Solar Thermal Engine Tests

An Overview

Advanced Space Propulsion Workshop

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Presentation

- Scope
- Engine Description
- Test Requirements
- Test Results
- Summary

Solar Thermal Test Articles

- Chart not available

Rhenium Engine Description

- Solar thermal engines are high temperature heat exchangers with nozzles.
- Fabricated by Chemical Vapor Deposition (CVD) of rhenium onto graphite mandrels.
- 100 % dense inner and outer shell. Electron Beam Welded.
- 10 % dense Rhenium Foam heat exchanger.
- 20 % dense rhenium foam support structure EB welded to outer shell via solid inner hub.
- Solid rhenium 0.25 inch O.D. propellant inlet tube EB welded to outer shell.
- SS 314 Secondary Support Structure:
  - Wagon Wheel: 8 pt. Bolted clevis rocker arm assembly
  - Spoke: 3 pt. Steel sleeves brazed to rhenium foam spokes
  - Propellant tube: fitting interface
- Engine capable of operating at > 4000°F
- Test temperature is 3000°F. Limited by heater.
- Engines designed as small scale “thermal storage” engines (SSE).
- Capable of operating as scalable “direct gain” engines.

Rhenium Solar Thermal Engine

- Chart not available

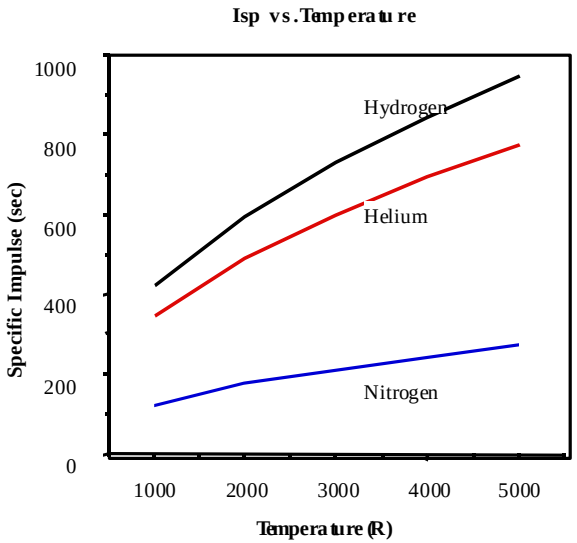
Engine Baseline

Performance Goals:

- Operating Temperature: 0-3000°F
- Engine Inlet Pressure: 60 psi
- Prop. (GN2) Flow Rate: 20 - 60 Lb/Hr
- Nozzle:
  - Throat Dia. ~ 0.128 in.
  - Area Ratio 245:1
- Thrust: 1 lb
- Thrust Duration: 30 sec
- Isp @ 0-3000° F N2: 50-200 sec.
  H2: 300-800 sec.
- Isp @ 4000° F N2: 230 sec.
  H2: 860 sec.
- Weight: ~ 20 lb.

Reference Configuration

- Spot Diameter: 1.5 in.
- Spot Power: 1500 W
- Aperture Diameter: 1.7 in.
- Absorber Cavity Length/Dia Ratio: 4



Engine Operation:

- Constant inlet pressure produces constant thrust over all temperatures
- Engine temperature defines flow rate and Specific Impulse (Isp)

Test Requirements

- Maintain as low a vacuum and inert atmosphere as practical before, during and after testing
  >> **Oxidation at high temperatures is primary risk to hardware**

- Ultra high purity GN2 with LN2 cold trap

- Silicon Carbide electric heater

- Electrical power for heater: 5000W
  3000°F Temperature limit

- Engine inlet pressure: 60 psia

- Propellant flow rate: 20 - 60 lb/hr

- Test article must be below 500°F before chamber pressurization

- General cleanliness

- Dynamically isolate engines to the extent possible (flexible feedline connection) for thrust measurement with strain gauges.

