A Simple Representation of the Impact of a Loop Heat Pipe on a Space System

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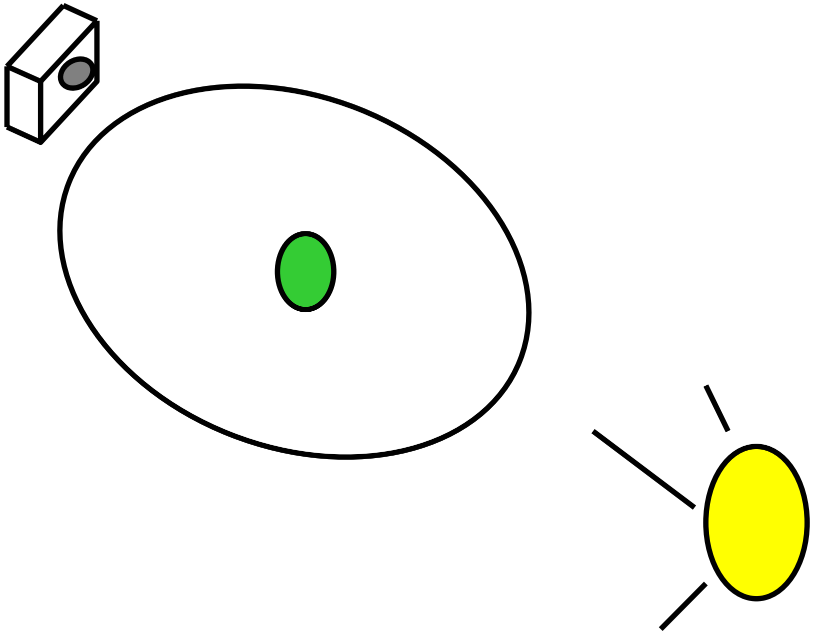
Abstract

- As two phase thermal control devices like loop heat pipes become more common, it is necessary to develop a method to simply represent their effects in a system-level model. Thermo-hydraulically simple models are available, but they still are too slow to include in system models that will be used routinely during concept development. This discusses an attempt to create a model that will represent the gross impact of an LHP on an orbiting space vehicle.
- The approach taken is to model the LHP as a node connected to the radiator through an array of variable conductors. The value of each conductor is dependent on the source temperature. By varying the shape of the conductance function, a broad range of potential responses is possible.
- The thermo-hydraulic model of the loop heat pipe was run at various input powers over its range of viability. The variable conductor model was correlated against the results using the Sinda solver. The variable conductor model was then embedded in a spacecraft system model.
- Though the variable conductance model is applicable only over a fairly limited range of operating conditions, it has proven very useful the development of the system and has provided excellent insight into the behavior of the operating space vehicle.

An Geostationary Instrument Deals With Widely Varying Heat Loads

- We are developing concepts for a geostationary instrument
- GOES experience shows that varying heat loads must be managed
  - Diurnal
  - Annual

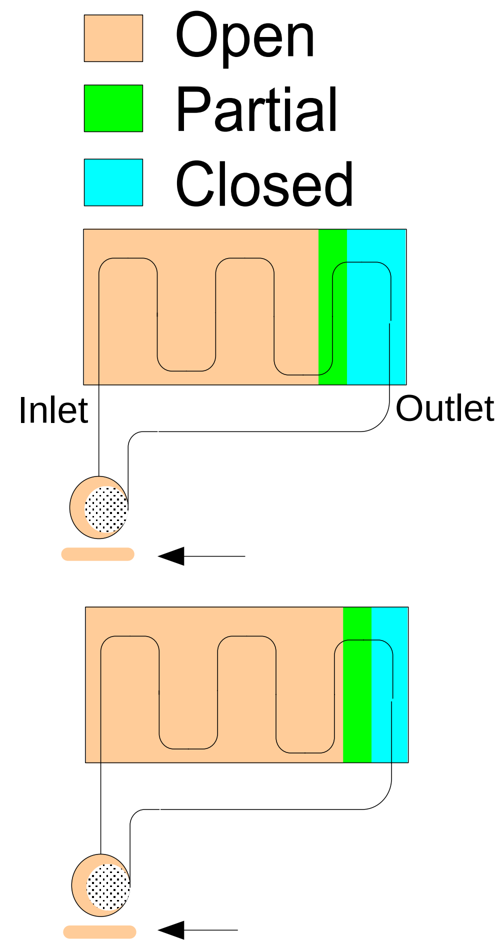


One Way to Deal With the Load is a Loop Heat Pipe

- LHP is a viable design option
  - Can transport internal loads to external radiator
  - Can control evaporation temperature
- Need some way to model it at system level
- Thermo-Hydraulic Model Simulates Two-Phase Physics (Reference 1)
- Converted from SinAps to Thermal Desktop/FloCad
  - Changed variables to reflect our design, and added heated compensation chamber

