

Development and Testing of HTP Monopropellant Thruster for Space Applications

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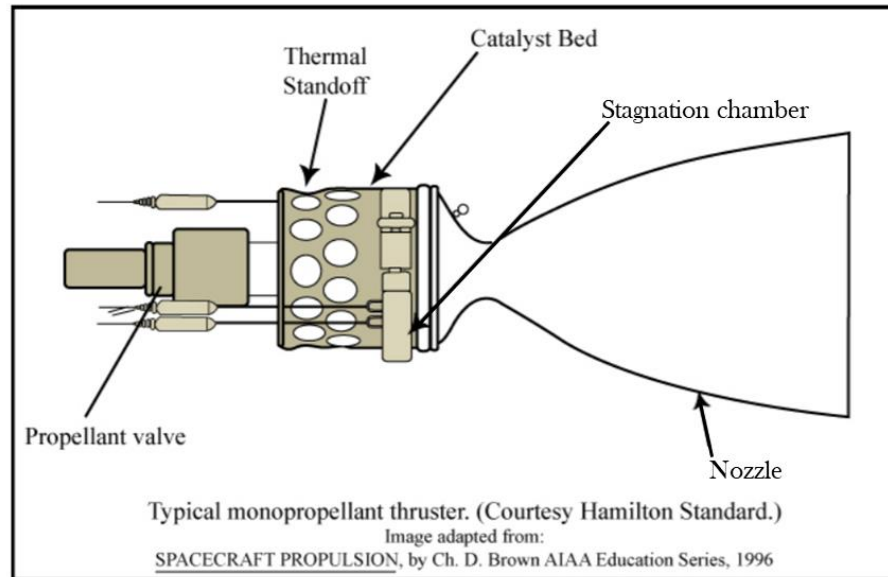
Centro di Ateneo degli Studi e Attivita Spaziali "Giuseppe Colombo"



February 25th 2022



Introduction to Monopropellant Thrusters



- Single propellant flows through a catalyst bed
- Exothermal decomposition of the propellant creates hot gas mixture
- The decomposition products are exhausted through the nozzle to obtain thrust
- Conventional propellant – Hydrazine (N_2H_4)

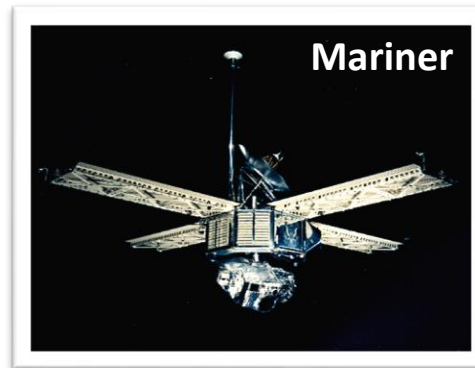


Main Characteristics & Applications

- Relatively low decomposition temperature $\approx 760^{\circ}\text{C}$
- No thermal protection
 - \Rightarrow **Simple motor structure**
- Stop and restart capability
 - \Rightarrow **Operational versatility**



RCS for micro-launcher
upper stage

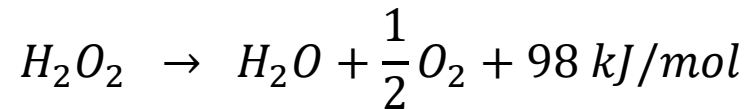


Satellites or space vehicles
maneuvering and de-orbiting



Why HTP?

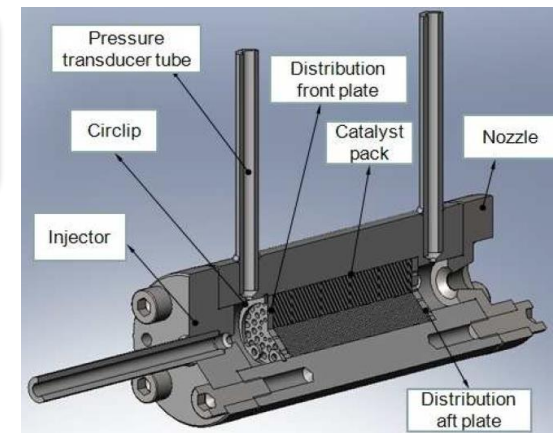
HTP (High Test Peroxide), concentration > 80%



- “Green” propellant, reduced pollution and toxicity
 - Safety during handling, manufacturing and testing
 - Storable at room temperature
- ⇒ **Low operative cost**

- High volumetric specific impulse
- ⇒ **Compatible for space applications**

In this research, the goal is to improve TRL of HTP monopropellant thruster



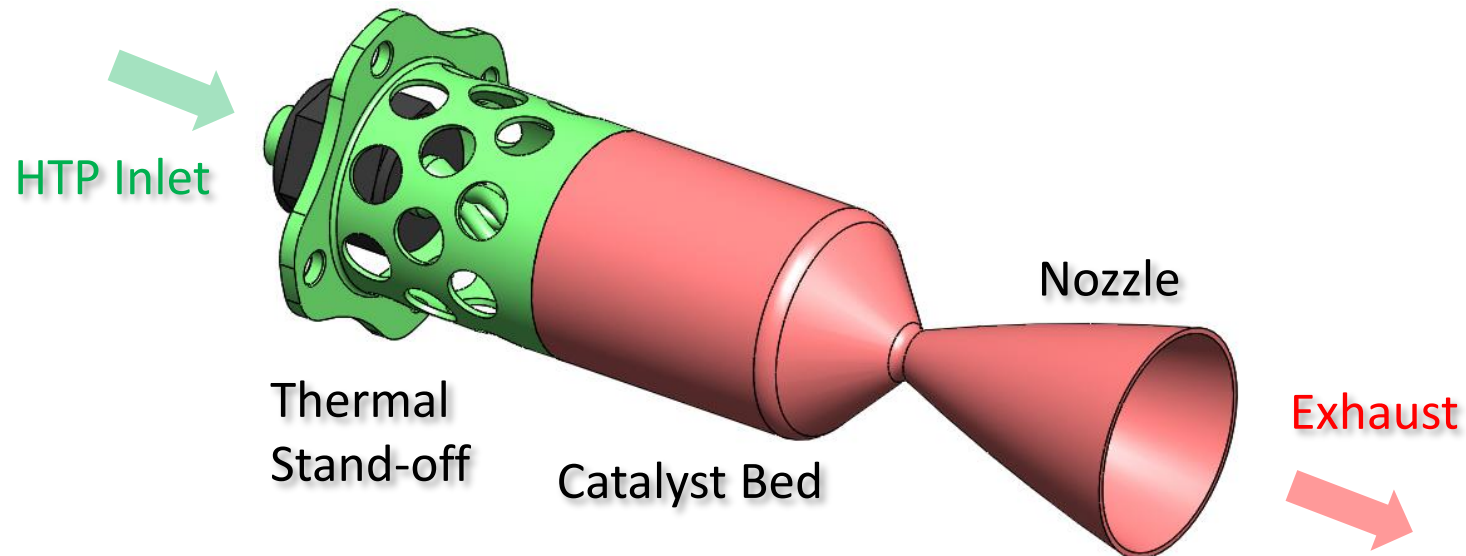
Review

- **Thruster design**
 - CFD investigation of channeling phenomena
 - Thermal analysis of the nozzle
 - Structural analysis
- **Fire test campaign**
 - 4 thruster configurations
 - Over 500 ignitions
 - Various working points – 3 ÷ 30[N]
 - Pulses and continuous operation up to 100sec
- **Cold flow tests**
 - Cavitating venturi characterization
 - Injector characterization
- **Propulsion system design considerations**
 - Priming method
 - Pressure build-up due to HTP decomposition in tank

Thruster Design

Main Characteristics:

