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**NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.**

**EXPLOSION OF AVIATION
KEROSENE (JET A) VAPORS
(22 pages)**

Report Documentation Page				Form Approved OMB No. 0704-0188	
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Explosion of Aviation Kerosene (Jet A) Vapors

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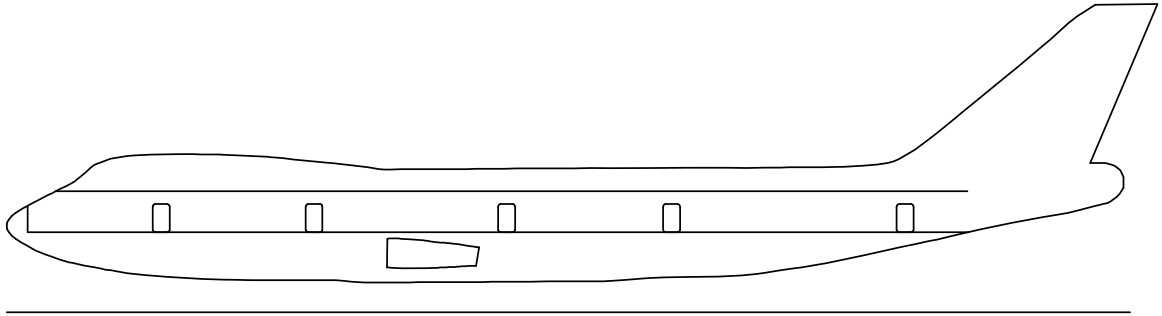
October 7, 1997



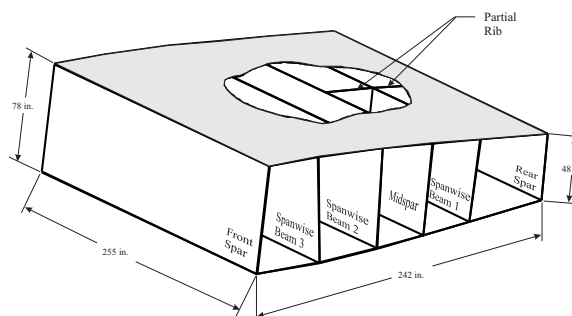
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Caltech Research Program

- Motivated by TWA 800 crash investigation



- Present Jet A data base inadequate
- Issues:
 - Chemical composition of fuel vapors vs liquid
 - * Effect of temperature (T)
 - * Effect of fuel amount (M/V)
 - How does flammability depend on ignition energy?
 - Laminar and turbulent flame speeds?
 - Combustion within multi-compartment, vented tanks?



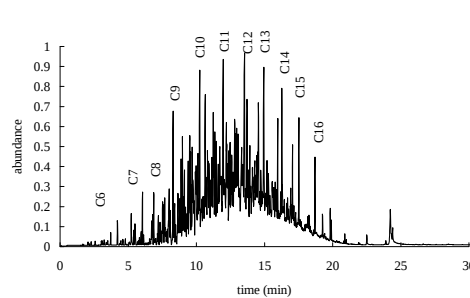
Scope of Presentation

Results of basic studies on Jet A

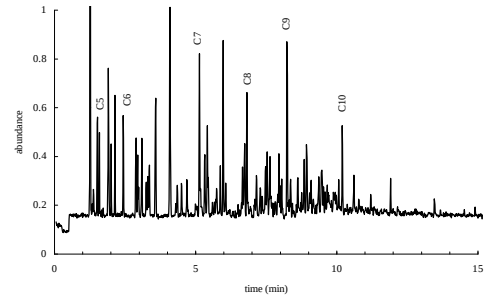
- Chemical composition
- vapor pressure
- Ignition energy and flammability
- Flame speed
- Explosion development

Chemical Composition I.

- Kerosene is a mixture of many species,



Liquid



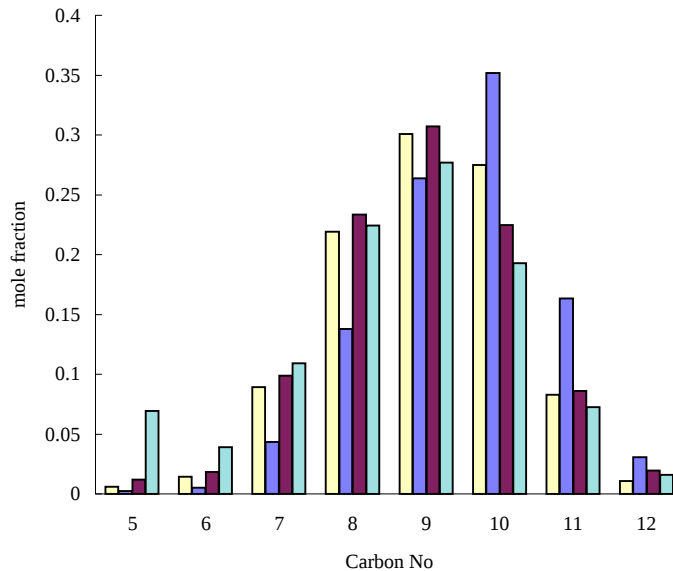
Vapor (40°C, 300 kg/m³)

Gas-Chromatograph Mass Spectrometer studies at CIT.

