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# Gravity Effects in Condensing and Evaporating Films

NCMR
FLUIDS AND COMBUSTION

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*Strategic Research to Enable NASA's Exploration Missions*
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# Research Overview

- **Objective**
  - Understand film condensation/evaporation behavior (and implications for heat transfer) in variable gravity environments
- **Problems studied**
  - Film condensation and evaporation on planar surfaces at normal gravity (+1g, -1g) and reduced gravity ≈ 0.01g (aircraft)
  - 2-3 minutes of low-gravity testing desirable

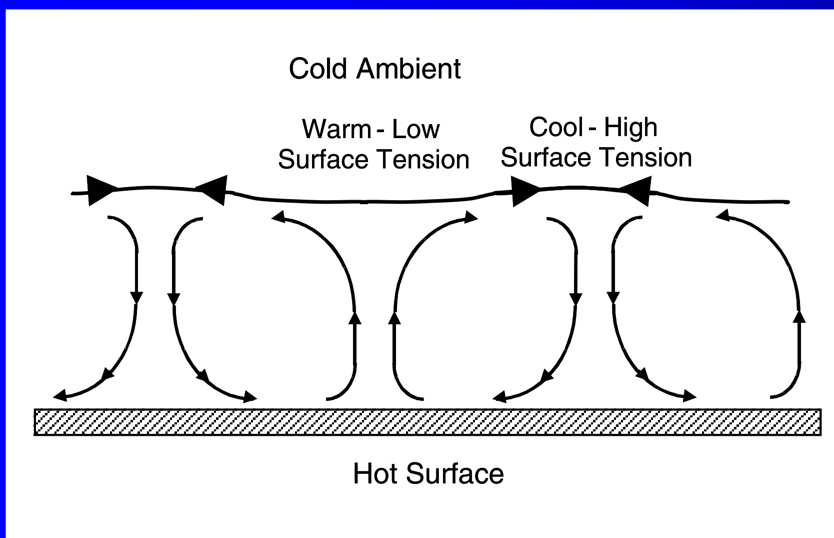
# NASA Recognizes Critical Need for Condensation & Evaporation Research to Enable Human Exploration of Space


- [1] Strategic Research Workshop on Two-phase Flow, Fluid Stability and Dynamics: Issues in Power, Propulsion and Advanced Life Support Systems, Sponsored by Office of Biological and Physical Research, NCMR, NASA Glenn Research Center, Cleveland, Ohio, May 15, 2003.
- [2] Survey of Present and Future Challenges in Low-g Fluids Transport Processes, NASA Contract C-74461-N, Final Report to NASA Glenn Research Center, M.M. Weislogel, TDA Research, Inc., Wheat Ridge, CO.
- [3] National Research Council, Space Studies Board, Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies, National Academic Press, 2000.
- [4] Workshop on Research for Space Exploration: Physical Sciences and Process Technology, NASA/CP-1998-207431, NASA LeRC, Aug. 5-7, 1998
- [5] Workshop on Research Needs in Space Thermal Systems and Processes for Human Exploration of Space, Sponsor NASA OLSMA, Host NASA GRC, Cleveland, July 25-26, 2000.
- [6] Workshop on Research Needs in Fluids Management for the Human Exploration of Space, Sponsored by NASA OLSMA, NASA Glenn Research Center, Cleveland, Ohio, Sept. 22, 2000.
- [7] Carpenter, B.M., Process Research in Support of the Human Exploration and Development of Space: Issues in Program Development, Space V, Space Engineering/Construction/Operations, Proceedings of the 5th International Conference on Space '96, Vol. 1, pp 509-515, Albuquerque, NM, 1996.
- [8] Salzman, J.A. (1996) Fluids management in space-based systems, Engineering, Construction, and Operations in Space V, Proc. of the 5th Int. Conference on Space '96, Vol. 1, pp. 521-526
- [9] Weislogel, M.M., Fluids Management Challenges in Space-Based Systems, Space 98, 6th International Conference and Exposition on Engineering Construction and Operations in Space, ASCE, Proceedings, 218--224, April, 1998.
- [10] Workshop on Critical Issues in Microgravity Fluids, Transport, and Reaction Processes in Advanced Human Support Technology, NASA TM-2004-212940, NASA Glenn Research Center, Cleveland, Ohio, February 2004.
- [11] The Mission of Microgravity and Physical Sciences Research at NASA, Committee on Microgravity Research, National Academy Press, Washington, D.C., 2001.
- [12] Solid Waste Processing and Resource Recovery Workshop Report - Volumes I and II, CTSD-ADV-474, 2001.
- [13] Space Technology for the New Century, Aeronautics and Space Engineering Council, National Academy Press, Washington, D.C., 1998.
- [14] Space Technology to Meet Future Needs, Aeronautics and Space Engineering Council, National Academy Press, Washington, D.C., 1998.
- [15] Workshop on Research Needs in Fluids Management for the Human Exploration of Space, NCMR, NASA Glenn Research Center, Cleveland, Ohio, September 22, 2003.
- [16] Workshop on Research Needs in Space Thermal Systems and Processes for Human Exploration of Space, NCMR, NASA Glenn Research Center, Cleveland, Ohio, July 25-26, 2003.
- [17] B. S. Singh and K. R. Sridhar, "Research and Technology Needs for Chemical Processes and Operations on Mars," Space 98, Proceedings of the Sixth International Conference and Exposition on Engineering, Construction and Operations in Space, Albuquerque, NM, 245-254, (1998).