Solar Thermal Engine Test Matrix

Inconel Engine Simulator Tests

Temperature (°F)	Inlet Pressure	Duration
500	30 psig	2 min
1000	30 psig	2 min
1000	30 psig	2 min
1000	60 psig	2 min
1500	30 psig	2 min
1500	60 psig	2 min
1750	30 psig	2 min
1750	60 psig	2 min
2000	Steady State Temperature Profile - No Flow	

9 Simulator Tests

Rhenium Wagon Wheel Engine Tests

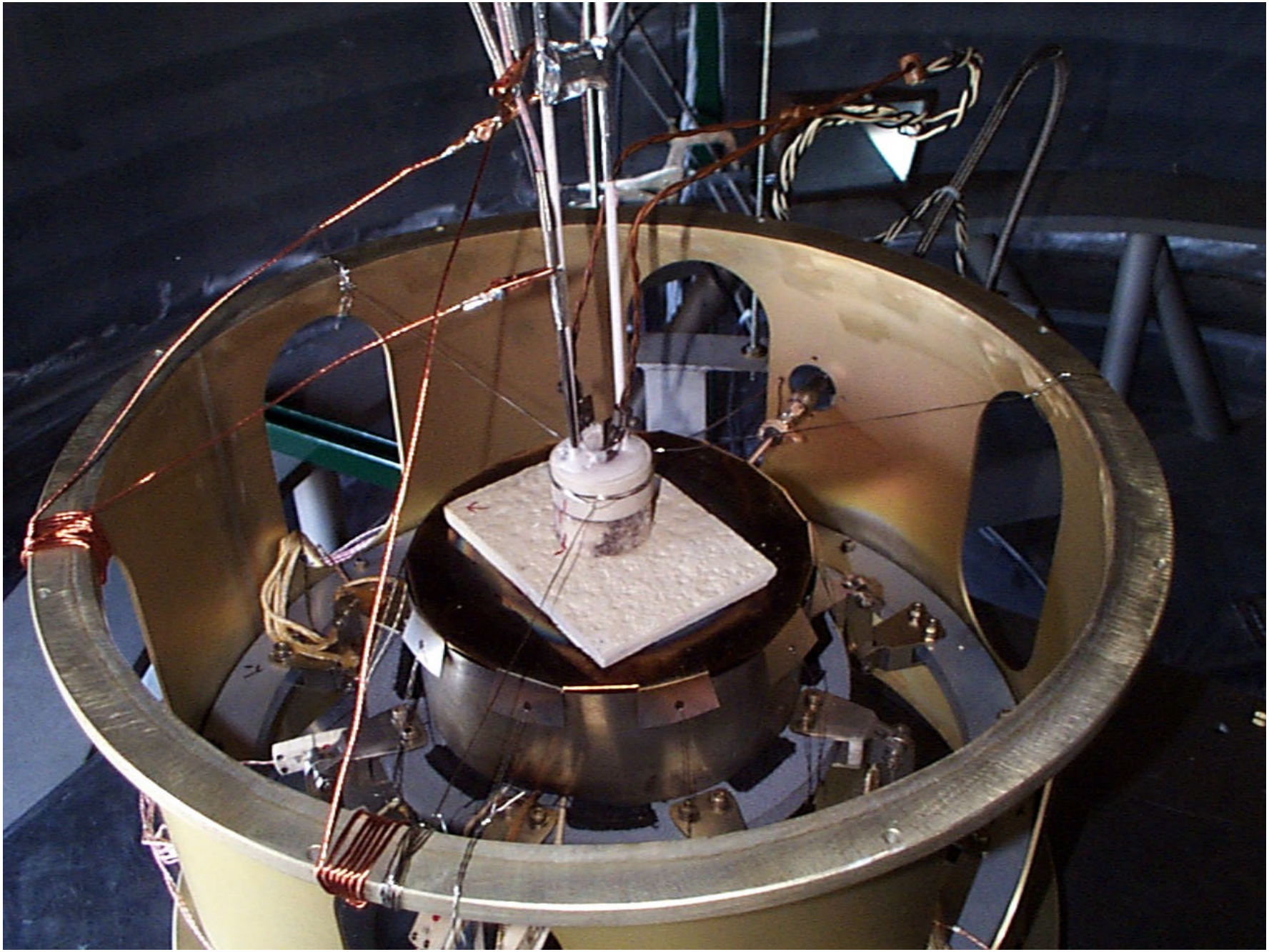
Temperature (°F)	Inlet Pressure	Duration
1500	30 psig	1 min
1500	45 psig	1 min
1500	60 psig	2 min
1000	30 psig	1 min
1000	60 psig	1 min
1500	60 psig	30 sec
2000	60 psig	30 sec
2000	60 psig	30 sec
2000	60 psig	30 sec
2500	60 psig	30 sec
2000	60 psig	30 sec
2500	60 psig	30 sec
2500	80 psig	30 sec
2000 (approx)	30 psig	11 min
2000 (approx)	30 psig	110 min
3000	45 psig	1 min
3000	45 psig	1 min
3000	15 psig	70 min
2625	30 psig	10 min
2700	15 psig	145 min
2500	5 psig	48 min
2700	Steady State Temperature Profile - No Flow	
2500	5 psig	53 min

