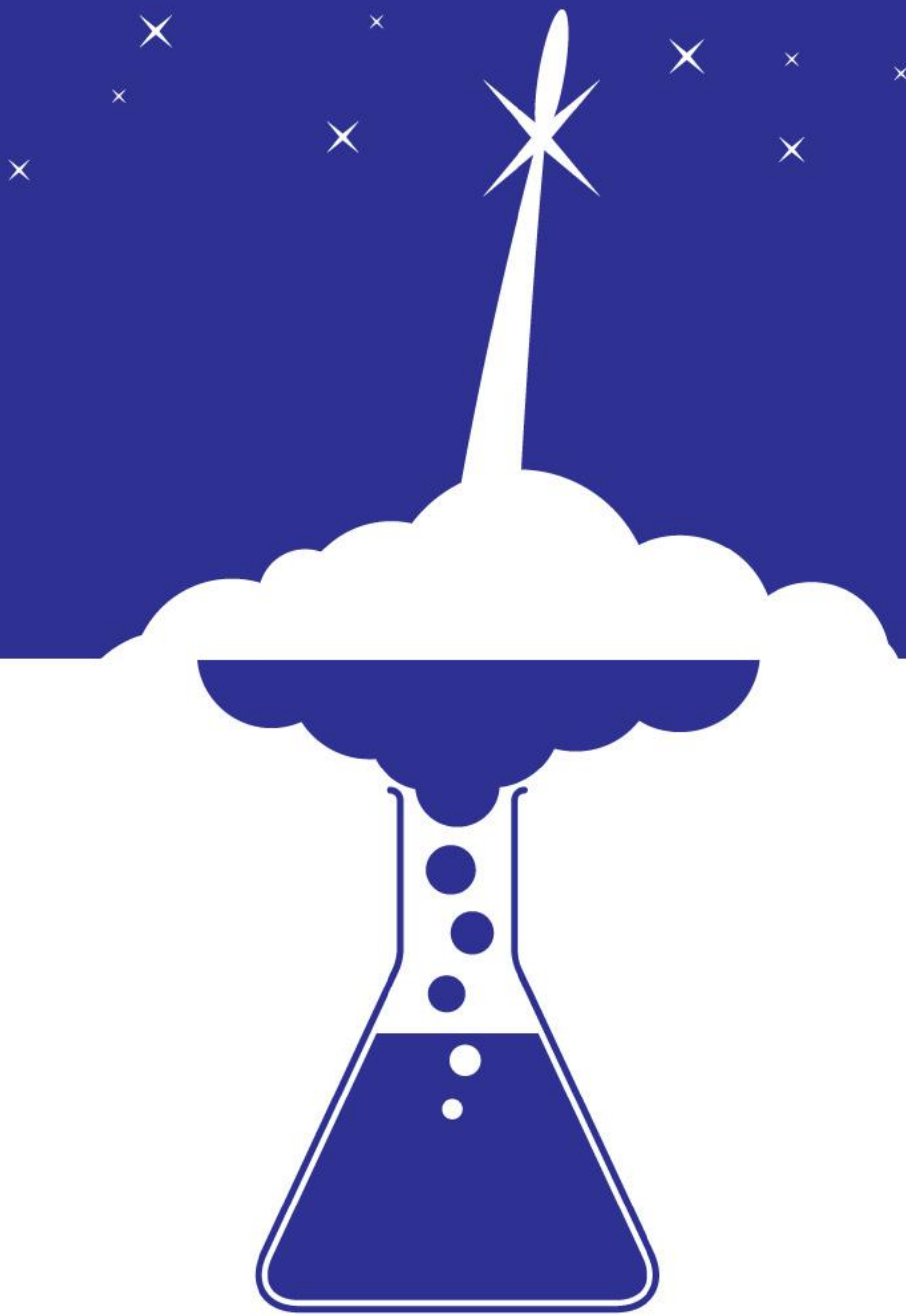


Composite Overwrapped Pressure Vessel (COPV) Pressurization

By Mark Ventura

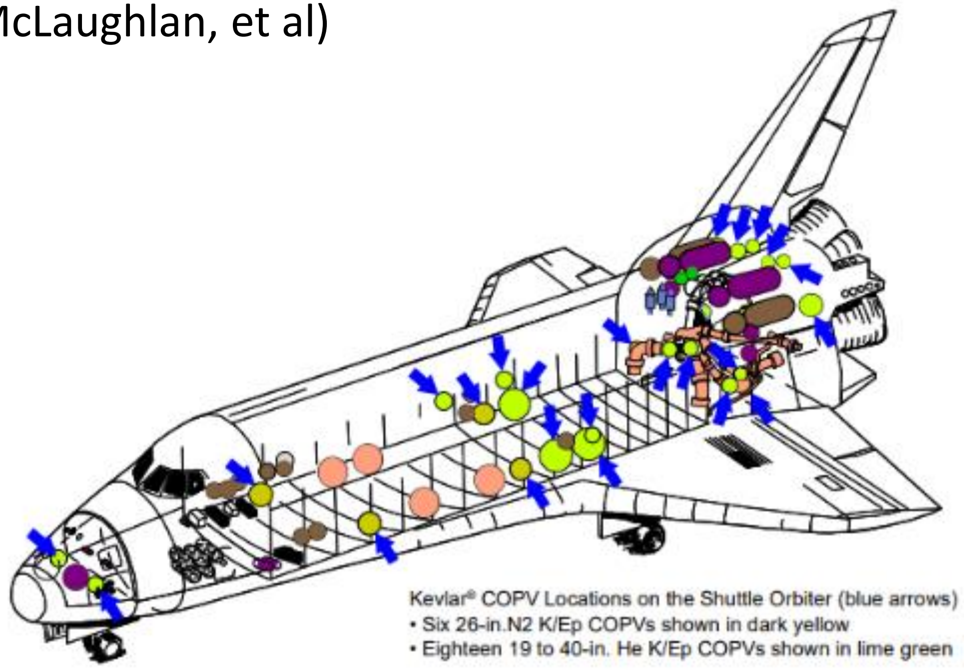
1/25/2023

Huntington Beach, CA, VESM109-001

ACADEMIC-INDUSTRY LIQUID ROCKET SYMPOSIUM 2023

COPV Pressurization

(ref. McLaughlan, et al)



- Background, Definitions, Historical Context
- Hazards
- Basic Process
- First Law of Thermodynamics
- Joules-Thompson Effect
- Parametrics
- Operational Topic

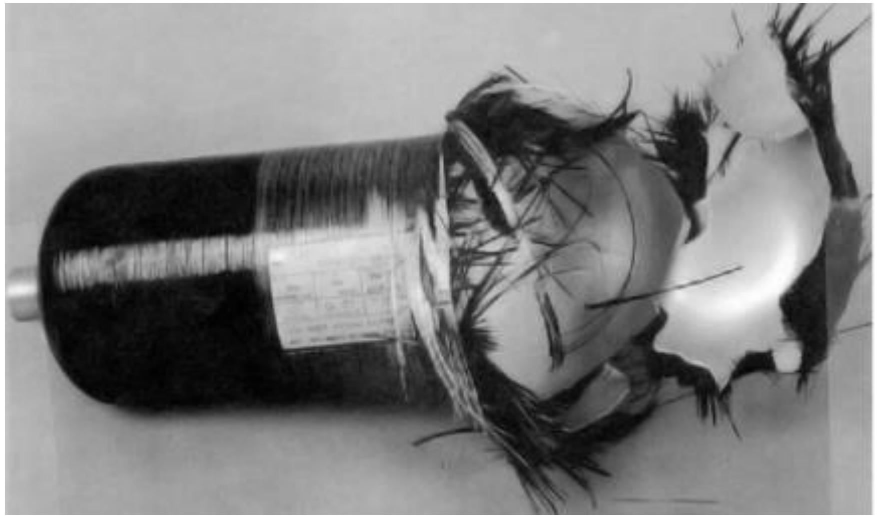
The information provided in the seminar is not meant to be inclusive of all information needed to understand cryogenics. The information provided is meant as a guide to assist in education. The referenced information as is not inclusive of all pertinent information about cryogenics. VES holds itself harmless from any action that results from the use of this information. VES holds itself harmless from any errors provided in this seminar. The information in this seminar is incomplete without the oral portion of the presentation.

