Effectiveness of Linear Spray Cooling in Microgravity

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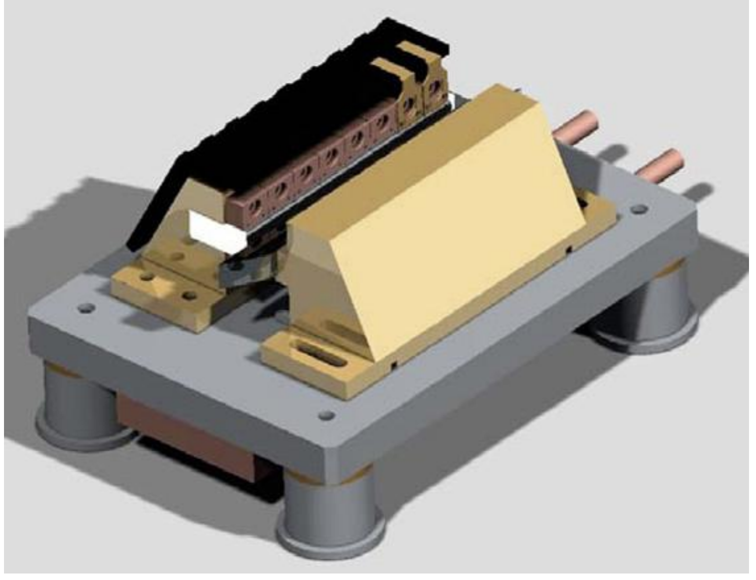
Heat dissipation requirements

- Remove heat fluxes of 100-1000 W/cm^2
- Applicable to laser diodes, computer processors, etc.



Laser Diode Array
(Silk et al, 2008)

Heat dissipation requirements

- Current Solutions
  - Flow boiling
  - Microchannel boiling
  - Jet impingement
  - Spray cooling

*Spray cooling is the most promising because it achieves **high heat transfer** coefficients at **low flow rates**.*

Limited previous microgravity research

- Sone et al. (1996): single spray perpendicular to heated surface (100 mm away)

→ 14% variation in the critical heat flux from 0 to 1.8 Gs

- Yoshida, et al. (2001): single spray perpendicular to heated surface (100 mm away)

→ Microgravity significantly effects critical heat flux

- Golliher, et al. (2005): single spray angled 55^{o} in 2.2 sec. drop tower

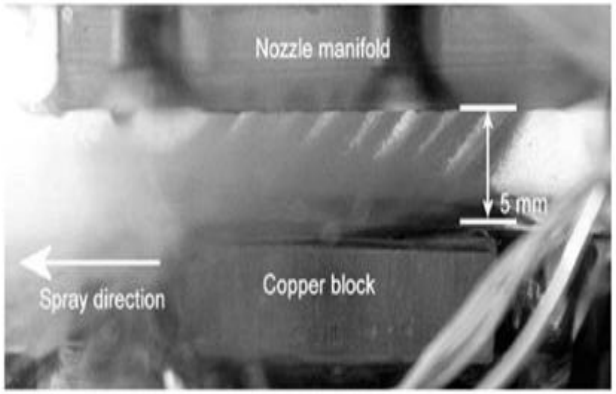
→ Significant pooling on the heated surface due largely to surface tension

- Yerkes et al. (2004): single spray in micro- and enhanced-gravity.

→ Noted a decrease in Nusselt number with acceleration

Spray cooling – linear array

- Single-spray systems do not cover a large area (> 1 cm^2)
- Regner and Shedd investigated a linear array of sprays directed 45° onto a heated surface

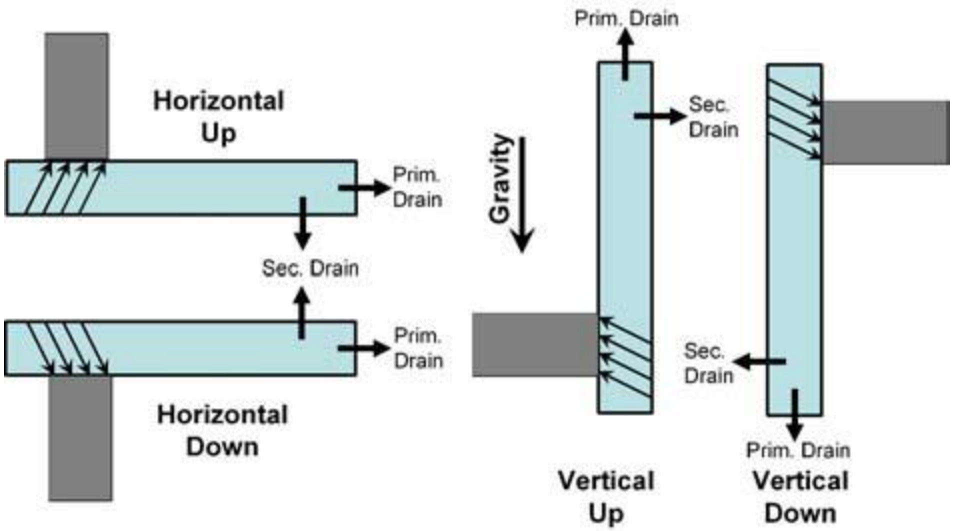


(Shedd, 2007)

- Directs fluid flow towards a defined exit to avoid fluid management issues

Experiment basis & hypothesis

Linear spray research showed performance independent of orientation



(Regner, B. M., and Shedd, T. A., 2007)

Experiment basis & hypothesis

Predict that with similar spray array, spray cooling will function independent of gravity

