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

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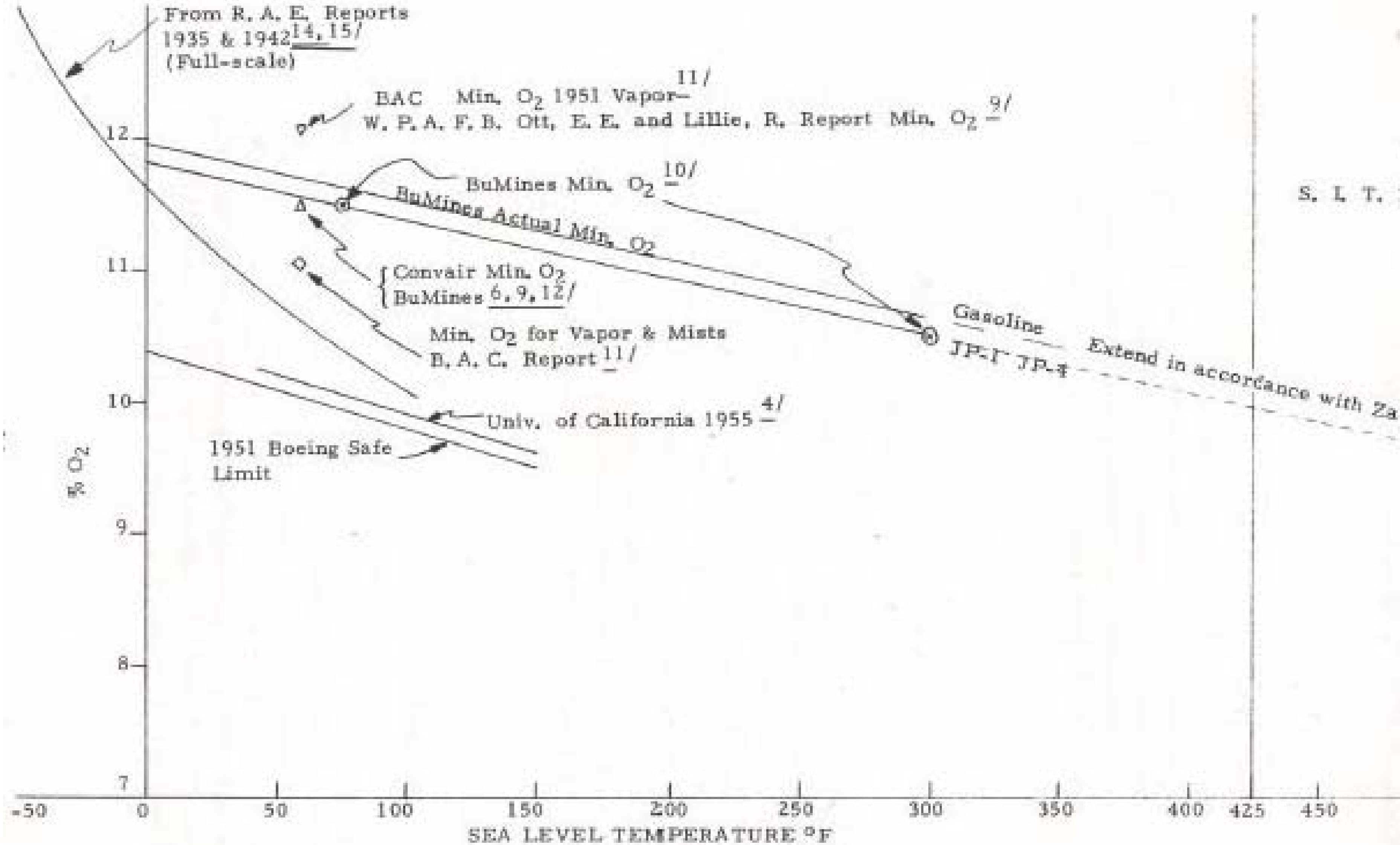
# Background

- 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)

