Modeling Jet-A Vaporization in a Wing Fuel Tank

DHAVAL D. DADIA

Constantine Sarkos, Richard Hill
Steven Summer, Robert I. Ochs
Federal Aviation Administration
Atlantic City Airport, New Jersey

Dr. C.E. Polymeropoulos, Dr. Tobias Rossmann
Rutgers, The State University of New Jersey
Piscataway, New Jersey

Motivation

- Combustible mixtures can be generated in the ullage of aircraft fuel tanks.
- Work currently being done to reduce flammability of wing tanks.
- The proposed model will predict existing ullage concentrations during typical ground and flight conditions.

Current Work

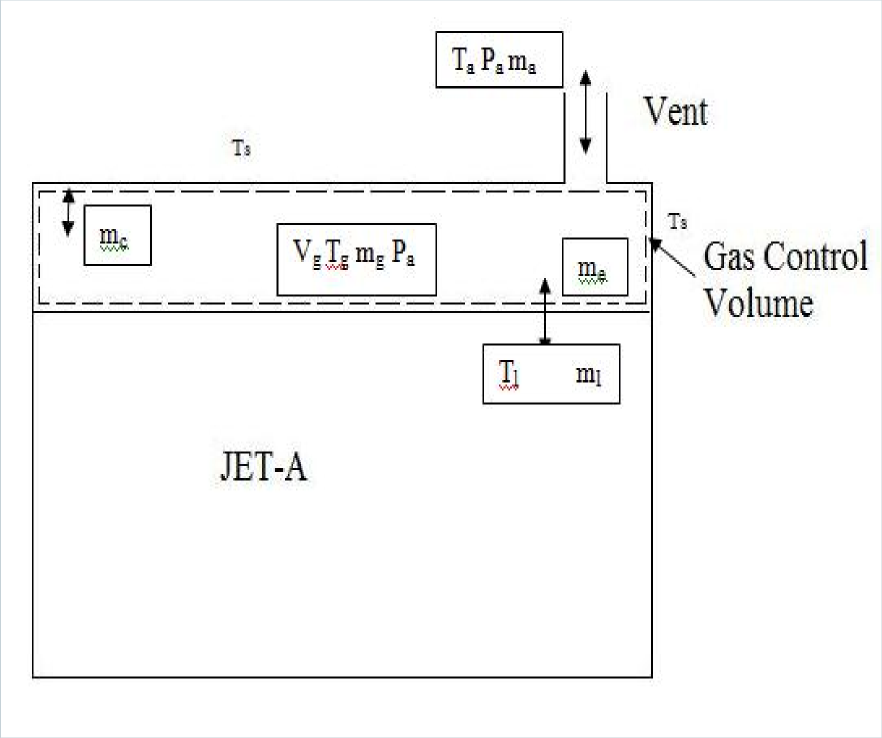
- Predicting the influence of the following parameters in the development of flammable mixtures in the ullage.
  - Surface temperature
  - Fuel Temperature
  - Ullage temperature
  - Pressure
  - Amount of fuel in the tank

Overview

- Description of model
  - Mass Transfer Considerations
  - Assumptions
  - Heat and Mass Conservation Relations
  - Heat and Mass Transfer Correlations
- Jet-A characterization
- Results
  - Altitude Chamber
  - Air Induction Wind Tunnel
  - Flight Test NASA 747 SCA

Mass Transfer Considerations

- Natural convection and forced convection heat and mass transfer
  - Liquid vaporization
  - Vapor condensation
- Variable ambient pressure and temperature
- Vented Tank
- Multi-component fuel



Assumptions for Estimating Ullage Vapor Composition

- Well mixed gas and liquid phases
  - Buoyancy induced mixing
- Quasi-steady transport using heat transfer correlations
- Low evaporating species concentrations
- Time dependent values of liquid fuel, and tank wall temperatures are known.

Supplementary Assumptions

- Gases and vapors follow ideal gas behavior.
- Tank pressure is the same as the ambient pressure.
- Condensate layer forms on the tank walls.
- Condensation occurs at the tank wall temperature.
- No liquid droplets in the ullage and no liquid pool sloshing.
- Fuel consumption is neglected.

Heat and Mass Conservation Relations

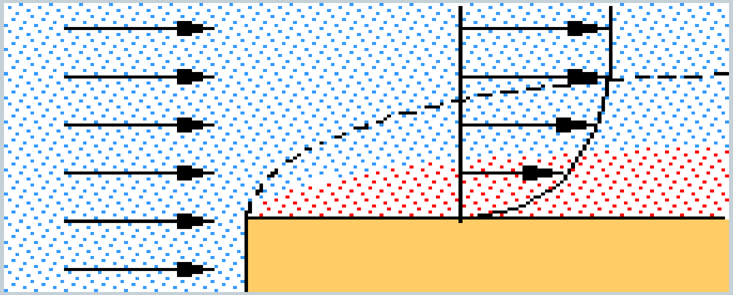
- Fuel Species Evaporation and Condensation

- Henry’s Law

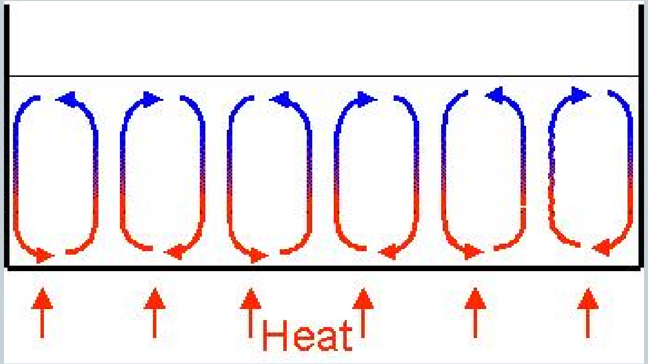
- Species vapor pressure was calculated using Wagner’s or Frost-Kalkwarf-Thodos equations.

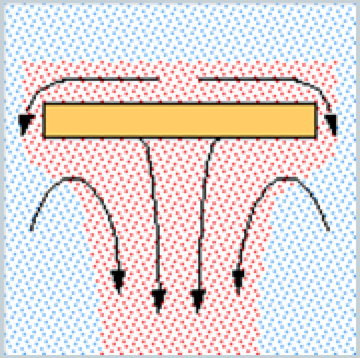
Heat and Mass Transfer Correlations

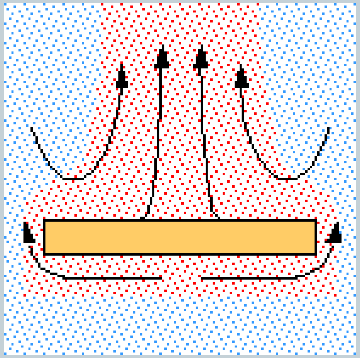
- Heat Transfer and Mass Transfer Correlations used:
  - Forced Convection over a flat plate



  - Various modes of natural convection







Jet-A Characterization

- Jet-A fuel can be characterized in terms of a number of n-alkane hydrocarbons determined by gas chromatography.

