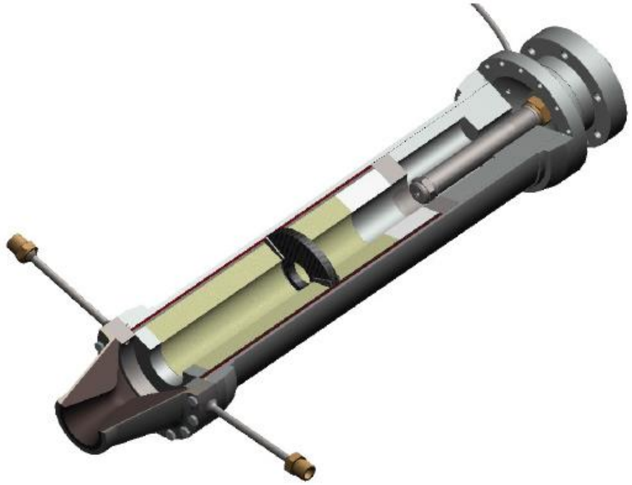
To increase low regression rate and low combustion efficiency:

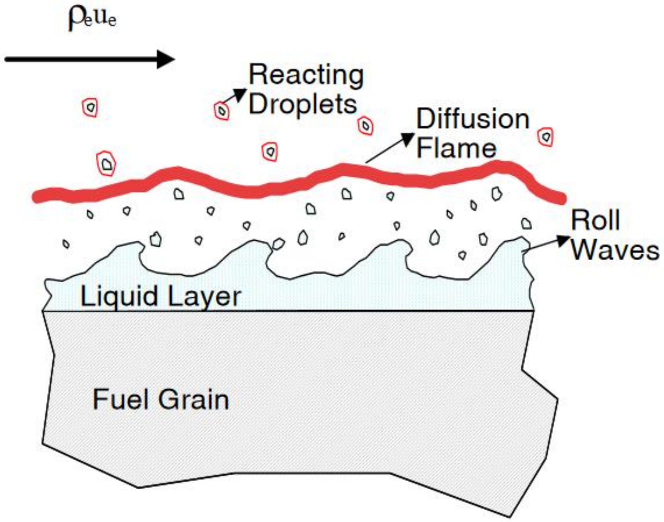
- Solid fuel additives
- Liquefying solid fuels
- Diaphragms
- Nonconventional injector designs

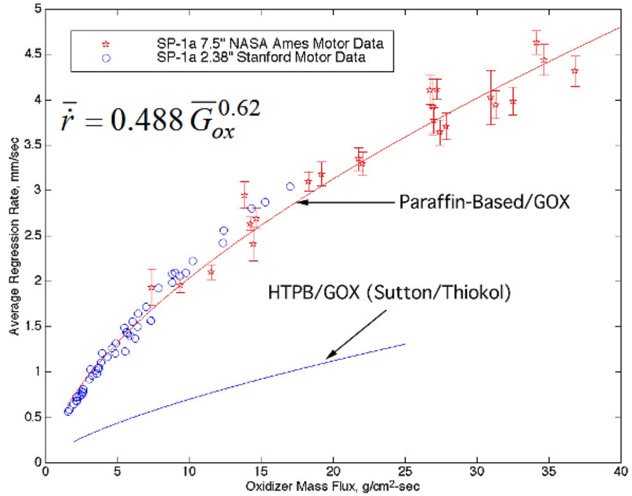




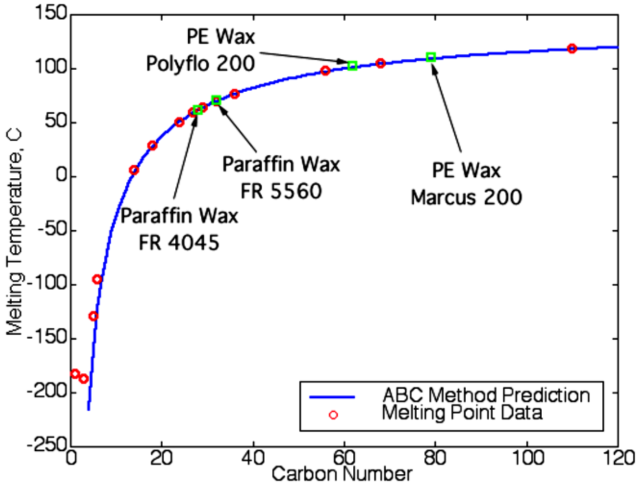
Introduction to HRMs (4/4)