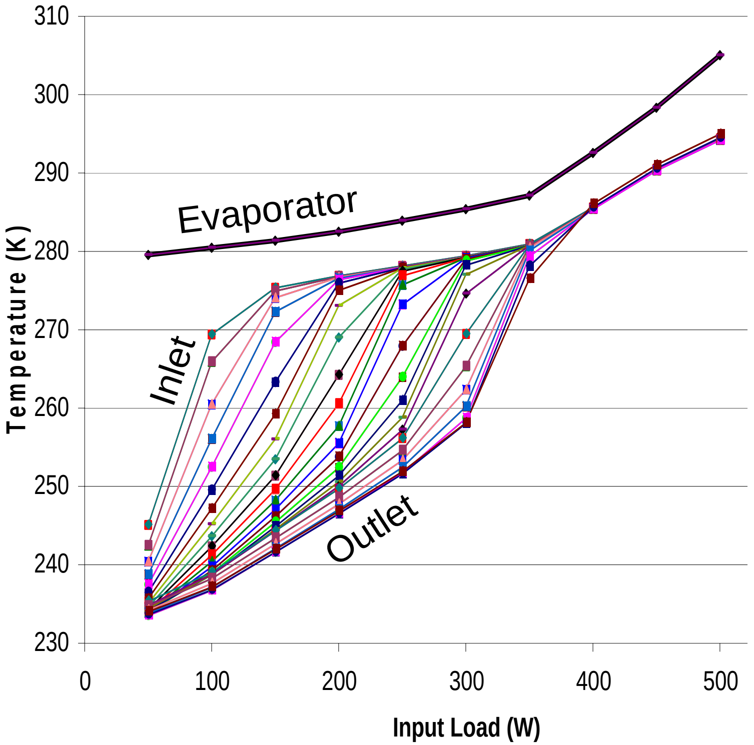
Top Level LHP Behavior Inspires Reduced Representation

LHP Behavior	Reduced
➢ Liquid evaporates	➢ Load removed
➢ Condensation in radiator until all input heat load is rejected	➢ High conductance from evaporator to radiator
➢ Beyond, radiator decoupled from load	➢ Low or zero conductance from evaporator to radiator
➢ At increasing load, full condensation takes longer	➢ More radiator is connected



LHP Integrated with Radiator in Orbit Produces Credible Results

- Controlled compensation chamber temperature
- Ramp up of evaporator temperature
  - Drop ~ 40 W/K
- Radiator opens as load increases
  - Eventually becomes fully open
- Fluid Model used as “True” behavior in future calculations



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Model is 'Expensive' to Run

- A thermohydraulic model, even simplified, is difficult to incorporate
  - Takes a lot of calculations per time step
  - Needs small time step to resolve fluid physics
    - Fluid variations are not particularly important to external thermal performance with slowly varying boundary conditions
    - Spending a lot of time on things that don't affect the results much
  - Transient instabilities can stop the entire analysis run
- We need a representation that is
  - Fast enough for parametric analysis of the system
  - Robust
  - Accurate enough that we don't make big mistakes in architecture

