UNIVERSITÀ DEGLI STUDI DI PADOVA

Study and development of a H_2O_2 based liquid rocket engine

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Outline:

- Introduction
- Catalyst bed
- Combustion chamber
- Nozzle
- Embedded configuration
- Conclusion

HTP in Padua

Hydrogen peroxide

- INTEROX® ST 60
- Excellent stability
- Supplied in intermediate bulk containers (IBCs)

SOLVAY

↓

Reduced management, storage and processing costs

HTP (High Test Peroxide)
On site concentration up to 95%

$$H_2O_2 \leftrightarrow H_2O + 1/2O_{2(g)} + 98kJ/mol$$

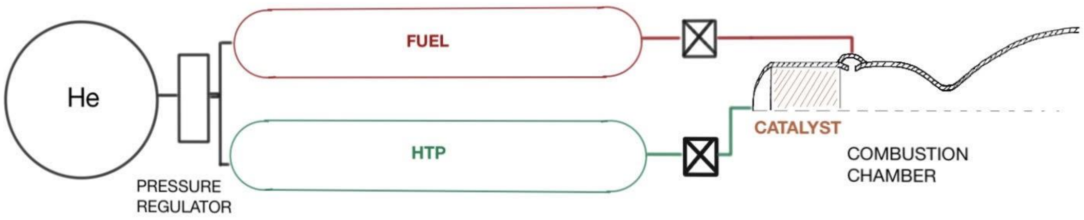
Versatility based on solid catalyst

- Monopropellant
- Bipropellant

Disadvantages

- Short catalyst life
- Poisoning

HTP based LPRE



Main characteristics:

- Oxidizer and fuel stored in tanks
- Two controllable feeding lines
- Solid catalyst for HTP decomposition
- Fuel injection plate
- Combustion chamber & Nozzle
- Different cooling system solutions

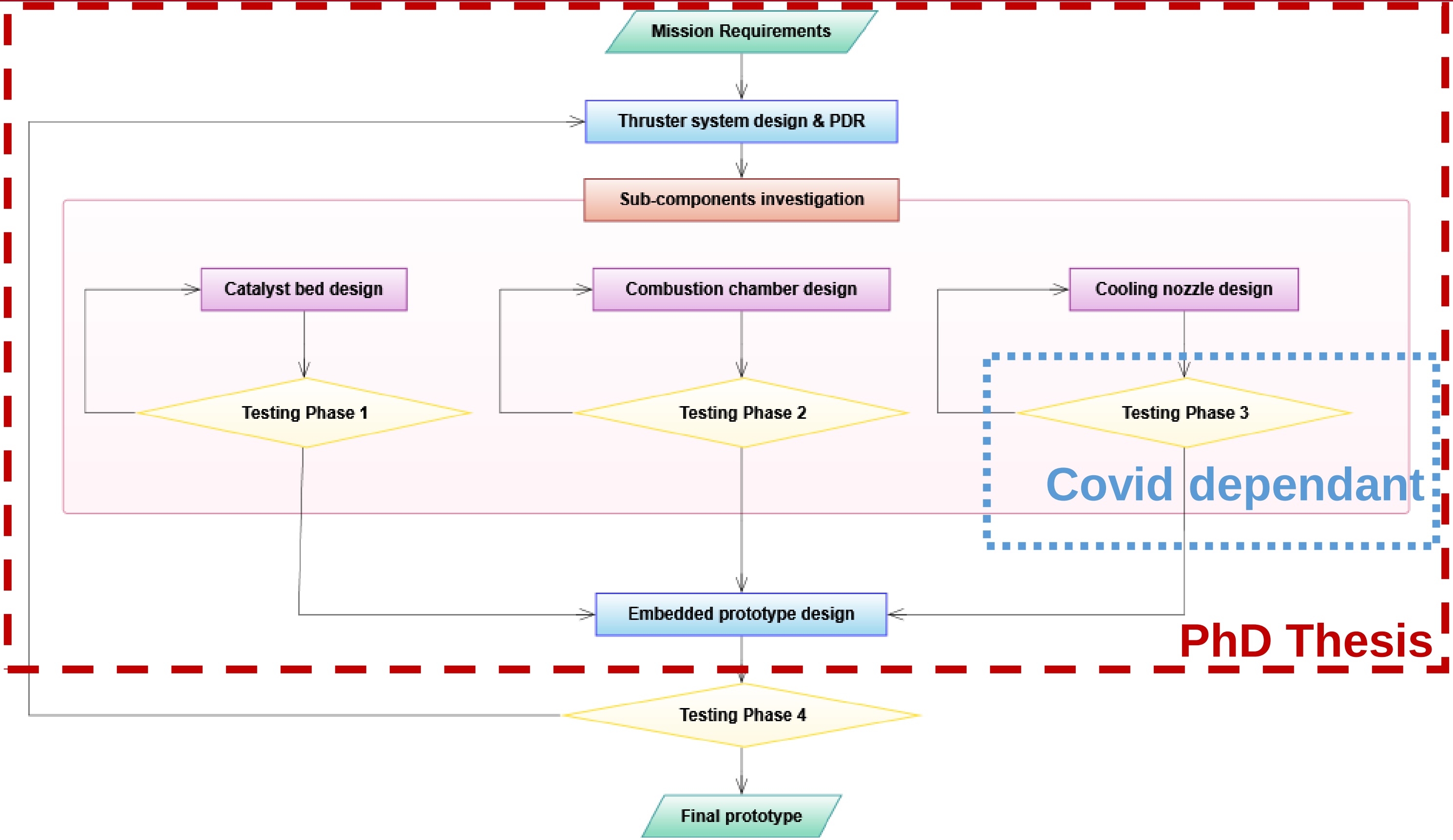
Advantages

- High specific impulse
- Operation flexibility
  - Multiple ignition
  - Mass flow throttling
  - Mixture ratio control
- No igniter
- Long burning times

