Development and Testing of a Small Hybrid Rocket Motor for Space Applications

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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
Introduction to HRMs (1/4)

Liquid rocket motors

Solid rocket motors

Hybrid rocket motors
Crosshead:

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
To increase low regression rate and low combustion efficiency:

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

\[ \nu_e \]

Reacting Droplets

Diffusion Flame

Roll Waves

Liquid Layer

Fuel Grain

Thermomechanical properties

\[ \bar{r} = 0.488 \, G_{ox}^{0.62} \]

Paraffin-Based/GOX

HTPB/GOX (Sutton/Thickol)

PE Wax Polyflo 200

Paraffin Wax FR 4045

Paraffin Wax FR 5560

PE Wax Marcus 200

ABC Method Prediction

Melting Point Data
Applications of small HRMs

Sounding rockets

Orbit raising and reentry maneuvering systems

Deorbiting systems

Maneuverable adapter rings
Define suitable hybrid rocket envelope

\[ R = \frac{D_f}{D_0} \]

\[ VL = 1 - \frac{1}{R^2} \]

\[ \frac{G_0}{G_f} = R^2 \]

\[ \frac{aG_0^n t_b}{D_0} = \frac{R^{2n+1} - 1}{4n + 2} \]
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 focuses 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)

Liquid layer theory verified
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?