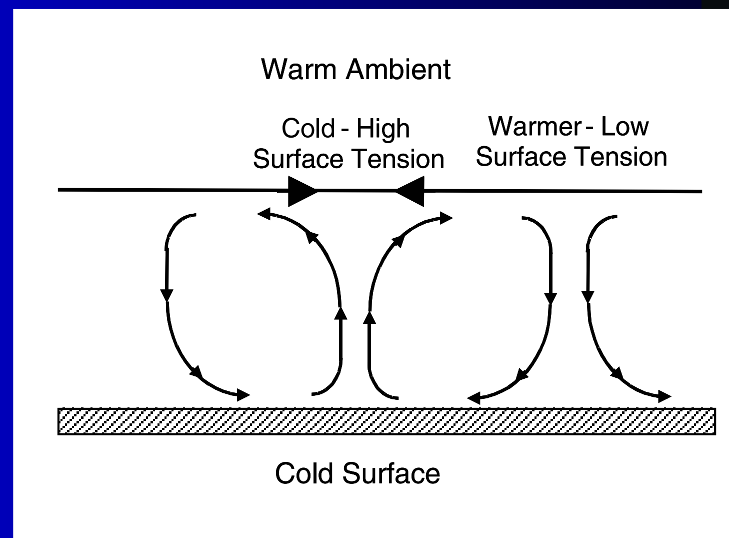
## Condensation and Evaporation Research in Reduced Gravity is Enabling for AHST Technology Needs

- **Humidity Control**
  - Mechanisms which inhibit or exacerbate liquid film motion
  - Condensate control in ducts
  - Condensers/evaporators for crew atmosphere
- **Air Revitalization ($O_2$ production via electrolysis)**
  - Control of water transport
  - Separation of dissolved gases from water
- **Water Purification (Potable Water via VCD)**
  - Stability of large area condensed liquid films
  - Mechanisms for shedding condensed films in reduced gravity
- **Environmental Control and Heat Rejection**
  - Evaporation and condensation heat transfer
  - Stability of evaporating/condensing films