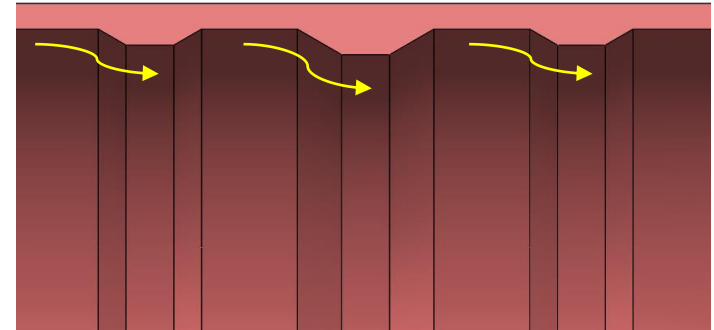
- Additive Manufacturing (3D print)
- Minimum Components
- Weight Optimization < 100 gr
- Multiple Configurations



Anti-Channeling Feature

Channeling:

- By-pass of liquid HTP near the wall
- Decomposition efficiency is decreased

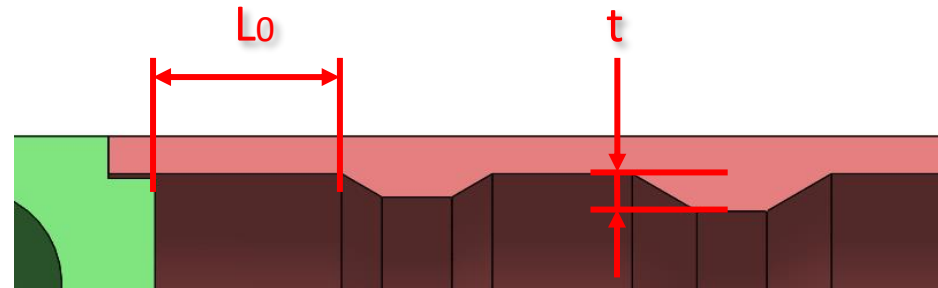


Suggested Solution:

- Disturbance to the near-wall flow
- Preventing a by-pass flow
- Directing the fluid through the bulk catalyst
- CFD investigation leads to selected design

Anti-Channeling Feature

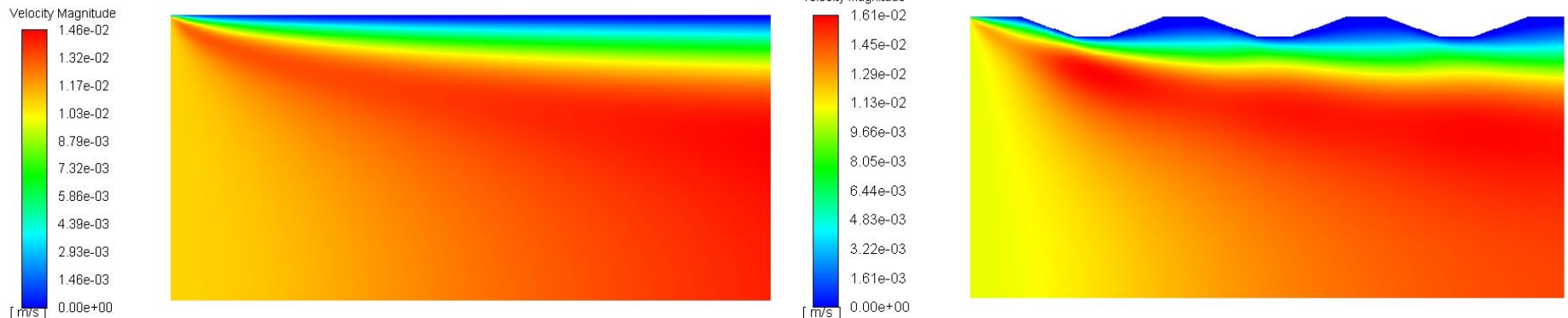
- 2D RANS Simulation
- Axisymmetric Model
- Steady-State
- Fluid: Liquid HTP
- Laminar Flow



n = number of disturbances

Results:

- Boundary layer thickness increase
- Outlet mass flow at 1mm distance from the wall decrease $\approx 40\%$

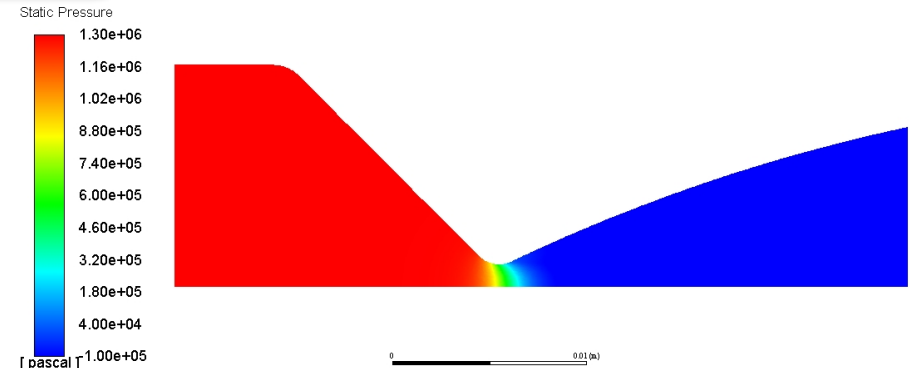
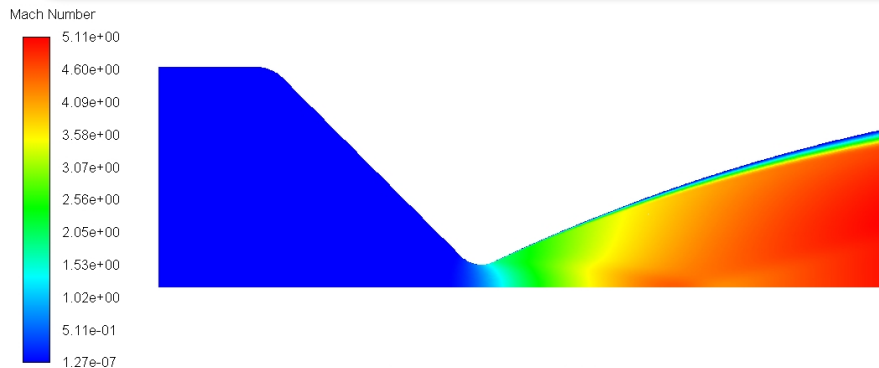
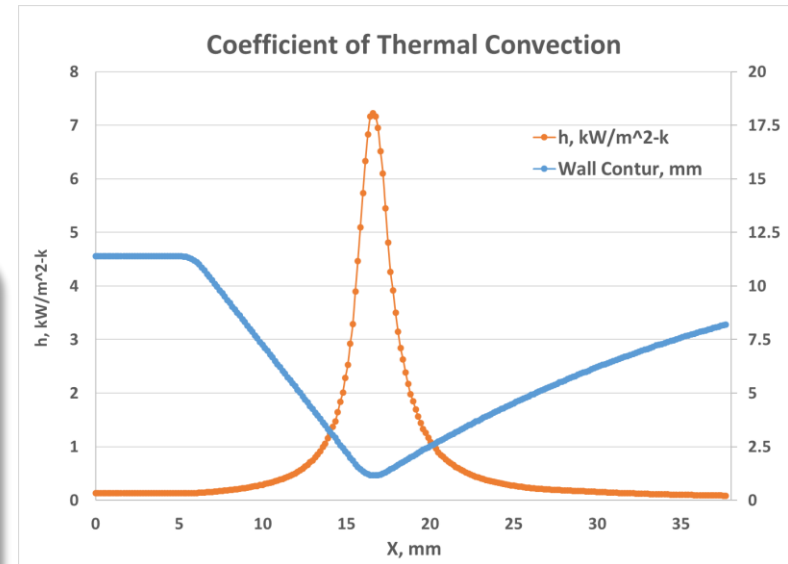


