TFAWS 2016

Cryogenic Tank Pressurization and Liquefaction System Modeling

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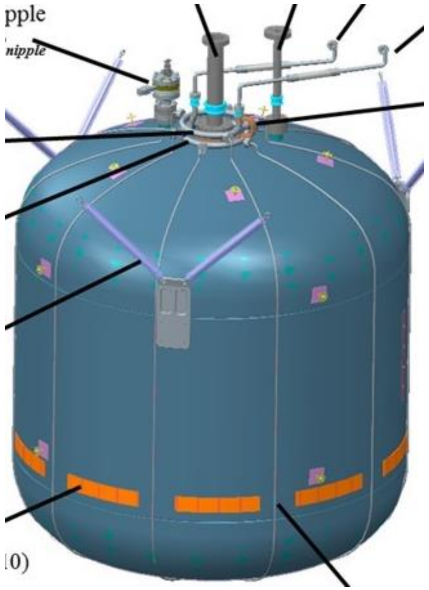
ISRU Liquefaction Overview

- **PROBLEM**: Commodities from ISRU must be liquefied for efficient storage on surface of Mars
- **MAJOR TRADES:**
    - Liquefaction Methods
        - Tube on tank, tube in tank, conduction, in-line liquefaction, Linde Cycle
    - Where to Liquefy?
    - When to Liquefy?
- Infeasible to test everything
- **APPROACH:** Start off with cryogenic tank pressurization model

GO_2
273.15 K
1 atm
2.2 kg/hr

Liquefaction →

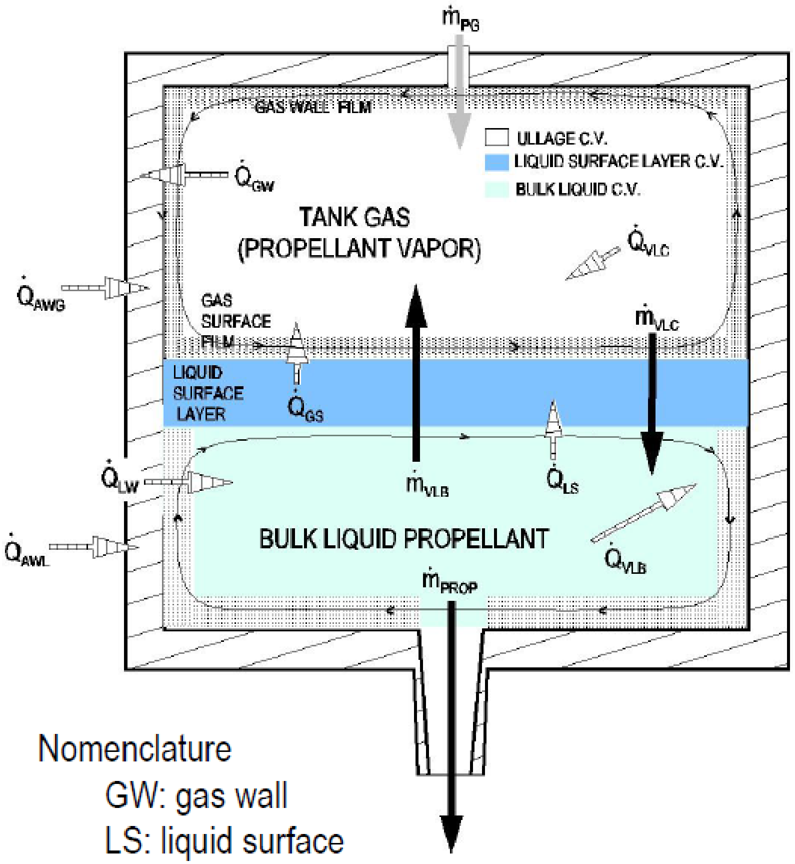
LO_2
90 K
1 atm
2.2 kg/hr



Tube on tank

Tank Pressurization

- Heat Transfers
  - $\dot{Q}$ between liquid and tank wall touching liquid
  - $\dot{Q}$ between liquid and surface layer
  - $\dot{Q}$ between gas and surface layer
  - $\dot{Q}$ between gas and tank wall touching gas
  - $\dot{Q}$ between environment and wall touching liquid
  - $\dot{Q}$ between environment and wall touching gas
- Mass Transfers
  - Mass transfer between liquid and gas
  - Propellant leaving tank
  - Gas entering tank



