Gossamer Orbit Lowering Device (GOLD) for Safe and Efficient CubeSat Deorbit

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Topics

• GOLD System Overview
• GOLD CubeSat Applications and Demo Flight
• GOLD Design and Development Status
• Example CubeSat System Performance
• Comparison of De-orbit Methods and their Risks
• Summary
GOLD System Overview
Gossamer Orbit Lowering Device (GOLD) for CubeSat Deorbit

GOLD† Overview

- **Applications**: de-orbit of CubeSats, defunct satellites, and spent launch vehicle stages; debris mitigation
- **Orbits**: LEO to about 1,500 km altitude
- **Concept**: Increases cross-section area by inflation-maintained ultra-thin envelope which accelerates natural atmospheric drag decay from centuries to months
- **System**: UV and AO protected envelope, inflation control and pressure maintenance, controller, sensors & power
- **CONOPS**: 1) attached to satellites or upper stages before launch, 2) delivered to derelict satellites by orbital tenders, or 3) targeted & controlled reentry of large space platforms
- **Risk**: Lower probability of destroying operating satellites and creating new debris than bare spacecraft or other de-orbit methods

† - Patent US 6,830,222 issued December 14, 2004
GOLD CubeSat Applications and Demo Flight
CubeSat Deorbit

- Satellites are required to meet the **25-year rule**: limitation in the maximum orbital lifetime for orbiting spacecraft proposed in 2002 by the IADC
  - Despite debris mitigation policies, space junk is a growing environmental concern

- Number of CubeSats in Earth orbit will increase significantly in near future
  - Growing use of CubeSats for education, tech demonstrations, or commercial use.

- On an **Operational CubeSat**, a 2-m diameter GOLD envelope, including inflation system, would only require a ~2 in (~5 cm) cube and would weigh < 3 oz. (~85 g). Can use 3-9 µm thick Mylar or aluminized Kapton
CubeSat GOLD Demo Flight

- GAC is planning a GOLD CubeSat demo flight.
- GAC is looking for CubeSat developers to partner with.
- 3U CubeSat: 2U for GOLD and solar panels, and 1U for CubeSat bus
- Demo envelope material: Linear Low-Density Polyethylene (LLDP)
- Expecting to use CubeSat resources instead of independent power system
CubeSat Deployed GOLD System
GOLD Design and Development Status
Operational System Components

- **Essential components:**
  - Ultra-thin and lightweight inflated envelope
  - Envelope storage container
  - Inflation and pressure maintenance system

- **Additional components depending on requirements:**
  - Gas reservoir
  - Sensors
  - Controller
  - Satellite interfaces
  - Power
Technical Analysis Completed

- State of envelope near entry conditions
- Effects of solar activity on performance
- Effects of space environments (AO†, UV, solar pressure, gravity gradient and aerodynamic forces, thermal, etc.)
- Orbital debris and meteoroid environment
- Envelope holing and leakage
- System dynamical analysis during deployment and operations

† - Atomic oxygen
System Design Studies Completed

- System requirements and functional block diagram
- Mass, volume and power breakdown with contingencies
- Film and coating material research, trade studies and availability
- Envelope design, packaging and deployment
- Inflation gas and its storage options
- Preliminary system and subsystem design
- Sensor requirements and analysis
- Cost estimates
Example System and its Performance
Compliance with the 25-year rule normally restricts satellite deployments to altitudes of about 600 km or less, but with the use of GOLD a CubeSat can comply with the 25-year rule at much higher altitudes.

Sample Results Using NASA’s Debris Assessment Software (DAS)

