Modeling Wing Tank Flammability

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Motivation

- Numerous accounts of wing tank explosions across the world
- Current flammability models are for center wing tanks
- The proposed regulation for wing tank safety are mostly based on center wing tank models
- Models will predict ullage concentrations existing during typical ground and flight operations

Current Work

- Flammable mixtures can be achieved in the wing tank
- Experiments are being conducted to build flammability models for wing tanks
- Current work involves
  - Predicting the influence of the surrounding temperatures on the characteristic fuel surface temperature
  - Creating a model that will predict flammability in wing tanks using heat transfer correlations

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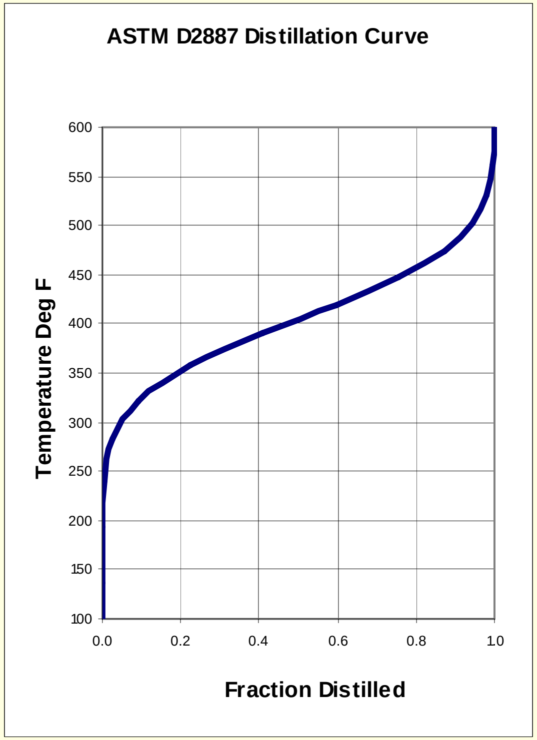
Overview

- Single Thermocouple Method
- Difference between Center Wing Tank and Wing Tank
- Center Wing Tank Flammability Model
- Heat and Mass Transfer Correlations
- Experiments

Distillation Curve

- Jet fuel is a mixture of many different hydrocarbons
- Fuel composition is characterized by the number of alkane reference hydrocarbons
- The approach reduces the number of components from over 300 down to 16 species (C5-C20 alkanes)
- Liquid compositions of different JP-8 samples with varying flashpoints are presented in terms of the mole fractions of C5-C20 alkanes



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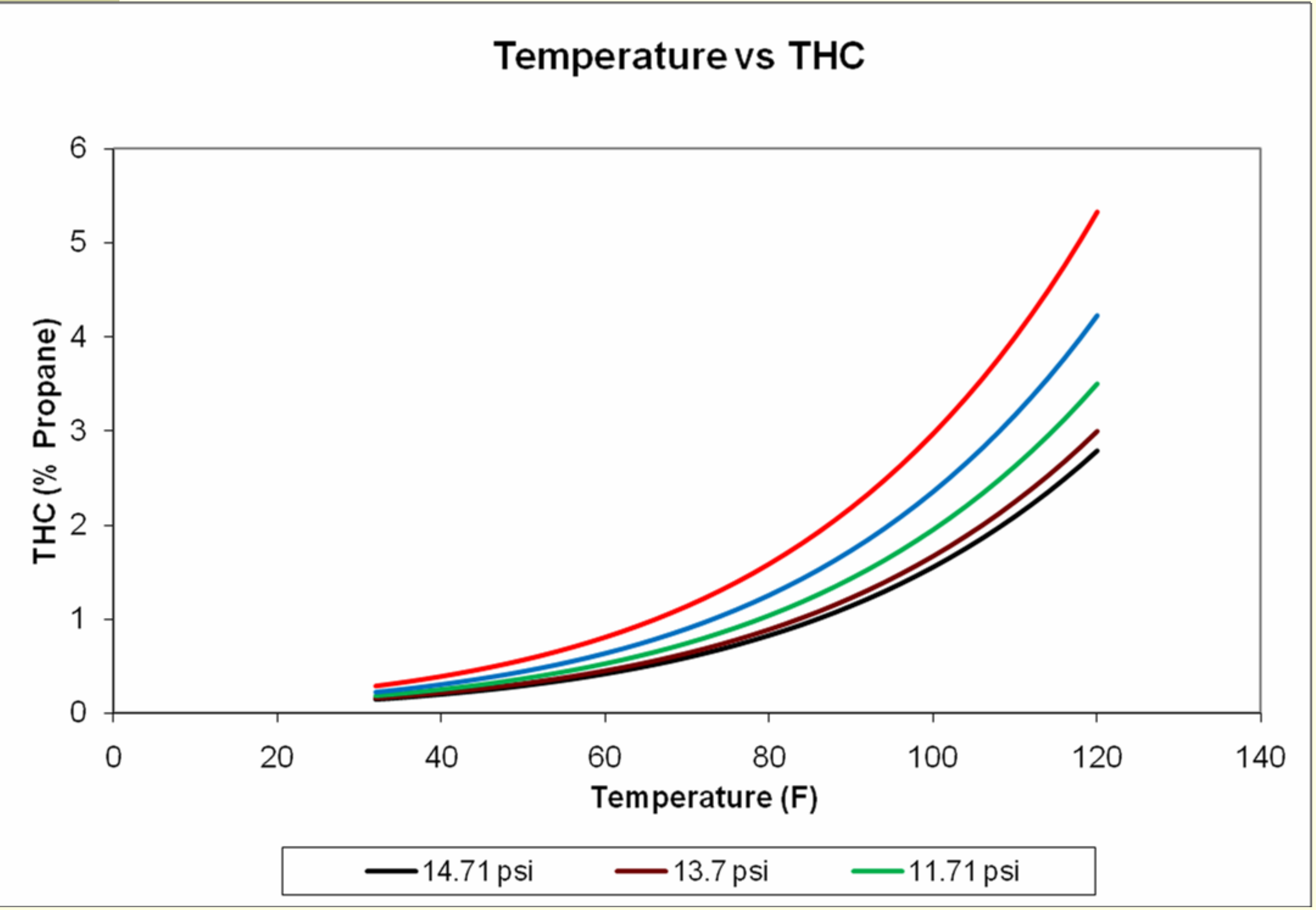
Single Thermocouple Method



Uses Fuel Air Ratio (FAR) calculator by Ivor Thomas

- Calculates fuel air ratio over a range of altitudes and temperatures
- All compounds with same carbon number were assigned together
- Fuel is segregated based on boiling points of alkane species respective of their carbon number

