Progress on the Development of a Comprehensive Heat Transfer Model for Industrial Liquid Quenching Processes

Jeffrey Franklin, Ph.D., P.E.

Andrew Banka, P.E.

William Newsome, Ph.D.

ASM International Heat Treating Society
An Affiliate Society of ASM International

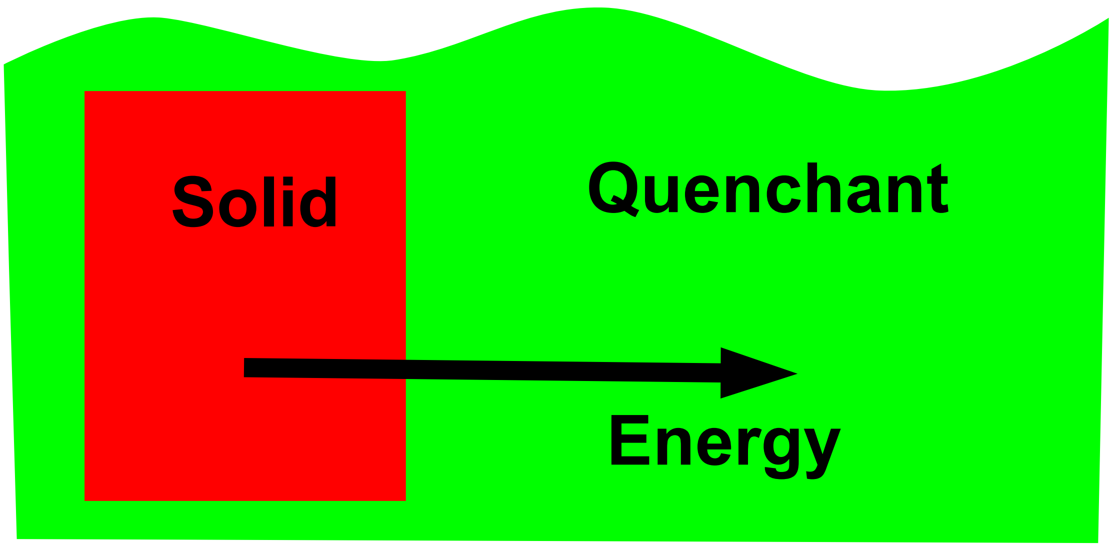
Airflow Sciences Corporation

Presentation Overview

- Modeling objectives and approach
- Initial Model Development
  - *ivf* SmartQuench test probe
  - Overview of three boiling models
- Comparison with *ivf* probe data
- Flow boiling test fixture
- Path for numerical model improvements

Fundamental Model Objectives

- Heat transfer model (CFD Framework)
- Characterize energy movement
- Focus on surface heat flux rates



Better surface heat flux predictions

↓

Better material property predictions

Surface Relationship

$$q = h\left(T_{\mathrm{fluid}} - T_{\mathrm{solid}}\right)$$

Surface Relationship

The devil is in the details!

$$q = h\left(T_{\text{fluid}} - T_{\text{solid}}\right)$$

Surface Relationship

$$q = h\left(T_{\text{fluid}} - T_{\text{solid}}\right)$$

Temperature of fluid where?
What about vapor at surface?

Surface Relationship

$$q = h\left(T_{\text{fluid}} - T_{\text{solid}}\right)$$

How is this defined when boiling occurs?
What other fluid properties does it depend on?

Addressing The Details

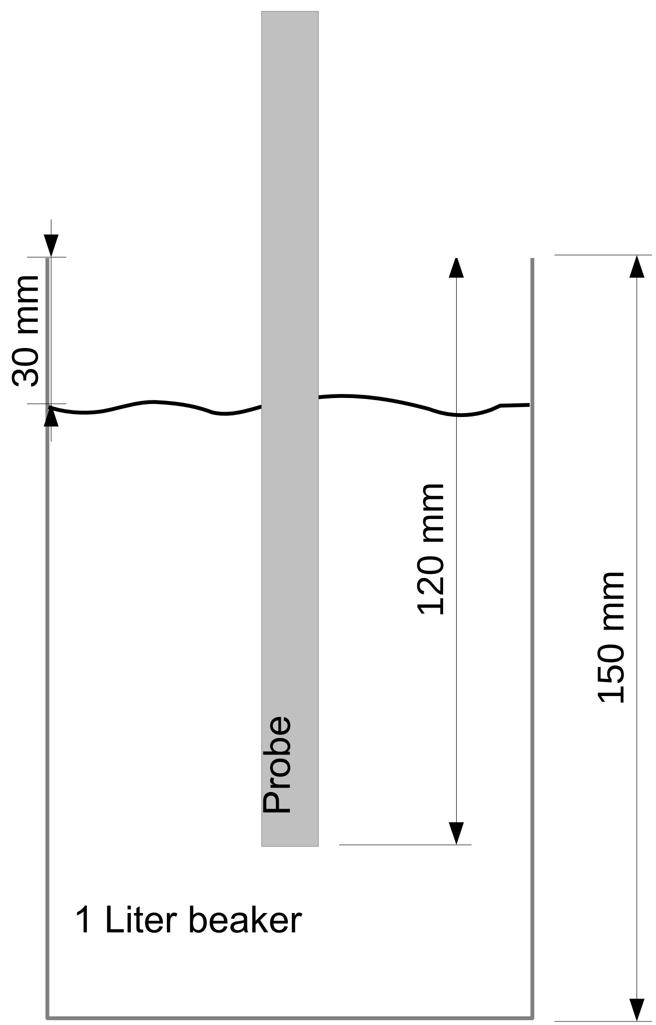
- Rely on additional physics
  - Include smaller length scale physics
    - Bubble dynamics
    - Near surface quenchant fluid velocity
    - Surface properties
  - Include material property variations
- Experimental data
  - Visual observations
  - Measured experimental data