- This approach reduces the number of components in the fuel from 300 to 16 (c5-C20 alkanes).

- This output of the approach is in terms of mole fractions.

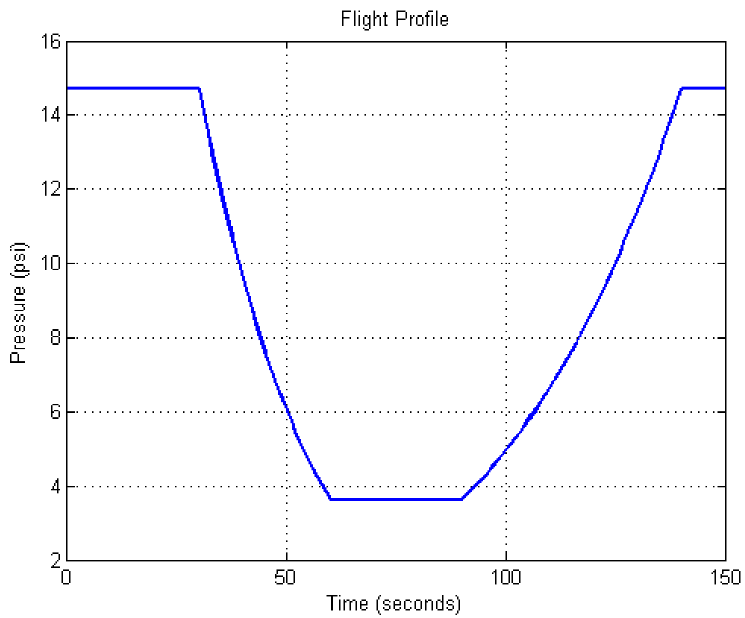
EXPERIMENTAL AND COMPUTATIONAL RESULTS

ALTITUDE CHAMBER TEST

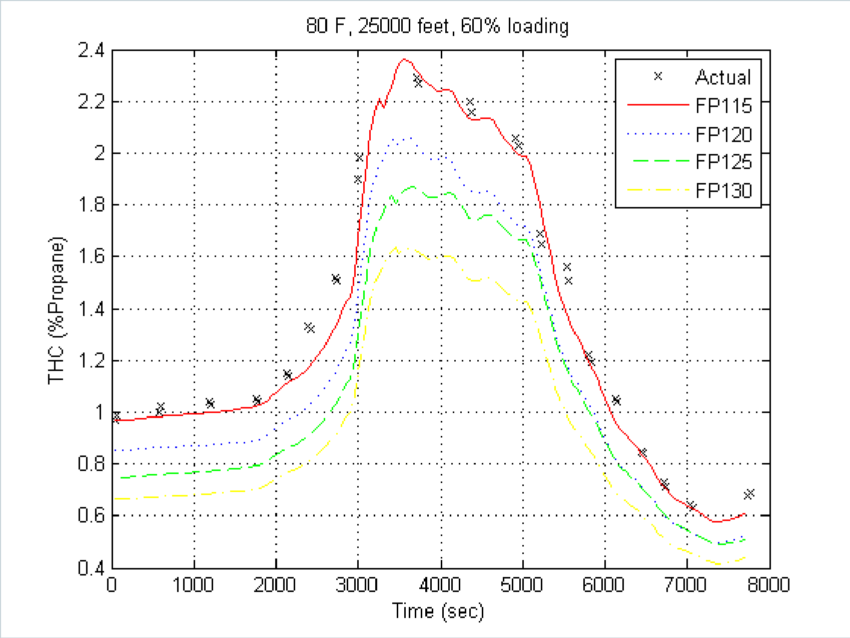
WIND TUNNEL TEST

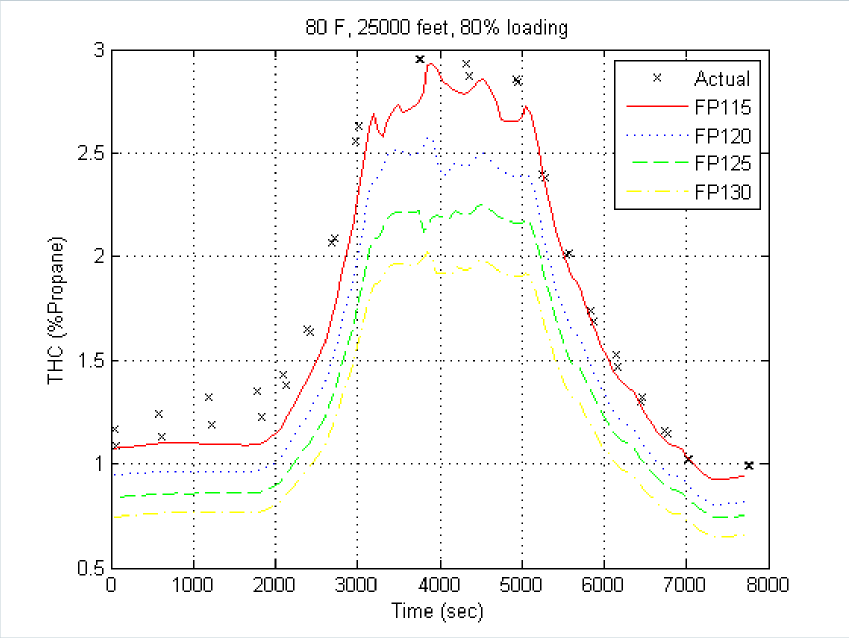
FLIGHT TEST