Nomenclature

GW: gas wall
LS: liquid surface
VLB: boiling
VLS: vaporized liquid from surface
VLC: condensed liquid vapor

$$P_{tg} = \frac{m_{tg} T_{tg} R_u}{V_{tg}}$$

Modeling Approach

Tank Pressurization Model Comparison

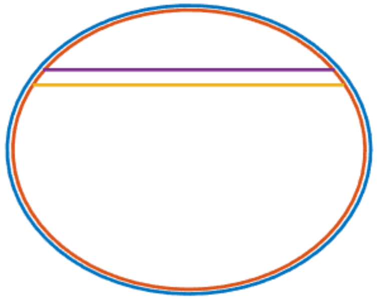
MATLAB

-First principles analysis

-Based on algorithm used for Shuttle External Tank

-Gas temperature uniform

-Temperatures of wall exposed to gas and liquid are uniform



Thermal Desktop

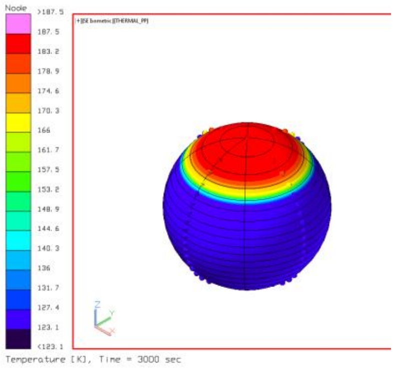
-Complex transient model

-Industry software, finite element based

-Gradient in wall temperature (nodal)