# Differing Role of Surface Tension on Condensing/Evaporating Film Stability

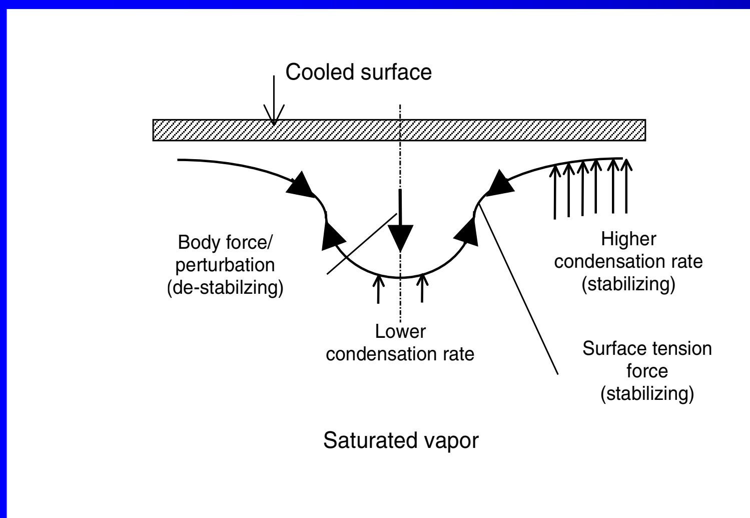



Evaporating film - surface tension variations de-stabilizing

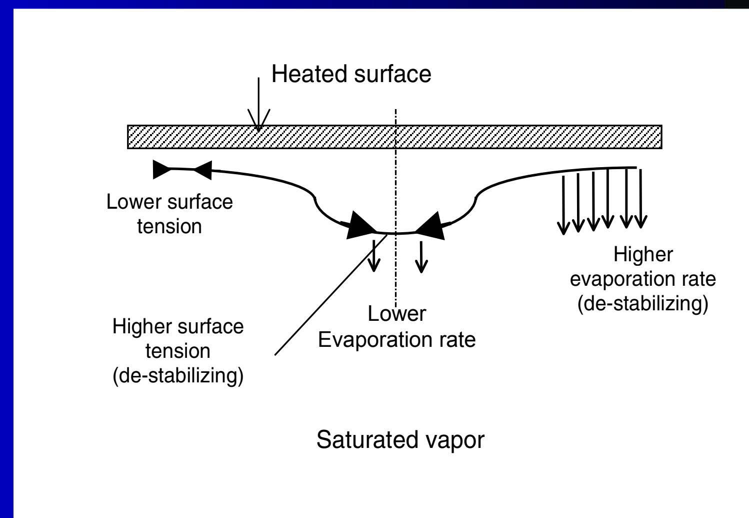



Condensing film- surface tension variations stabilizing

# Fluid Mechanisms in Condensing and Evaporating Films in Reduced Gravity




Condensing film in low-g




Evaporating film in low-g

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# Research Plan

- **1-g (normal gravity) laboratory experiments (UW/WPI)**
- **Reduced gravity experiments on board NASA parabolic-trajectory aircraft (NASA Glenn Research Center)**
- **Numerical modeling using unsteady Navier-Stokes equations by a finite element method based on a front tracking technique (Prof. A.N. Alexandrou, University of Cyprus)**

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# Experimental Configurations for Condensing Films

- **Geometries**
  1) Stabilizing gravitational body force (+1g, condensing surface "upwards")
  2) De-stabilizing gravitational body force (-1g, "downwards")
  3) Reduced gravity with external perturbation
- **Fluid configurations**
  1) Condensing film (thermal plus mass addition effects)
  2) "Pumped" film with isothermal mass addition through porous substrate

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# Experimental Configurations for Evaporating Films

- **Geometries**

  1) Stabilizing gravitational body force (+1g, evaporating surface "upwards")

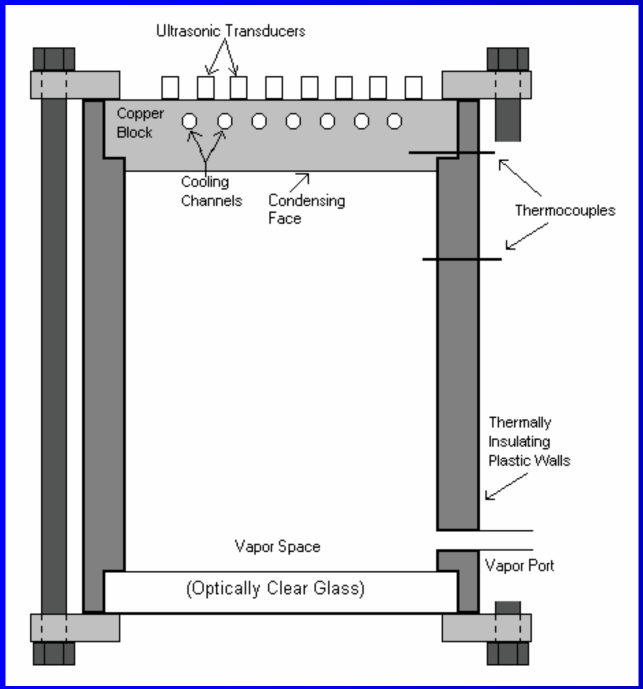
  2) De-stabilizing gravitational body force (-1g, "downwards")

- **Fluid configurations**

  1) Evaporating film (thermal and mass removal effects)

  2) Heated, non-volatile film (thermal effects only)

# Laboratory Condensation Test Cell

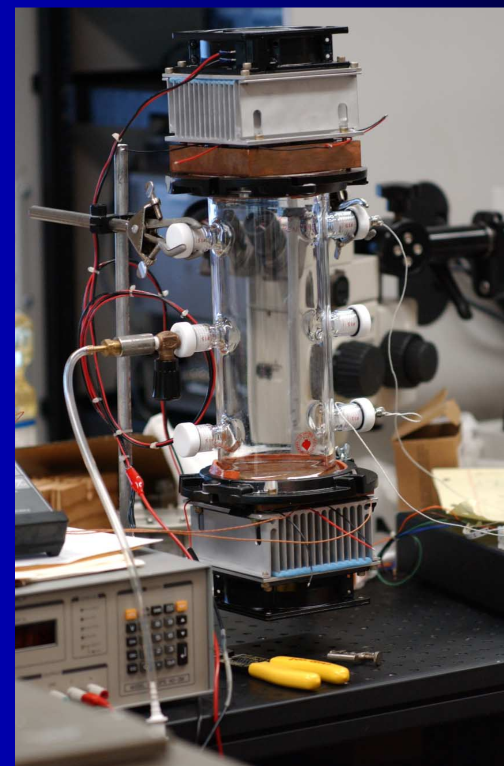



Schematic

Actual

# Aircraft Experiment

Aircraft rig with
volume control system



A/C rig test cell with dual
thermoelectric elements

# Condensation Study
# Current Test Conditions

- **Condensation experiments**
  - 10 cm diameter cooled brass plate
  - Fluids: Methanol and n-pentane
  - Enclosed test cell, typical operating pressure 50-70 kPa
  - Subcooling range $T_{sat} - T_{wall} = 4 - 16$ C
- **“Pumped film” experiments**
  - 10 cm diameter perforated stainless plates
  - Fluids: Silicone oil (125 and 50 cSt)
  - Pumping rates 2-12 ml/min

