Observations of Thermosyphon Flooding in Reduced Gravity Environments

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# Planetary Applications of Fission Power

- Several architecture studies have examined the use of Fission Power Systems (FPS) for the human exploration of the moon and Mars.

- For a 40 kW_e installation, radiators would be needed to dissipate approximately 140 kW_t of waste heat.

- A 180 m^2 radiator panel over 10 years would have 3.6 hits of sufficient kinetic energy to damage fluid flow.

- The design solution to mitigate the risk of rupturing a fluid line is to utilize multiple heat pipes.

  - In the event of a micrometeoroid hit to a single heat pipe, only the fluid in the heat pipe is lost.

- The design solution also includes high thermal conductivity composite facesheets to distribute heat across the radiator panel.

Nuclear Fission:
Powering Exploration to New Levels
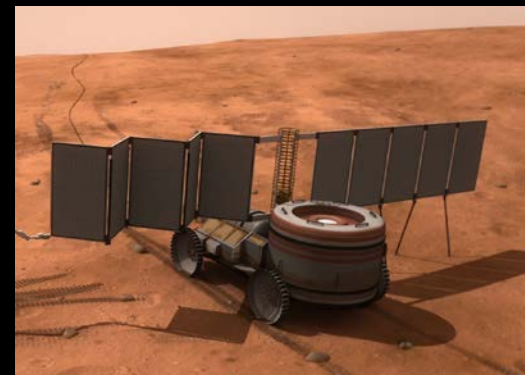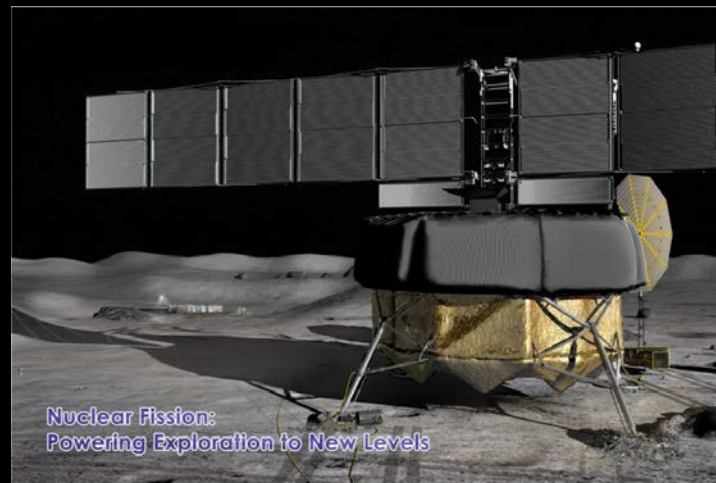
FPS Preliminary Reference Concept

- A guide for technology development.

