3U Cubesat aerodynamic design aimed to increase attitude stability and orbital lifetime

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1. Introduction
2. Proposed aerodynamic shape for 3U CubeSat
3. Increasing orbital lifetime with deployable nose section
4. Increasing attitude stability with center of mass shift
5. Conclusions
1. INTRODUCTION

Nanosatellites launches

Nanosats predicts over 2500 nanosatellites to launch in 6 years
INTRODUCTION

Nanosatellites types

- 0.25U CubeSat: 25.1%
- 0.5U CubeSat: 5.0%
- 1U CubeSat: 13.9%
- 1.5U CubeSat: 77.2%
- 2U CubeSat: 170.6%
- 3U CubeSat: 0.0%
- 3.5U CubeSat: 0.0%
- 4U CubeSat: 0.0%
- 5U CubeSat: 0.0%
- 6U [1x6U] CubeSat: 0.0%
- 6U CubeSat: 0.0%
- 8U [4x2U] CubeSat: 0.0%
- 8U CubeSat: 0.0%
- 12U CubeSat: 65.2%
- 16U CubeSat: 33.1%
- Other nanosats (1-10 kg): 78.3%
- PocketQube: 51.9%
- TubeSat: 60.2%
- ThinSat: 120.5%
- Other picosats (0.1-1 kg): 34.1%

Launched
Not launched
CubeSats stabilization types

Active:
- reaction wheels
- magnetorquers
- micropulsed plasma thrusters

Passive:
- gravitational
- aerodynamic
INTRODUCTION

Aerodynamical stabilization

*Shuttlecock*  
*3U CubeSats with deployable panels*

Rawashdeh et al. Aerodynamic attitude stabilization for a ram-facing CubeSat, 2009

QARMAN CubeSat (Von Karman Institute), 2020
Problems related to the use of deployable panels

- increase of the aerodynamic drag
- decrease of the orbital lifetime

The aim of the study

Increase the orbital lifetime and attitude stability of a standard 3U Cubesat by modification of its shape and adjusting the position of the center of mass
Assumptions

1. The deployable panels are rigid flat plates
2. The attitude motion of the satellite takes place in the orbital plane
3. Center of mass of the satellite lies on its longitudinal axis
4. The aerodynamic characteristics of the satellite do not depend on the Mach number
5. The aerodynamic damping is negligible
6. Air density changes with altitude according to the US Standard Atmosphere
Main idea: use of a pyramidal nose

Standard design with blunt nose

Proposed design with pyramidal nose
Deployment process animation
Deployment process

Initial state → Stabilizing panels deployment... → Panels deployed → Nose section deployment... → Fully deployed
Geometry of CubeSat with panels and pyramidal nose
### Considered CubeSats parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite body length</td>
<td>0.3 m</td>
</tr>
<tr>
<td>Satellite body cross-section area</td>
<td>0.01 m²</td>
</tr>
<tr>
<td>Panel length</td>
<td>0.3 m</td>
</tr>
<tr>
<td>Panel deployment angle</td>
<td>30°</td>
</tr>
<tr>
<td>Nose section deployment angle</td>
<td>0 (blunt), 63.5° (pyramidal)</td>
</tr>
<tr>
<td>Principal moments of inertia of the satellite</td>
<td></td>
</tr>
<tr>
<td>with deployed nose section and panels</td>
<td></td>
</tr>
<tr>
<td>transverse</td>
<td>0.025 kg·m²</td>
</tr>
<tr>
<td>longitudinal</td>
<td>0.005 kg·m²</td>
</tr>
</tbody>
</table>
Pyramidal nose decreases aerodynamic drag by the factor of 1.5!

\[ C_D = 5.0 \]

\[ C_D = 3.4 \]

Aerodynamic coefficients were calculated using Newton method.
See P. Gallais Atmospheric re-entry vehicle mechanics, 2007
Axial force coefficient

\[ C_D = C_A \bigg|_{\theta=0} \]
Normal force coefficient

![Graph showing normal force coefficient for two different nose shapes: Blunt nose and Pyramidal nose. The x-axis represents angle θ in radians, and the y-axis represents the normal force coefficient C_N. The graph illustrates the deviation from zero for different angles, highlighting the performance of the two nose shapes.](image-url)
Restoring pitch torque coefficient

Here $\Delta$ is the dimensionless center of mass shift
Re-entry equations

\[ \dot{h} = V \sin \gamma, \]
\[ \dot{V} = -\frac{D}{m} - g \sin \gamma, \]
\[ \dot{\gamma} = -\frac{\cos \gamma}{V} \left( g - \frac{V^2}{R + h} \right), \]

where

\[ D = C_D \frac{1}{2} \rho(h)V^2 A \text{ is the aerodynamic drag} \]
Orbital altitude evolution

Altitude loss in 100 days is 40 km less!
4. INCREASING ATTITUDE STABILITY WITH CENTER OF MASS SHIFT

Attitude motion

Gravity gradient torque

\[ M_g = 3 \left( J_z - J_x \right) \frac{\mu}{(R + h)^3} \cos \theta \sin \theta \]

Aerodynamic restoring pitch torque

\[ M_a = C_m \frac{1}{2} \rho(h)V^2 Al, \]

\[ C_m = \sum_{j=1}^{k} (b_j + d_j \Delta) \sin j\theta \]
Potential energy of 3U CubeSat

\[ U = -\int \left( M_a + M_g \right) d\theta = \]
\[ \frac{1}{2} \rho(h)V^2 Al \sum_{j=1}^{k} \frac{(b_j + d_j \Delta)}{j} \cos j\theta + \frac{3(J_z - J_x)\mu}{2(R + h)^3} \cos^2 \theta \]

\[ h = 670 \text{ km} \]
\[ h > h_* : \]
\[ \theta = 0 \text{ is unstable} \]

\[ h = h_* = 641 \text{ km} \]

\[ h < h_* : \]
\[ \theta = 0 \text{ is stable} \]
Critical altitude of 3U CubeSat with pyramidal nose

![Graph showing critical altitude of 3U CubeSat with pyramidal nose]

- **Blunt nose**

**4. INCREASING ATTITUDE STABILITY WITH CENTER OF MASS SHIFT**

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5. CONCLUSIONS

Profits of the pyramidal nose and center of mass shift

• Increase of the orbital lifetime
• Better attitude stability
• Increase of the upper limit of the operational altitude range
REFERENCES


[7] Gallais P Atmospheric re-entry vehicle mechanics 2007


THANK YOU

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