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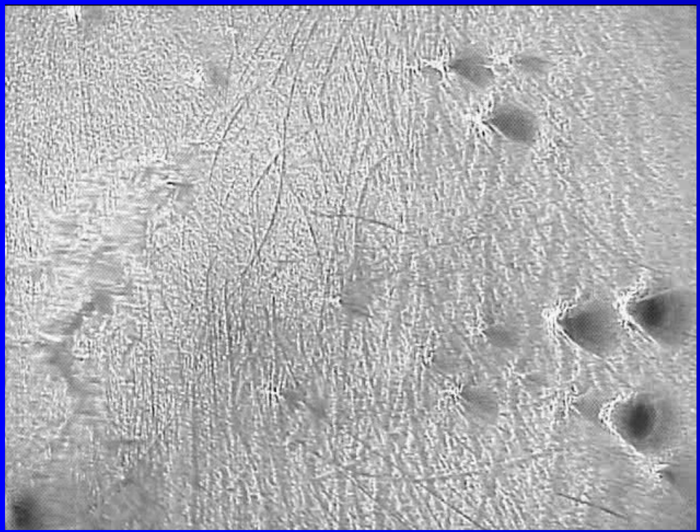
# Diagnostics

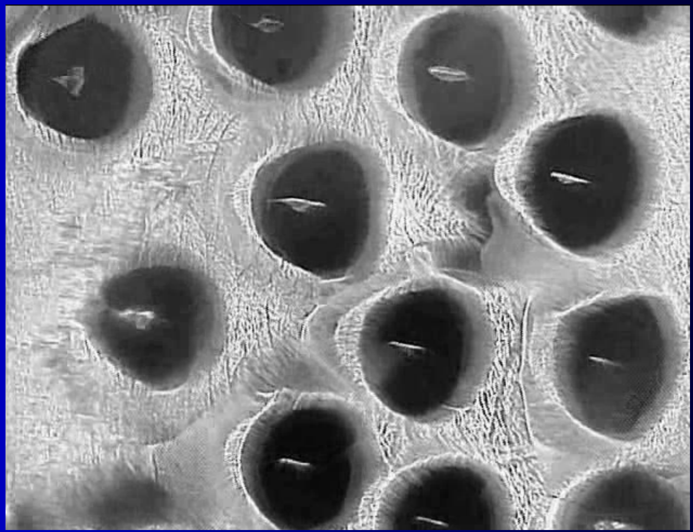
- **Double-pass shadowgraph imaging**
  - Synchronized with data acquisition
  - Disturbance wavelengths
  - Time to drop formation/break off (condensation) or dry-out (evaporation)
- **Thermal measurements**
  - Thermocouples (surface, vapor temperatures)
  - Imbedded heat transfer sensors
  - Numerical inverse method employed to determine surface heat flux
- **Ultrasound gauging**
  - Single and multiple sensors
  - Film thickness and growth rate

# Shadowgraph Images of Condensing *n*-pentane Film in Unstable (-1g) Configuration

$T_{wall}$ = 11 C,  $T_{sat}$ = 17 C,  $P_{sat}$ = 50 kPa



At start of condensation



37 s after the start of condensation

# Condensing n-Pentane Film in Normal Gravity (-1g) at Constant Pressure

**Click here to play movie**

$P_{sat}$ = 50 kPa, $T_{sat}$ = 16.5 C, $T_{wall}$ = 11 C

Video real time

# Condensing n-Pentane Film in Normal Gravity (-1g) with Cyclic Pressure

Click here to play movie

$P_{sat}$ = 36-48 kPa $T_{sat}$ = 8.8-15.5 C, $T_{wall}$ = 11 C

Cycle period 180 s; video rate 2.4 x real time

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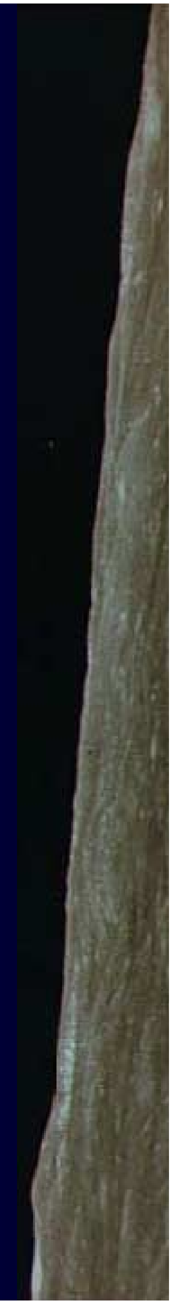
# Non-condensing "Pumped" Film in Normal Gravity (-1g)