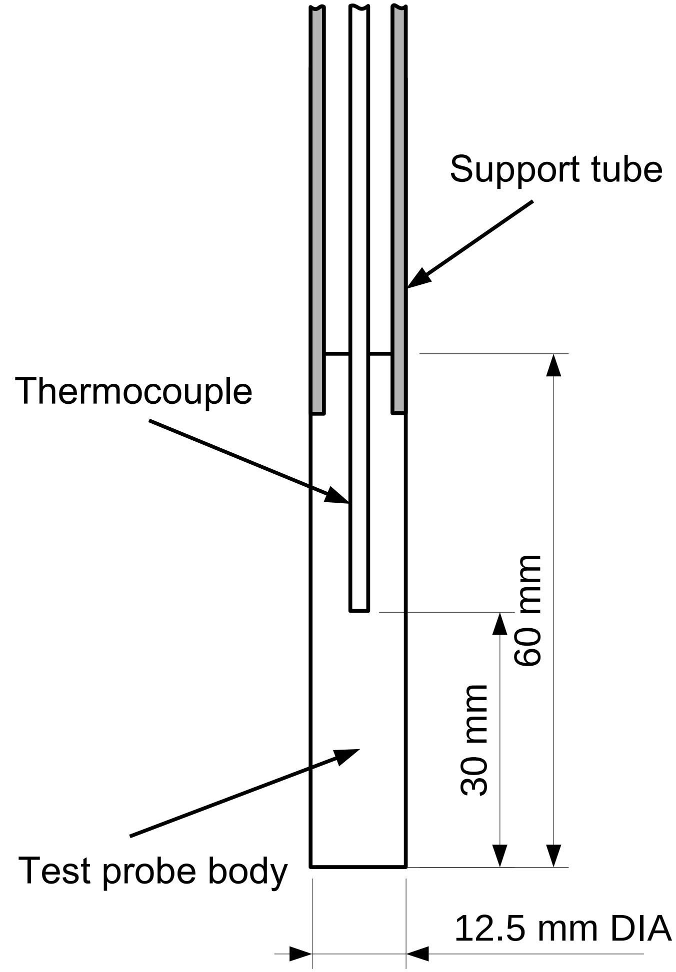
Model Development Path

- Adopt *ivf* SmartQuench test/probe
- Utilize experimental data to nail down equation details
  - Develop three separate approximations for surface heat flux.
- Use models to reproduce *ivf* data
- Evaluate/Validate model results

ivf SmartQuench Test Probe

(ISO/ASTM Compliant)