Nozzle Thermal Analysis

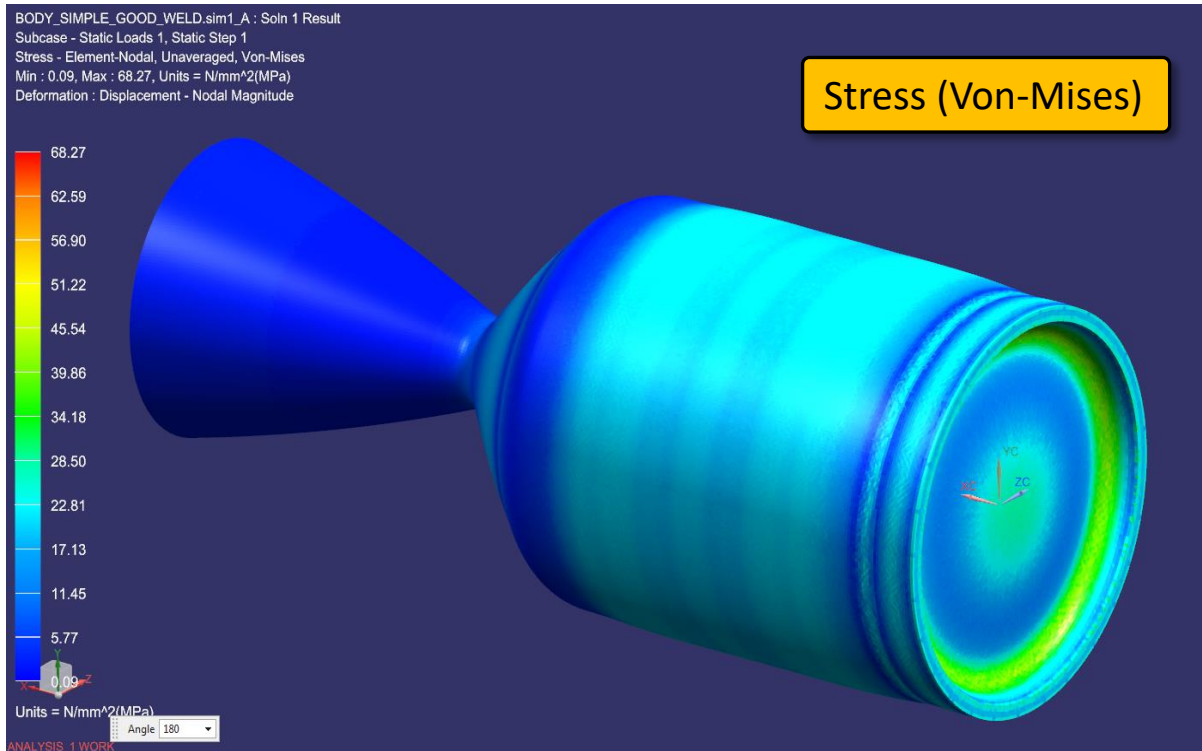
- 2D RANS Simulation
- Steady-State
- Fluid: HTP decomposition products

Results:

- Evaluation of Convection Rate $\approx 2.4 \text{ W/cm}^2$
- Coefficient Of Thermal Convection
- Low Temperature Gradient at the wall $< 5^\circ\text{C}$
- Low Thermal Stress



Structural Analysis



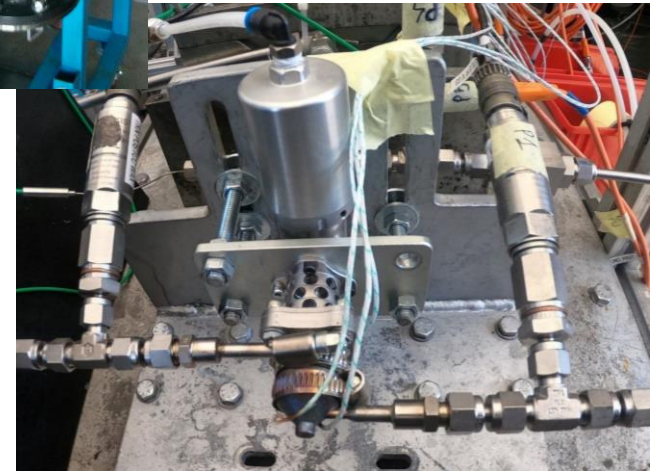
- Load Case: Max. Internal Pressure
- High Safety Factor

Test Campaign

Equipped Test Facility

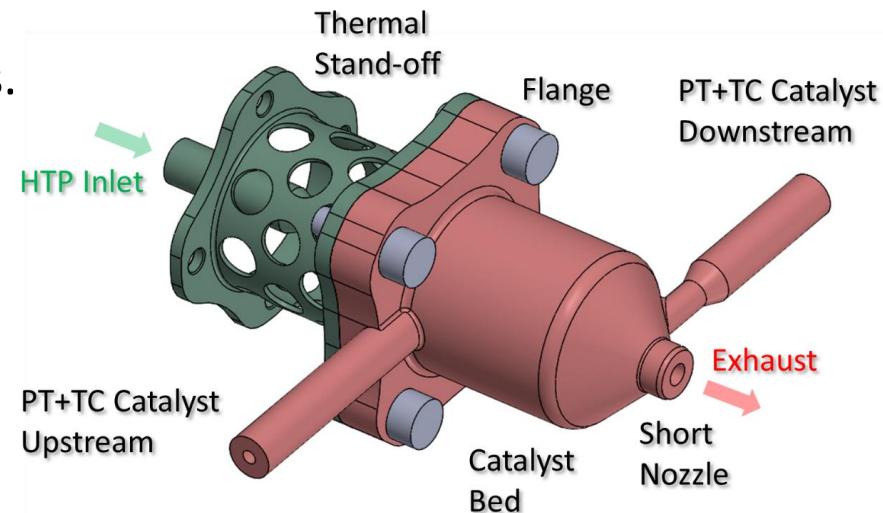
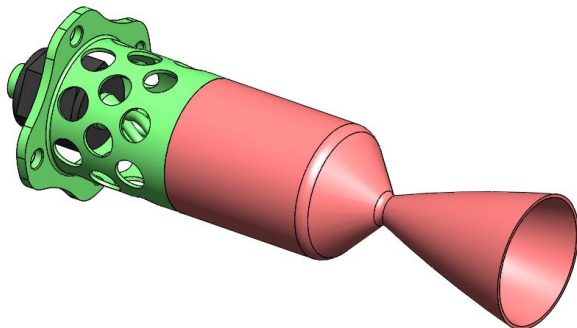