50 cSt Silicone Oil



**Click here to play movie**

Pumping rate 4 ml/min

→ average film growth rate = 8.2 μm/s

Video rate 0.4 x real time

# Non-condensing “Pumped” Film in Normal Gravity (-1g)

50 cSt Silicone Oil

**Click here to play movie**

Pumping rate 12 ml/min

→ average film growth rate = 24.7 μm/s

Video rate 0.4 x real time

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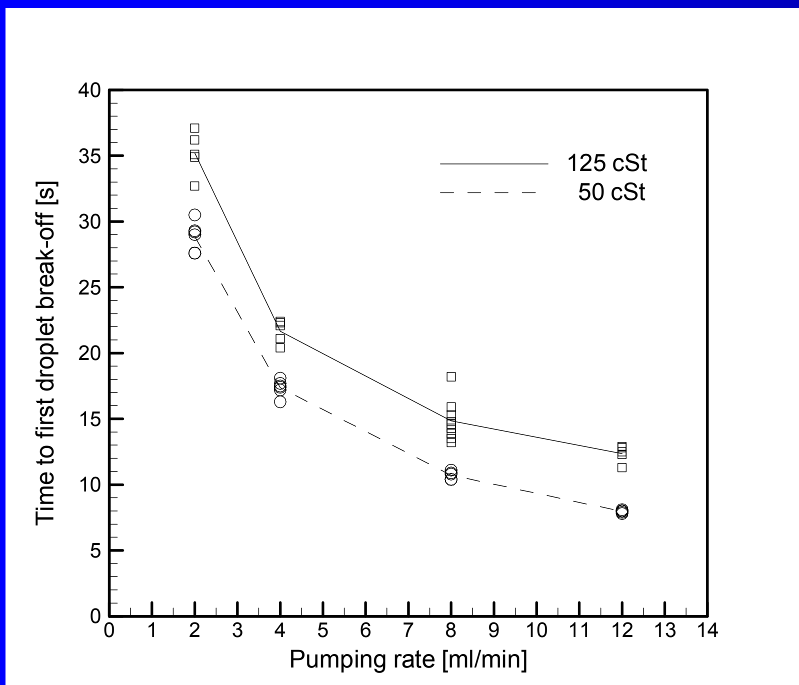
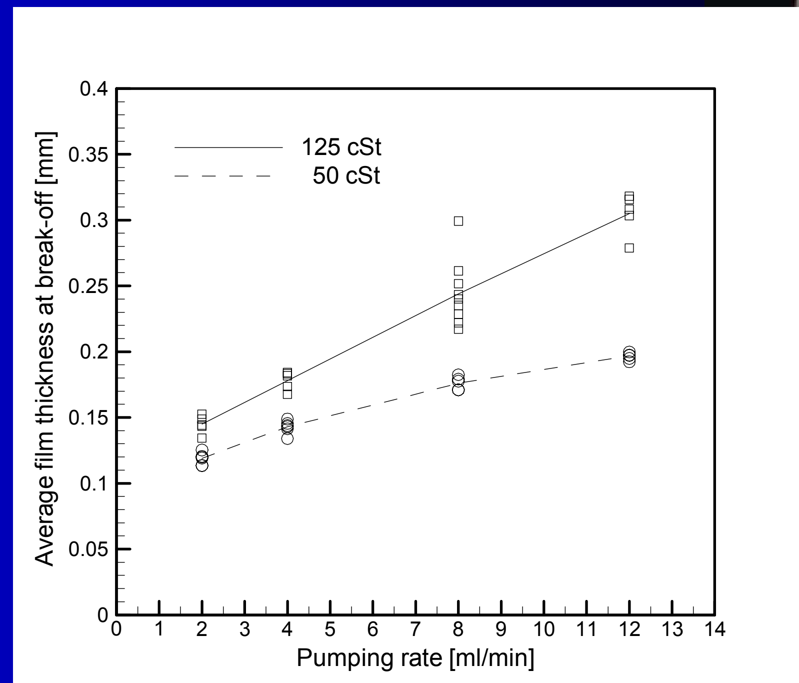
# Non-condensing “Pumped” Film in Normal Gravity (-1g)

