Jet Propulsion Laboratory
California Institute of Technology

Hybrid Propulsion In-Situ Resource Utilization Test Facility Results

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Motivation

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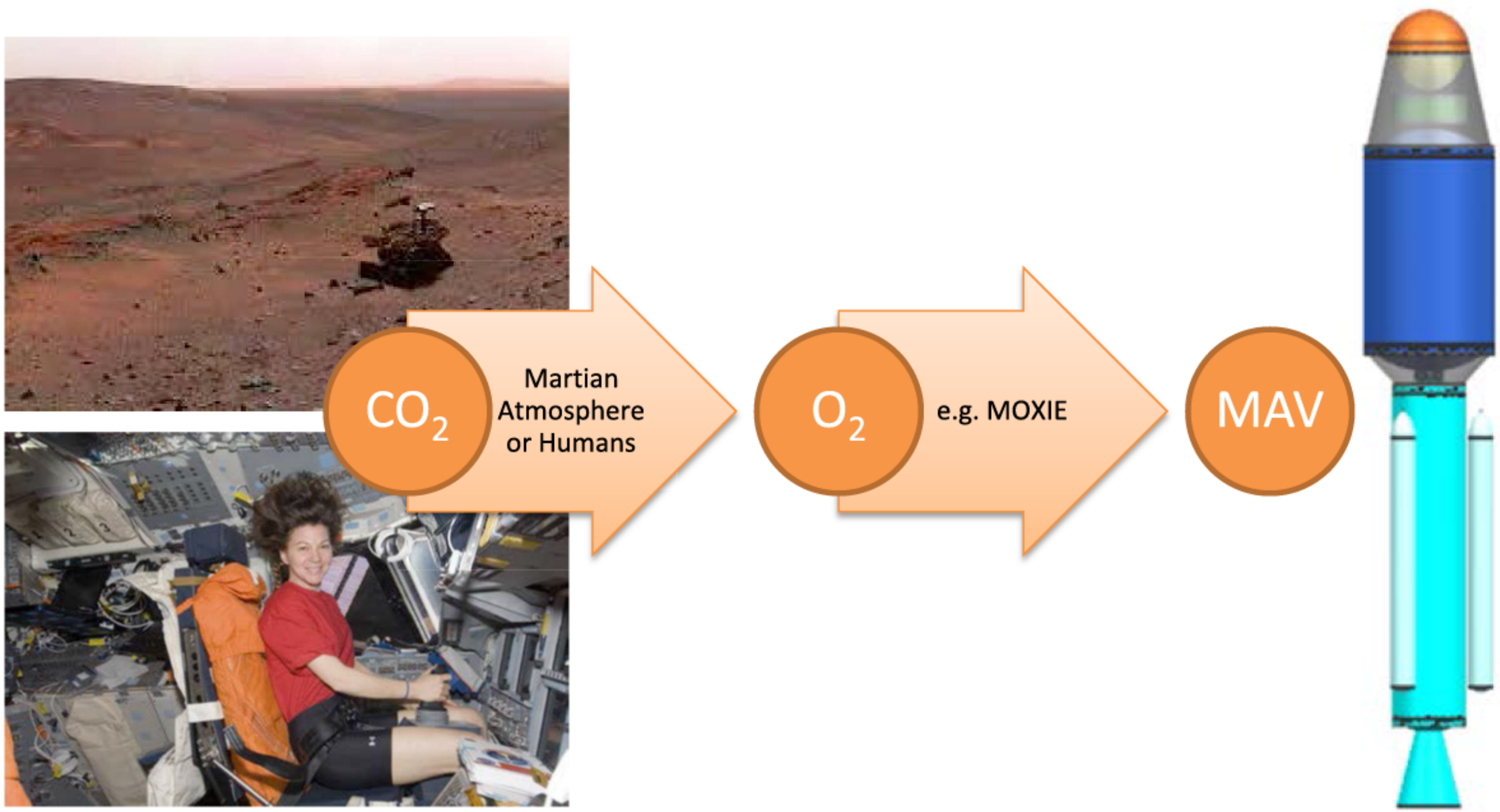
- What if we could fill our propellant tanks at OR on the way to Mars



Motivation, cont.

- What are the potential challenges for an ISRU MAV?
  - Throttling – hybrid performance at very low oxidizer mass flux rates
  - Packaging – how compact can the hybrid system be?
  - Performance with "ISRU" oxidizer – oxidizer could potentially be O_2 mixed with CO_2

Motivation, cont.

- What are the potential challenges for an ISRU MAV?
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Other objectives are "in process."