23 Wagon Wheel Tests

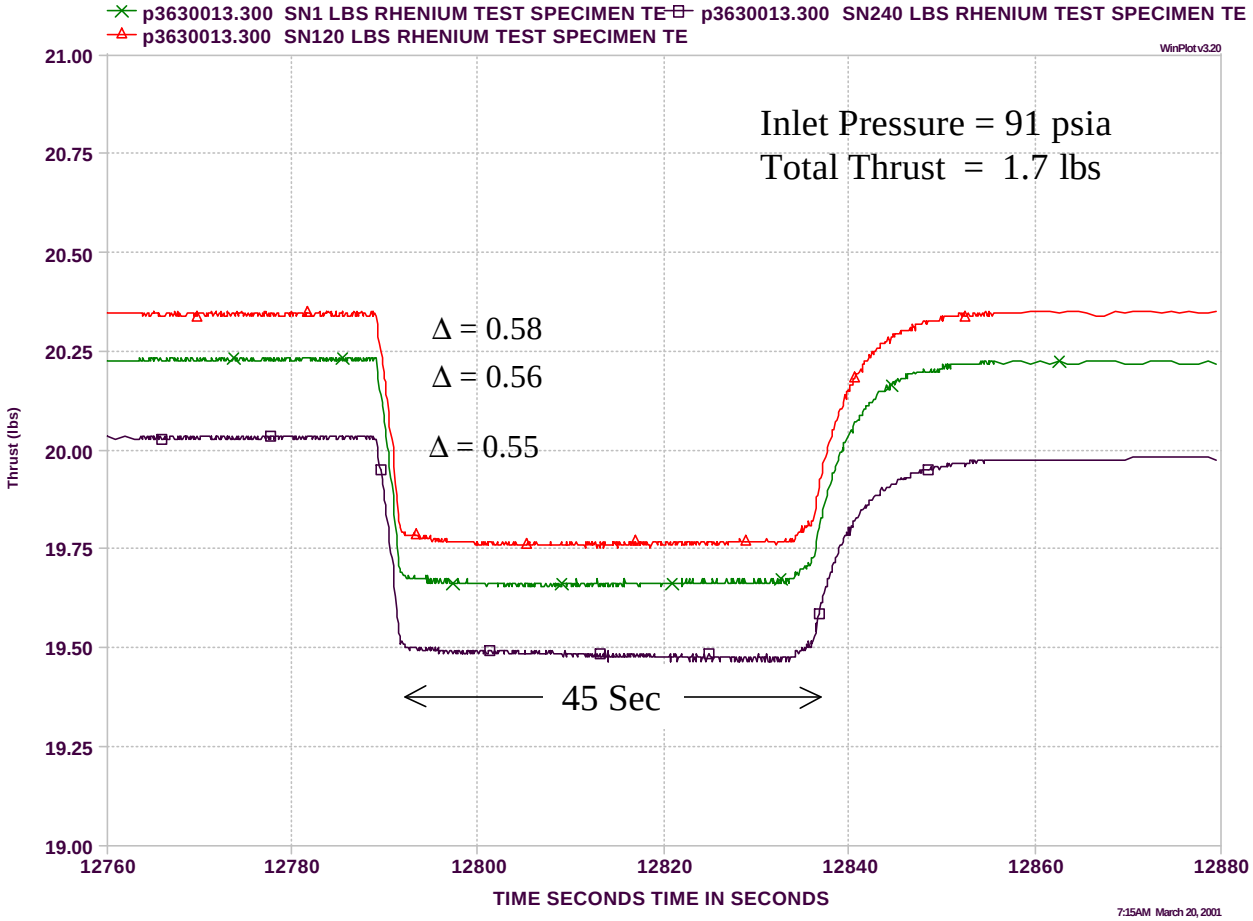
Wagon Wheel Test Article

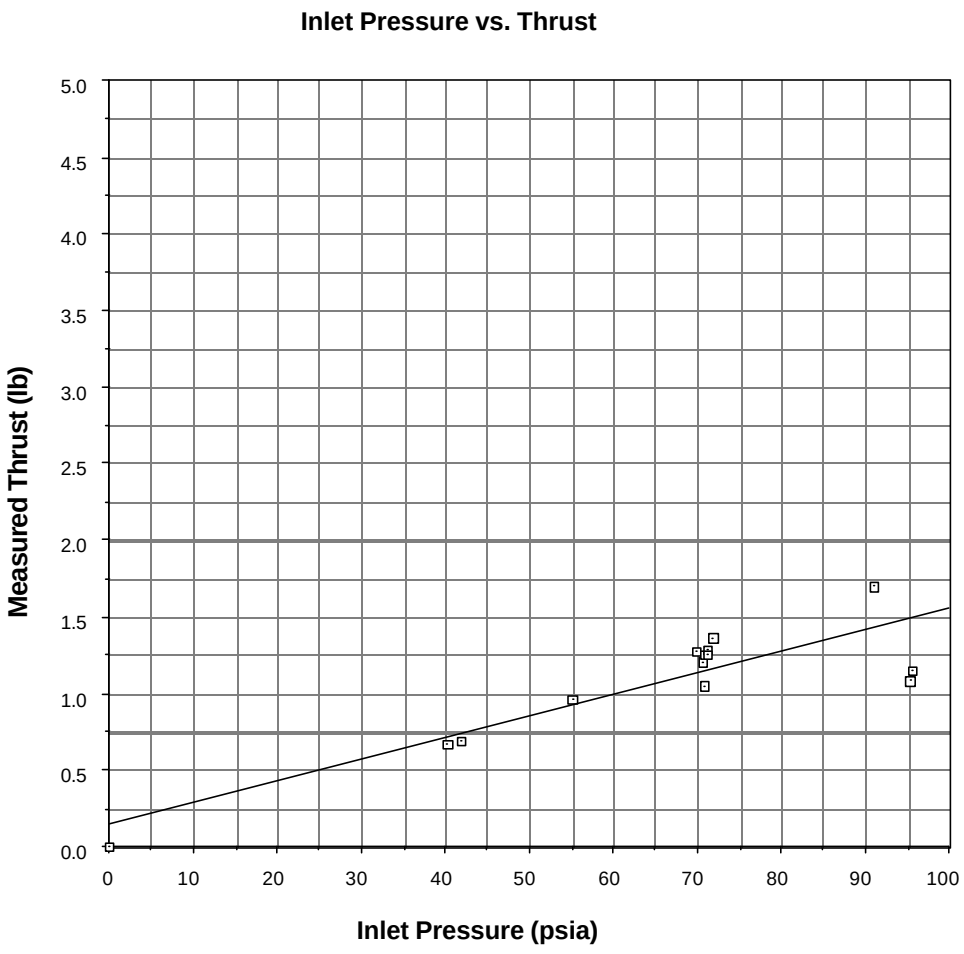