Disadvantages

- High manufacturing costs
- Technological complexity
- Solid catalyst weight

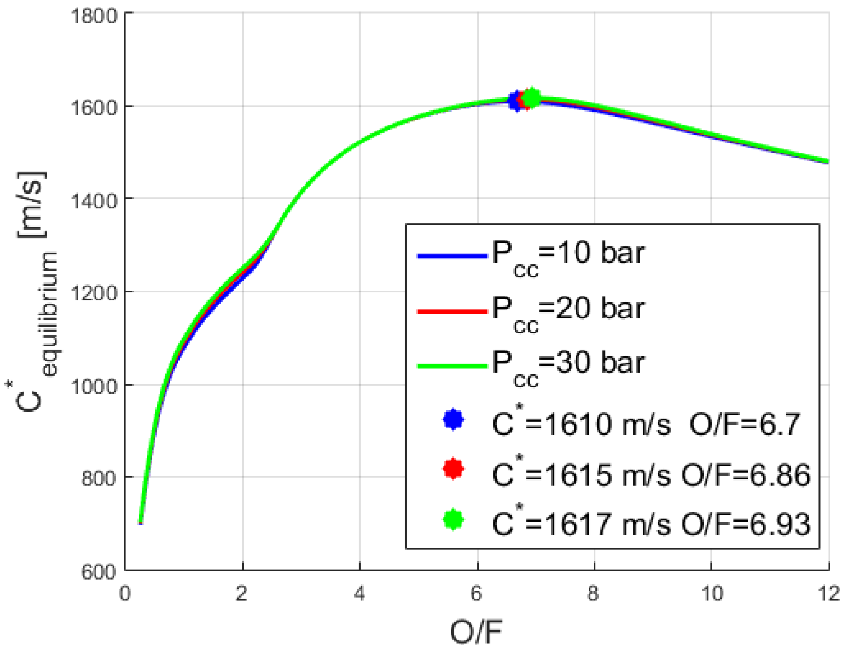
Work Structure



Project parameters

Kick apogee motor

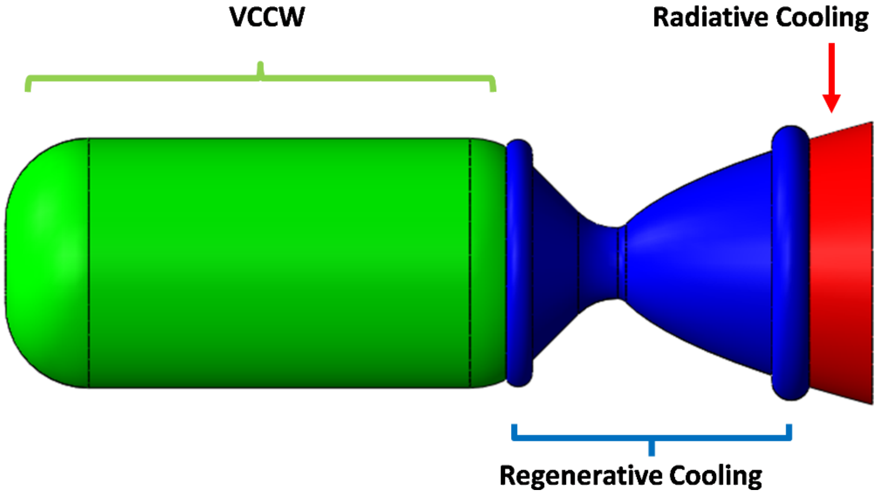
Oxidizer	HTP 91,5	w%
Fuel	Jet-A	
O/F	6,5	
MEOP	1	MPa
Oxidizer mass flow	120	g/s
ε	330	
Thrust vacuum	465	N
Isp	342	s



Cooling solutions

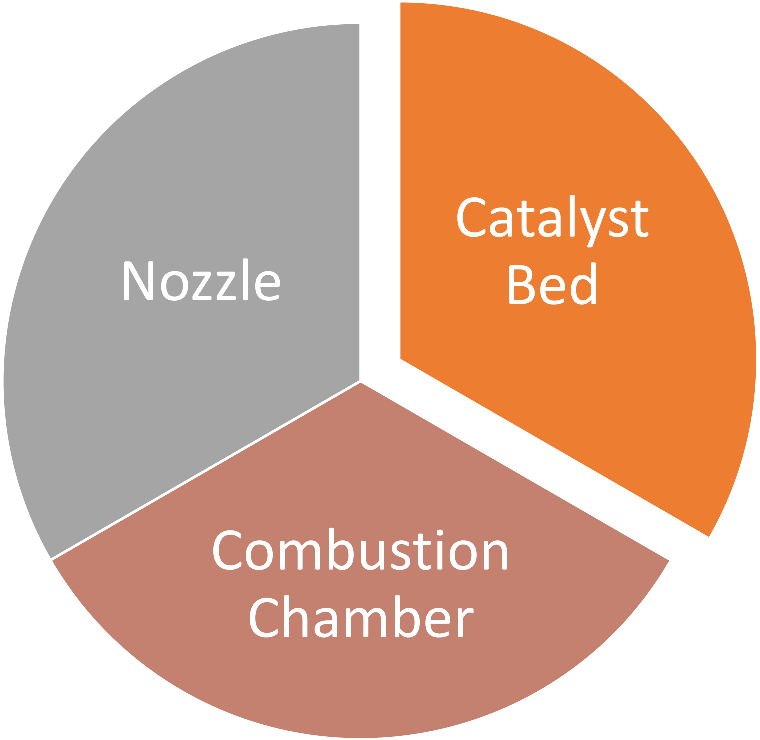
Passive methods
- **Radiative cooling**
- **Very expensive materials**
- **Small scale thruster**

Active methods
- **Regenerative cycle**
- **Technological complexity**
- **High manufacturing costs**
- **Large scale thruster**



Monopropellant:
- **Decomposition temperature ≈ 1000 K**
- **Nickel based alloys temperature compatibility**
- **Additive manufacturing**