Test Set Up – JPL Hybrid Lab

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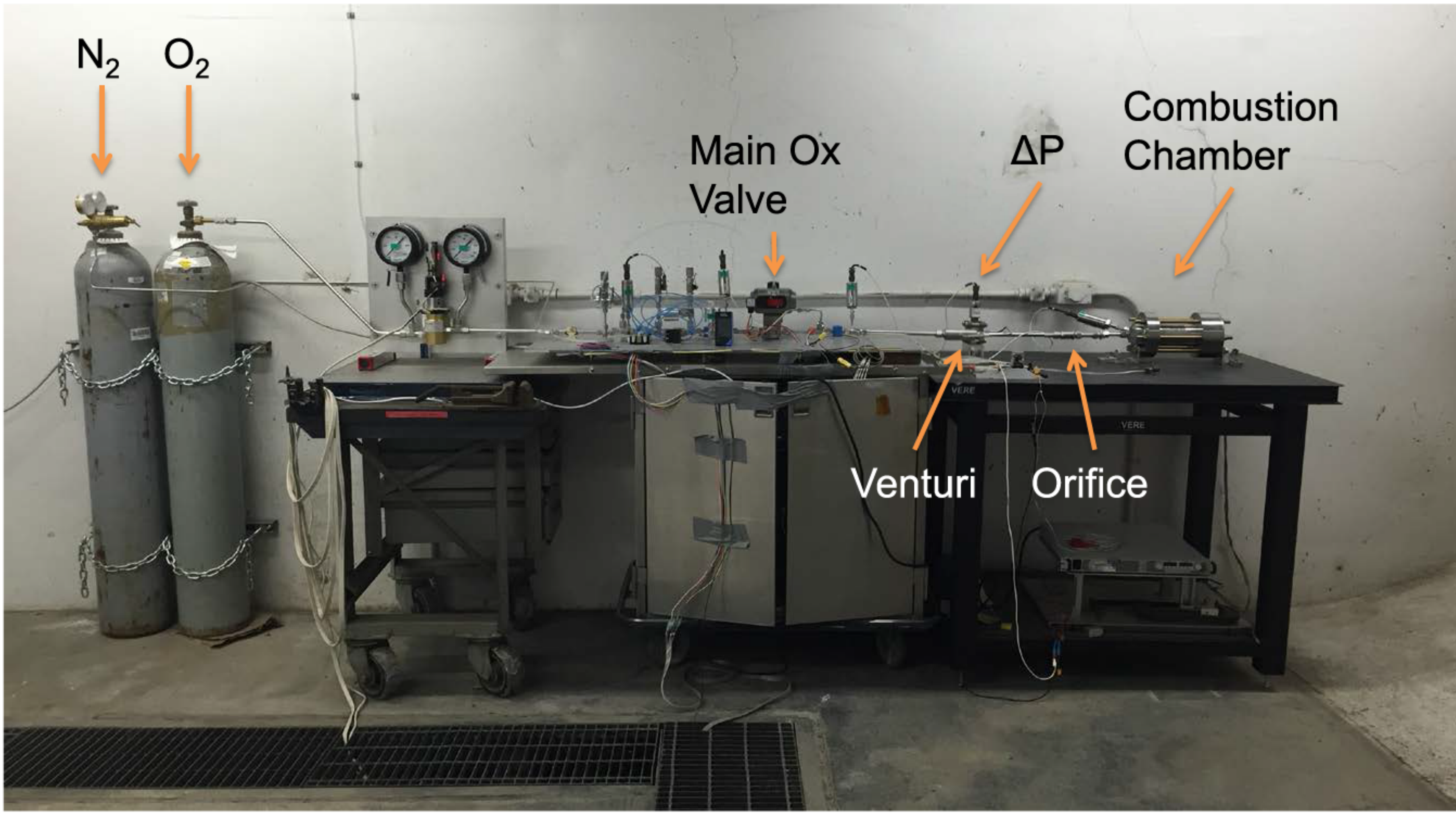