Altitude Chamber Test Setup

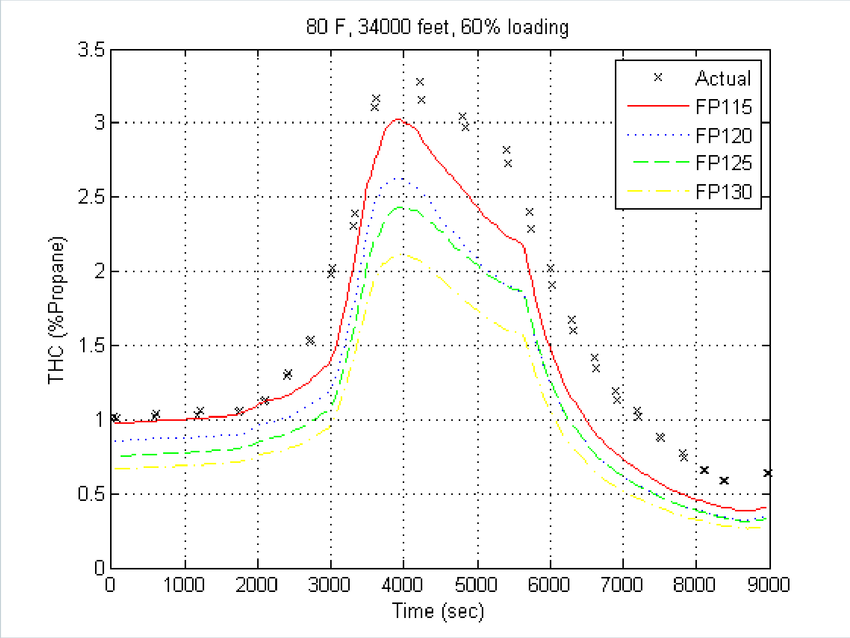


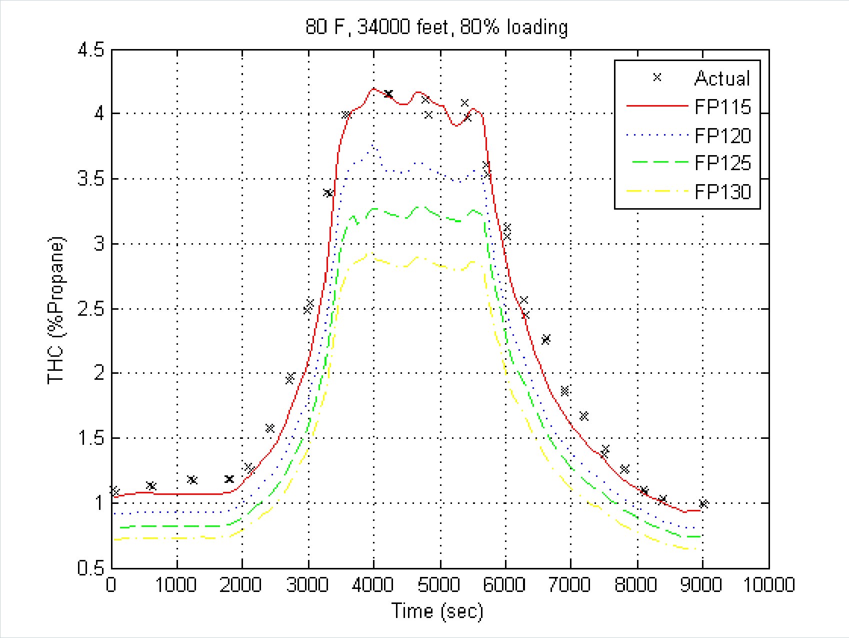
Experimental Results





Experimental Results





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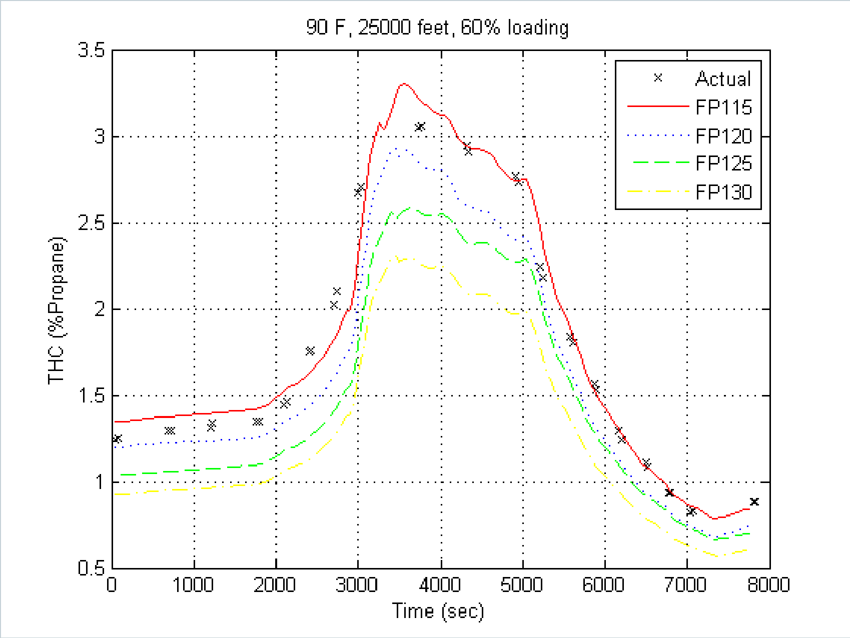
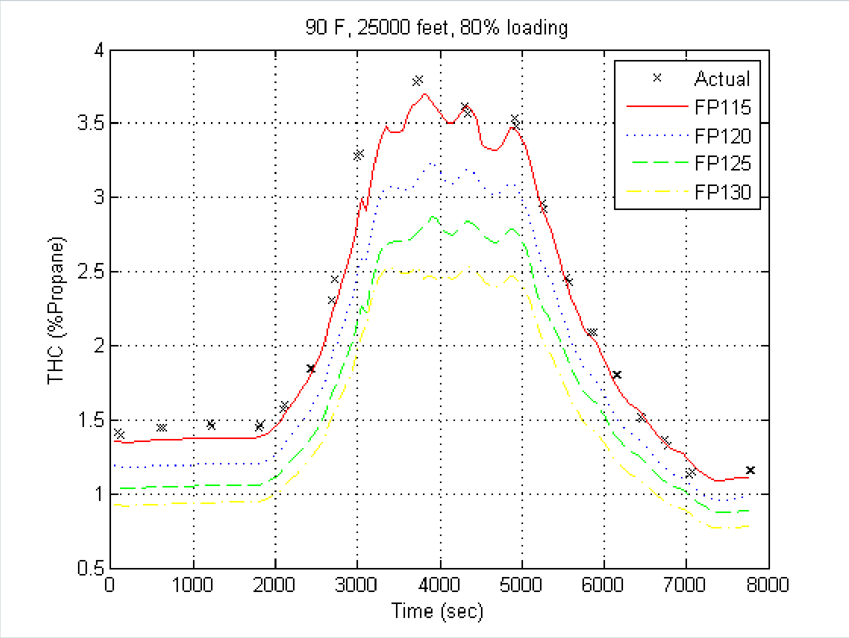
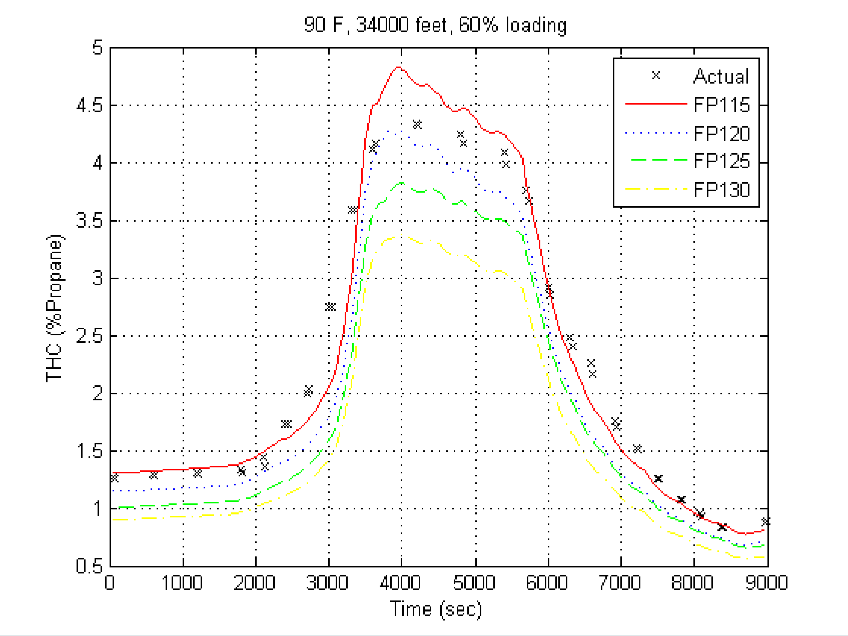
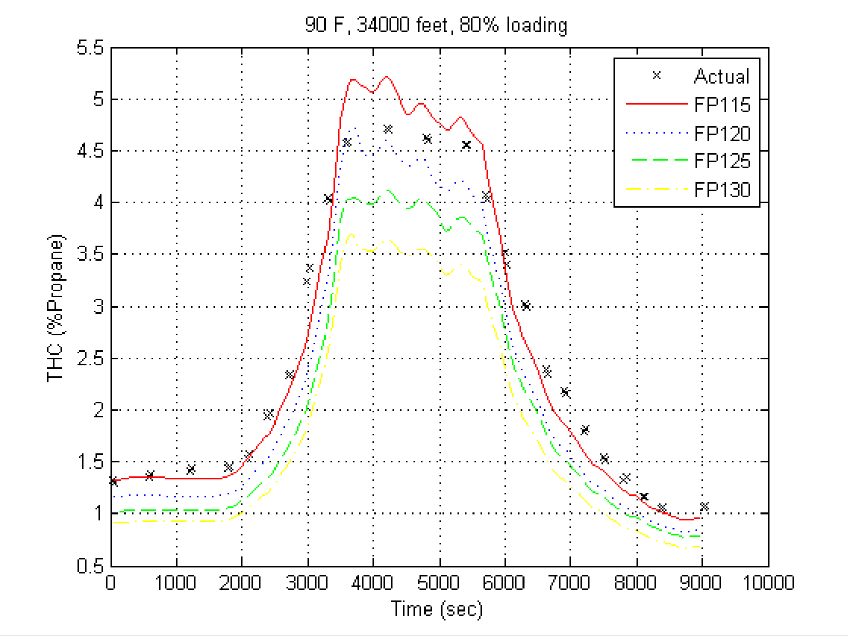




