



www.ascend.events

Ice Growth Model for Polar Water Capture Systems

Beau M. Compton, Diane L. Linne, and Andrew J. Ring

NASA Glenn Research Center

Background

- NASA GRC-led study outlines an ISRU pilot plant system to extract water from the permanently shadowed regions (PSR) and process it on the sunlit ridge
 - Goal: 1000 kg oxygen in one year
- Solar array-powered electrolysis system assuming 225 days of continuous sunlight
- Water needs to be extracted as vapor and delivered to ridge as ice via a tanker

ASCEND™

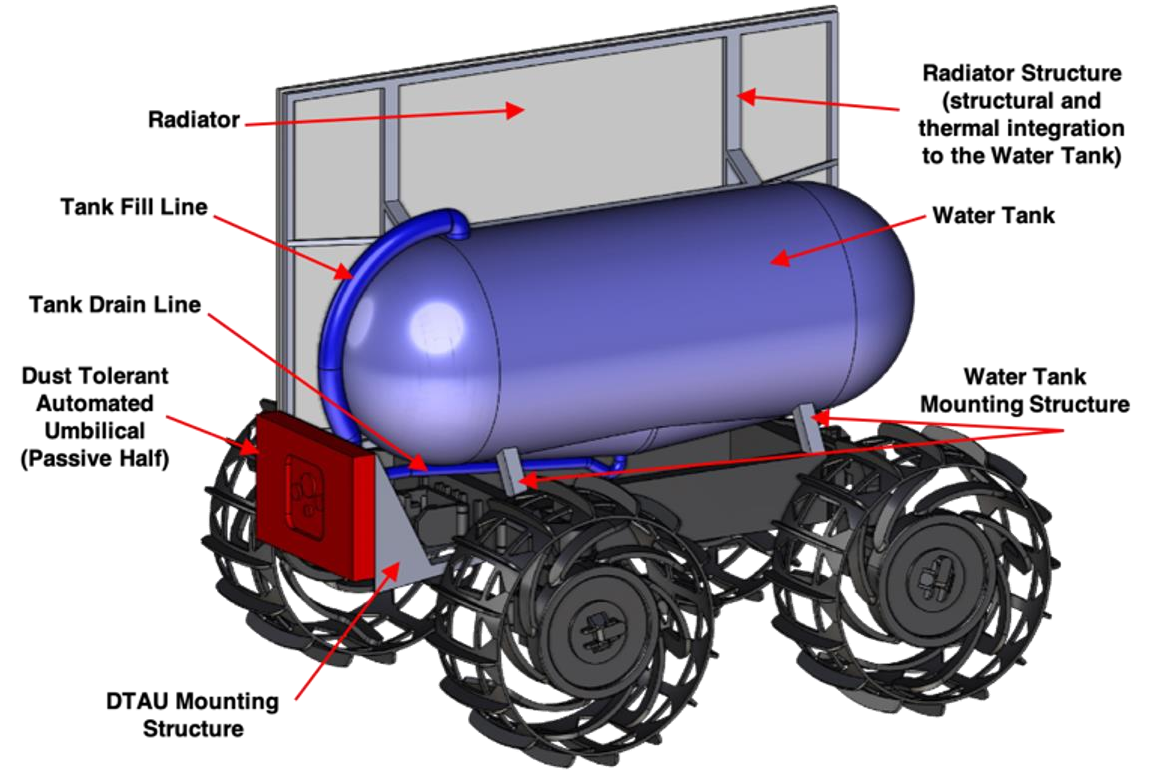
LIVE
Las Vegas
15-17 Nov. 2021

ONLINE
EVERYWHERE
8-10 + 15-17 Nov. 2021

LIVE
Washington, DC
15 Nov. 2021

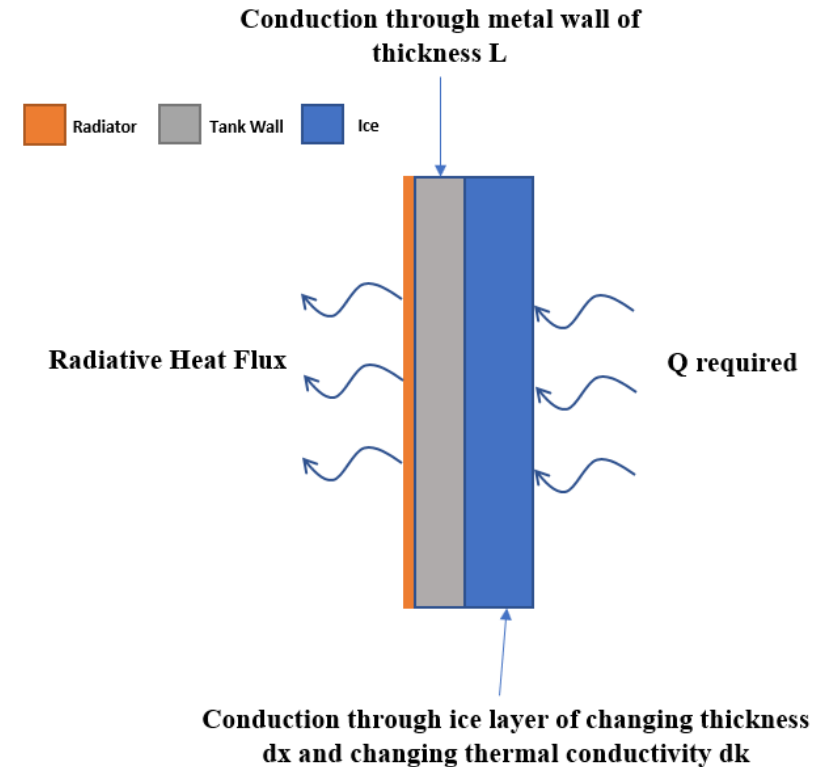
Background

- The tanker was sized based on total ice volume with 20% ullage