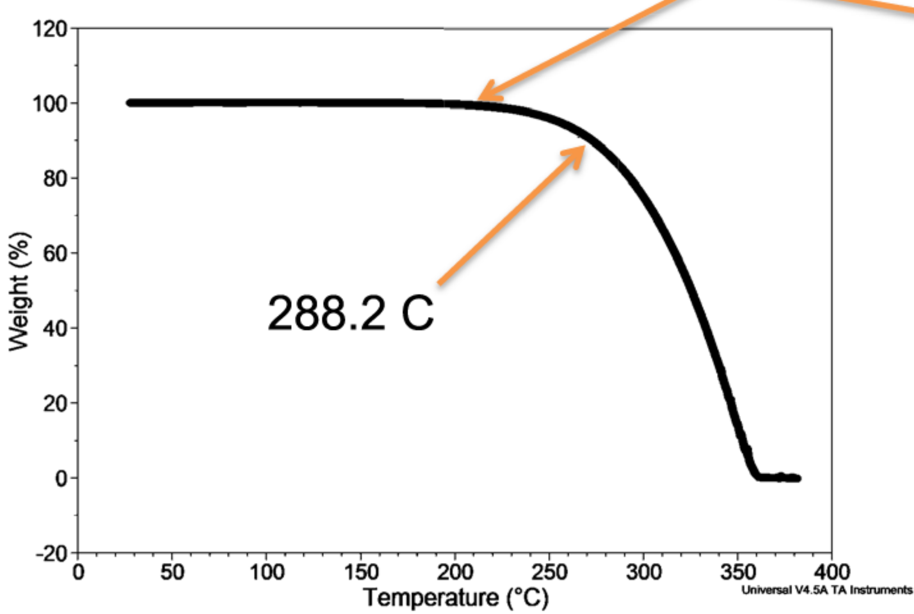
Fuel Properties

- There are many types of “paraffin wax,” so several chemical analyses were conducted to give a baseline to the fuel being discussed here
- Looking beyond the current tests, two analyses were completed to inform IRSU missions
  - Glass transition temperature (for low temperature conditions, e.g. Mars)
  - Volatiles analysis

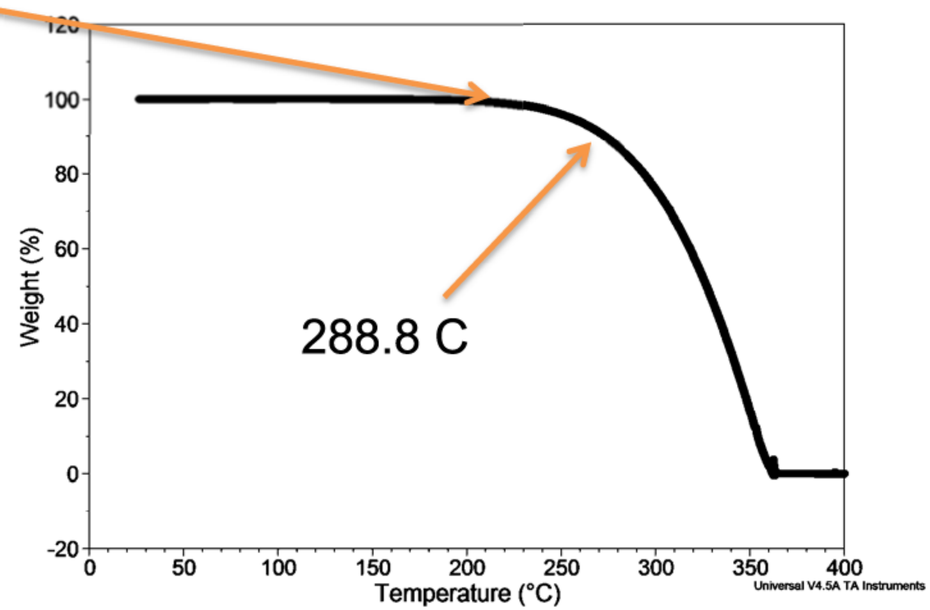
Chemistry Analysis

Volatiles

- Why is thermogravimetric analysis necessary?
  - Volatiles will not be allowed in space environment
  - To enable other tests (ensure hardware isn't damaged)
- No appreciable loss of volatiles
  - Thermal decomposition occurs at about 288 C for both samples
  - Mass loss of only 0.035% by 200 C