Try to Capture the Essence of Behavior Without Modeling All the Physics

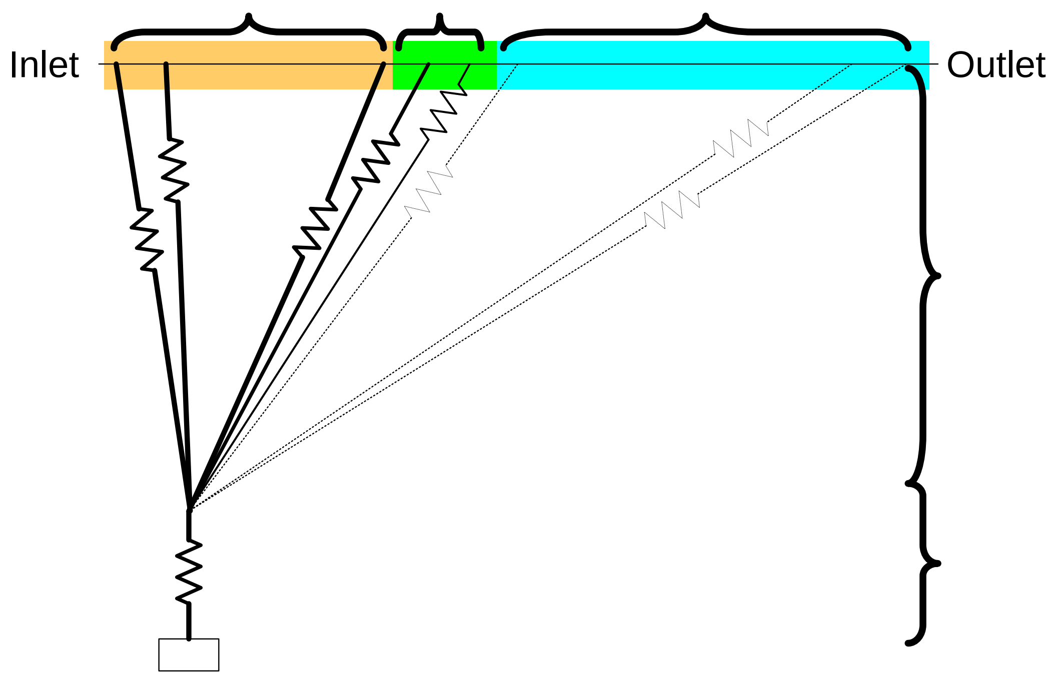
- In simplest terms, a controlled LHP looks like a variable resistor
  - Resistance is dependent on source temperature
- We're most interested in the temperature drop from the evaporator to the radiator
- Secondary goal is temperature variation across the radiator

Model LHP as Array of Variable Conductors

- Break radiator into segments
- Connect each to evaporator through a variable conductor
- When cold, all are off
- As the heat input increases, conductors turn on in sequence based on rising evaporator temperature

Conductor Behavior Tailored to Mimic Reality

- Model it in Sinda
- Derive values of conductors



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In Sinda, this is a SIVA

- A SIVA is similar to more familiar SIV conductor
  - Interpolation is based only on the first node temperature

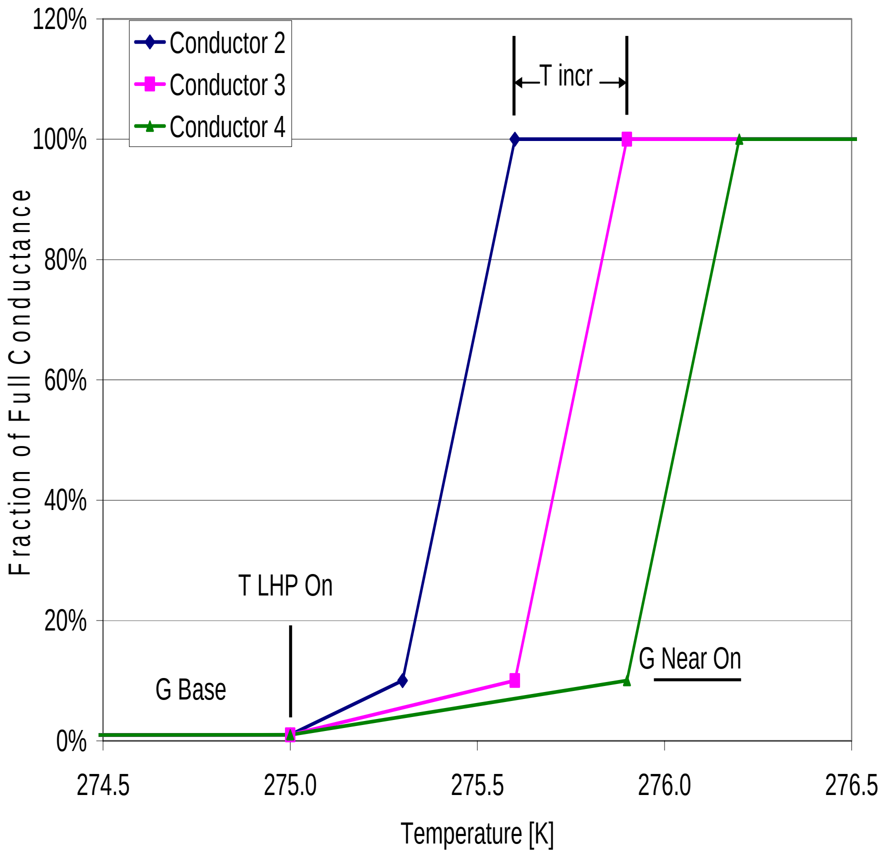
Evaporator node	Radiator node	Value array	Scaling factor

```
SIVA 101,HUB.10, RAD.101, hp.A101,fac
                    .
                    .
                    .
SIVA 125, HUB.10, RAD.125, hp.A125,fac
```