- No thermal analysis was performed to determine feasibility of depositing all water vapor on tank walls



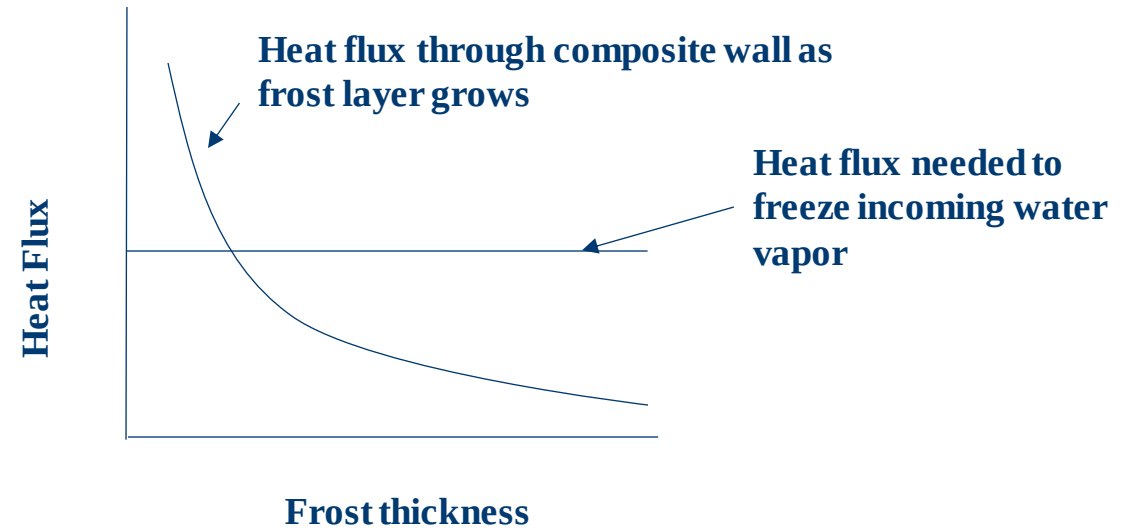
Thermal Challenge

- As the frost layer builds, the heat transfer will decrease as frost has a lower bulk thermal conductivity than the tank wall and radiator
- An increasing thickness will also contribute to a growing thermal resistivity
- The rate at which the heat transfer changes with frost layer growth needs to be determined



Thermal Challenge

- Using this flat plate model for a composite wall, we need to determine when the heat flux will reach the minimum value required to continue to deposit the incoming vapor
- Little research has been done to evaluate heat transfer through a frost layer in near-vacuum conditions