- Chemical composition is the key to understanding combustion
- New Studies needed for quantification
 - C1-C8 equivalence, headspace GC at University of Nevada, Reno (Woodrow)
 - Detailed speciation at Desert Research Institute, Reno (Sagebiel)

Vapor and liquid composition are very different, depend on both temperature and mass loading.

Chemical Composition II



Results of UNR/DRI studies

- Mean molar mass of vapor 120 to 140 depends on fuel origin, handling & weathering
- H/C ratio of 1.8 in vapor
- Over 160 species in vapor, up to C=12.
- Depletion of light ends observed for small mass loading
- Light ends enhanced at higher temperatures

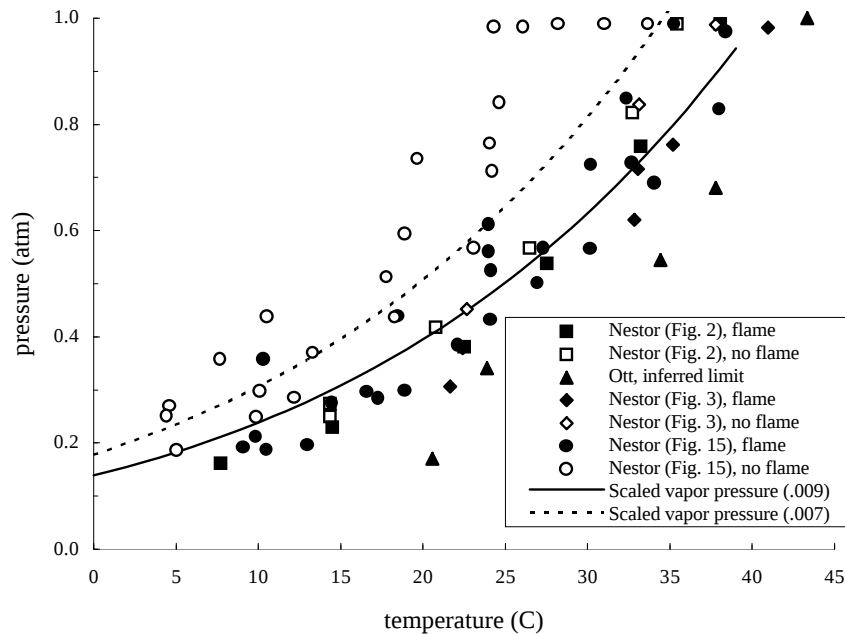
Significance of Vapor Pressure P_σ

- Liquid evaporation creates flammable vapor-air mixtures
- P_σ determines fuel-air mixture fraction

$$\text{mole: } X = \frac{P_\sigma(T_{fuel})}{P_{air}} \quad \text{mass: } f = \frac{P_\sigma(T_{fuel})}{P_{air}} \frac{W_{fuel}}{W_{air}}$$

- Flammability limits

$$f > f_{LFL} \sim 0.035 \quad \text{or} \quad X > X_{LFL} \sim 0.7 - 0.8\%$$



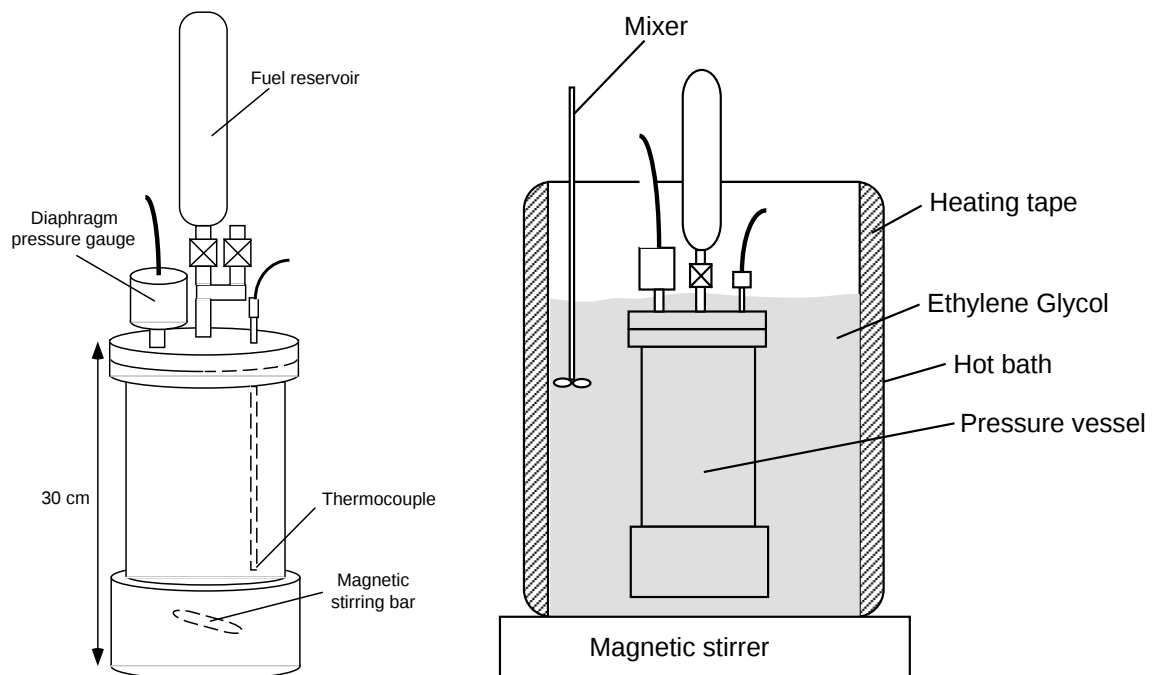
- Determines peak pressure caused by combustion

$$\Delta P_{max} = \frac{W_{fuel}}{W_{air}} \frac{q}{c_v T_1} P_\sigma(T_{fuel})$$