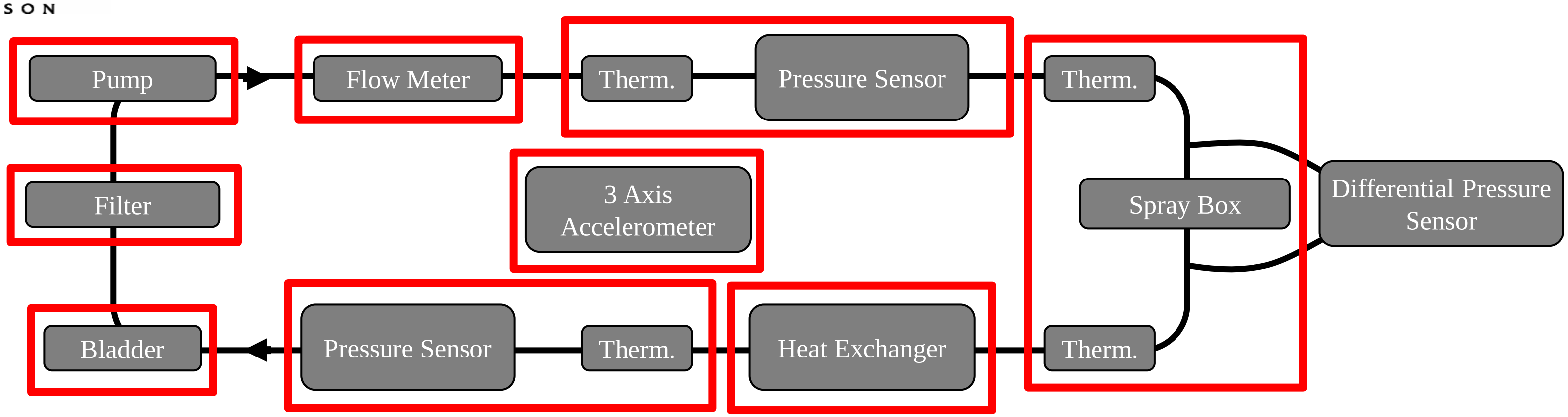
Experiment design

Goal: determine variation of heat transfer coefficient *h* with gravity

$$h = \frac{q''}{T_s - T_{in}}$$

q'': heat flux measured from heater power
T_s: Temperature of heated surface
T_{in}: Temperature of spray

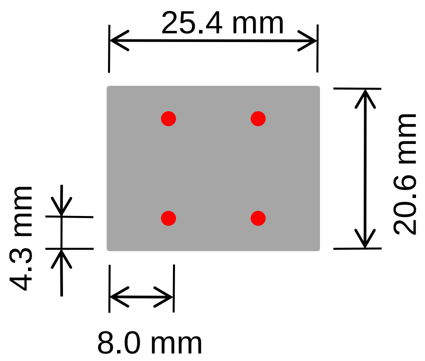
Closed-loop system



Liquid coolant:
FC-72

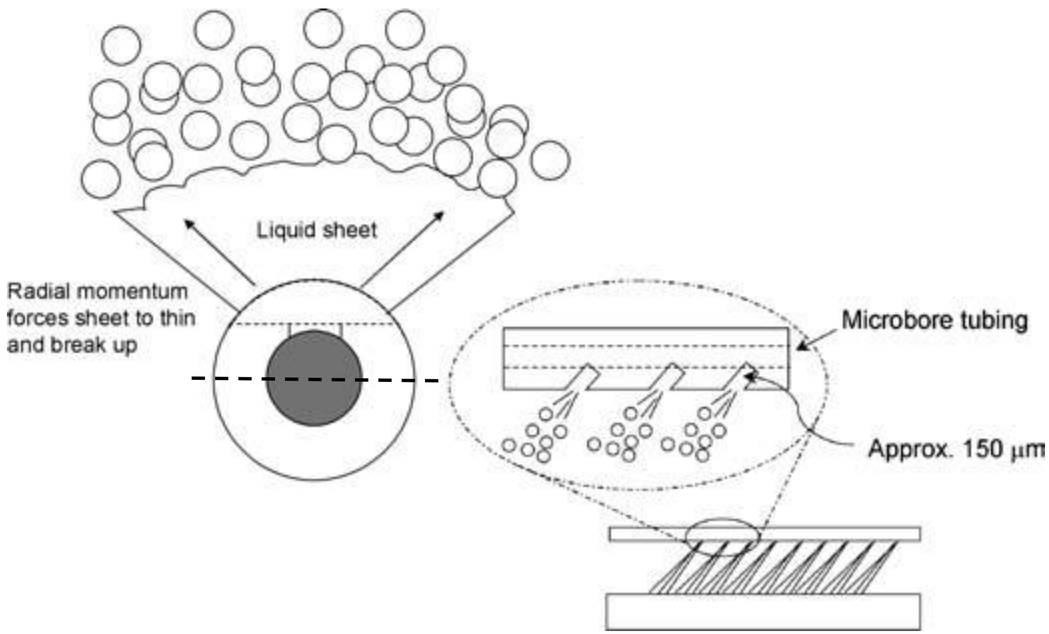
Heater design

- Ohmite TGHG 1 Ω precision current sense resistor
- Four T-type thermocouples embedded in heater

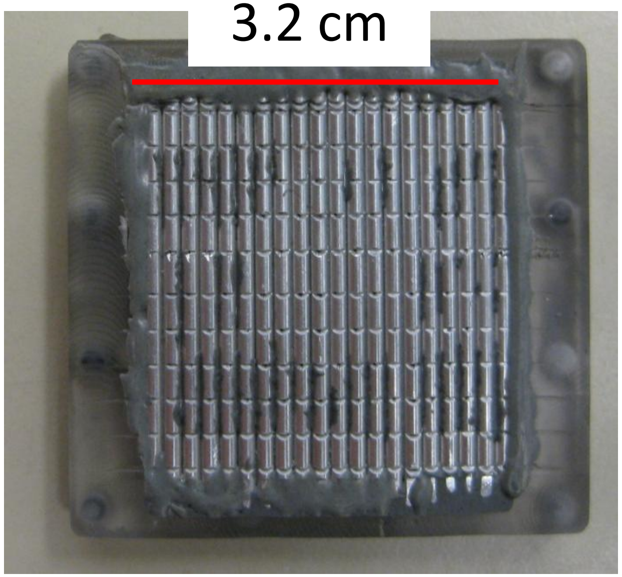


Spray array design

Made from microbore tubing:

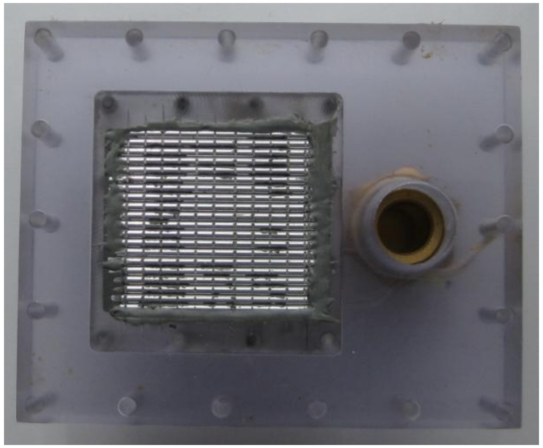


Shedd, 2007

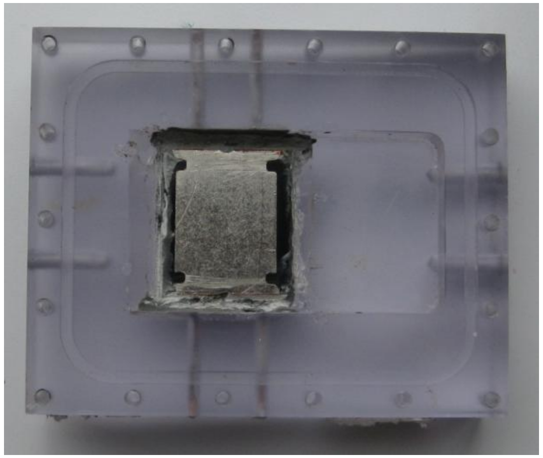


Spray array & spray box

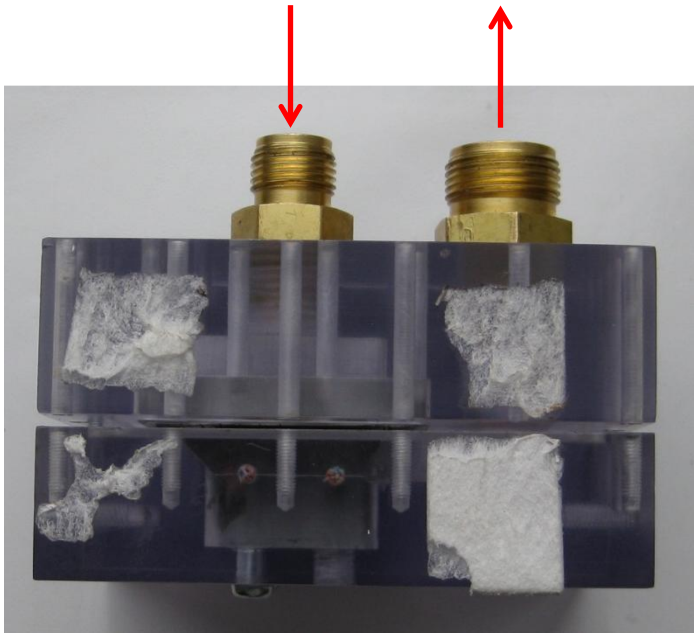
Top half:
spray array



Bottom half:
heater



Fluid inlet & outlet

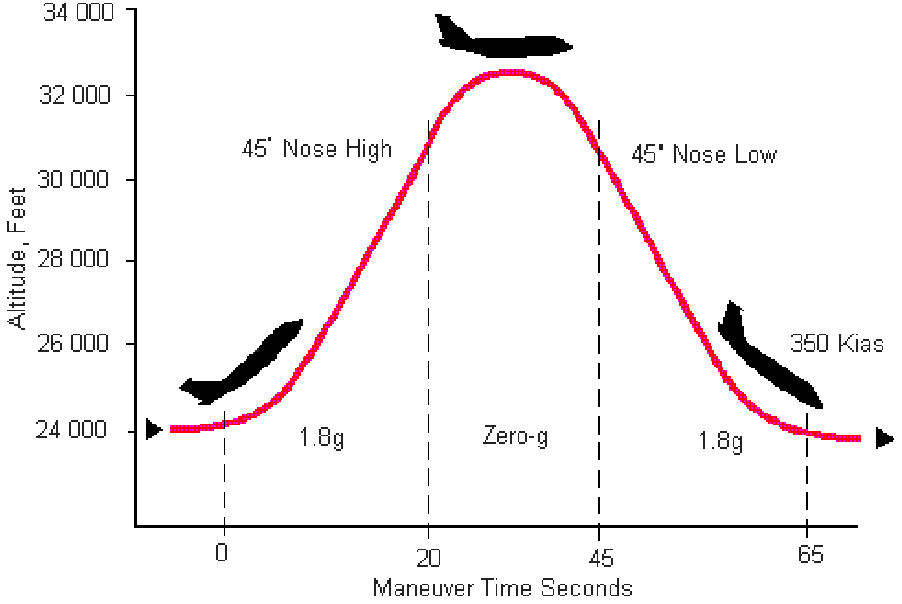


G

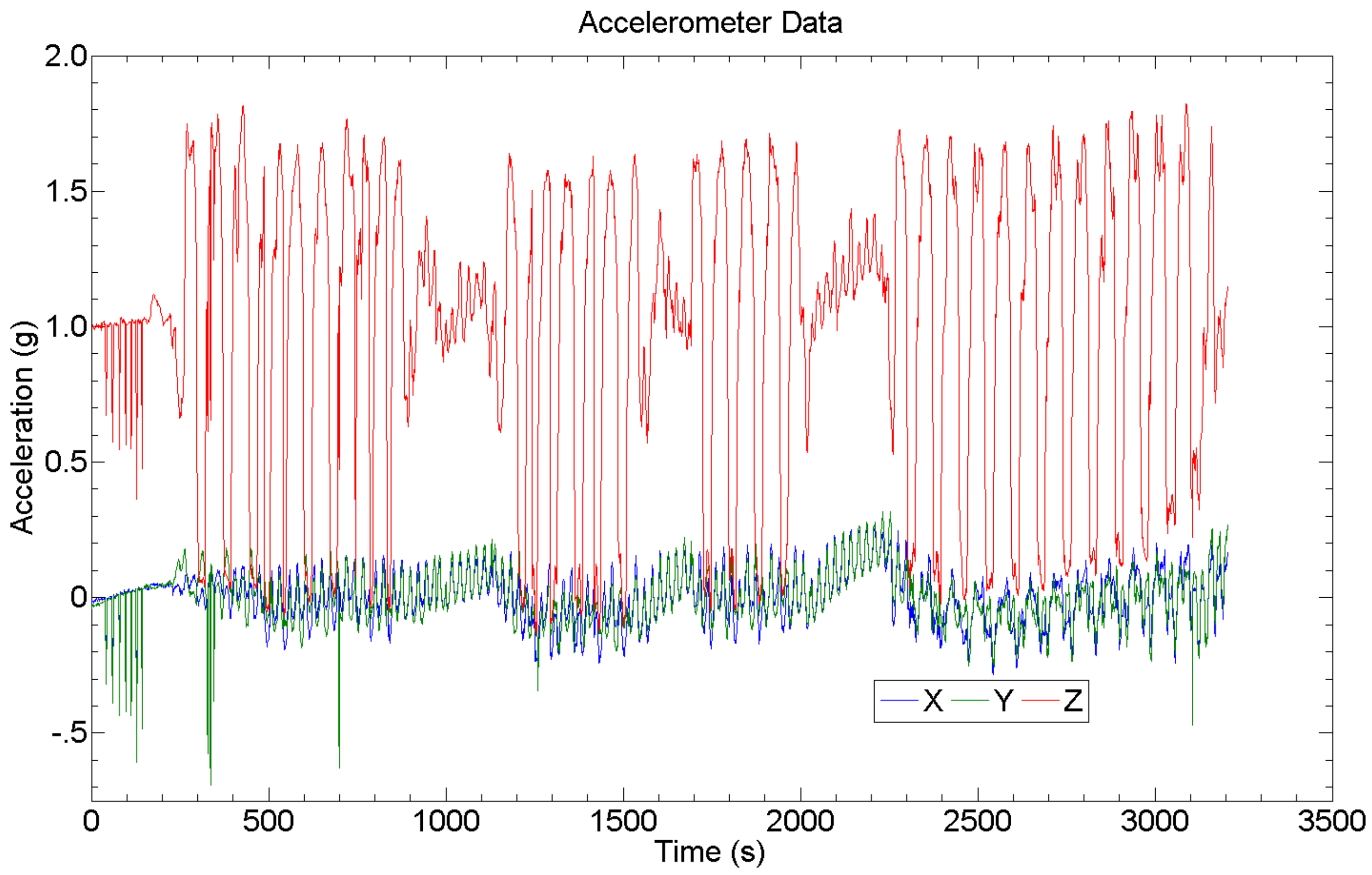
Z-direction

Microgravity environment