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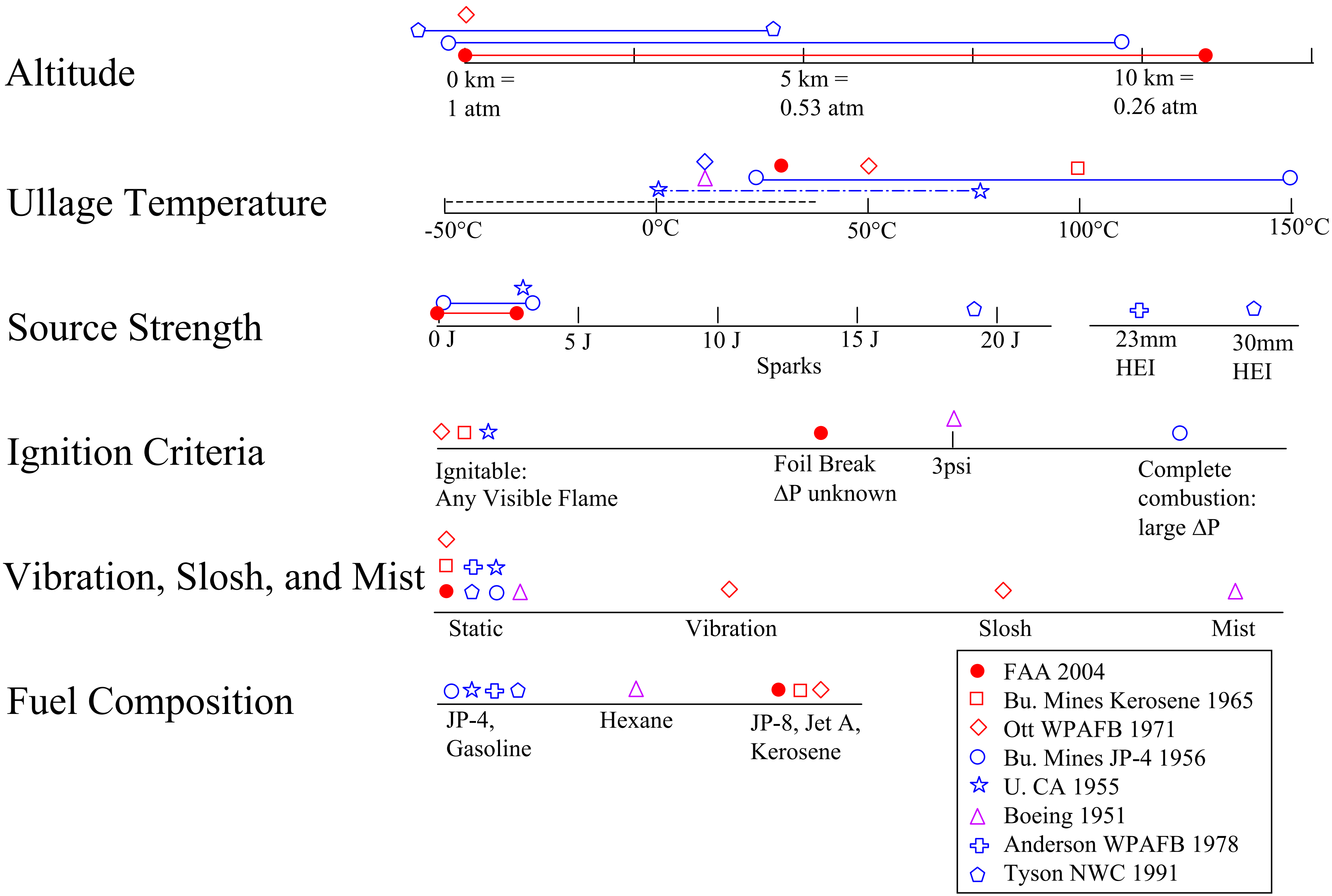