Test Bed



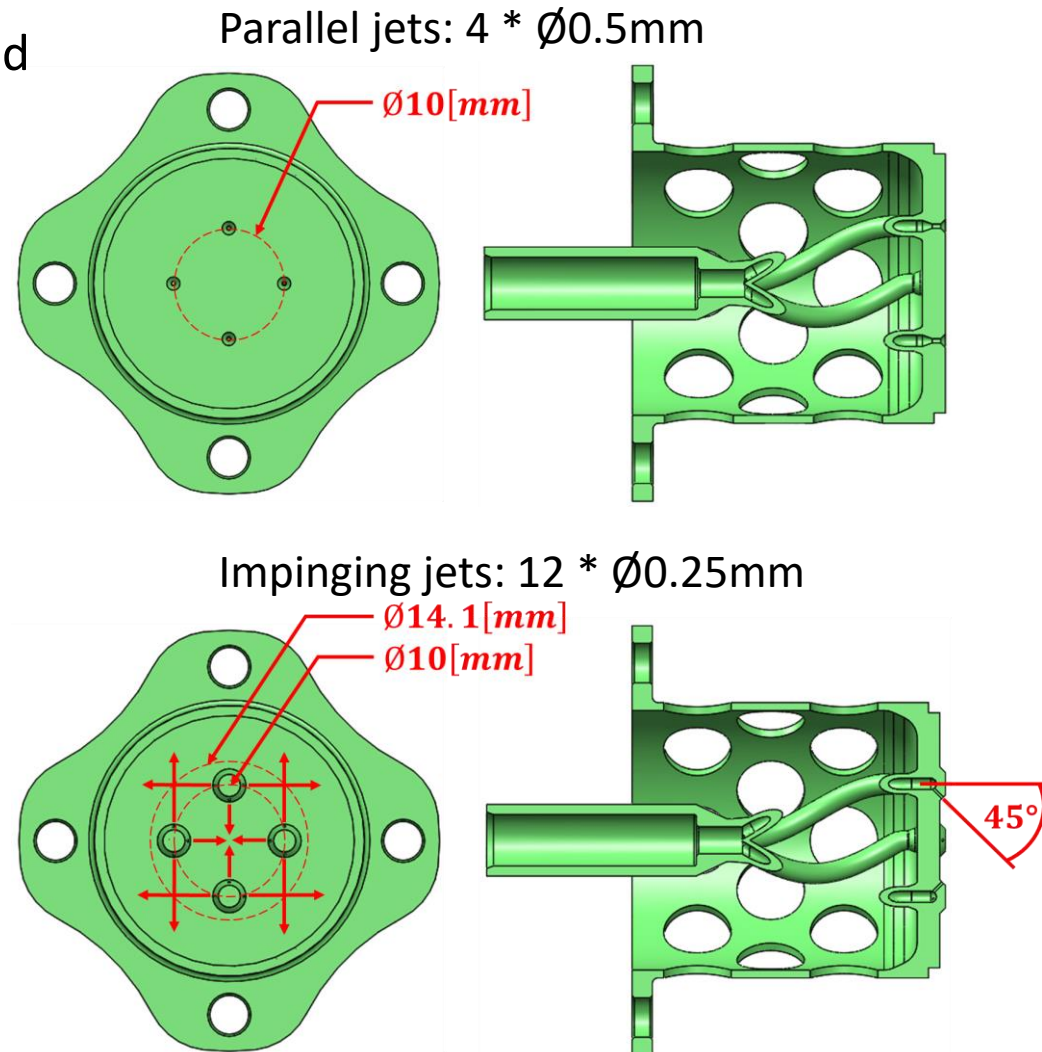
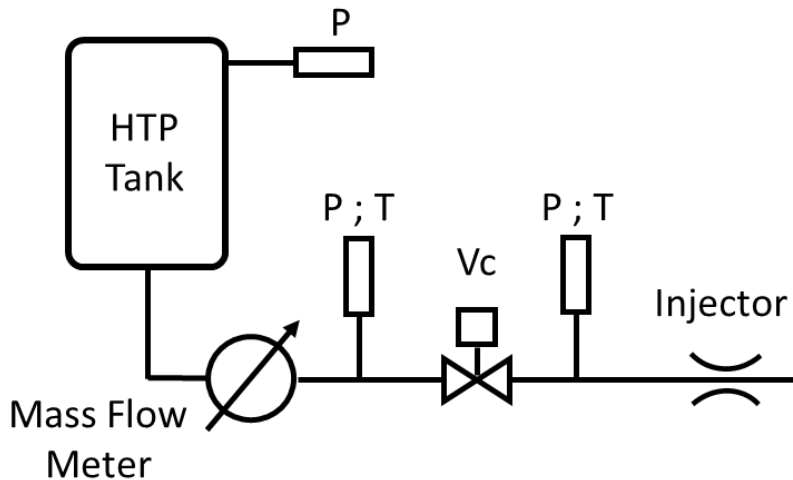
Thruster Design Modifications For Testing

- The Thruster can be assembled in **different configurations for parametric investigation**, for example different injector type, as part of experimental campaign.
- The body can be disassemble after firing test for catalyst bed examination.
- Activation by **test valve**, not optimized for size, weight and performance.
- Ports for pressure & temperature **measurements**.
- **Short nozzle**, to be used in ground tests.



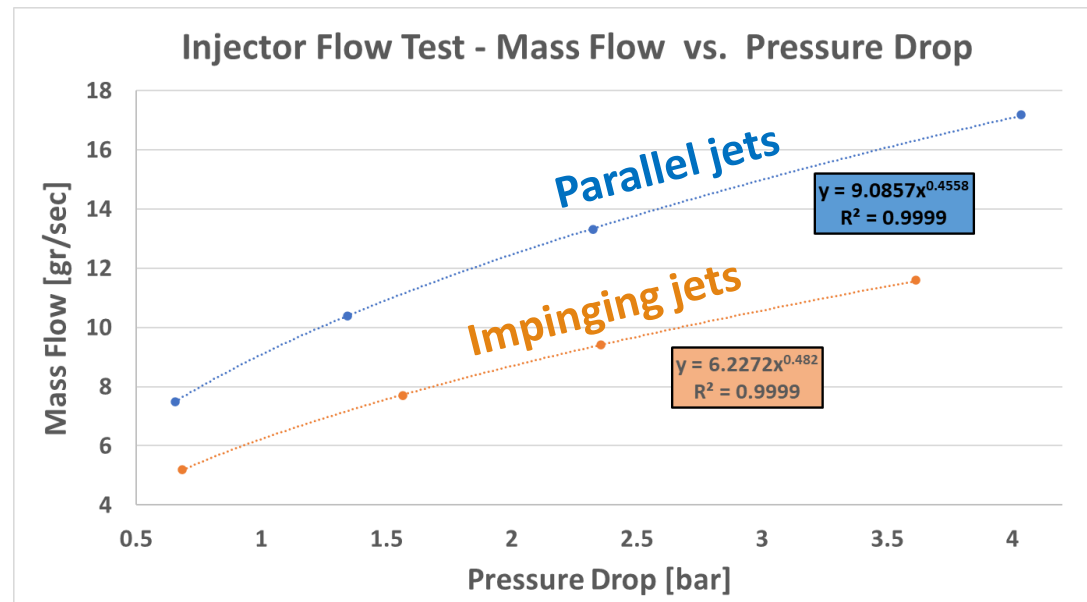
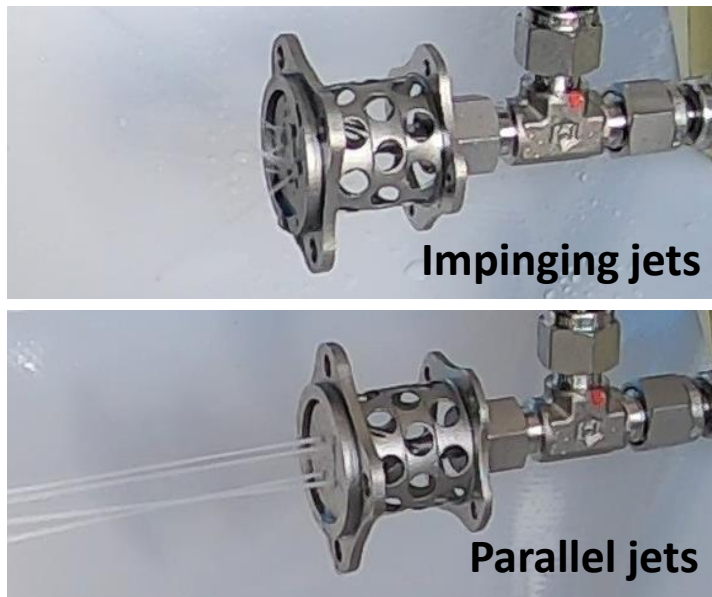
Injector Cold Flow Test

- Two injection patterns are tested
- HTP mass flow up to 17gr/sec
- Measurements:
 - HTP Mass Flow
 - Pressure drop
 - Jet shape evaluation