- Chart not available

Engine Module in Chamber

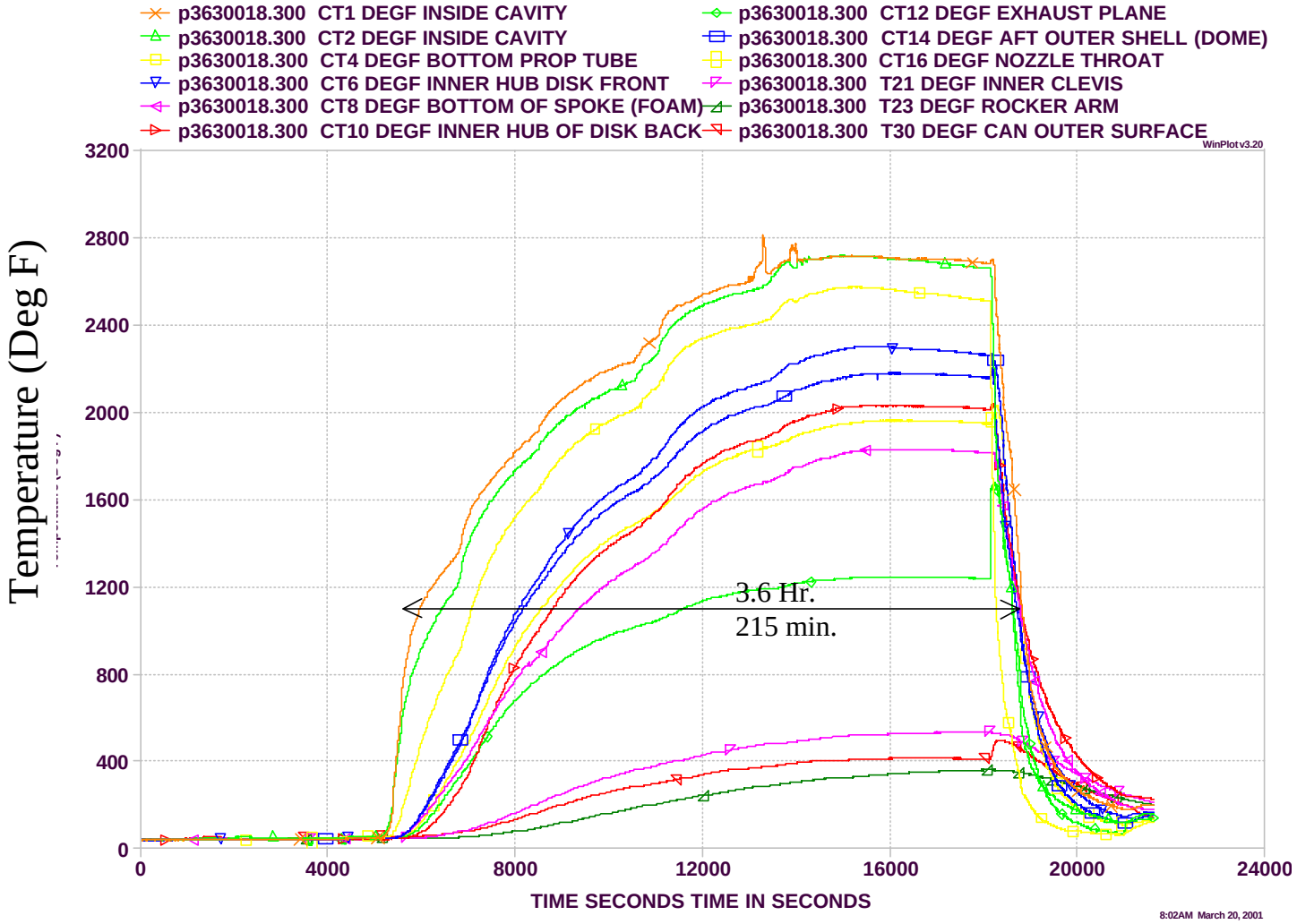


Strain Gauge Thrust Measurement