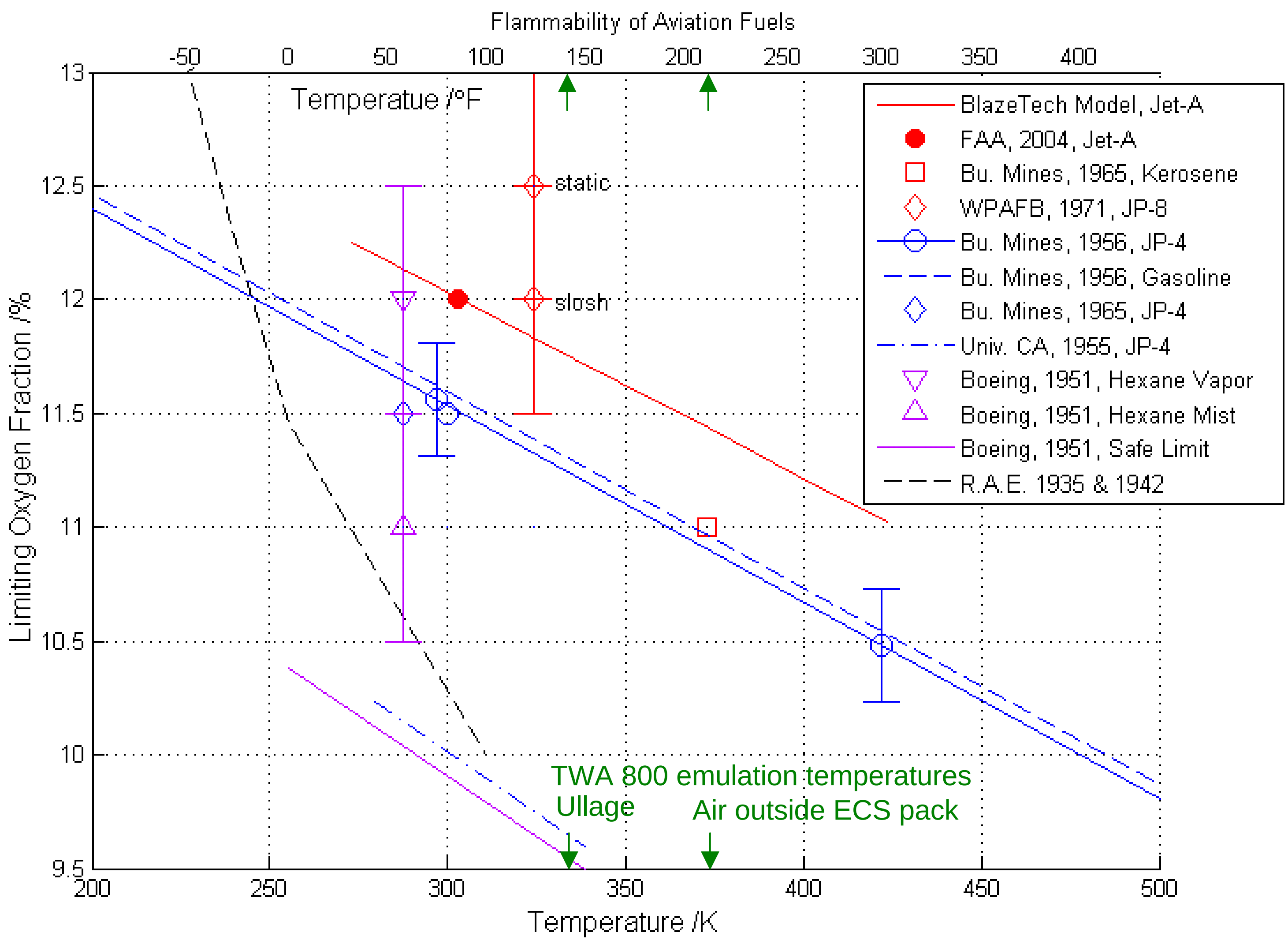
Zinn, "Inerted Fuel Tank Oxygen Concentration Requirements" DOT/FAA-RD-71-42, 1971