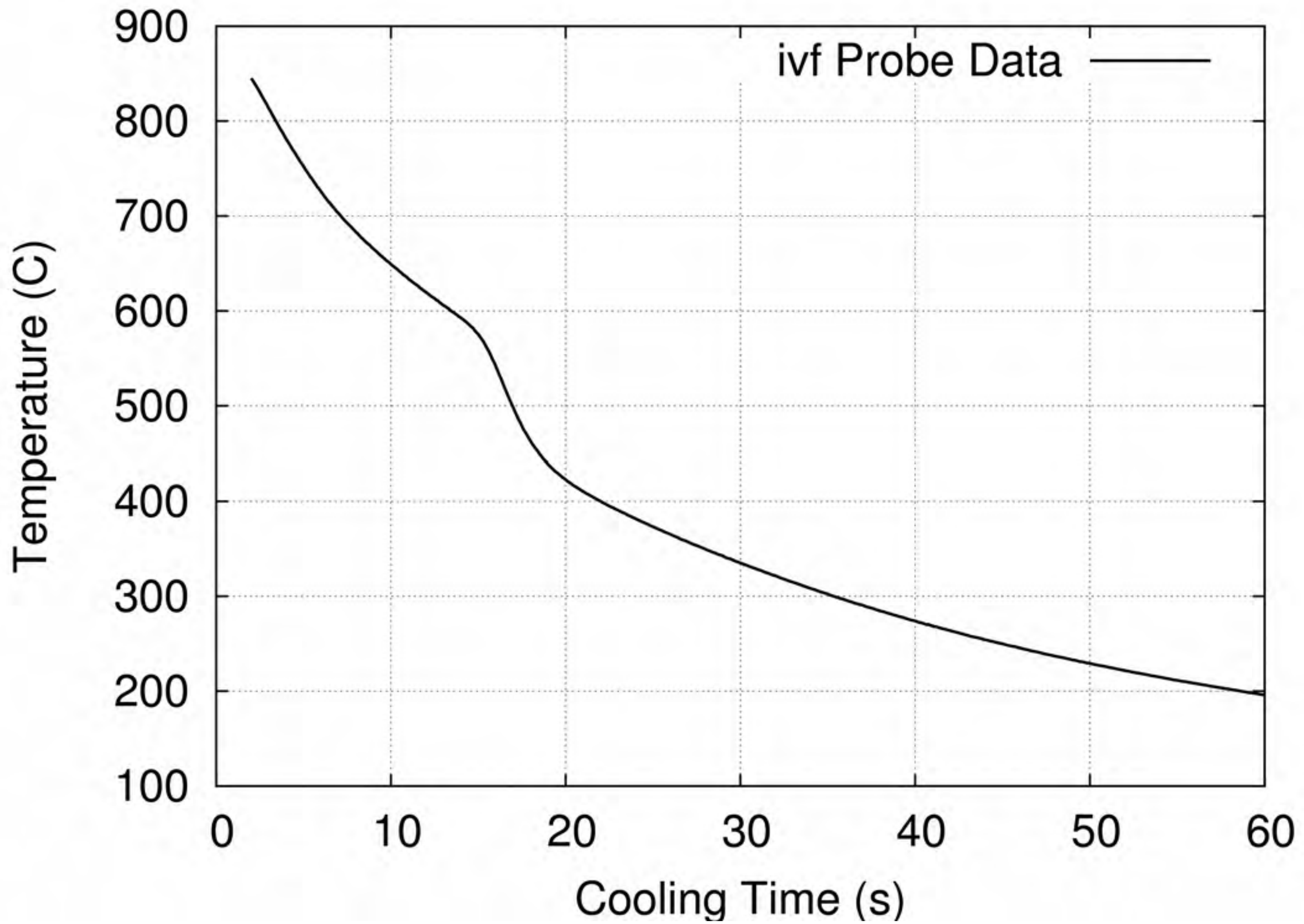




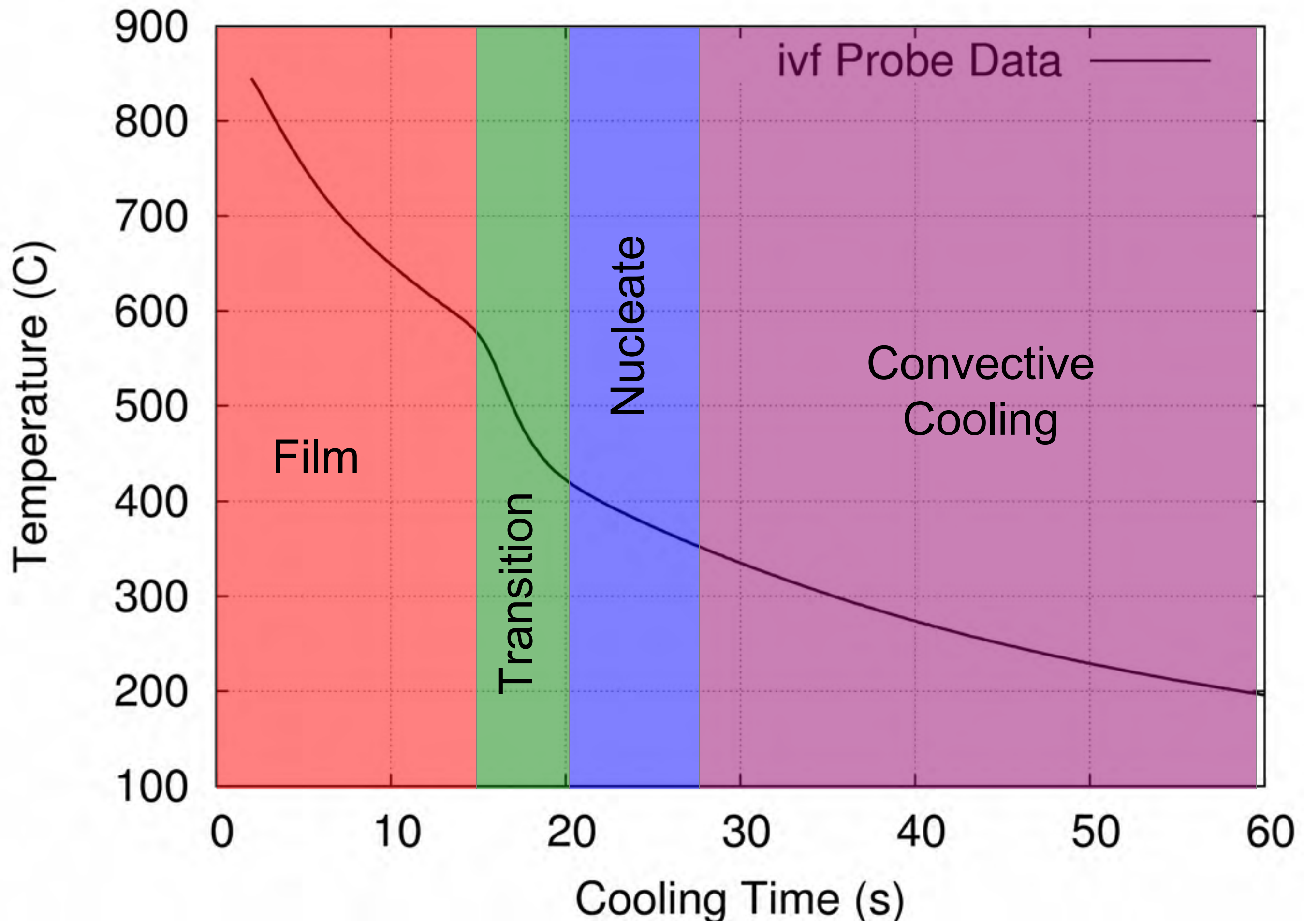
ASM INTERNATIONAL Heat Treating Society
An Affiliate Society of ASM International