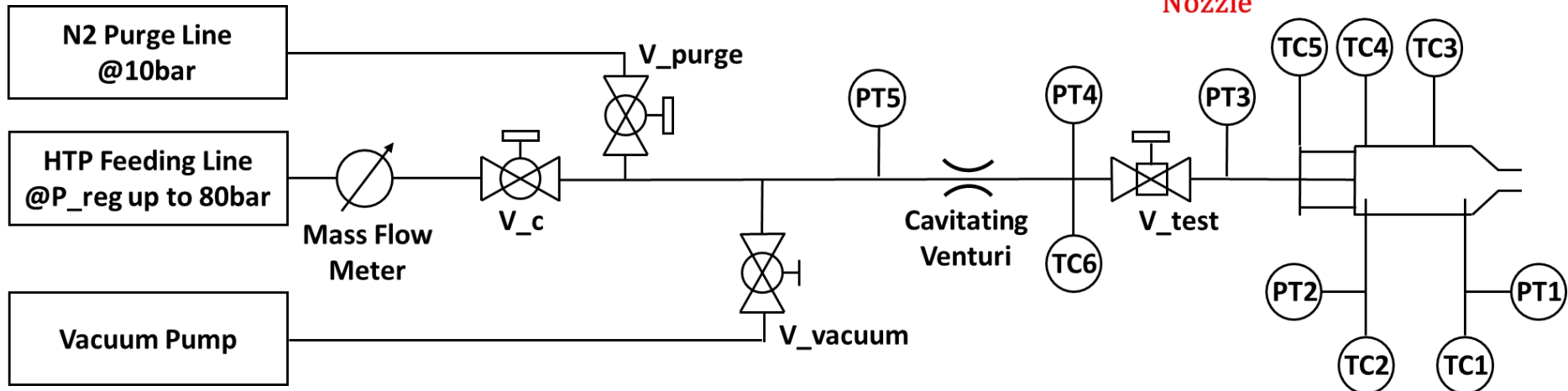
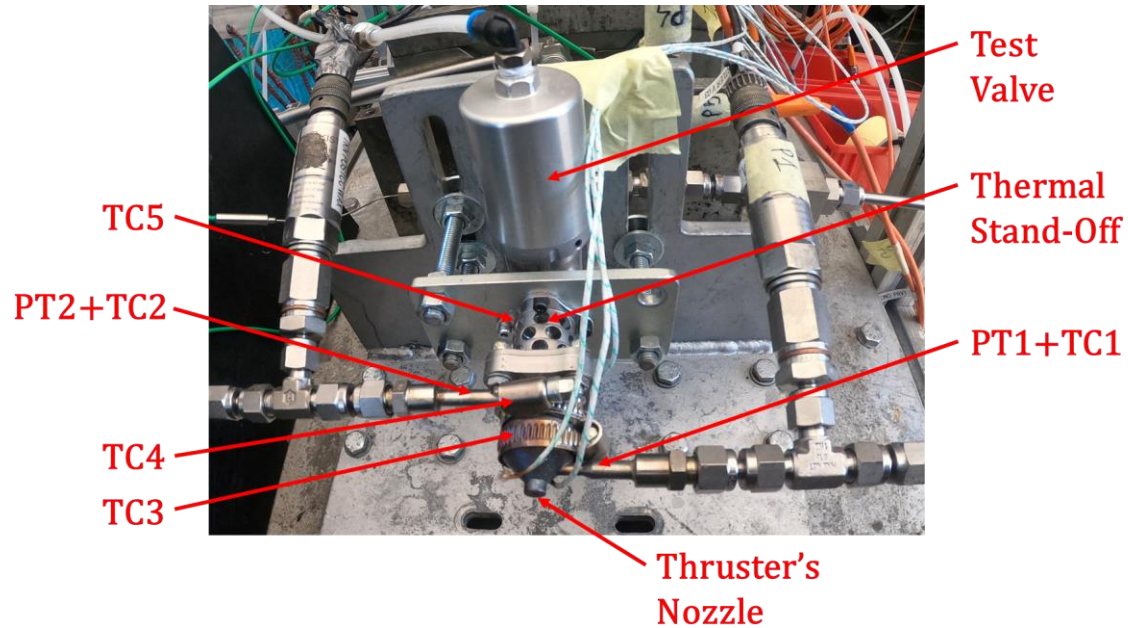
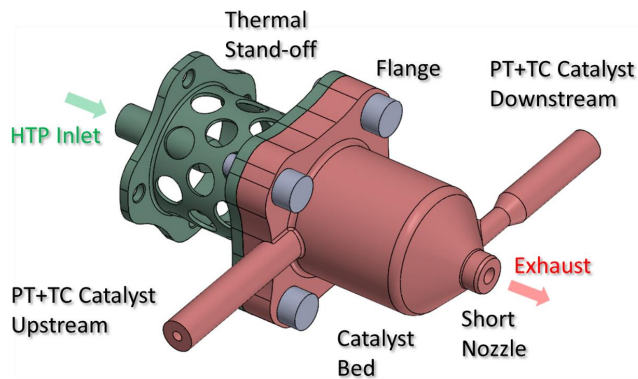
Injector Cold Flow Test - Results

- $\dot{m} = A_{inj} \cdot C_d \sqrt{2\rho\Delta P}$ (\rightarrow for same injector geometry $\dot{m} \propto \sqrt{\Delta P}$)
- Pressure drop is lower with parallel jets injection
- Parallel jets injection provides higher impact velocity with the catalyst which contribute to HTP reaction
- Impinging jets injection provides better atomization, increasing contact area of HTP with the catalyst



Fire Test Set-Up and Measurements

**HTP concentration
in tests 91%**



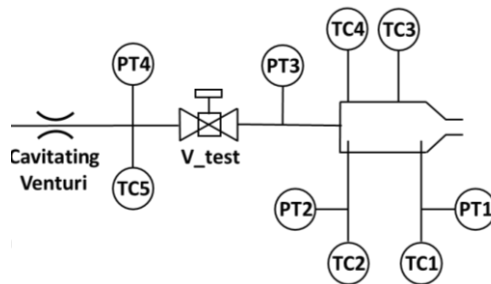
Test Results - Example

continuous operation:

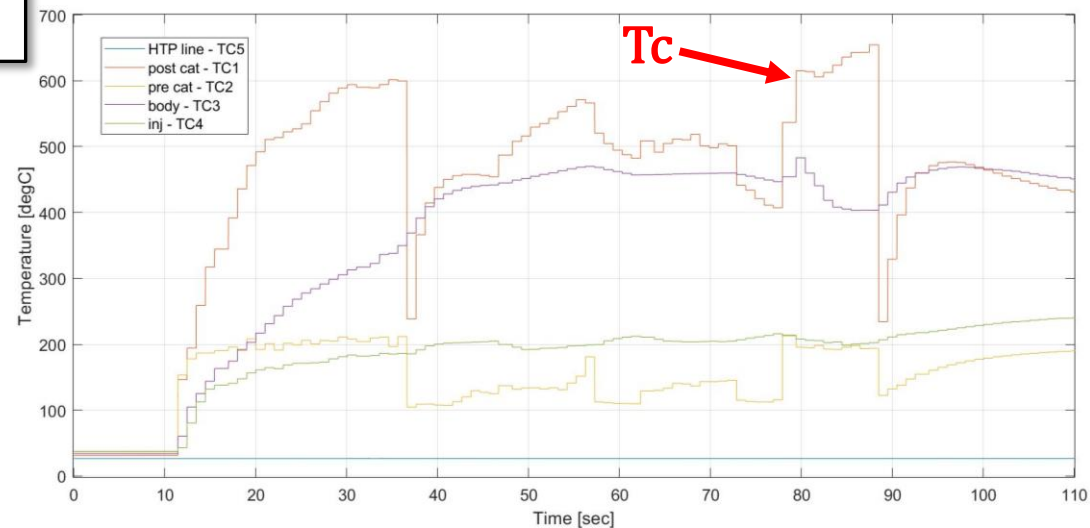
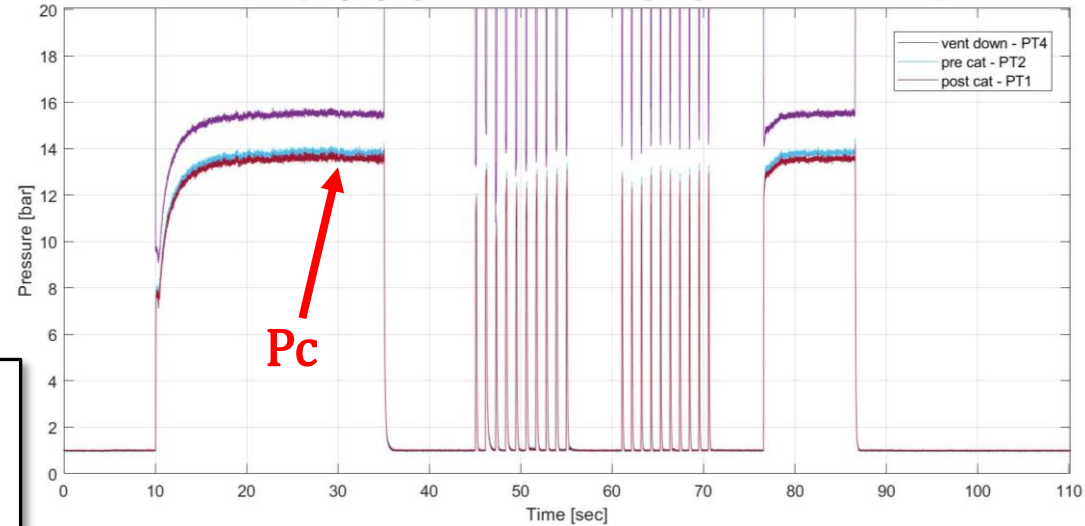
- Cold-start 25[sec]
- hot-start 10[sec]

Pulses:

- {125[msec] ON – 1[sec] OFF} * 10
- {75[msec] ON – 1[sec] OFF} * 10



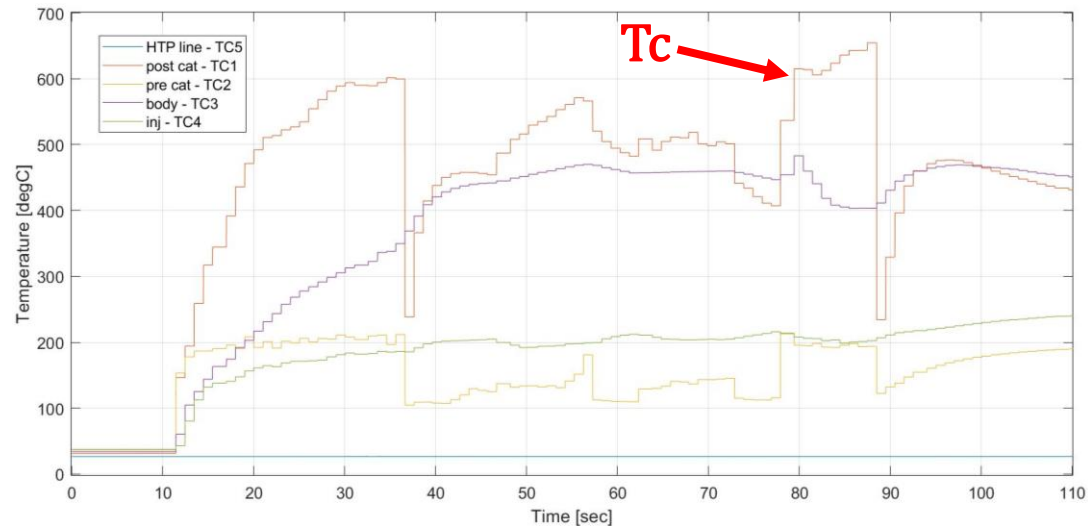
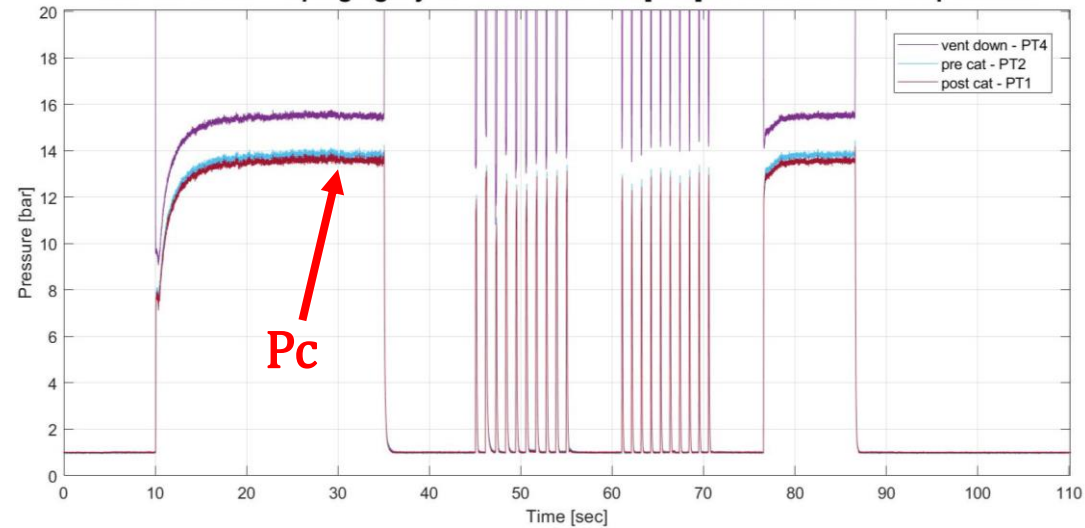
HTP Thruster - Impinging Inj. & Throat Dia. 2.32[mm] - Pressure and Temperature



Performance Evaluation

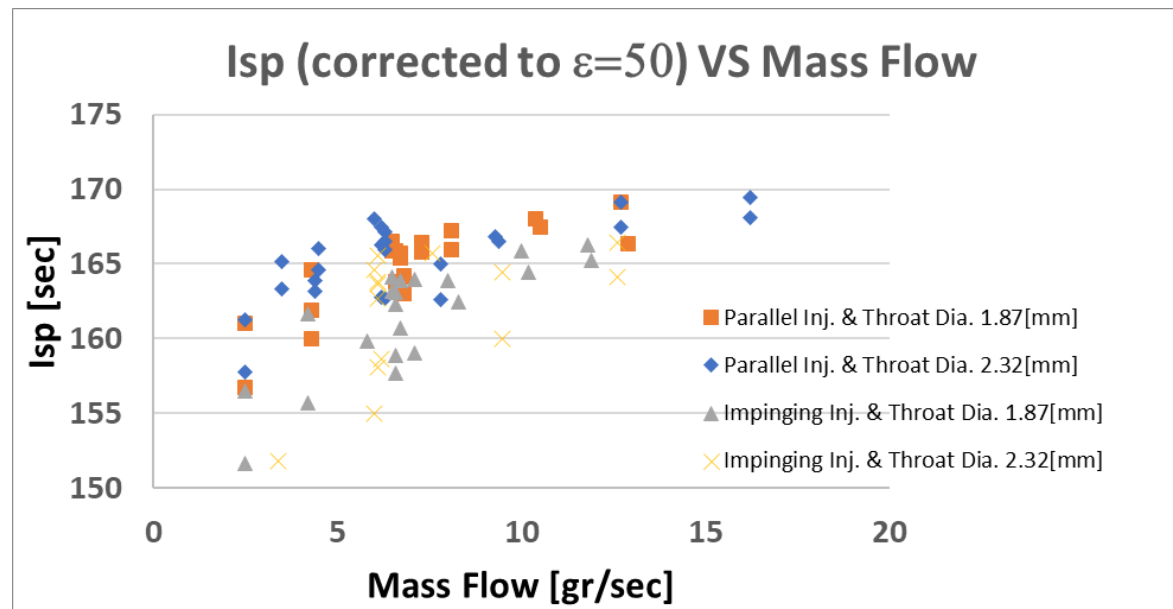
Mass Flow	6.1 [gr/sec]
P_c	13.6 [bar]
$T_{c,max}$	655°C
ΔP_{cat}	0.3 [bar]
ΔP_{inj}	1.4 [bar]
C^*_{exp}	939 [m/s]
η_{c^*}	99.2%
I_{sp} (vacuum, $\epsilon = 100$)	169 [sec]
Rise Time 70%Pss @Cold-start	820 [msec]
Rise Time 70%Pss @Hot-start	21 [msec]
Decay Time 10%Pss	> 200 [msec]