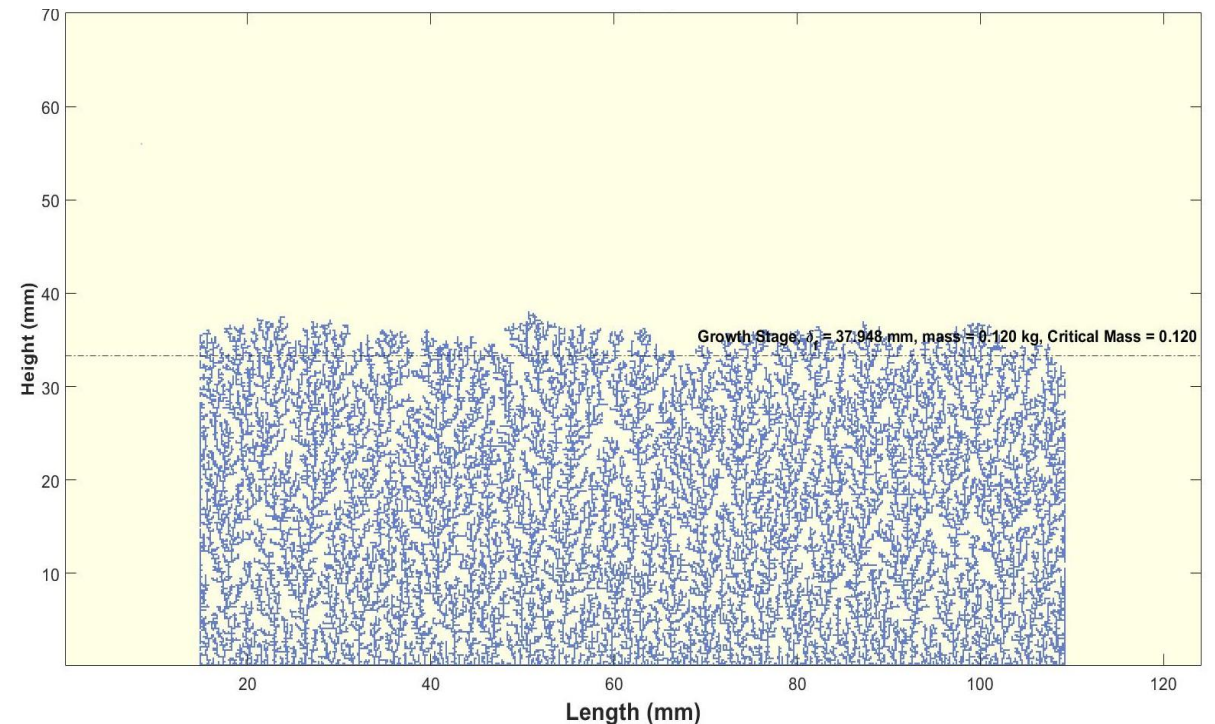


Diffusion-Limited Aggregation (DLA) Model

- Frost is grown in two phases:
 - Initial growth stage
 - Particles are released from the top of the control area and move randomly downwards, favoring an increase in frost thickness
 - Alternating growth and densification stages
 - Particles are released from the top of the control (growth)
 - Particles are released only inside the frost layer which favors an increase in density
- A minimum density is achieved when the density stage is removed, resulting in approximately 350 kg/m^3
 - The number of particles released in the densification stage can be increased which leads to denser frost

Diffusion-Limited Aggregation (DLA) Model

- DLA approach was used to model the buildup of frost layer over time with density measurements taken for a given number of particles depositions
- Bulk thermal conductivity is calculated using a common correlation by Yonko & Sepsy:
$$\kappa_f = 0.0140 + 0.00668\rho_f + 0.000175\rho_f^2$$
 - This correlation is generally applicable in the range of 243 – 263 K



Example of frost growth simulation using DLA approach

Experimental Tests

- Experiments will be conducted in a vacuum chamber located in CW-14 at NASA GRC
- Pressure will be held between 100 – 500 Pa to simulate tanker conditions



