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

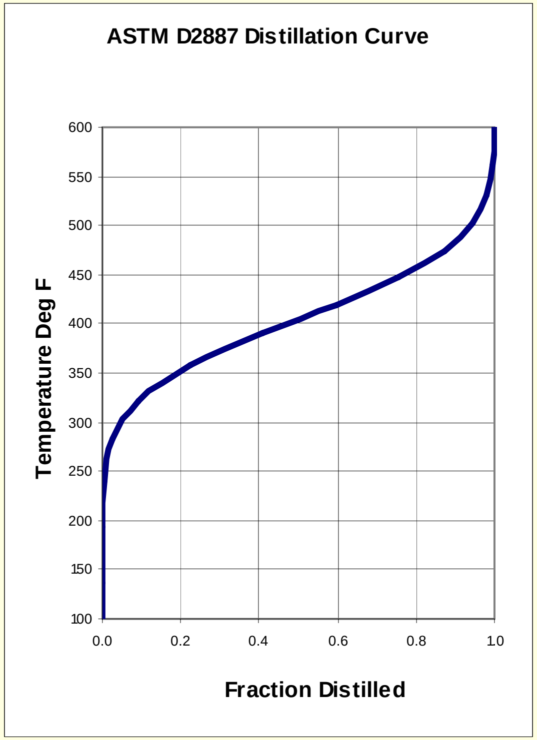
- Flammable mixtures can be achieved in the wing tank
- Experiments are being conducted to build flammability models for wing tanks
- Current work involves
  - Predicting the influence of the surrounding temperatures on the characteristic fuel surface temperature
  - Creating a model that will predict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

Overview

- Single Thermocouple Method (STM)
- Difference between Center Wing Tank and Wing Tank
- Center Wing Tank Flammability Model
- Heat and Mass Transfer Correlations
- Experimental Results
- Computational Results

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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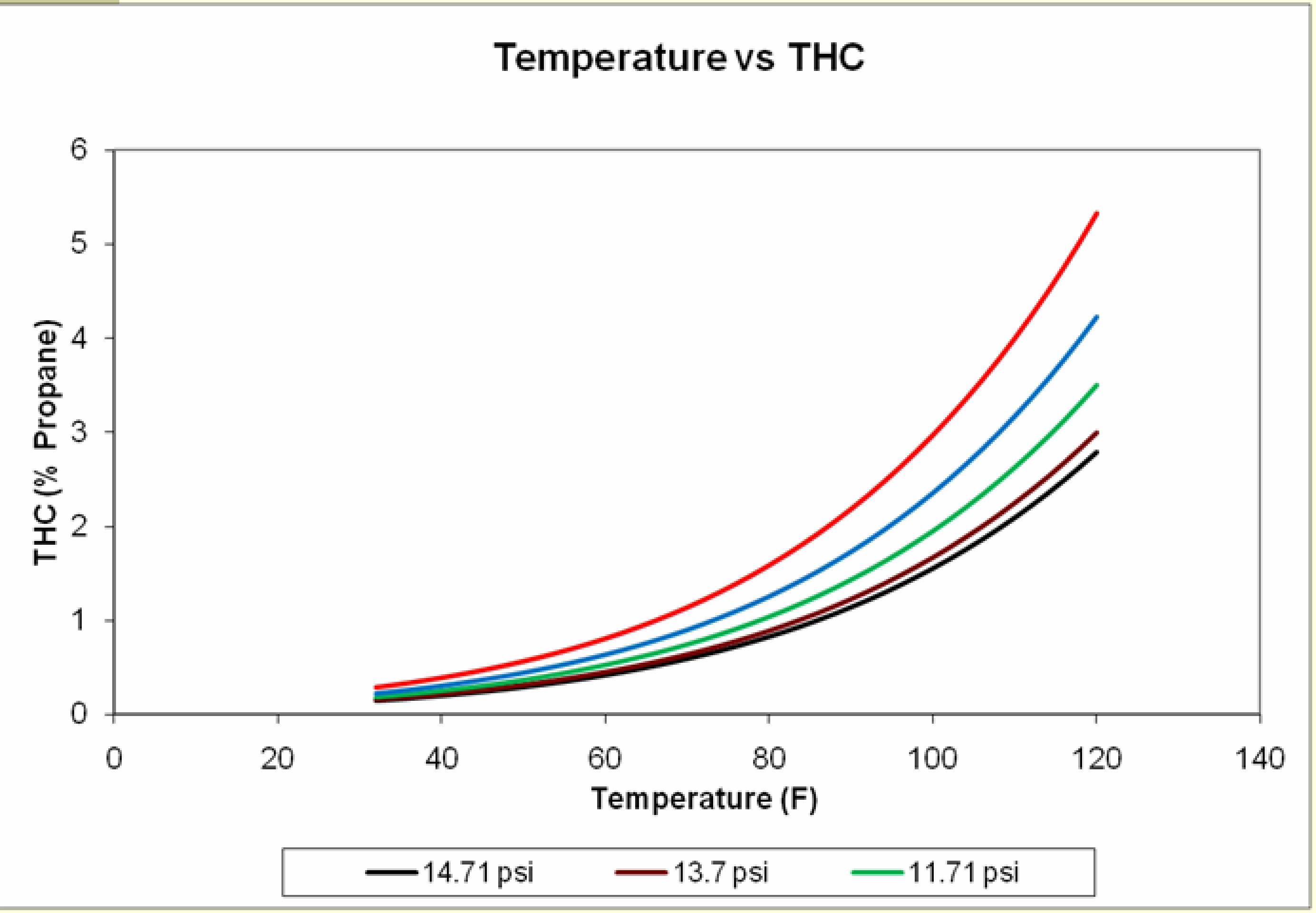
Single Thermocouple Method



