ACTIVE DEBRIS REMOVAL MISSION WITH SMALL SATELLITE

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2nd Mission Idea Contest
4th Nano-satellite Symposium on October 10th - 13th, Nagoya
SPACE DEBRIS: an increasing problem...

6000 satellites launched from 1957 and 2008, but only about 800 are actually operational

Space junk includes space hardware and fragments of broken up, exploded, collided or abandoned spacecrafts

More than 12,000 in total are regularly tracked

Collision IRIDIUM 33 – COSMOS 2251

1st Prevision of the first collision in 2009!!
Most of them are in LEO!

1 collision every 4 years!

+ 75% of population growth in the next 200 ys!
1. INTRODUCTION (2/2)

Why an ADR mission?

ADR is the only option to preserve the future Earth environment

Population growth stops!

5 debris/yr
2. MISSION OBJECTIVES (1/5)

Polyurethane foam

Polyol and Isocyanate react together, expanding more than 20 times their volume and creating a rigid foam.
2. MISSION OBJECTIVES (2/5)

The IDEA...

Use the expansion of the foam to increase the wet surface of the debris

Increase of atmospheric **DRAG** and faster deorbiting

Before....

...After

Re-entry time: from $>100$ yr to $<20$ yr
2. MISSION OBJECTIVES (3/5)

How to attach the foam to the debris?

cubesat with a device (ADR SYSTEM) that mix the components and shoot the foam against...
2. MISSION OBJECTIVES (4/5)

Same satellite architecture and devices, but different chemical foam composition.

**Advantages:**
- Lower cost
- Less risks of ADR failure due to lower density of the foam
- Possibility of removing multiple debris with one mission (More ADR sys)

**Disadvantages:**
- Slow mitigation: debris deorbiting is due to atmospheric drag and re-entry time depends on the orbit and the mass.

\[
B = c_d \frac{A}{m}
\]

\[
(t_f - t_0) = \frac{H}{B \sqrt{\mu r}} \frac{1}{\rho(r_0)}
\]
2. MISSION OBJECTIVES \((5/5)\)

1) Removal of a specific debris properly identified

2) Qualification of a new deorbiting system for nanosatellite

3) Qualification of a new concept for cubesat/nanosatellite structure
3. CONCEPT OF OPERATION (1/2)

Debris Identification:

Norad n°33856 - Iridium 33 debris

Ground segment:

Kiruna station

Easiest access to polar orbit to perform correct rendezvous.
**3. CONCEPT OF OPERATION (2/2)**

**Deployment of deorbiting system:**

Extractable sails are deployed increasing A/m ratio of the cubesat and causing it to deorbit.
PERFORMANCE ANALYSIS

Project data:

- Components stored Volume: 67152 mm$^3$
- Nominal expansion ratio: 30
- Debris size: 100x100x100 mm - 1 kg
- Starting A/m: 0.01

Hypothesis:

- Foam assumes a spherical shape once is formed
- Final volume: 2.014 mm$^3$
- Added wet surface: 4.08 dm$^2$

-Absence of gravity
-No constraints
-Omnidirectional expansion
Starting point:
More than 100 yr!!
4. KEY PERFORMANCE PARAMETERS (3/4)

Orbit lifetime of the debris reduced more than 80%

Deorbiting of cleaner satellite respects IADC guidelines

Vacuum space INCREASES expansion ratio over the nominal value

Performance could be better !!
4. KEY PERFORMANCE PARAMETERS (4/4)

<table>
<thead>
<tr>
<th>Functional Parameters Table</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F1</strong></td>
</tr>
<tr>
<td><strong>F2</strong></td>
</tr>
<tr>
<td><strong>F3</strong></td>
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<tr>
<td><strong>F4</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance Parameters Table</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P11</strong></td>
</tr>
<tr>
<td><strong>P12</strong></td>
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<tr>
<td><strong>P21</strong></td>
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<tr>
<td><strong>P22</strong></td>
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<tr>
<td><strong>P31</strong></td>
</tr>
<tr>
<td><strong>P32</strong></td>
</tr>
<tr>
<td><strong>P41</strong></td>
</tr>
</tbody>
</table>
## 5. SPACE SEGMENT (1/12)