Experimental vacuum chamber in CW-14

ASCEND™

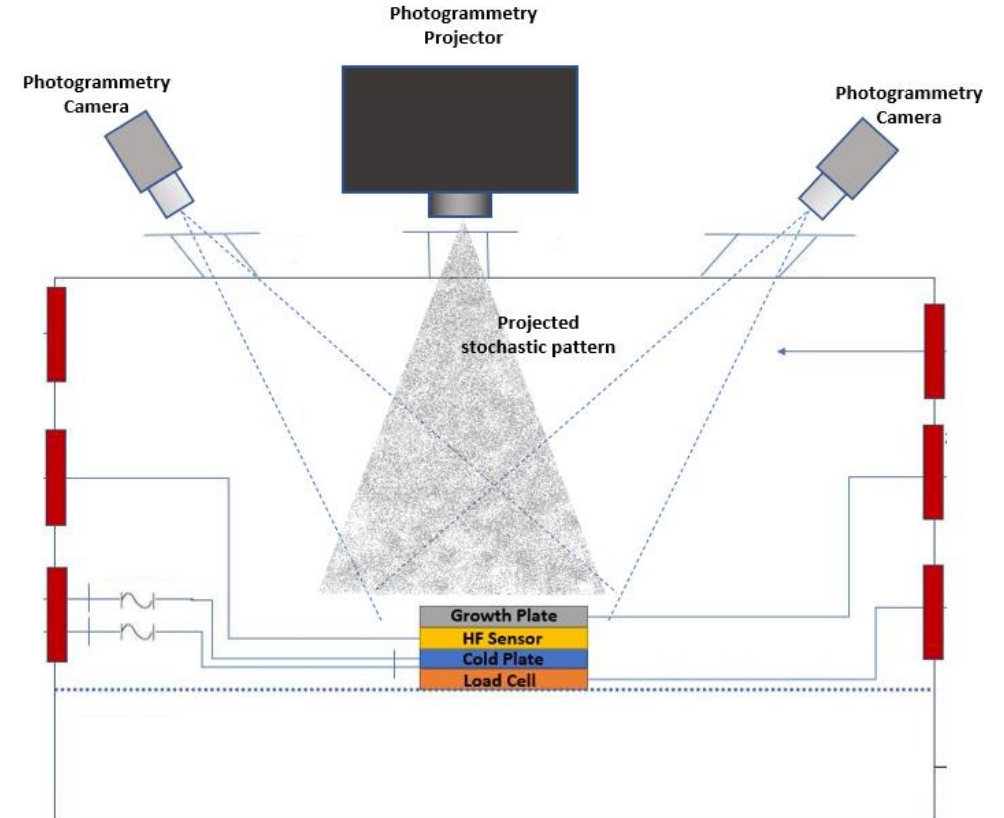
LIVE
Las Vegas
15–17 Nov. 2021

ONLINE
EVERYWHERE
8–10 + 15–17 Nov. 2021

LIVE
Washington, DC
15 Nov. 2021

Experimental Tests

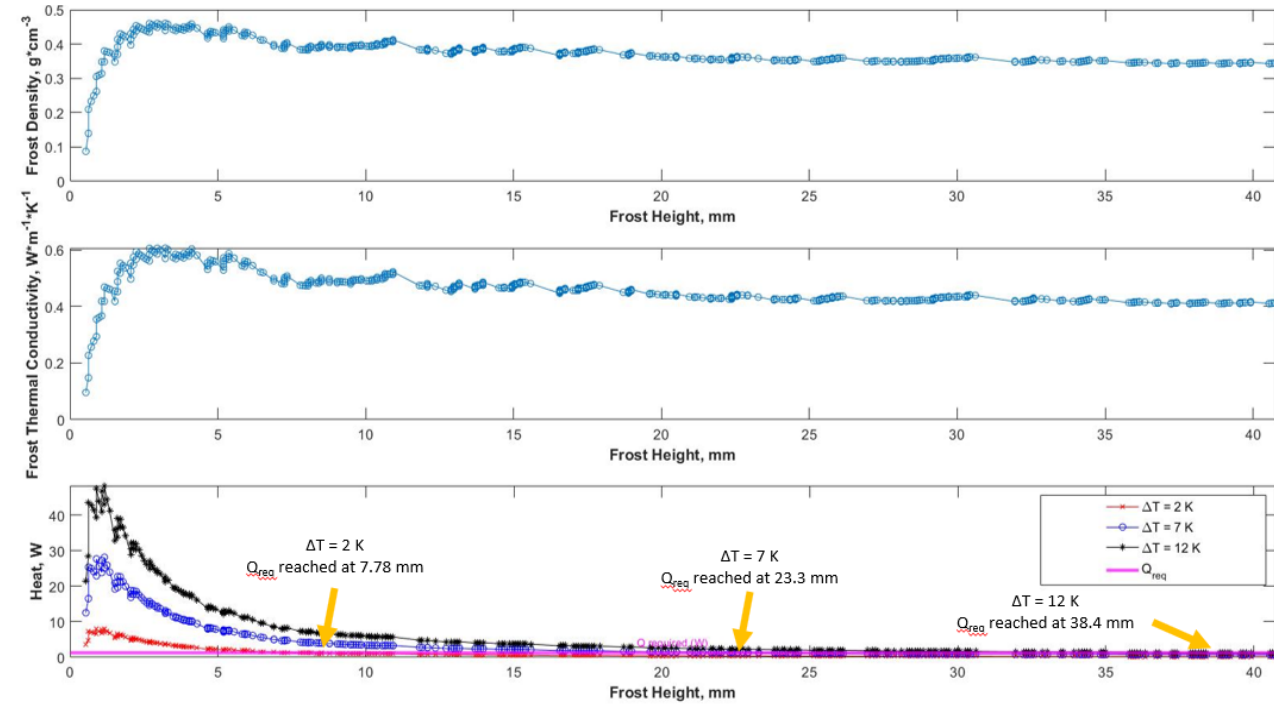
- A load cell will measure the changing frost layer mass
- A cold plate will be cooled as low as -35 C
- A heat flux sensor will measure the changing heat flux
- Two cameras will make frost thickness measurements using photogrammetry