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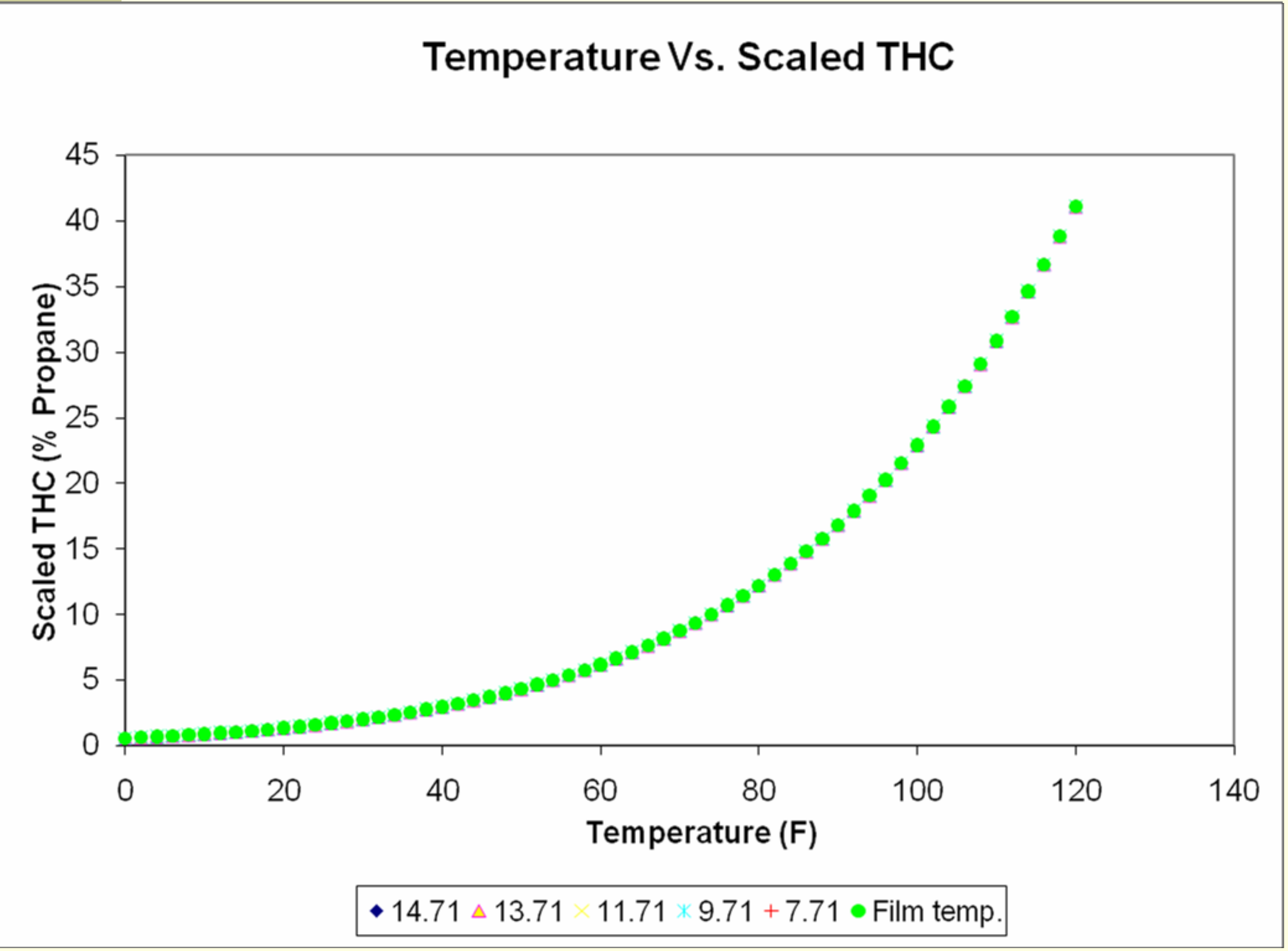
Single Thermocouple Method



- At constant temperature the THC increases as the pressure decreases
- Polynomial correlation between Scaled THC and temperature
- Film temperature is calculated at a given pressure and THC

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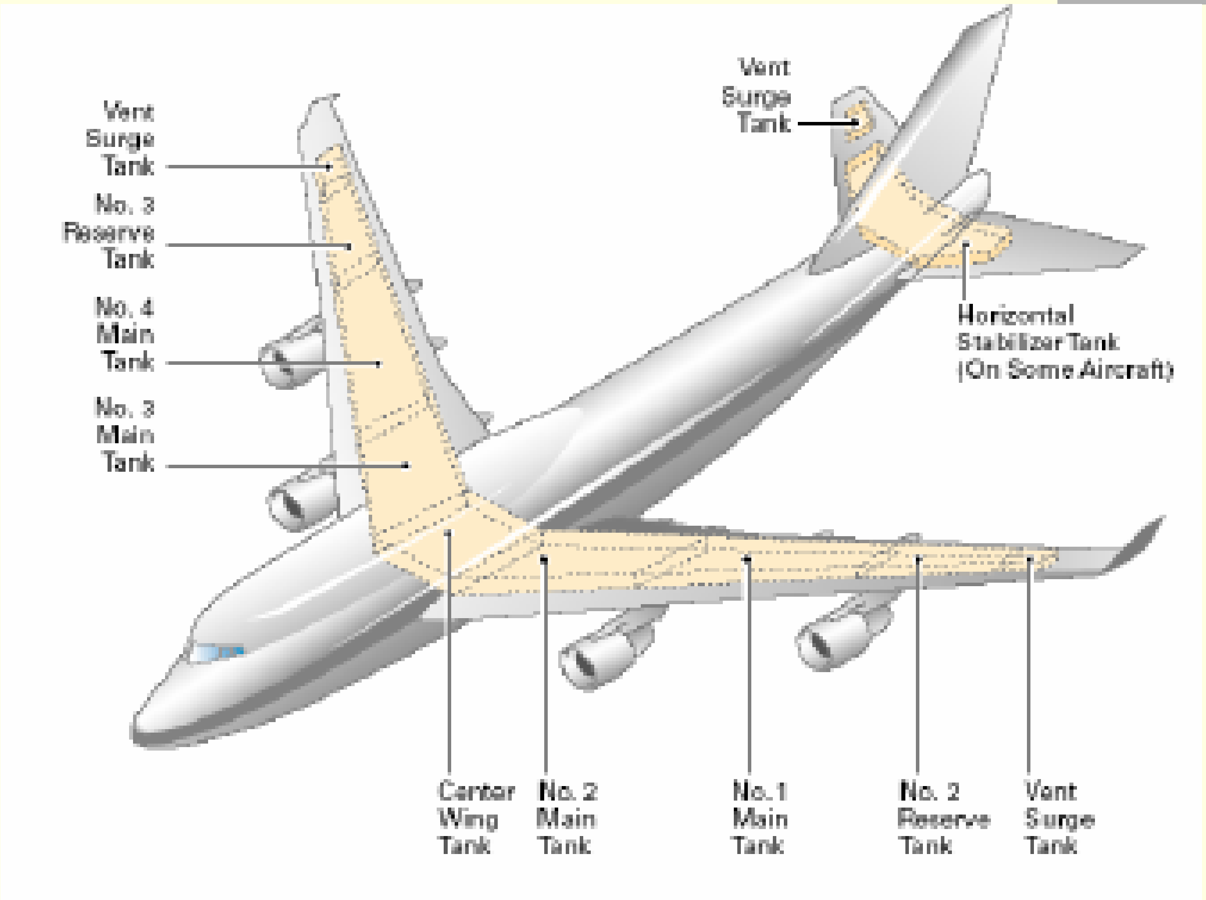
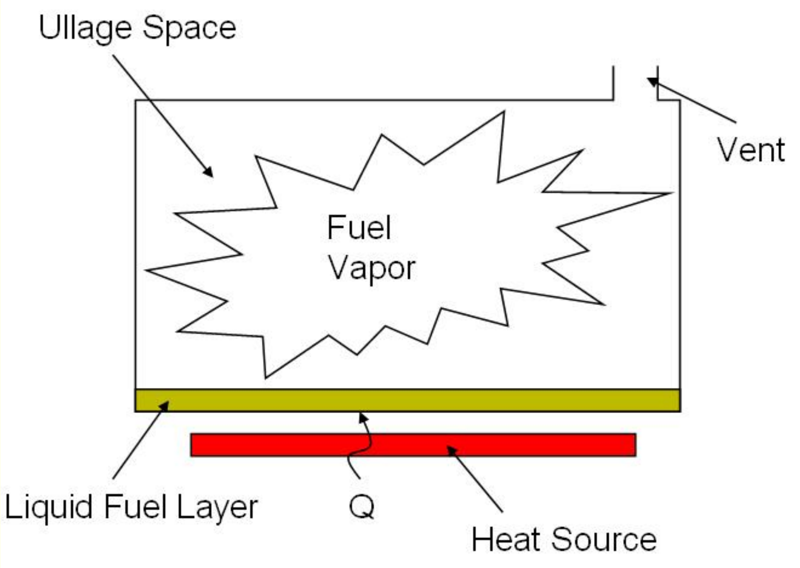
Fuel Tanks