<table>
<thead>
<tr>
<th>Component</th>
<th>Description/Function</th>
<th>Mass [g]</th>
<th>Power [W]</th>
<th>Dimension [mm]</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>ABS 3U cubesat</td>
<td>200</td>
<td>-</td>
<td>100x100x300</td>
<td>Developed by students with free spare parts</td>
</tr>
<tr>
<td>ADR system</td>
<td>Catcher device based on polymeric foam.</td>
<td>600</td>
<td>-</td>
<td>100x50x30</td>
<td>Developed by students with free spare parts</td>
</tr>
<tr>
<td>Deorbiting system</td>
<td>Deployable sails</td>
<td>200</td>
<td>-</td>
<td>100x100x10</td>
<td>Developed by students with free spare parts</td>
</tr>
<tr>
<td>Power system</td>
<td>2x6 NiMh battery</td>
<td>2x360</td>
<td>-</td>
<td>50x100x30</td>
<td>8000 €</td>
</tr>
<tr>
<td></td>
<td>12 triple junction solar panel</td>
<td>100</td>
<td>-</td>
<td>100x100x10</td>
<td></td>
</tr>
<tr>
<td>Attitude control &amp; determination</td>
<td>Magnetorquer and reaction wheels, solar sensor</td>
<td>250</td>
<td>0.5</td>
<td>45x45x10</td>
<td>10000 €</td>
</tr>
<tr>
<td>Propulsion system</td>
<td>ION Electrospray Thruster</td>
<td>950</td>
<td>5.00</td>
<td>96x96x70</td>
<td>20000 €</td>
</tr>
<tr>
<td>Proximity determination sys</td>
<td>Camera ad sensors</td>
<td>50</td>
<td>0.16</td>
<td>10x9x7.34</td>
<td>2000 €</td>
</tr>
<tr>
<td>PCB</td>
<td>SRL specific design</td>
<td>80</td>
<td>0.04</td>
<td>85x83x18</td>
<td>800 €</td>
</tr>
<tr>
<td>TX/RX</td>
<td>VHF downlink/UHF uplink/S-band</td>
<td>100</td>
<td>0.15</td>
<td>-</td>
<td>10000 €</td>
</tr>
<tr>
<td>Thermal system</td>
<td>Flexible thermal heater for foam components.</td>
<td>-</td>
<td>4.00</td>
<td>-</td>
<td>100 €</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>3.250 Kg</td>
<td>-</td>
<td>-</td>
<td>50900 € (without launch)</td>
</tr>
</tbody>
</table>
## 5. SPACE SEGMENT (2/12)

<table>
<thead>
<tr>
<th>POWER SYSTEM</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Power</td>
<td>1.64 W</td>
</tr>
<tr>
<td>Peak Power</td>
<td>5 W (During Rendezvous maneuver)</td>
</tr>
<tr>
<td>Battery Pack 1 Power</td>
<td>0.55 A/h @ 7.2 V</td>
</tr>
<tr>
<td>Battery Pack 2 Power</td>
<td>0.55 A/h @ 7.2 V</td>
</tr>
<tr>
<td>Solar Panels</td>
<td>~0.50 A @ 5 V</td>
</tr>
</tbody>
</table>
5. SPACE SEGMENT (3/12)

Structure

- Plastic material: ABS
- Rapid prototyping technique

Addition of material layer by layer

FDM: fused deposition modelling

Optimization of the useful volume

Short time of manufacturing and low costs
5. SPACE SEGMENT (4/12)

Advantages:
- Possibility to create very complex shapes
- Easy customization of inner and external details
- Lighter structure
- Short time of manufacturing

Disadvantages:
- Lower mechanical properties than aluminum
- Not isotropic item
- Impossibility to thread the material

LOWER COSTS!!
5. SPACE SEGMENT (5/12)

Deorbiting system:

Based on 4 deployable poliurethane foam sails

- Designed to stabilize and keep the correct attitude
- $A/m$ ratio increased up to $0.05 \text{ m}^2/\text{kg}$
- Low storage volume (~7% of a 3U cubesat)
5. SPACE SEGMENT (6/12)

ADR System

- Two separated tanks in aluminium to store polyol and isocyanate.
- Flexible thermal heaters to warm up the fluids and bring them at the correct temperature of 324 K.
- Electrovalves to keep the channel closed and the system locked.
- Oversized in order to resist to the pressure due to spring force.
- The fluids are forced to flow through electrovalves to the connector.
- A designed connector is used to bring the two fluids in the same channel.
- Fluids are forced together in a static mixer that promotes the mixing triggering the reaction.
The architecture of ADR system is based on the same functional principle experienced in Redemption Experiment.
In vacuum condition has been registered an over expansion!

