

Factors Affecting the Limiting Oxygen Concentration Required for Ignition in an Aircraft Fuel Tank

by

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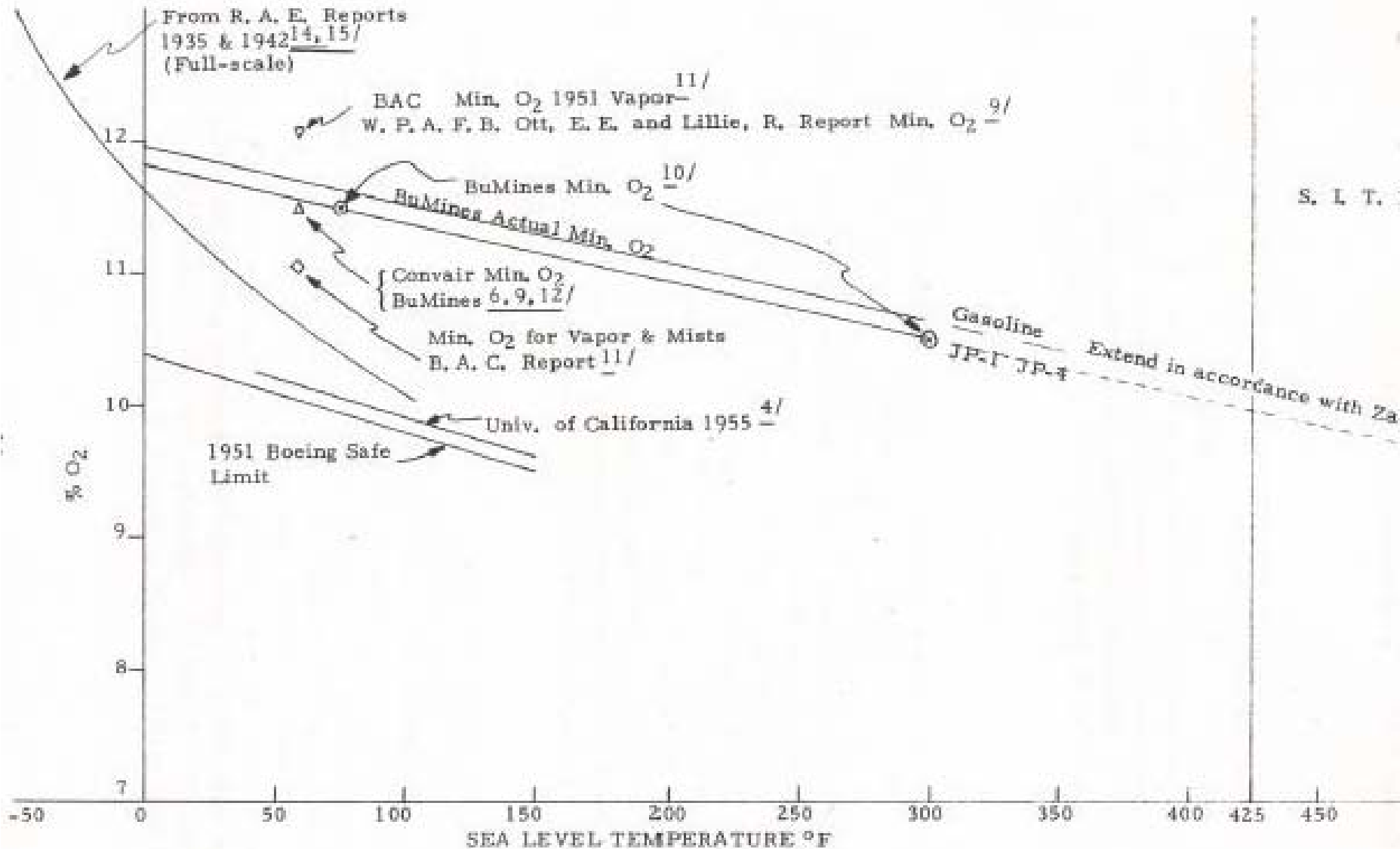
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Background

- LOC = Limiting Oxygen Concentration required for ignition during nitrogen inerting
- Used to be 9% based on old studies by Bureau of Mines and the military
- Recently changed to 12% based on:
 - Recent FAA LOC test data
 - Available inerting technology
 - Probabilistic argument on what is a sufficient level of safety improvement to the entire fleet
- This talk addresses factors affecting LOC test data