# Experimental Ranges



# 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 ≈ 0%, Bu.Mines 0.5%, U.CA 1.5% (inc source)
   - Well covered by FAA study
2. Ullage Temperature: ≈ 0.5% if ullage at 200°F
3. Vibration and slosh:
   - WPAFB used tank with slosh and vibration. Difference 0.5±0.5%.
   - Boeing used hexane vapor and mist. Effect 1±0.5%
4. Gradients in Concentration: Depends on mixing.
   - U.CA 1±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**

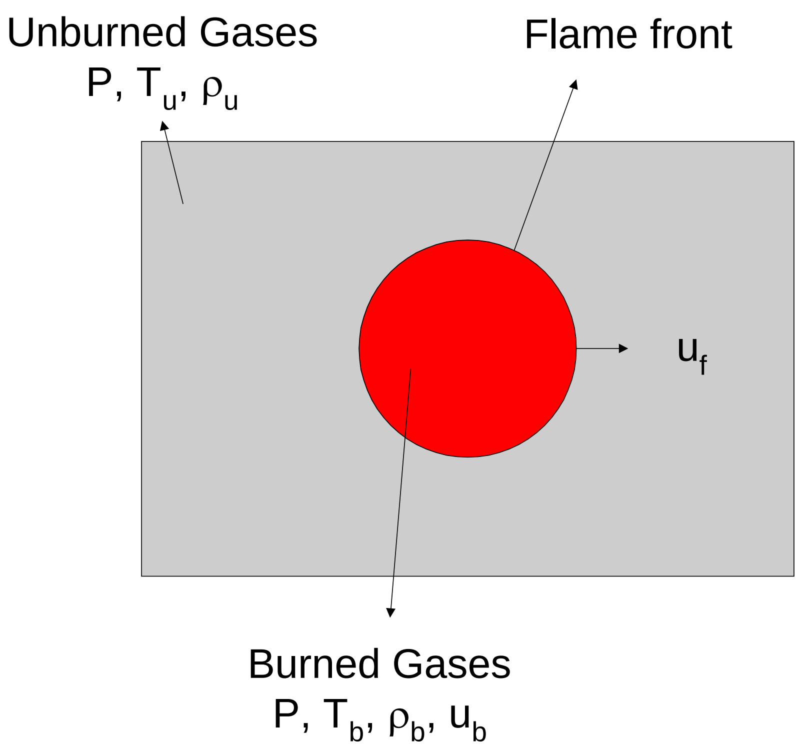
**Flammable volume inside fuel tank**

**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 >> deflagration speed
- BlazeTank solves the coupled equations of:
  - Continuity
  - Energy conservation
  - Species conservation
  - Experimental burn rate (fuel, stoichiometry, T and P)