Vent Surge Tank
No. 3 Reserve Tank
No. 4 Main Tank
No. 3 Main Tank
Vent Surge Tank
Horizontal Stabilizer Tank (On Some Aircraft)
Center Wing Tank
No. 2 Main Tank
No. 1 Main Tank
No. 2 Reserve Tank
Vent Surge Tank

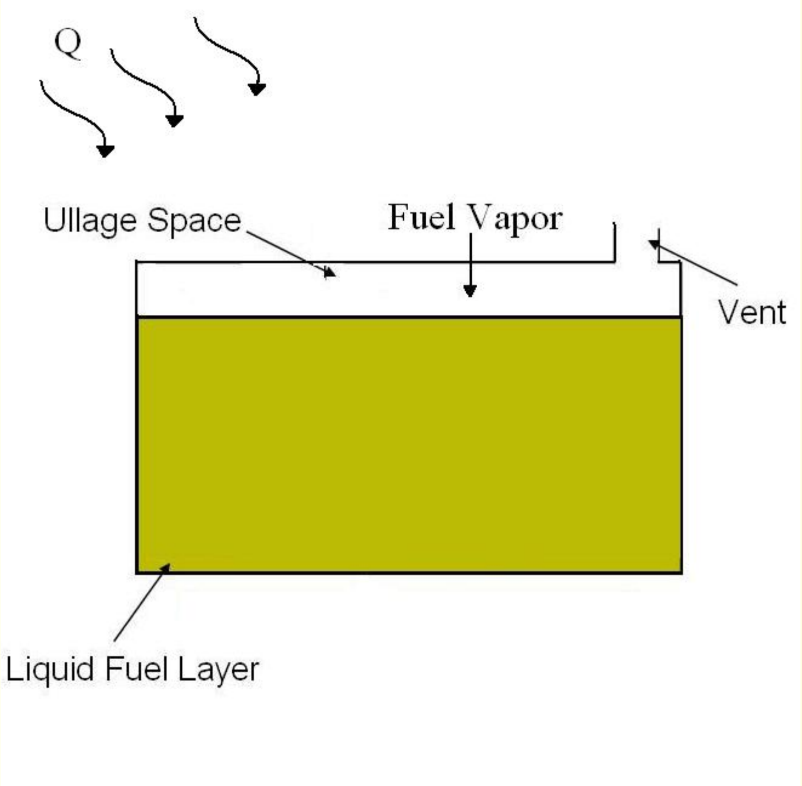
Center Wing Tank (CWT)

- The CWT has thin layer of fuel at the bottom of the tank
- Model assumes the tank to be at a 30% load
- The bottom of the CWT is heated from heat released underneath the tank



Wing Tank (WT)

- The WT is mostly filled with fuel
- Model assumes the tank to be at a 80% load
- The top of the WT is heated from ambient heat source such as the Sun



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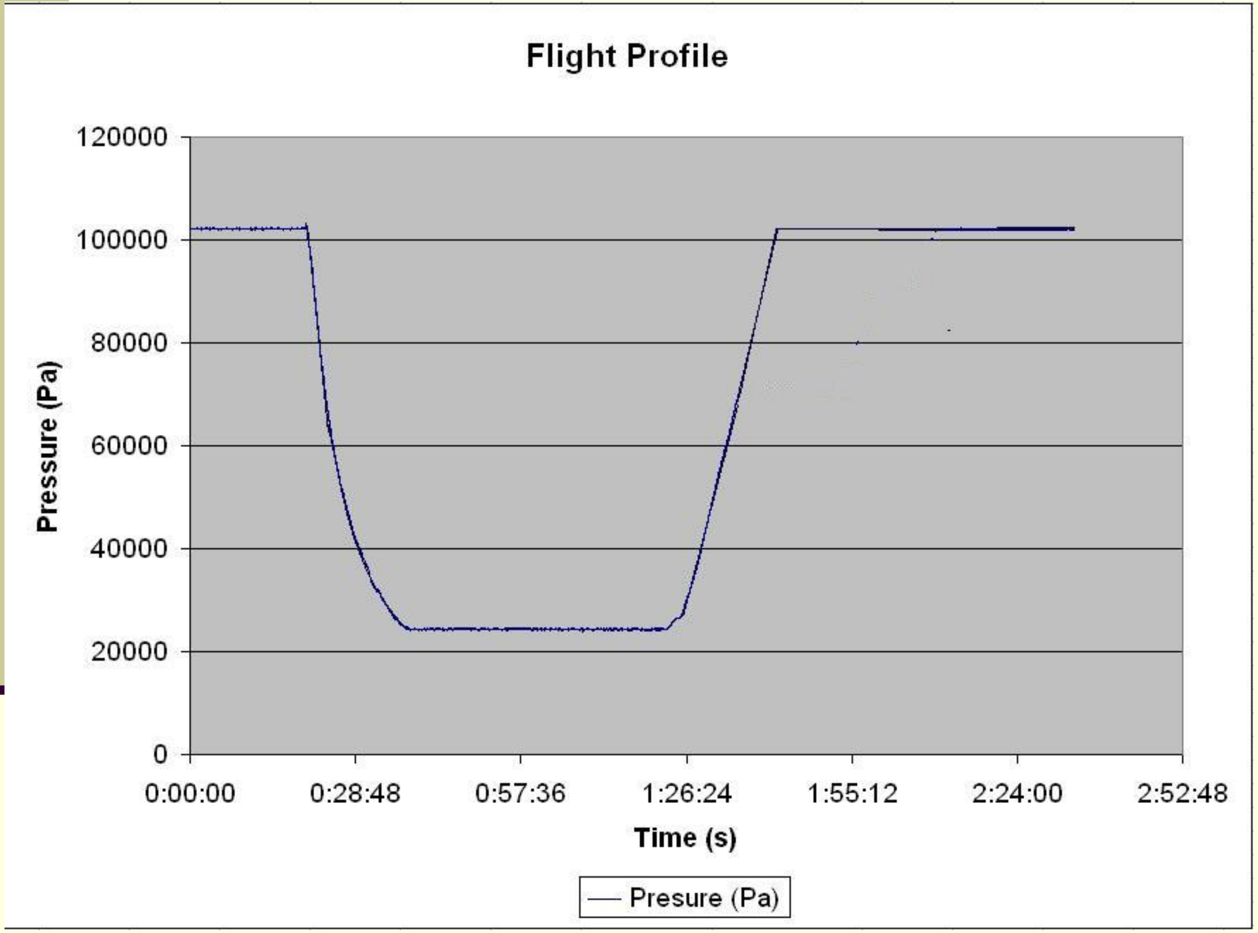
Flight Profile



- The following flight profile will be used in the altitude chamber
- Cruise at 35000 feet
- Total flight time is 3 hours

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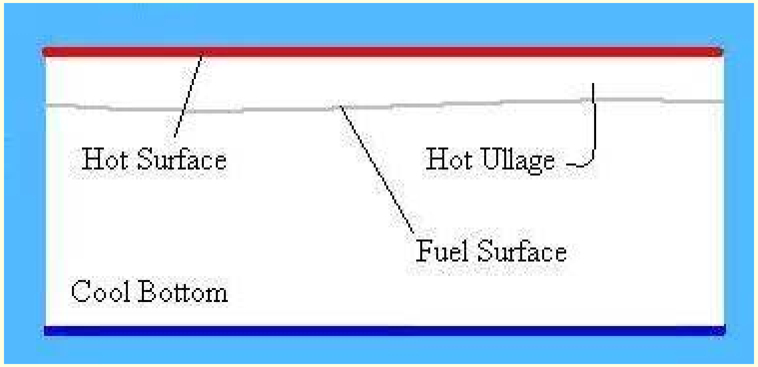
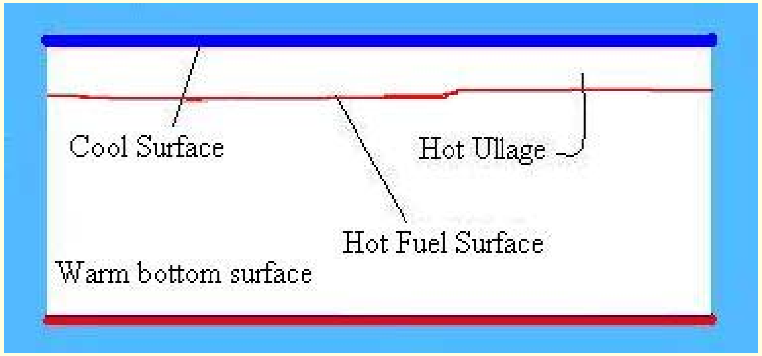
Sorting Data