- Power levels, temperatures, pressures, flow rates, and efficiencies become notional requirements.
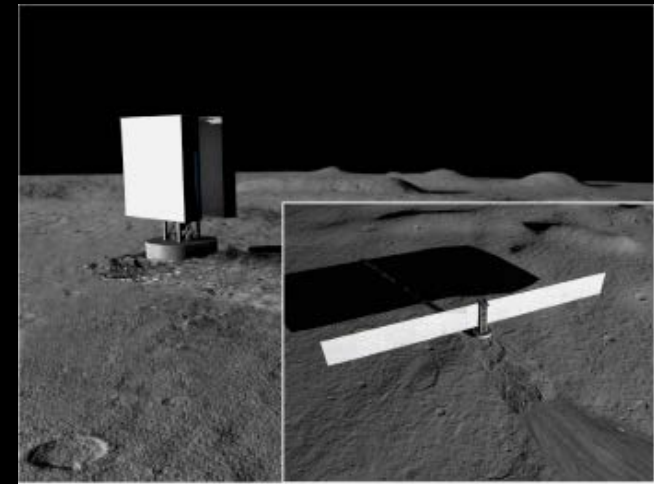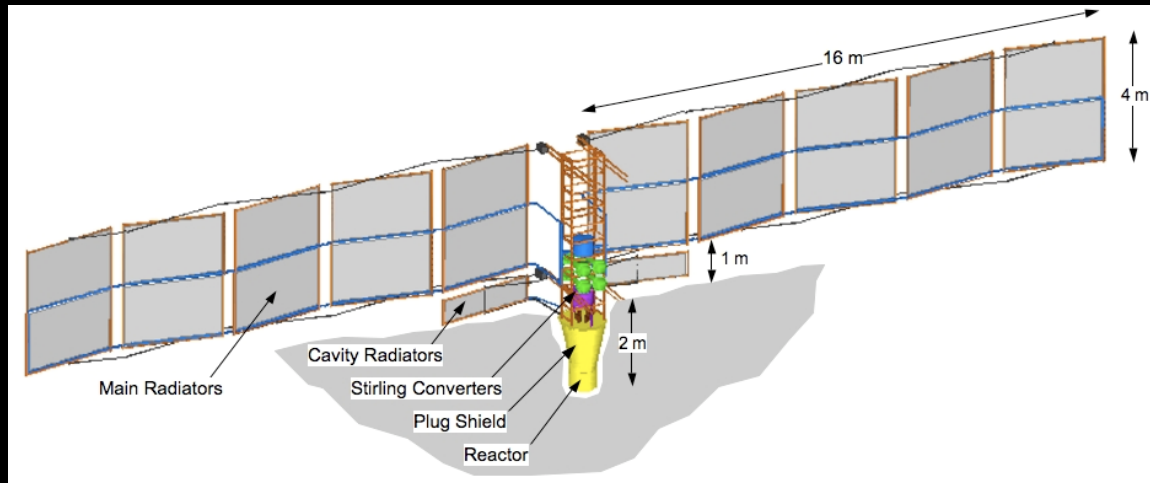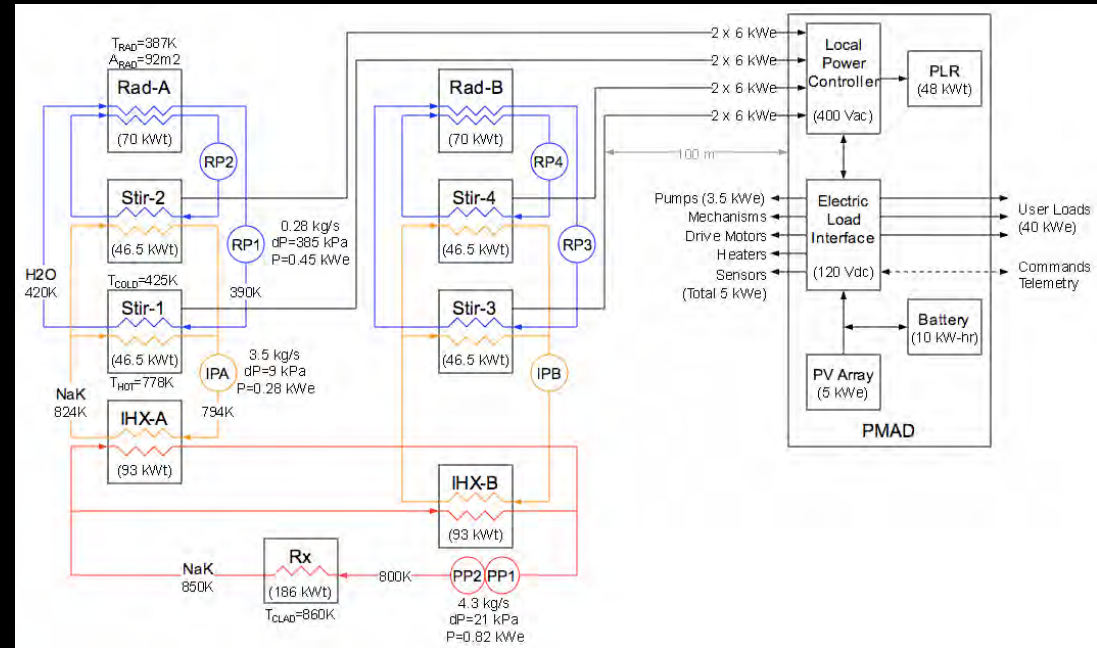
Heat Pipes Operating as Thermosyphons

- Radiators equipped with thermosyphons spread and reject waste heat effectively.

- With the aid of gravity, thermosyphons can be used within appropriate heat transfer limits.
  - The limit of most concern is the flooding limit.