Neat Paraffin

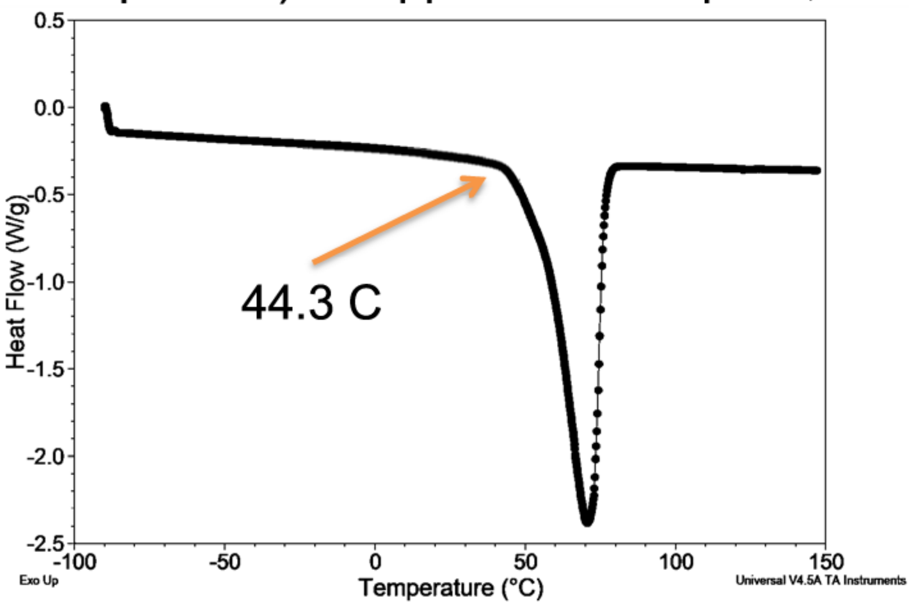


Blackened Paraffin

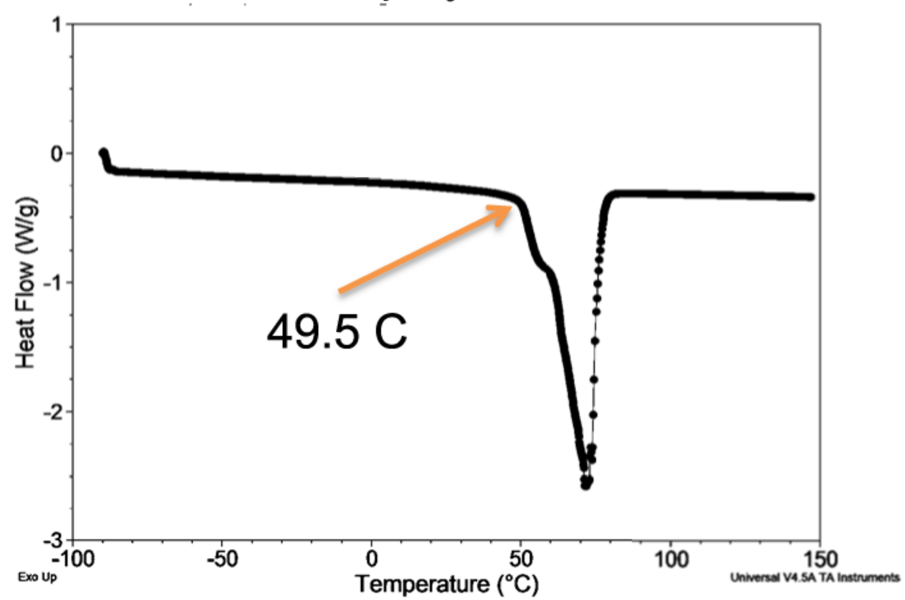
Chemistry Analysis

Phase Transition

- Differential Scanning Calorimetry (DSC) – Phase transition is indicated by a major change in the amount of heat required to keep the sample at the same temperature as a reference.
- Melt temperature of neat paraffin is 44.3 C and blackened paraffin is 49.5 C
  - The blackened paraffin was made by adding dye to the same batch of neat paraffin
- The melt temperature is taken as the onset for metals and organics (like paraffin) as opposed to the peak, which can be used for polymers.



