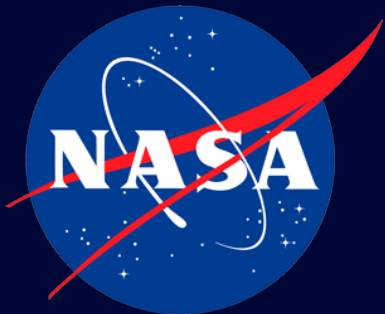


3D Printed Hybrid Motor Fuel Grains

Annual Arizona Space Grant Consortium 2015

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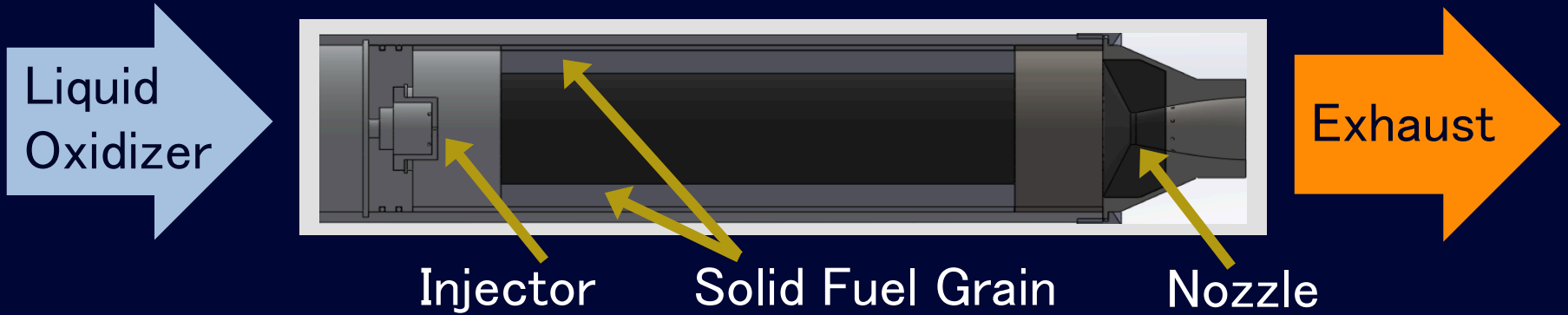


Objectives

- ▶ Assess performance of **additive manufacturing** for:
 - Viability (Quality, Ease of Use)
 - Regression Rate
 - Material Performance
- ▶ Comparison to **current methods** with traditional materials for application in a launch vehicle



Hybrid Overview

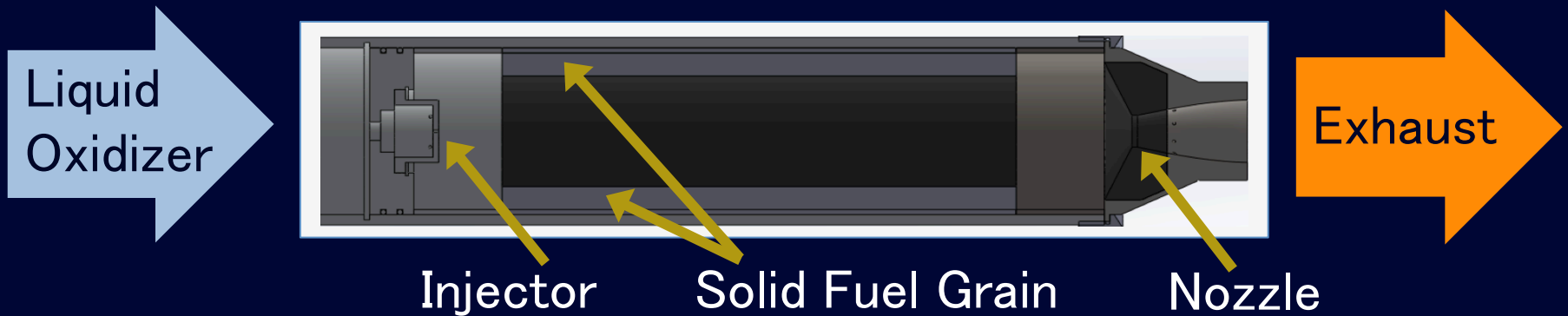


Solid Fuel Grain

Single Burn Port



Hybrid Overview



Key Characteristics:

- Inert Mass Fractions
- Safe Handling/Storage
- Start-Stop-Start
- Low Regression Rate

Regression Rate:

$$\dot{r} = a (G_{ox})^n \quad G_{ox} = \left(\frac{\dot{m}_{ox}}{A_{port}} \right)$$

Fuel Mass Flow Rate:

$$\dot{m}_f = \rho_f A_b \dot{r}$$



Efficiency & Performance

Two General Improvement Methods:

- ▶ Multiple combustion ports along length of grain
- ▶ Increase effective length of grain
 - Swirl Oxidizer Injection
 - Helical Combustion Ports

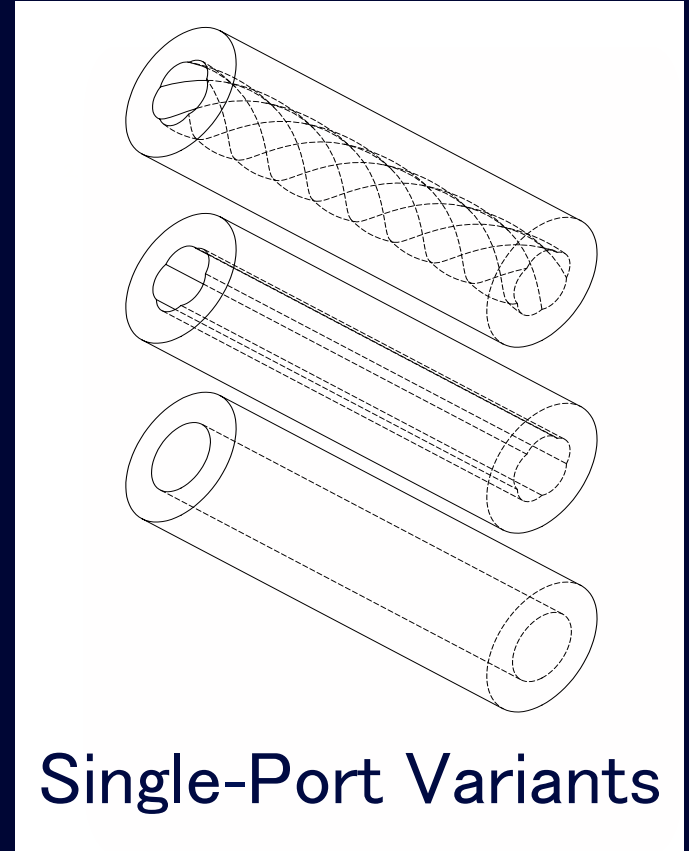


Why Print?

► Material selections

- Polylactic Acid (PLA)
 - Acrylonitrile Butadiene Styrene (ABS)
 - Higher Density*
 - Higher Regression Rate*
 - Lower O/F Ratio*
- * Compared to HTPB

► Enable manufacturing of multi-port geometries

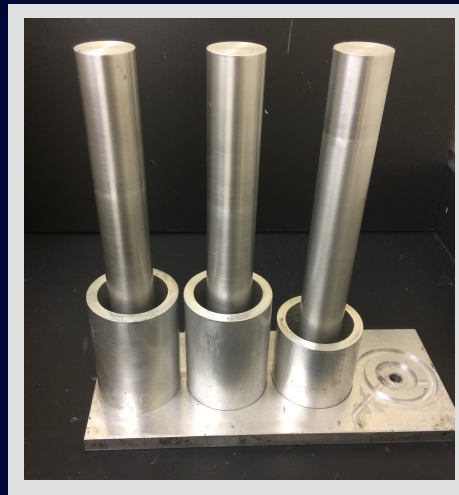


Why Print?