Airflow Sciences Corporation

ivf Quench Probe Data (Houghton 3420 Quench Oil)



ivf Quench Probe Data (Houghton 3420 Quench Oil)



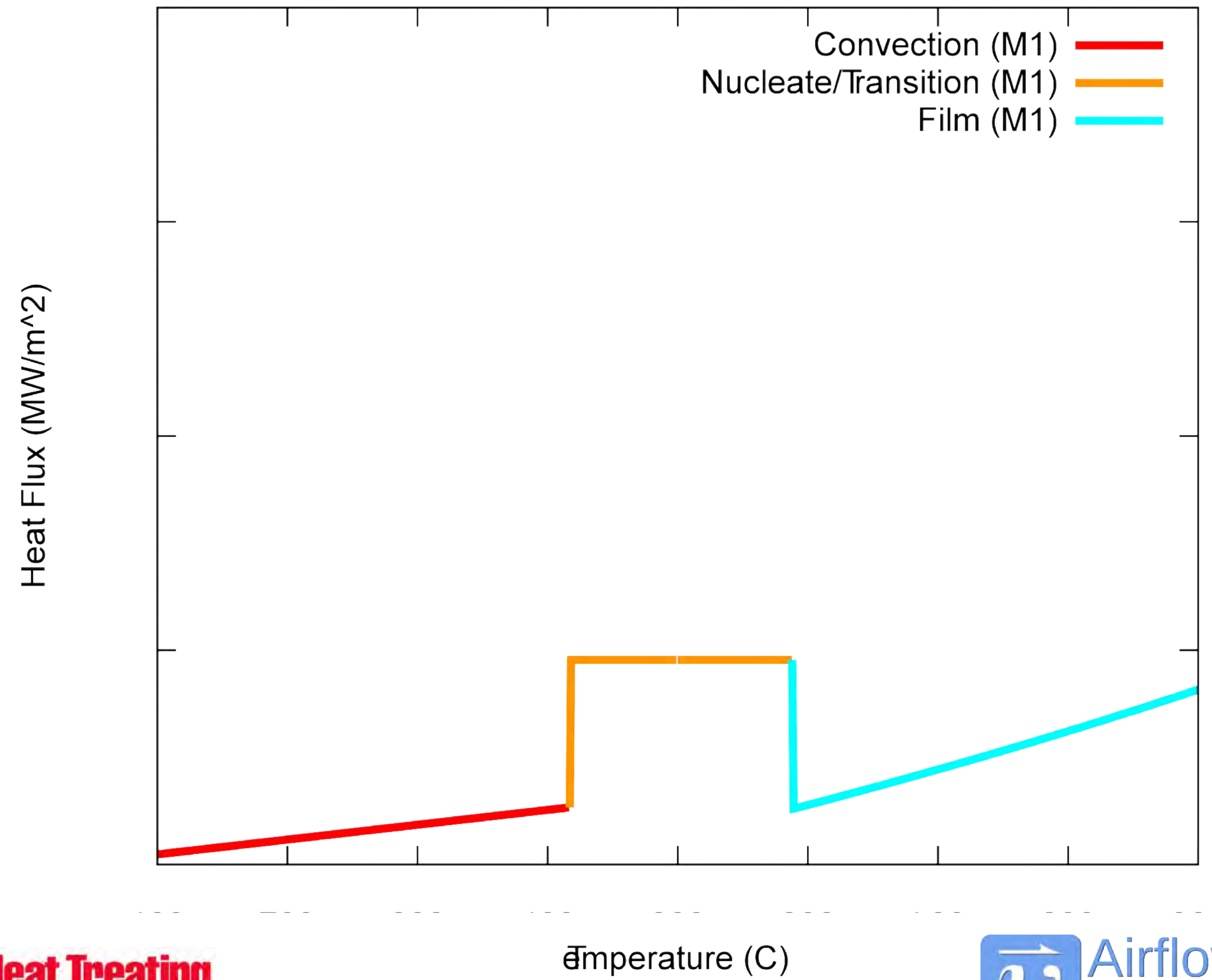
- Divide surface heat transfer model up into typical boiling regimes.

Surface Heat Flux (Three Methods Explored)

- Method 1 (Simplest Approach)
  - Assume constant heat flux for nucleate and transition boiling
- Method 2 (Add more physics)
  - Include nucleate boiling physics
    - Bubble Dynamics
    - Surface characteristics
- Method 3 (Add more physics)
  - Include film boiling approximation