Basic Physics, Definitions, Historical Context

- COPV's are commonly used for high pressure gas storage as well as expanding into larger scale low pressure structure
- Material is composed of high strength fibers bound in a binder matrix
- Fibers and resulting materials have anisotropic directional material properties both mechanical and thermal

- Commonly made with a metallic inner liner
- Early tank circa Apollo used fiberglass, then Kevlar, and now various carbons
- Liners vary in material: None, elastomer, stainless steel, aluminum, titanium
- High energy dense device
- AKA "Cold Gas Bomb"

Hydrostatic Pressure Burst



Pneumatic Pressure Burst

(ref. McLaughlan, et al)

General Failure Modes

- Overview reference McLaughlan, et al (Forth, S.), Composite Overwrapped Pressure Vessels, A Primer, NASA/SP–2011–573

- Boss failures
- Over Pressure
- Stress Rupture
- Liner failure, various
- Mechanical damage
- Others

COPV Pressurization Hazard

- Structural failure can kill, maim, and injure
  - Localized high pressure gas expansion and loads, trauma
  - High velocity composite pieces
  - High velocity liner shrapnel
  - Hearing loss

- Pressurization increases bottle internal temperature
- Heat conducts outward into bottle walls to environment
- Excessive heat will cause composite to weaken and potential failure at bottle operating pressure caused by degraded material properties

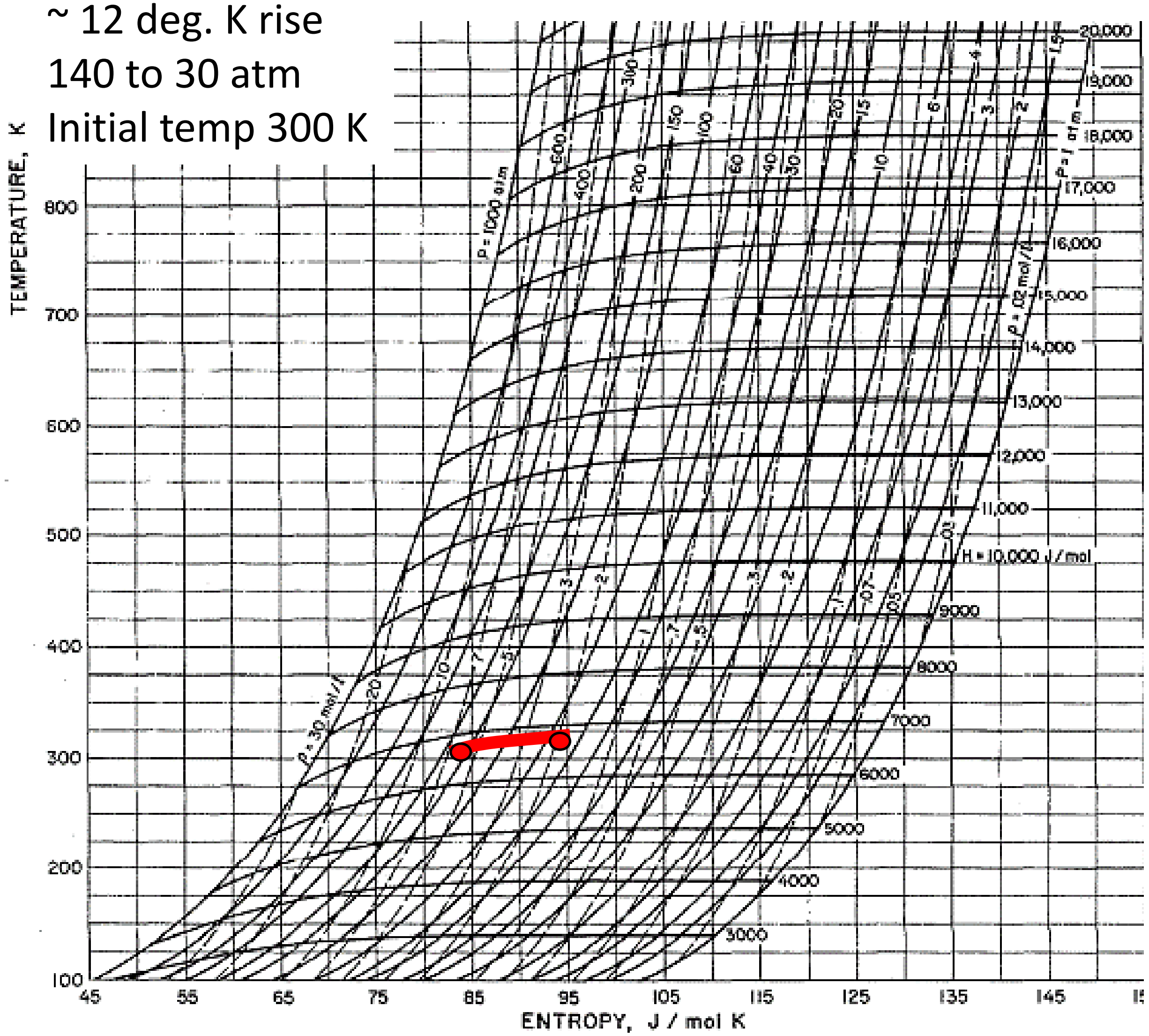
- Pressurization schedule needs to control maximum bottle structural temperature
- Treat bottle contained pneumatic energy as deflagration like explosive hazard