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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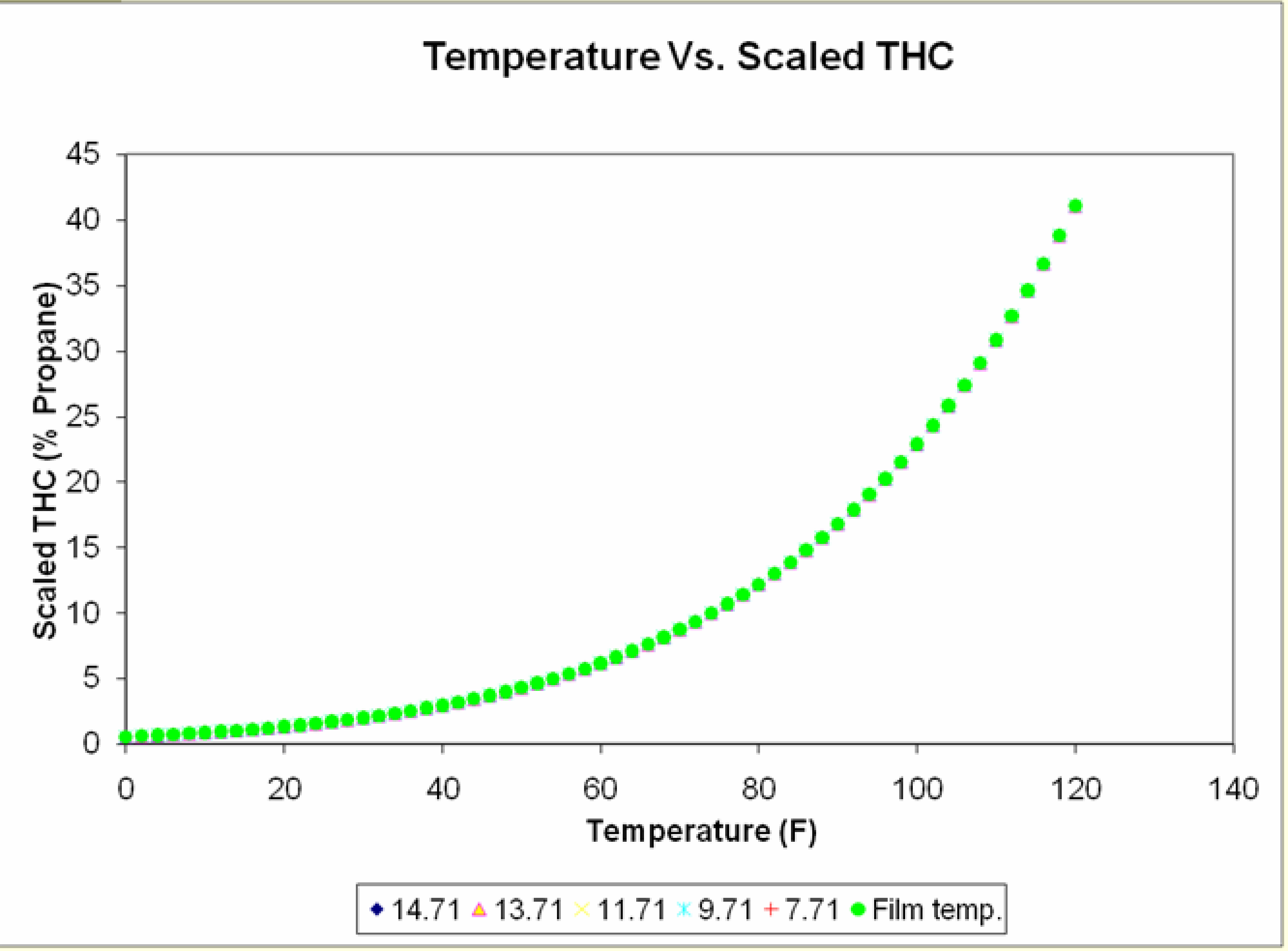
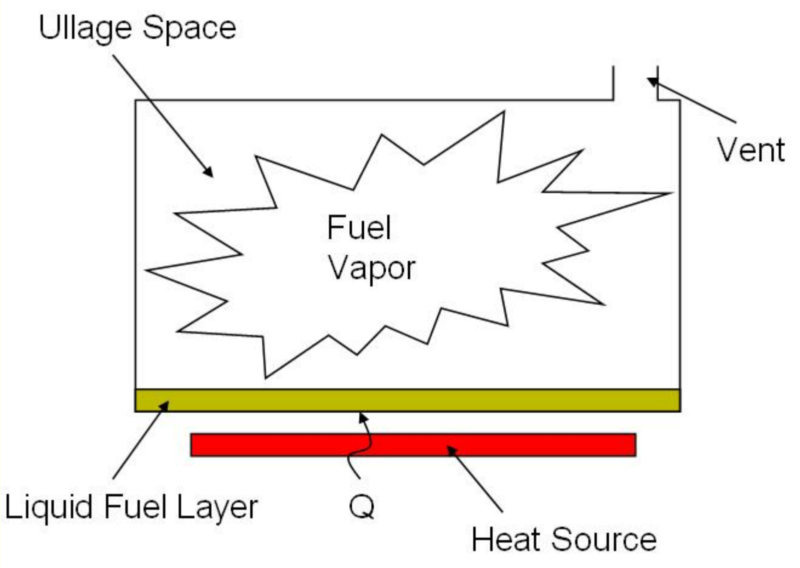
Single Thermocouple Method



- 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

Center Wing Tank (CWT)

- The CWT has thin layer of fuel at the bottom of the tank
- 30% Mass Loading
- The tank is heated from the bottom due to heat released from underneath the tank



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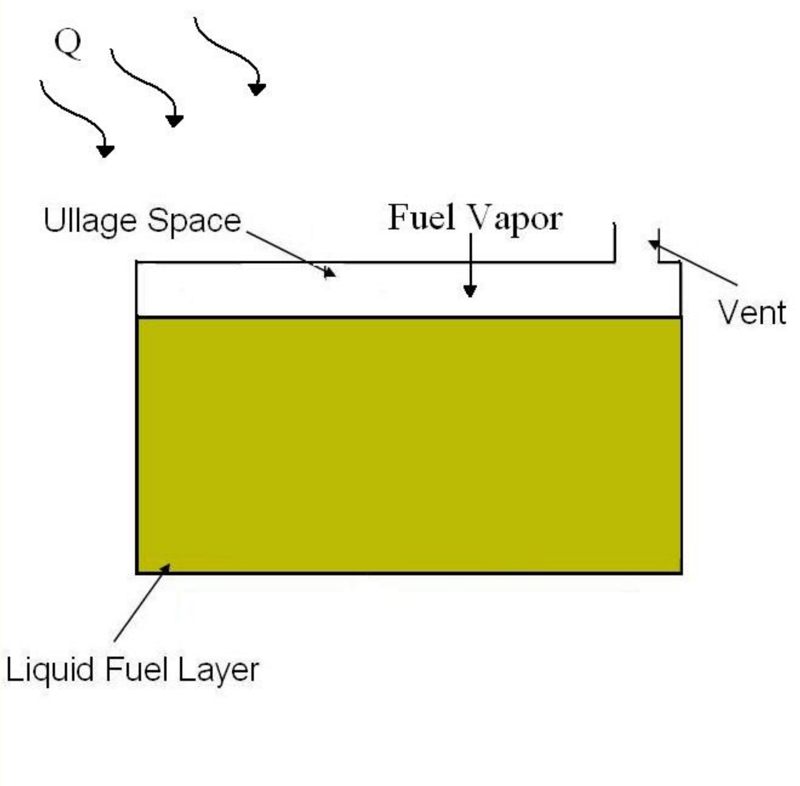
Wing Tank (WT)

- The WT is mostly filled with fuel
- 80 % Mass Loading
- The tank is heated from the top from an ambient heat source such as the Sun



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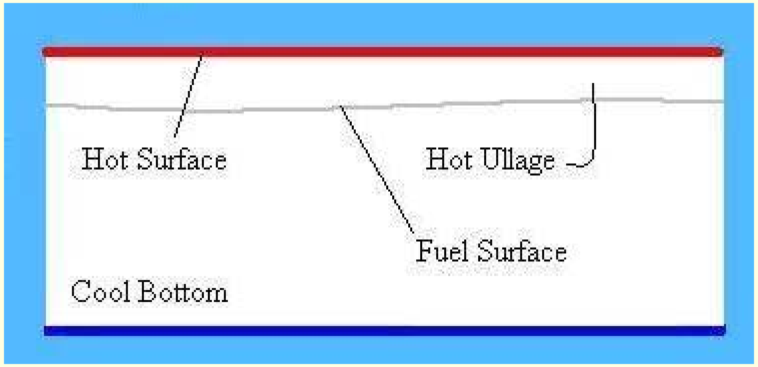
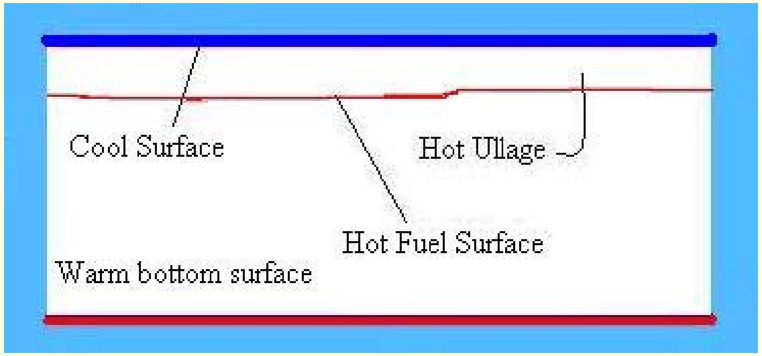
Sorting Data