Vapor Pressure Measurements

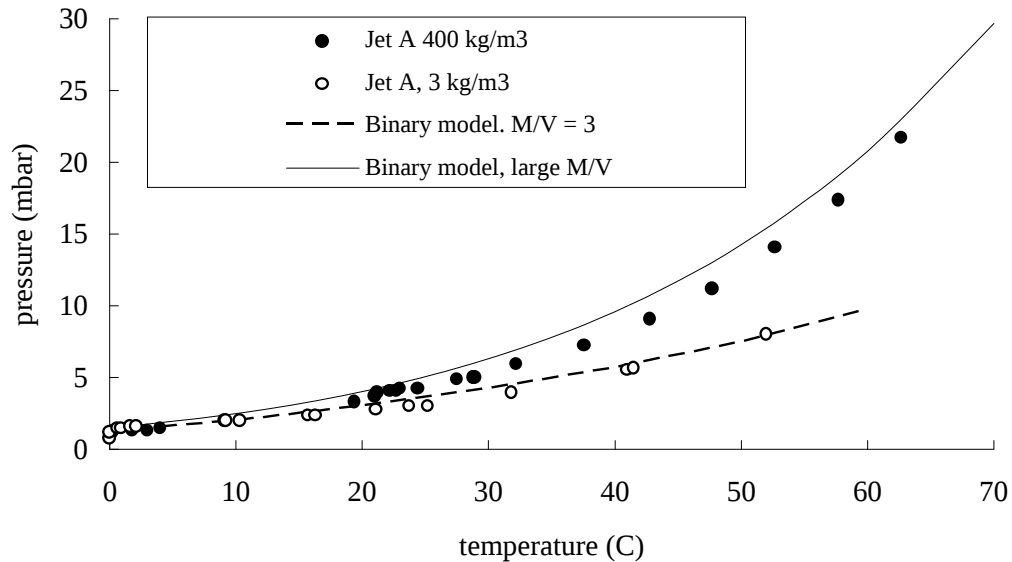
Issues:

- dissolved air. (degassing)
- multicomponent (stirring)
- batch dependent
- Reid method inadequate
- existing correlations unreliable
- New measurements needed

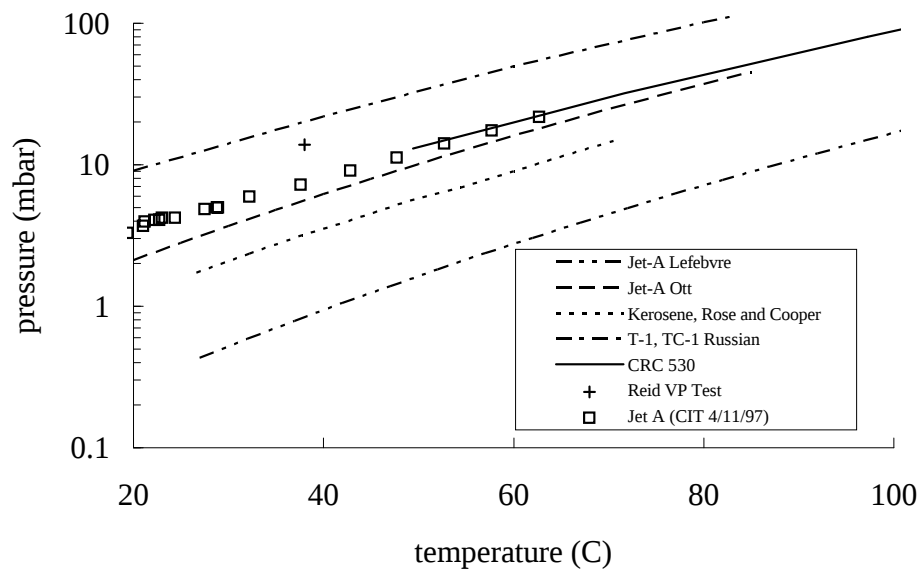


Vapor Pressure Results

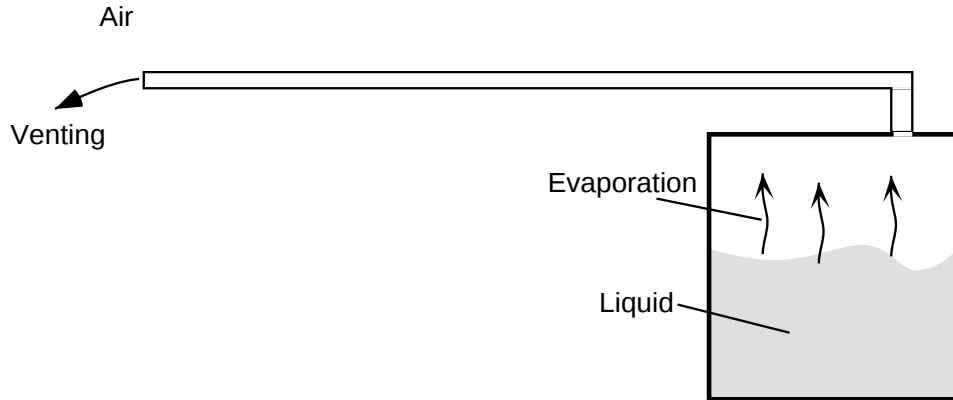
Raw data, simple mixture model:



Comparison with published "data":



Multicomponent Mixture



Issues:

- wide range of C_nH_m in Jet A
- preferential evaporation of “light ends”
- dependence of P_σ , composition on M/V

Simple model:

- use 8 components from UNR measurements
 - mixture vapor pressure

$$P_\sigma = \sum x_i \gamma_i P_{\sigma,i}$$

- activity coefficients γ_i estimated ≈ 1 .
- Requires validation

Flammability and Explosion

- Flammability depends on many factors
 - Ignition source (energy, temperature)
 - Fuel state (vapor vs mist, mass loading)
 - Turbulence
 - Temperature
 - Pressure

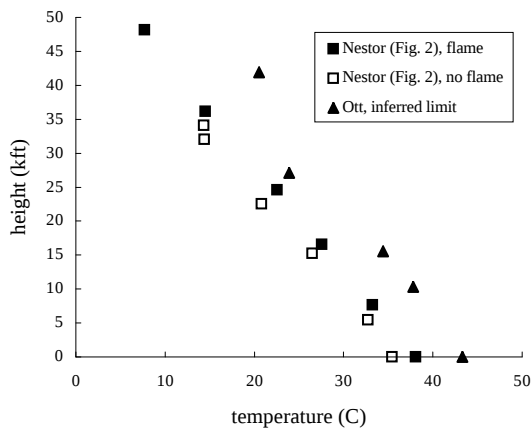
Standard approaches:

- Flash point test (ASTM D56) Jet A: 40 to 60 °C
LAX Jet A, 46 to 48°C
10 to 15 °C above explosion limits. Not representative of actual explosion behavior.
- Vessel studies.
Previous work used fixed energy (16-25 J), large mass loading (100 to 120 kg/m³)

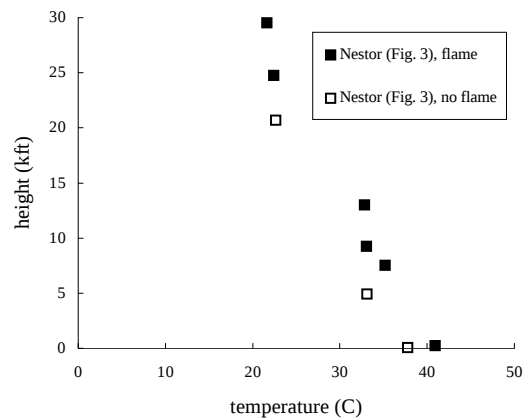
Not representative of many ignition sources, and empty fuel tank conditions.

Previous Studies on Flammability

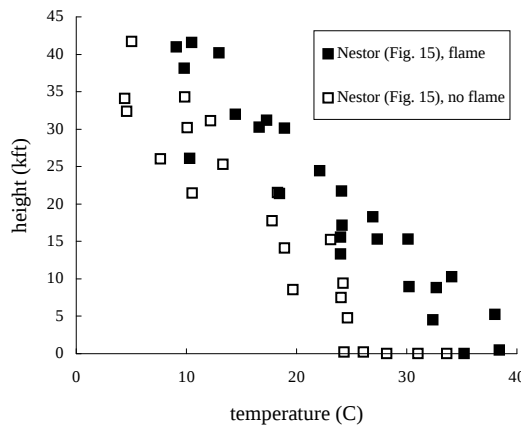
- L. J. Nestor 1967 "Investigation of Turbine...", Report DS-67-7, Naval Air Propulsion Test Center.
- E. E. Ott 1970 "Effects of Fuel Slosh..." AFAPL-TR-70-65.
- T. C. Kosvic et al. 1971 "Analysis of Aircraft Fuel...", AFAPL-TR-71-7.



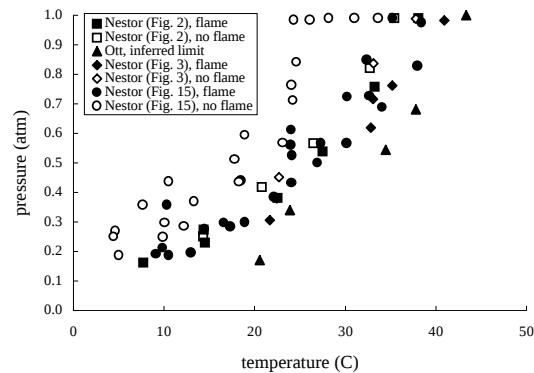
(a)



(b)