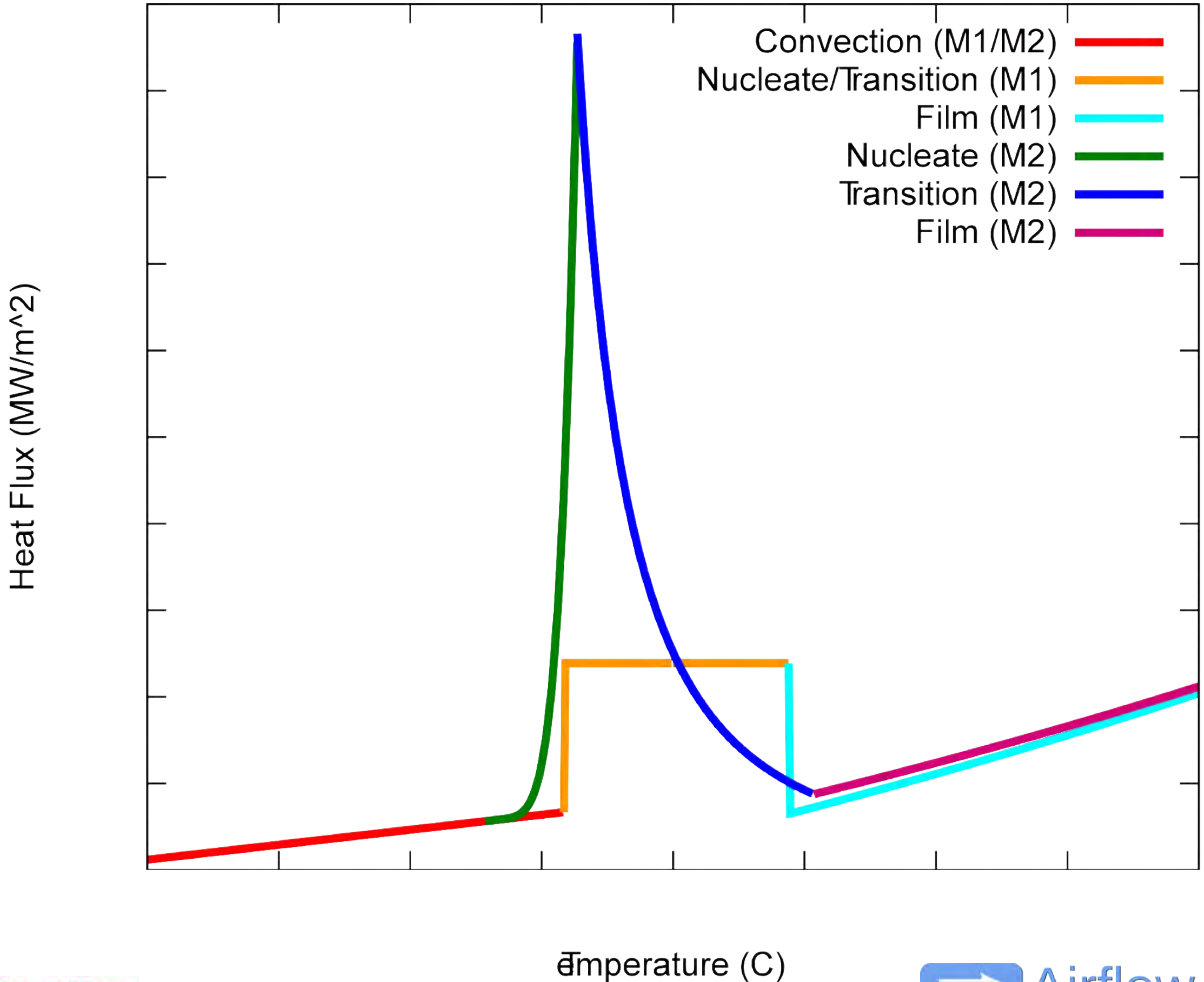
Method 1

Surface Heat Flux vs. Solid Surface Temperature



Method 2

Surface Heat Flux vs. Solid Surface Temperature

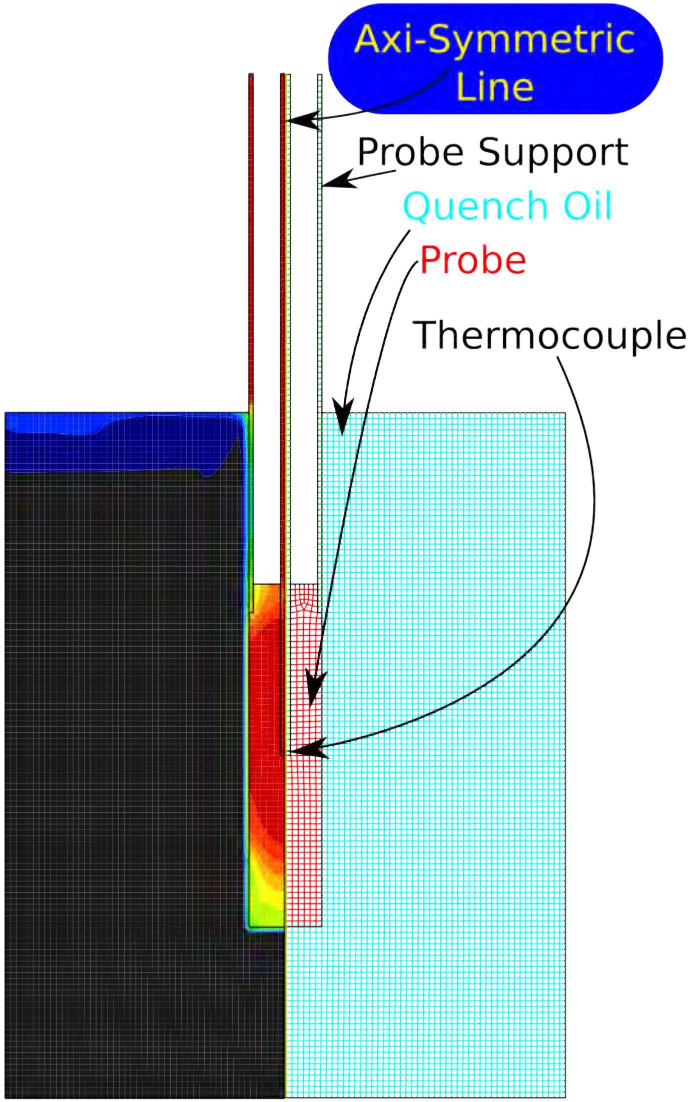


Heat Treating Society
An Affiliate Society of ASM International®