HTP Thruster - Impinging Inj. & Throat Dia. 2.32[mm] - Pressure and Temperature



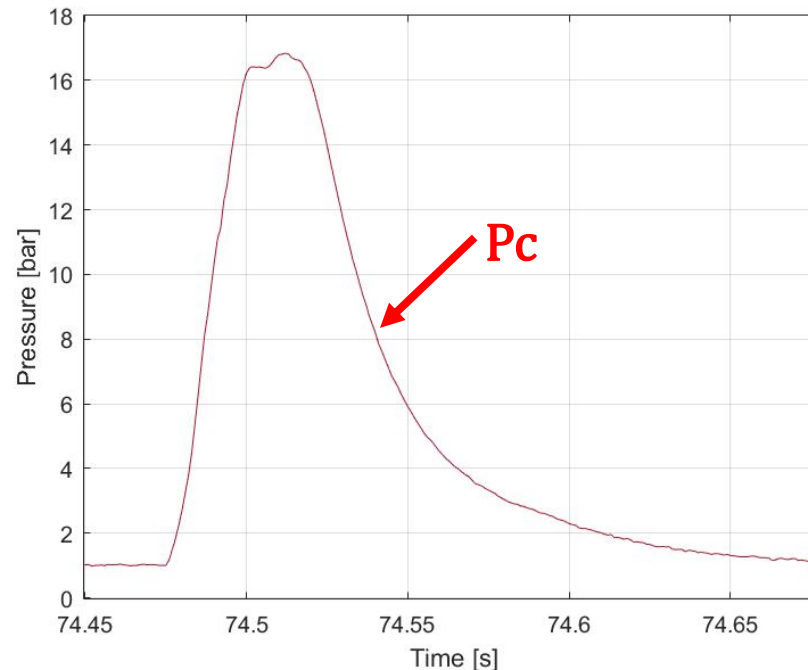
Exploring Various Working Points

- Thruster compatibility to Blowdown mode operation was successfully tested by varying working point
- Stable operation at wide range of thrust, from 3[N] to 30[N]
- Specific impulse decrease for very low thrust
- Parallel injection provides better efficiency



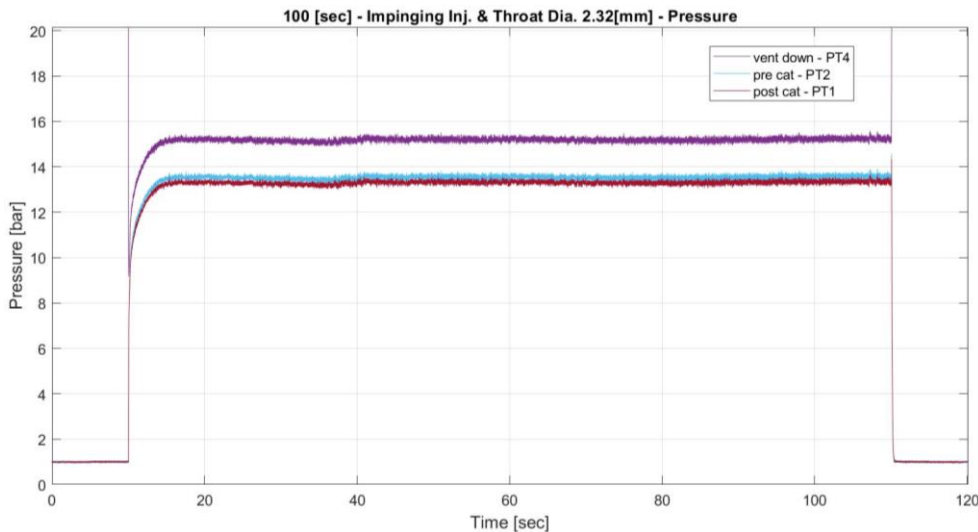
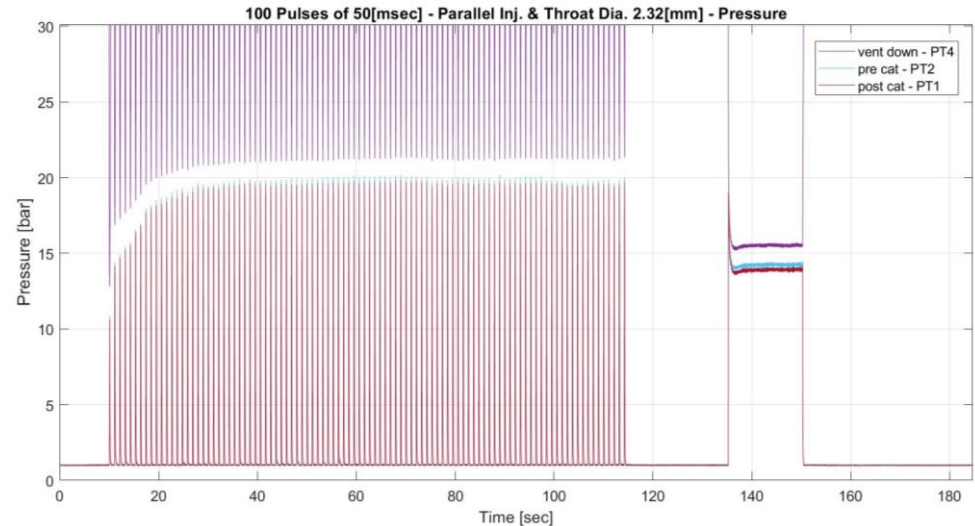
Minimum Impulse Bit

- Some applications, like precise attitude control, require the ability of the thruster to provide small amount of energy
- Evaluation according to minimal pulse tested of 45[msec]: **MIB = 0.8 [N-s]**



Test Results – Extended Mode Operation

- 100 Pulses of 75[msec] and then continuous operation 15[sec] – **successfully tested**