- 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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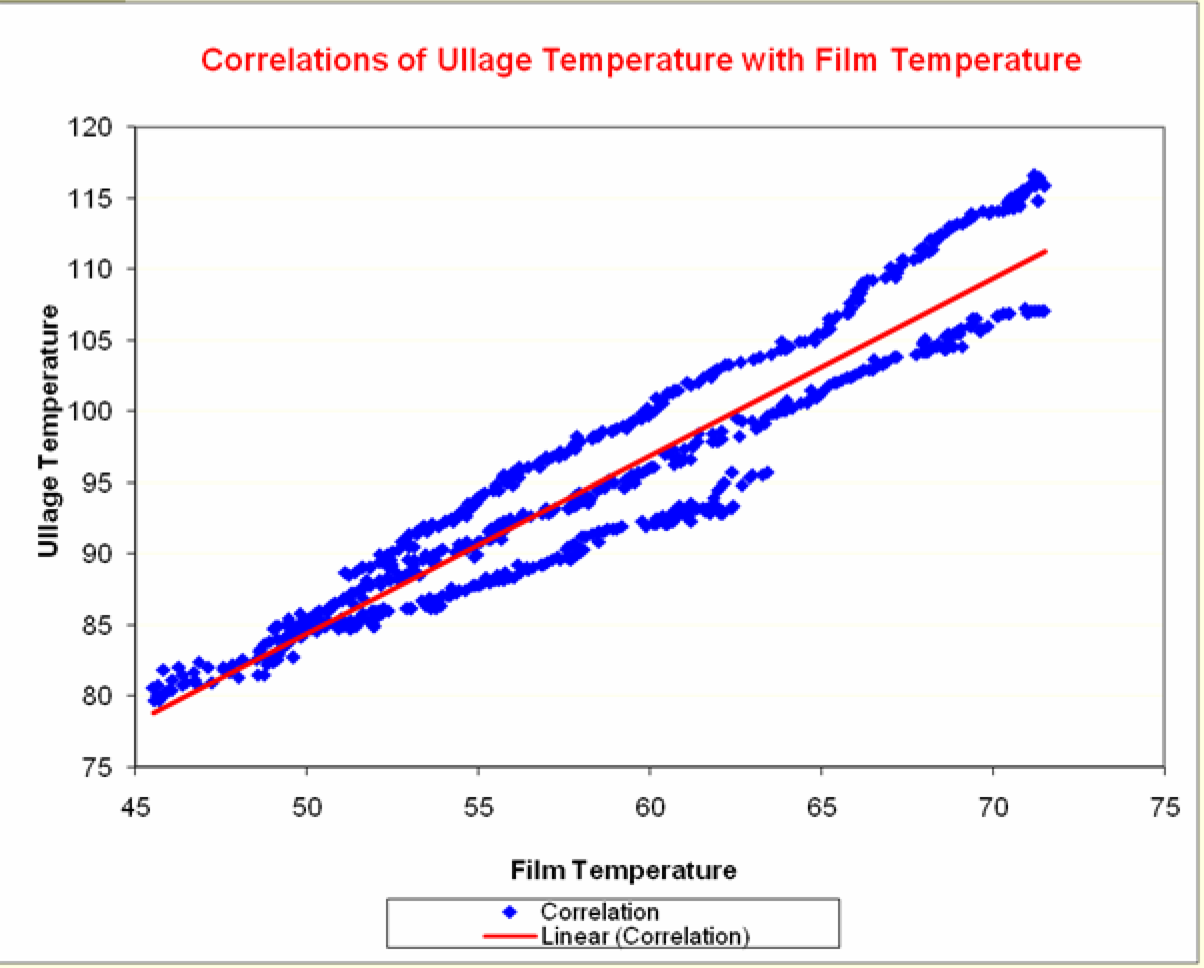
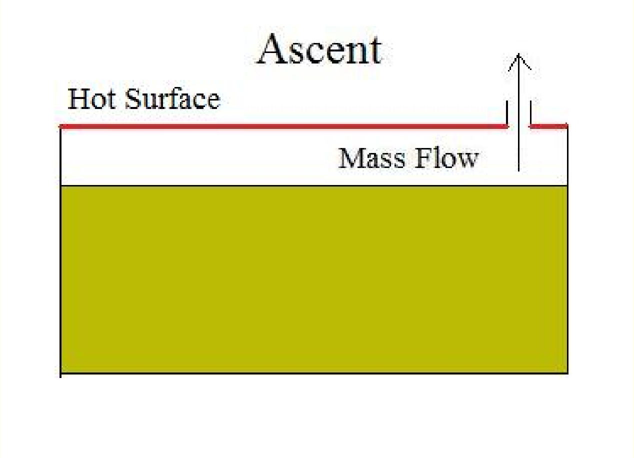
Correlations