- Understanding these limits requires testing of thermosyphons in Reduced Gravity Environments (RGEs).
  - Drop towers
  - Parabolic flights
  - Sounding rockets

- Parabolic flights provide the opportunity to achieve both lunar and Martian gravity environments.
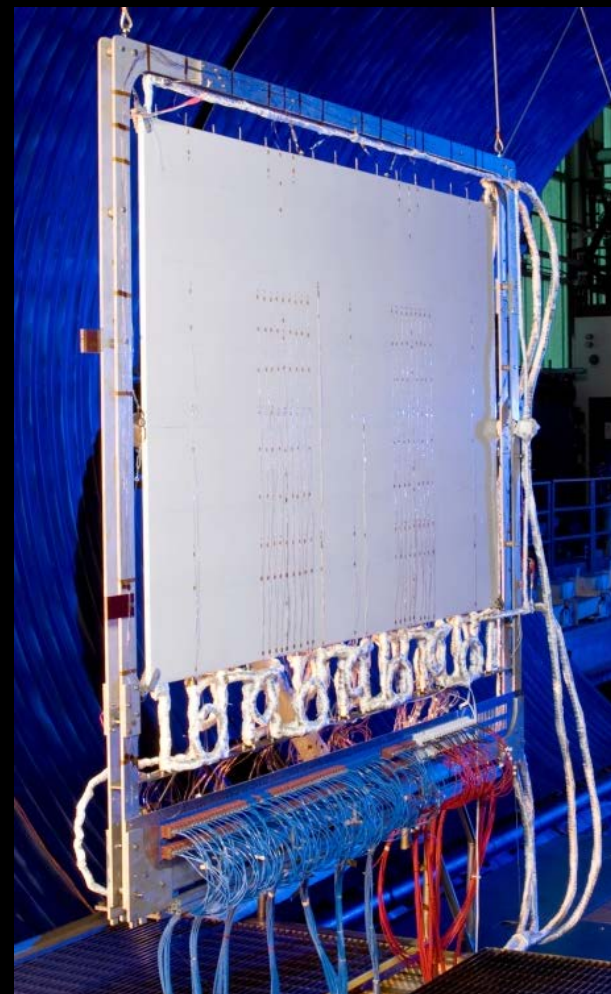
Experiment Justification

- In the literature, it was found that the flooding limits of thermosyphons have never been tested in RGEs.

- If existing flooding models were incorrect then the heat rejection system could be under-designed, leaving significant risk that the thermosyphons could reach their flooding limit.

- Upon flooding, the reactor and power converters would have to be powered down.
  - A decrease in temperature would allow thermosyphon recovery.

- After recovery, the fission power system may have to operate at a lower power level.

The Flooding Limit

- Heating in the evaporator vaporizes fluid which travels upward into the condenser.

- Vapor condenses on the condenser wall and travels back down to the evaporator with the aid of gravity.

- As heating increases, more vapor is formed and travels at a higher velocity up the pipe.

- As more vapor condenses, the fluid thickness on the wall increases.

- The increasing mass flow and shrinking vapor throat area create high shear between the vapor and the fluid.