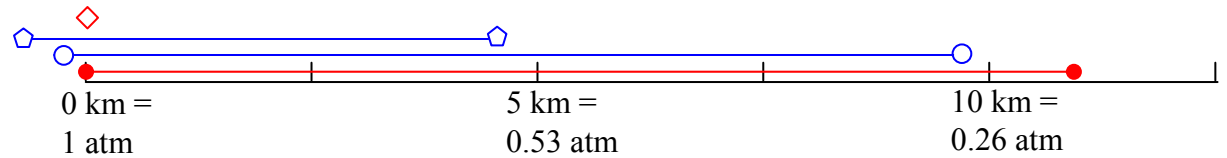
Historical Data on LOC (from Zinn)



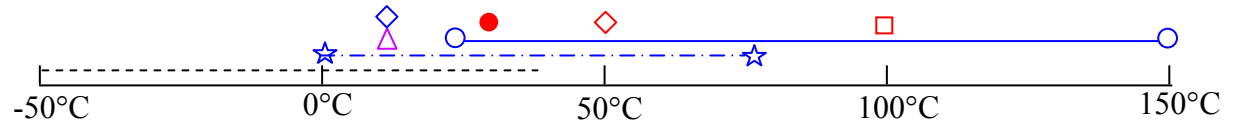
S. I. T.