- The data is sorted because of the difference in the driving force
- The data is sorted into
  - Ascending Profile
    - The top surface is hotter than the fuel surface
    - The ullage temperature governs the film temperature
  - Descending Profile
    - The fuel is hotter than the top surface
    - The fuel temperature governs the film temperature





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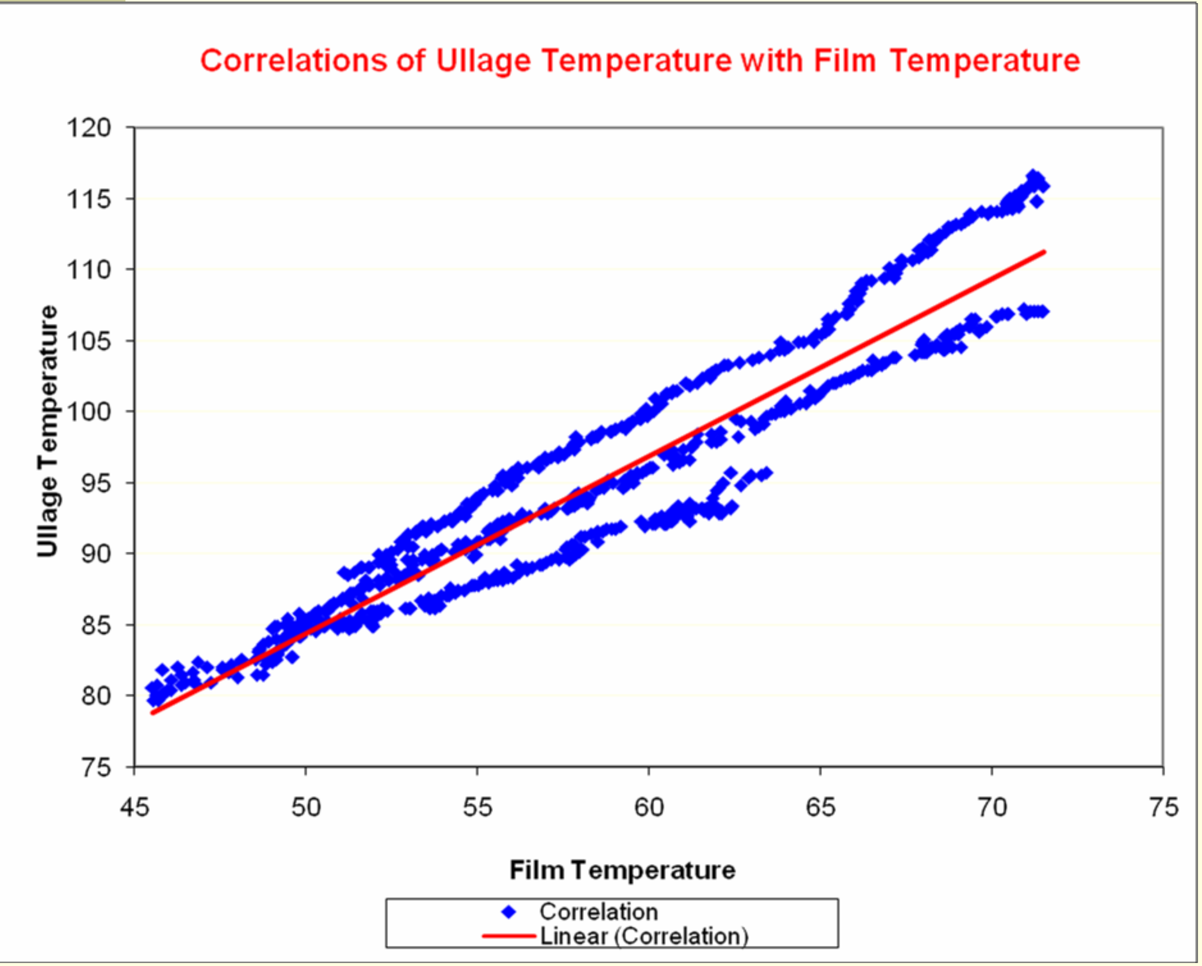
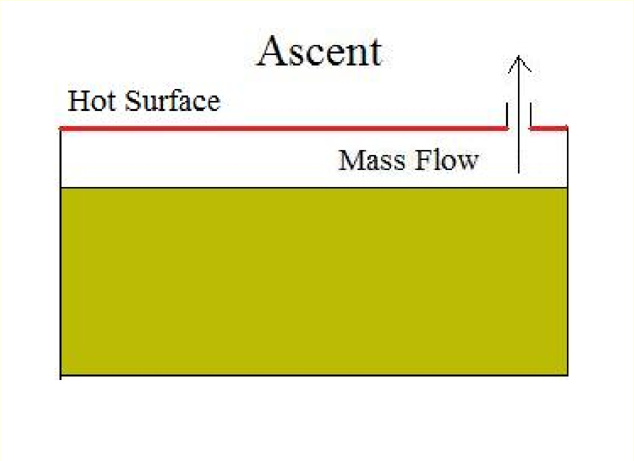
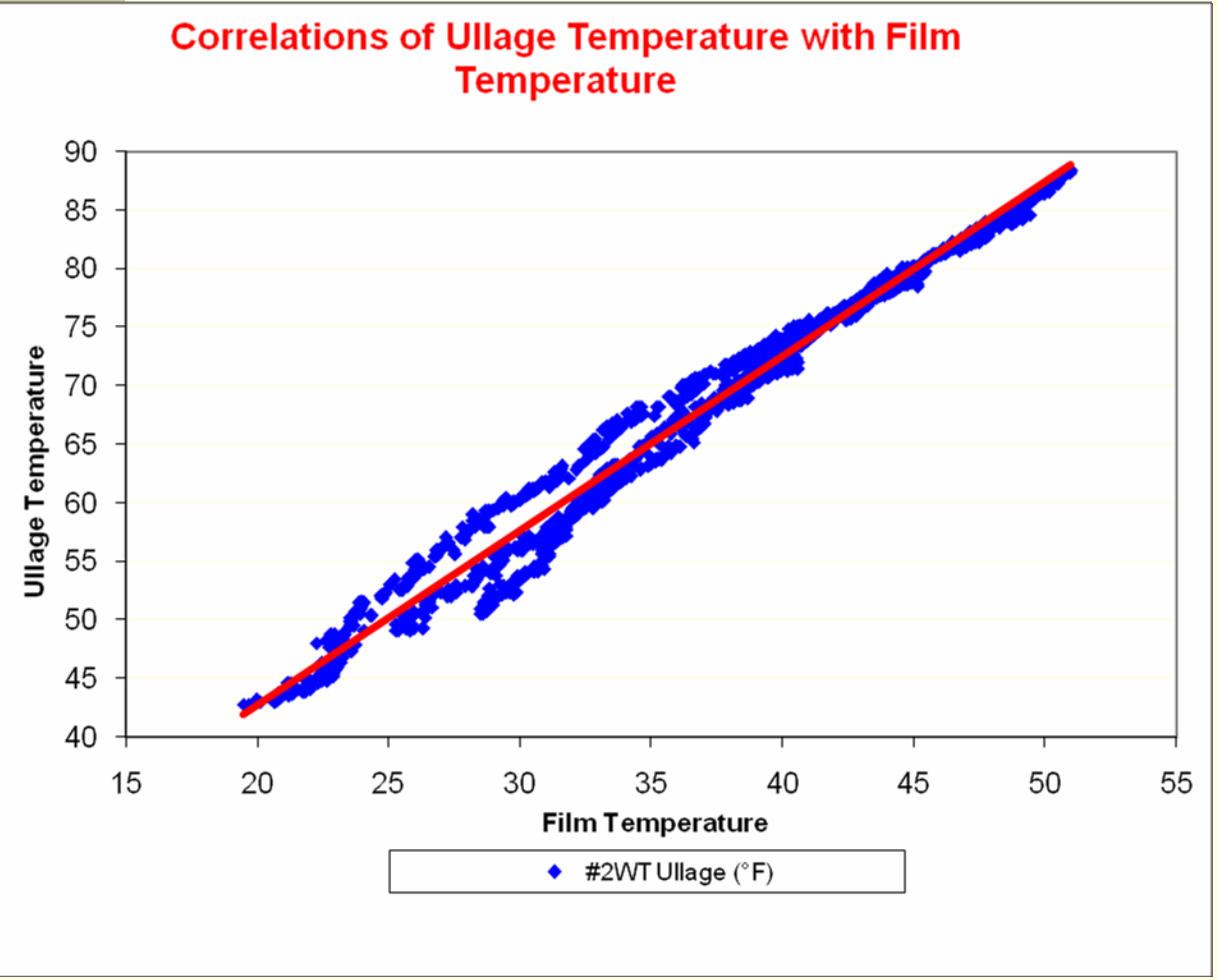
Correlations