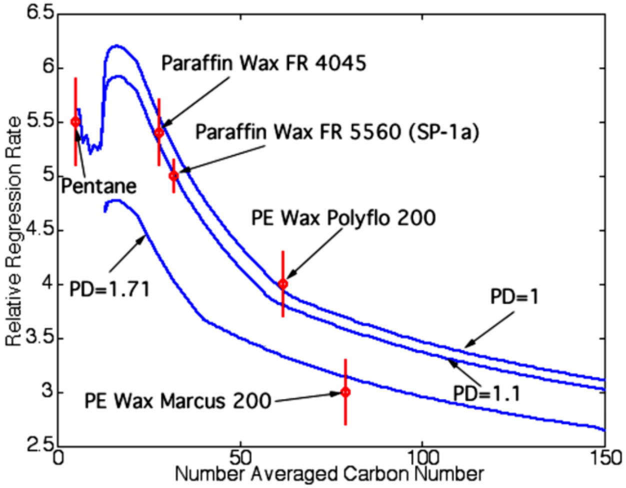
Entrainment





Thermomechanical properties

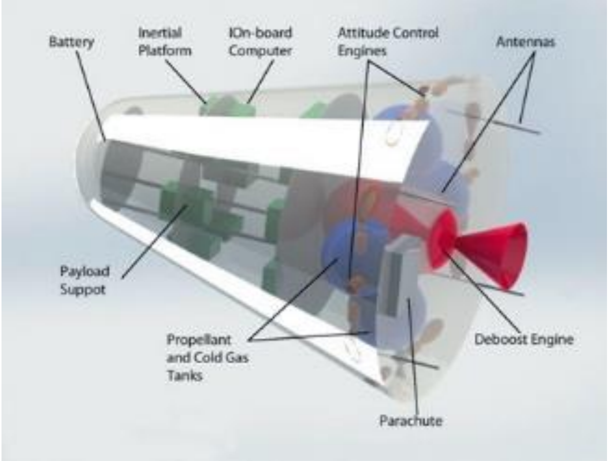




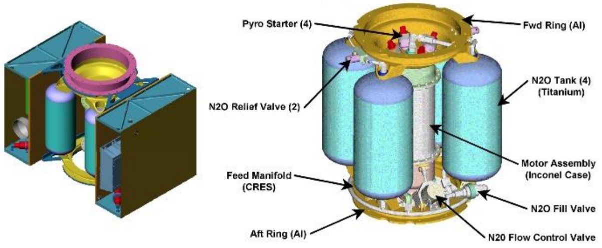
Applications of small HRMs

Sounding rockets

Deorbiting systems



Orbit raising and reentry maneuvering systems



Maneuverable adapter rings

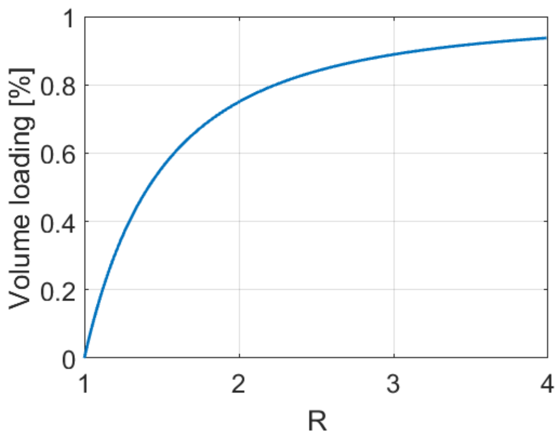