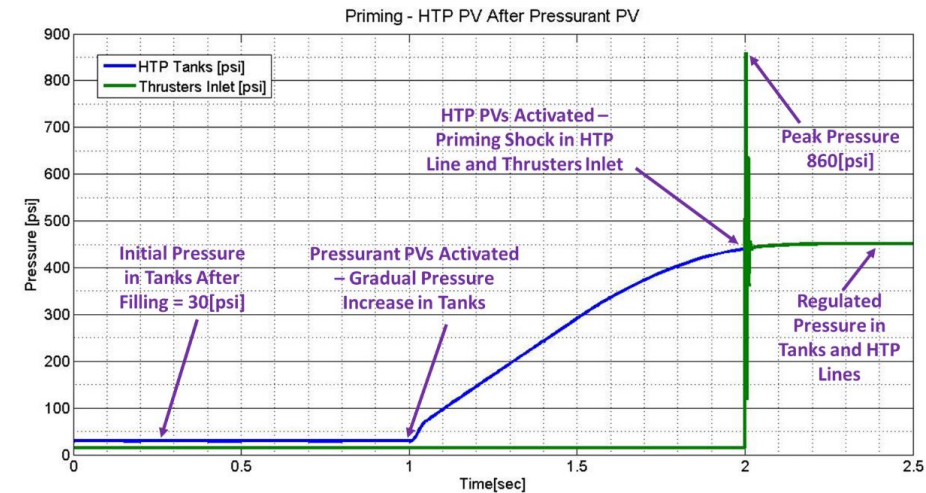
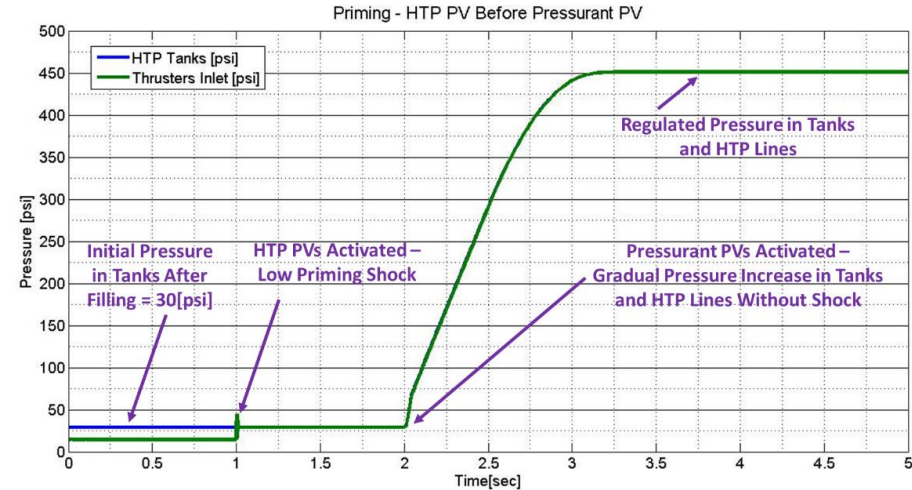
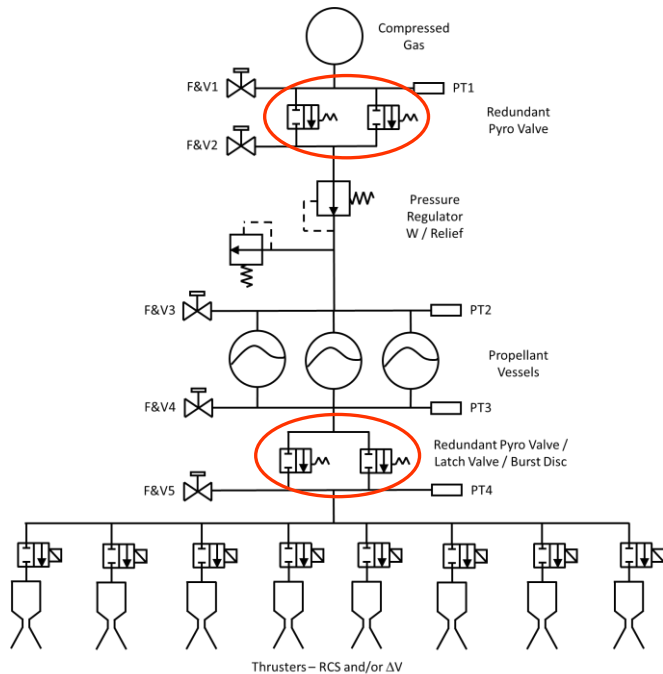
- 100 [sec] continuous operation – **successfully tested** with all thruster's configurations

Propulsion System Design Considerations

- Propulsion system design based on HTP thrusters
- Modeling of system components with commercial software
- **Simulations were done for different cases and requirements, using thruster performance from fire tests**
- Useful tool for system optimization:
 - Priming method investigation
 - Pressure drop in feeding lines
 - HTP mass flow at different working points

Priming Method Investigation

- System priming includes 2 actions:
 - Filling the HTP lines
 - Pressurization
- Investigation shows **that filling HTP lines before pressurization** reduces hydraulic shock significantly



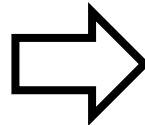
Modeling of HTP Decomposition in Tank

Motivation:

- **Safety** – Prediction of pressure rise in the tank as a function of HTP decomposition rate
- **Performance** – Evaluation of HTP concentration by pressure measurement

Model Inputs:

- Tank Volume and Fill fraction
- Initial HTP concentration
- Initial Pressure
- Environmental Temperature

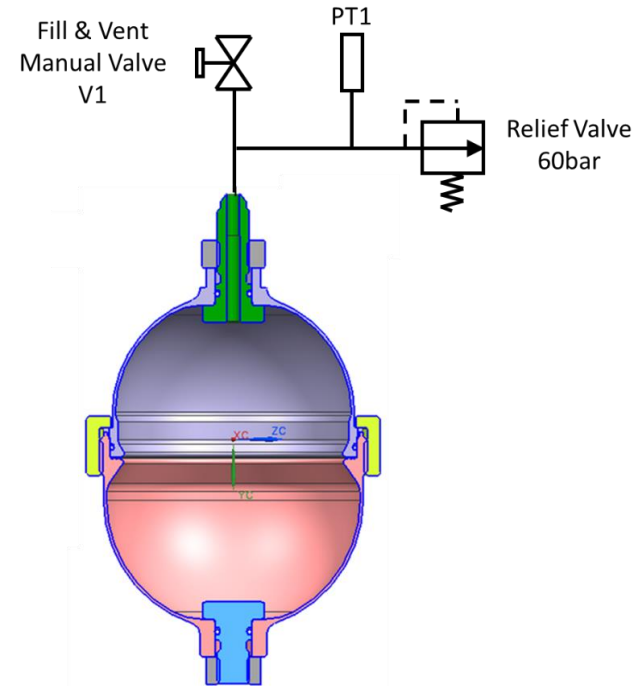


Model Outputs:

- HTP concentration and density
- Final Pressure
- Partial pressure of released oxygen
- Mass of H₂O₂ and water

HTP Decomposition in Tank – Model Validation

- Small scale Aluminum tank of 460cc
- Fill fraction: 50% / 90%
- Initial pressure: 2bar / 10bar
- Exposure time to HTP 90%wt: 1week / 1month
- **Measurement of Pressure and concentration**



- Measured pressure is compared to predicted pressure according to decomposition rate.
- **Good agreement, error < 2%.**

PhD Activity

Level	Work Package	Hours	1st Year				2nd Year				3rd Year		
1.0	Bibliographic Research	210	150	60									
1.1	State of the Art Research	70	70										
1.2	Methods of Numerical Analysis	70	40	30									
1.3	Methods of Experimental Analysis	70	40	30									
2.0	Numerical Investigation	1100	150	250	330	270	100						
2.1	Motor Design	150	100	50									
2.2	Injector Design	150	50	100									
2.3	Thermal Analysis	150		100	50								
2.4	Test Matrix	350			200	150							
2.5	Data Analysis	300			80	120	100						
3.0	Experimental Activity	850					100	350	300	100			
3.1	Experimental Set-up	250					100	150					
3.2	Test Matrix	350						150	200				
3.3	Data Analysis and Validation	150						50	100				
3.4	Experimental Correlation	100								100			
4.0	Propulsion System Design	800								200	350	250	
4.1	Definition of System Configurations	100								100			
4.2	System Modeling and Simulation	150								100	50		
4.3	Test matrix	300									300		
4.4	Data Analysis and Validation	250										250	
5.0	HTP Long Term Storability	300									100	200	
5.1	Analytical Model development	100									100		
5.2	Tests for Model Validation	150										150	
5.3	Data Analysis	50										50	
6.0	Thesis and Documentantion	500				50				50	100	100	200
	Total Hours	3760				1260				1200			1300

Thank you for your attention

Any questions?