-Higher Fidelity than MATLAB Model

-Takes less time to build



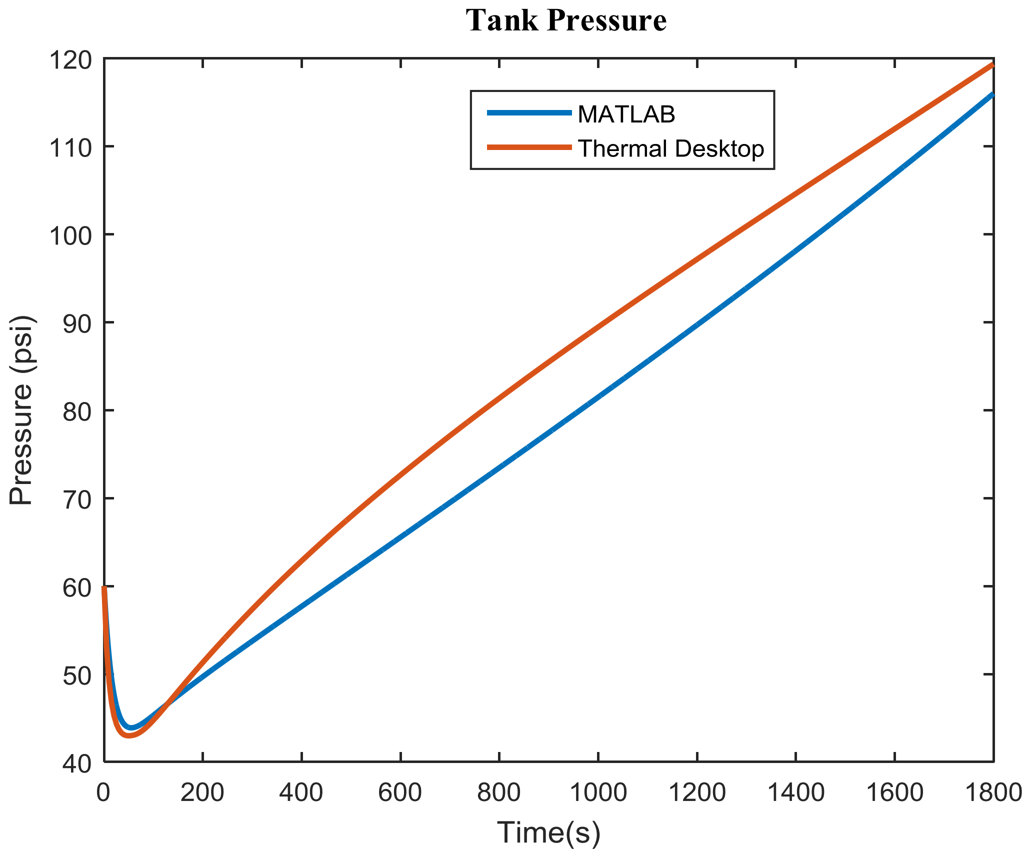
Morpheus/Cold Helium Data

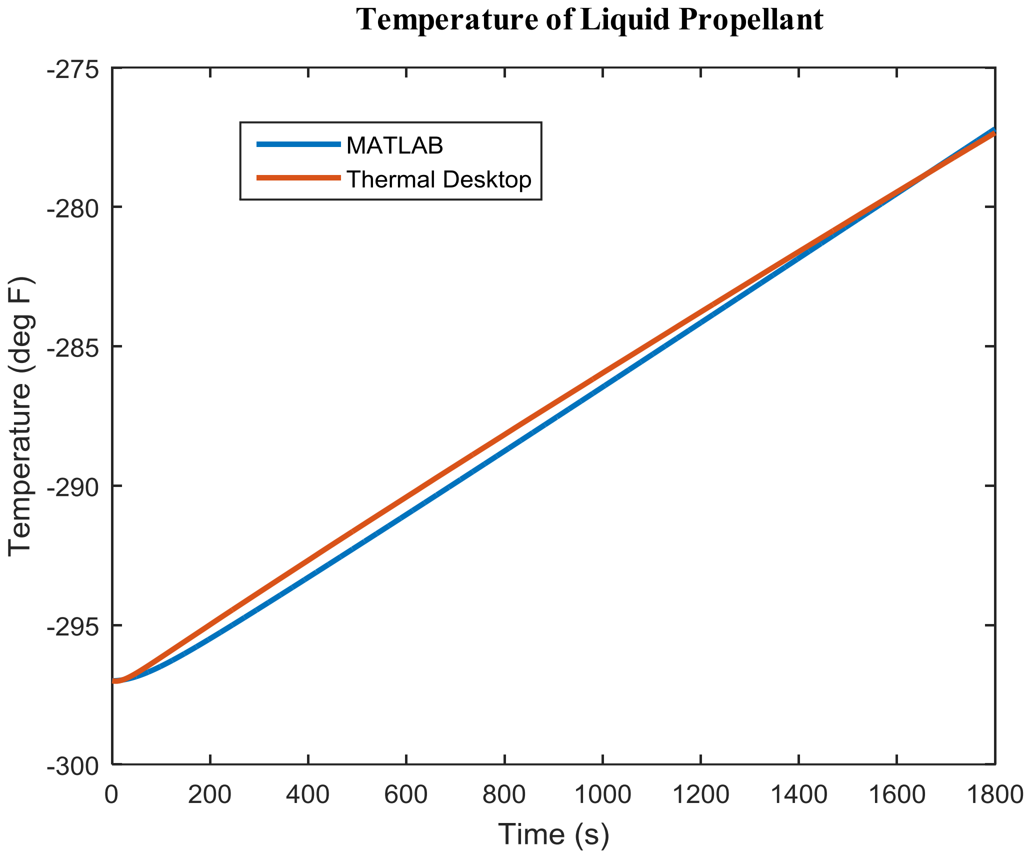
-Pressurization data from Cold Helium hot fires

-Anchor model

Comparison Results

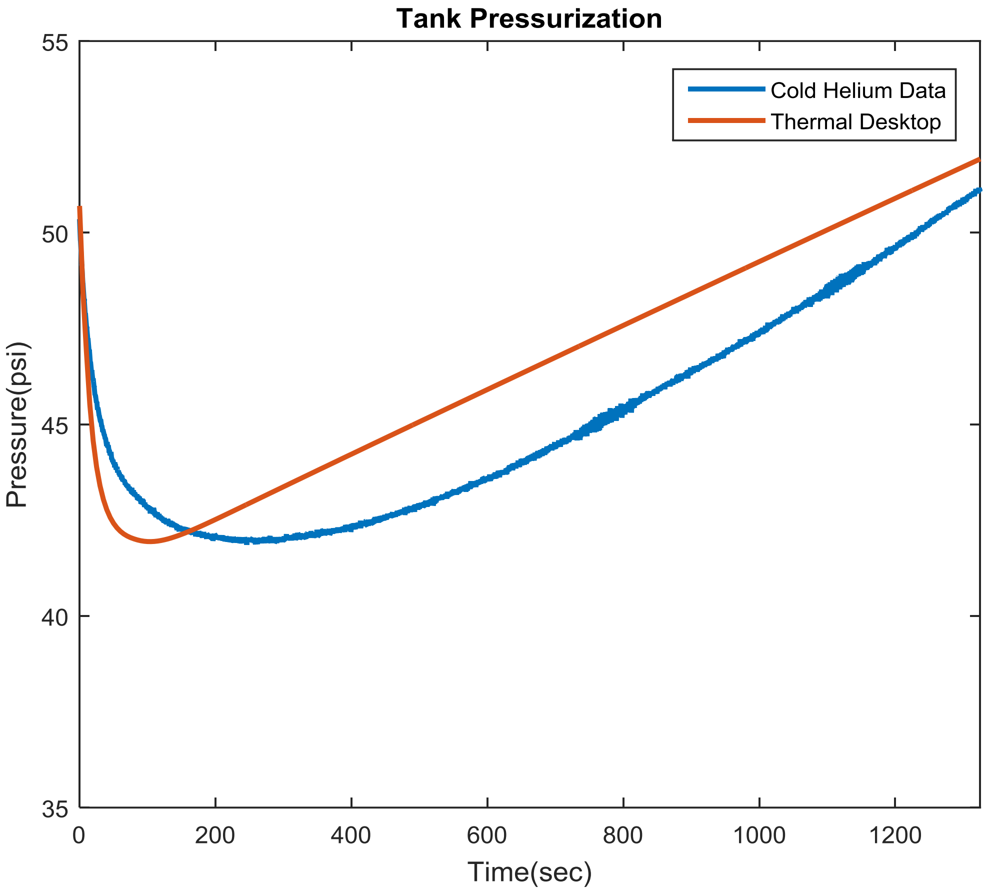
- MATLAB and Thermal Desktop Models compared well