Neat Paraffin

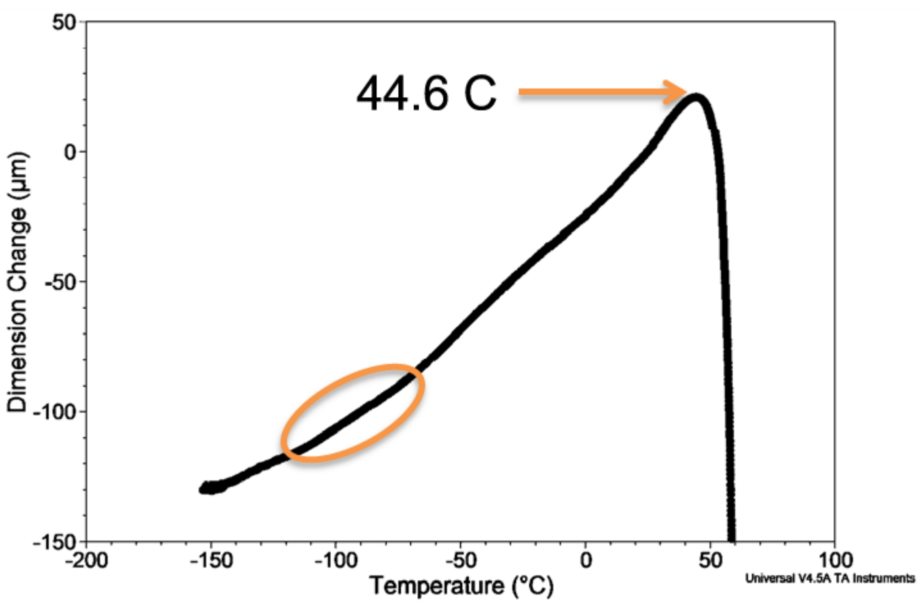


Blackened Paraffin

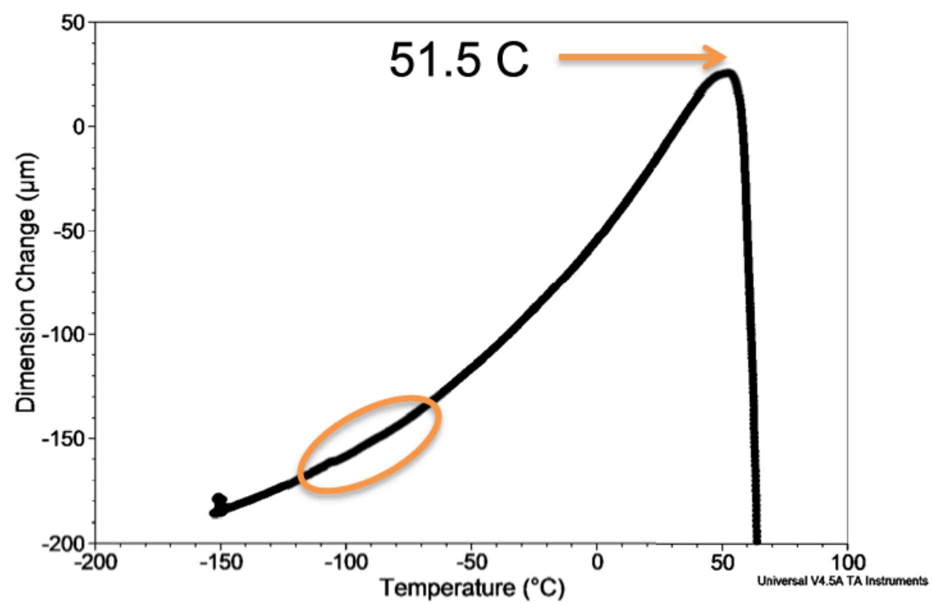
Chemistry Analysis

Phase Transition & Coeff. of Thermal Expansion

- Thermomechanical Analysis
  - The melt point is confirmed by the peak of the curve (consistent with the DSC results)
  - Glass Transition cannot be determined, but likely a weak transition around -90 C



Neat Paraffin



Blackened Paraffin

Hotfire Results

Summary

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Test Number	Test Date	Maximum