## Silicone Oil

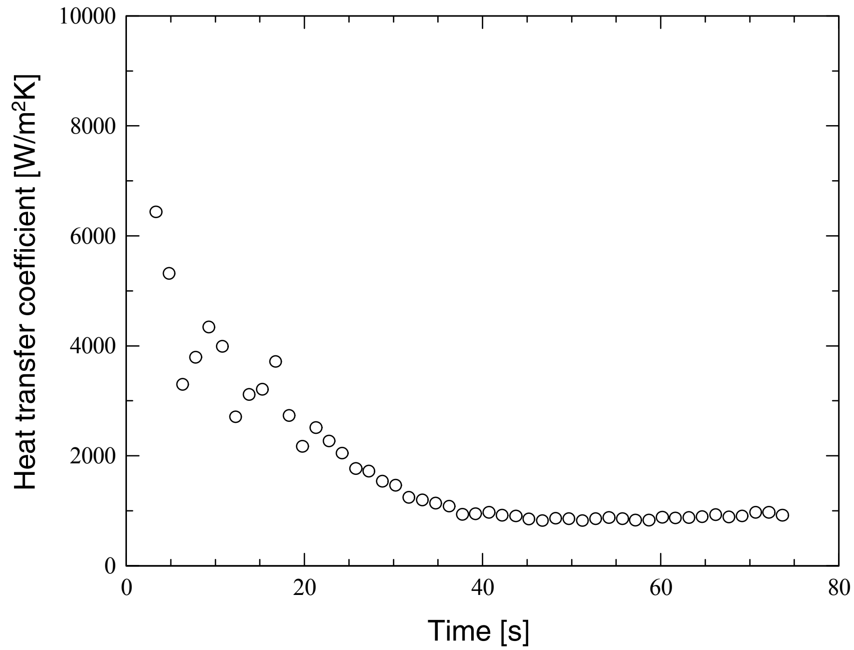



Time to first droplet break-off decreases with increasing pumping rate




Film thickness at first droplet break-off increases with increasing pumping rate

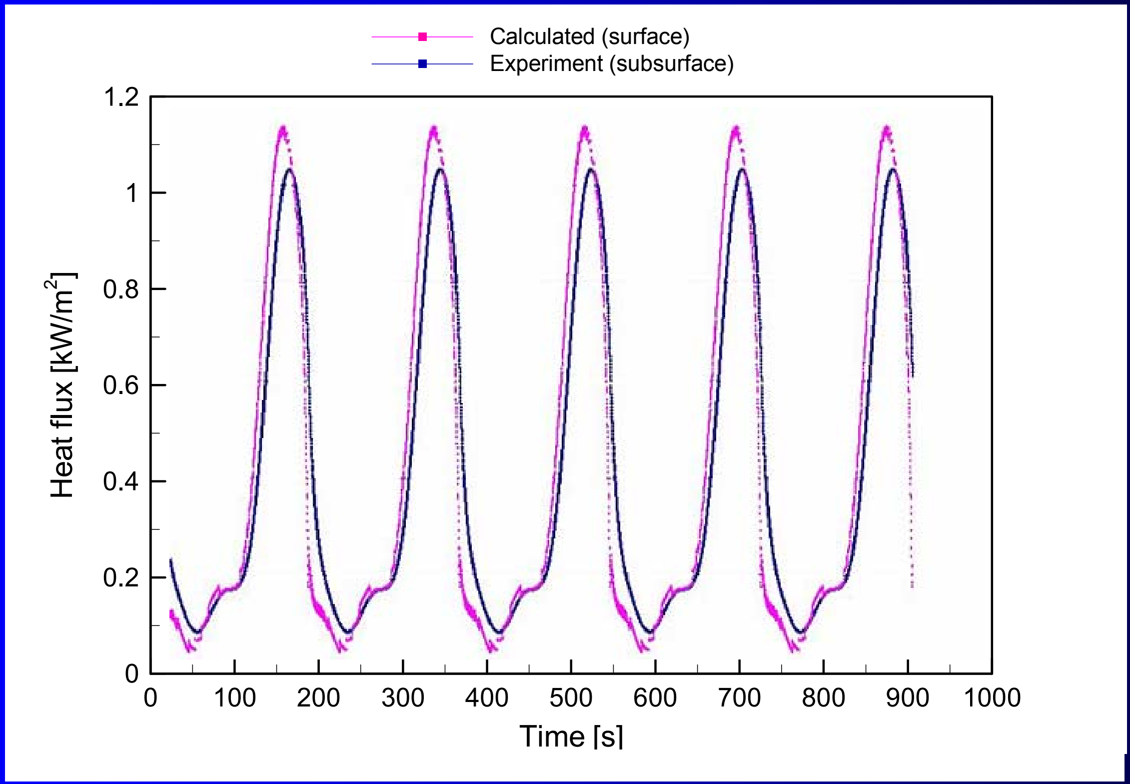
# Heat Transfer Coefficient in Developing, Unstable Condensing Film in Normal Gravity