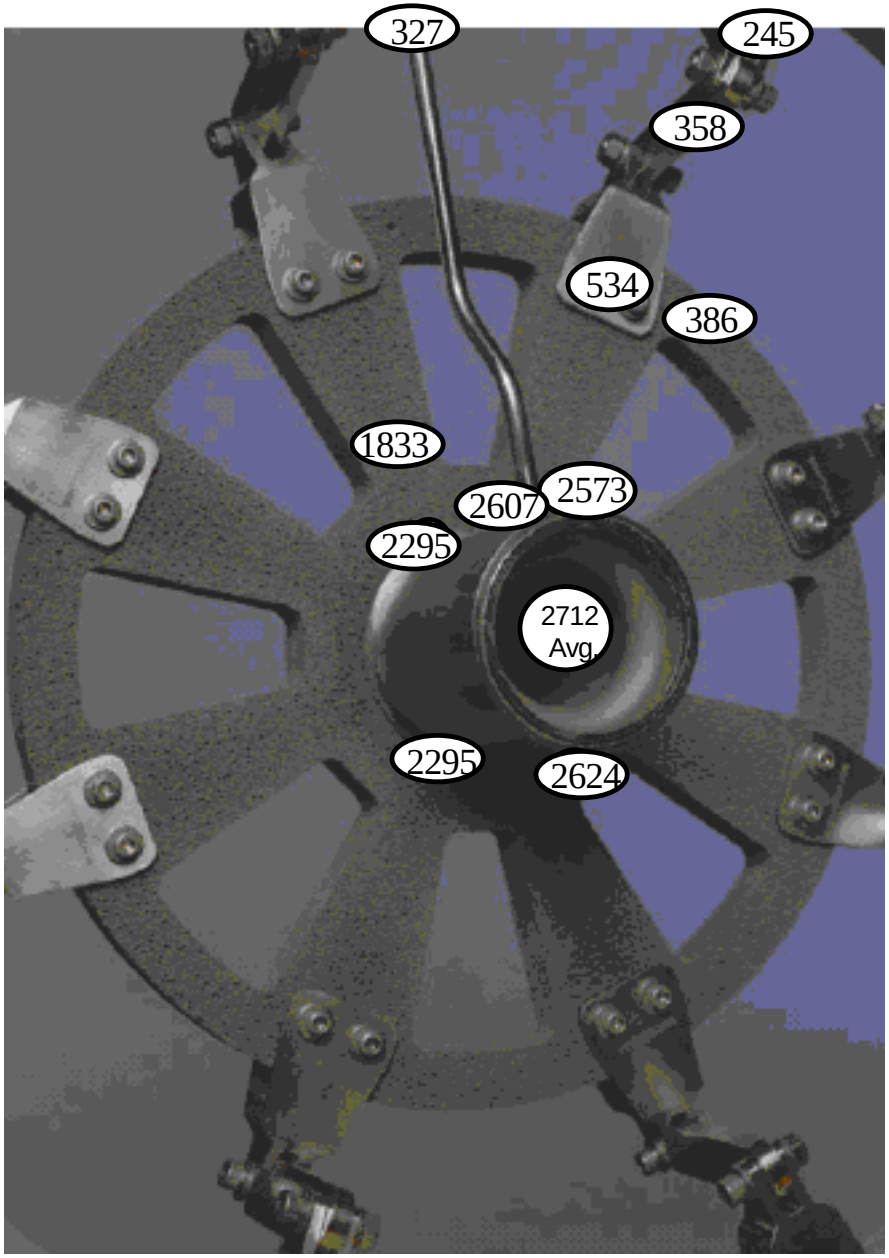


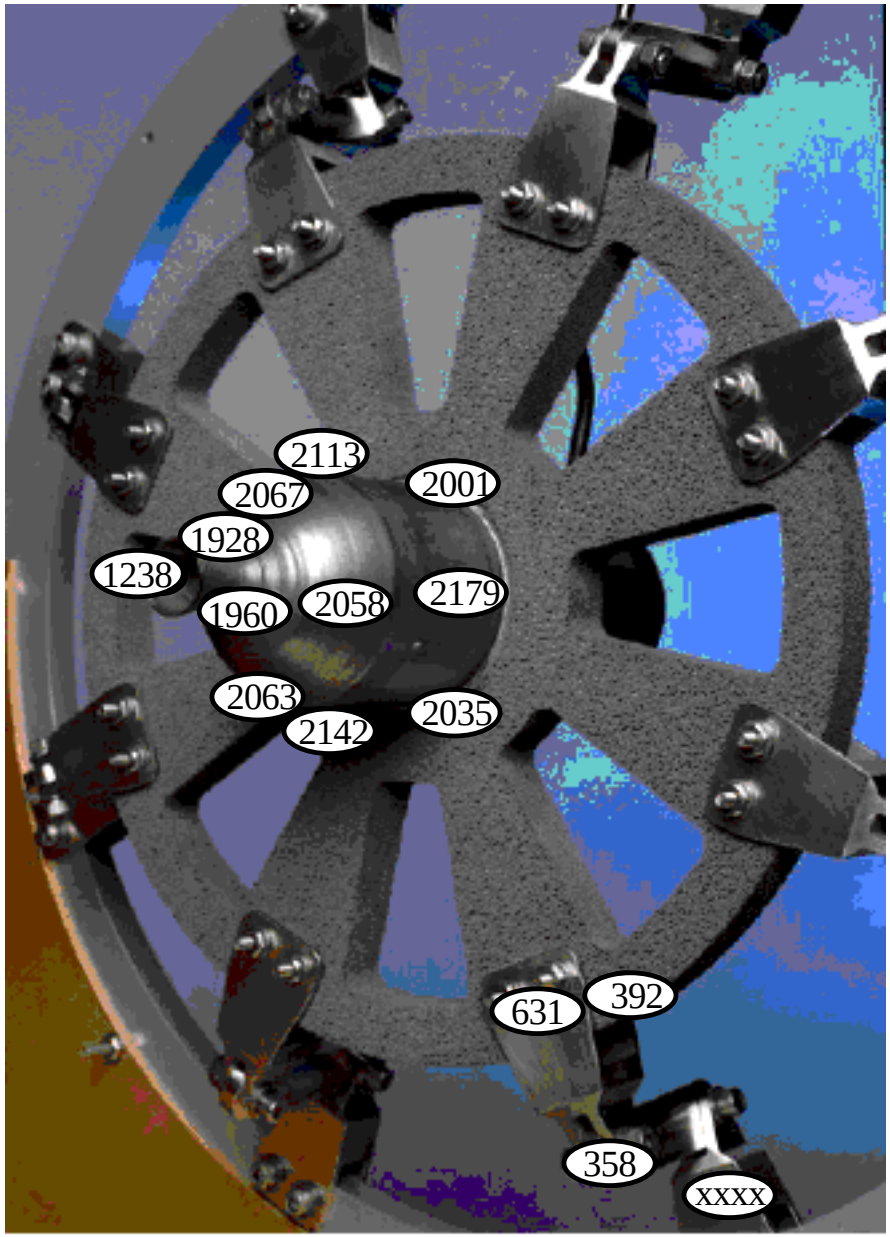

Inlet Pressure vs. Thrust
Measured Thrust (lb)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
70
80
90
100
Inlet Pressure (psia)

Steady State Temperature Profile

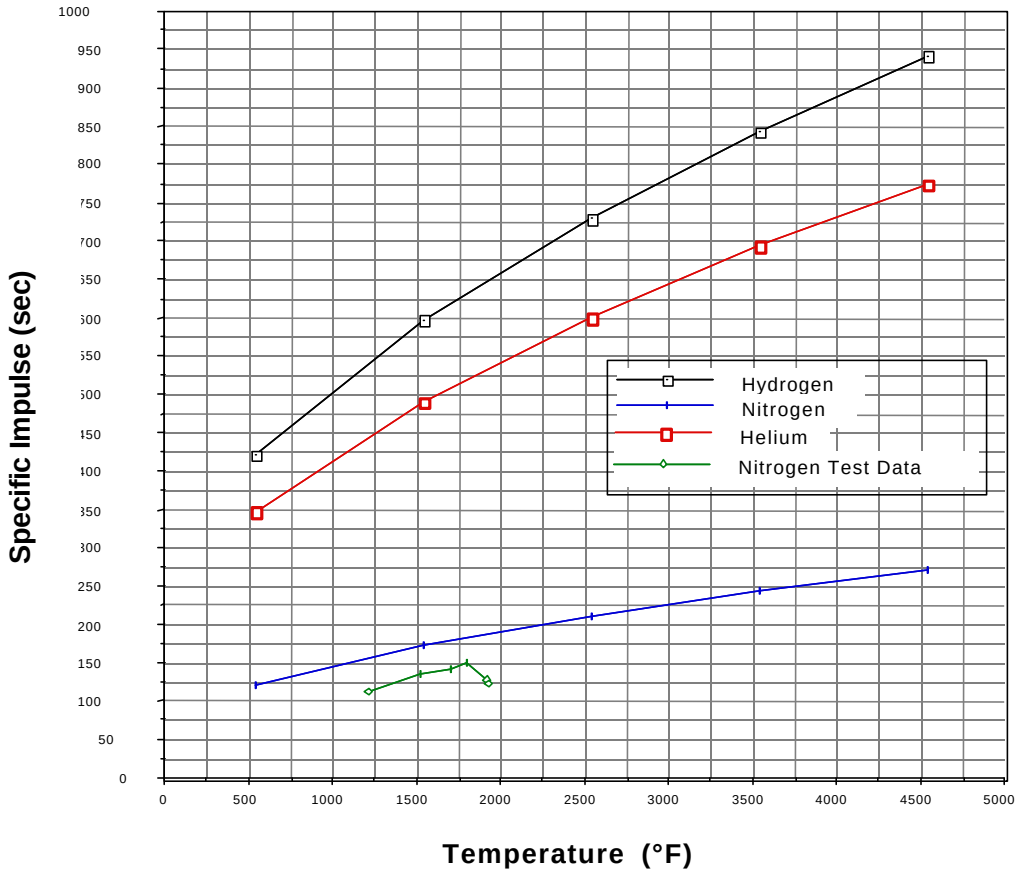


Wagon Wheel Thermocouple Locations and Steady State Temperatures (°F) ~ 1000 Watts Heater Power



