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EXPLOSION OF AVIATION KEROSENE (JET A) VAPORS
(22 pages)
Explosion of Aviation Kerosene (Jet A) Vapors
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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,

![Graph of chemical composition over time for liquid and vapor](image)

**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.
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 $P_\sigma$

- Liquid evaporation creates flammable vapor-air mixtures

- $P_\sigma$ determines fuel-air mixture fraction

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

- 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":

Jet A 400 kg/m3
Jet A, 3 kg/m3
Binary model, M/V = 3
Binary model, large M/V

Jet-A Lefebvre
Jet-A Ott
Kerosene, Rose and Cooper
T-1, TC-1 Russian
CRC 530
Reid VP Test
Jet A (CIT 4/11/97)
Multicomponent Mixture

Issues:

- wide range of $C_nH_m$ in Jet A
- preferential evaporation of “light ends”
- dependence of $P_{\sigma}$, 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 $\gamma_i$ estimated $\approx 1$.
- 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

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

![Graph showing flammability data]

- **Flammable 3 kg/m³**
- **Nonflammable 3 kg/m³**
- **Flammable 200 kg/m³**
- **Nonflammable 200 kg/m³**

- **Energy (J)** on the y-axis.
- **Temperature (°C)** on the x-axis.
- **Peak pressure (bar)** on the y-axis for the lower graph.

Legend:
- 3 kg/m³, CIT 1.8 l
- 200 kg/m³, CIT 1.8 l
- Ott, center ignition
- Ott, end ignition
- 3 kg/m³, CIT 1180 l
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

[Diagram of HYJET Facility]

[Graph showing pressure over time for Driver and Receiver]
Jet A, 40°C I.

- Receiver Pressure, bar vs. Time, s
  - 300, 400, 500, 700 ml
  - 200 ml
  - 150 ml
  - No Fuel (100°C)
  - Inject at 14 kft
  - Inject at 35 kft

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Jet A, 40°C II.

LAX Jet A in air at 14 kft

300 ml at 40°C
(Injected at .239 bar)

30 ml at 100°C

Receiver Pressure, bar

Time, s

fuel loading factor (kg/m³)

peak pressure (bar)
• 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 $M/V \geq 3 \text{ kg/m}^3$
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