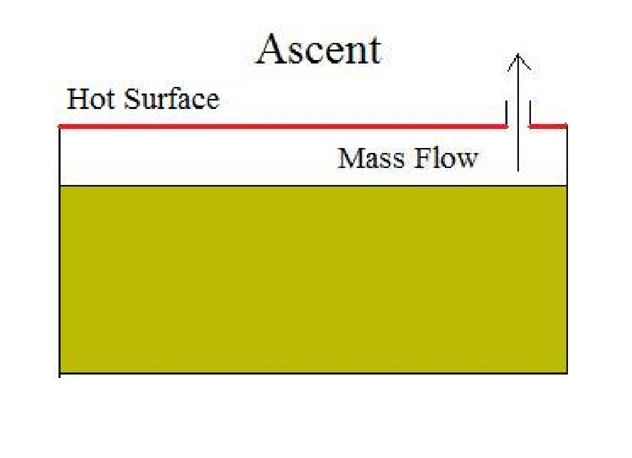
- Ascending profile
- Correlations between ullage temperature and fuel temperature
- Ullage temperature is greater than liquid fuel temperature
- Correlation coefficient 0.89



Correlations



- Ascending profile
- Correlating ullage temperature with film temperature
- Liquid fuel temperature is greater than ullage temperature
- Correlation coefficient 0.976



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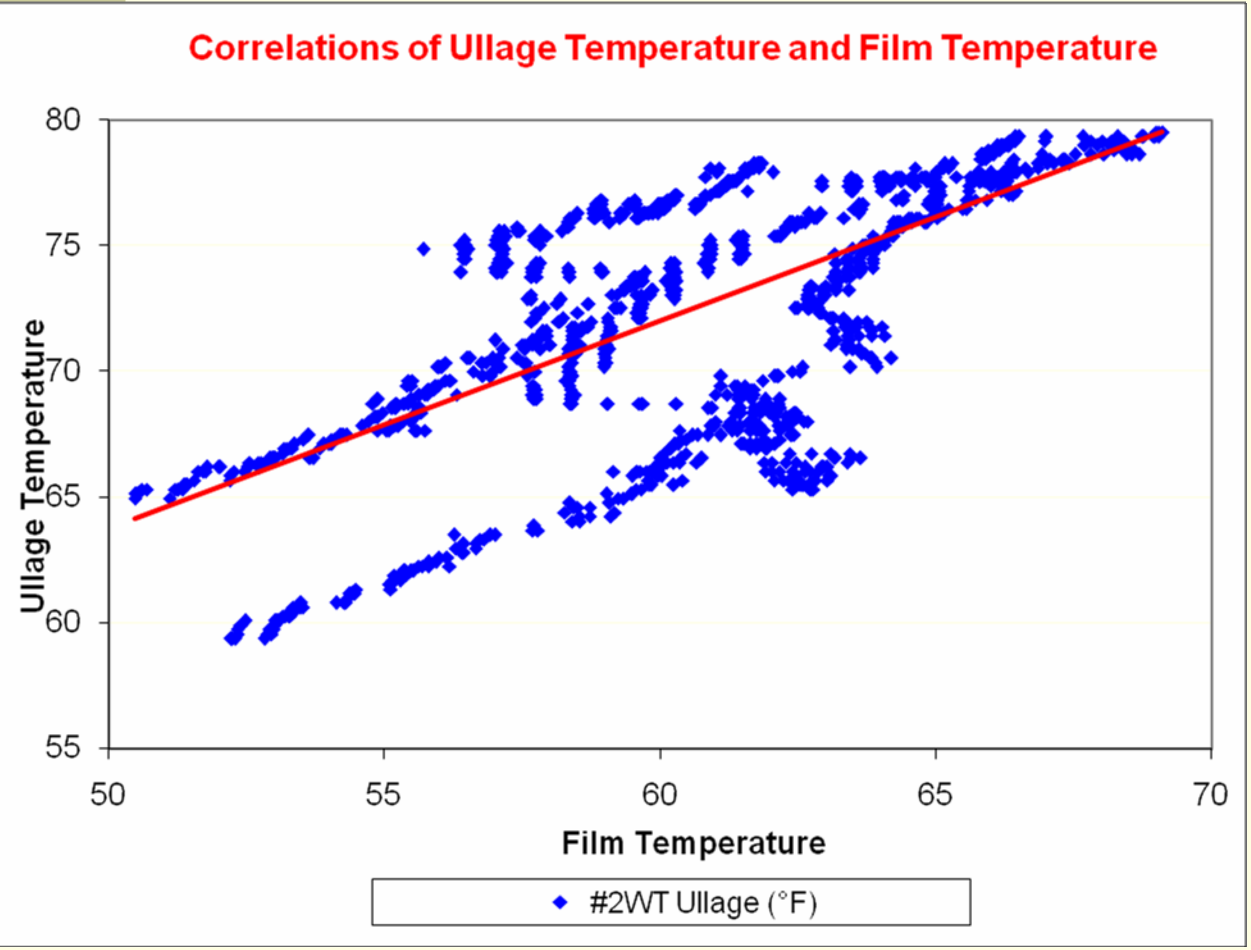
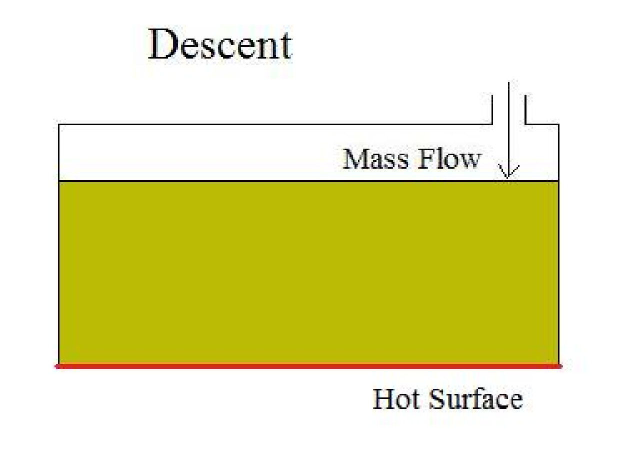
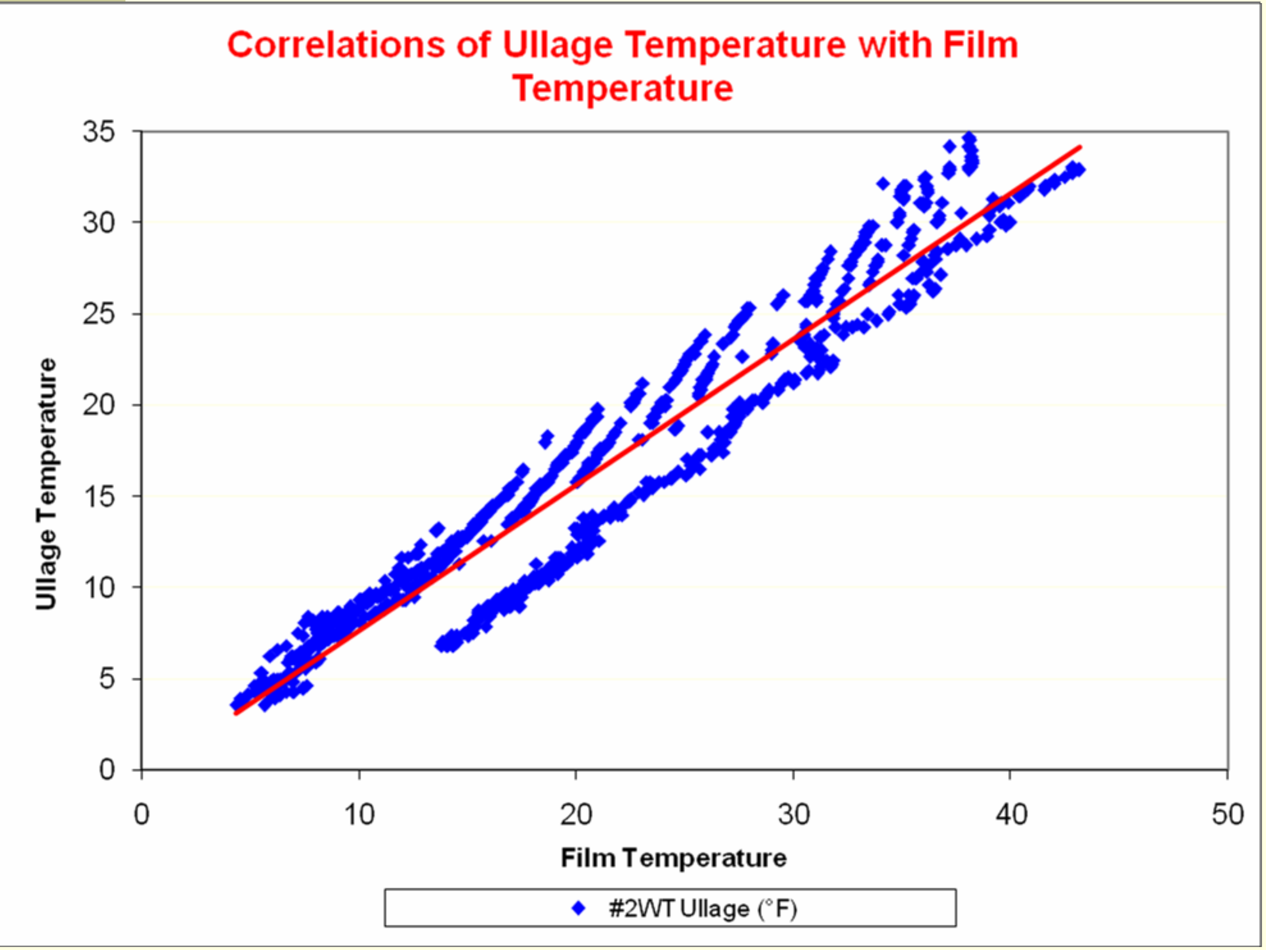
Correlations