Experimental Results





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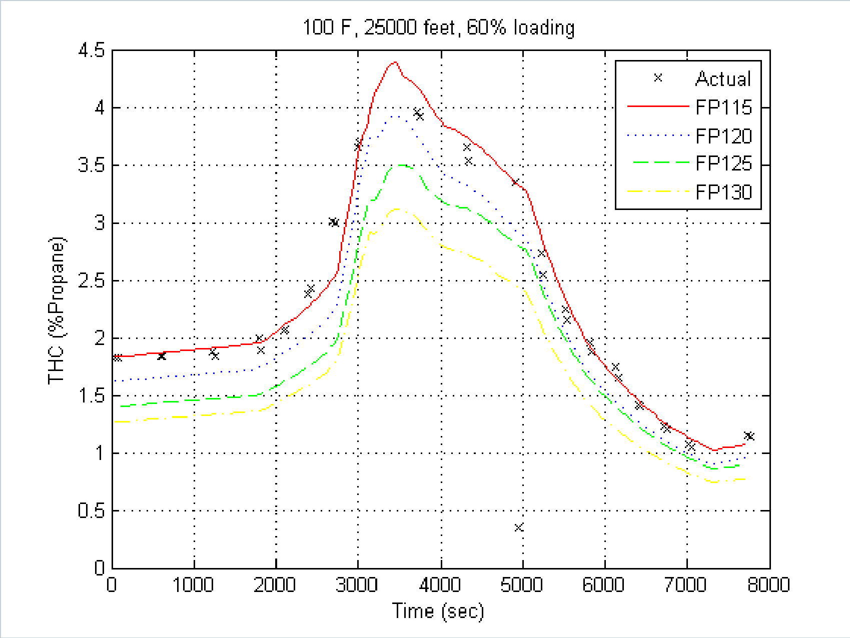
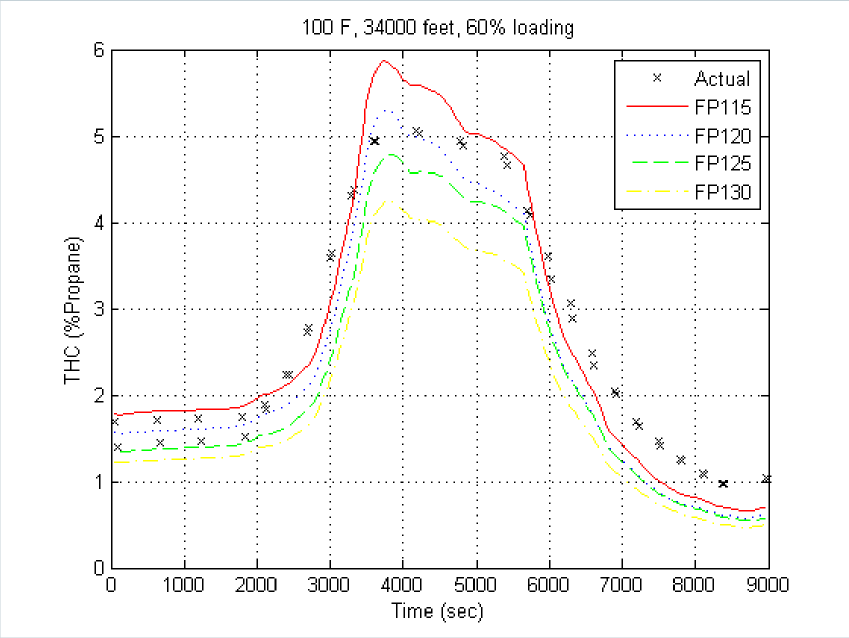
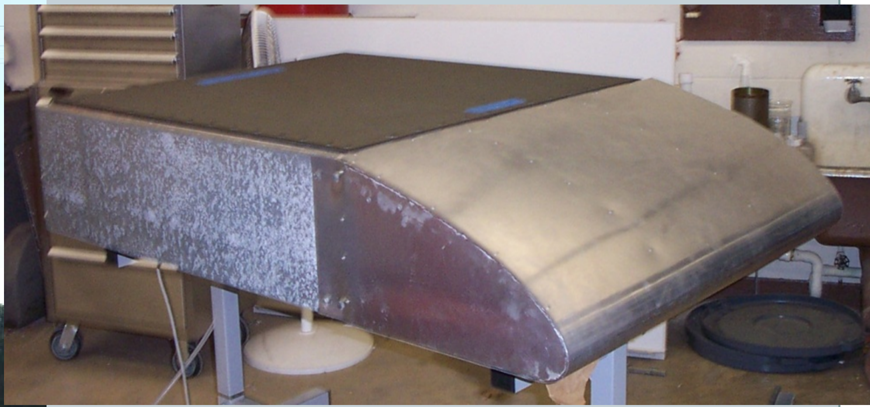