- This shear force overcomes the gravity force and the condenser floods.
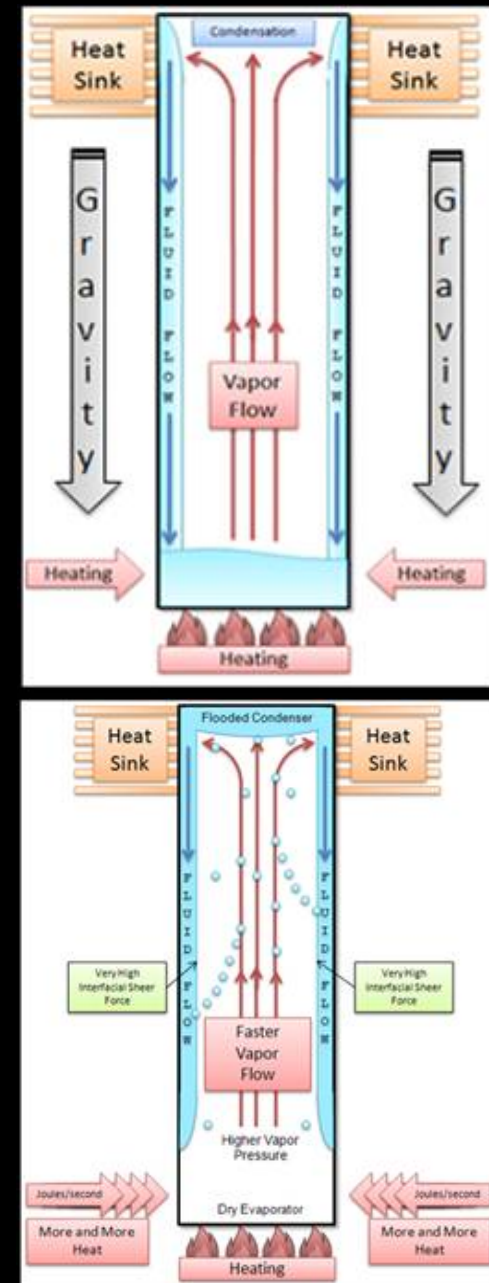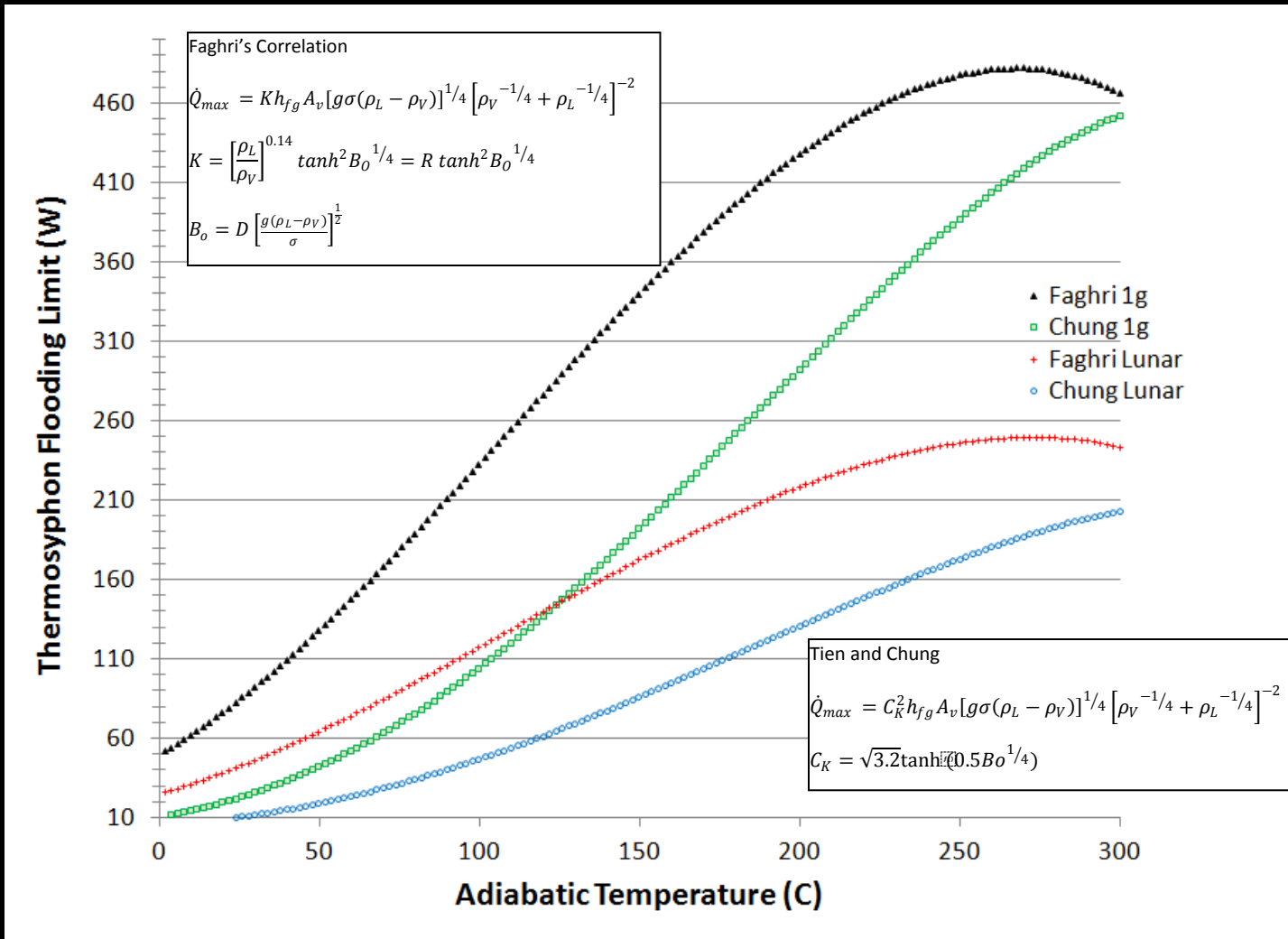
Experiment Setup