- 30 microgravity (nominally 0 g) parabolas lasting 20-25s each
- 1.8 g is experienced between microgravity



Microgravity environment



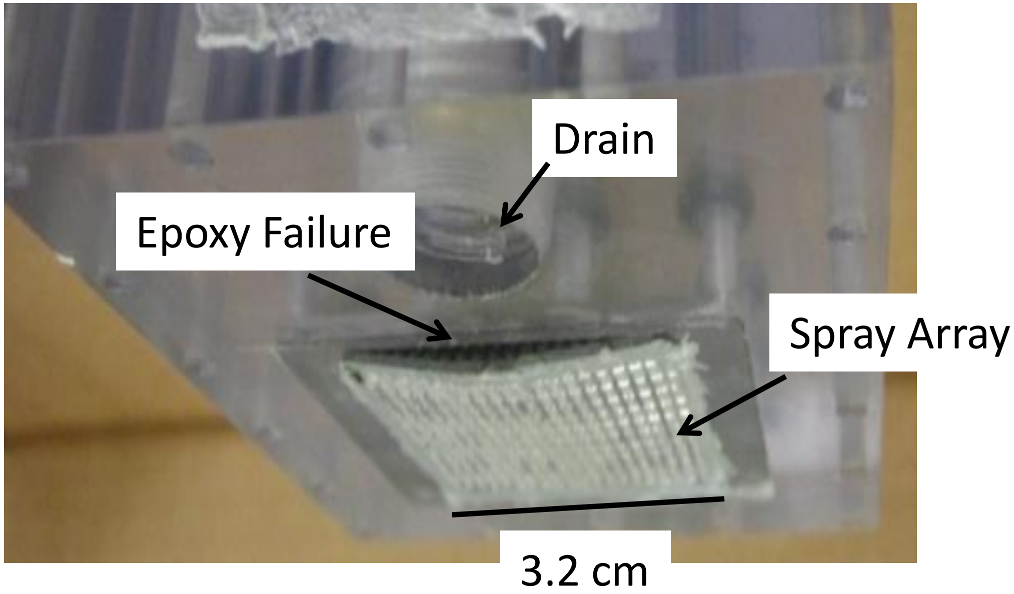
Procedure: Flow rate *Q* & heat flux *q"*

Q (L/min):	*q"* (W/cm^2):
0.67	24.9
2.67	25.8
3.81	26.6

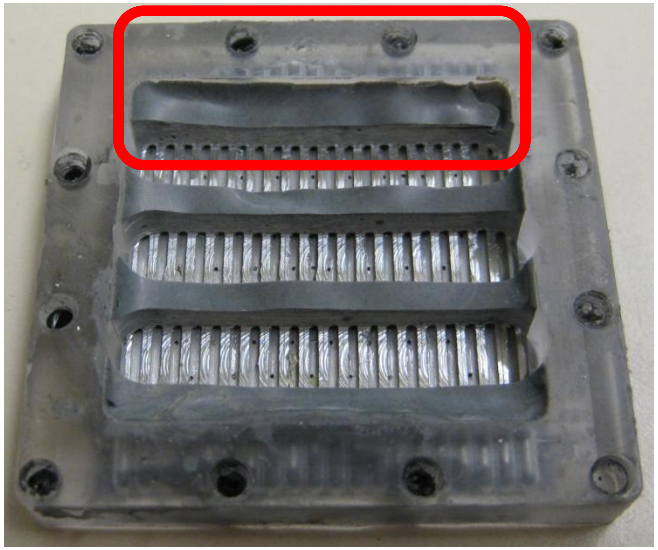
Very conservative heat fluxes used due to experimental nature