Define suitable hybrid rocket envelope

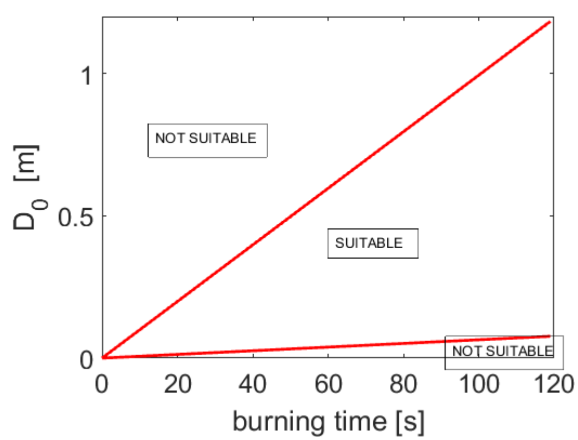
$$R = \frac{D_f}{D_0}$$

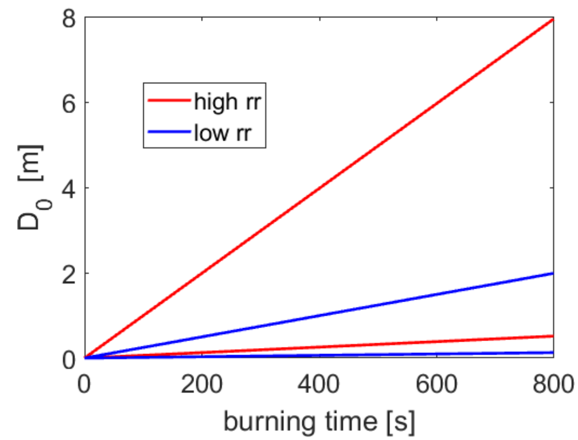
$$VL = 1 - \frac{1}{R^2}$$

$$\frac{G_0}{G_f} = R^2$$

$$\frac{a G_0^n t_b}{D_0} = \frac{R^{2n+1} - 1}{(4n+2)}$$

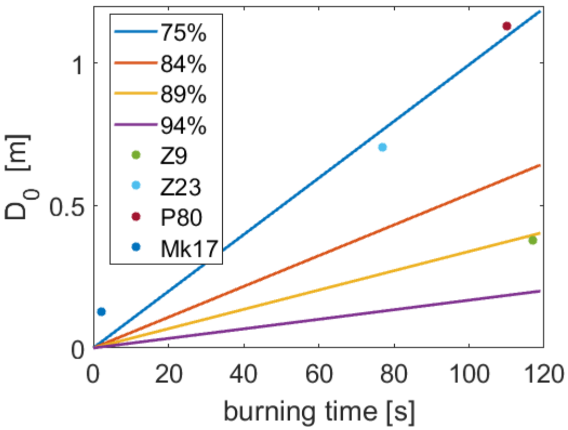


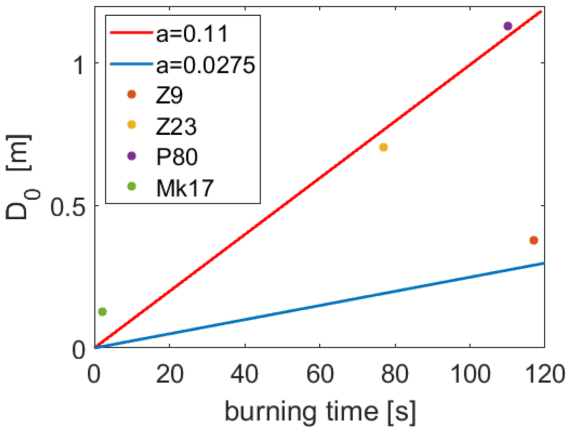




Relation between motor size and burning time:

- Parametric with volume loading
- Parametric with regression rate

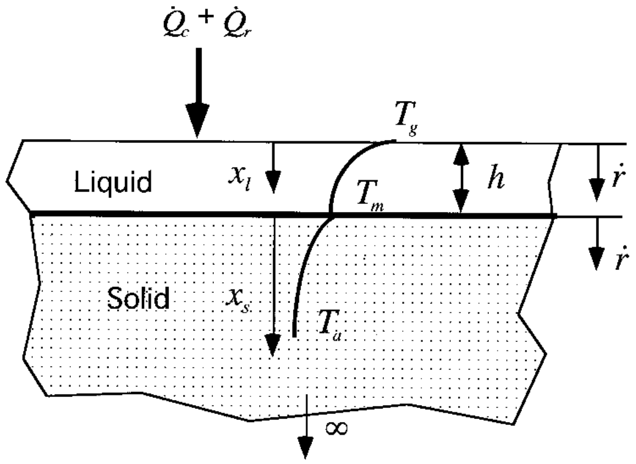


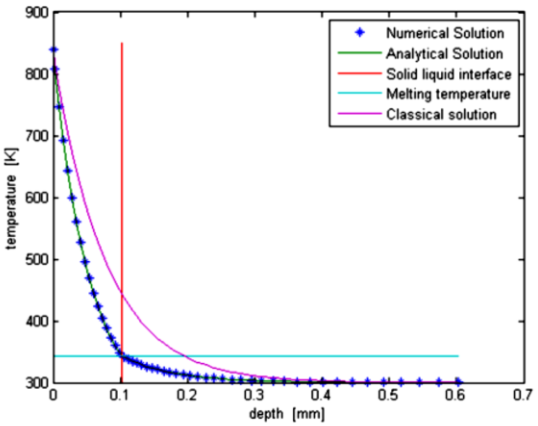


High regression rate is needed for large motors and high volume loading

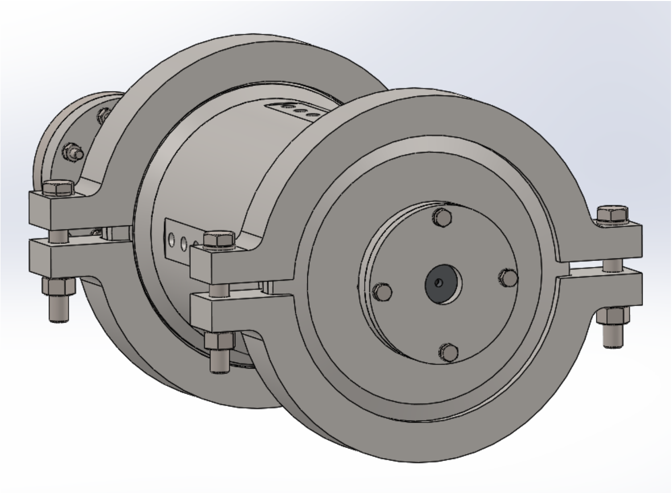
The study focus on two main objectives:

- Demonstrate the feasibility of a HTP/paraffin hybrid motor with a long burning time
- Demonstrate paraffin liquid layer theory: heat does not penetrate inside the fuel grain during the burn





A HTP/paraffin lab-scale motor has been designed, built and tested at the hybrid propulsion group facility



Hybrid 1 kN motor:

- Catalytic reactor
- Combustion chamber

Catalytic reactor:

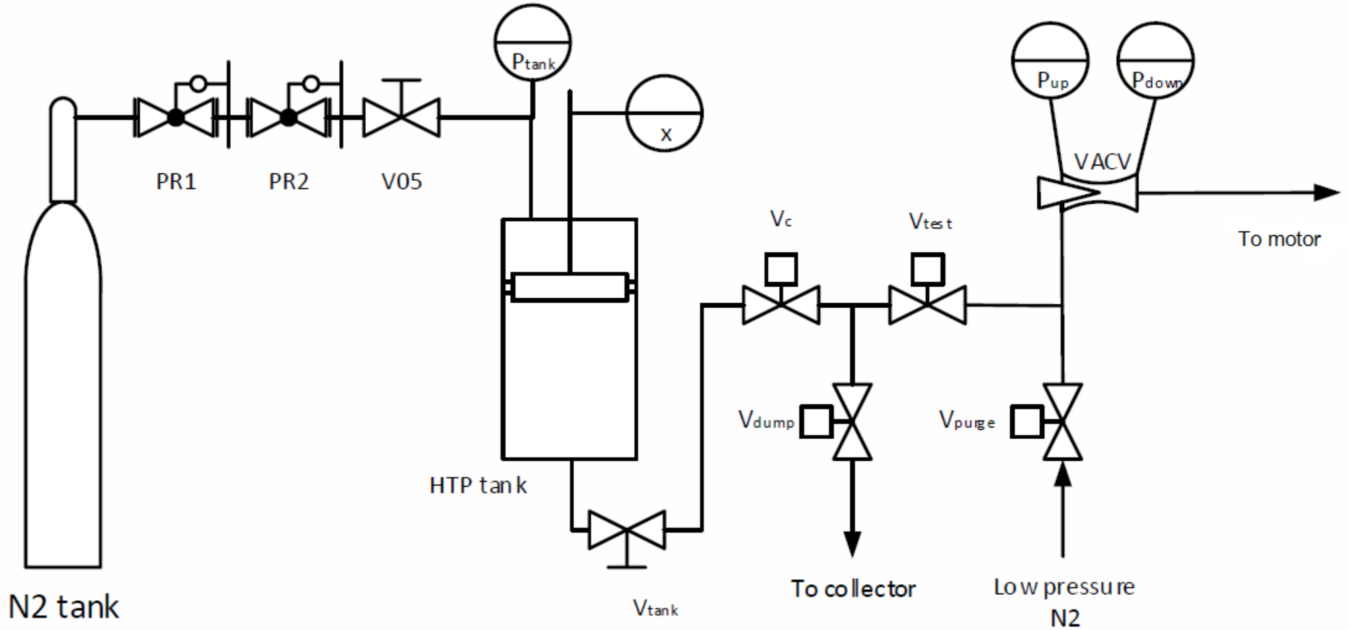
- Decomposes the 90% HTP to oxygen and water
- Gaseous form with a temperature of about 700-800 °C