- Twelve 0.25" O.D. x 0.035" wall Ti/H_2O thermosyphons

- Individual evaporators heated electrically

- Maximum heat input: 350 W/each

- Forced air cooling w/aluminum-finned condensers

- National Instruments PXI realtime DAC system

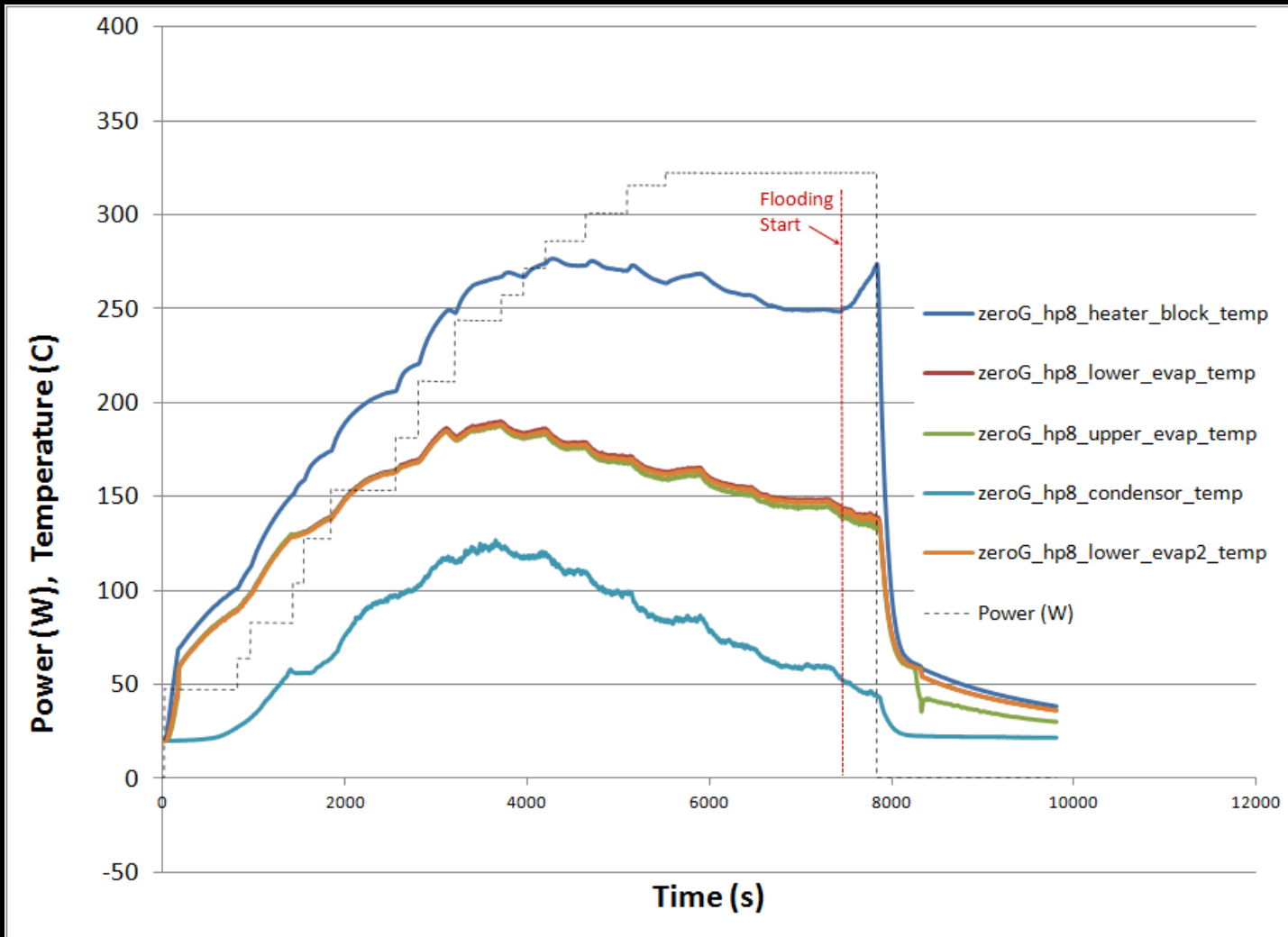- Labview programming
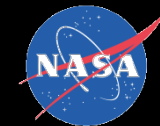
- Laptop computer control
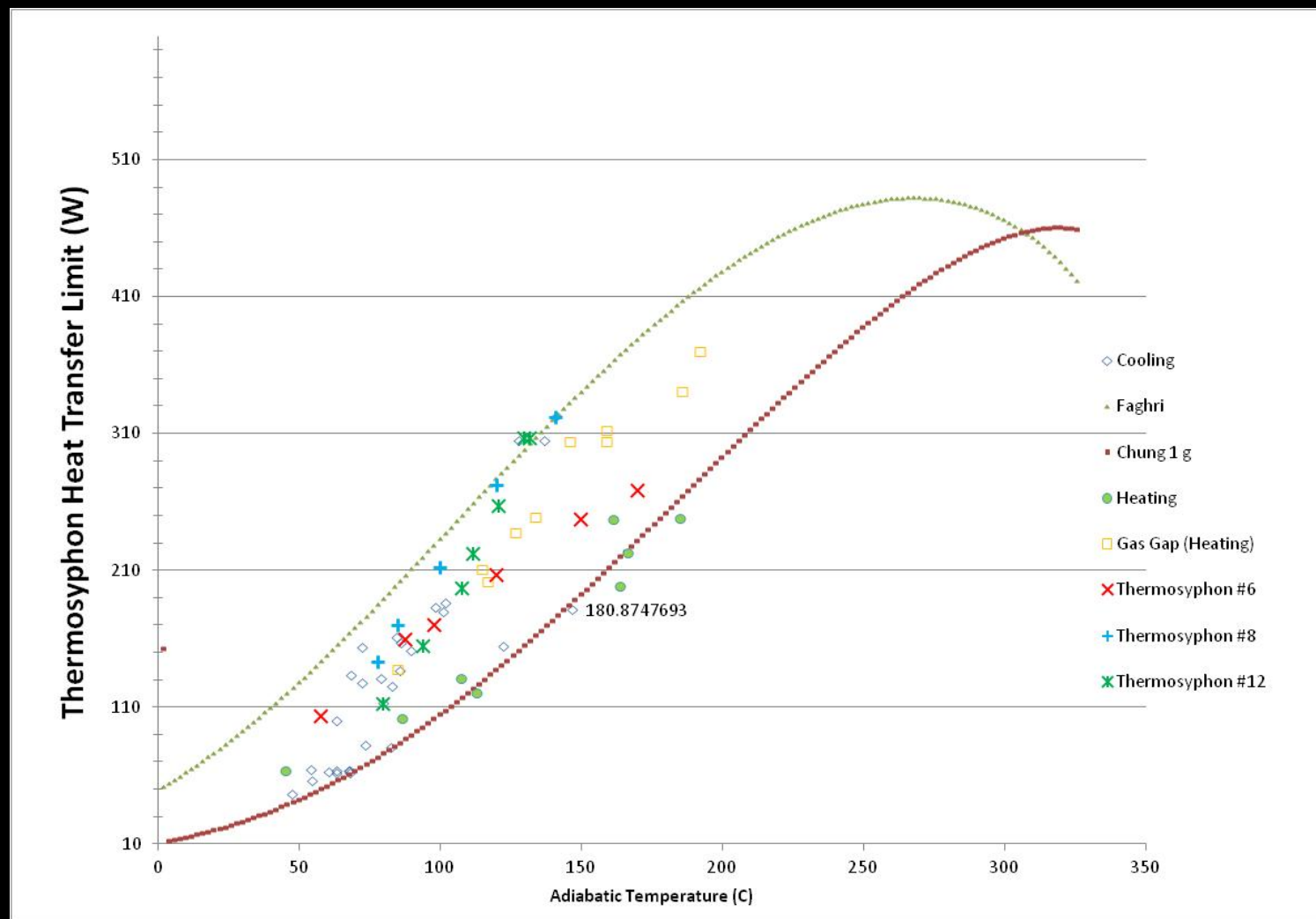
Predictions via the Bond Number