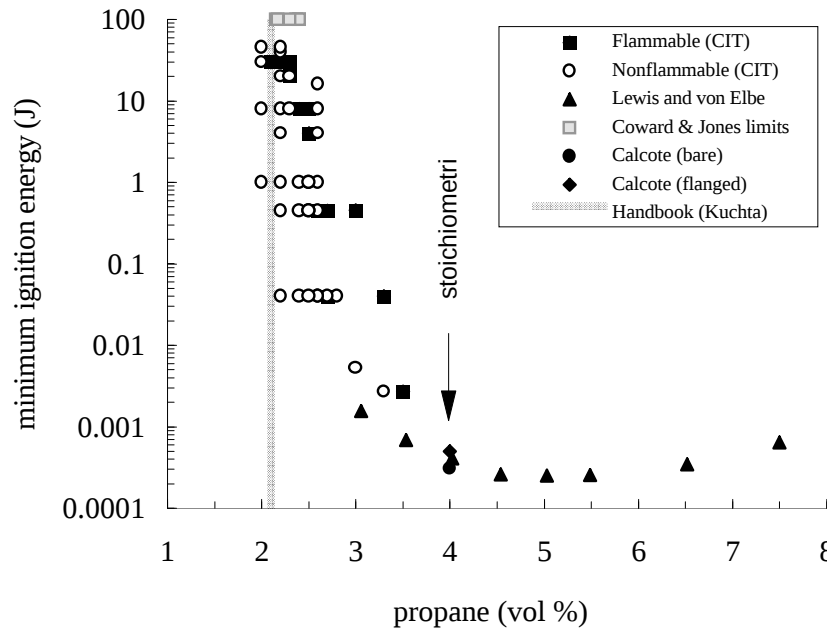


(c)



(d)

Ignition Energy



Propane-Air mixtures, 300 K, 1 bar

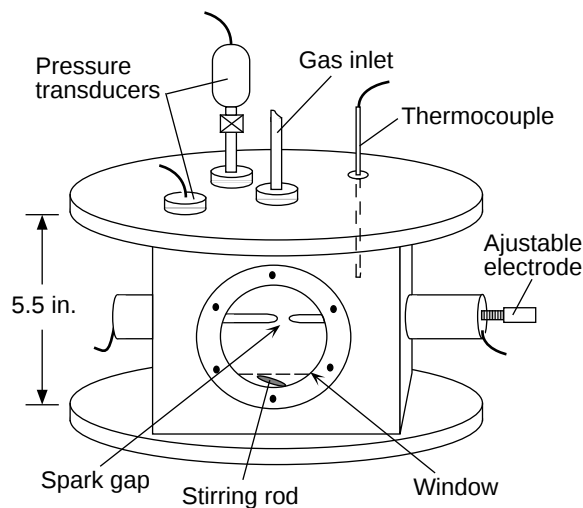
- Minimum of 0.25 mJ occurs for rich mixtures
- Strong dependence on concentration
- Ignition energy very high (100 J) near LFL
- Not previously measured for JET A vapor
- thermal sources require separate consideration

CIT Ignition Testing

Emphasizes:

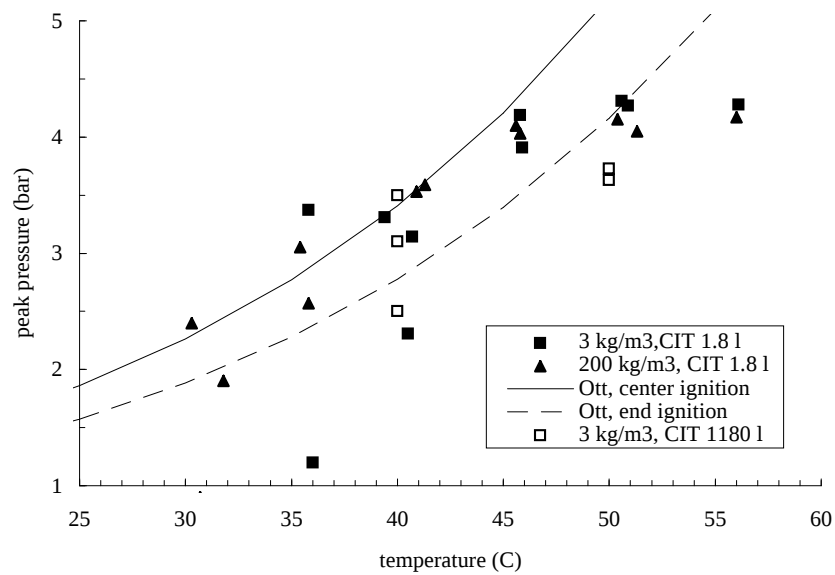
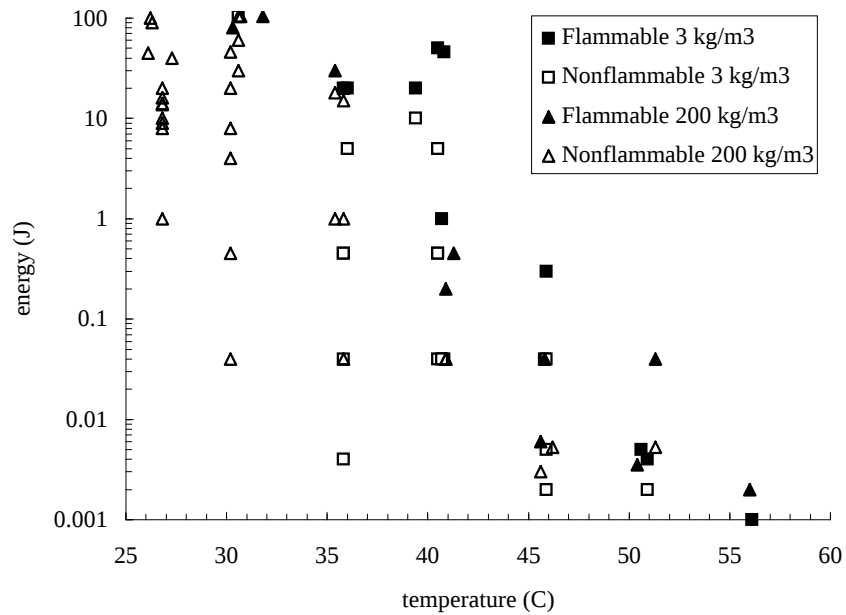
- fuel mass loading M/V
- spray injection vs stagnant pools
- ignition energy
- jet ignition vs sparks