- Data in the array drives the network behavior

Rising Ramp Allows Smooth Turn On

- Each conductor ramps from 0 to 100%
- Some tweaks needed for stability

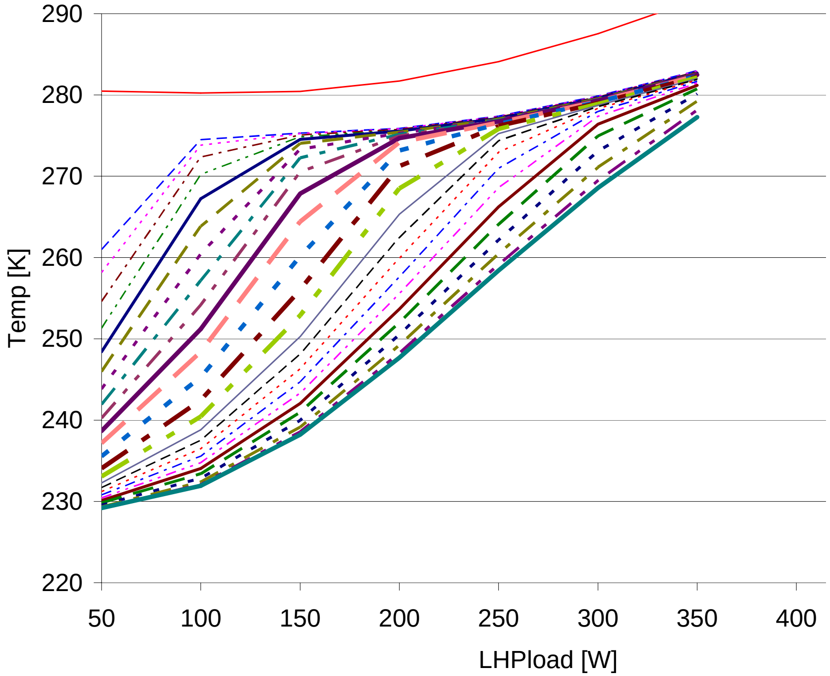


Use Optimizer to Match Simplified to Detailed Model

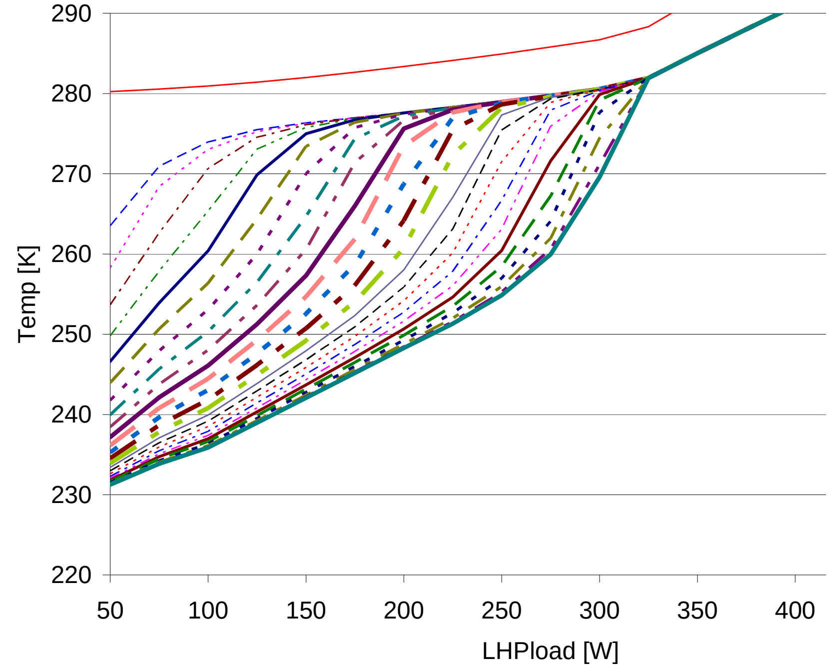
- Run the thermo-hydraulic model for range of loads
  - 50 to 350 W input in 50 W steps
  - Varying beta angles
  - NOT trying to handle anything but normal operation
- Fit simplified to detailed model using the Sinda optimizer