Outline

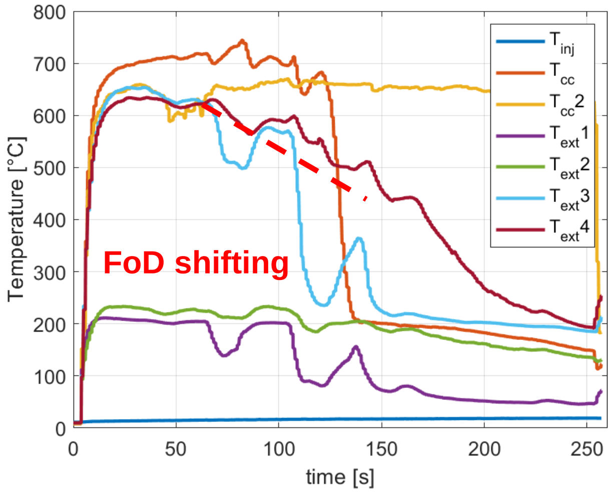


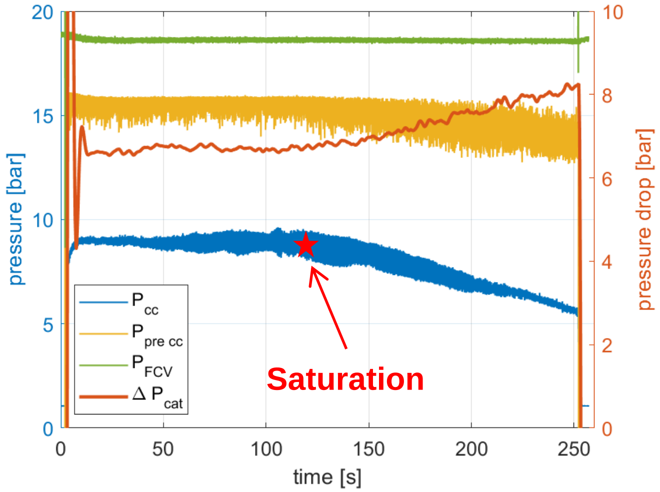
Catalyst bed questions?

- *How long does a catalytic bed last with ST HTP?*
- *How much is the pressure drop across the catalytic bed?*
- *Is it possible to print the engine in AM?*

10 N Monopropallant

SSF long burn test





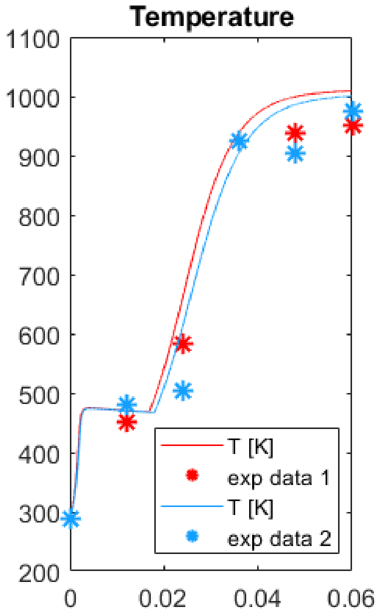
Design background:
Starting from previous experience on hybrid rockets catatlyst bed.

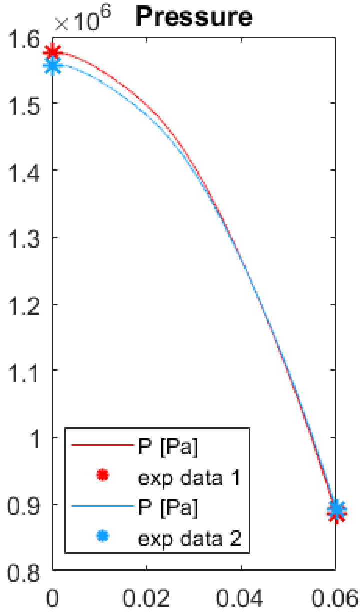
Catalyst bed

tb [s]	c* eff	Twall_max [°C]
120	0,97	680

Outcome

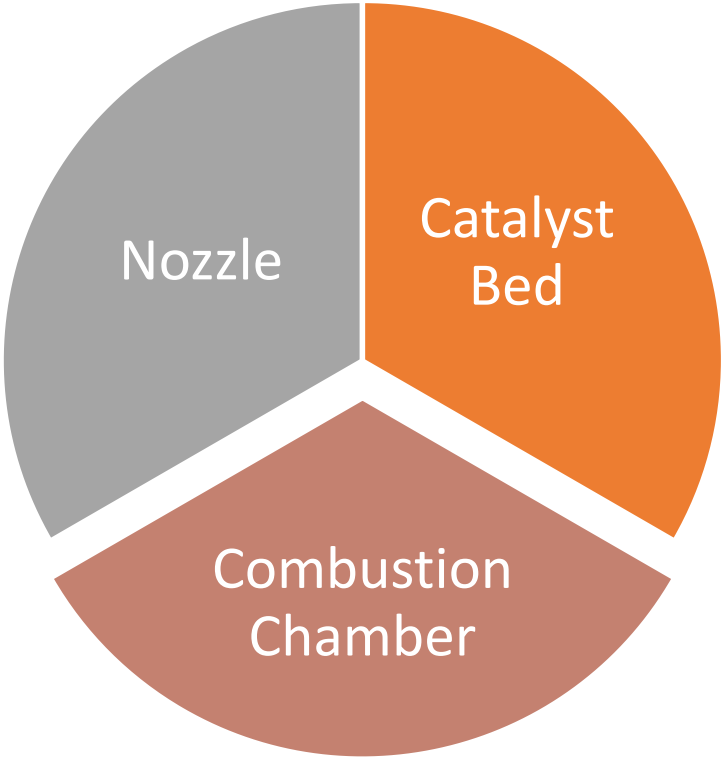
1. 3D printing Knowledge
2. Material capabilities (AISI 316 L)
3. Catalytist Saturation ~ Linear scaling
4. Pressure drop modeling