Cold Helium Pressurization Data

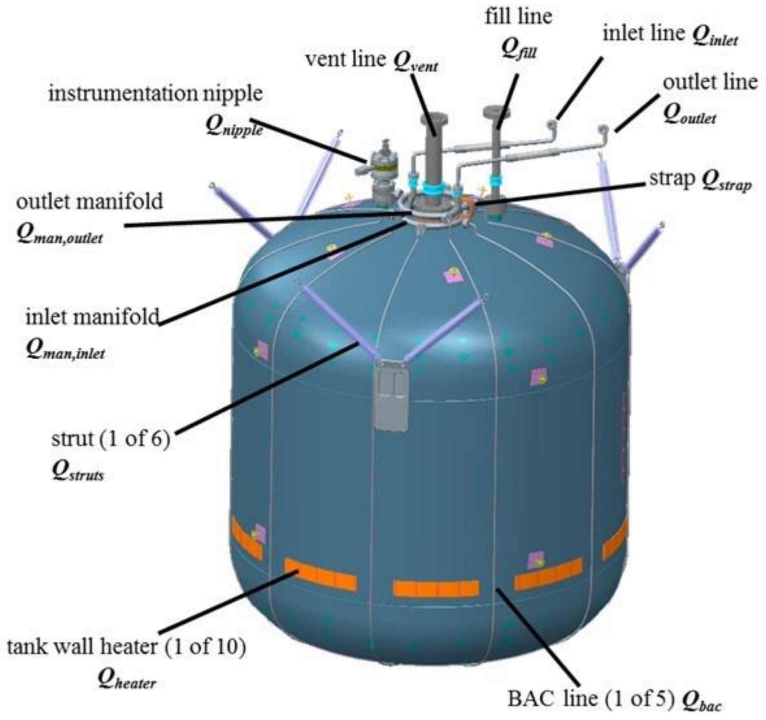
- Tank pressurization data available from Cold Helium tests
  - Tanks pressurized to ~50 psig, then closed off for ~25 min
- Initial Conditions
  - Ullage temperature: -125° F
  - Tank wall average temperature: -200° F
  - Ullage fraction: 26%
  - Propellant temperature: -297° F
- Next steps for model:
  - Model liquid, ullage thermal stratification



Tube on Tank Concept

- Broad area cooling distributes cooling with tubing network over the outer surface of tank
  - Cold gas (neon) is circulated in tubing loops in around cryo tank to eliminate boil-off
  - Tubing is welded and epoxied to tank wall