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



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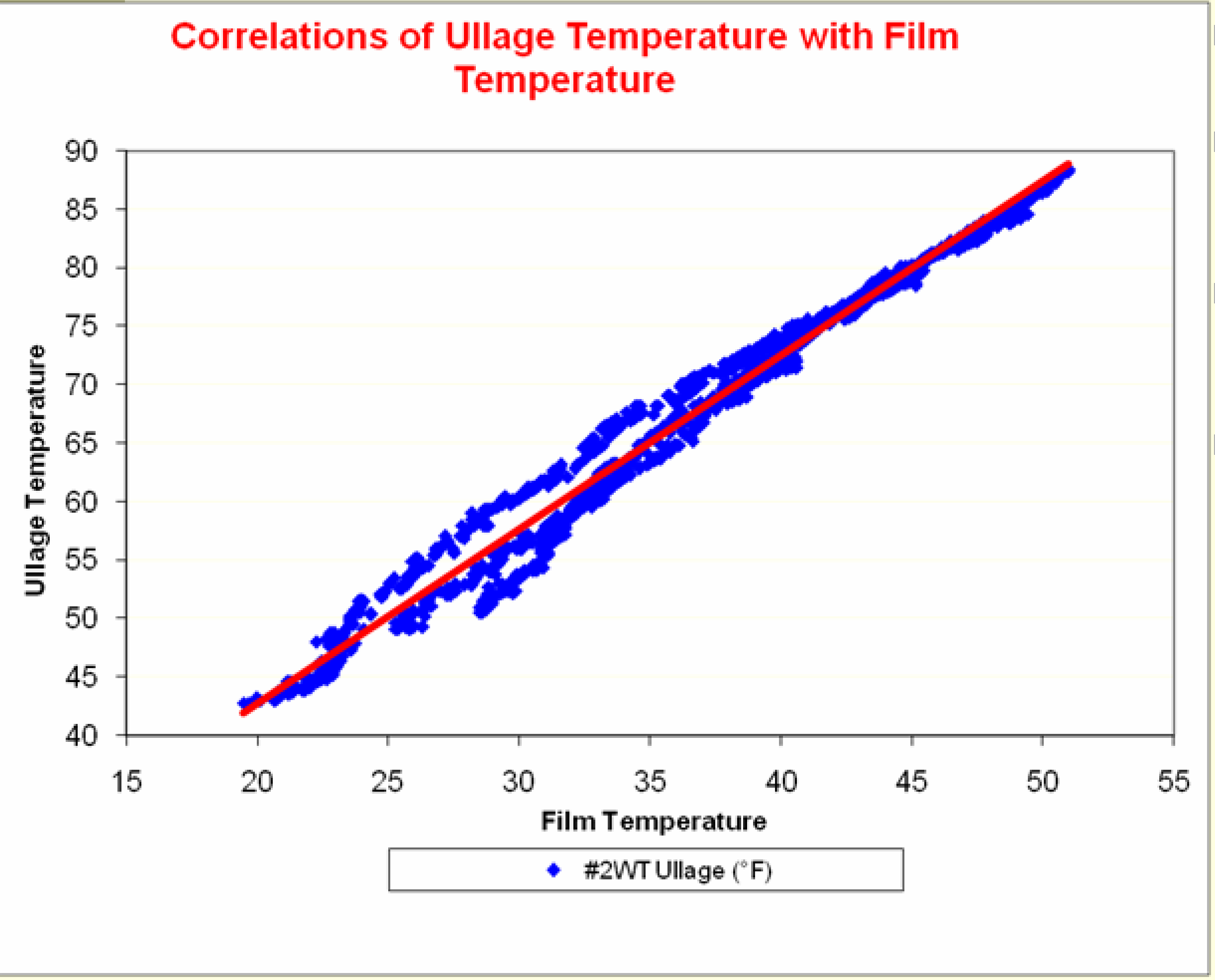
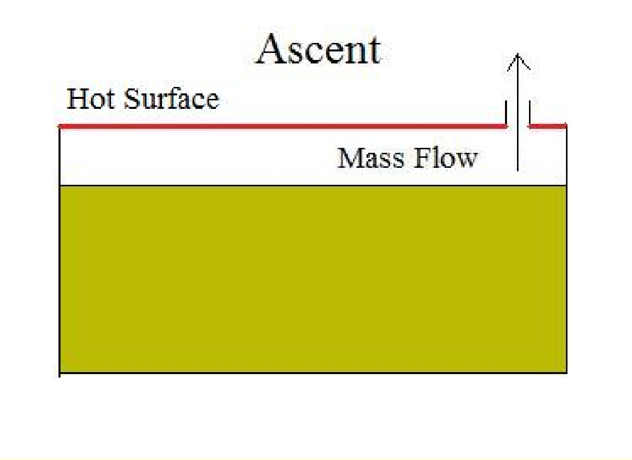
Correlations



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



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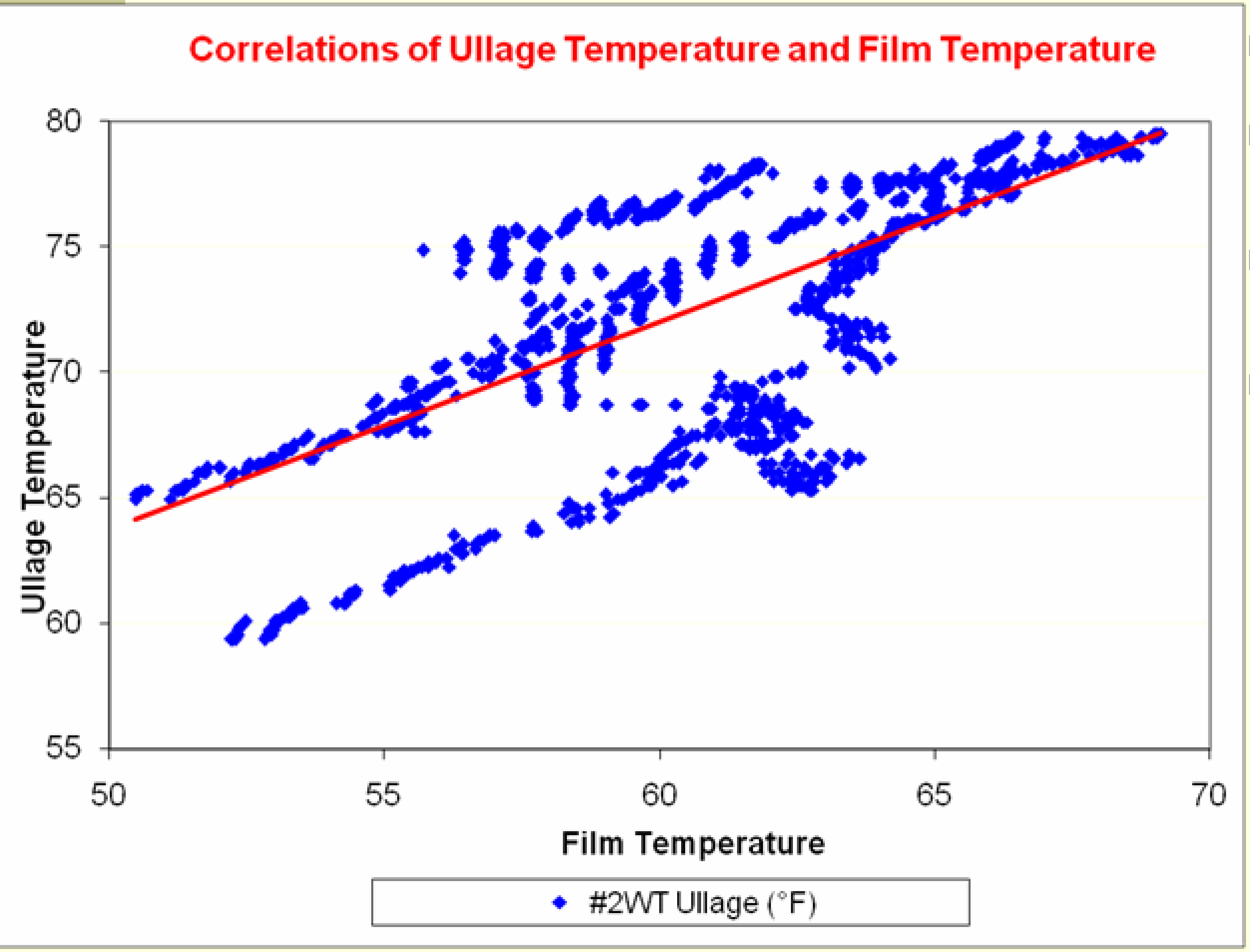
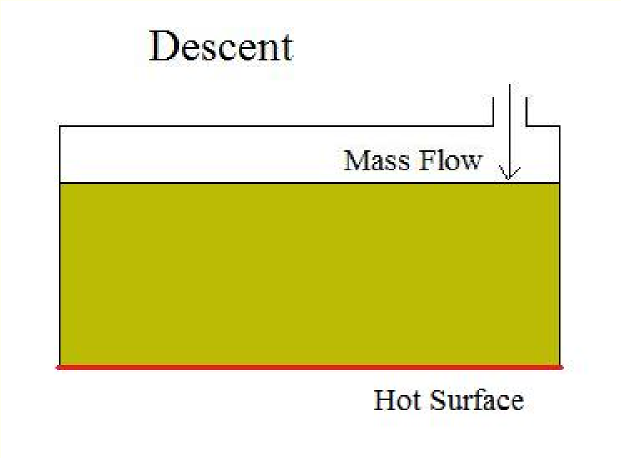
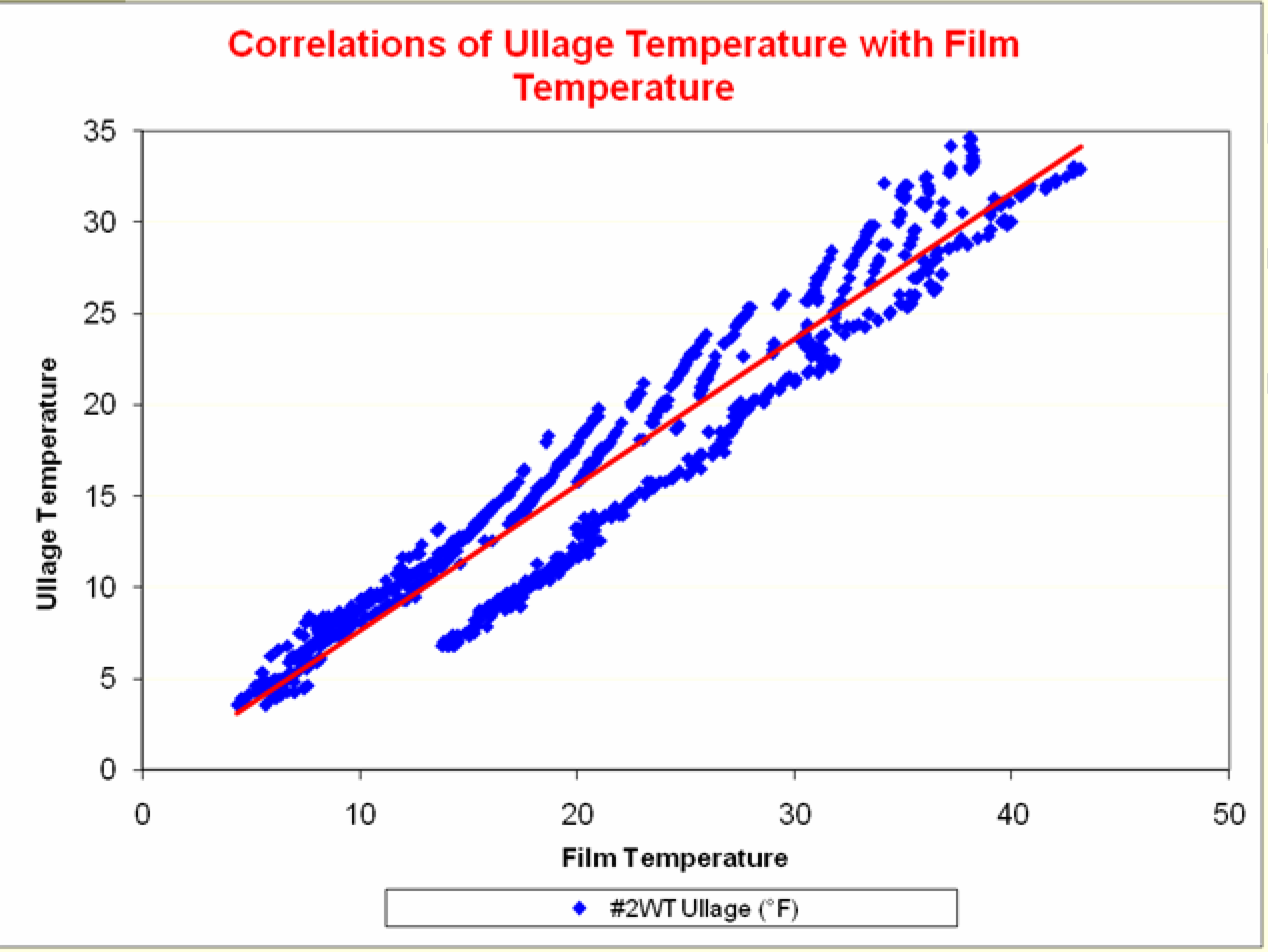
Correlations