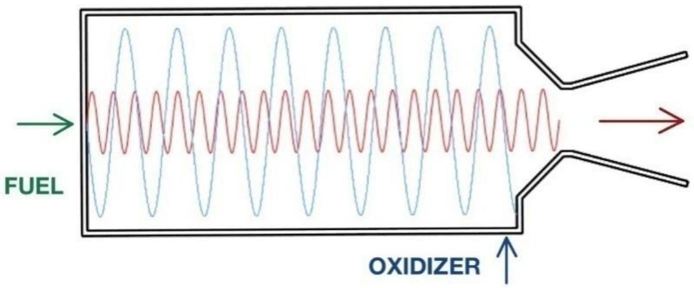


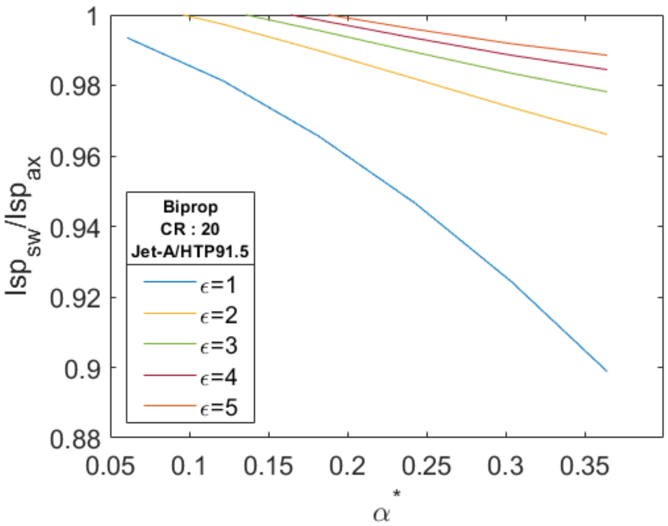
M. Santi, I. Dorgnach, F. Barato, D. Pavarin, *Design and Testing of a 3D Printed 10 N Hydrogen Peroxide Monopropellant Thruster,* AIAA Propulsion and Energy 2019 Forum

Outline



Double vortex cooling solution





Main characteristics:

- **Tangential oxidizer injection at the haft end**
- **Double co-spinning counter-flowing vortex**
- **Fuel injection at the head end**
- **Flame trapped in the inner vortex**

Disadvantages

- **Slightly I_{sp} reduction**

Advantages

- **Reduced chamber dimension**
- **Cost reduction**
  - **Standard materials**
  - **3D printable**

Design philosophy

Variable to be investigated:

- **Chamber length**
- **Chamber diameter**
- **Nozzle throat**
- **Oxidizer injection velocity**
- **Oxidizer split injection**
- **Fuel injection position**
- **Fuel atomization**
- **Head end geometry**
- **Nozzle-combustion chamber interface geometry**
- **L/D (derived)**
- **CR (derived)**
- **L* combustion chamber characteristic length (derived)**
- **SN_g geometrical swirl number (derived)**

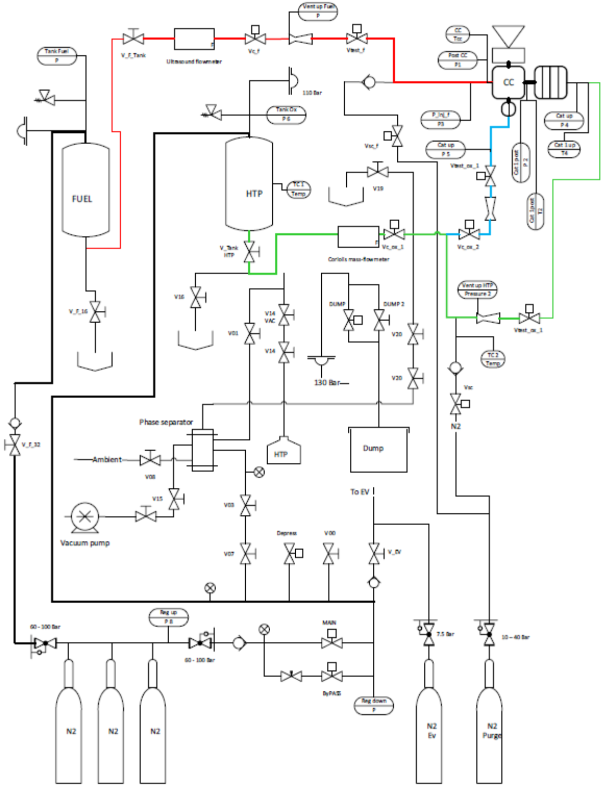
→

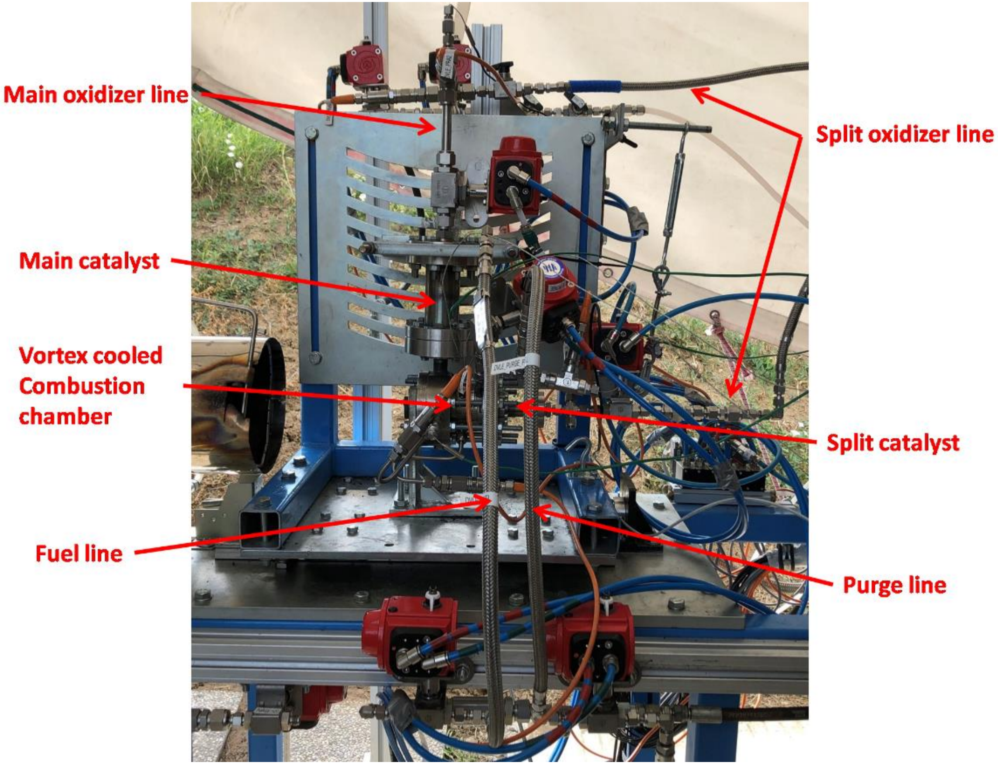
Main engine characteristics:

- **Modular**
- **Cost reduction**
  - **Standard materials: AISI 316 L**
  - **Components reduction**
  - **3D printing fuel injectors**

$$SN_g = \frac{(R_{inj} - R_{port})R_{inj}}{NR_{inj}^2}$$

Experimental setup





Test campaign definition

Test campaigns
- I_{sp} efficiency
- Cooling capabilities

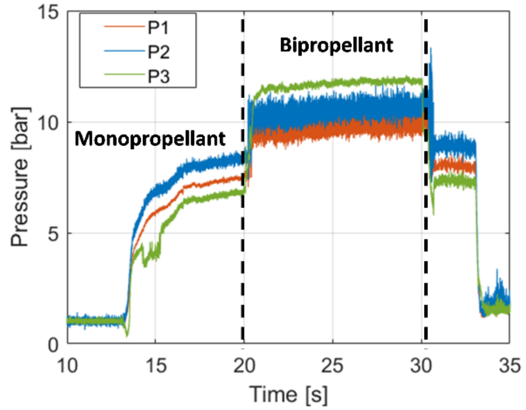
1st test campaign
- Combustion chamber size

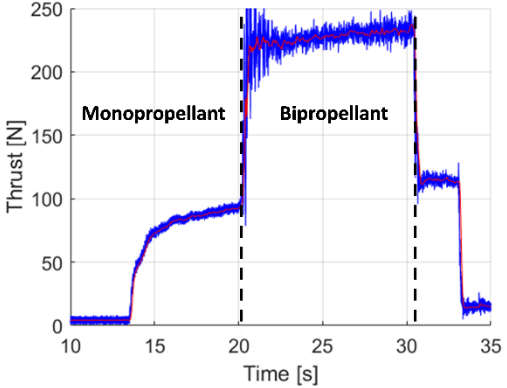
2nd test campaign
- Split oxidizer injection (With auxiliary catalyst)

$$\eta_{I_{sp}} = \frac{\frac{F}{\dot{m} g_0}}{I_{vac_{CEA}} - \varepsilon \frac{c^*_{CEA}}{g_0} \frac{P_a}{P_0}}$$

$$\eta_{c^*} = \frac{\frac{P_c A_t}{\dot{m}}}{c^*_{CEA}(P_c, OF)}$$

Fire test result



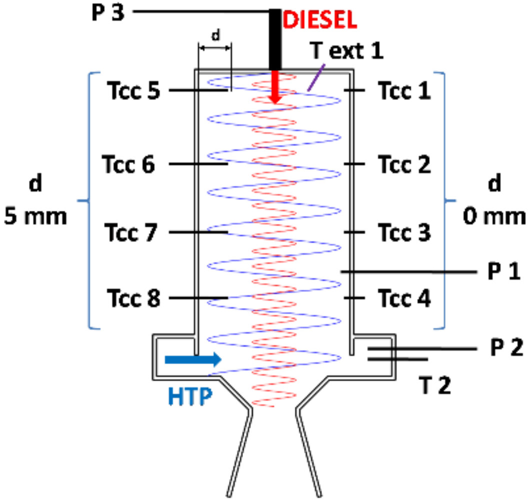


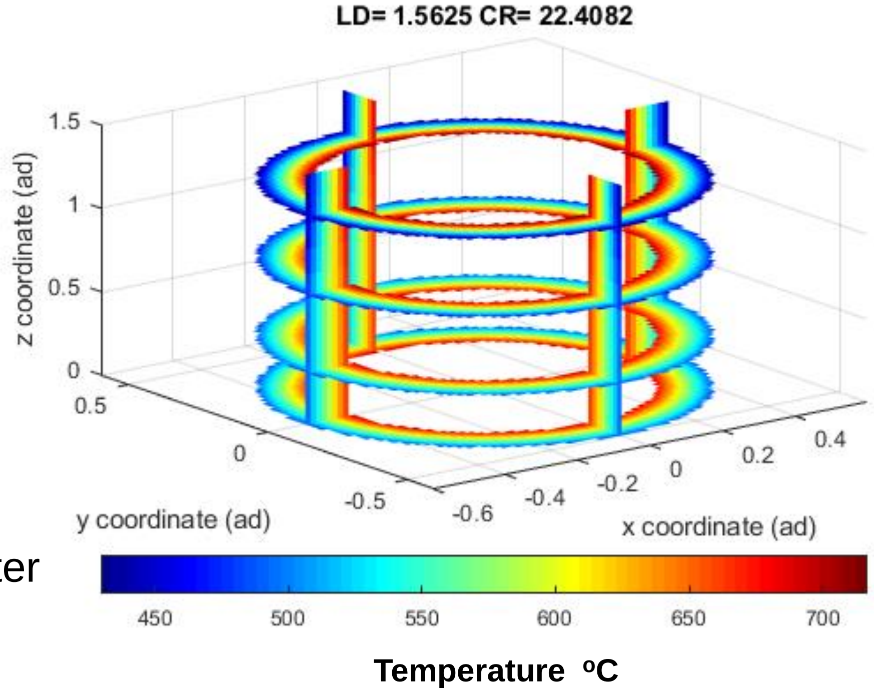
More than 100 fire tests

Testing procedure:

1) Monopropellant start up
2) Bipropellant phase
3) Monopropellant & fuel purging
4) Oxidizer purging