Faghri's Correlation

$$\dot{Q}_{max} = K h_{fg} A_v [g\sigma(\rho_L - \rho_V)]^{1/4} \left[\rho_V^{-1/4} + \rho_L^{-1/4}\right]^{-2}$$

$$K = \left[\frac{\rho_L}{\rho_V}\right]^{0.14} tanh^2 B_0^{1/4} = R\ tanh^2 B_0^{1/4}$$

$$B_o = D \left[\frac{g(\rho_L - \rho_V)}{\sigma}\right]^{\frac{1}{2}}$$

- ▲ Faghri 1g
- ▢ Chung 1g
- + Faghri Lunar
- ○ Chung Lunar

Tien and Chung

$$\dot{Q}_{max} = C_K^2 h_{fg} A_v [g\sigma(\rho_L - \rho_V)]^{1/4} \left[\rho_V^{-1/4} + \rho_L^{-1/4}\right]^{-2}$$

$$C_K = \sqrt{3.2}\ tanh(0.5 Bo^{1/4})$$

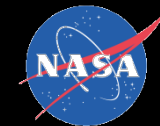**Thermosyphon Flooding Limit (W)** vs **Adiabatic Temperature (C)**

Establishing the Flooding Limit (1g)
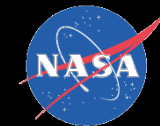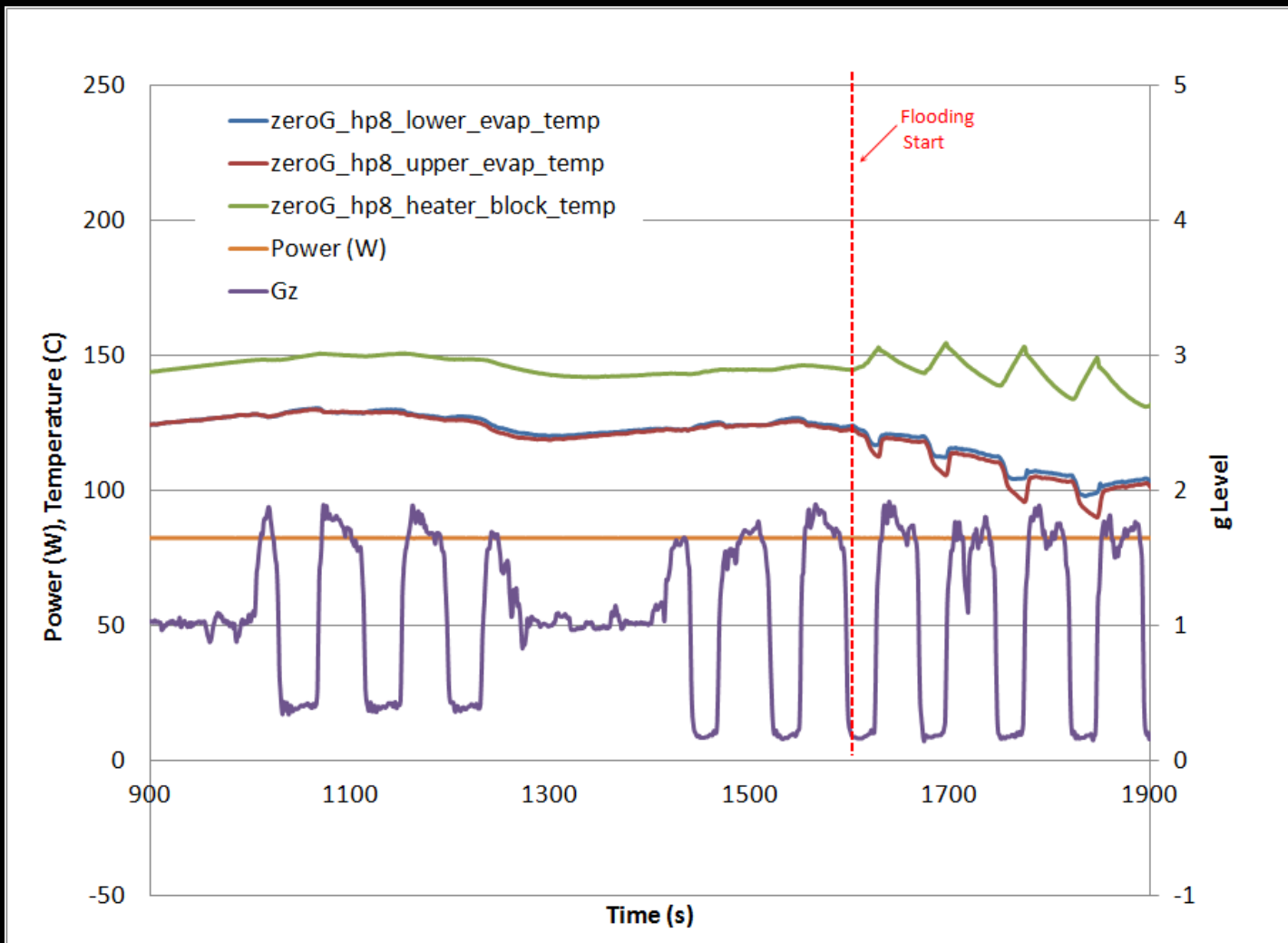
Initial 1g Flooding Limit Data