Wind Tunnel Experimental Setup



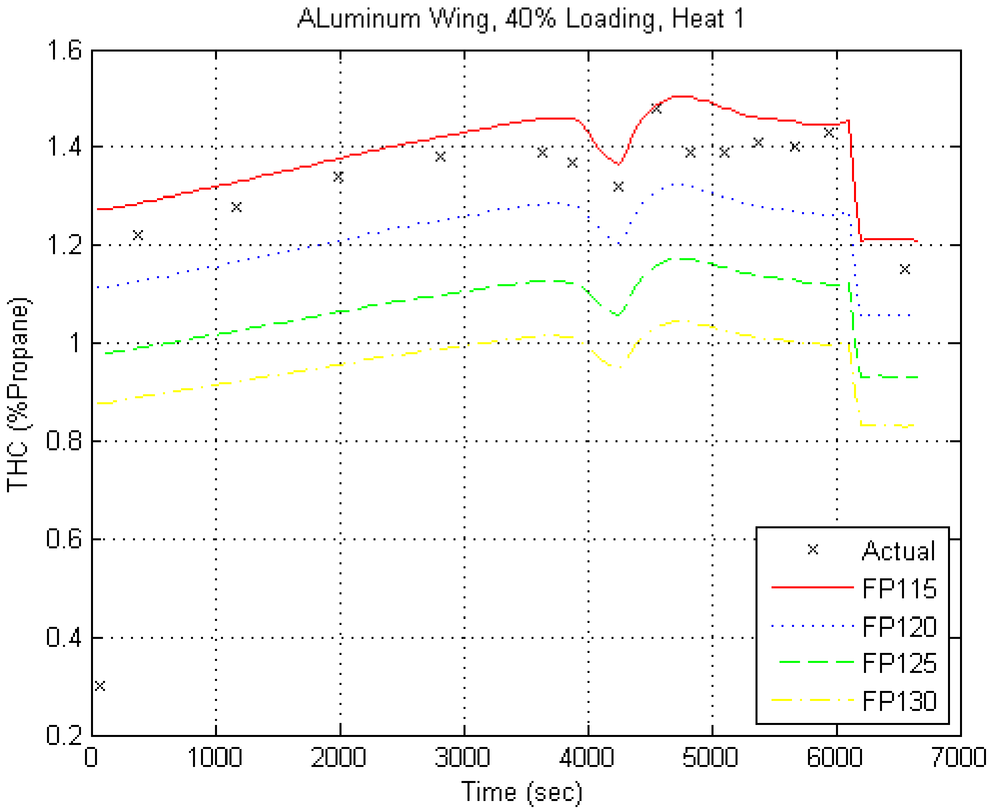
Wind Tunnel Test

Test Type

Aluminum Wing Tank

Mass Loading:40%

Heat Setting: 1



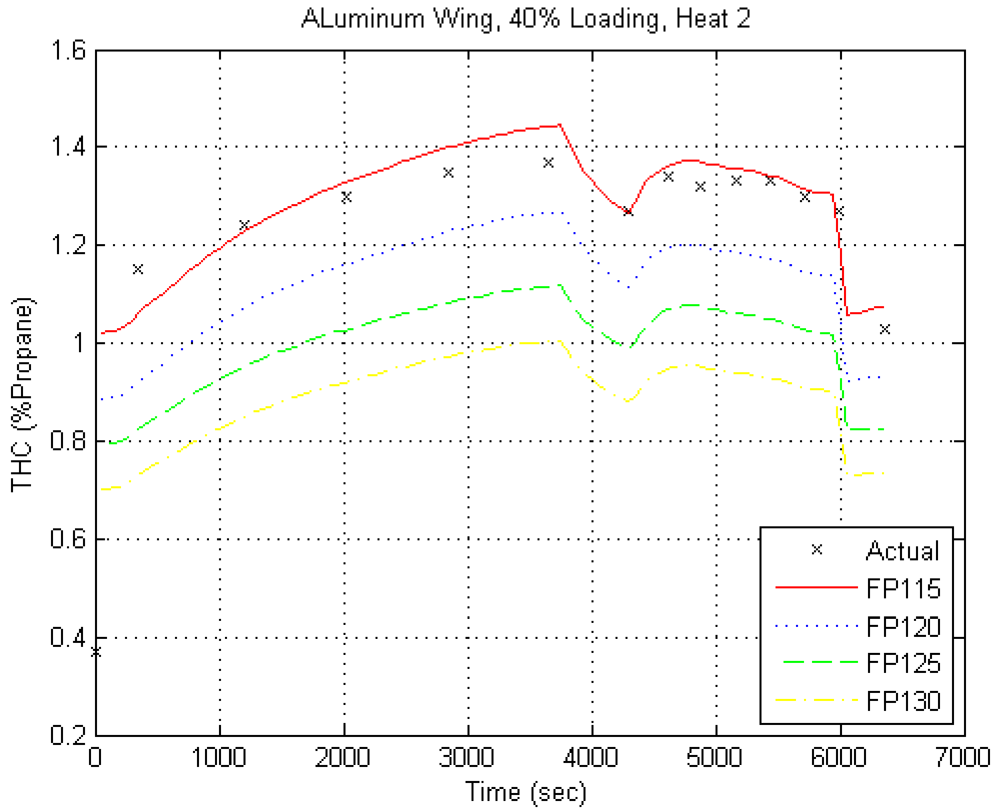
Wind Tunnel Test

Test Type

Aluminum Wing Tank

Mass Loading:40%

Heat Setting: 2



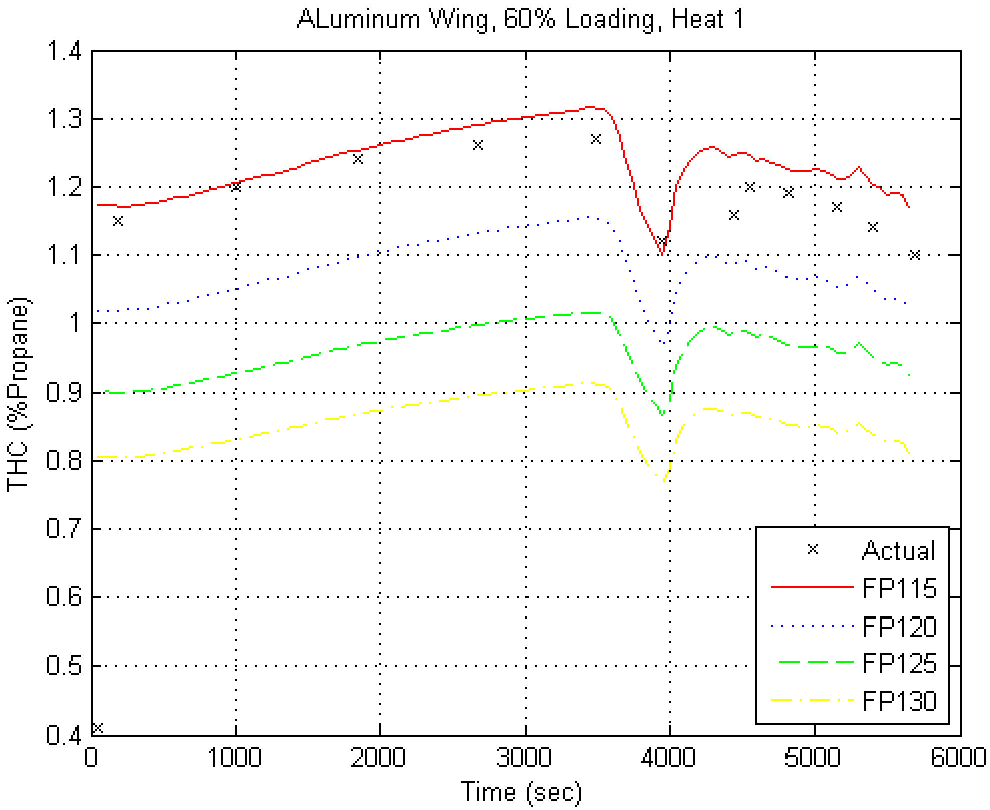
Wind Tunnel Test

Test Type

Aluminum Wing Tank