Joule-Thomson Effect The Red Herring

- Change in temperature of a fluid when it expands at constant enthalpy (isenthalpic)
  - NOT ISENTROPIC
  - Most gases have a temperature drop from this effect

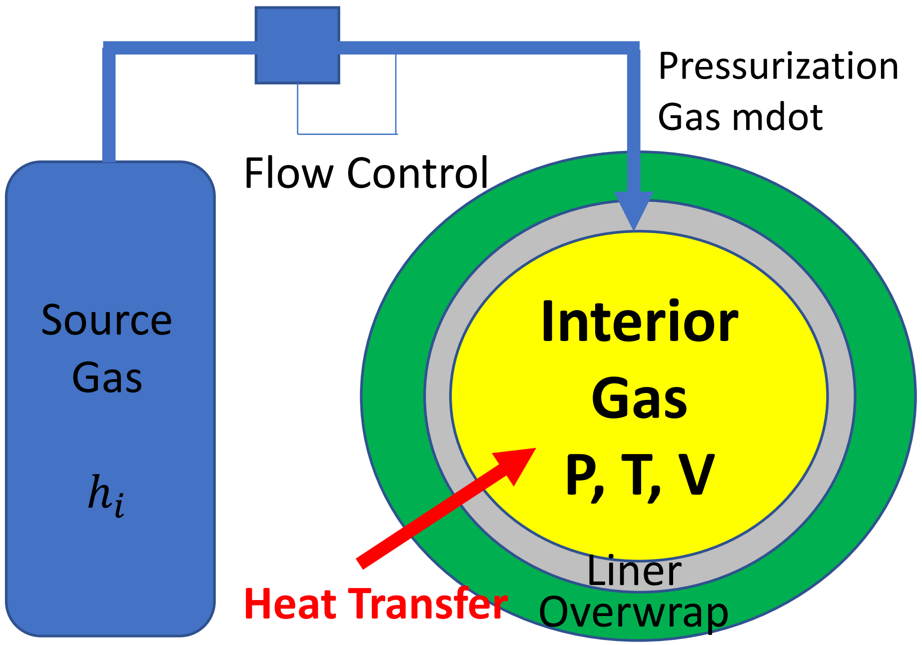
- Isenthalpic helium throttling has a temperature rise at room temperature
- ***<u>This has little to no effect on the tank gas heating from pressurization</u>***

~ 12 deg. K rise
140 to 30 atm
Initial temp 300 K



Mc Carty, Robert D., Thermodynamic Properties of Helium 4 from 2 to 1500 K at Pressures to 108 Pa, : Journal of Physical and Chemical Reference Data 2, 923 (1973)

Transient 1st Law for a Control Volume Quasi Steady-State, 1st Order Differential Equation



$$\delta Q + \delta W + \left(h + \frac{v^2}{2} + zg\right)_i * dm_i - \left(h + \frac{v^2}{2} + zg\right)_o * dm_o = dU$$