Unstable (-1g) condensing n-pentane film

$T_{wall}$ = 11 C, $T_{sat}$ = 17 C, $P_{sat}$ = 50 kPa

# Heat Transfer for Unsteady Condensing Film (-1g)




$P_{sat}$ = 36-48 kPa $T_{sat}$ = 8.8-15.5 C, $T_{wall}$ = 11 C

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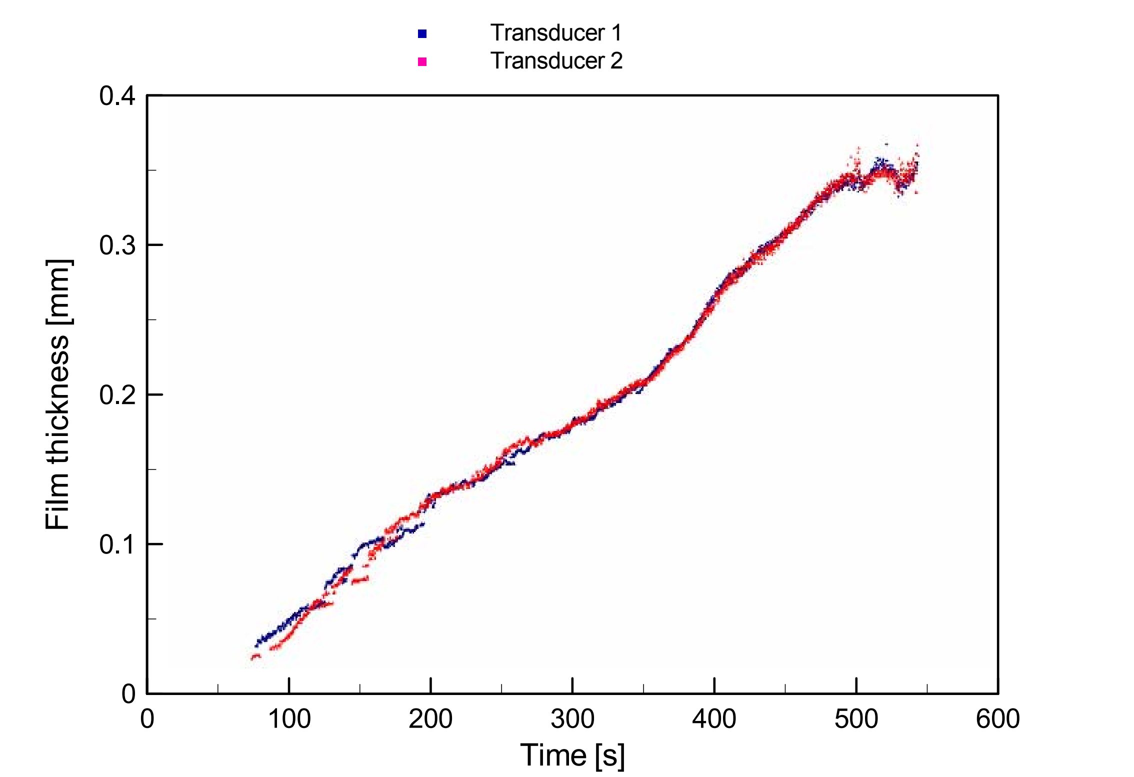
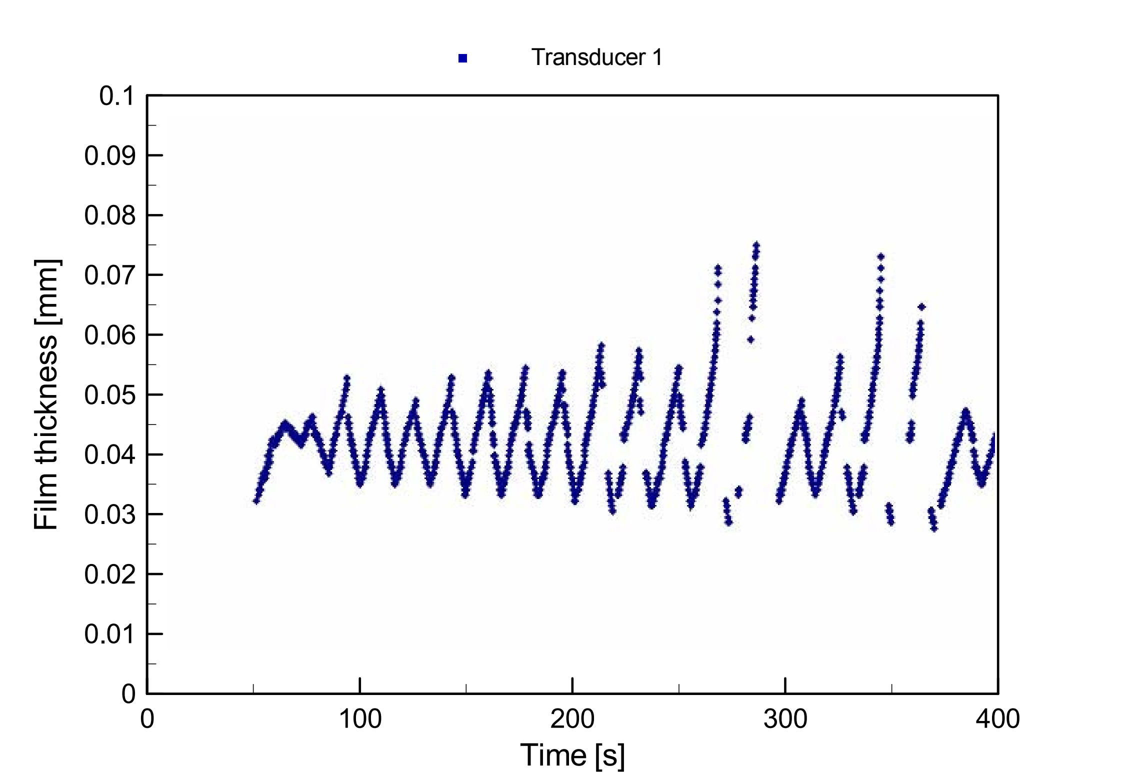
# Ultrasound Measurement of Film Thickness