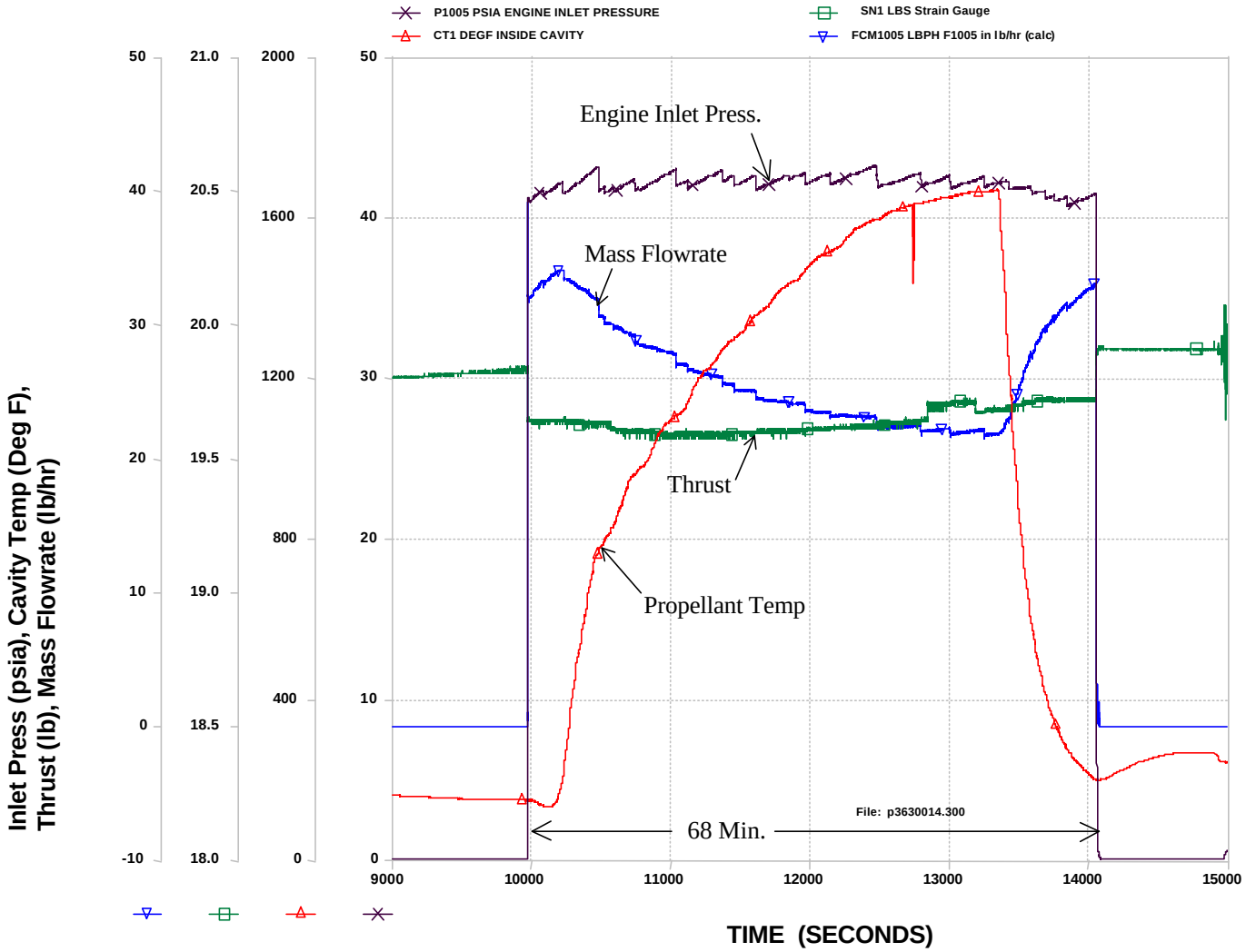


Specific Impulse vs. Temperature



Solar Thermal Engine Operating Principal

Constant inlet pressure produces constant thrust over all temperatures.
Propellant temperature define flow rate and specific impulse.



Solar Engine Testing

Summary

- Engines tested in “Thermal Storage” and “Direct Gain” mode
- Thrust measurement (strain gauges) system worked well.
  i.e. good agreement with predictions
- Good steady state temperature profile
  i.e. Secondary support structure (SS) well below temperature limits
- Verified engine operating principle
  - Constant inlet pressure produces constant thrust over all temperatures
  - Temperature determines propellant flow rate, Isp
- Max temperature achieved ~ 3100°F in absorber cavity (limited by heater)
  - Engines capable of operating > 4000°F
- Only “Wagon Wheel” configuration tested
  - “Spoke” engine remains pristine