Bunch of math

$$\dot{T} \cong \frac{\dot{Q} + \dot{m}_i(h_i - u)}{Mc_v}$$

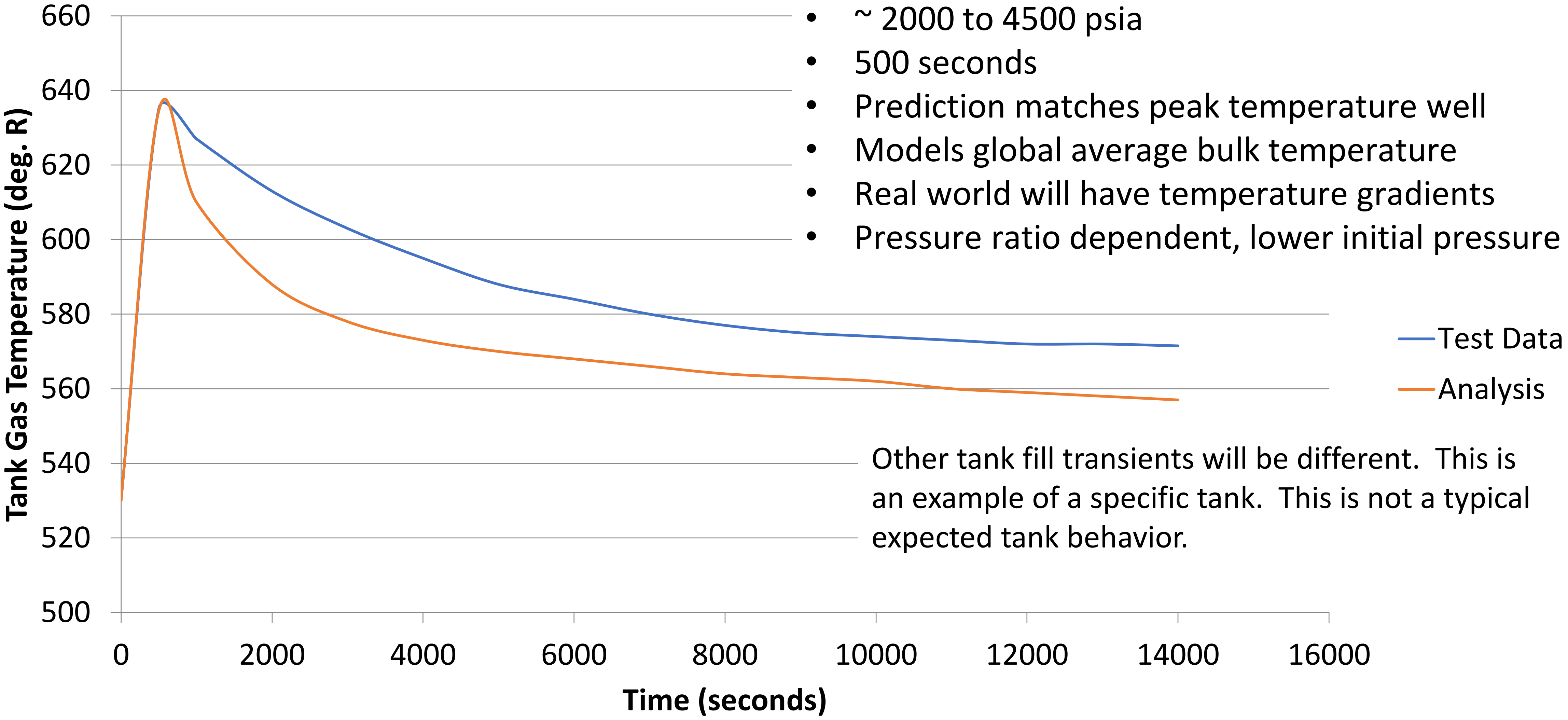
Wark, Kenneth, Thermodynamics 4th Ed., McGraw-Hill, New York, 1983