<table>
<thead>
<tr>
<th></th>
<th>CubeSat without GOLD</th>
<th>CubeSat GOLD Demo</th>
<th>CubeSat GOLD Operational</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CubeSat Size</strong></td>
<td>1U</td>
<td>3U</td>
<td>1U</td>
</tr>
<tr>
<td><strong>CubeSat Mass</strong></td>
<td>Approx. 1 kg</td>
<td>Approx. 2 kg</td>
<td>Approx. 1 kg</td>
</tr>
<tr>
<td><strong>Area/Mass Ratio</strong></td>
<td>0.01 m²/kg</td>
<td>1.57 m²/kg</td>
<td>3.14 m²/kg</td>
</tr>
<tr>
<td><strong>Ballistic Coefficient</strong></td>
<td>45.45 kg/m²</td>
<td>0.2894 kg/m²</td>
<td>0.1447 kg/m²</td>
</tr>
<tr>
<td><strong>Solar Conditions</strong></td>
<td>Solar Min</td>
<td>Solar Max</td>
<td>Solar Min</td>
</tr>
<tr>
<td><strong>Max Altitude for &lt; 25 Year Decay Time</strong></td>
<td>630 km</td>
<td>645 km</td>
<td>1165 km</td>
</tr>
<tr>
<td><strong>Max Altitude for &lt; 1 Year Decay Time</strong></td>
<td>365 km</td>
<td>475 km</td>
<td>585 km</td>
</tr>
<tr>
<td><strong>Decay Time from 833 km Altitude</strong></td>
<td>&gt; 100 years</td>
<td>&gt; 100 years</td>
<td>3.67 years</td>
</tr>
</tbody>
</table>

Assumptions: $c_D$ (Drag Coefficient)=2.2; Solar Min is around 2018 and Solar Max is around 2023; Orbital Inclination=45 deg (results are not very sensitive to inclination)

For an altitude of 833 km, a CubeSat using GOLD could reenter in about 8-12 months at solar mean conditions and in about 4 months at solar max conditions.
Decay Time vs. Altitude

Time to Entry as a Function of Altitude

- Beta = 3.0
- Beta = 1.0
- Beta = 0.3
- Beta = 0.1
- Beta = 0.03

- Cd of 2.2
- MSIS90 Ave. High Atmosphere

2 kg CubeSat, 833 km altitude, 2 m dia GOLD envelope

Three Years
One Year
One Month
One Week

Gossamer Orbit Lowering Device (GOLD) for CubeSat Deorbit

Global Aerospace Corporation

CubeSat Workshop, August 9, 2015
Comparison of De-orbit Methods and Their Risks
Area-Time Product Summary

- Bare Spacecraft Natural Decay over 700 years
- Bare Spacecraft Natural Decay over 100 years
- Rigidizable Space Inflatable Sphere
- 25-Year Rule
- Boom Supported Film Aerobrake
- Electro-Magnetic Tether
- Gravity Gradient Tape
- Inflation-maintained Ultrathin Envelope Sphere
- Immediate & Controlled Propulsive De-orbit

Area-Time Product (m²·yr)

- High-energy Collisions
- Low-energy Collisions

GOLD
## Comparison of De-orbit Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>GOLD</th>
<th>Electromagnetic Tether</th>
<th>Boom-supported Aerobrake</th>
<th>Gravity-gradient Tape</th>
<th>Rigidizable Space Inflatable</th>
<th>PROPULSIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk of Large Debris Object Generation</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Highest</td>
<td>Lowest</td>
</tr>
<tr>
<td>Risk of Disabling Other Satellites</td>
<td>Low</td>
<td>Highest*</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Lowest</td>
</tr>
<tr>
<td>Variable De-Orbit Rate</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Targeted Reentry</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Works with Tumbling Derelict Satellites</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>Works Equally Well for Any Orbit Inclination</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Works for Any Spacecraft Attitude</td>
<td>Yes</td>
<td>No</td>
<td>No†</td>
<td>No</td>
<td>Yes†</td>
<td>No</td>
</tr>
<tr>
<td>Works for Any Orbit Altitude</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Relative Mass</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Cost to Add to Satellite</td>
<td>Low/Medium</td>
<td>Low/Medium</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Highest</td>
</tr>
</tbody>
</table>

**Legend:**
- ‡ - Above a certain altitude, gravity gradient and solar pressure forces dominate drag forces
- † - Only if near spherical
- * - Without avoidance manoeuvres by either spacecraft.
GOLD Summary

• GAC is planning a GOLD CubeSat demo flight
• GAC is looking for CubeSat developers to partner with
• 3U CubeSat: 2U for GOLD system and solar panels, and 1U for CubeSat
• Increase atmospheric drag area of satellite using an ultra lightweight, inflation-maintained envelope
• Effective for space objects up to about 1,500 km altitude depending on object mass and solar activity
• Relatively mature design. Vacuum chamber tests and a flight demo are needed
• Low probability of destroying operating satellites and of creating new, dangerous debris
• Does not require a cooperative satellite to work
• Is highly scalable – CubeSats to large space platforms
• Satellite/stage integration and cost are also scalable