Study and Development of Throttleable Hybrid Rocket Motors

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September 22^{nd} 2017

Throttleable Hybrid Rocket Motors

Nammo test, Spartan Project

Applications

- Launchers
- ADV
- Flying test beds

For a fixed nozzle throat, throttleability is achieved by controlling the oxidizer flow ⇒ Flow control valve (FCV)

Advantages

- Increase trajectory efficency
- Peculiar mission profiles requiring deep throttling
- Requires to control a single feeding line

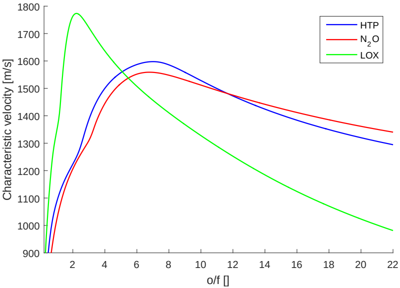
Disadvantages

- Increase system complexity
- o/f shifting

$C^\star$ Penalties

- Circular port
- Port fuel consumpion
- Marxman power law

$$o/f = \frac{\dot{m}_{ox}^{1-n}\ {D_{port}}^{2n-1}}{4^n\ \pi^{1-n}\ a\ \rho_f\ L}$$



$$n = 0.5 \ \Rightarrow no\ D_{port}\ sensitivity$$
$$n = 1 \ \Rightarrow no\ \dot{m}_{ox}\ sensitivity$$

$$n \in [0.45\ 0.8]$$

	$90\%HTP$	N_2O	LOX
Maximum c^* [m/s]	1598	1559	1773
c^* Sensitivity [m/s]	-22.4	-16.3	-369.9
c^* Penalty TR=5 (balanced)	95.3%	95.9%	96.2%
c^* Penalty TR=5 (fuel rich)	88.0%	84.5%	82.7%
c^* Penalty TR=10 (balanced)	91.6%	92.8%	93.2%
c^* Penalty TR=10 (fuel rich)	78.3%	78.5%	75.4%

Arbitrary throttling ⇒ o/f shift ⇒ Performance reduction

FCV selection

Techniques:

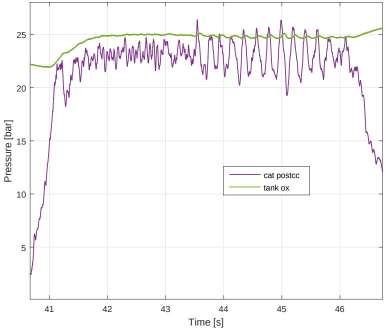
- Pure dissipative valve
- Variable area injection
- Parallel feeding lines
- Variable area cavitating venturi

For a CV:

$$\dot{m}_{ox} = C_d \; A_{th} \sqrt{2 \; \rho_{ox} \left(p^{\circ} - p_{sat}\right)}$$

Peculiarities

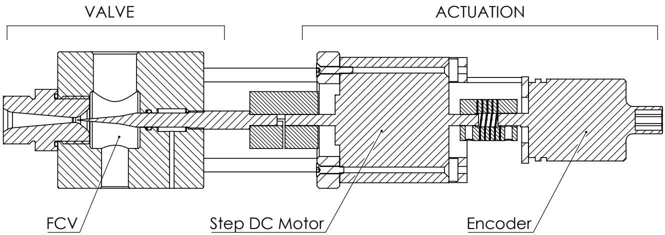
- variable area $\Rightarrow$ flow control
- if $p^{\circ}_{up} > [0.8 \; 0.9] \; p^{\circ}_{down} \Rightarrow$ tank - combustion chamber uncoupling

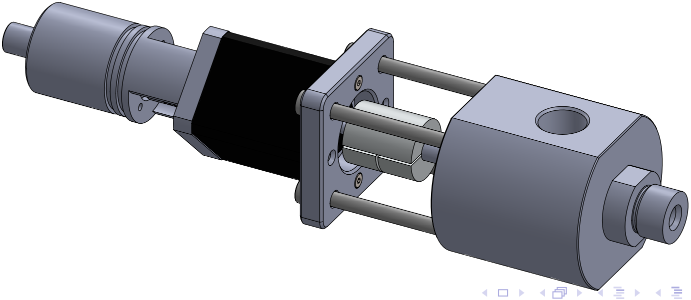


This year:

- Flow control valve design concluded
- Integration and testing
- Flow control valve characterization
- Static hybrid rocket motor fire tests

FCV: Design





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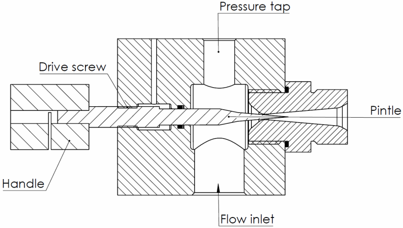
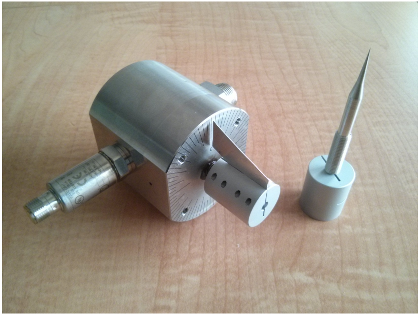


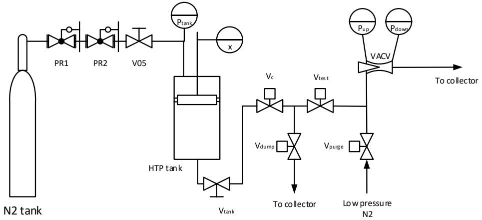
Minimum mass flow range	30 [g/s]
Maximum mass flow range	300 [g/s]
Maximum operating pressure	80 [bar]
Venturi throat diameter	2.2 [mm]
Upstream throat radius	3.3 [mm]
Venturi divergence angle	10 [deg]
Pintle apex angle	10 [deg]
Maximum pintle stroke	11 [mm]
Useful pintle stroke	7 [mm]