Experimental Ranges

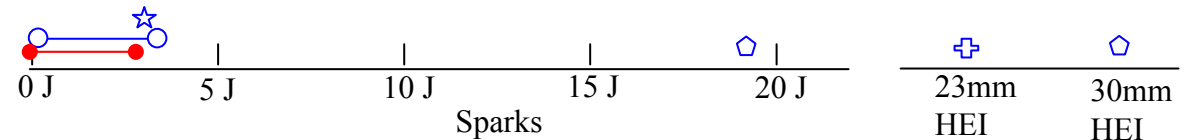
Altitude



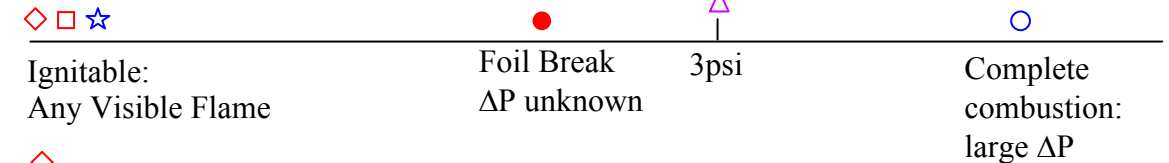
Ullage Temperature



Source Strength



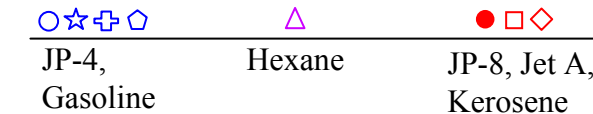
Ignition Criteria



Vibration, Slosh, and Mist

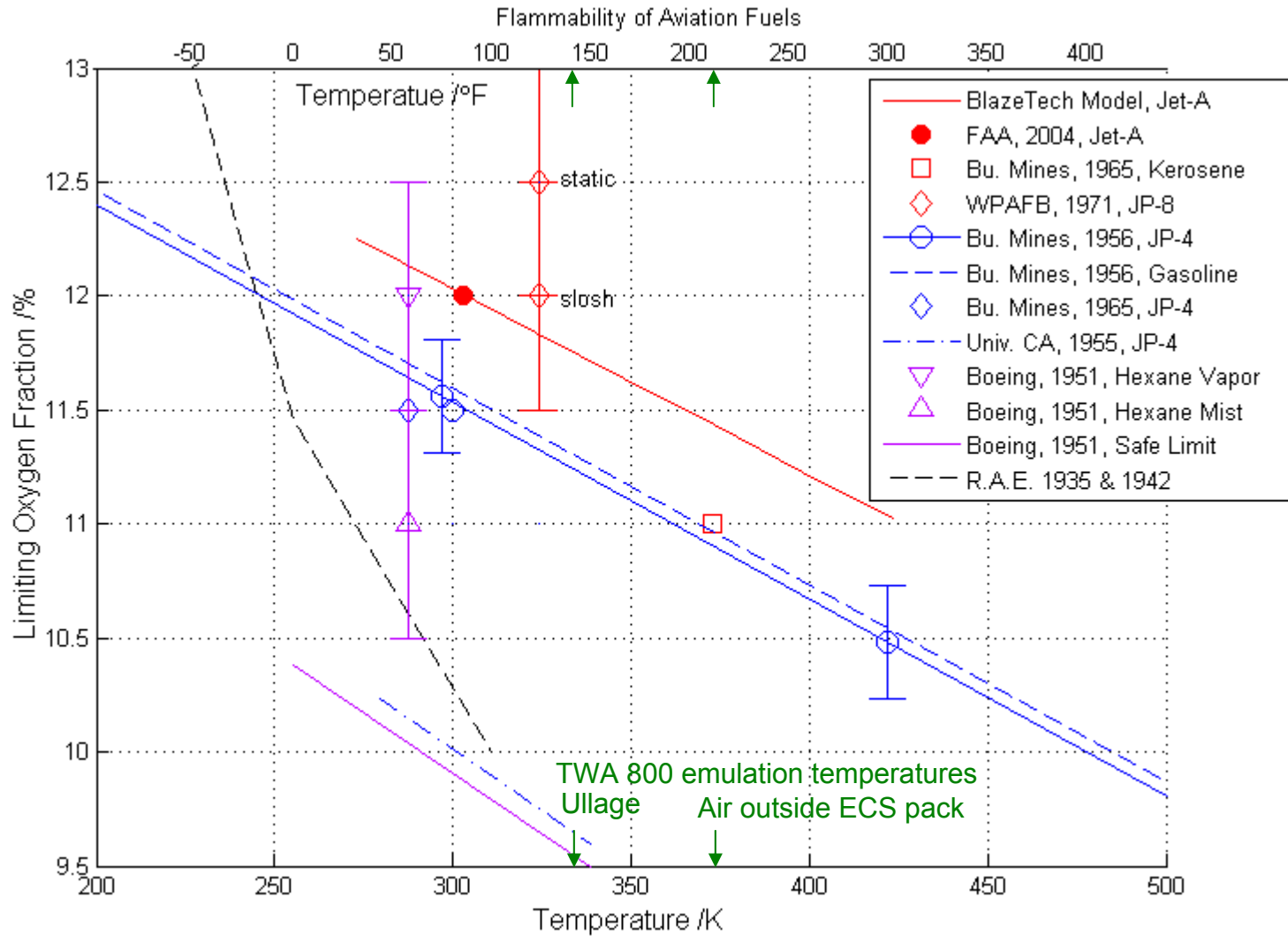


Fuel Composition



- FAA 2004
- Bu. Mines Kerosene 1965
- ◇ Ott WPAFB 1971
- Bu. Mines JP-4 1956
- ☆ U. CA 1955
- △ Boeing 1951
- ⊕ Anderson WPAFB 1978
- ◇ Tyson NWC 1991

Historical Data on LOC



Revised from a graph compiled by Zinn, DOT/FAA-NA-71-26, 1971

General Observations

- General agreement on effect of altitude
- Uncertainty in LOC data is +/- 0.5% for a given set of conditions with most experimental setups
- Recent FAA data agrees with old data
- BlazeTech model predicts correct dependence of LOC on ullage temperature
- No comment on R. A. E. since we could not find their report
- Many factors can decrease LOC below 12%

Reported Drops in LOC below 12%

1. Source Strength/Ignition Criteria:
 - Effect: WPAFB $\approx 0\%$, Bu.Mines 0.5% , U.CA 1.5% (inc source)
 - Well covered by FAA study
2. Ullage Temperature: $\approx 0.5\%$ if ullage at 200°F
3. Vibration and slosh:
 - WPAFB used tank with slosh and vibration. Difference $0.5\pm 0.5\%$.
 - Boeing used hexane vapor and mist. Effect $1\pm 0.5\%$
4. Gradients in Concentration: Depends on mixing.
 - U.CA $1\pm 0.5\%$ with and without a fan to aid mixing
 - O_2 enters tank near vent
5. Variations in Jet A composition depending on grade:
 - 0.5% between JP-4 and Jet A
 - Expect it to be less across various grades of Jet A

Combined Effect is neither obvious nor additive

Model of Ullage Flammability – Overall Architecture

Model Inputs

Fuel Conditions: type, amount & temperature

Tank Geometry and dimensions

Ignition Characterization: Source location, type and strength

Flight Profile: Altitude versus time, Fuel extraction rate to engine, and Fuel and tank wall temperatures