Airflow Sciences Corporation

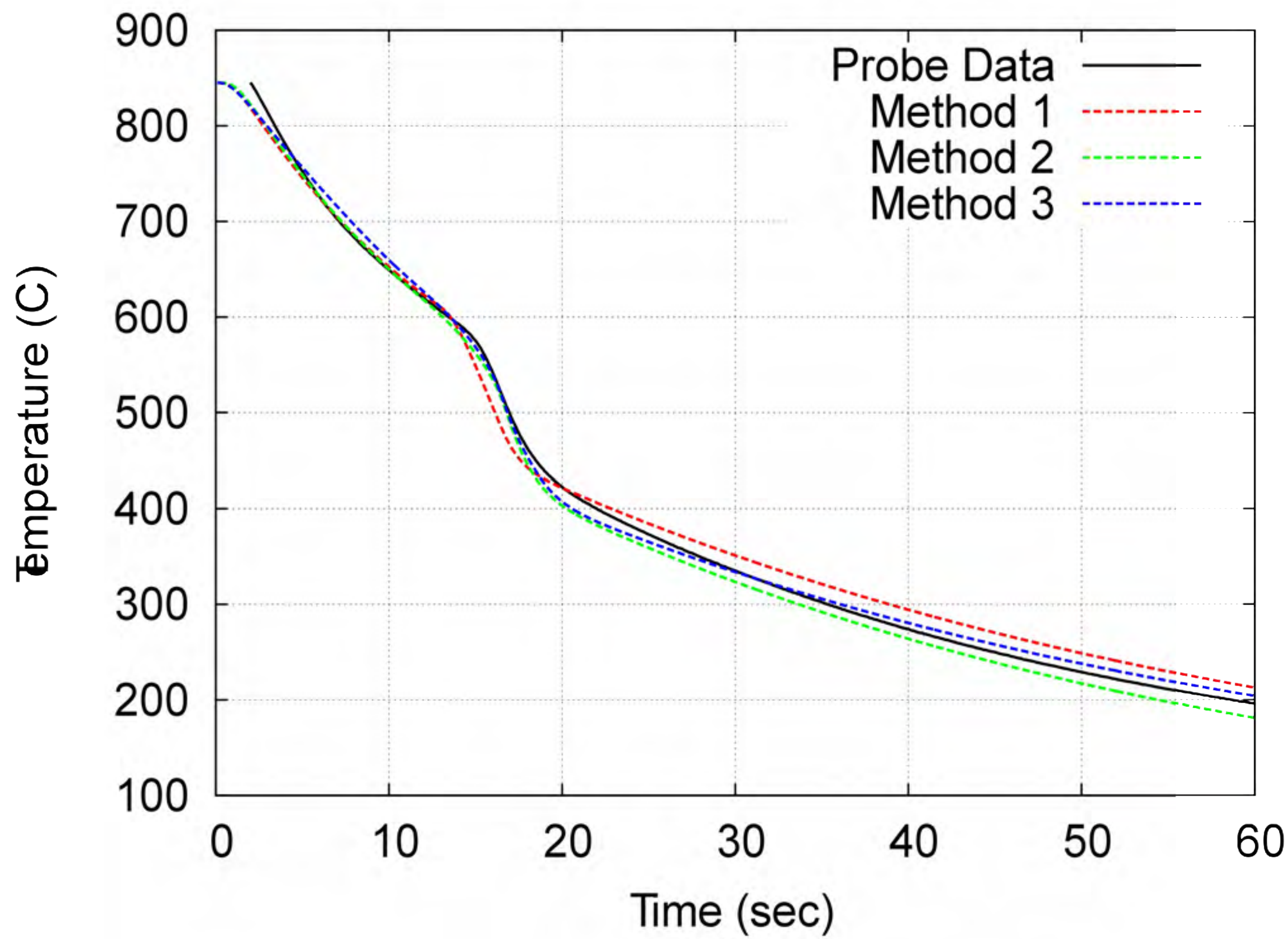
ivf Probe CFD Simulation

- 2D Axi-Symmetric model
- Transient
- Internal probe geometry details included
- Developed heat flux models applied at probe surface