► Casting Method

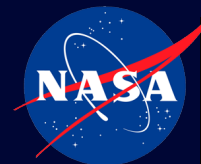
- Design Geometry
- Machine Rods
- Mix and Cast Propellant
- Cure
- Test Fire

Casting Rack
(HTPB)



► Printing Method

- Design Geometry
- Print
- Test Fire
- ✓ Less Labor
- ✓ Less Material Waste
- ✓ Rapid Development



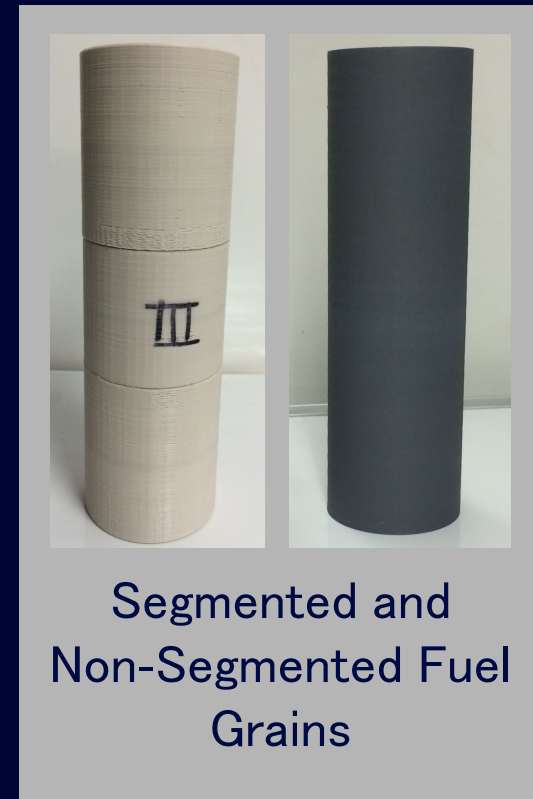
Fuel Grains

Standard Single Port Grains

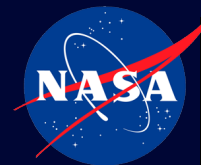
- ▶ Segmented to model large-scale conditions
- 8 Total Grains
- 4 Segmented Modified
- Epoxy into Phenolic Liners



Segment Unions
Post and Pre-Facing



Segmented and
Non-Segmented Fuel
Grains



Original Project Breakdown

Print

- ABS
 - Segmented
 - Single Piece
- PLA
- Machine New Injectors
- Cast HTPB

Baseline Tests

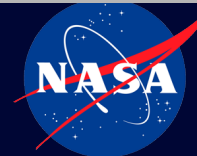
- HTPB
- ABS and PLA Initial Hot Fires



Old and New Hybrid Small-Scale Injectors

Further Tests

- Single-Port Grain Sets
- Multi-Port Geometry Grain Sets



Revised Project Breakdown

Print

- ABS
 - Segmented
 - Single Piece
- PLA
- New Injectors
- Compressed Gas Overhaul
- CG Regulators
- HTPB Recast
- Configuring New Printer

Baseline Tests

- HTPB
 - Test Revisions due to CG changes
 - Regulator Tests
- Injector Test Plan (Cold Flow) and Testing
- ABS and PLA Initial Hot Fires

Further Tests

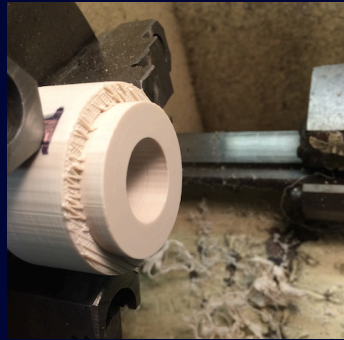
- Single-Port Grain Sets
- Multi-Port Geometry Grain Sets



Intermediate Results

- Viability (Quality, Ease of Use)

✓ YES But...



