BASIC RESEARCH IN PLASMA-ENHANCED CPMBUSTION

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PLASMA DYNAMICS FOR AEROSPACE APPLICATIONS

RUSSIAN AJAX HYPERSONIC FLIGHT VEHICLE (1994)

TECHNICAL CHALLENGES
- Uniform Plasma Generation
- Power Required; System Impact
- High Re, Q Environment
- Measurement/Modeling

PAYOFFS
- Drag Reduction
- Thermal Management
- Flight Control
- Size, Weight reduction
- Few Moving Parts
- Power generation
- Ignition/Combustion Enhancement
THEME OBJECTIVE: Understand, Predict, And Control Weakly Ionized Flows To Revolutionize The Performance Of Aerospace Vehicles
PLASMA DYNAMICS FOR AEROSPACE APPLICATIONS

RESEARCH

- Aerodynamic Drag Reduction
- MHD Flow Control
- Glow Discharge Flow Control
- Plasma Generation
- Ignition / Combustion Enhancement

AFOSR PROGRAM MANAGER TEAM

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PLASMA DYNAMICS FOR AEROSPACE APPLICATIONS

PAYOFFS

Localized Plasma Discharges

MHD Flow Control

Hypersonic Drag Reduction

Plasma Ignition

Near Term  Intermediate Term  Long Term

Time
2009 MULTIDISCIPLINARY UNIVERSITY RESEARCH INITIATIVE

CHEMICAL ENERGY ENHANCEMENT BY NONEQUILIBRIUM PLASMA SPECIES

The Legacy
PLASMA IGNITION

PLASMAignition Alternatives

- Glow Discharge (Adamovich/Ohio State)
  \[ \frac{dV}{dt} = 0 \]

- Streamer Discharge (Gundersen/USC)
  \[ \frac{dV}{dt} > 1 \text{kV/\mu s} \]

- Nanosecond Discharge (Starikovskii/MIPT)
  \[ \frac{dV}{dt} > 1 \text{kV/ns} \]

AFOSR PM:Tishkoff/NA
PLASMA IGNITION

SHOCK TUBE EXPERIMENTS DEMONSTRATE IGNITION DELAY REDUCTION BY FAST IONIZATION WAVES

- Results Validate Previous Model Predictions

![Graph showing CH₄:O₂:N₂:Ar mixture with prediction at 0.05 MPa]

<table>
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<tr>
<th>Pressure (MPa)</th>
<th>FIW?</th>
<th>Polarity</th>
<th>Additive</th>
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<td>No</td>
<td>-</td>
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<tr>
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<td>-</td>
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<td>Yes</td>
<td>-</td>
<td>Air</td>
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<tr>
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<td>Yes</td>
<td>+</td>
<td>CO₂</td>
</tr>
<tr>
<td>0.05</td>
<td>Yes</td>
<td>-</td>
<td>CO₂</td>
</tr>
</tbody>
</table>

- Nanosecond Corona Discharge at 0.2 MPa Pressure And By Volume Nanosecond Discharge At 0.05 MPa Pressure
- Ignition Not Possible Without Fast Ionization Wave At 0.05 MPa Pressure

Starikovskii/MIPT
PLASMA IGNITION

PLASMA STREAMER DISCHARGES MODELED

• Provides Initialization For Calculations Of Plasma-Enhanced Combustion

Excitation Chemistry

\[ \text{N}_2^+ \rightarrow \text{N}_4^+ \ (0.1 \text{ ns}) \]
\[ \text{N}_4^+ \rightarrow \text{O}_2^+ \ (1 \text{ ns}) \]
\[ \text{O}_2^+ \rightarrow \text{O}_4^+ \ (5 \text{ ns}) \]
\[ \text{e}^- \rightarrow \text{O}_2^- \ (70 \text{ ns}) \]

• Modeling Based On Solving Transport Equations For Primary And Secondary Electrons

• Experimental Validation Through Measurements Of Electric Field Strength For Streamer Discharges In Oxygen-Nitrogen Gas Mixtures

Starikovskii/MIPT
100% INCREASE IN DIFFUSION FLAME QUENCH VELOCITY GRADIENT REALIZED WITH GLIDING ARC DISCHARGE

- Means To Stabilize Combustion In Scramjets
- Gliding Discharge Initiated By Helical Inner Electrode And Stabilized Near The Quenching Limit By Field From A 0.15 Tesla Magnet, Producing 20-50 Hz Rotation
- Plasma-Based Thermal Addition Found To Be Negligible, Implying Non-Thermal Plasma Stabilization

Ju/Princeton