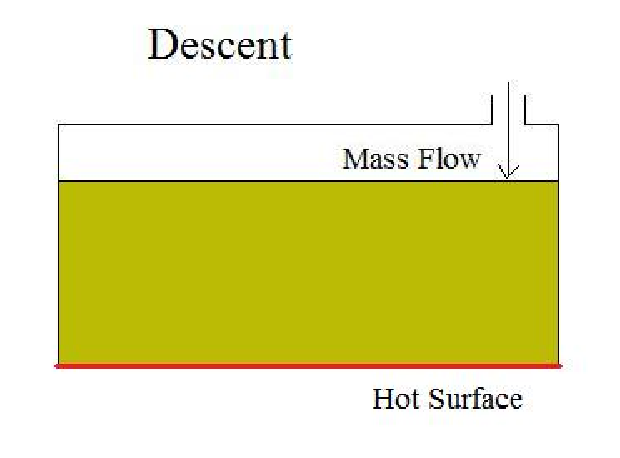
- Descending profile
- Correlations between ullage temperature and fuel temperature
- Ullage temperature is greater than liquid fuel temperature
- Correlation coefficient 0.41



Correlations

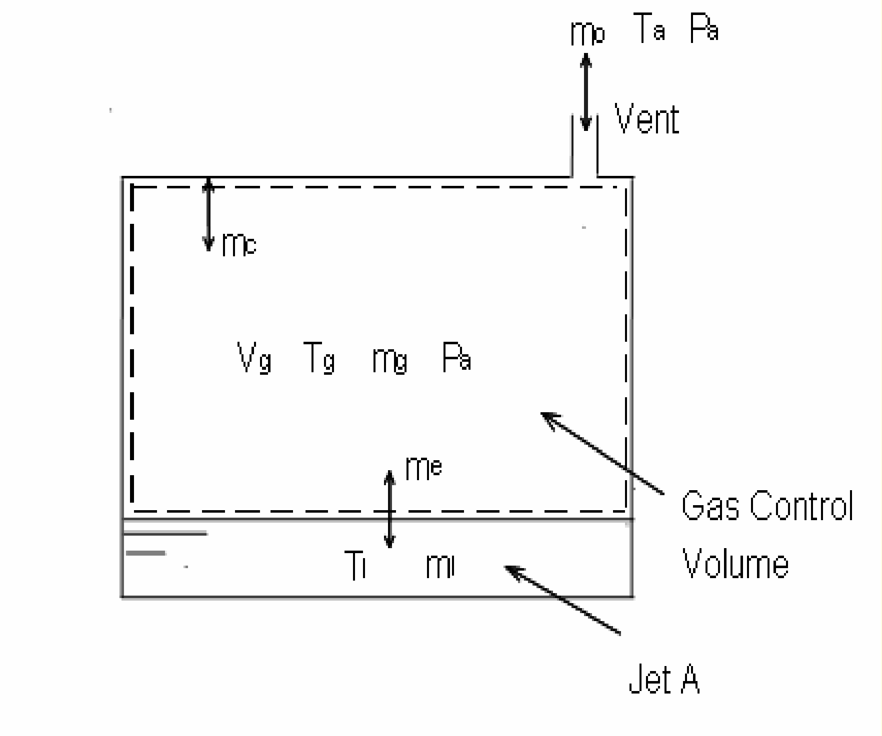


- Descending profile
- Correlations between ullage temperature and fuel temperature
- Liquid fuel temperature is greater than ullage temperature
- Correlation coefficient 0.93



Base Model

- Current CWT Model (Polymeropoulos 2004)*
- Natural convection flow field between the heated floor and the unheated ceiling and sidewalls
- Ullage gases are well mixed due to natural convection and mass transfer
  - Liquid vaporization
  - Vapor Condensation
- Natural convection flow is in the turbulent regime



* JET A VAPORIZATION IN A SIMULATED AIRCRAFT FUEL TANK, Polymeropoulos and Ochs 2004

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Principal Assumptions

- Well mixed gas and liquid phases
  - Buoyancy induced mixing
- Quasi-steady transport using heat transfer correlations
- The analogy between heat and mass transfer for estimating film coefficients for heat and mass transfer
- The liquid fuel and wall temperatures are known from experiments