- Regression Rate

✓ Theoretical: Improvement Over HTPB

○ Experimental: Awaiting Testing

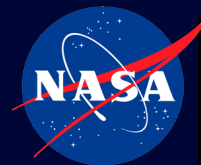
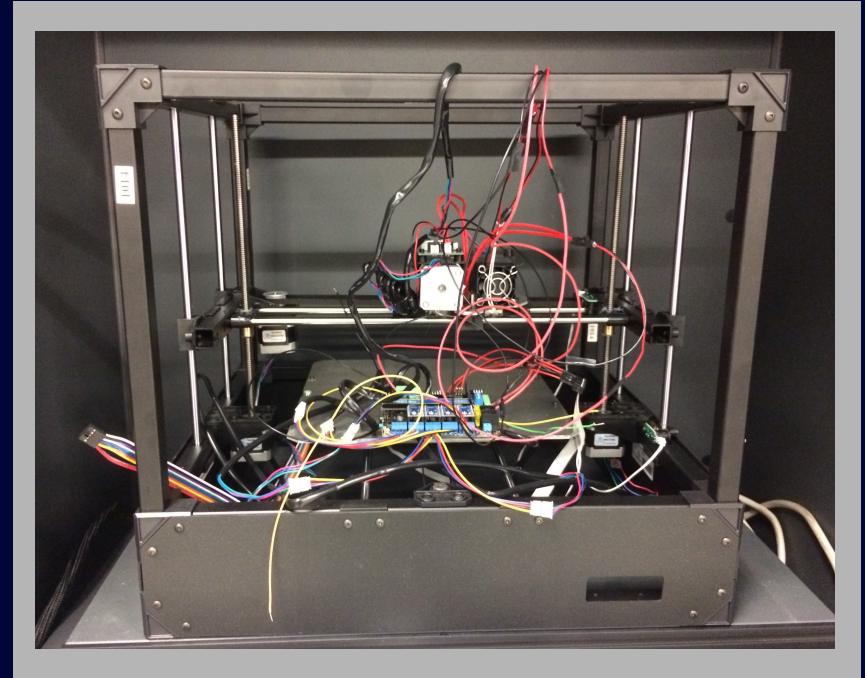
- Material Performance

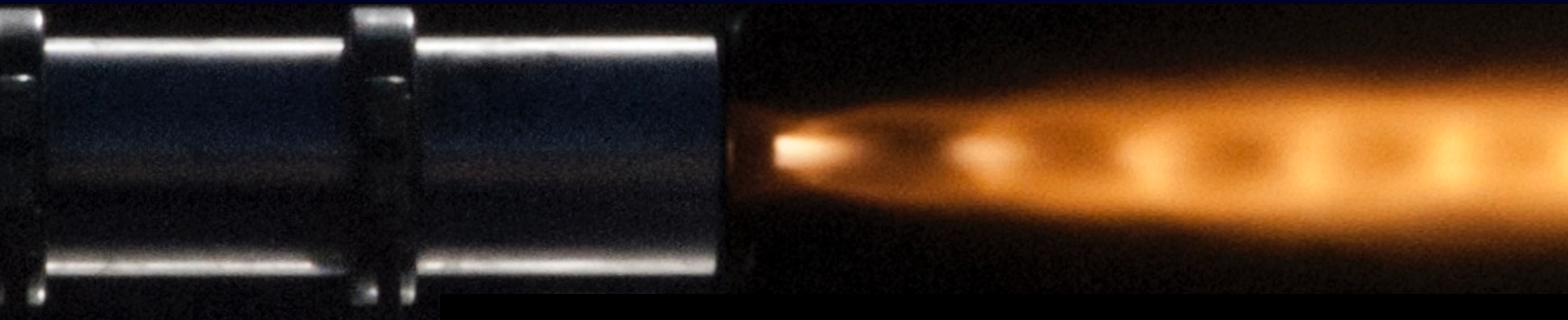
○ Experimental: Awaiting Testing



Next Steps

- ▶ Rigidbot Printer Calibrations
- ▶ Test Prints
- ▶ Injector Cold-Flow Tests





Thank You