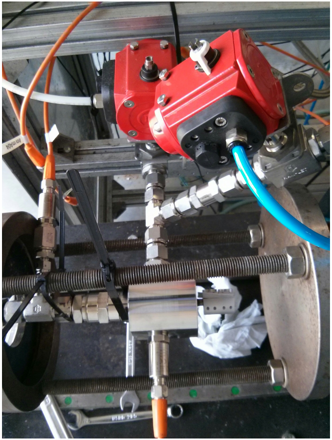
Features

- Conical pintle/spike
- Manually moved pintle
- Pressure tap for feedback



FCV characterization: Set-up

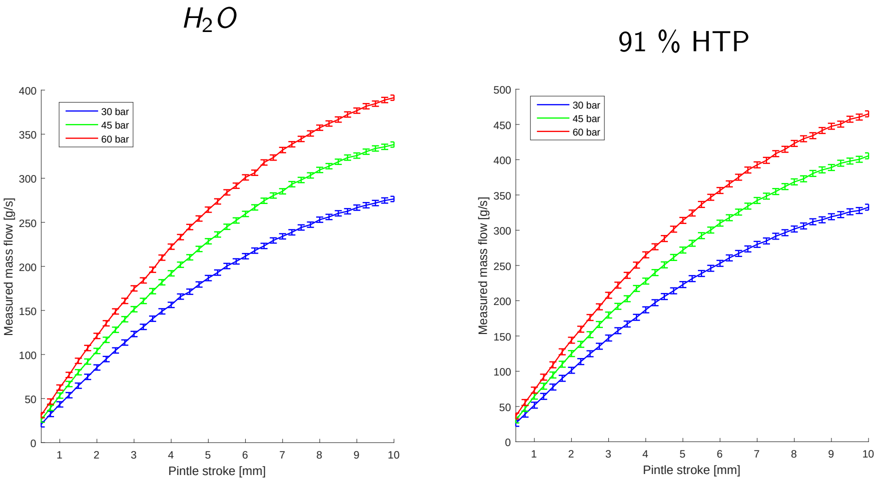




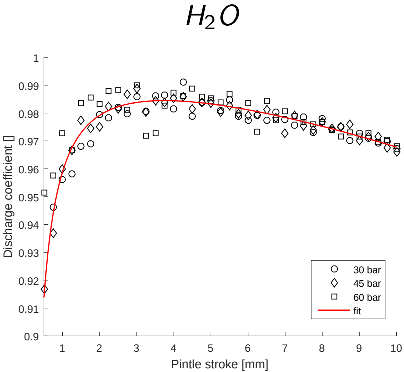
Features

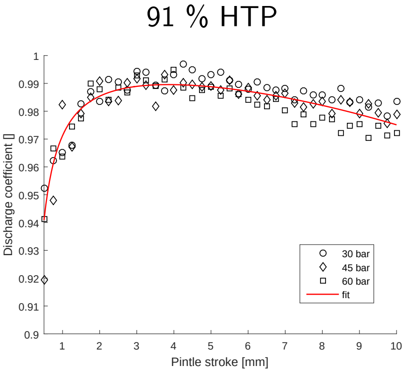
- HTP tank (piston separator)
- Flow control valve
- Catalytic bed (not shown)
- Test motor (not shown)
- Purging line

FCV characterization: Results



FCV characterization: Results



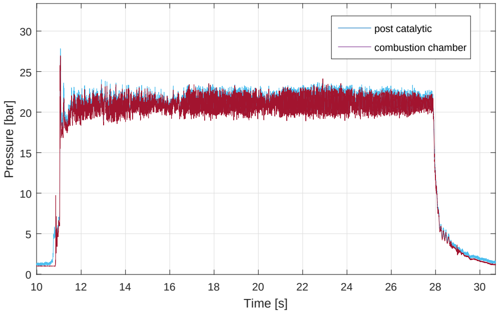


$$C_{D,H_20} = 1.008 - 2.626\ x - 93.14\ x^2 - 4.643 \cdot 10^{-5}/x,\ \ R^2 = 0.93$$

$$C_{D,HTP} = 1.003 - 0.7345\ x - 174.5\ x^2 - 3.086 \cdot 10^{-5}/x,\ \ R^2 = 0.86$$

Test Motor: Fire test campaign

A test campaign was conducted to characterize the test motor behavior with different mass flows. Tests were conducted in the fuel rich region.



Test #	$\dot{m}_{HTP}$ [g/s]	t_b [s]	p_{cc} [bar]
1	56.5	25	8.6
2	137.9	16	20.9
3	219.0	7	33.1
4	282.1	5	43.5

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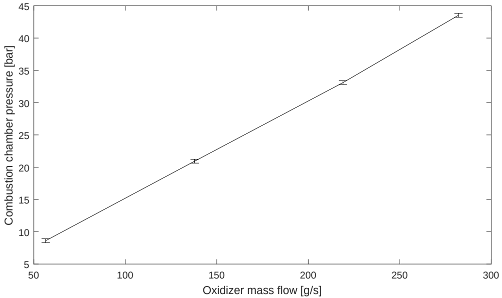

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Conclusion and Future work

- A variable area cavitating venturi to be used as flow control valve in hybrid rocket motors was developed and characterized
- Our test motor was tested with four different oxidizer mass flows reaching a 1:5 throttling ratio
- Automatically control the pintle stroke implementing a DC motor
- Characterize the dynamic behavior of flow control valve and test motor
- Throttling tests

Conclusion

Thank you! Any question?