Inerting: ground vs. in-flight and percent concentration

BlazeTank

Output

Temp. and concentration vs. height and time

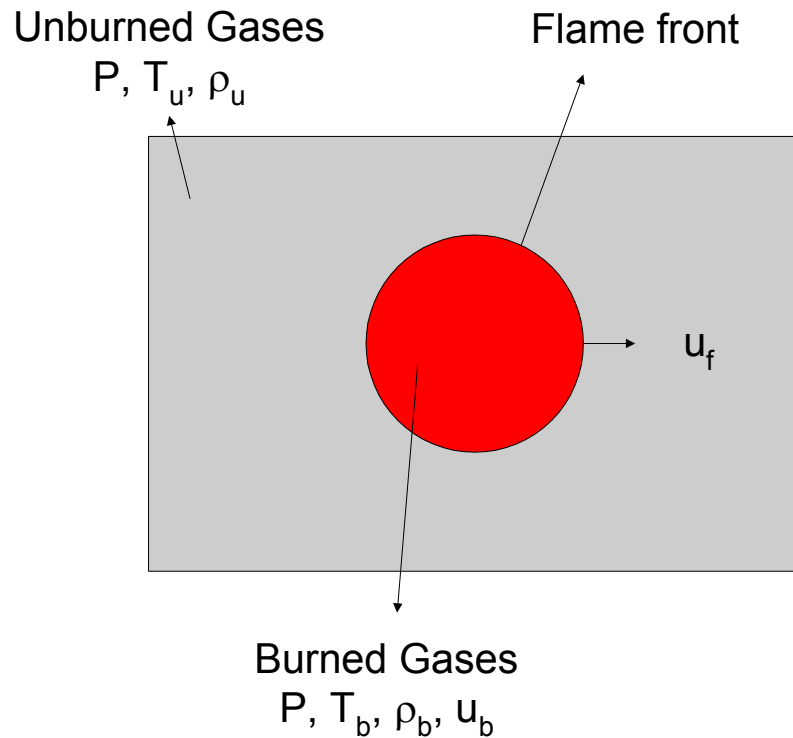
Flammable volume inside fuel tank

Ignition and Propagation

If ignition occurs, Temp., burn rate and Overpressure vs. time

Limiting Oxygen Concentration

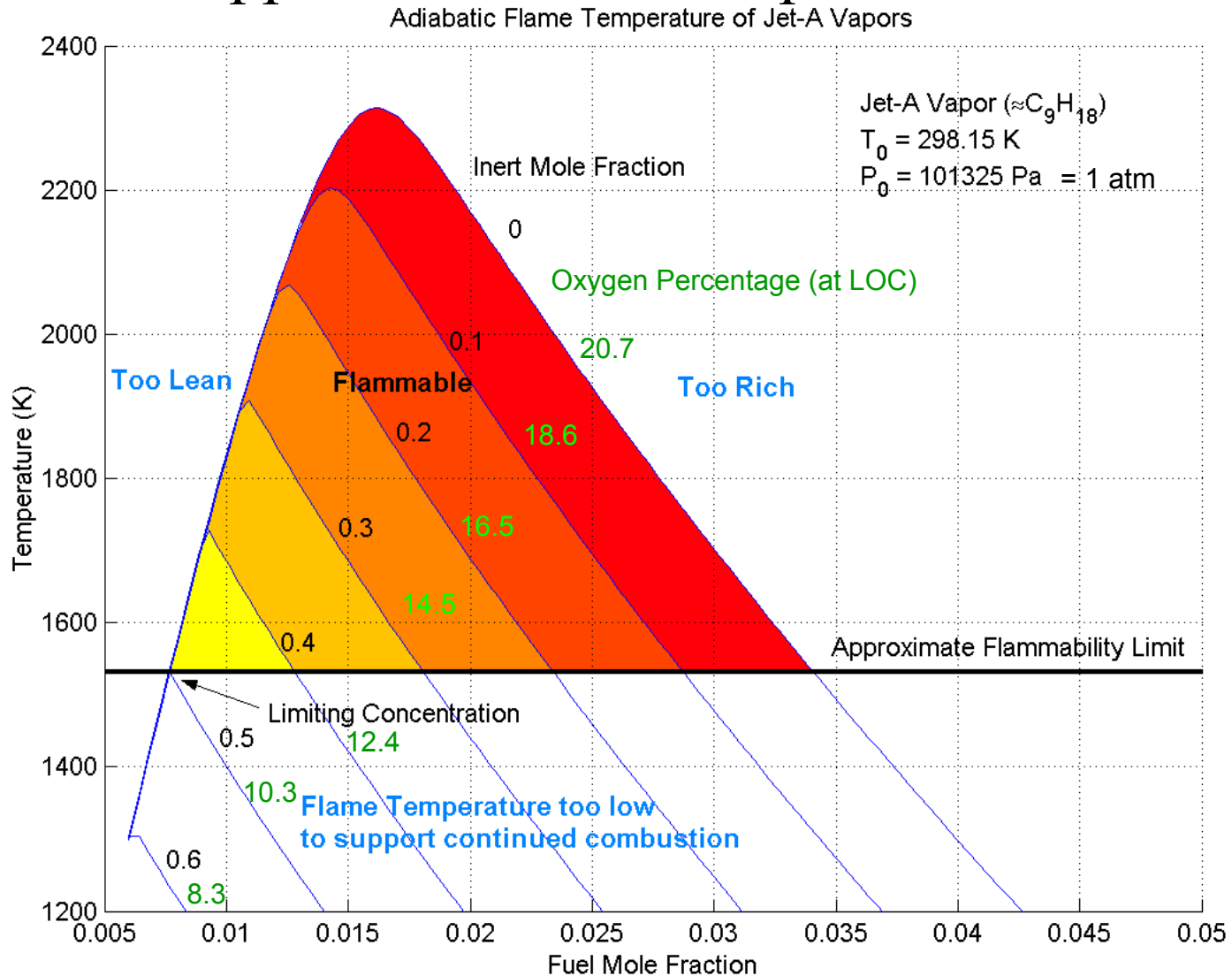
Deflagration Module in BlazeTank



- Key assumptions
 - Ullage consists of 2 zones: premixed unburned gases and burned gases separated by a flame sheet
 - Unburned gases are pressurized by expanding burnt zone
 - Pressure in ullage remains spatially uniform because it equilibrates at acoustic speed \gg deflagration speed
- BlazeTank solves the coupled equations of:
 - Continuity
 - Energy conservation
 - Species conservation
 - Experimental burn rate (fuel, stoichiometry, T and P)