Ivf Probe CFD Simulation

Predicted Thermocouple Temperature History



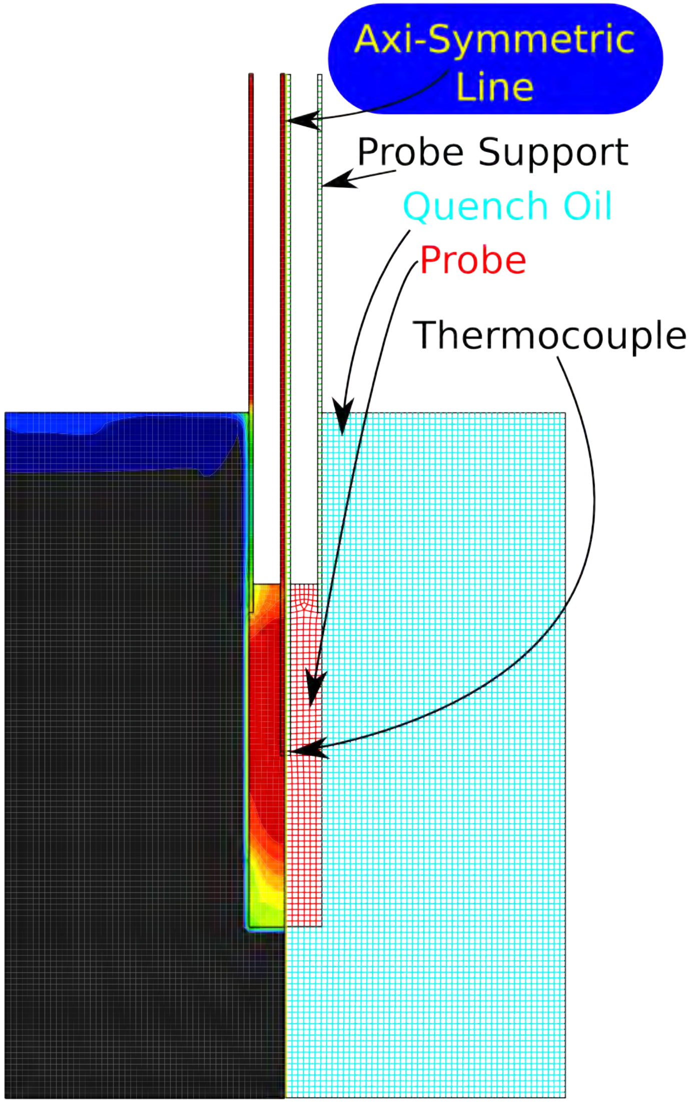
ASM International

Heat Treating Society
An Affiliate Society of ASM International®

Airflow Sciences Corporation

Moving Beyond The Paradox

- Multiple surface heat flux approximations can and do result in similar thermocouple histories.
- Need steady state surface heat flux data vs. surface temperature

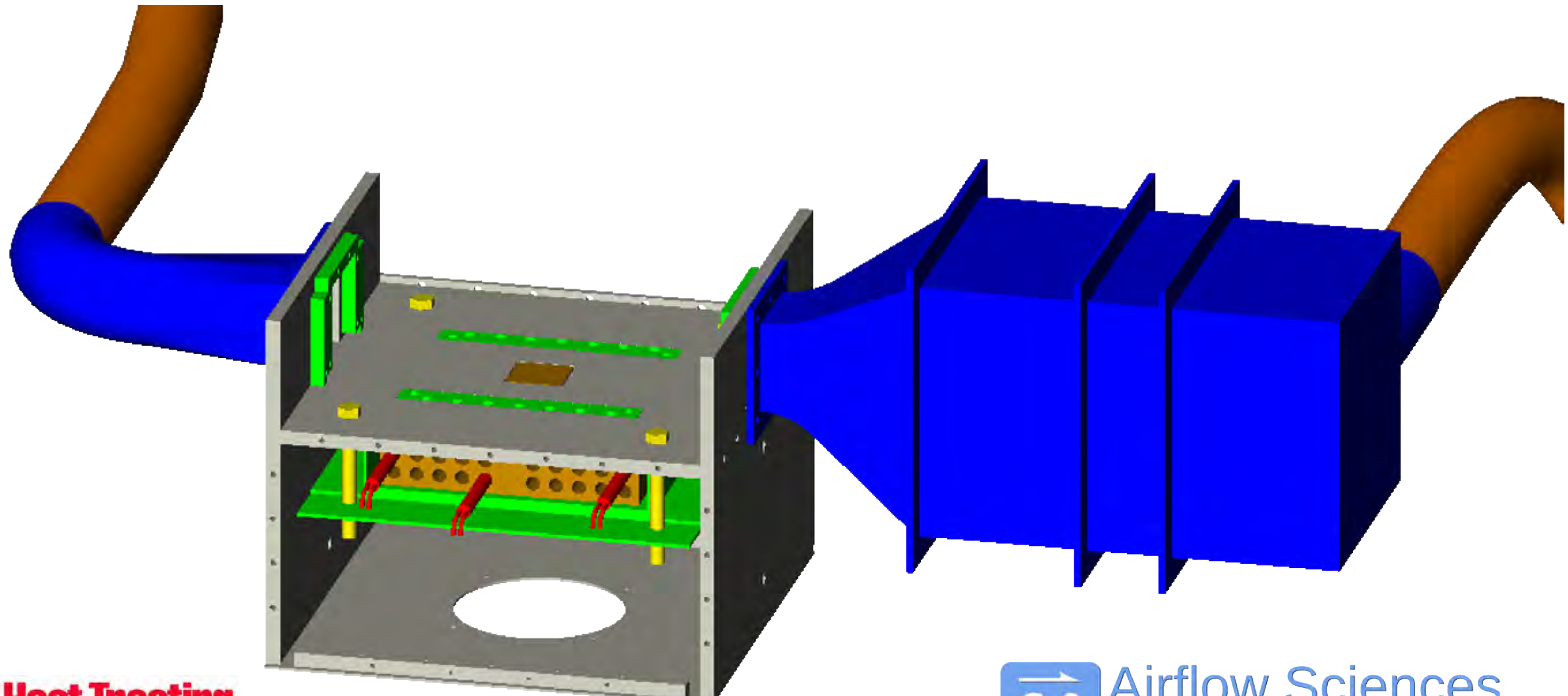


Flow Boiling Test Fixture

- Design/Construct flow boiling test fixture
  - Target gathering steady state heat flux data
- Build matrix of experimental data for model development and validation.
  - Steady state heat flux
    - Vary surface temperature
    - Fluid velocity
    - Surface orientation
    - ……