Flight Week 1, September 2011

- 40 parabolas per day

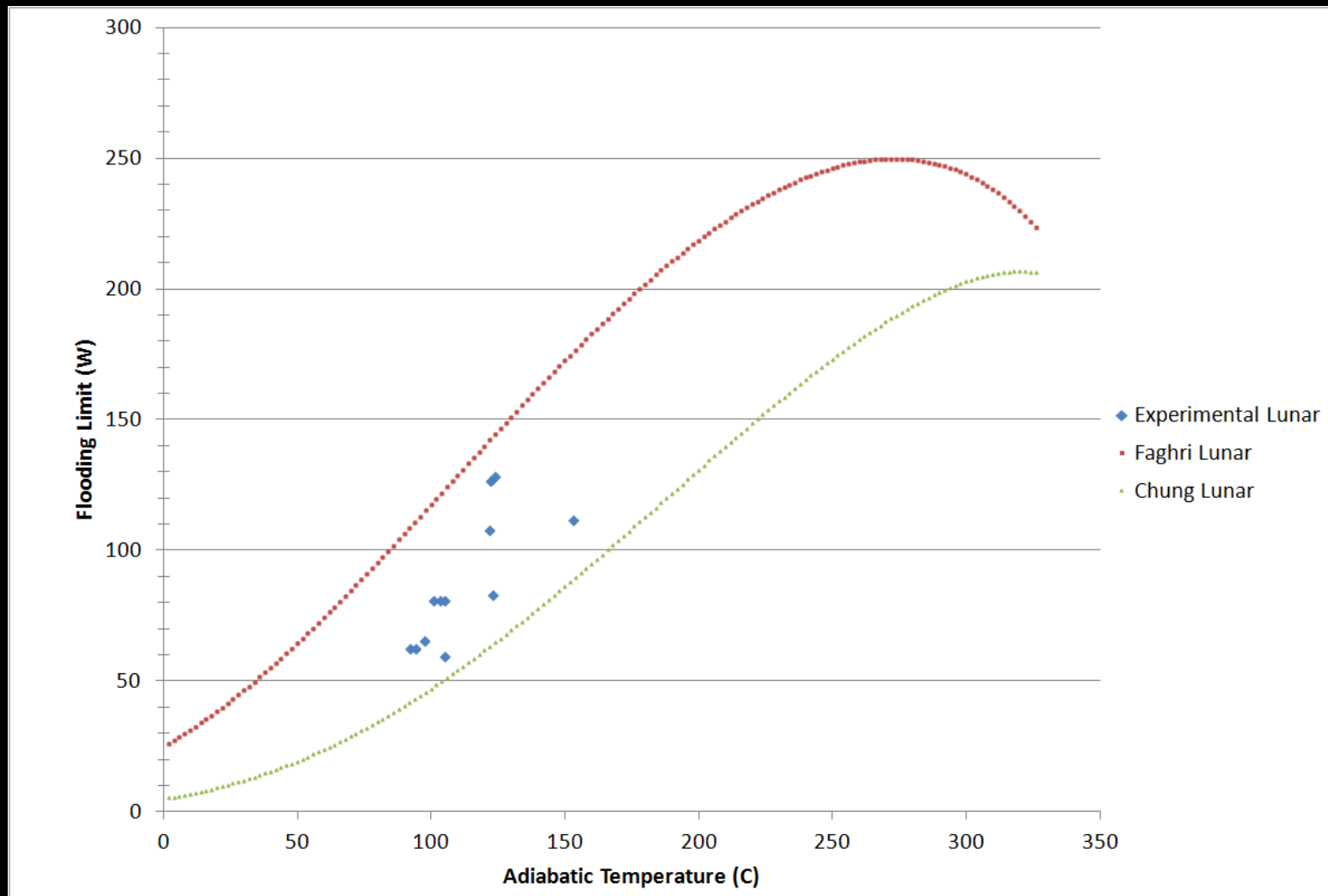- 12 Lunar, 3 Martian, 25 zero

- 4 days totaling 160 parabolas

Data Analysis

Lunar Results

Conclusions

- The observed RGE flooding limit falls between Faghri and Chung's correlations providing boundaries for analysis.

- Initial results show that correlation models may have discrepancies in the slope at lower temperatures as compared to the test data, both in 1g and reduced g.

- Follow on work is continuing in 2012 to reduce data scatter and provide an improved correlation.