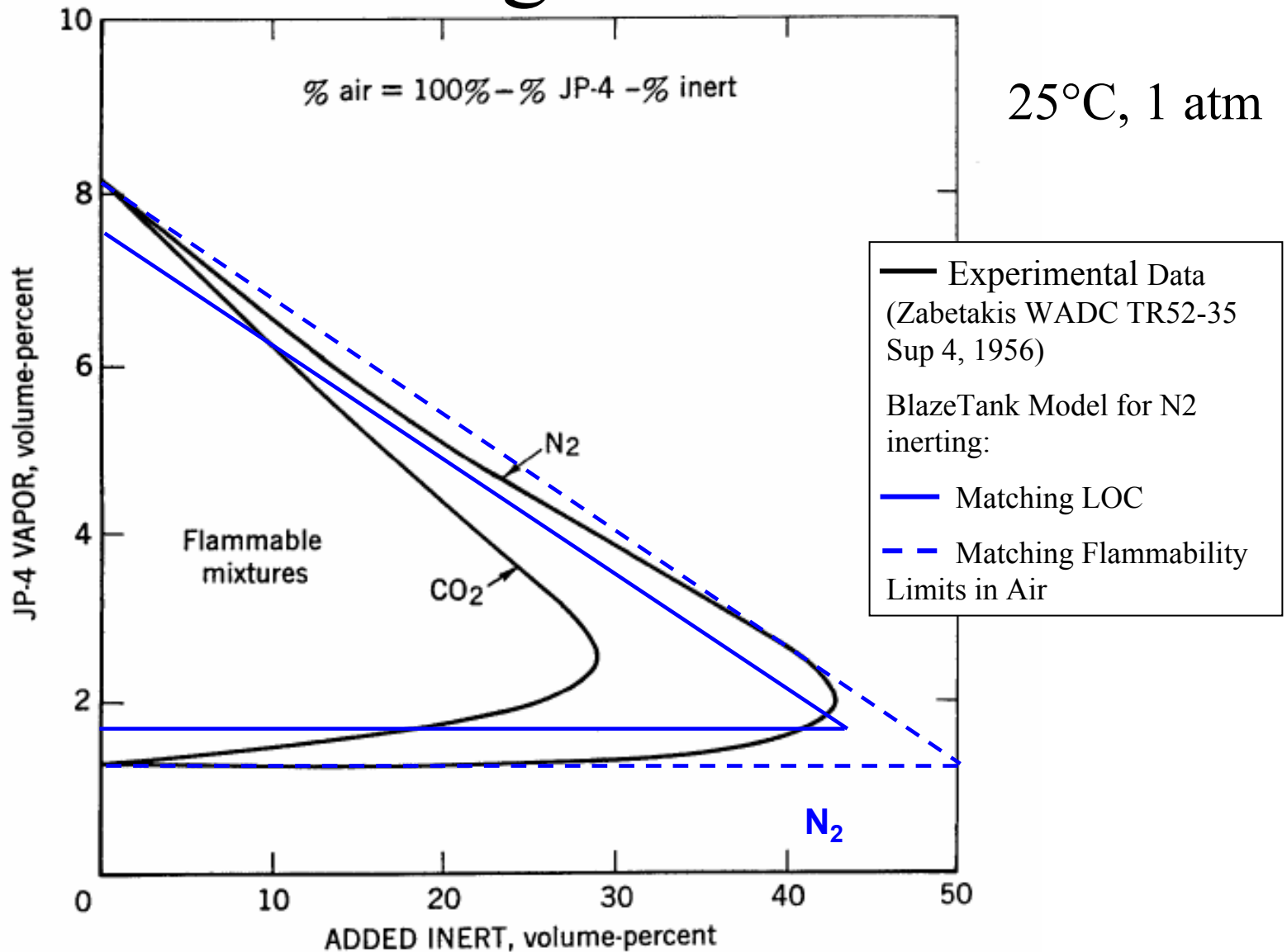
LOC Predictions by BlazeTank

First Approach: Flame Temperature Cut-off



Does not know the cut-off temperature a priori

Inerting of JP-4



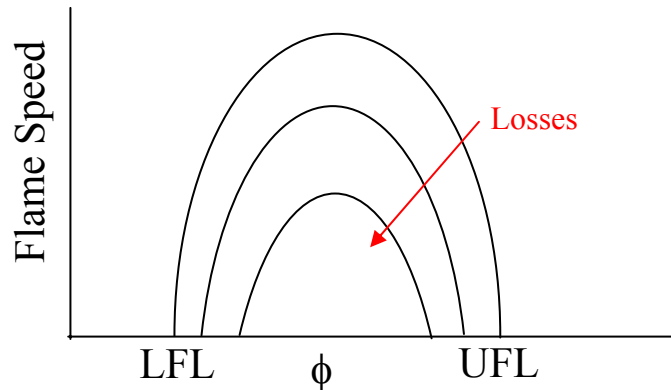
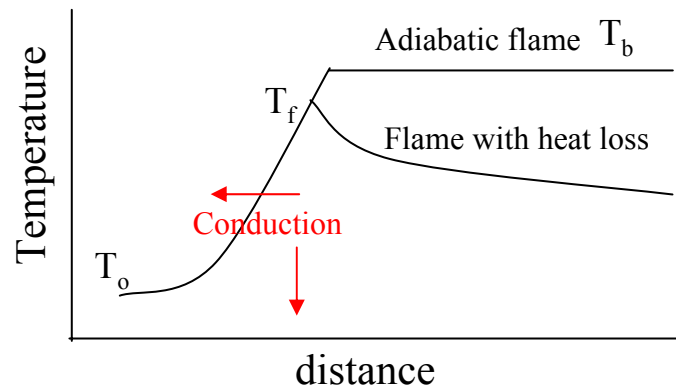
Doesn't match both LFL,UFL and LOC

LOC Prediction by BlazeTank

Second Approach: Zero Burning Velocity

If ullage cannot propagate a flame, it is not flammable

$U_f(\phi, T_a, T_b, Losses) = 0$. ϕ , T_a known, T_b from equilibrium chemistry.
Use lower flammability limit to determine the heat losses.



Conclusions

- Recent FAA tests neglect key factors that can lower LOC:
 - Slosh and vibration, ullage temperature, variations in fuel composition and gradient effects
- Their combined effect is not obvious and may not be simply additive
- They can be quantified by testing or modeling (such as BlazeTank™)
- Modeling can be used to optimize:
 - The design of inerting systems
 - Their operation (when and how much to inert) so as to minimize load on engine
- Some inerting is better than none but one should err on the conservative side

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