Mass Loading:60%

Heat Setting: 1



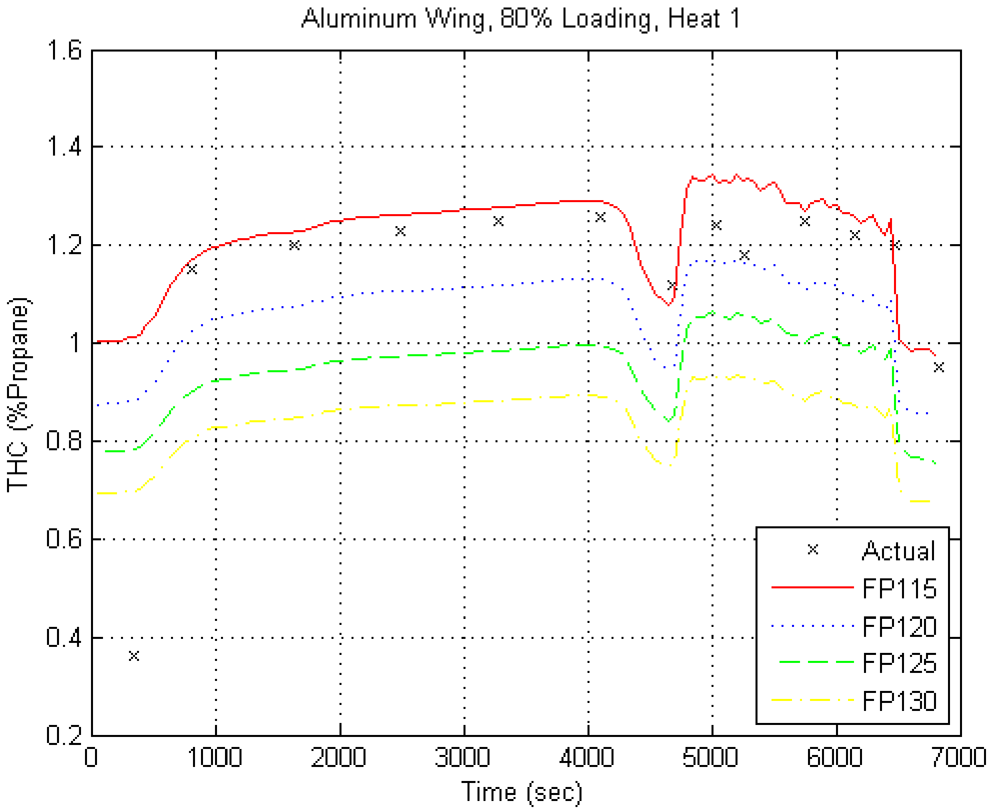
Wind Tunnel Test

Test Type

Aluminum Wing Tank

Mass Loading:80%

Heat Setting: 1



Flight Test NASA 747 Experimental Setup

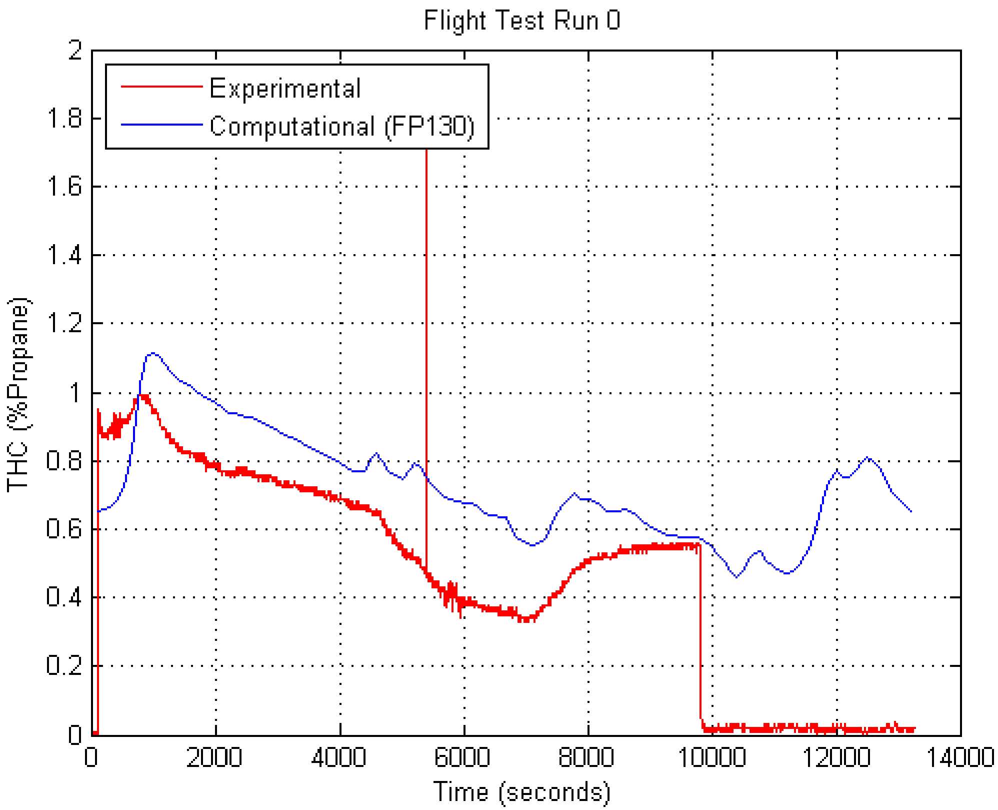
Flight Test

❖Experimental THC values not recorded after about 10,000 seconds.

❖Altitude Chamber correlations used.