N-pentane Film, Stable (+1g) Configuration



# Ultrasound Measurement of Film Thickness

N-pentane Film, Unstable (-1g) Configuration



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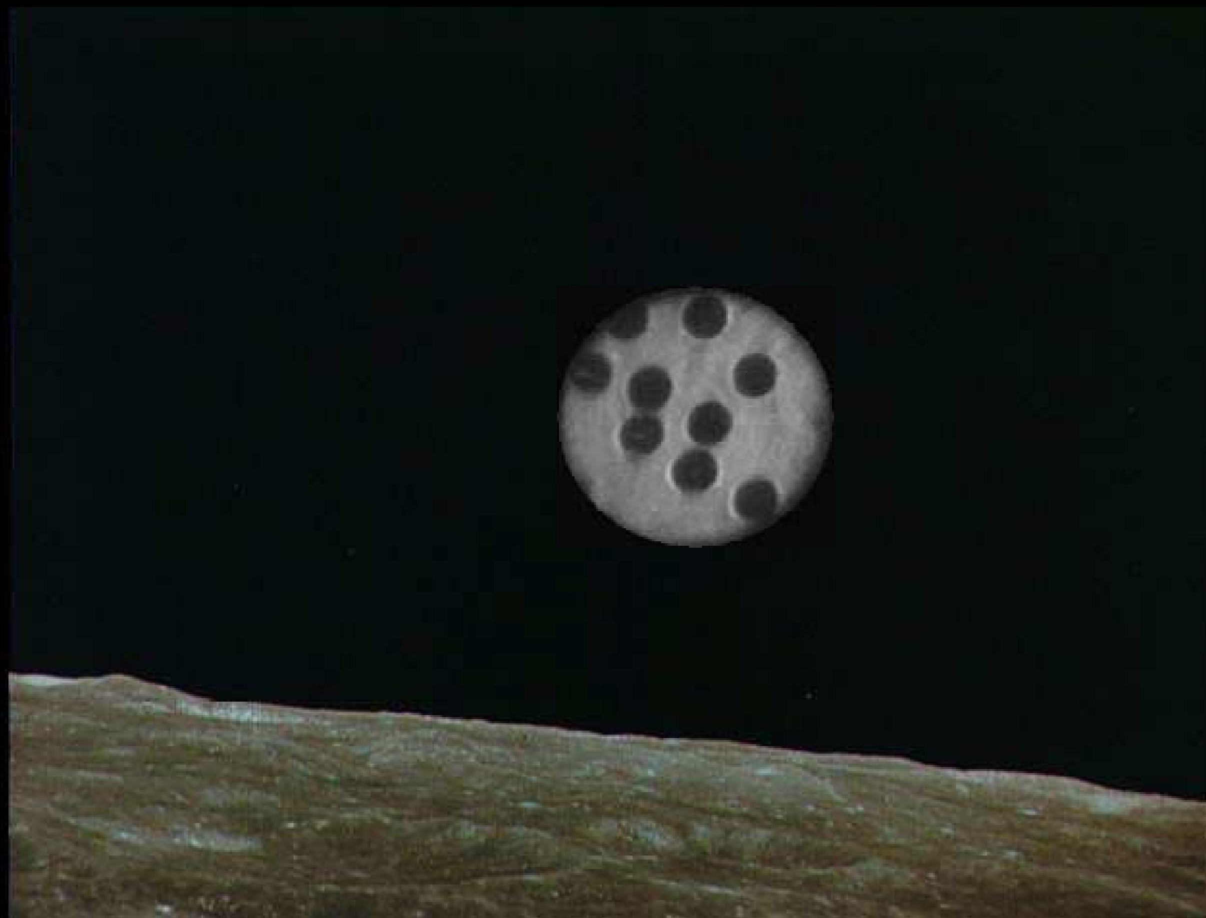
# Summary

- **Condensation and evaporation research is critical to meeting the technology needs of the AHST development effort**
  - Evaporation and condensation heat transfer and film stability and phase separation phenomena are strongly dependent on gravity level
  - Development of empirical correlations, theoretical models, CFD codes for these processes are all important to the success AHST technology development

- **Research conducted to date in the current project includes**
  - Film imaging and heat transfer measurements of steady and unsteady condensing films in the laboratory
  - Ultrasound gauging to determine the thickness of stable condensing and non-condensing films and in recording fluctuations in unstable films
  - The use of non-condensing, mechanically pumped films which simulate the growth and instability associated with unstable condensing films in the absence of thermal effects

# Questions?



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