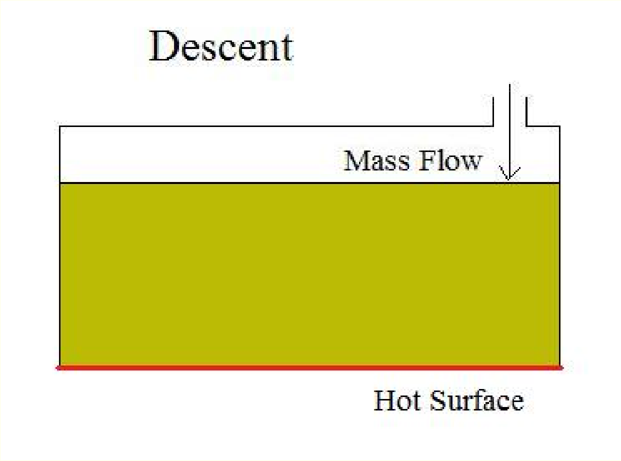
- Descending profile
- Correlations between ullage temperature and fuel temperature
- Ullage temperature is greater than liquid fuel temperature
- Correlation coefficient 0.41



Correlations



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

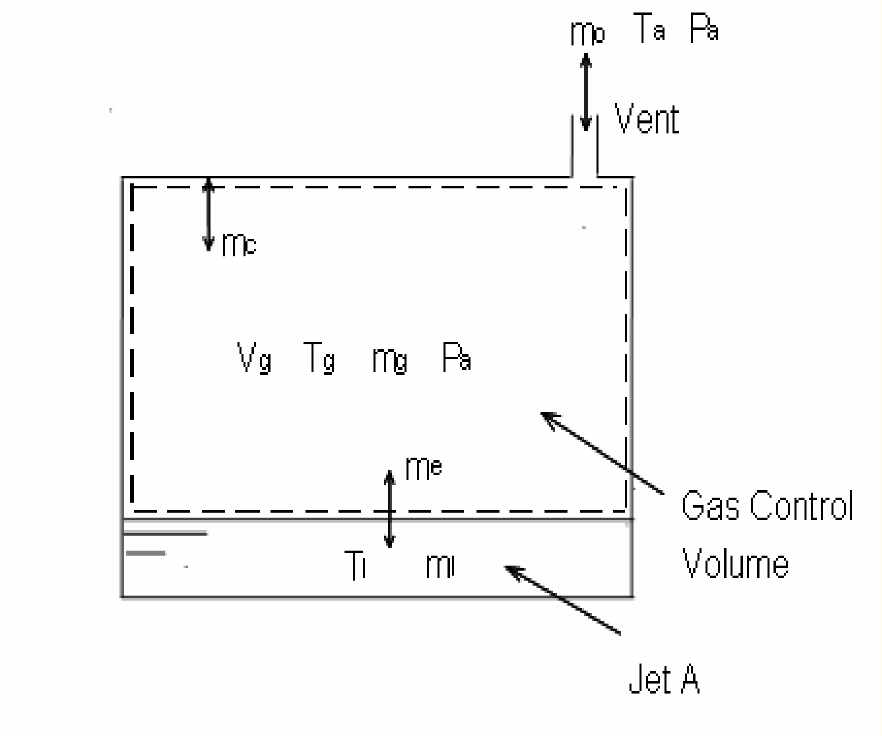


Summary of STM

- Correlation works best when:
  - Liquid fuel temperature is larger than the ullage temperature
    - Fuel temperature is the driving force
  - During Ascending pressure profile
    - Vapor pressure remains constant