Epoxy seal failure

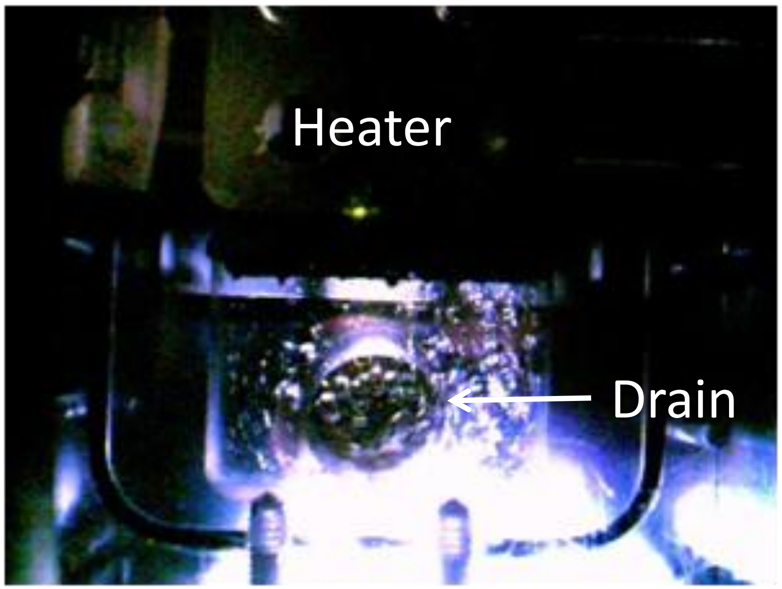
Epoxy cracked due to fluid pressure in pre-flight testing