Chamber Pressure (P_c, psia)	Nozzle	Oxidizer Mass Flow (g/s)	Oxidizer Mass Flux Range (G_o, g/cm²s)	Mass of Fuel Burned (g)	Burn Time (s)	O/F	Average* Regression Rate (mm/s)
5	3/18/2015	122	Small	43	14.3-3.8	131	3.5	1.1	2.9
6	4/29/2015	73	Large	37	13.6-7.0	30	1.3	1.6	2.8
7	5/13/2015	86	Large	45	15.5-7.5	38	1.5	1.8	2.6
8	6/10/2015	142	Small	45	15.5-4.4	114	3.6	1.4	2.3

Supercritical Test

Test 5

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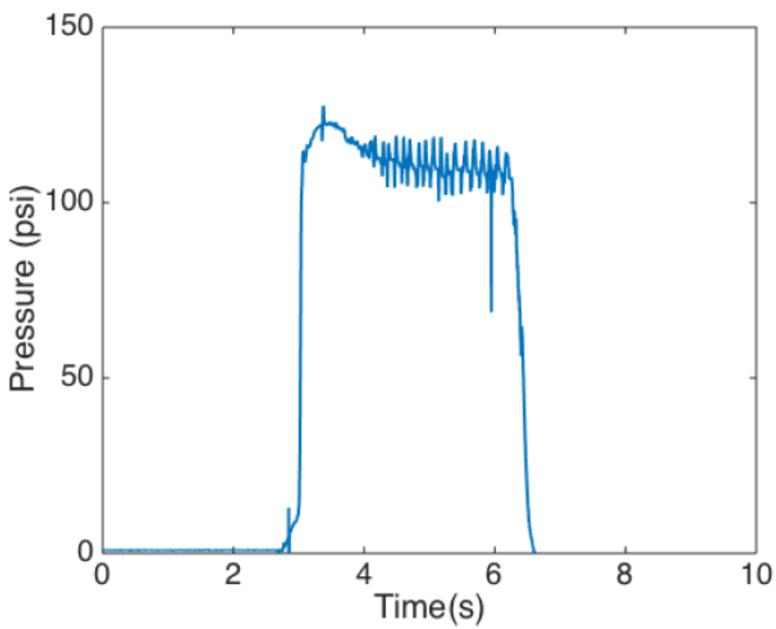
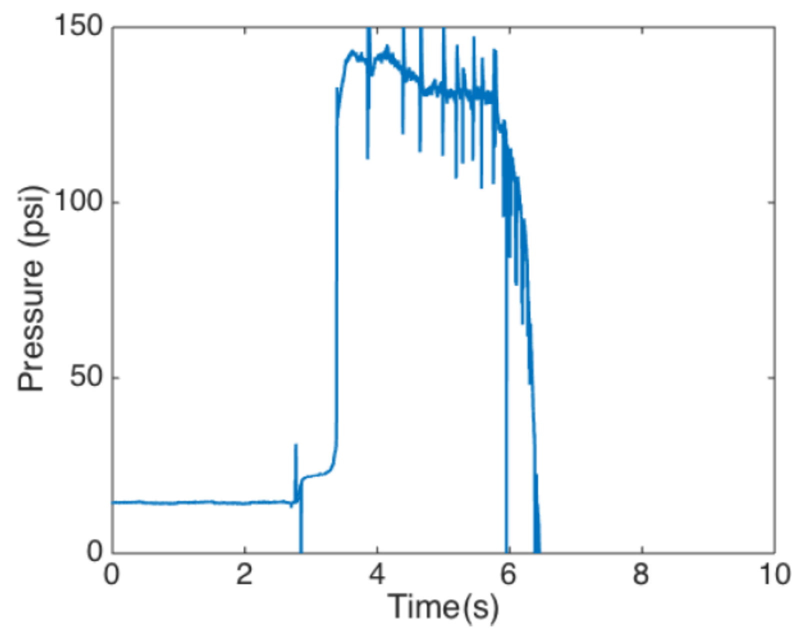
Test Results