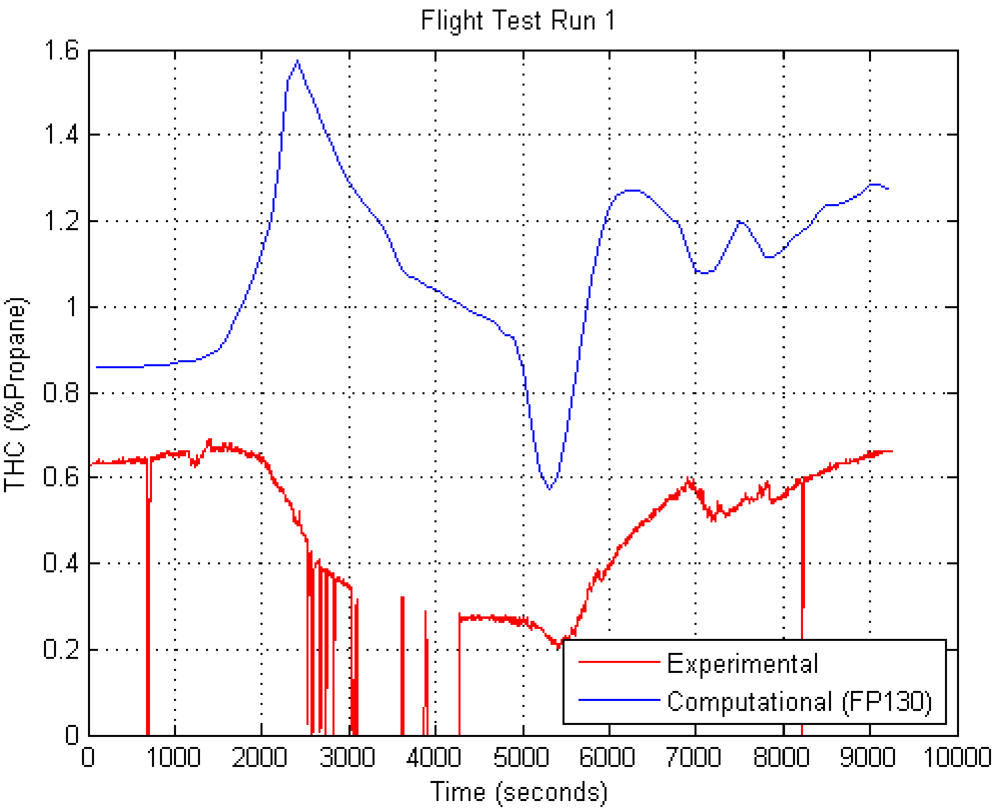
❖Normal input data set used.

❖Flight test THC data was measured using NDIR



Flight Test

- ❖Altitude Chamber correlations used.
- ❖Normal input data set used.
- ❖Data does not match computational data once the plane ascends.



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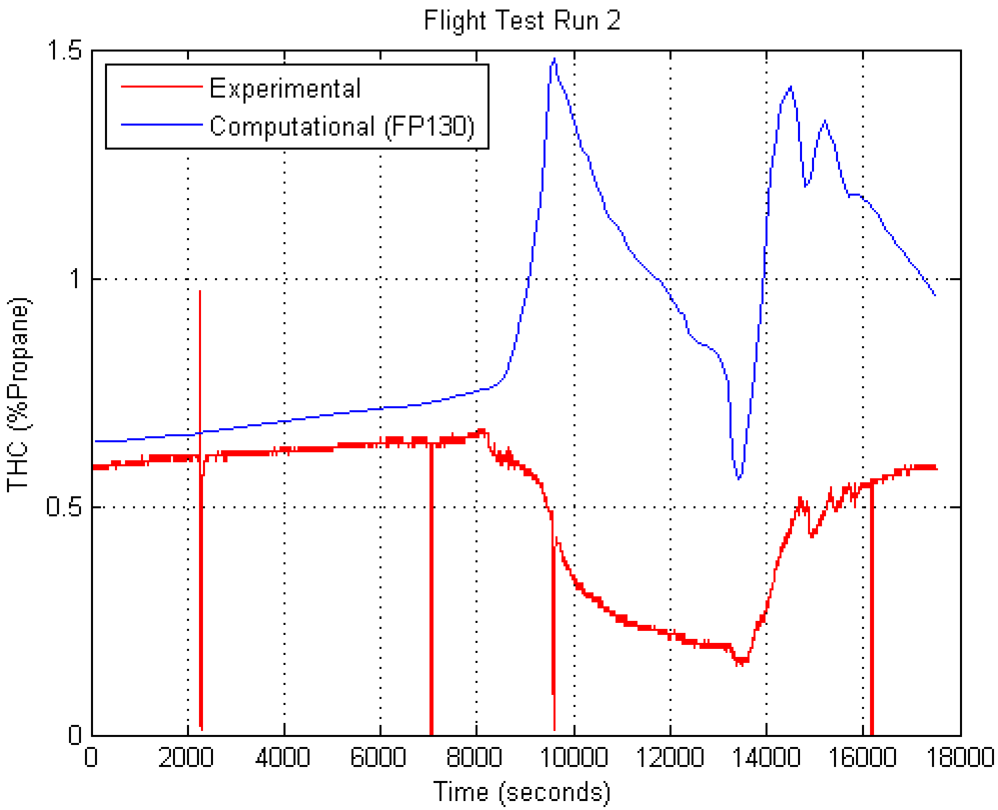
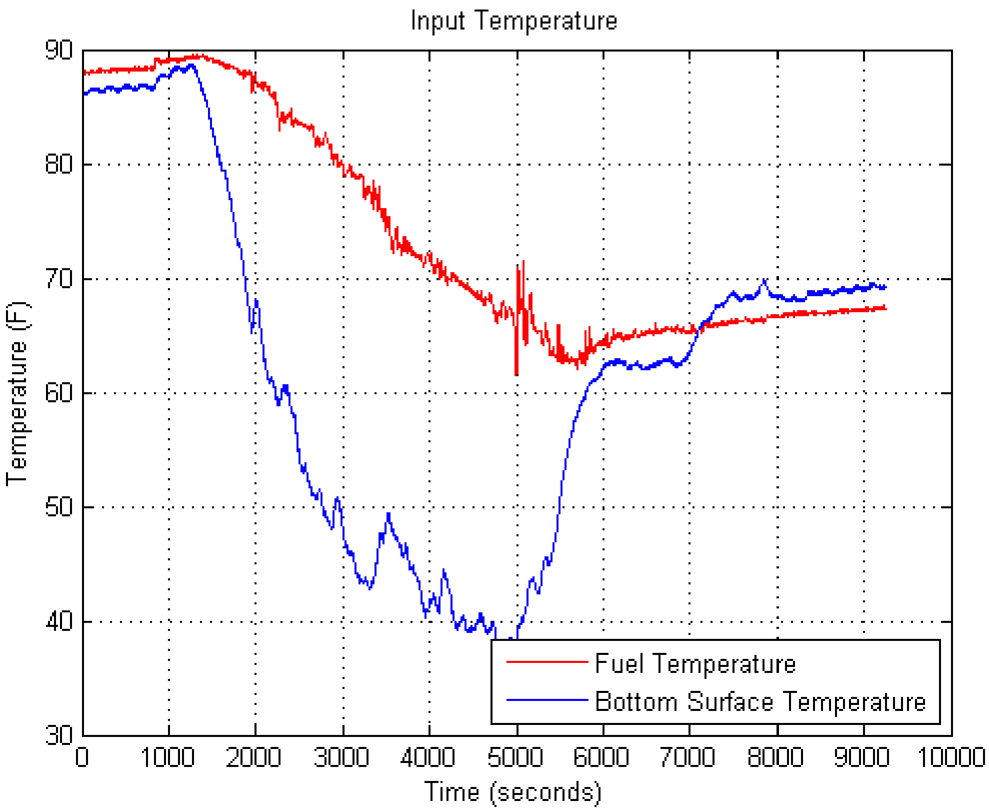