PADUA University & DUNA Corradini Group facilities

Thanks DUNA Corradini know-how has been possible to modify the chemical composition
5. SPACE SEGMENT (9/12)

Final heaters configuration and power budget

Current: 0.45 A
Voltage: 7.2 Volt
Power = ~4 W
Time = 300 s
5. SPACE SEGMENT (10/12)

ADR Vacuum test

ADR architecture has been experienced in Redemption Experiment:

Vacuum test at DUNA Corradini facilities
5. SPACE SEGMENT (11/12)

REDEMPTION experiment flown in the space 19 March 2012; Liftoff was from Kiruna ad ESRANGE space center of Swedish Corp.

Because some electrical problems the experiment didn’t start and the rocket didn’t deploy the parachute and the payload crash on ground.

After the crash the ADR system was still working if activated and there was not leakages.

In general the ADR system can be considered suitable for the space as survived at real rocket launch and during the test it was working during the vacuum condition and will be tested.
ABS Structure FEM analysis and vibration test:

Using electrodynamic shaker, two sinusoidal sweep sessions have been performed before and after random vibration test to check structural alteration.
6. ORBIT DESCRIPTION

DEBRIS ORBIT
Altitude: 705 x 741 Km
Inclination: 86.32 deg
RAAN: 296.43
Mean Anomaly: 308.256
Perigee argument: 52.092

DELIVER ORBIT
Altitude: 700 x 700 Km
Inclination: 86.32 deg
RAAN: na
Mean Anomaly: na
Perigee argument: na

ACCESS FROM KIRUNA GROUND STATION
Average access duration: 652 sec
Minimum access duration: 215 sec
Maximum access duration: 860 sec

Sunlight: ~60min
Eclipse: ~30min
7. IMPLEMENTATION PLAN (1/2)

First period (up to 6 months) used to prepare different options for the PDR. After the PDR, start to build prototypes and fix the troubleshooting to arrive with the best frozen design to the CDR. After the CDR, start the final manufacturing. The best situation would be to have 18 months from the “kick off.”
7. IMPLEMENTATION PLAN (2/2)

Risk register table

<table>
<thead>
<tr>
<th>RISK</th>
<th>PROBABILITY</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrocutter to open deorbiting system Failure</td>
<td>Very low</td>
<td>Double line for Power On signal and double number of Pyrocutters</td>
</tr>
<tr>
<td>Injector of ADR System failure</td>
<td>Very Low</td>
<td>Ground test in order to find the best configuration</td>
</tr>
<tr>
<td>Temperature of liquid of ADR system to low</td>
<td>Medium</td>
<td>Injection during light-day orbit period and pre heating system for fluids</td>
</tr>
<tr>
<td>ABS Structure Failure</td>
<td>Medium</td>
<td>During vibration test a safety factor of 2 will be used in addition to the value suggested by user manual of the launcher</td>
</tr>
<tr>
<td>Missing rendezvous</td>
<td>High</td>
<td>Using tested and affordable algorithm to design the system. Use of specific software for simulation</td>
</tr>
</tbody>
</table>

A verification matrix and tests need to be setted fo each risk in order to mitigate the risk register.

In particular it must be not present hig risk before the launch.
8. REFERENCES (1/1)

[1] J-C. Liou, N.L. Johnson, N.M. Hill *Controlling the growth of future LEO debris populations*


[3] Davide Rastelli, *Confronto tra un cubesat in ABS e un cubesat in alluminio nell'ambito*


[5] Niccolò Bellini, Alfredo Locarini, Stefano Naldi, Davide Rastelli, Marcello Valdatta, *AZ1 4*


Thanks to our supporter

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