Experimental concept for model validation; frost-height measurement photogrammetry concept

Expected Results

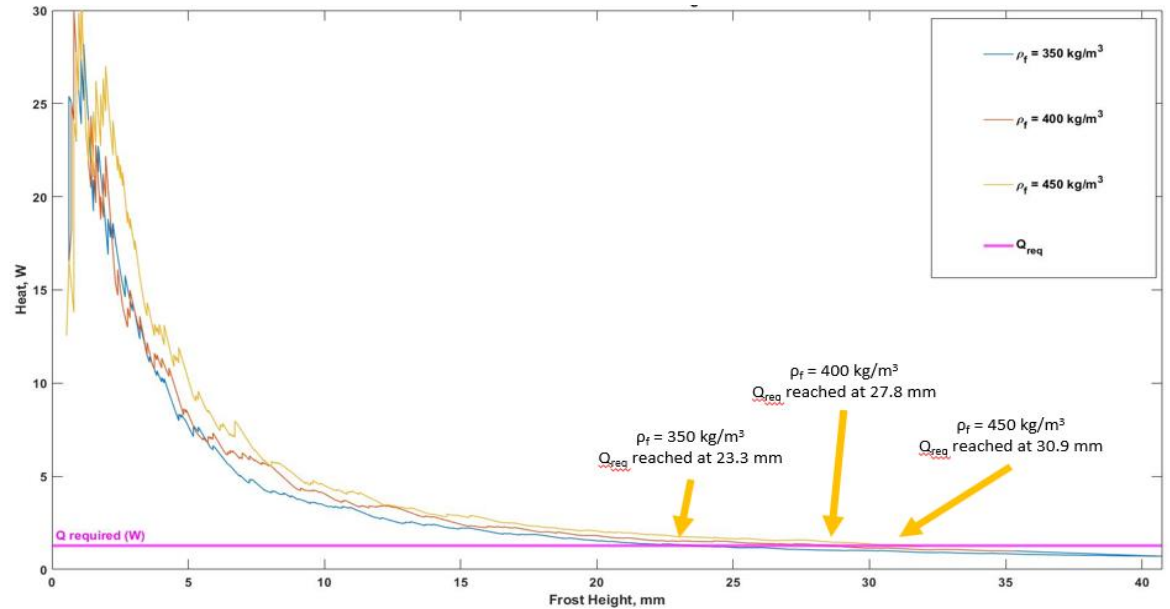
- Using different temperature differentials through the frost layer (ΔT), a maximum frost layer thickness is predicted
- Analysis shows that maximum frost thickness is highly sensitive to assumed ΔT across the frost layer



Expected results from the model demonstrating max frost height at ΔT values of 2, 7, and 12 K

Expected Results

- Analysis of the effect of frost density indicates that maximum frost growth is moderately sensitive to changes in density
- Frost density will be calculated from the experimental data to allow for tuning of the DLA model



Heat removed versus frost height as a function of frost thickness with frost densities varied

Summary

- Analysis suggests depositing extracted water for trip out of PSR is the most energy efficient method
- Need to understand how thick an ice layer will grow on internal tank surfaces before deposition halts
 - Maximum ice layer thickness will determine amount of internal surface area required to capture desired amount of water vapor for trip out of PSR
- Developed a DLA model that evaluates heat transfer through a growing frost layer
- An experiment is developed to evaluate the accuracy of the model

Thank You

 ASCEND

#ascendspace   





ASCEND™

LIVE
Las Vegas
15–17 Nov. 2021

ONLINE
EVERYWHERE
8–10 + 15–17 Nov. 2021

LIVE
Washington, DC
15 Nov. 2021

www.ascend.events

Powered by  **AIAA**