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



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* 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

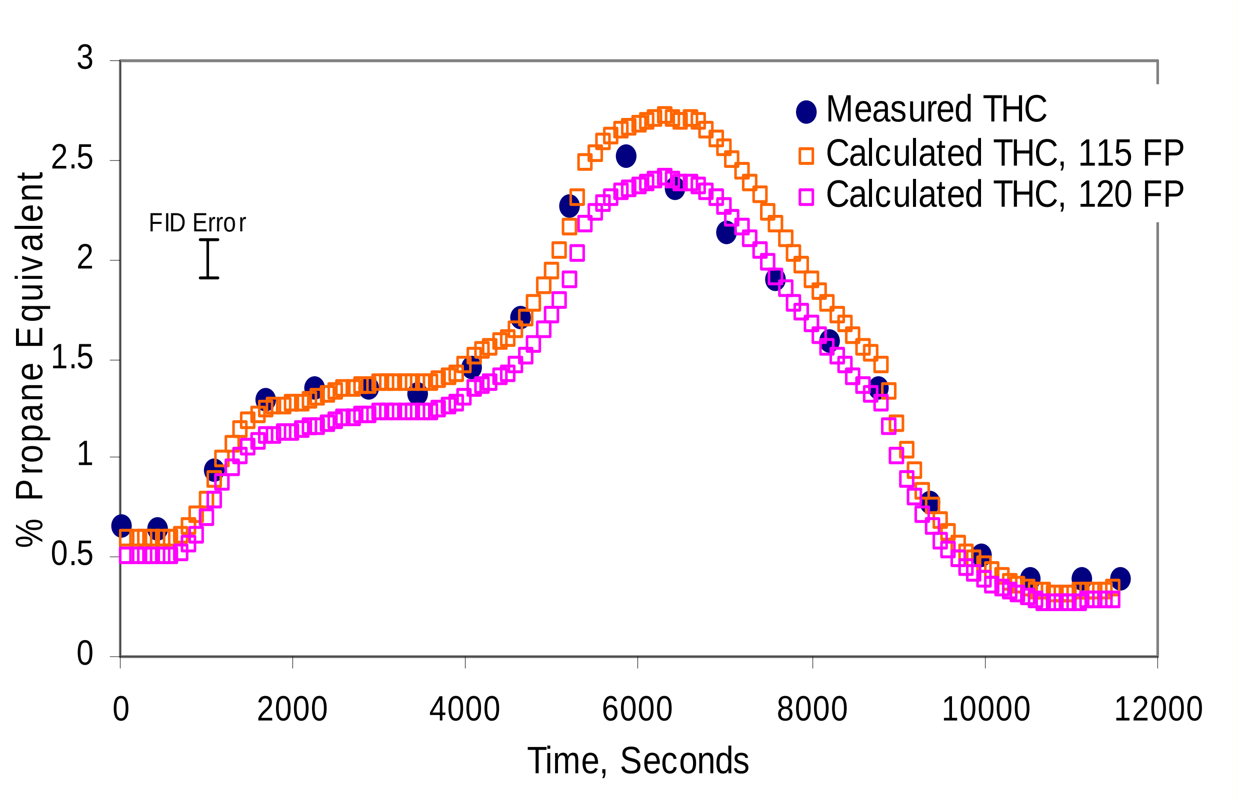
Computational Method

- 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 2006

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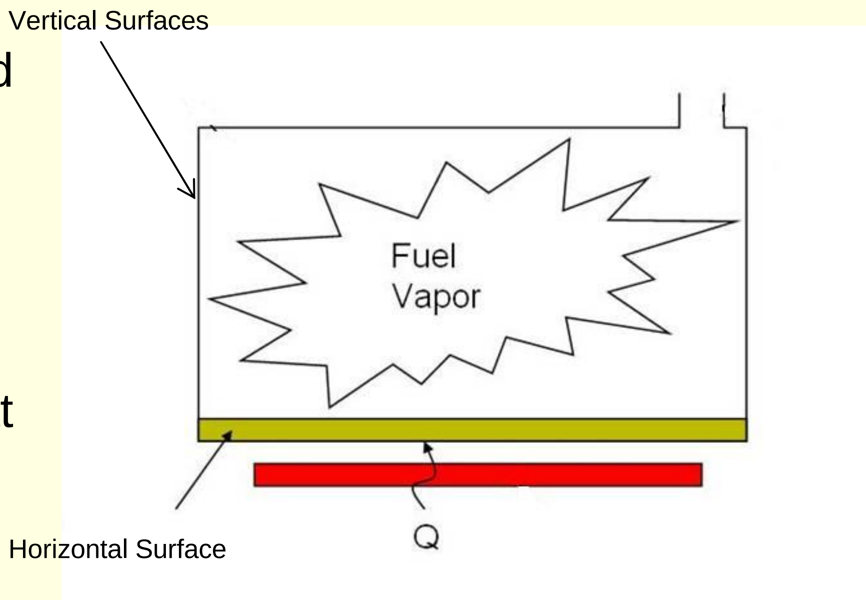
CWT Correlations

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



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

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Experiments

- Experiments were conducted
  - For 60% and 80% mass loadings
  - For equilibrium temperatures from 80°F to 100°F
  - For cruising altitudes of 25000 feet and 34000 feet