Supercritical Pressure

- Chugging – low oxidizer mass flux
- Higher frequency instability and longer ignition time believed to be due to secondary flow choking

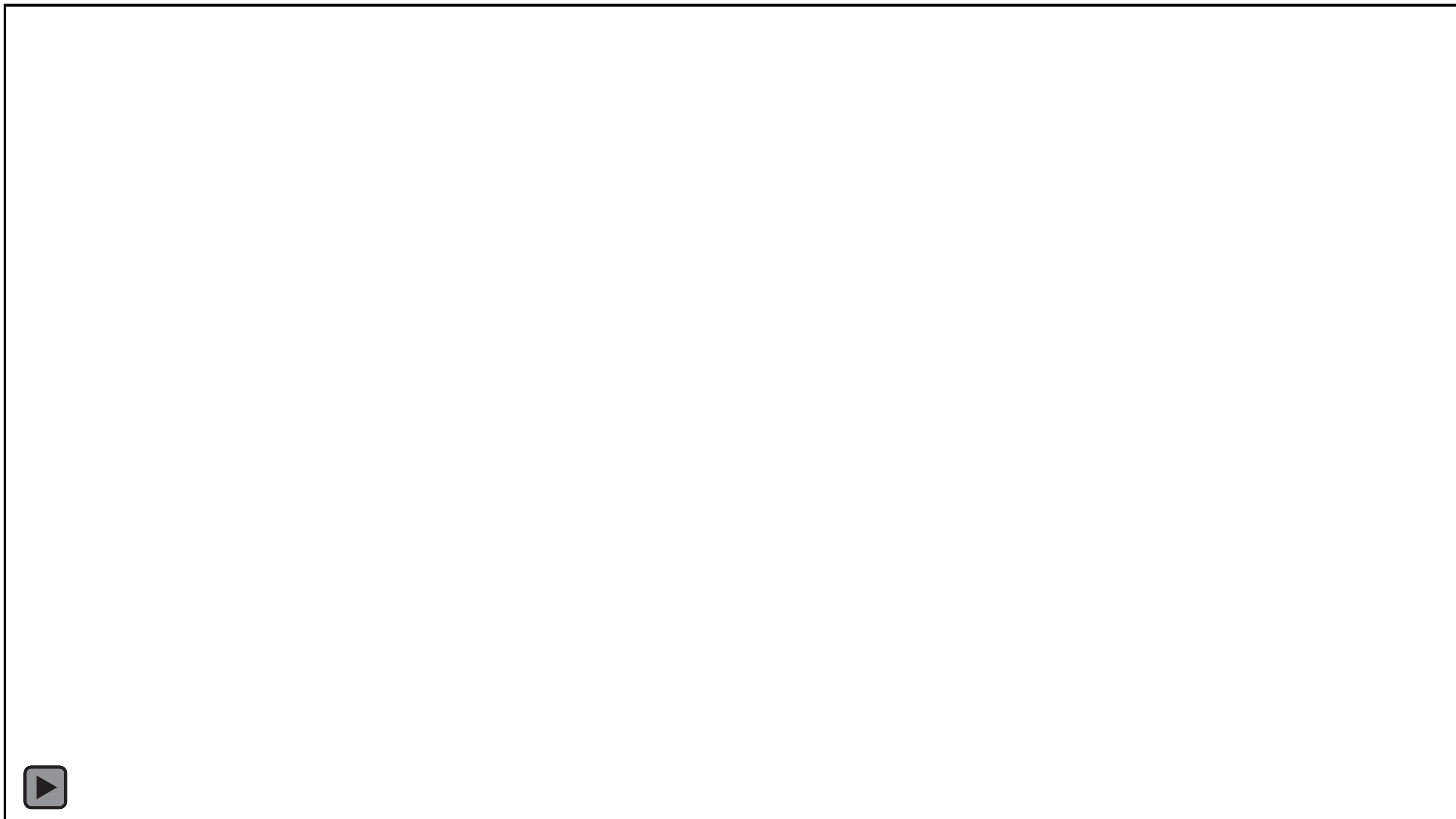


Test 5, 43 g/s



Test 8, 45 g/s

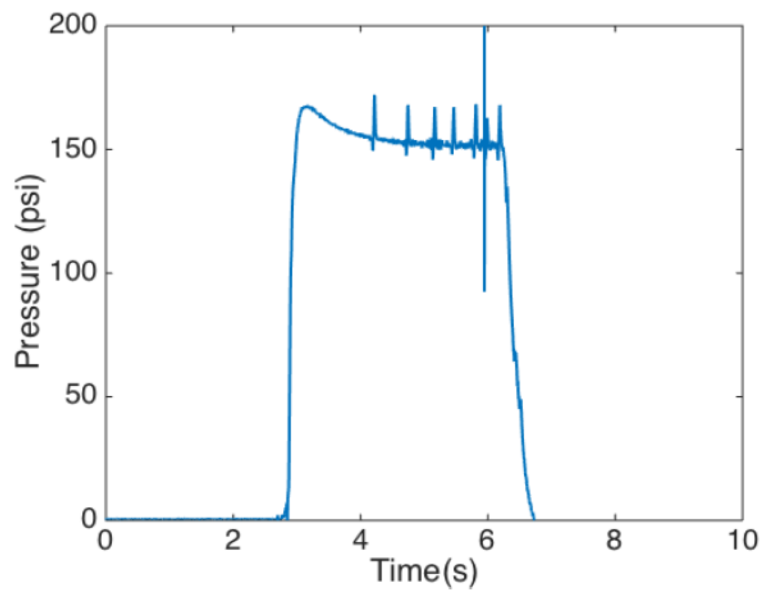
Supercritical Test



Test Results

Supercritical Pressure

- Higher frequency instability is removed (single choke point)
- Slightly higher oxidizer mass flow (55 g/s)
- Chugging begins at oxidizer mass flux of about 7 g/cm^2s