Conservation of mass solves for density

Real gas state equation solves for pressure

Liner and overwrap are transient thermal masses

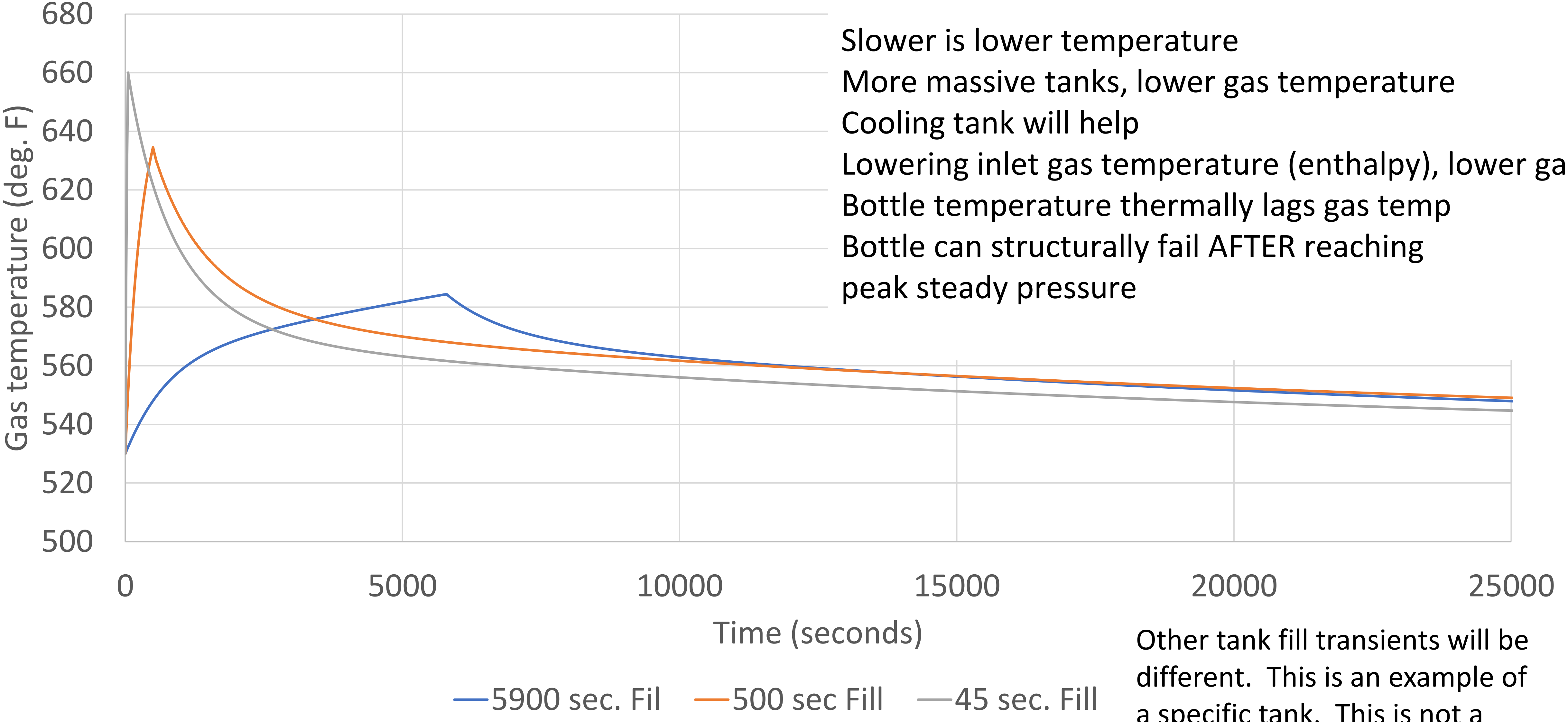
Transient Pressurization   Spacecraft GHe Tank



- ~ 2000 to 4500 psia
- 500 seconds
- Prediction matches peak temperature well
- Models global average bulk temperature
- Real world will have temperature gradients
- Pressure ratio dependent, lower initial pressure

Other tank fill transients will be different. This is an example of a specific tank. This is not a typical expected tank behavior.