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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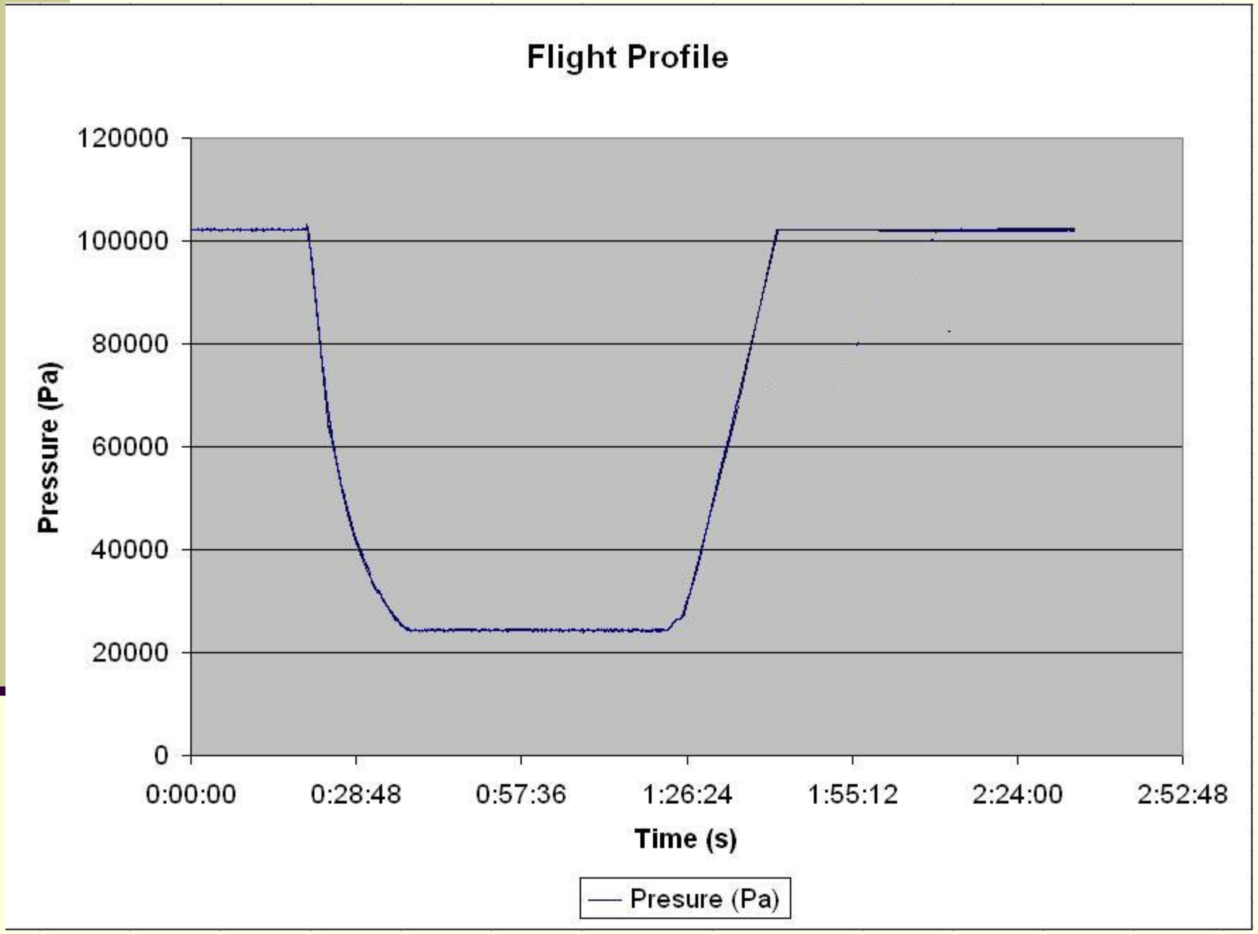
Experimental Setup

- An aluminum fuel tank of dimensions 24”w x 24” d x 36” h was used
- Access panels on top for thermocouple penetration, ullage sampling, vent, and the fill tube
- Thermocouples measured surface, ullage, fuel surface and bulk fuel temperatures
- The vent was equipped with a mass flow meter

Flight Profile



- The following flight profile will be used in the altitude chamber
- Cruise at 35000 feet
- Total flight time is 2.5 hours

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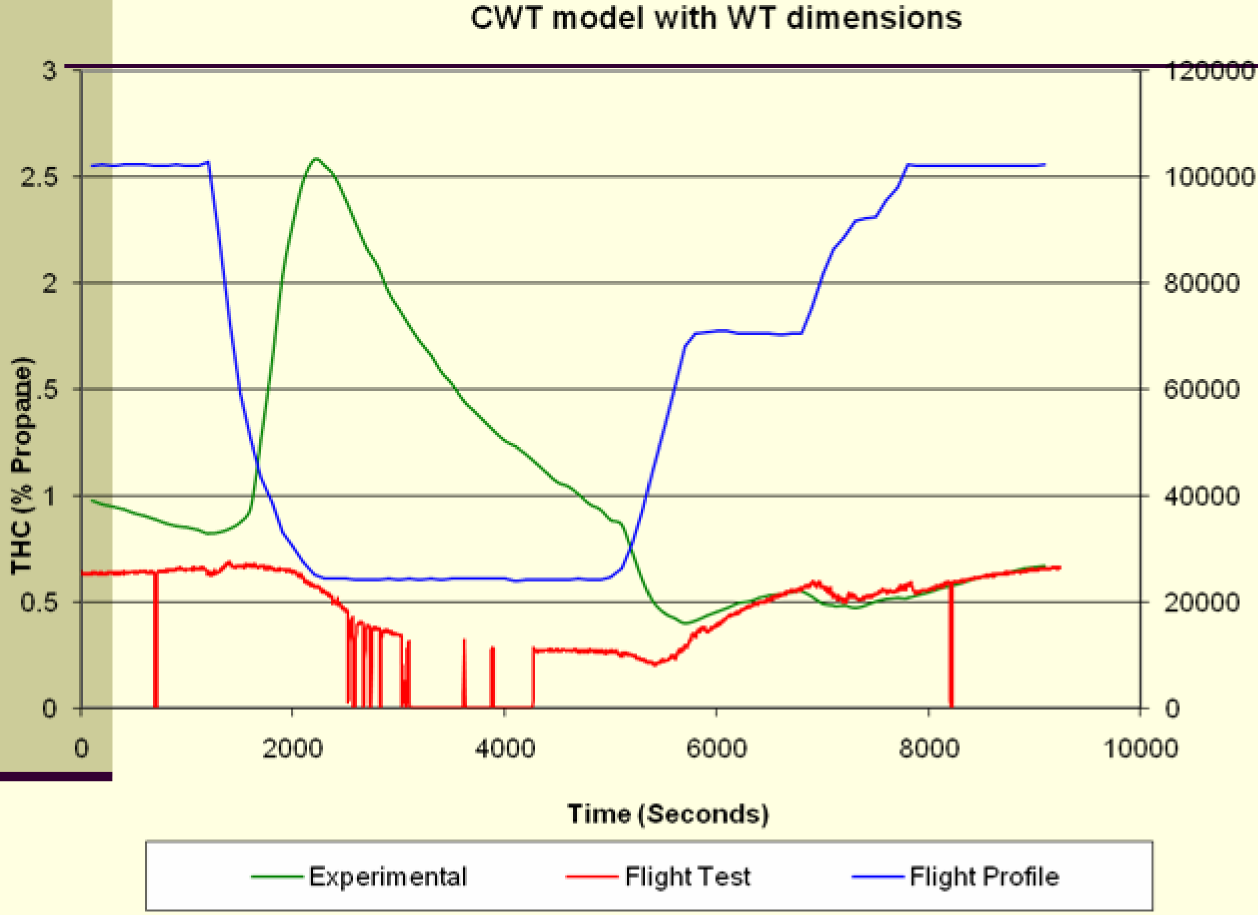
Combination of Models



