Effect of Equivalence Ratio on Ignition and Flame Propagation of $n$-Hexane-Air Mixtures using Moving Hot Particles

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Accidental Ignition

- Accidental ignition
  - electrostatic ignition of fuel
  - lightning strike
  - electrical faults in pumps, fuel quantity instrumentation
  - hot surface ignition

- Characterize fuel-oxidizer properties ($n$-hexane)
  - ignition delay time (Burcat et al. and Zhukov et al.)
  - heating rate on the low temperature oxidation of hexane by air (Boettcher et al.)
  - minimum ignition temperature (Boettcher)
  - minimum ignition energy (Bane)
  - laminar burning speed (Coronel)

TWA 800, NY 747-100, July 17, 1996

China Air Flight 120 caught fire in Okinawa Japan (BBC News, August 20, 2007)
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Hot Particle Ignition Sources

- Lightning attaches to the top of the fastener and causes damage to the resin and fibers on the backface of the composite laminate
- The breakup of the composite is due to its poor electrical conductivity that leads to resistive heating


Ignition at edge of carbon fiber composite structure, Boeing
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Ignition at edge of carbon fiber composite structure, Boeing
Stationary Hot Particle Ignition


- D. Roth et al. Combustion Science and Technology, 186 (2014) 1606–1617

M. Beyer and D. Markus (2012)

Roth et al. (2014)
Moving Hot Particle Ignition

- S. Patterson. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 28 (1939) 1-22
- S. Patterson. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 30 (1940) 437-457

R. Silver (1937)

S. Patterson (1940)
## Current study

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<tr>
<th>Material</th>
<th>$d$ (mm)</th>
<th>$V_p$ (m/s)</th>
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\[
d = 6.0 \text{ mm}
\]
Experimental Setup: Combustion Vessel

- Combustion vessel
- Reactive mixture
- N₂ line
- Pneumatic actuator sphere
- Optical shutter
- Window
- Supports
- 0.1 L
- 22 L
Experimental Setup: Particle Heating Chamber

- CW CO₂ laser: \( P_{max} = 80 \) W
- Irradiation from two sides
- Feedback control during heating
- Temperature measurements at two locations
Materials and Methods

Experimental Setup

Experimental Setup: Particle Heating Chamber

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Optical Diagnostics: Shearing Interferometer

P: polarizer, L: lens, WP: Wollaston prism, A: Analyzer
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Finite fringe configurations
Optical Diagnostics: Shearing Interferometer

\[ \rho = \rho(x, y, z, t) \]

\[ \rho \equiv \rho_0 \]

\[ g \]

disturbed beam

reference beam
Optical Diagnostics: Shearing Interferometer

\[ \rho = \rho(x, y, z, t) \]

\[ \rho = \rho_0 \]

Materials and Methods

Optical Diagnostics

Effect of Equivalence Ratio on Ignition

S. Coronel (Caltech)
Optical Diagnostics: Shearing Interferometer

\[ \rho = \rho(x, y, z, t) \]

\[ \rho \neq \rho_0 \]

Effect of Equivalence Ratio on Ignition

25th ICDERS 10 / 19
Interferograms of Hot Particle Wake: $\Phi = 0.9$

\[ T_{\text{sphere}} = 979 \pm 27 \text{ K} \]

\[ T_{\text{sphere}} = 981 \pm 20 \text{ K} \]
Ignition Threshold: $d = 6.0 \text{ mm}$

INSENSITIVE TO COMPOSITION
Results

Experimental Results

Probability of Ignition Distribution

Alumina sphere, $d = 6$ mm

- Ignition
- No ignition

Probability of ignition

95% confidence envelope

NARROW OVERLAP REGION
Probability of Ignition Distribution

Alumina sphere, $d = 6$ mm

- Probability of ignition
- 95% confidence envelope

Temperature (K)

Probability of Ignition

10$^{-1}$
10$^{-2}$
10$^{-3}$
10$^{-4}$
10$^{-5}$
10$^{-6}$
10$^{-7}$
10$^{-8}$
10$^{-9}$
10$^{-10}$
10$^{-11}$
Ignition Location: $\Phi = 0.9$
Results

Experimental Results

Ignition Location: Comments

IGNITION OCCURS NEAR SEPARATION REGION OF SPHERE

J. MELGUIZO-GAVILANES and J. E. SHEPHERD, HOT SURFACE IGNITION AND FLOW SEPARATION #267
Flame Propagation

\[ \Phi = 0.9 \quad \Phi = 1.0 \quad \Phi = 1.2 \quad \Phi = 1.7 \quad \Phi = 2.0 \]

\[ 0.0 \text{ ms} \quad 3.5 \text{ ms} \quad 7.0 \text{ ms} \quad 10.5 \text{ ms} \]
Conclusions
Acknowledgements

The present work was carried out in the Explosion Dynamics Laboratory of the California Institute of Technology and supported by The Boeing Company through a Strategic Research and Development Relationship Agreement CT-BA-GTA-1
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Thank You