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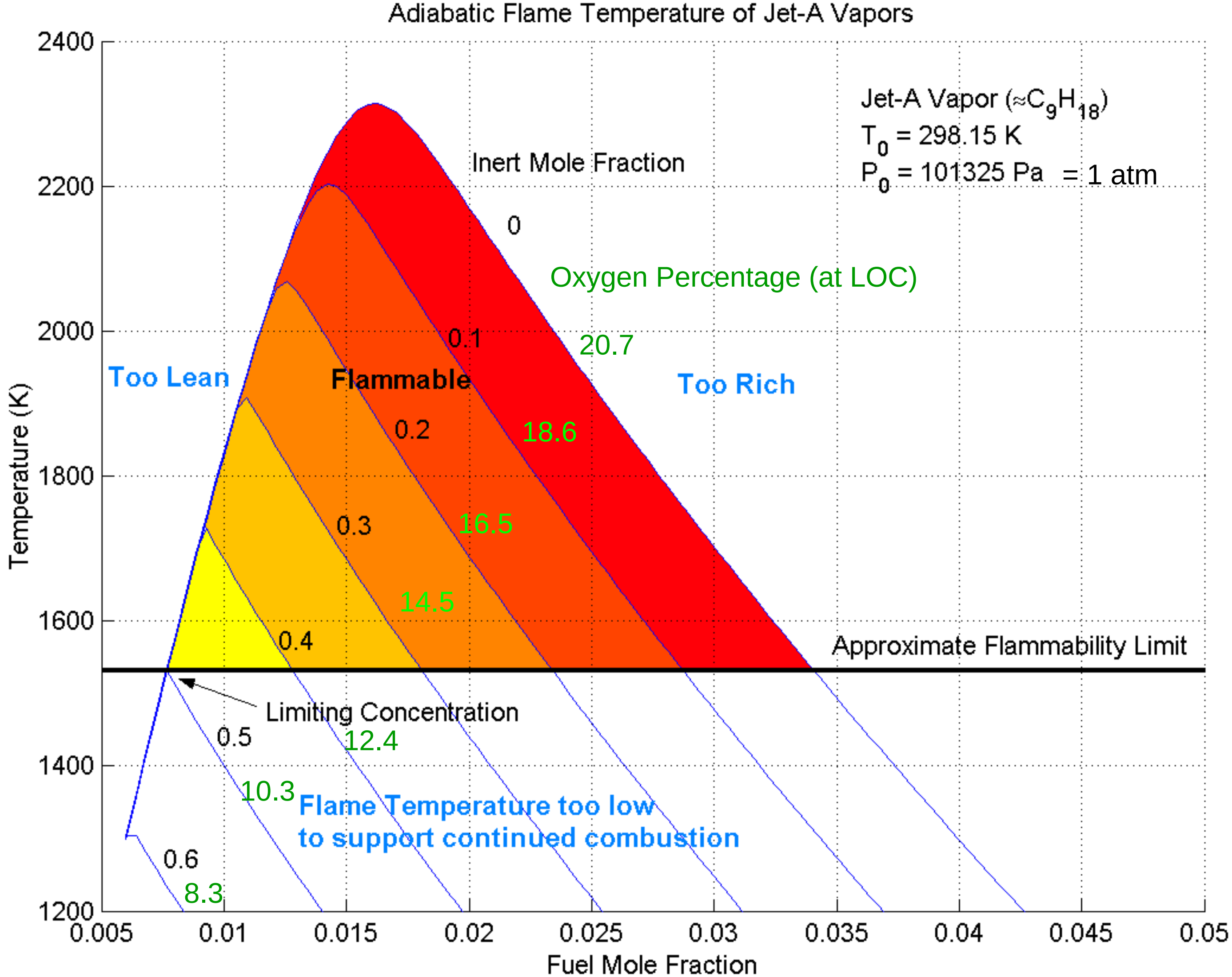
# LOC Predictions by BlazeTank