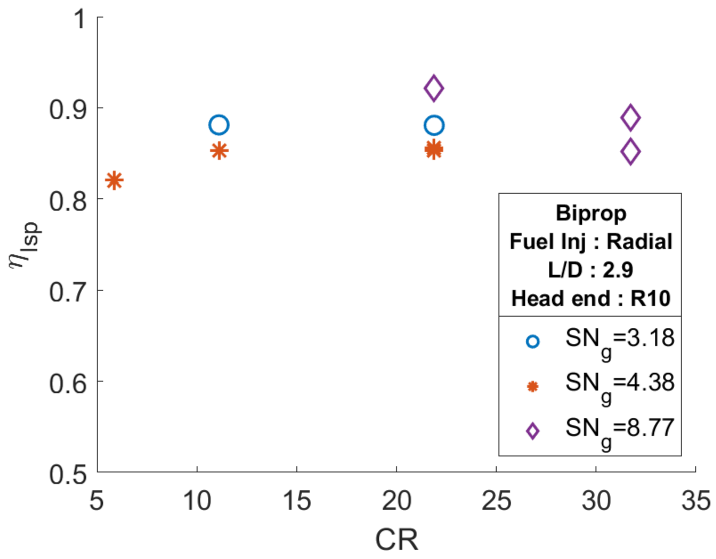
CC inner temperature

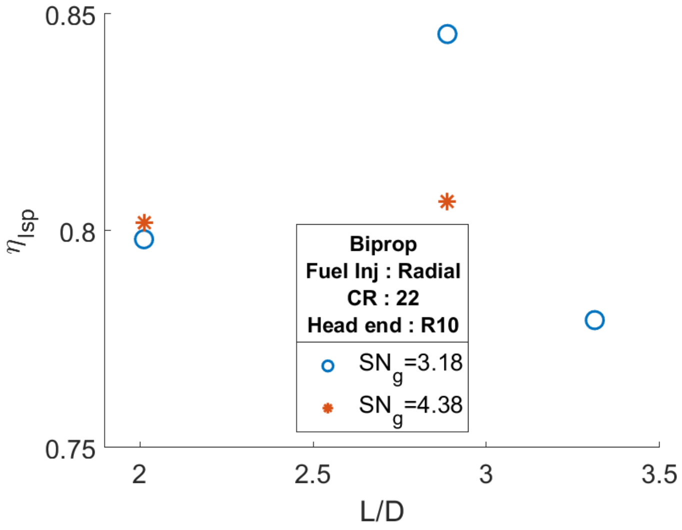




The temperature mapping proves that the outer vortex is composed by the oxidizer and the flame is therefore confined in the inner vortex

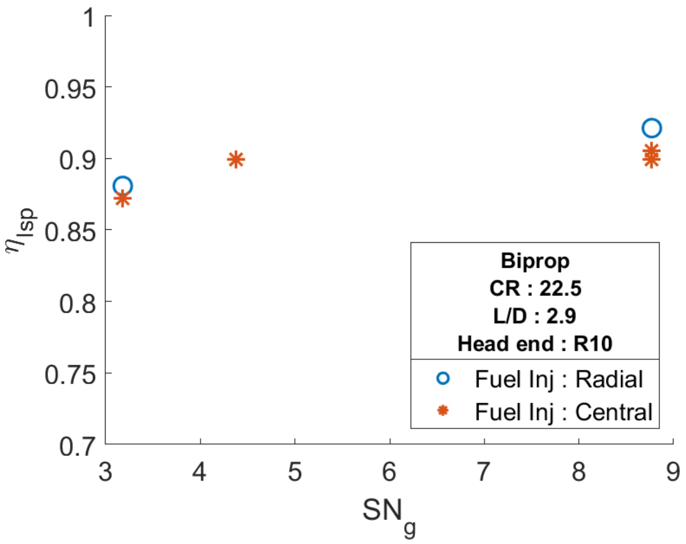
1st test campaign results-1

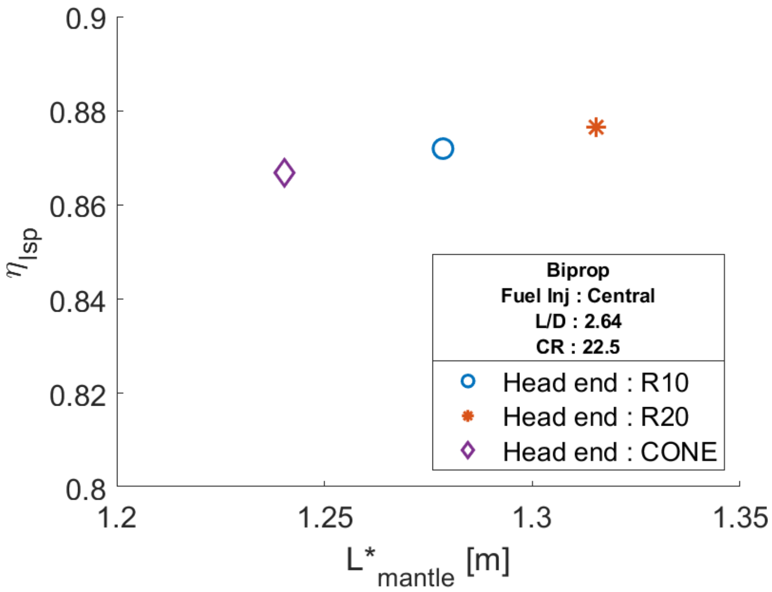




- CR between 10-20 have a quite stable I_{sp} efficiency
- There is a L/D value that maximize the I_{sp} efficiency
- For L/D > 3 the I_{sp} efficiency is reduced despite the higher L*