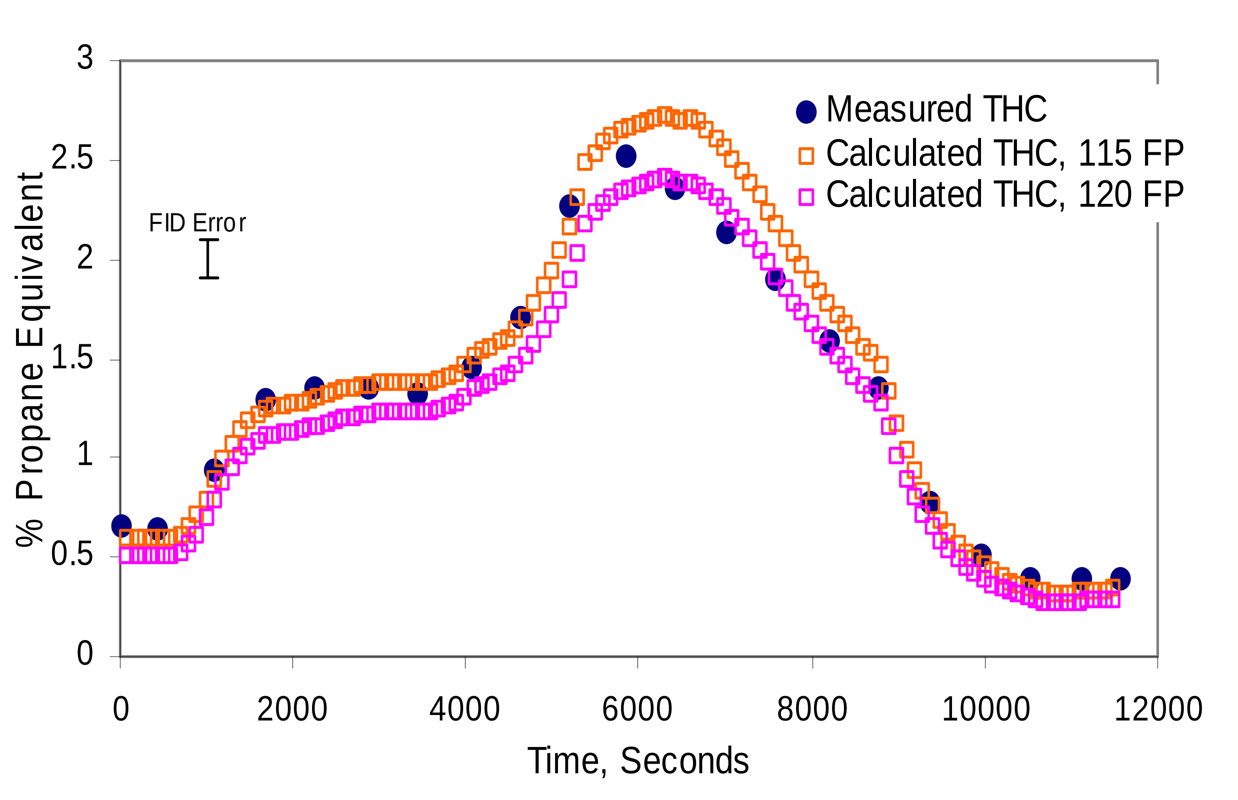
Computational Method

- Inputs
  - The tank geometry
  - Fuel loading
  - Liquid fuel composition
  - Tank pressure
  - Liquid fuel, and tank wall temperatures as functions of time

- Computes
  - Equilibrium species concentrations of Jet A in a uniform temperature, constant pressure tank
  - Temporal variation of vapor temperature and species concentration

CWT Model

- Simulation using center wing tank flight test data
- The calculated THC is in good agreement with the measured THC



*Vaporization of JP-8 Jet Fuel in a Simulated Aircraft Fuel Tank under varying ambient conditions - Ochs 200

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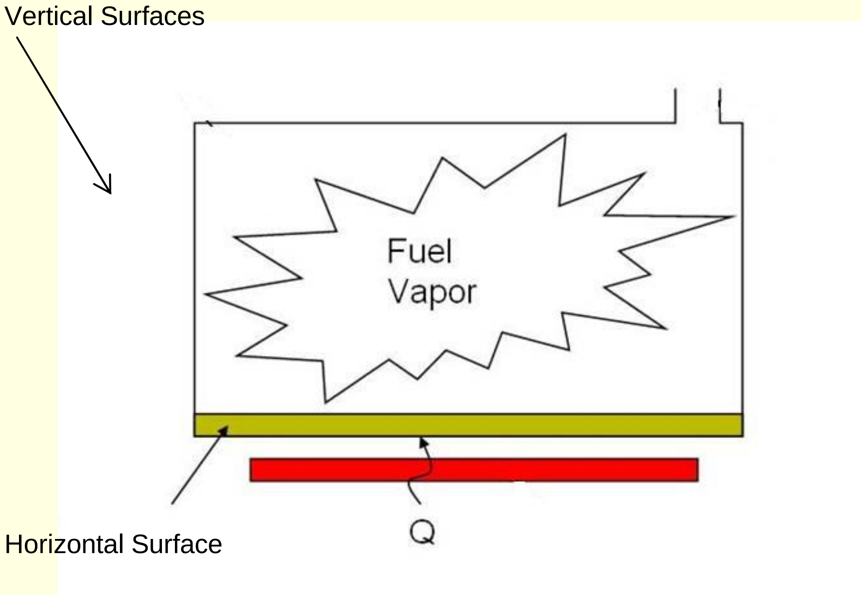
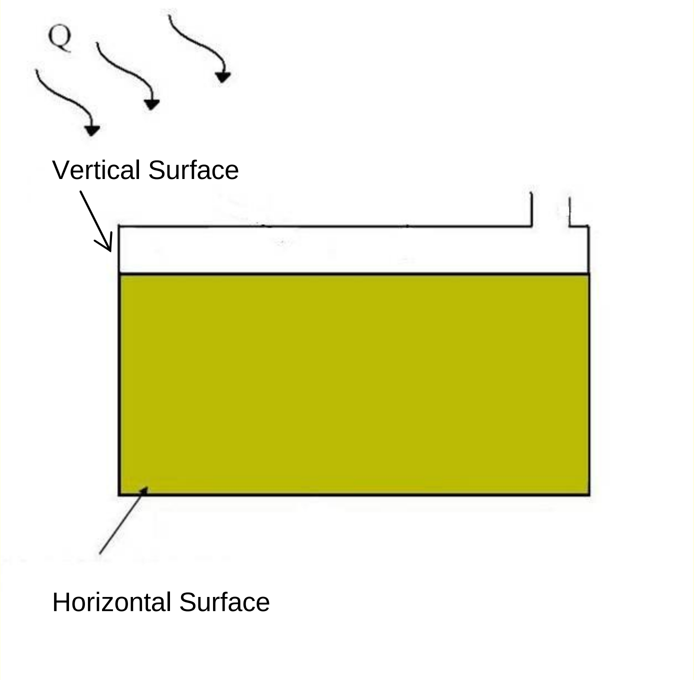
Original Correlations

- Heat & Mass Transfer Correlations
  - Horizontal surface:
    - Top surface: Lower surface of cooled plate
    - Top of Fuel Layer: Upper Surface of heated plate
  - Vertical Surface:
    - Forced Convection on a vertical flat plate