## First Approach: Flame Temperature Cut-off




Does not know the cut-off temperature a priori

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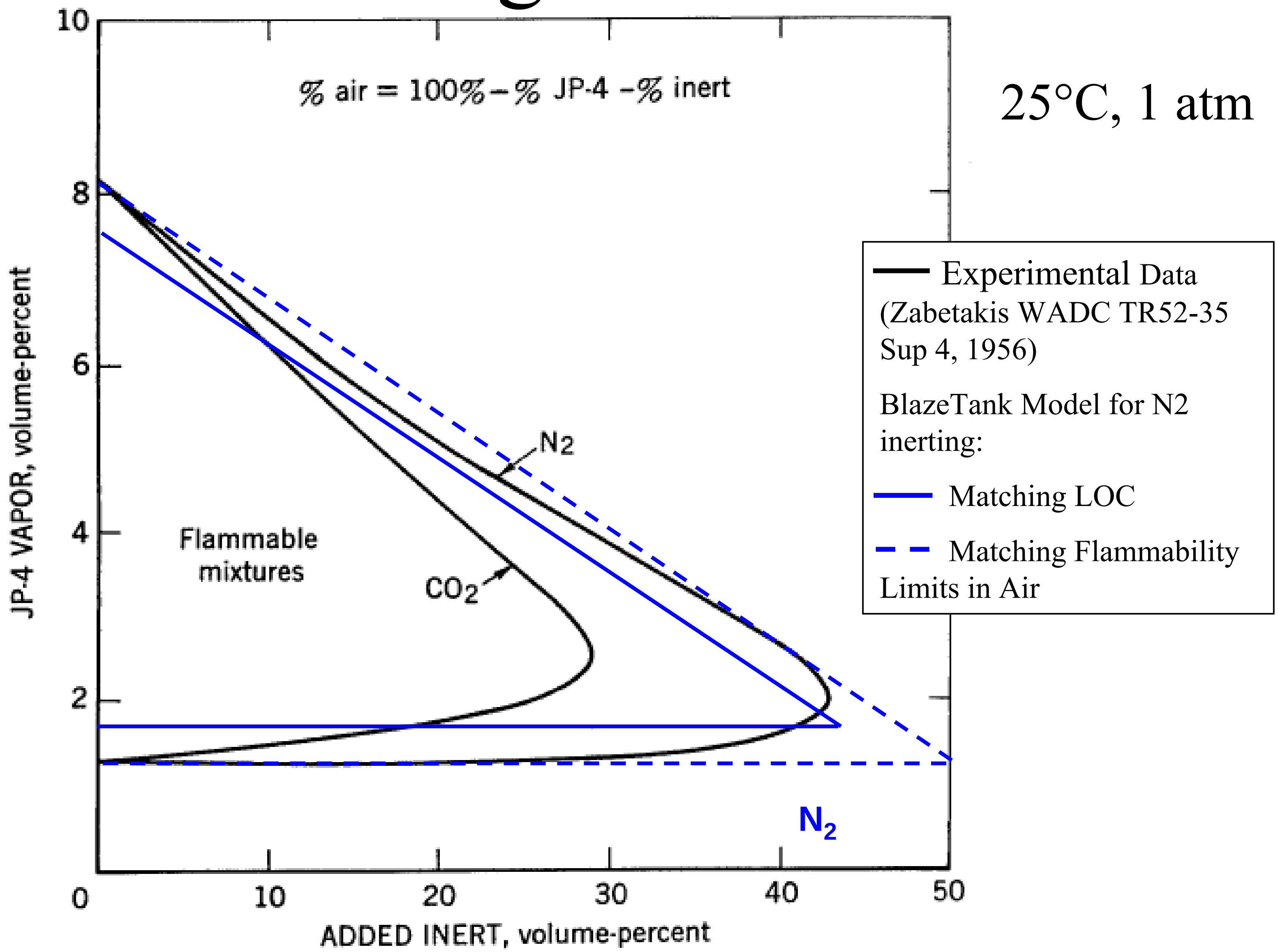
# Inerting of JP-4

25°C, 1 atm




Doesn't match both LFL,UFL and LOC

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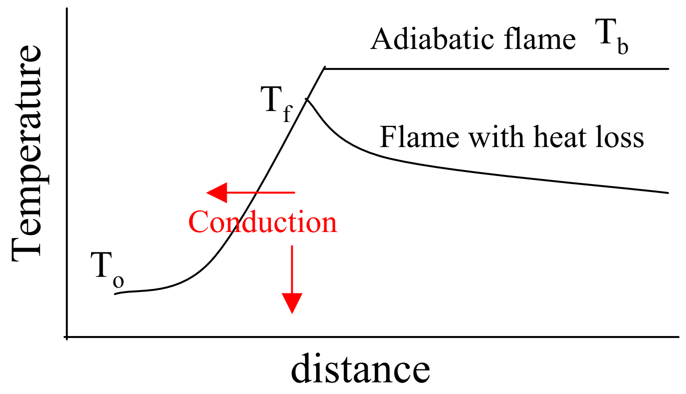
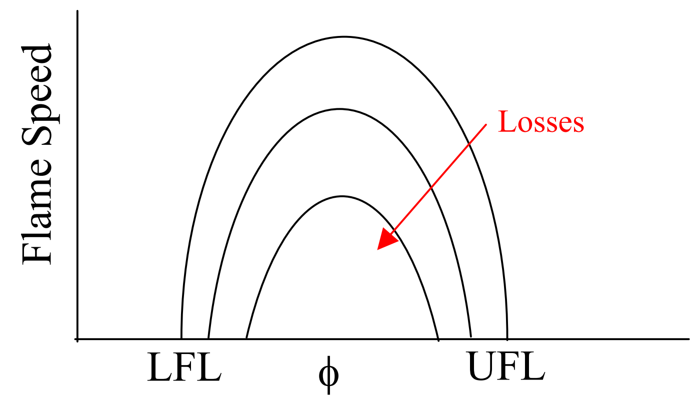
# LOC Prediction by BlazeTank

## Second Approach: Zero Burning Velocity

If ullage cannot propagate a flame, it is not flammable

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

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# 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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