- 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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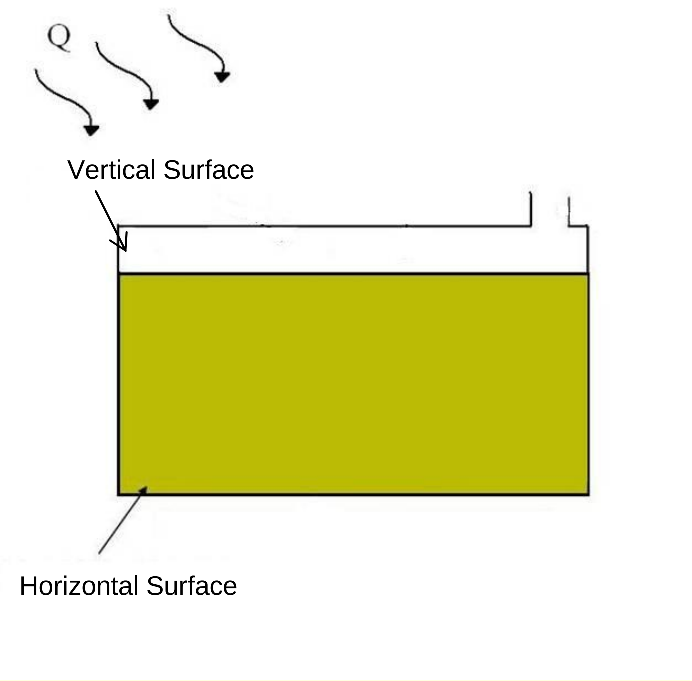
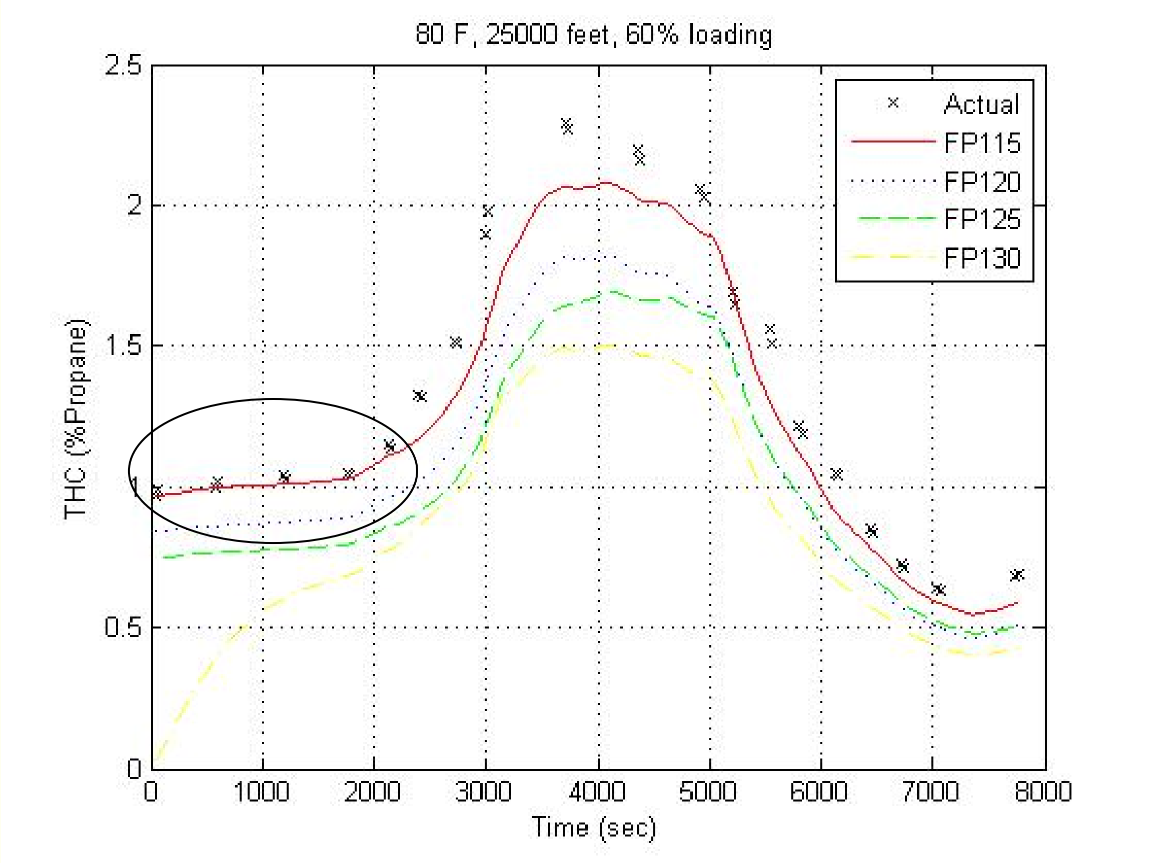
Wing Tank Correlations

- Heat & Mass Transfer correlations
  - Horizontal surface: (Ascending)
    - Top surface: Laminar Forced Convection on a flat plate
    - Top of Fuel Layer: Laminar Forced Convection on a flat plate
  - Horizontal Surface (Cruise and Descending)
    - Top surface: Turbulent Forced Convection on a flat plate
    - Top of Fuel Layer: Laminar Forced Convection on a flat plate
  - Vertical Surface:
    - Laminar Forced Convection on a flat plate



Test Results



Ascending Top Surface Heat Transfer Correlations

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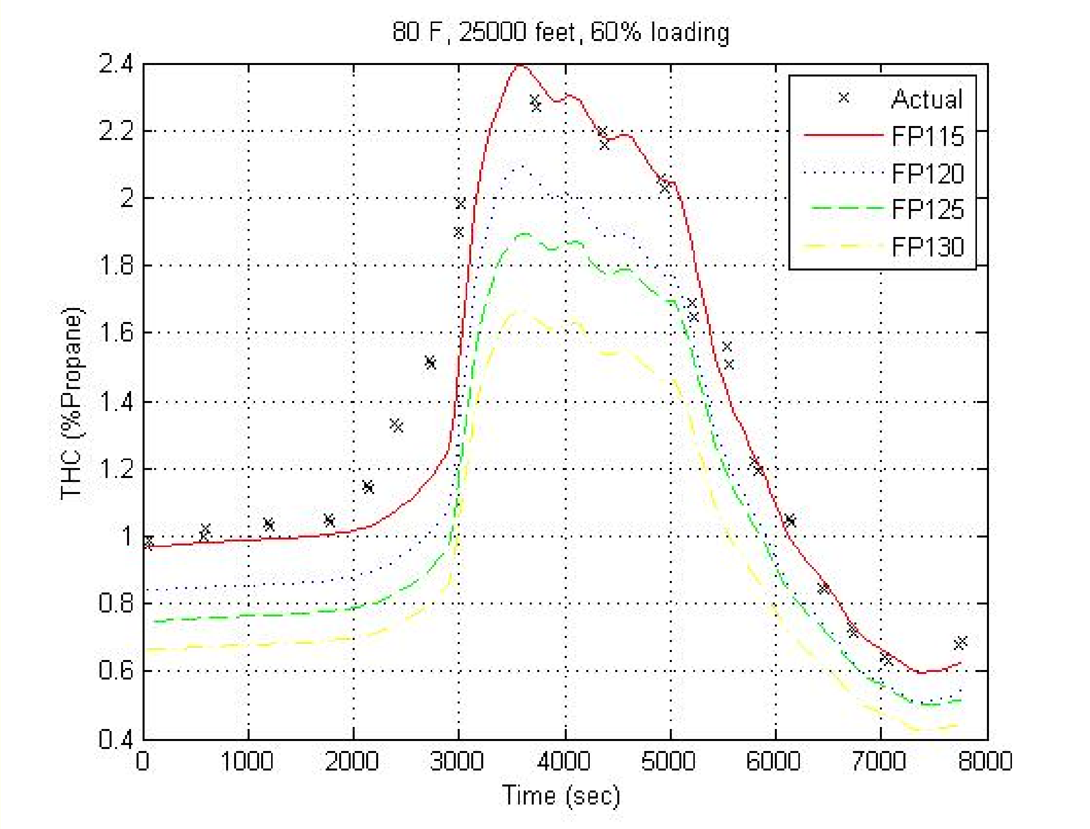
Test Results



Cruise and Descending Top Surface Heat Transfer Correlations

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Summary of Experimental Results

- Laminar Forced Convection during ascent
- Turbulent Forced Convection the rest of the flight
- Shows ullage gases are well mixed in the ullage
- High Reynolds number in the heat transfer cells in the ullage

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?