Ignition vessel:



- 1.84 liter volume
- video schlieren
- spark ignition source
- $P(t)$, $T(t)$
 - 1 mJ to 100 J
 - 3.3 mm gap

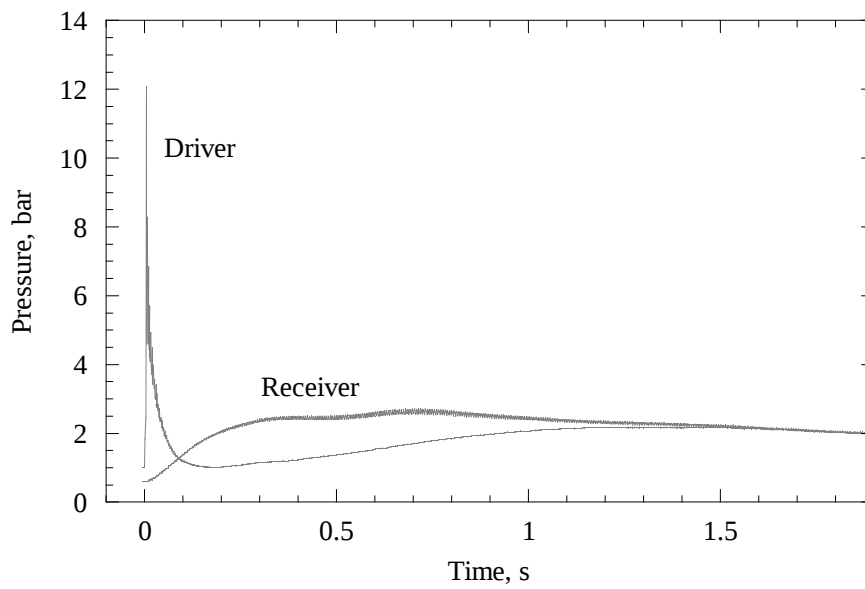
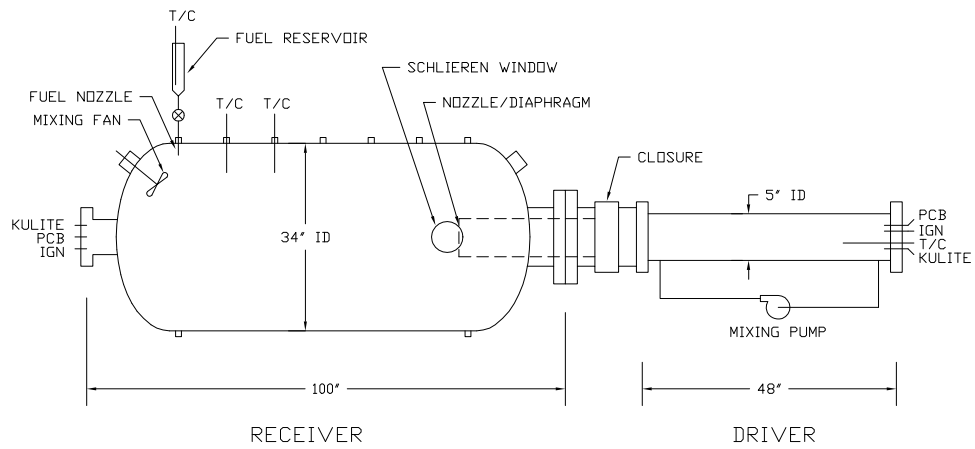
Jet A Flammability