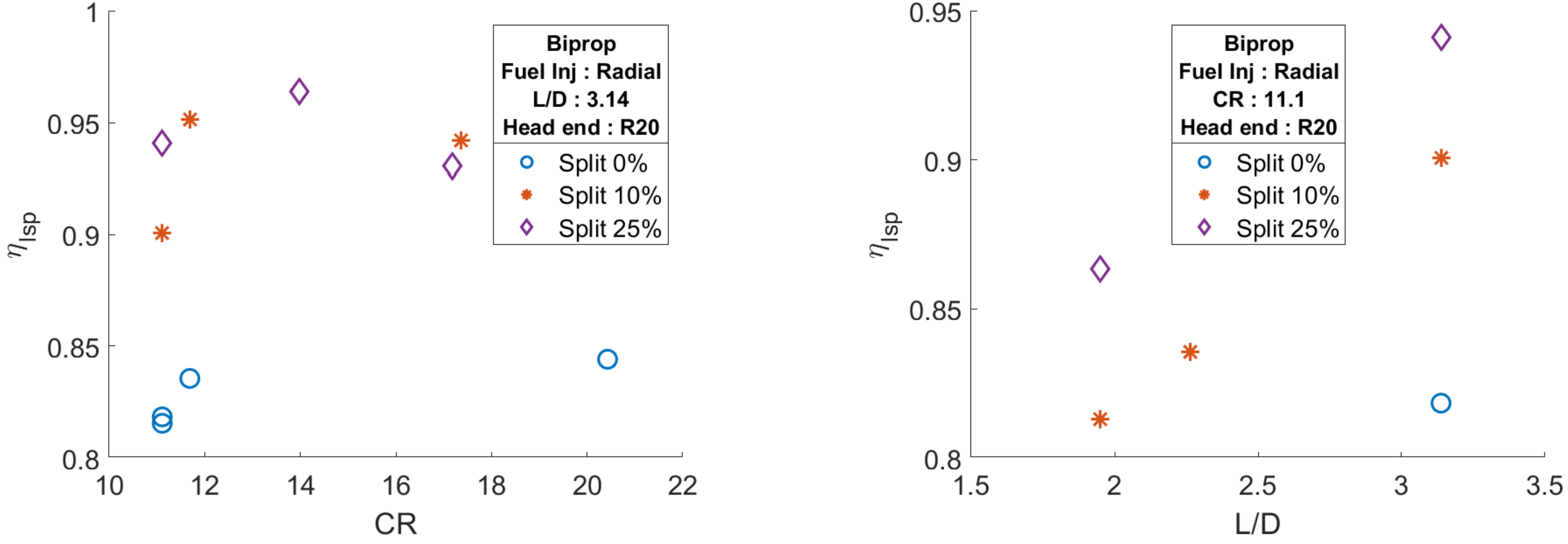
1st test campaign results-2





- Increasing the SN_g slightly affect the I_{sp} efficiency
- The influence of the head end geometries on the combustion behaviour is negligible

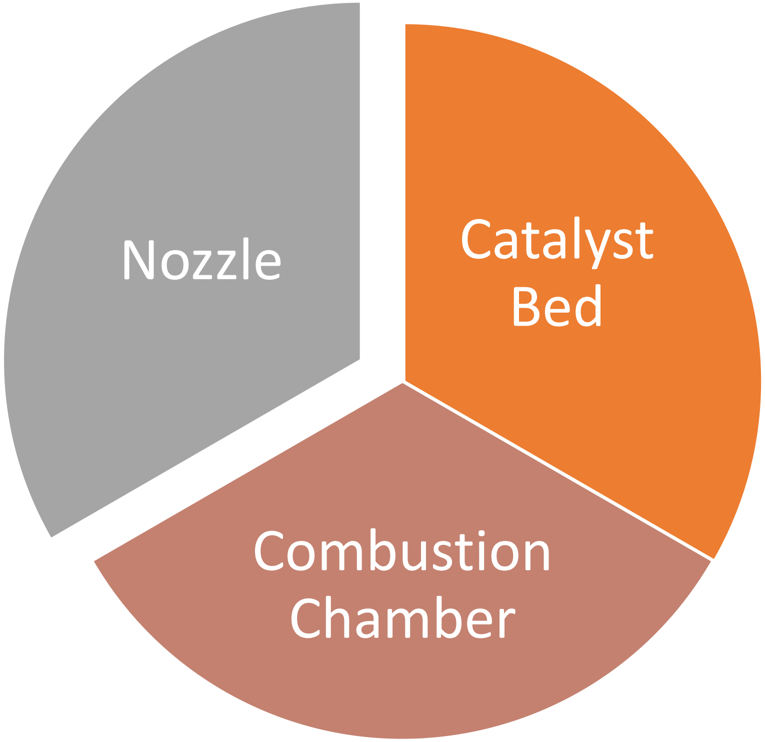
2nd test campaign results



- The presence of a split oxidizer injection deeply affects the I_{sp} efficiency
- Higher I_{sp} efficiency obtained with 25% split injection

M. Santi, M. Fagherazzi, F. Barato, D. Pavarin, *Design and testing of a hydrogen peroxide bipropellant thruster,* AIAA Propulsion and Energy 2020 Forum