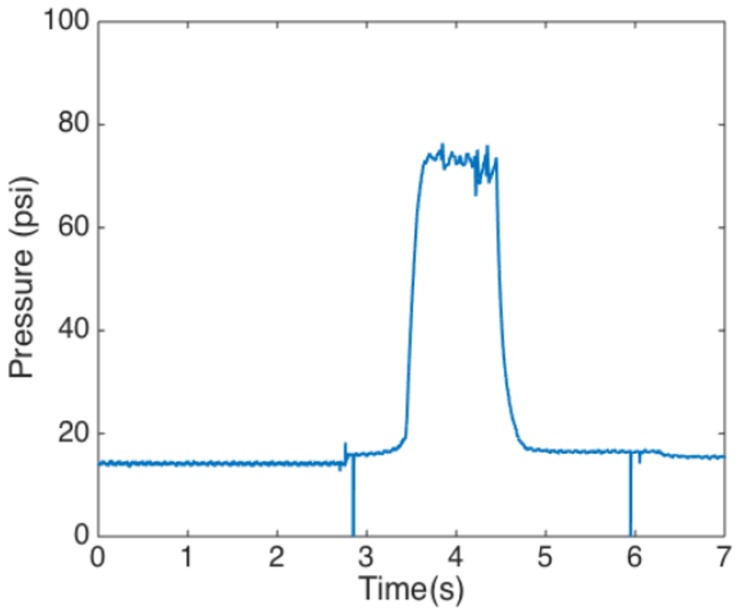


Subcritical Pressure Test

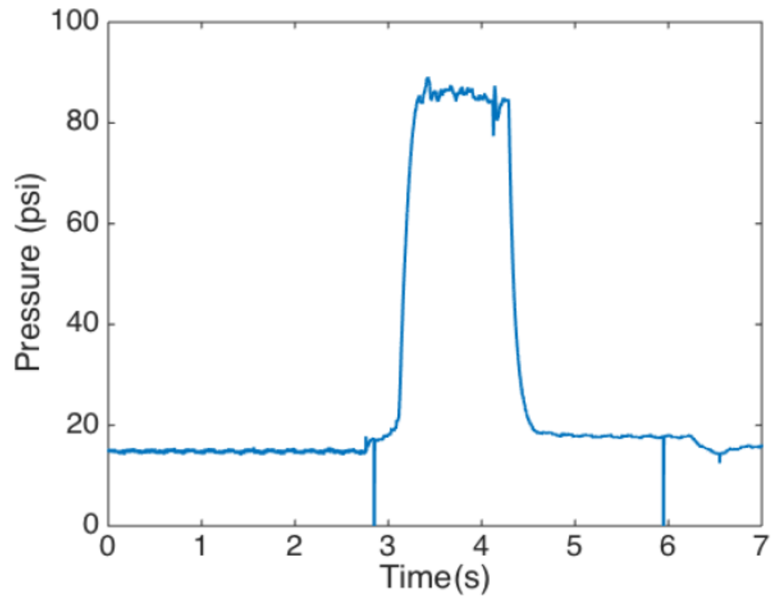
Test Results

Subcritical Pressure

- Long start up and early shut down



Test 6



Test 7

Subcritical Results

Flame Holding Instability

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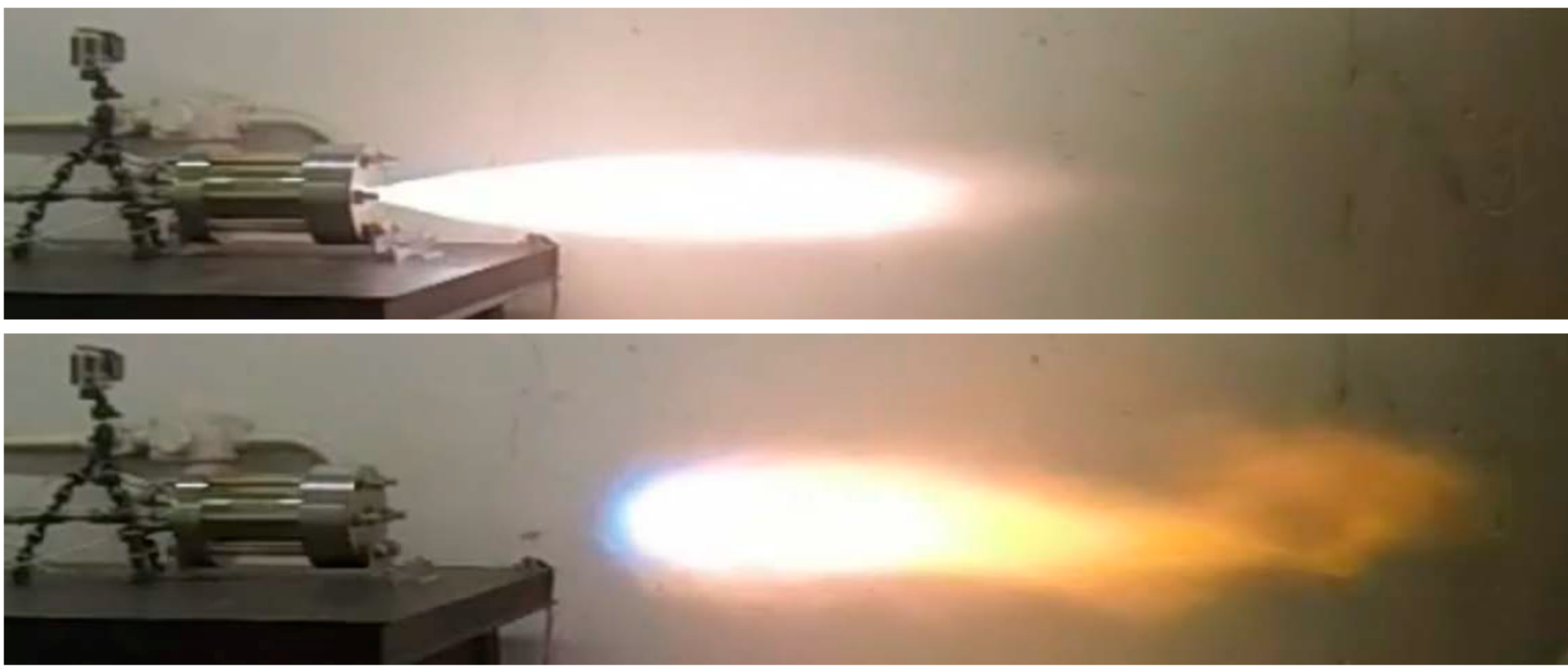
- Flame shedding out of chamber



Conclusions

- During deep throttling the following can be expected
  - Chuffing instabilities (low frequency) – still working to resolve limit at which this occurs
  - Higher fuel regression rate (up to 3 mm/s)
    - Thick liquid layer (HOWEVER, also lower melt temperature for this particular paraffin fuel)
  - Potential to eject the flame in the subcritical regime
- Very weak glass transition around -90 C.