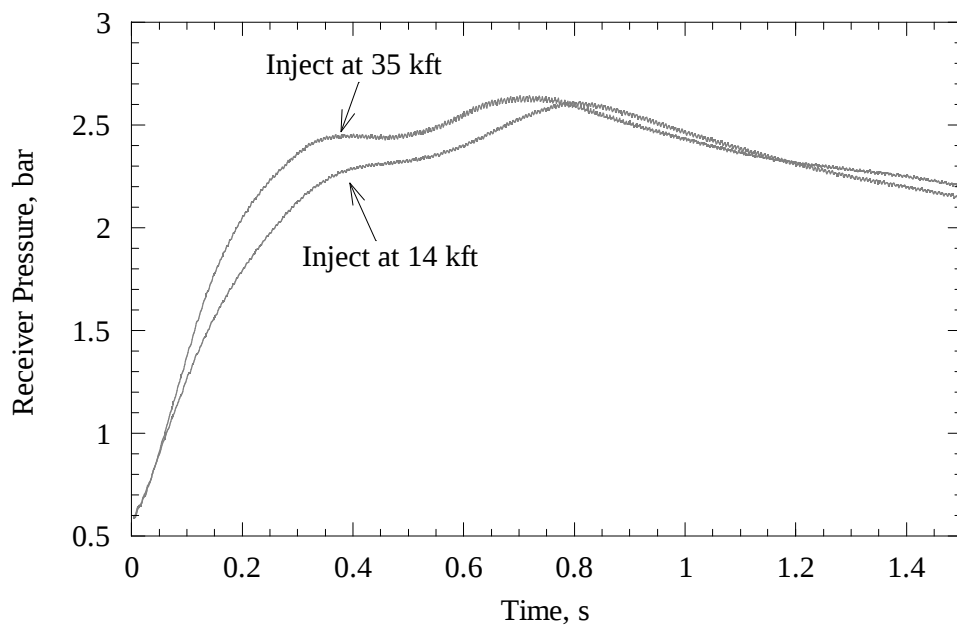
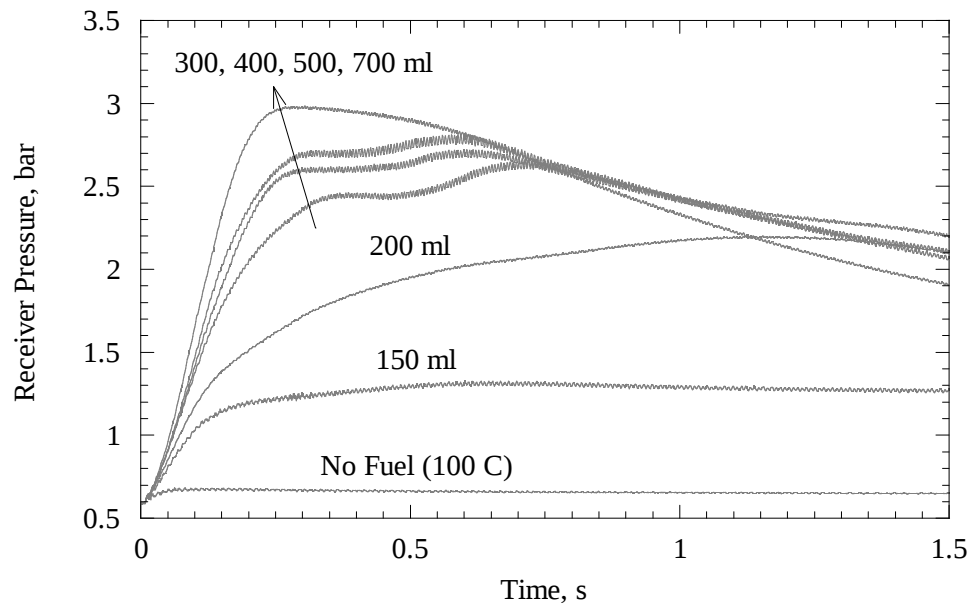
Explosion Development

- Issues
 - peak pressure
 - burn time
 - flame speed
 - quenching behavior
 - turbulent flame speed
 - multi-compartment burns
- Parameters:
 - mass loading M/V
 - fuel temperature T
 - ambient pressure P
 - ignition source, fans, partitions, etc.