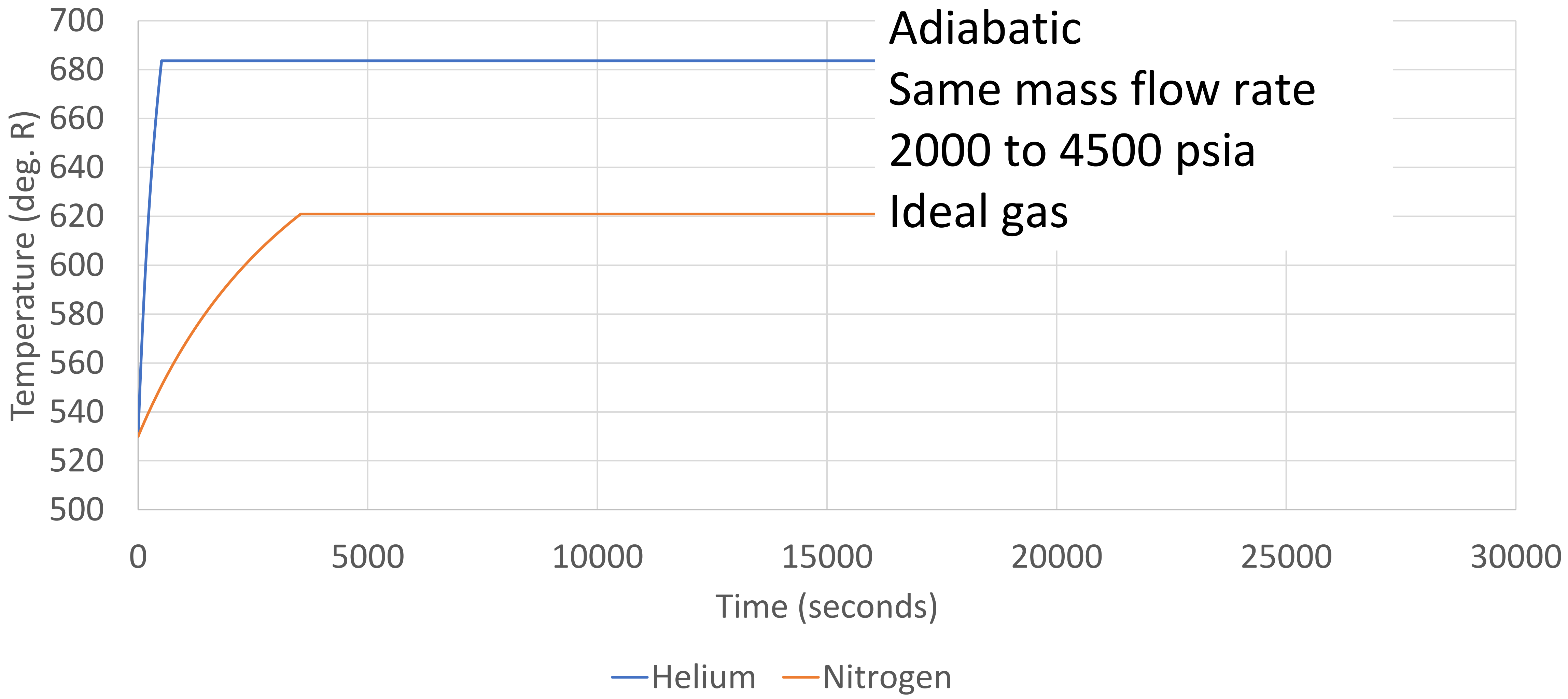
Parametric Behavior Based on Fill Rate



Slower is lower temperature
More massive tanks, lower gas temperature
Cooling tank will help
Lowering inlet gas temperature (enthalpy), lower gas
Bottle temperature thermally lags gas temp
Bottle can structurally fail AFTER reaching peak steady pressure

Other tank fill transients will be different. This is an example of a specific tank. This is not a typical expected tank behavior.

Comparison of Helium vs Nitrogen



Adiabatic

Same mass flow rate

2000 to 4500 psia

Ideal gas

Other tank fill transients will be different. This is an example of a specific tank. This is not a typical expected tank behavior.

Questions

- What is the highest pressure for a current DoT COPV? What is it used for?
- Approximately what amount of analytic error is caused by assuming ideal gas versus real gas properties for GHe and GN2 COPV thermodynamics?

- Which COPV will heat up more for the same fill process and same liner design: Carbon, Kevlar, Fiberglass?
- Which vessel is more dangerous with the same amount of exterior surface damage: Carbon COPV, Kevlar COPV, metal tank?