Two Systems Have Comparable Performance

- Evaporator and radiator segment temperatures
- Some differences are apparent, but evaporator response is similar



LHP Fluid Model



LHP Simplified Representation

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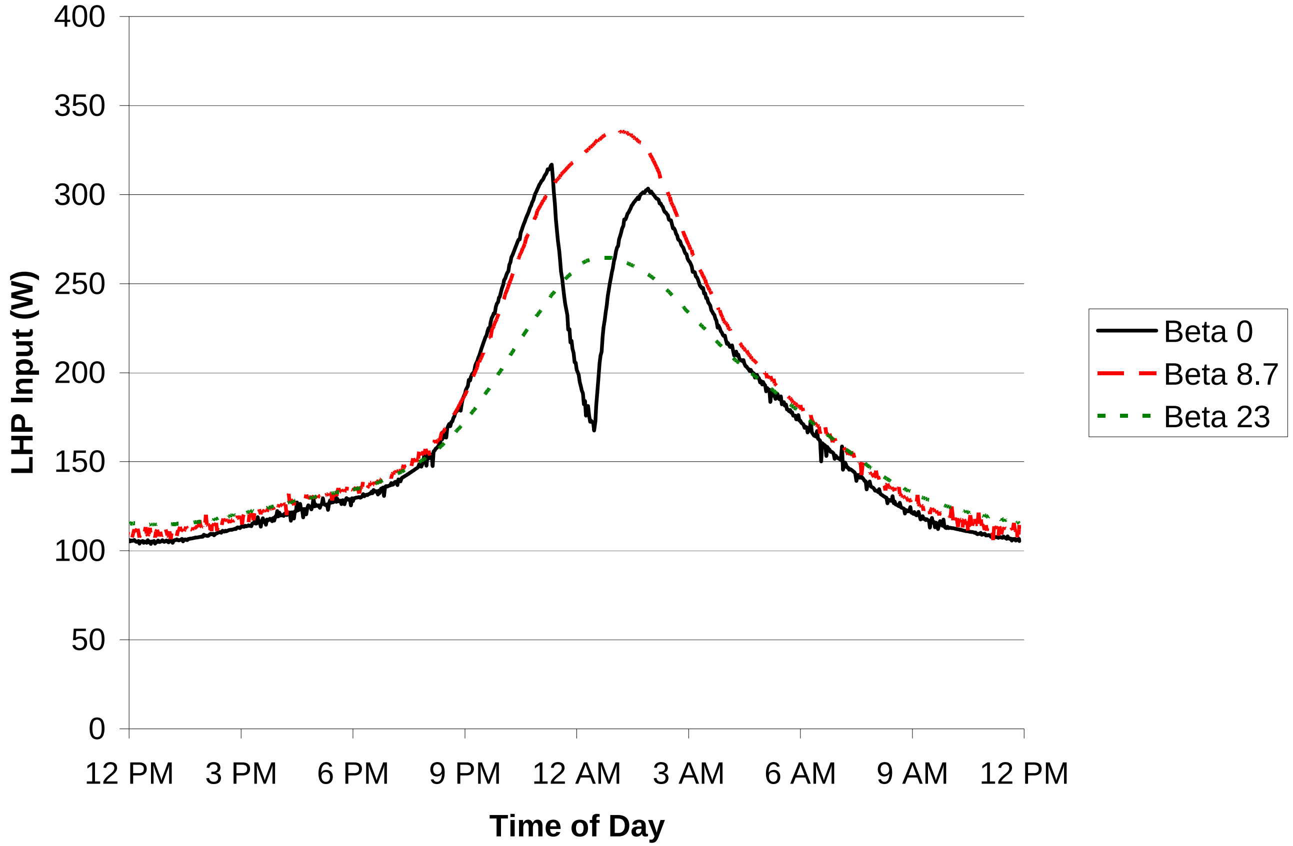
Installed in System Model, Performance Met Program Needs

- Able to run system model with fast turnaround
- Not driven by simulated LHP performance
- User has to be careful to keep the simulation within applicable bounds
  - Exceeding shutdown limits
  - Overrunning maximum heat input