Flight Test

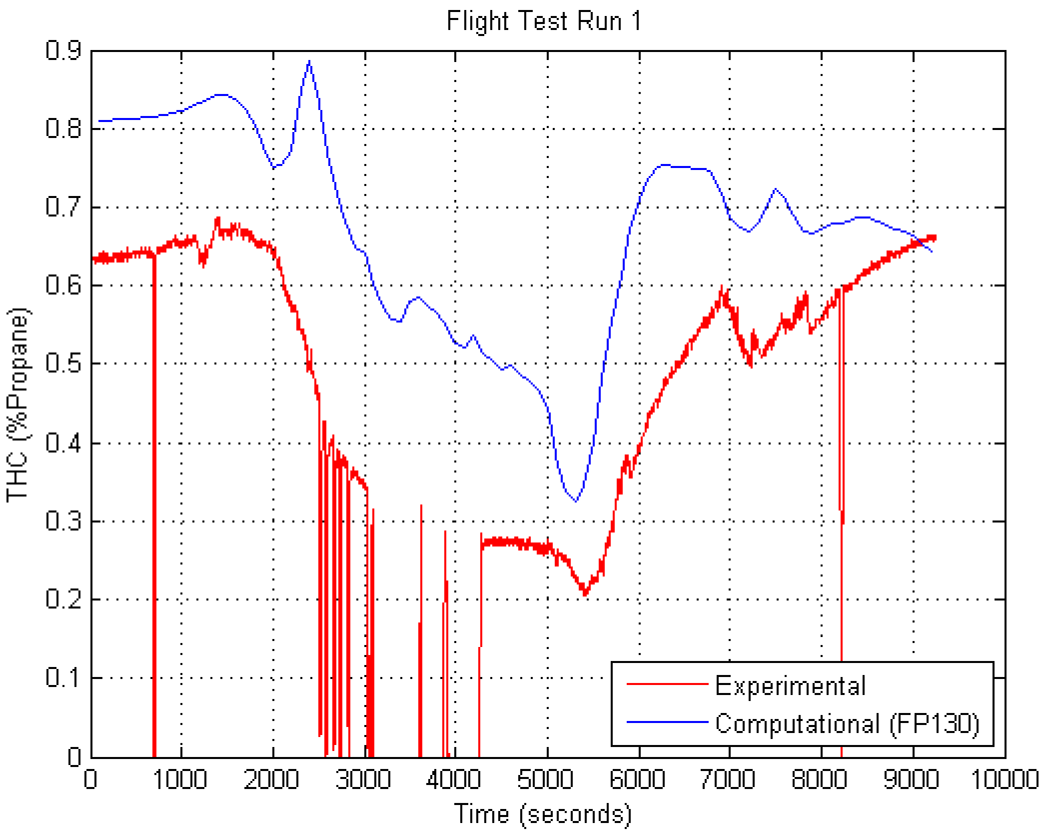
❖Difference between the fuel temperature and bottom surface temperature.

❖Bottom surface temperatures used as in put instead of fuel temperature



Flight Test

- ❖Altitude Chamber correlations used.
- ❖Bottom surface temperature used in the input instead of fuel temperature.
- ❖Computational data follows the trend of the experimental data.



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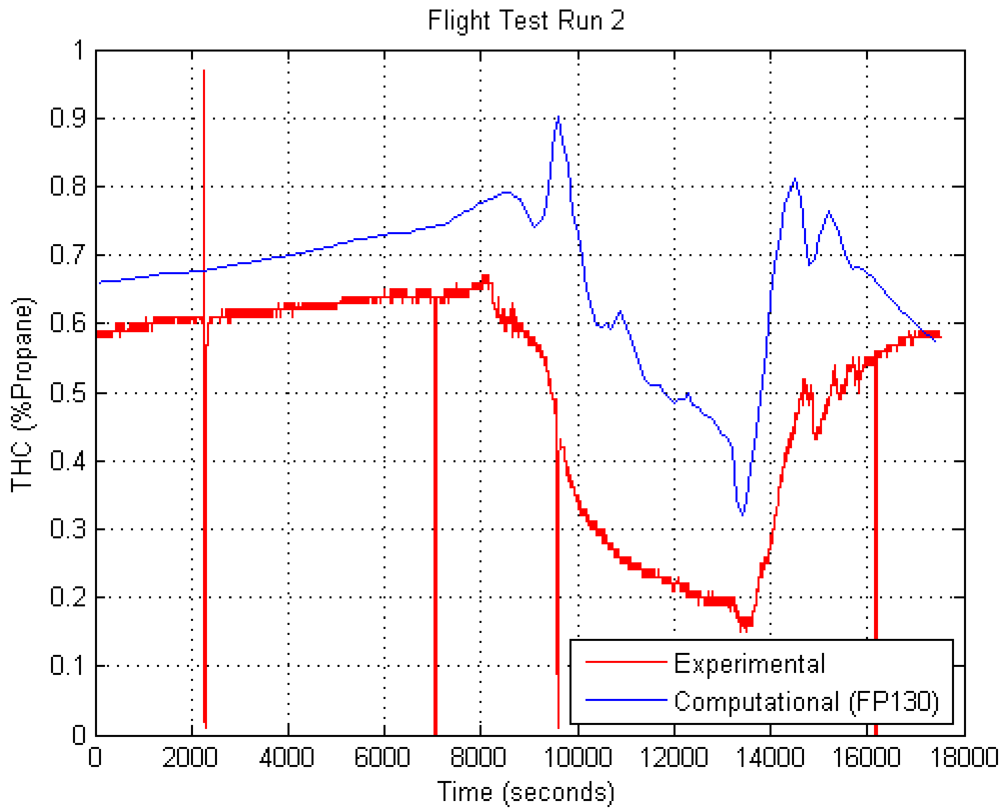

Conclusion

- Computational model validated by three different experimental tests.
- Computational model follows the general trend of the experimental results.
- Disagreement in flash point value of fuel in experimental cases caused due to model assumption.
- Disagreement in results in the flight test
  - Due to cold spots in the wing and thermal layering of the fuel.
  - Due to difference in measurement techniques. NDIR vs. FID

Questions?