Combustion chamber:

- Steel cylinder and two flanges (MEOP=40 bar and SF=4)
- Convergent nozzle
- 22 sensor holes (thermocouples and pressure sensors)

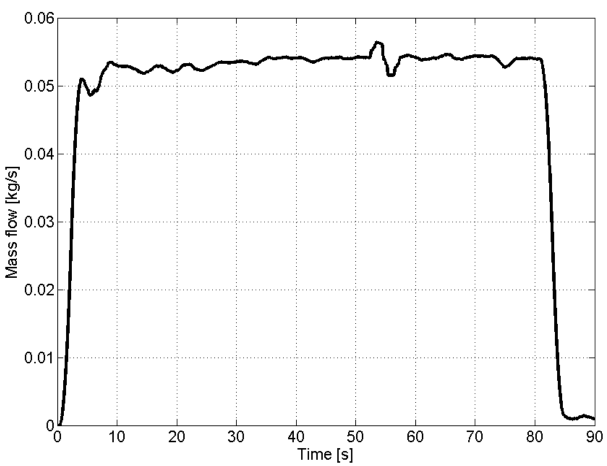
Fluidic line:

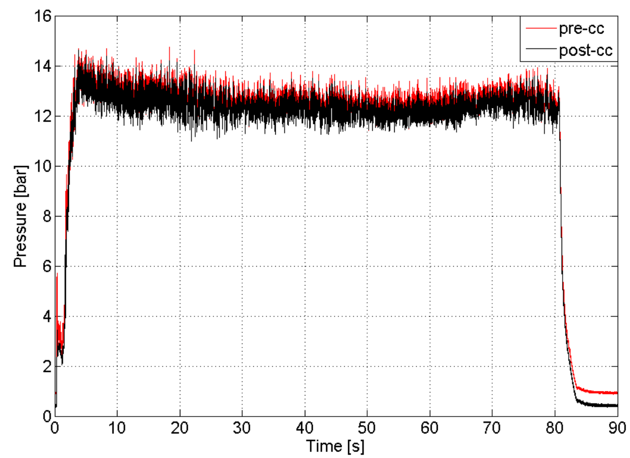
- High-pressure nitrogen tank
- Pressure regulation block
- Hydrogen peroxide tank
- Tubes and automated ball valves
- Variable area cavitating venturi



Test results:

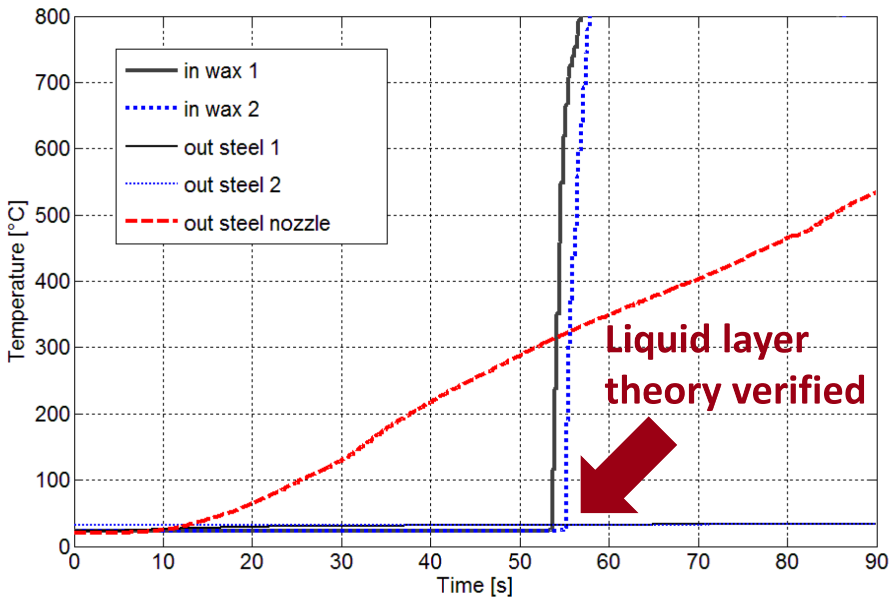
- Successful long burn test
- Constant oxidizer mass flow
- No nozzle throat erosion
- Constant pre-cc and post-cc pressures
- Small pressure oscillations
- Regression rate exponent n=0.5
- Regression rate exponent a=0.145

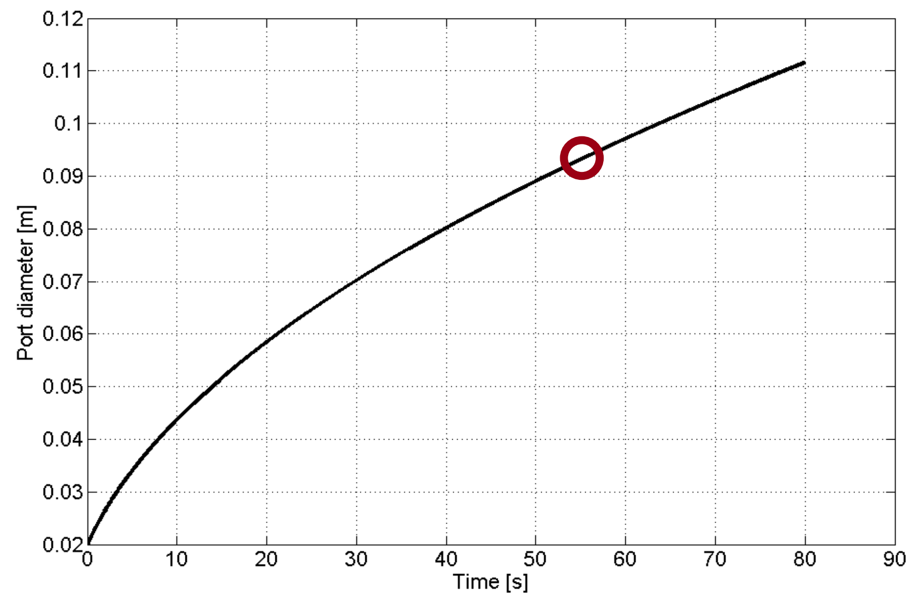




Temperature sensors:

- In wax 1-2: constant temperature until a steep increase around second 55 (thermocouples 10 mm inside the grain)
- Out steel 1-2: negligible temperature variation
- Out steel nozzle: continuous increment of the temperature (no insulation around the graphite and molybdenum parts)





Conclusions (1/2)

It was demonstrated that at first approximation there is a **linear relation between the regression rate multiplied by the burning time and the size of the motor** in order to keep a fixed shape of the fuel grain

For this reason, **high regressing fuels** are **better suited** for **larger thrusts-shorter burning times**, while the opposite occurs for low regressing fuels

With current technologies, single port hybrids are still **not suited** for **very short burning times** and **large thrusts** or for **very low thrusts** and **long burning times**

Conclusions (2/2)

A HTP/paraffin lab-scale motor has been designed, built and tested:

- The motor burned for 80 s in fuel-rich conditions without any issue
- The pressure profile was stable and flat showing no sign of grain failure/degradation
- The flat pressure profile without nozzle erosion also suggests a regression rate exponent near 0.5

Two thermocouples were inserted in the fuel grain:

- They remained near room temperature until they were exposed to the port flow
- The experiment thus demonstrated the validity of the liquid layer theory

Thank you for your attention!

Any questions?