Laser Driven Micro Flyer Hypervelocity Impact Effects on the Outer Surface of Spacecraft and Protection

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Outline

1. Backgrounds
2. Laser-driven Flyer technique
3. Hypervelocity Impact Effects
4. Protection Technique
5. Conclusion
1. Backgrounds

- Laboratory simulation of micrometeoroid/orbital debris impacts at velocities 7km/s has long been accomplished by conventional accelerators (light-gas guns, plasma-drag accelerators) (Expensive, low shot repetition)

- Laser Driven Flyer (LDF) (Compact, repeatable, relatively inexpensive)
2. Laser-driven Flyer technique

- Simulate micro-debris (diameter: ~1mm, thickness: ~several micrometers)

Schematic diagram of LDF in CAST
Laser-driven Flyer Experiment System

3 Key Parts

- Laser type
- Energy
- Beam profile

Laser System

Flyer Target

Materials
Structure
Deposition technique

LDF System

Measurement

Velocity
Planarity
Integrity
2.1 Laser system

- Laser beam ("top-hat" profile is desirable)

  spatial profile of "top-hat" can easily produce plane shock wave, launch integrity and hypervelocity flyer, but "gauss" or exist strong spot can not obtain integrity flyer.

3D Beam profile
2.2 Flyer target

- **Substrate materials**: fused silica or K9 glass
- **Monolayer**: AL
- **Multilayer**: Cr/AL
- **Thickness of flyer film**: 3~10μm
- **Deposition methods**: magnetron sputtering, electron beam evaporation, ion beam sputtering
2.3 Flyer Measurement

- **Velocity measurement** *(not easy: small size and low mass flyer)*
  - Laser profile velocity measurement system
    - **Measurement error:** <10% *(if $v<5\text{km/s}$, the error is no more than 4%, and $v\approx10\text{km/s}$ error ~9%)*

- **Oscillograph** *(Time resolution: 2.5GHz)*

- **Microscope** *(× 50)*
- **Flyer velocity up to 10km/s**
  - K9/Cr/Al (5mm/50nm/5μm) flyer target prepared using ion beam sputtering
  - A flyer plate with diameter about 1mm and 5 μm thick was accelerated to 10.4km/s at 853mJ laser energy.
3. Hypervelocity Impact Tests

3.1 Optical glasses

<table>
<thead>
<tr>
<th>diameter (mm)</th>
<th>thickness (μm)</th>
<th>velocity (km/s)</th>
<th>Impact parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>3.4</td>
<td>Single impact</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>4.2</td>
<td>Single impact</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>4.9</td>
<td>Single impact</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>5.5</td>
<td>Single impact</td>
</tr>
<tr>
<td>1.36</td>
<td>8</td>
<td>3.06</td>
<td>Single impact &amp; Cumulative impacts</td>
</tr>
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</table>

Impact parameter
Cumulative impacts

Single impact: transmittance degrades 23% ~ 45%
Cumulative impacts: 16% ~ 30%

( v=3.06km/s)
3.2 white paints (ZKS)

- Solar absorptance $\alpha_{S0} = 0.16$
- Hemispherical emissivity $\varepsilon_{H0} = 0.90 \pm 0.02$
- Cumulative impacts
  - $\alpha_s$ rise from 0.16 to 0.60
  - Linear factor 0.023 in thickness
  - Linear factor 0.244 in diameter
  - $\varepsilon_H$: no change
3.3 OSR (Optical Second Reflector)

($\alpha_s / \varepsilon_H$ : thermal control capability)

The solar absorptance of OSR rise after impact, but its emissivity without any change.
4. Protection Technique

- Parameters of DLC (Diamond-like carbon) film
  - thickness: 300nm
  - hardness: >30GPa
  - surface roughness < 20nm
  - Transmitts: >80%

- Sample:
  - O---OSR
  - C---OSR (including DLC)
4. Protection Technique

- Diamond-like carbon (DLC) films

  have the unique combination of properties: high values of hardness, elastic moduli, electrical resistivity, and chemical inertness.

  high values of hardness: crushed micro-debris to pieces.

  The DLC films decreased the mechanical damages of surface, play an active role in protection from micro-debris.
5. Conclusion

- A laser-driven flyer ground simulation system has been developed for the launch of flyer with 1mm in diameter and a few μm in thickness to simulate space debris hypervelocity impact, achieving velocities up to 10km/s. Although the experimental results are semi-quantitative and primary, our focus is on demonstrating the suitability of laser-driven flyer technique for space debris hypervelocity impact damage, rather than drawing specific scientific conclusions from the data.

- Diamond-like carbon (DLC) films showed promise effect in protection from micro-debris impact on the outer Surface of Spacecraft.
Thanks for your attention

- Any questions?