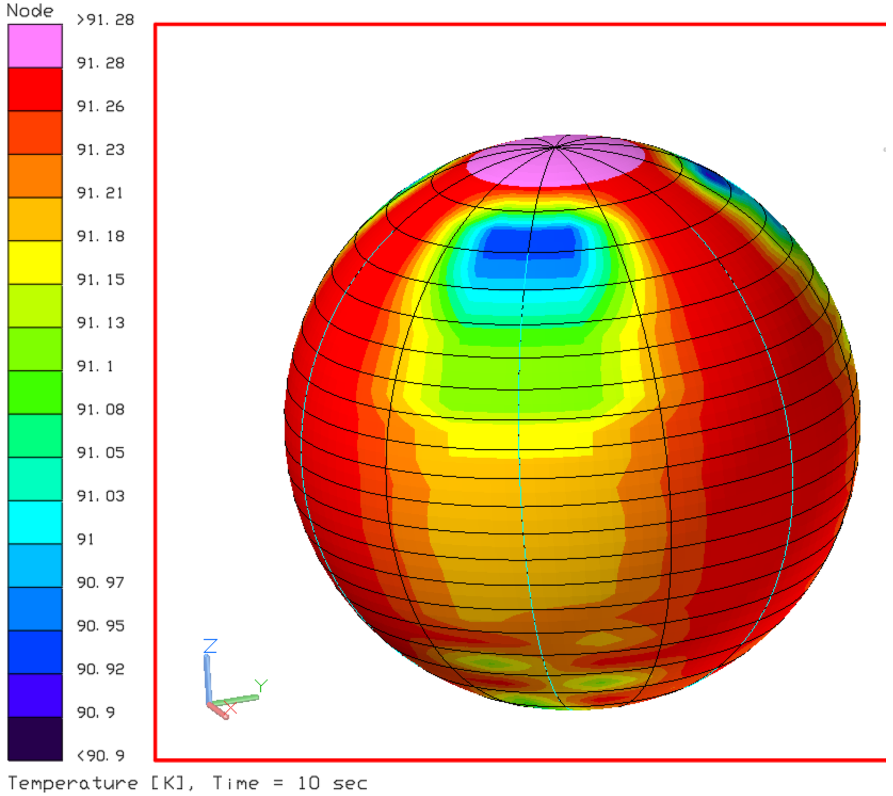
- Uses Reverse turbo-Brayton cycle



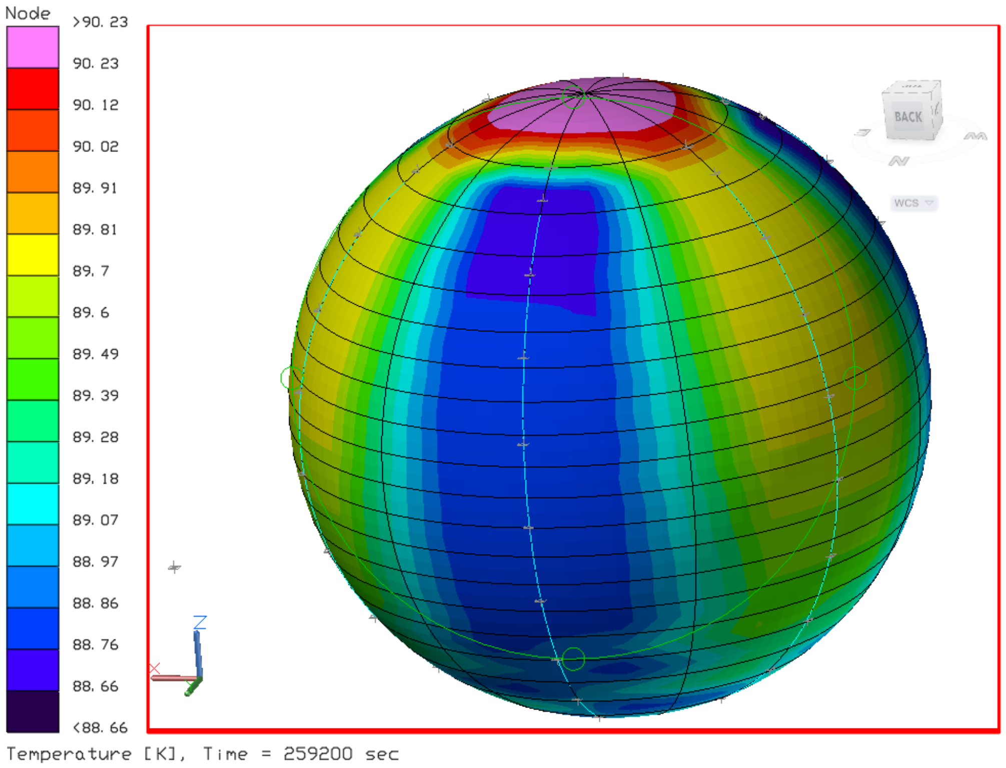
Zero Boil-off Tank

Current Work - Tube on Tank Transient Model

- Neon Gas flow in tubes
- Tubes and tank wall started at 90 K at time 0. initial ullage volume fraction: 99%



After 10 seconds



After 72 hours

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