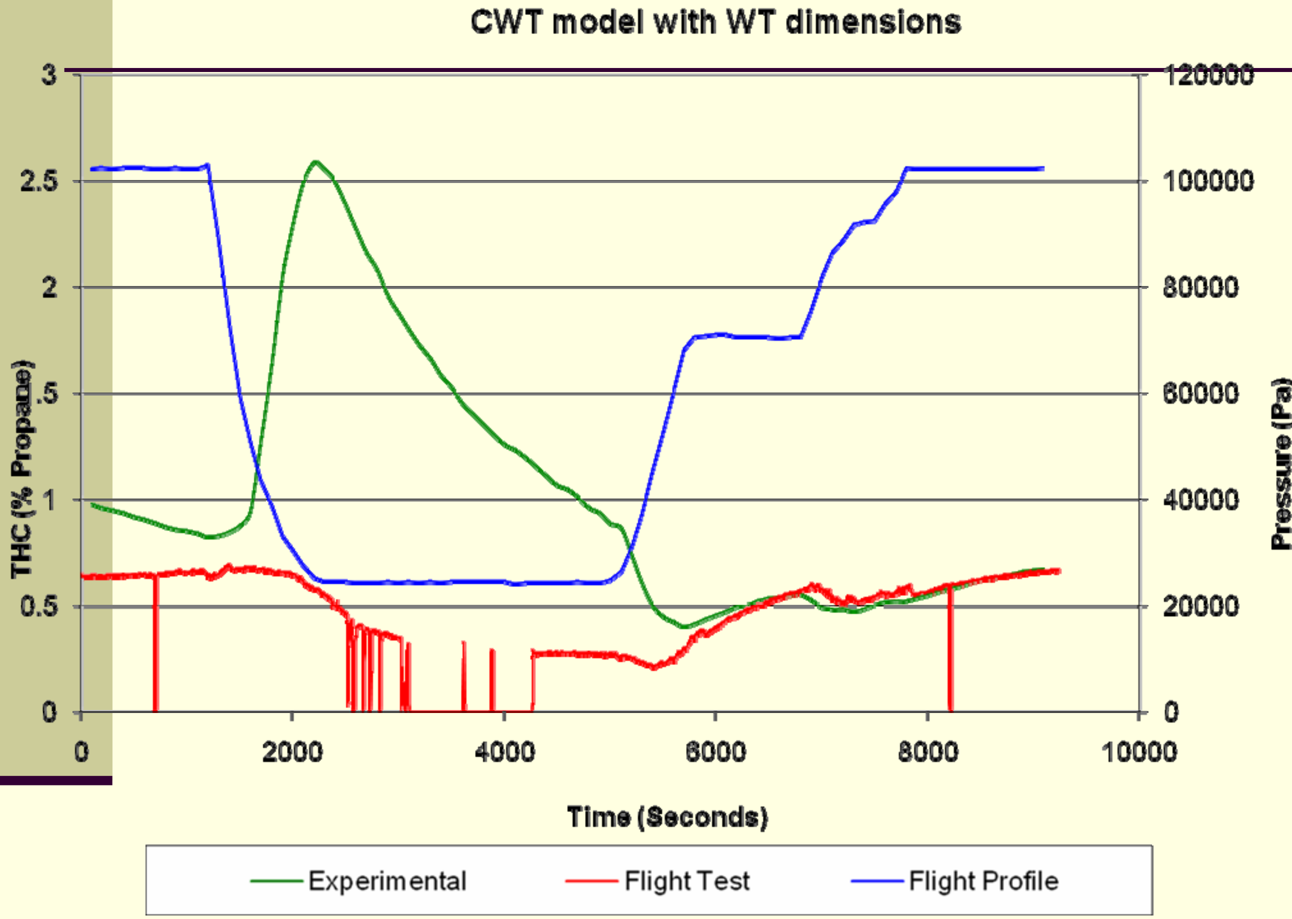


Changes in Correlations

- Heat & Mass Transfer correlations
  - Horizontal surface:
    - Top surface: Lower Surface of heated plate
    - Top of Fuel Layer: Upper surface of cooled plate
  - Vertical Surface:
    - Natural convection on a flat plate



Combination of Models



- Simulation using flight test data
- Using wing tank dimensions on a CWT flammability model
- Shows that the CWT model works for wing tanks in descending pressure profiles

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Difference in Model Correlations

- The CWT model differs from the WT model in the ascending and cruise conditions due to:
  - Percent load
  - Ullage height
  - Heat and mass transfer correlations
  - Heat source
  - Surface being heated

Experiments

- Experiments are being conducted
  - To compare calculated mass flow rates to actual mass flow rates
  - To determine the state of the ullage
    - Stratified – changes the heat and mass transport to pure diffusion
    - Well Mixed – changes the heat and mass transport correlations
  - To build an experimental base

Experimental Equipment

- Experiments conducted in an altitude chamber
- Designed to simulate temperature and pressure similar to a flight profile
  - Can simulate altitudes from sea level to 100,000 feet
  - Can simulate temperatures from -100˚F to +250˚F
- NDIR gas analyzer used to measure the total hydrocarbon concentration

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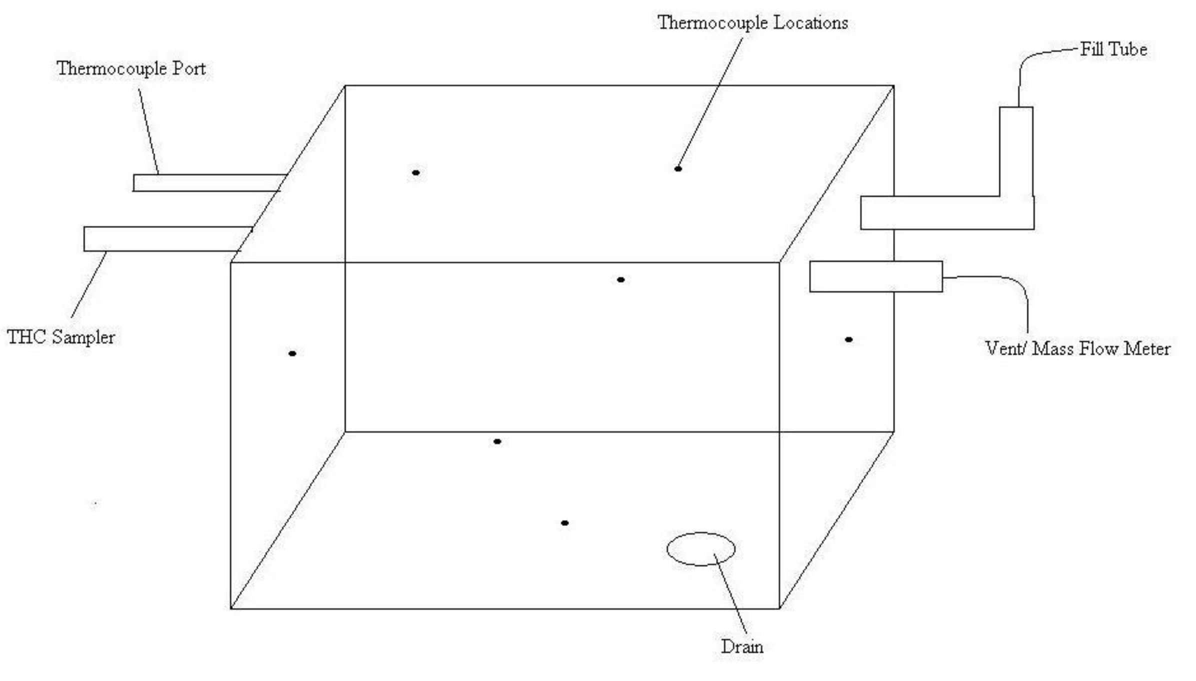
Experimental Setup

- An aluminum fuel tank of dimensions 24"w x 24" d x 36" h will be used
- Access panels on each side for thermocouple penetration, ullage sampling, vent, and the fill tube
- The vent is equipped with a mass flow meter
- A drain sealed using a 0.75" ball valve



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Conclusion

- Single Thermocouple method can calculate THC using data from a single thermocouple in the tank
- The differences between the WT model and the CWT model:
  - Percent Load
  - Ullage Height
  - Heat and mass transfer correlations
  - Heat Source
  - Surface being heated
- The CWT model cannot be applied in the ascending and cruise profiles, but can be applied in the descending profiles
- Experiments will be conducted
  - To confirm the state of the ullage
  - To compare computed data to experimental data

Questions?

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