Study and Development of Throttleable Hybrid Rocket Motors

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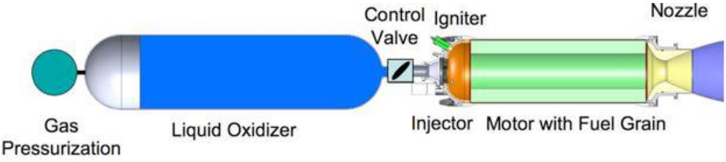
16 September 2016

Introduction to Hybrid Rocket Motors



Main characteristics

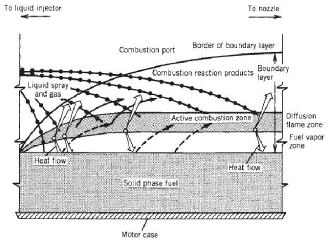
- Oxidizer in the tank, Fuel in the combustion chamber
- One controllable feeding line
- Different technological solutions and propellant formulations

Pros & Cons of Hybrid Rocket Motors

Advantages

- Safety during the handling and manufacturing
  $\Rightarrow$ Low operative cost
- Oxidizer flow control
  $\Rightarrow$ Mission abort and throttlability
- Simpler than liquid engines
  $\Rightarrow$ Low manufacturing cost
- Reduced pollution and toxicity (Green propellants)
- Safety during development
  $\Rightarrow$ Low development cost

Disadvantages



- Low regression rates
- Combustion efficiency
- O/F shift $\Rightarrow$ Lower specific impulse
- Unburned fuel sliver

Why throttleability

- trajectory efficiency
- peculiar mission profiles

Throttling methods

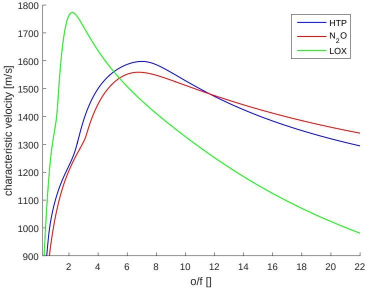
Methods derived from the liquid propulsive technology

- Variable injection area
  - ⇒ Maximum atomization
  - ⇒ Manufacturing requirements
  - ⇒ No catalytic injection
- Pressure drop
  - ⇒ Simple
- Variable area cavitating venturi
  - ⇒ Dissipative method
  - ⇒ Tank-CC uncoupling

Present work

- HRM throttleability general considerations;
- Throttling method selection;
- Fixed throat cavitating venturi fluid dynamic analysis;
- Numerical simulations arrangement and validation;
- Variable area cavitating venturi design (just started).

Throttleability of Hybrid Rocket Motors



	LOX	N_2O	HTP
max c* [m/s]	1773	1559	1598
c* sensitivity [m/s]	−369.9	−19.4	−22.3
Throttling 95% c*	5.6	6.2	5.3
Throttling 90% c*	15	18	13
Throttling 85% c*	37	45	30
Throttling 80% c*	90	165	70

Launch $\frac{T_{max}}{T_{min}} \sim 3$;

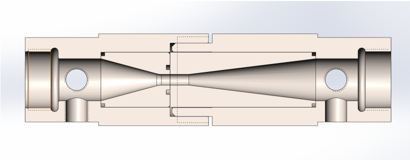
Soft Landing $\frac{T_{max}}{T_{min}} \sim 15$;

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

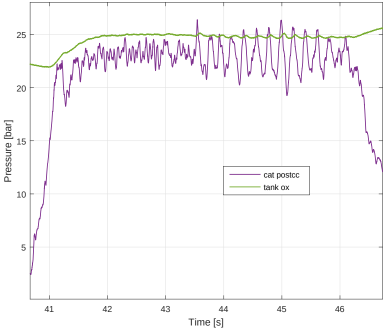
Arbitrary throttling ⇒ o/f shift ⇒ Performance reduction

Cavitating venturi: principles

A venturi tube operating with a throat pressure equal to the vapor pressure. In this condition the venturi is choked.