Outline

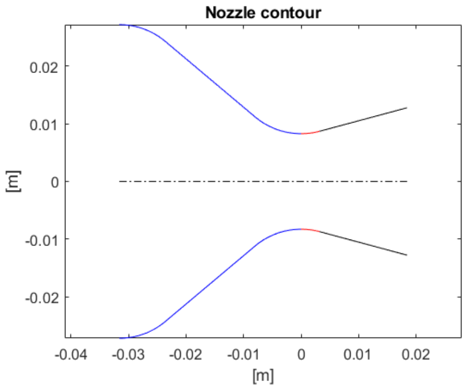


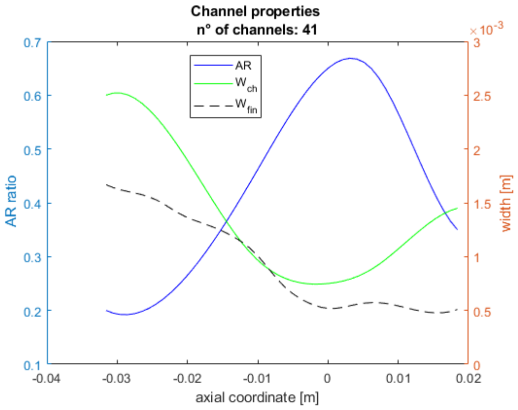
CN design

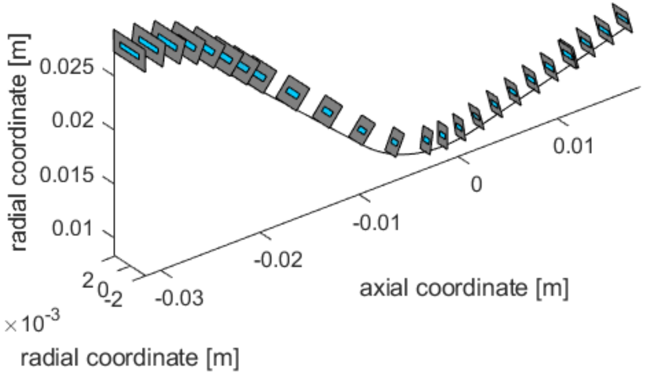
Coolant fluid: Hydrogen peroxide

1-D modeling
3 D printing

Input:

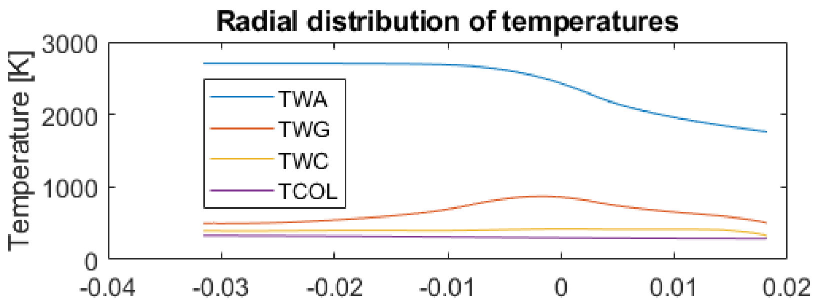


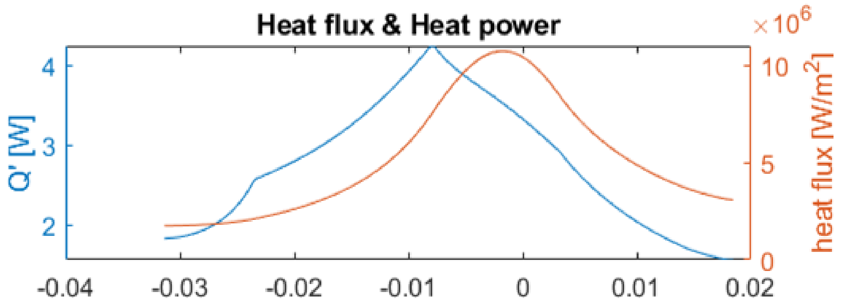


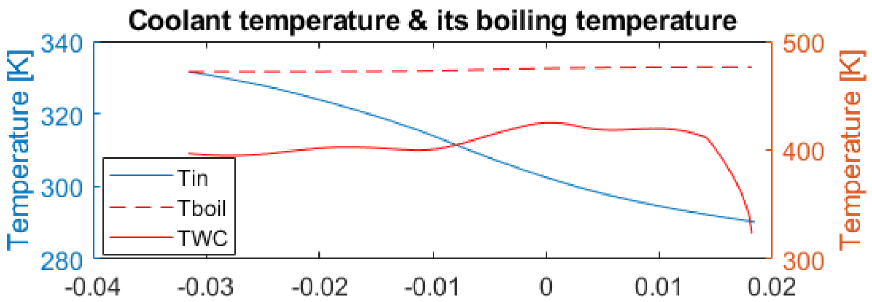


Cooling nozzle modeling

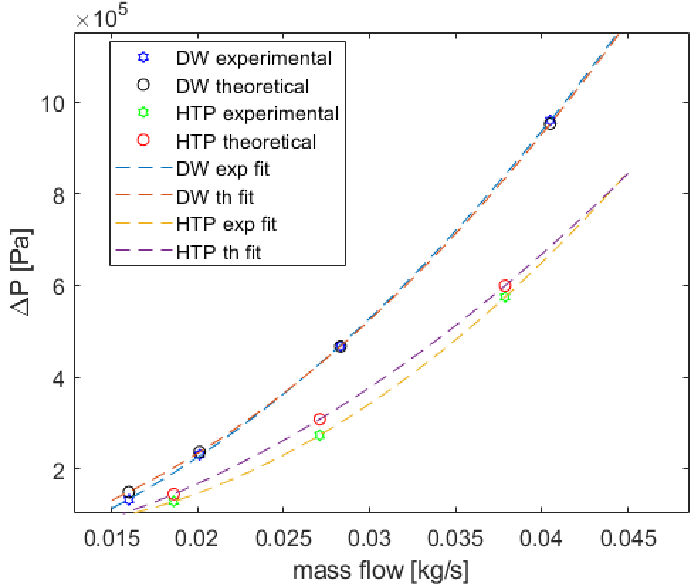
Output:







Leakage verification



Outline

Outline:

Conclusions

- *A 450N bipropellant thruster based on highly stabilized HTP concentrated from commercial feedstock and standard automotive diesel has been designed and tested*
- *The combustion chamber features a double vortex cooling solution*
- *Two test campaigns have been carried on to study the influence of several engine parameters on the propulsive efficiency*
- *The presence of the oxidizer outer shell has been demonstrated*
- *The potential cooling capabilities are confirmed*
- *An I_{sp} efficiency of 96% has been reached for a split injection of 25%*

Conclusions

- *A 10N monopropellant thruster based on highly stabilized HTP concentrated from commercial feedstock has been designed and tested*
- *The modeling capabilities has been upgraded*
- *Saturation level due to poisoning has been calculated*

Conclusions

- *A regenerative cooling nozzle 3D printed in Inconel has been designed*
- *Troubleshooting has been done on the manufacturing process*
- *A series of characterization tests has been planed with monopropellant and bipropellant, with axial and swirled flow*

Thanks for the attention

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