Epoxy seal failure

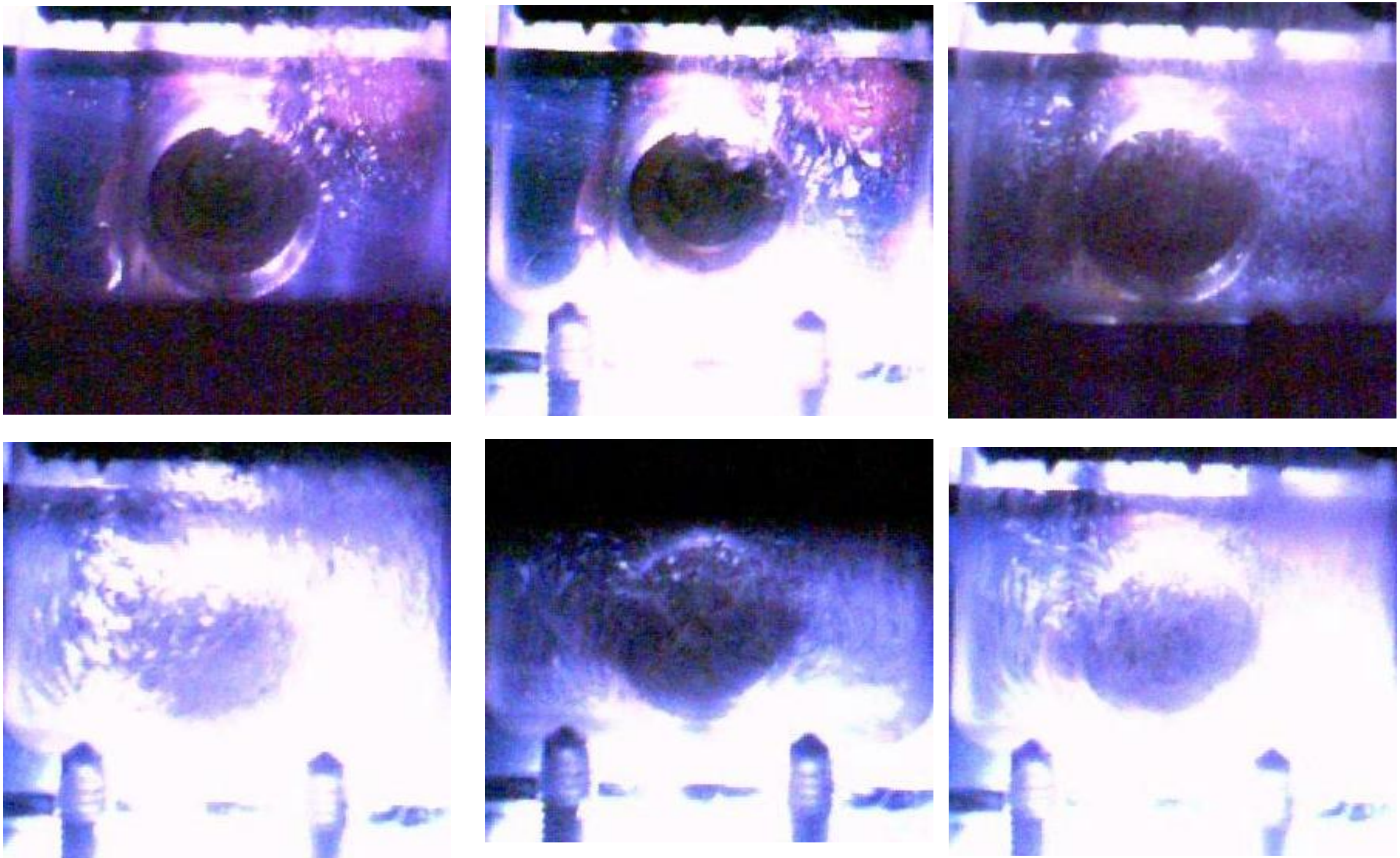


Visualization shows fluid behavior

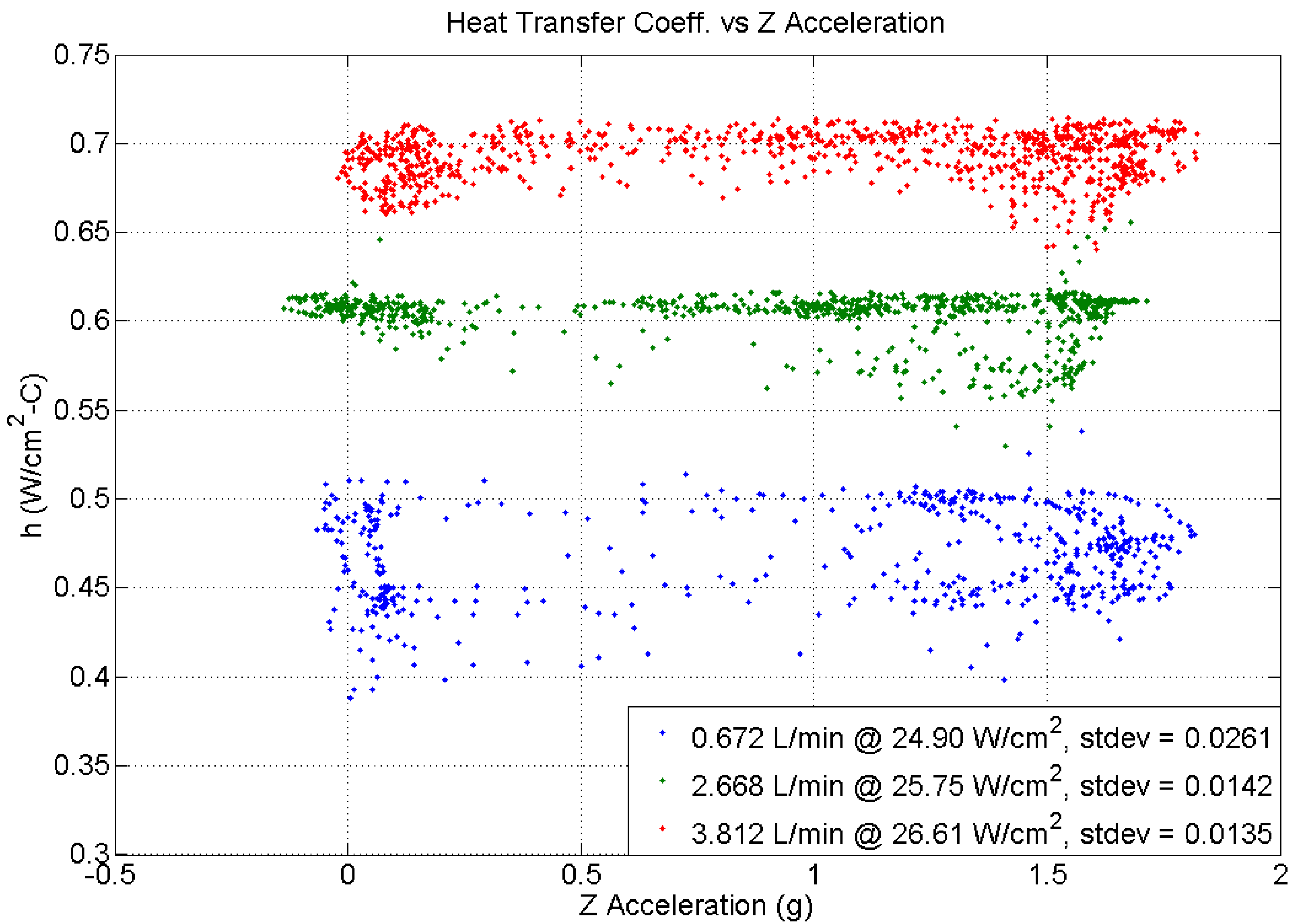


Camera

Complex fluid behavior

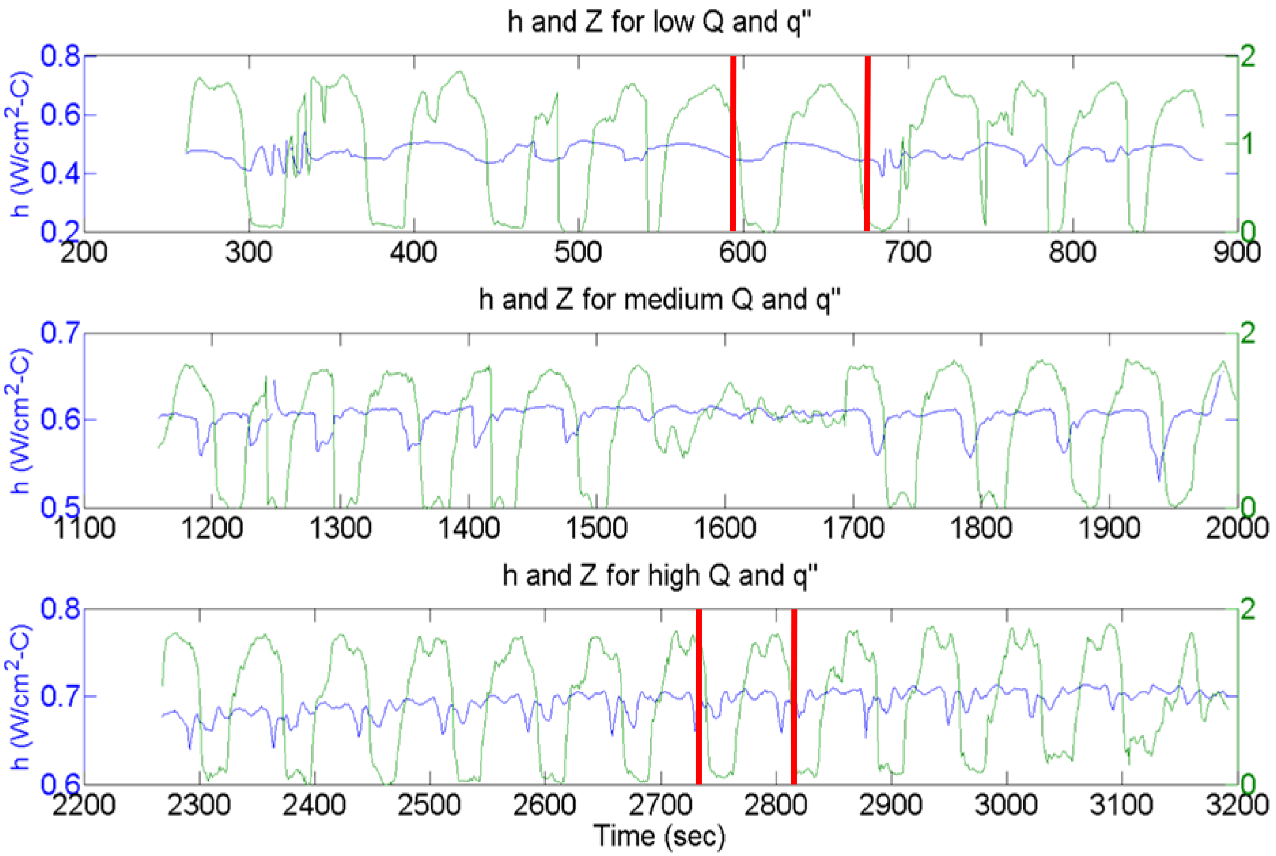


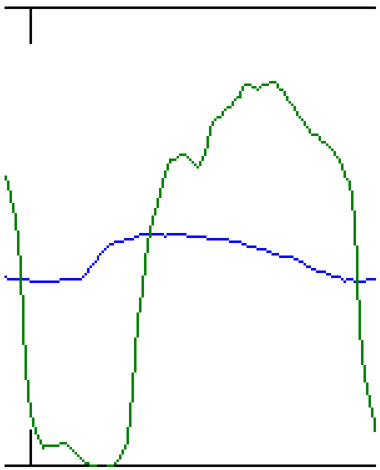
Flight data: flow rate dominates performance

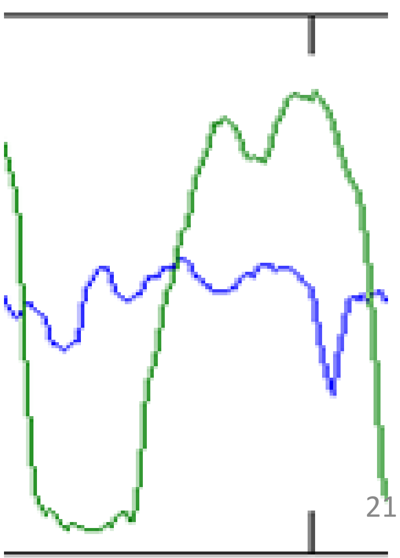


Δ*h* is consistent with Δ*g* for each flow rate