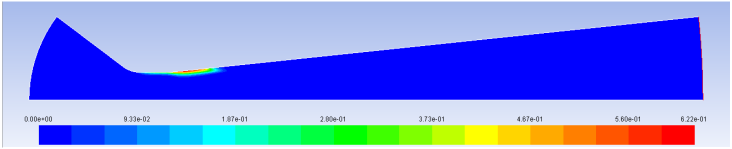


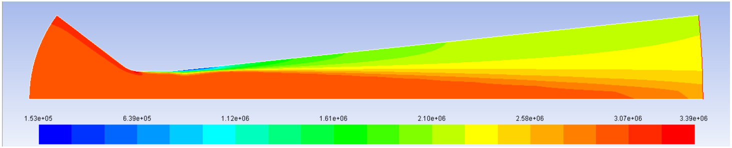
$$\dot{m}_{ox} = C_d \; A_{th} \sqrt{2 \; \rho_{ox} \left(p^{\circ} - p_{sat}\right)}$$



Peculiarities

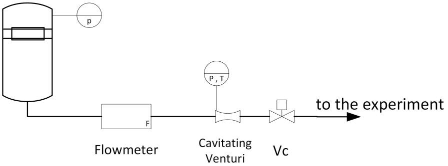
- variable area ⇒ throttling
- if $p^{\circ}_{up} > 0.9 p^{\circ}_{down}$ ⇒ tank - combustion chamber uncoupling





- 2D RANS Numerical simulations of fixed throat CV
- Schnerr-Sauer model: 2 parameters

Experimental activity: set-up & results



- Pressurized oxidizer tank
- Ultrasound flowmeter
- Fixed throat cavitating venturi
- Pneumatic valve

test n°	1	2	3	4	5	6	7	8
$\dot{m}_{ox}$ [kg/s]	2.347	2.182	2.288	2.319	2.053	1.978	2.068	1.968
p°_{up} [bar]	29.15	26.76	28.64	28.87	23.17	21.89	23.37	22.30
exp. C_D []	0.9185	0.8912	0.9046	0.9132	0.9026	0.8933	0.9038	0.8850
unc. C_D []	0.0266	0.0257	0.0271	0.0283	0.0275	0.0307	0.0269	0.0273
num1 C_D []	0.9544	0.9491	0.9398	0.9473	0.9588	0.9456	0.9544	0.9360
num2 C_D []	0.9125	0.9088	0.9138	0.8953	0.9047	0.9047	0.9082	0.8968

Experimental activity: set-up

Future work

- Conclude the fluid dynamic design and analysis of the variable area cavitating venturi, using the same cavitation model of the fixed throat venturi;
- Quasi-stationary characterization of the variable area cavitating venturi;
- Pintle position automatic control;
- Dynamic characterization VACV;
- VACV integration with the existing oxidizer line;
- Motor throttling tests

Activity organization

Level			Activity (Work Package)	hours	year I				year II				year III			
1	**0**	**0**	**State of the art analysis**	**270**	**230**	**40**										
1	1	0	Bibliographical research	70	70											
1	2	0	Numerical methods of design	100	80	20										
1	3	0	Experimental methods of analysis	100	80	20										
2	**0**	**0**	**Numerical Analysis**	**990**	**30**	**220**	**260**	**240**	**170**	**70**						
2	1	0	Definition of the driving parameters	80		80										
2	2	0	Design of the throttling systems	200	20	80	80	20								
2	3	0	Design of the engine	150	10	20	80	40								
2	4	0	Throttling Numerical Analysis	310		40	100	90	80							
2	5	0	Engine Numerical Analysis	250				90	90	70						
3	**0**	**0**	**Experimental Analysis**	**1680**				**20**	**150**	**230**	**290**	**270**	**240**	**240**	**160**	**80**
3	1	0	Experimental set-up arrangement	410				20	130	30	30	140	30	30		
3	2	0	Test campaign (Throttling device)	410					20	180	180	30				
3	3	0	Test campaign (Whole engine)	340								20	130	130	60	
3	4	0	Data analysis and validation	520						20	80	80	80	80	100	80
4	**0**	**0**	**Exploitation**	**120**											**20**	**100**
4	1	0	Cost-effective solutions	60											20	40
4	2	0	Deep-throttling main ascent/descent engines	30												30
4	3	0	Sounding rockets and small boosters	30												30
5	**0**	**0**	**Compilation of Thesis and Reports**	**690**					**20**	**50**	**50**	**70**	**100**	**100**	**150**	**150**

Conclusion

Thank you! Any question?