Variation in LHP Heatload

- Load input to LHP – up to 250 W diurnal variation



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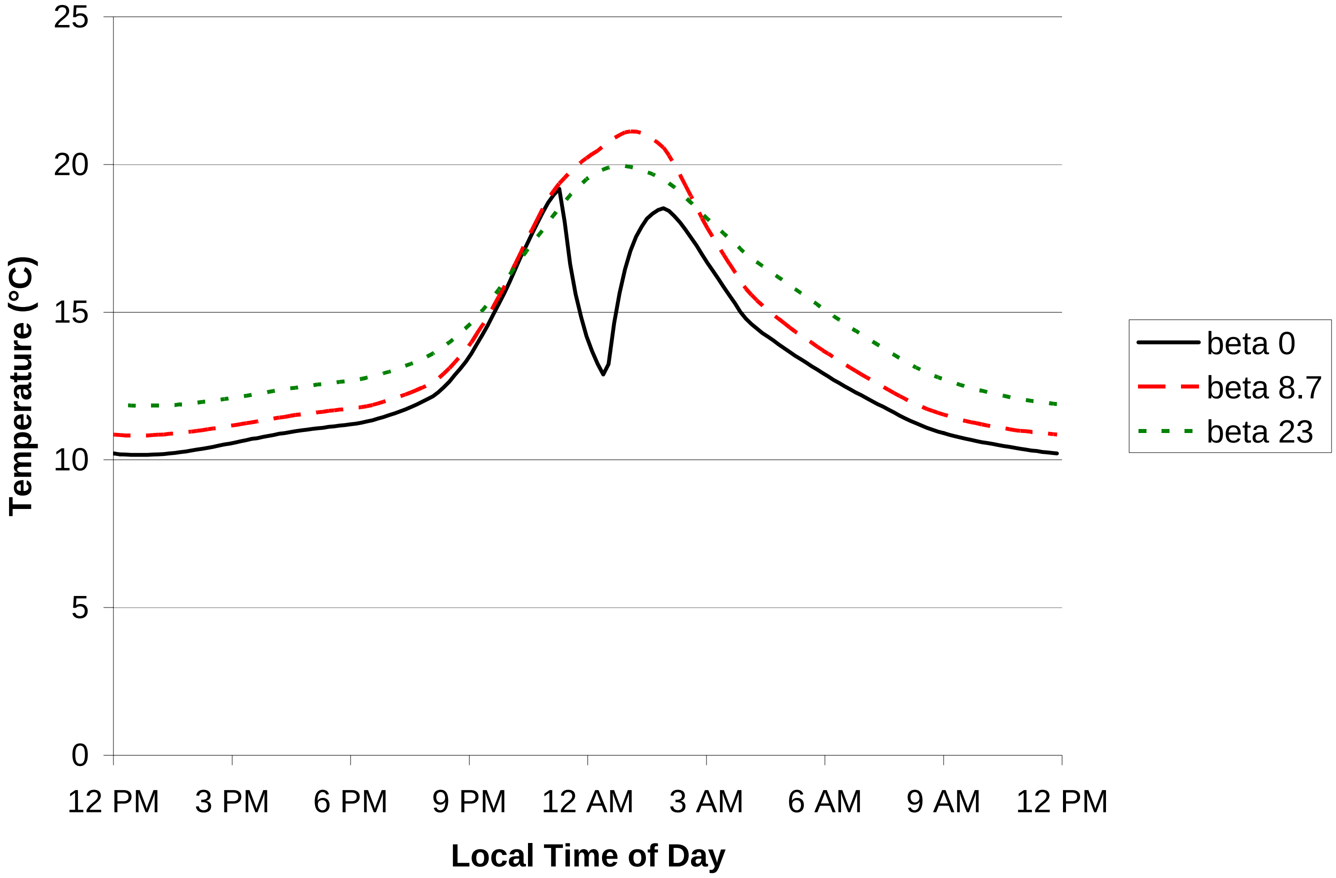
Stable Temperature Over Large Variation in Heat Load

- Temperatures at LHP baseplate vary ~ 10°C



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Opportunities for Improvement

- We're correlating a model to a model
  - Test data would be helpful
- Impact of external load variations require examination
  - Varying loads due to, beta angle, property variation
- Gradient in radiator too high
- Are we optimizing on the right thing
- Simulation of return line environment

Simplified Representation Functional, Useful for Conceptual Trades

- A representation of LHP behavior has been created
  - Suitable for concept development
- Within the limits of its capability, the representation has been useful
  - Fast enough for parametric analysis of the system
  - Robust
  - Provides an accurate enough result to guide architecture development

References

- 1) Cullimore, B. and J. Baumann, “Steady State and Transient Loop Heat Pipe Modeling”, SAE Paper Number 2000-ICES-105

Acknowledgements

- This work performed under contract NAS5-01119, ABI Formulation Phase

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