- h increases with microgravity
- Decreases with enhanced gravity

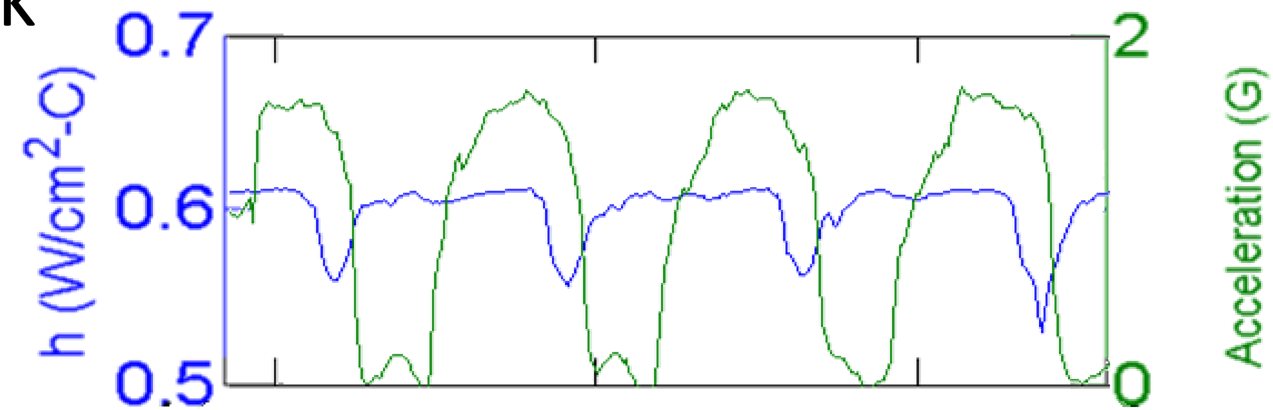




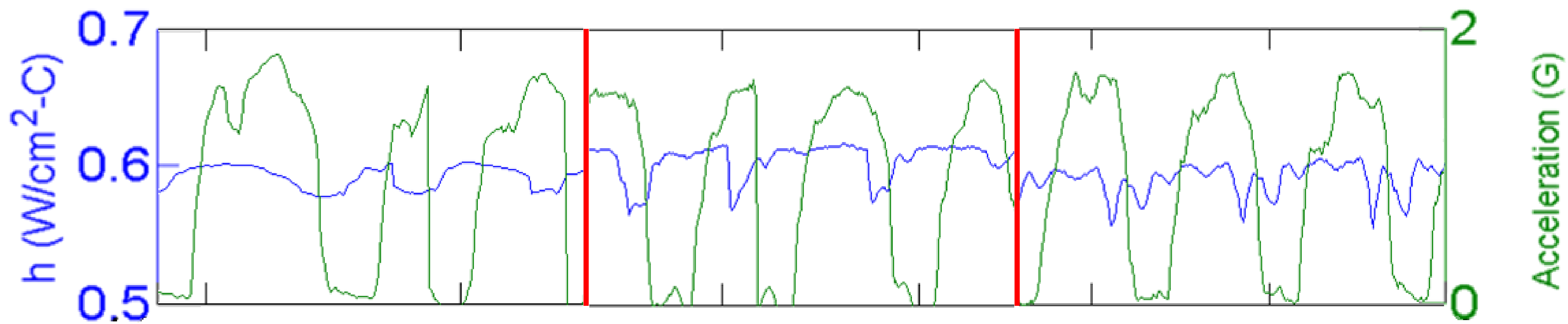


Possible Relationships

h vs. jerk



Increasing variability with flow rate:



Flow rate: 0.67 L/min 2.67 L/min 3.81 L/min

Shedd model for +/- 1 g

Shedd (2007) found a correlation of the form:

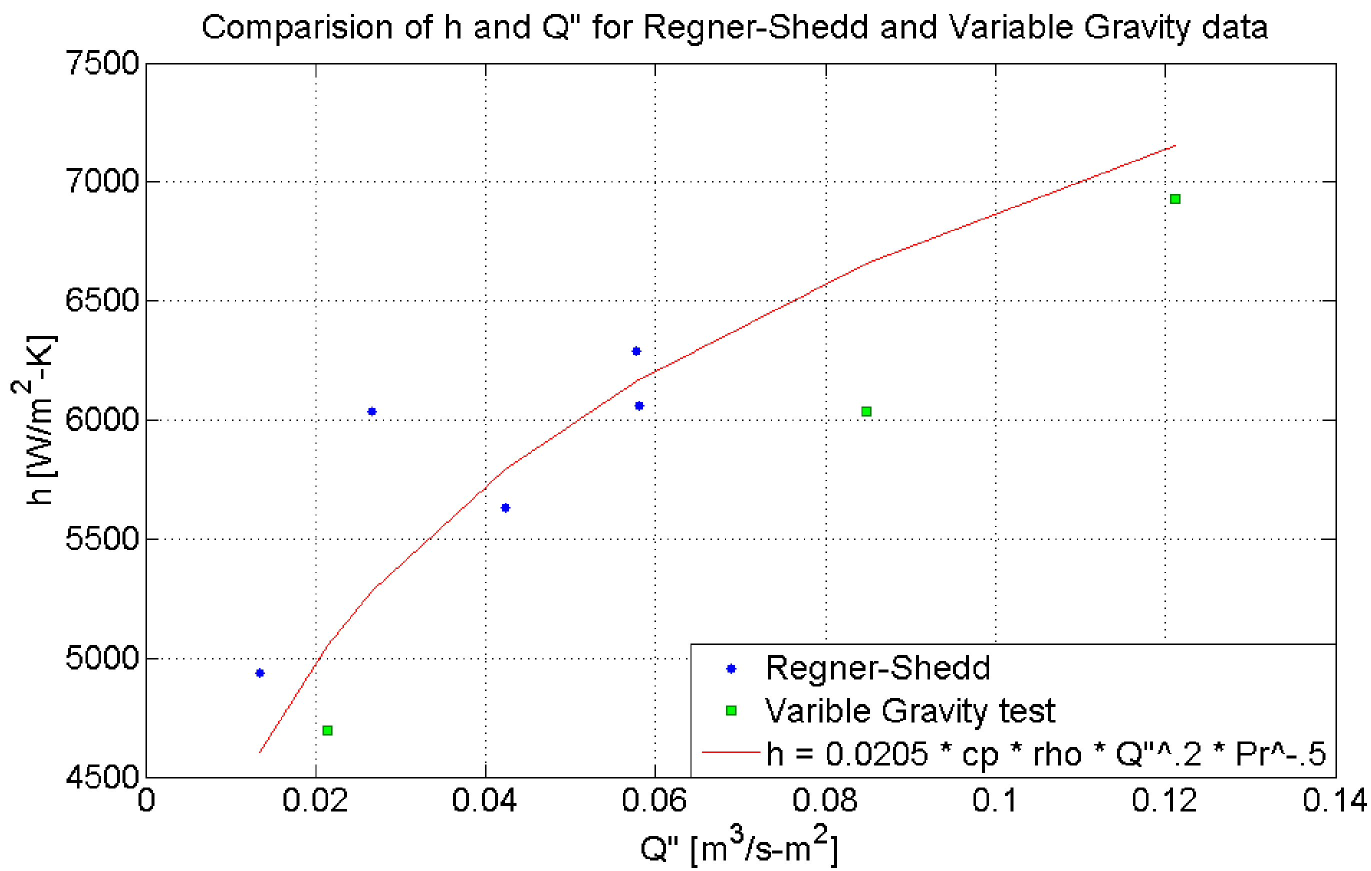
$$h = C\rho c_p \overline{Q"}^a Pr^{-.5}$$

where the heat transfer coefficient, *h*, is a function of

- the average spray droplet flux, *Q"*, and constants:
- the fluid's density, ρ,
- specific heat, c_p,
- Prandtl number, *Pr*,
- an arbitrary constant, *C* in [$m^{.5}s^{-.5}$], for a linear spray array,
- and a constant power, *a.*

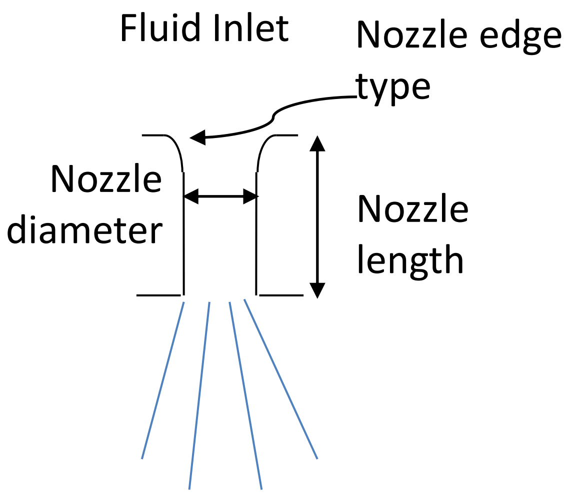
Microgravity results fit trend

- Q” is believed to be 10-20% high due to the broken epoxy on the spray array

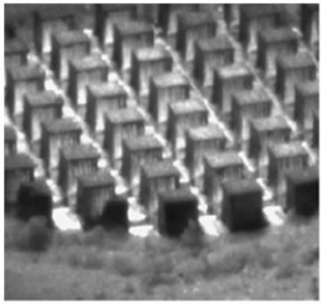


Future steps

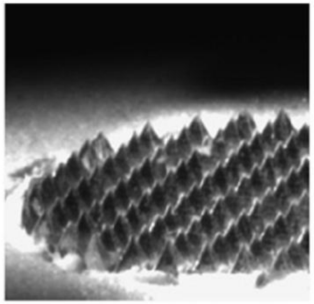
- Effect of spray characteristics
  - Spray hole diameter and length
  - Hole entrance and exit design



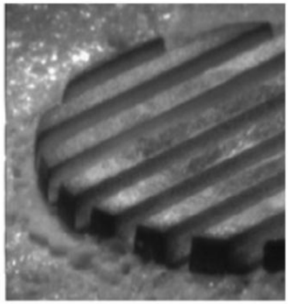
- Enhanced surfaces with linear spray cooling?



Cubic Pin Fins



Pyramids



Straight Fins

(Kim, J. 2007)

Conclusion

- Flow rate *Q* largely determines *h*
  - 2.61 % standard deviation of *h*
- Support for a simple relation between *h* and *Q*
  - Ability to predict microgravity performance with a 1g test
- Unforeseen correspondence with jerk and *Q*
- Further microgravity studies are needed

Thanks

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