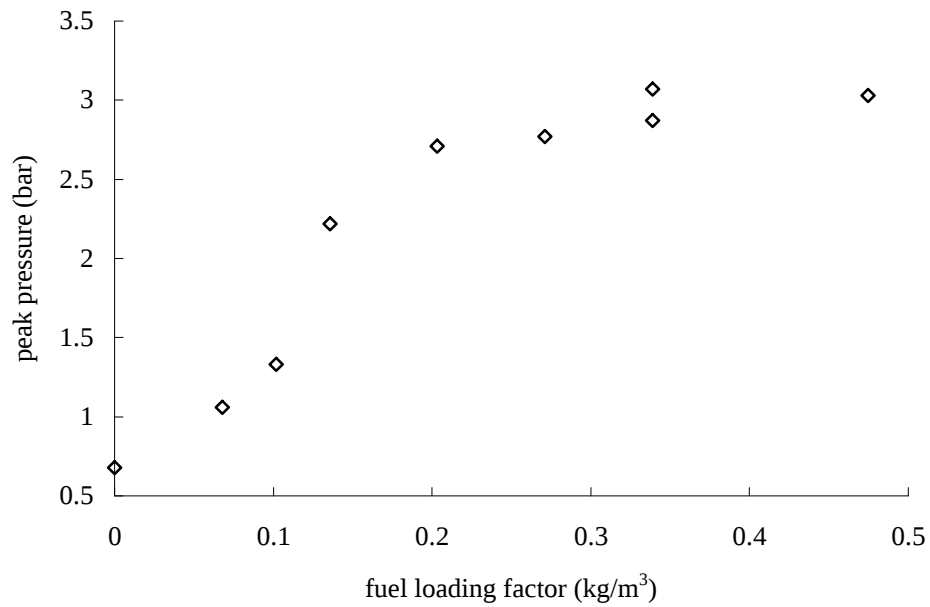
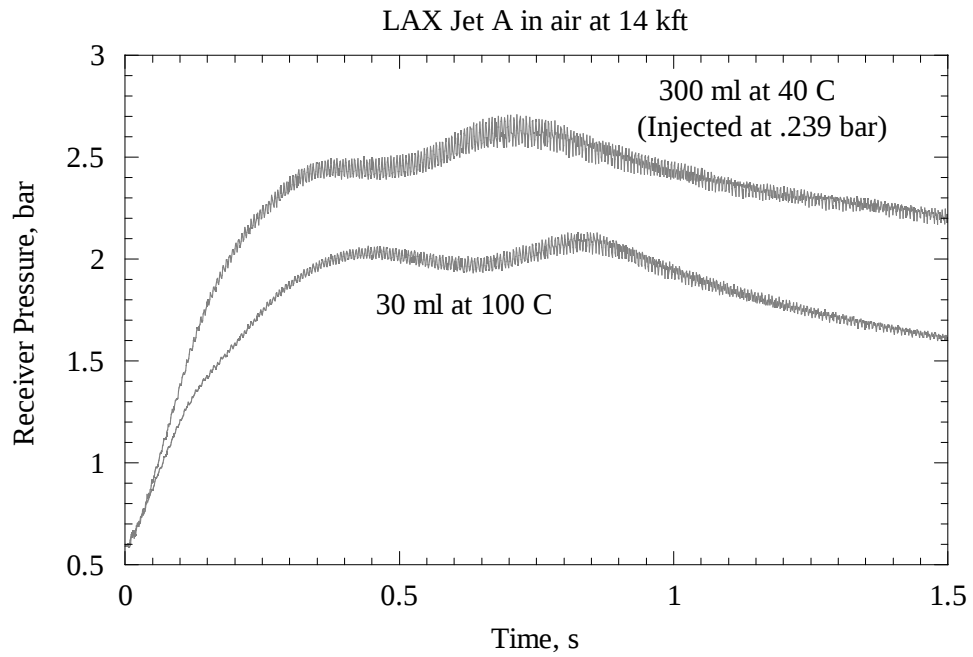
HYJET Facility



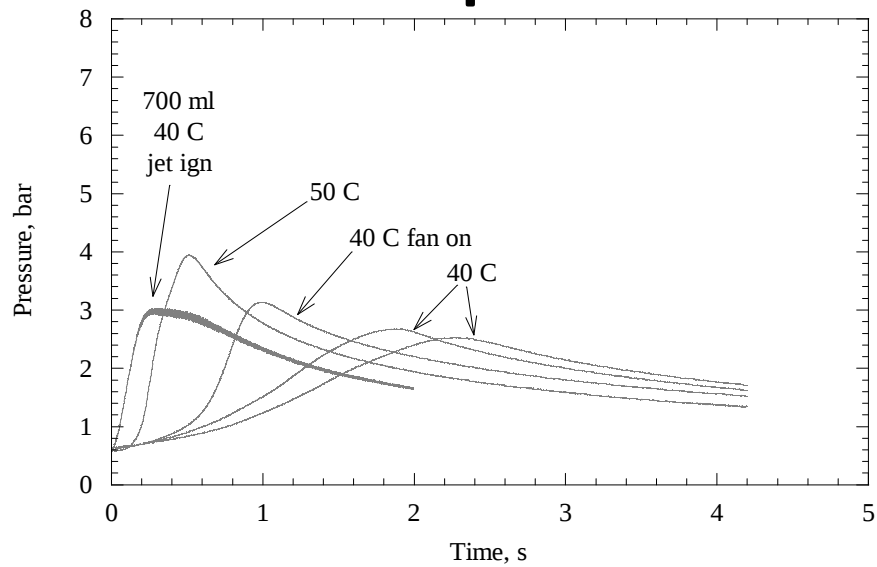
Jet A, 40°C I.



Jet A, 40°C II.



Jet A Explosions



- Effect of fuel loading and state
- 1180 liter vessel
- Stagnant puddle of fuel (1 gal) in 4 cases
- fan on in one case
- spray injection in one case

Summary I.

- vapor composition very different than bulk liquid
- vapor pressure alone not useful without vapor composition
- multicomponent fuels do not have unique vapor pressure
- mass loading M/V affects composition
- flash point is not a useful characterization of explosion hazard

Summary II.

- MIE a strong function of composition
- .25 mJ not characteristic of near limit fuels
- MIE of Jet A is 100 J at 35°C
- MIE of Jet A is < 1 mJ at 55°C
- mass loading M/V effect mild for MIE and peak pressure
- $\Delta P_{max} = 4$ bar at 40 to 55°C ($P_o = .585$ bar) for $M/V \geq 3$ kg/m³

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- John Sagebiel (DRI)