Test Fixture Overview (Heater Assembly)

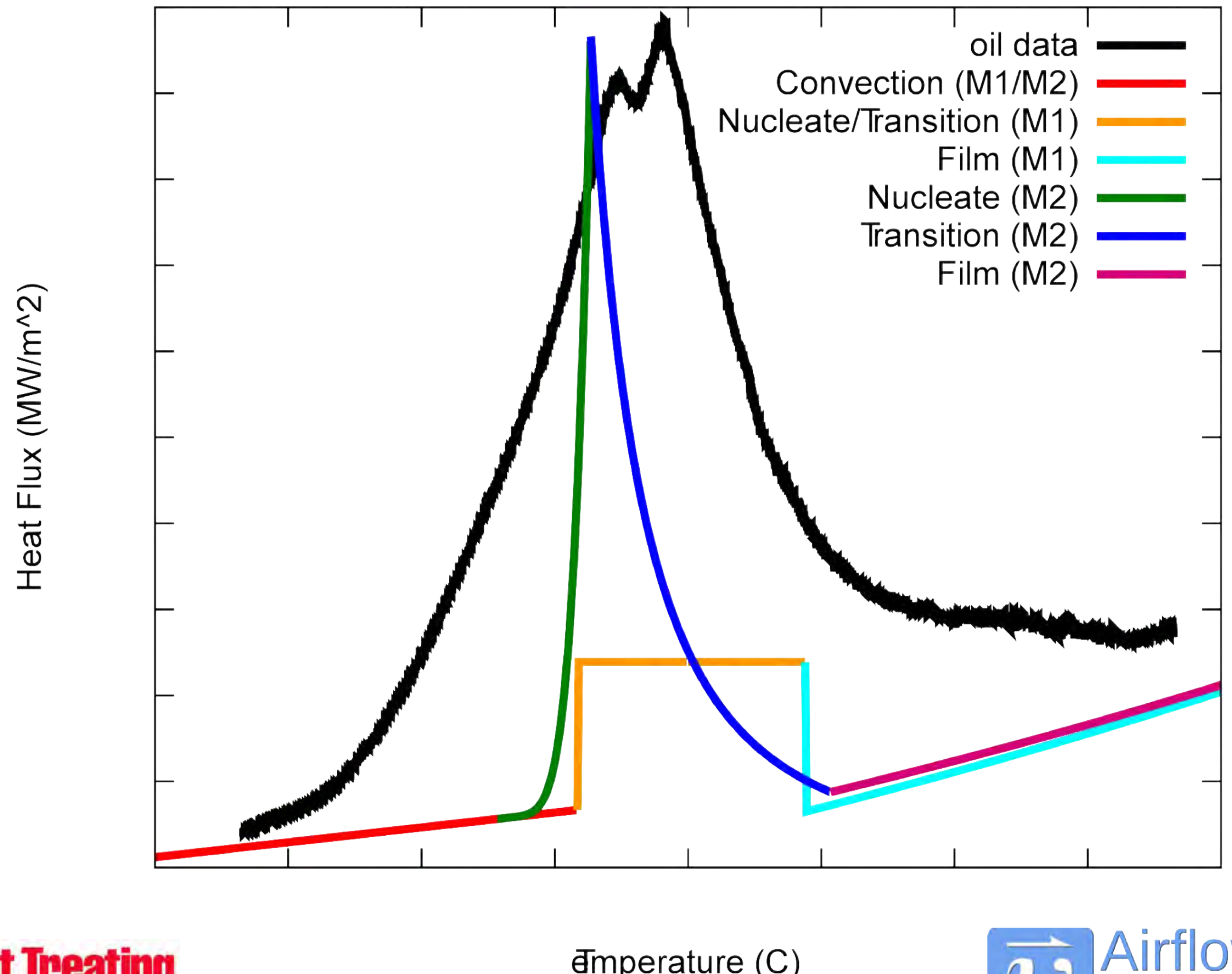
- Settling chamber to provide good flow quality
- Heated surface on side of test channel (omitted for clarity)
- Remaining side of test channel are glass for photo/observation



ASM International Heat Treating Society An Affiliate Society of ASM International

Airflow Sciences Corporation

Flow Boiling Data (Improve our models)



ASM INTERNATIONAL Heat Treating Society
An Affiliate Society of ASM International®

Airflow Sciences Corporation

Conclusions

- Current heat flux validation methods can show correlation using more than one surface heat representation. The paradox!
- High quality surface heat flux data is currently being gathered.
- The improved data will lead to surface heat flux models that can be validated with a higher degree of confidence.

Acknowledgment

- This material is based upon work supported by the United States Air Force under Contract No. FA8650-12-C-5110.
- Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the United States Air Force.

ASM International® Heat Treating Society℠
An Affiliate Society of ASM International®

Airflow Sciences Corporation