SAMARA UNIVERSITY

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

Место для спикера

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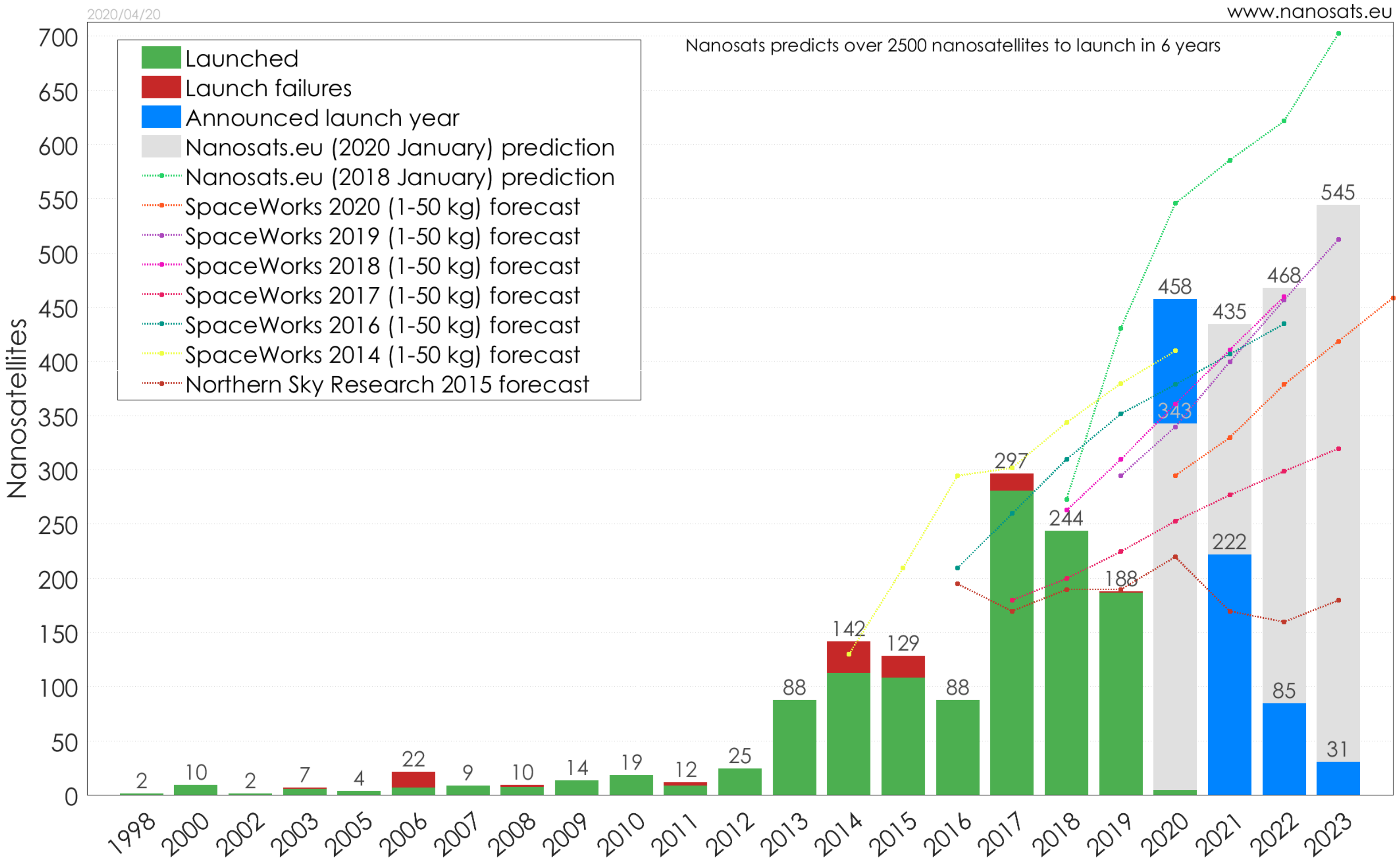
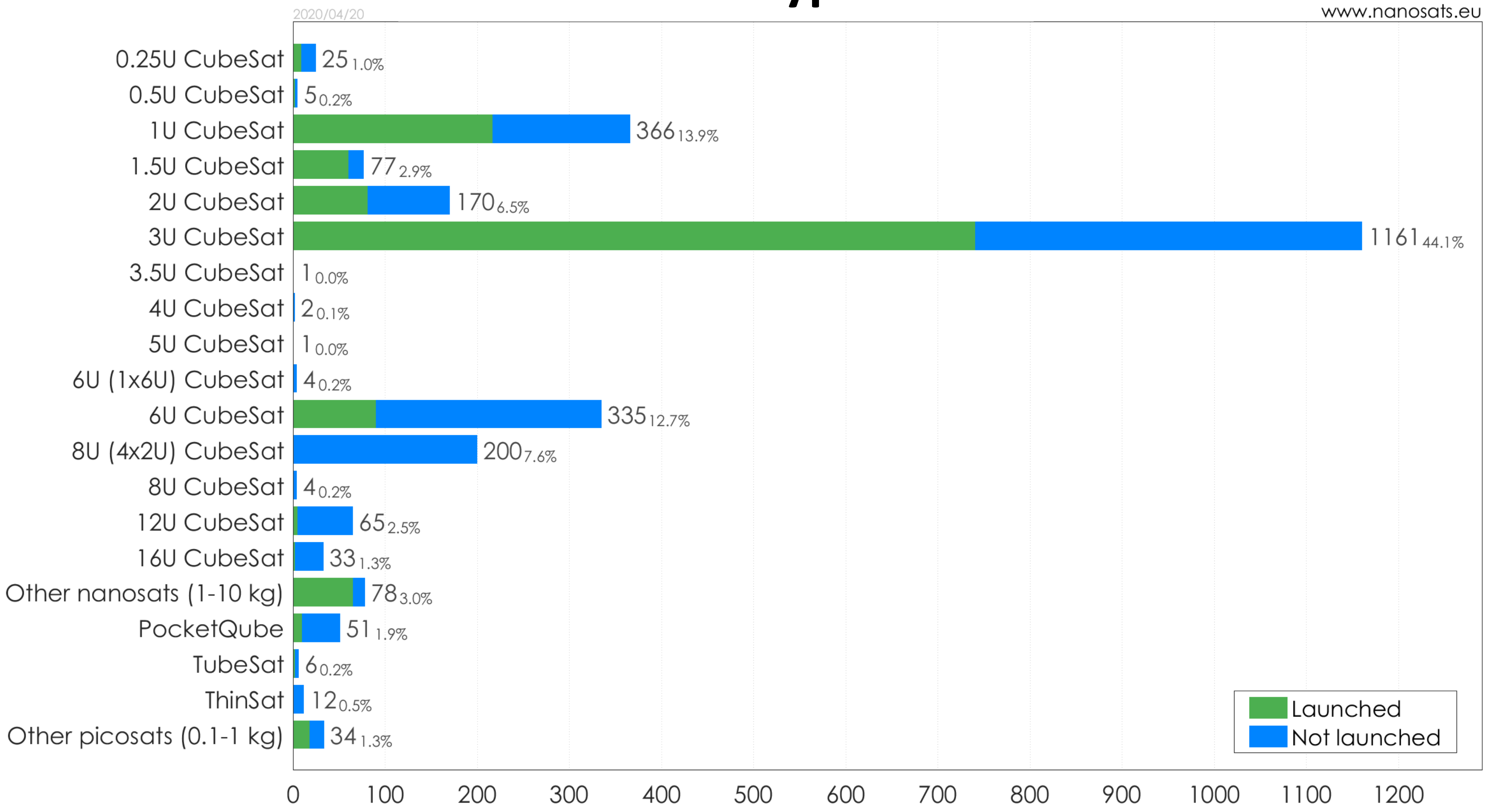
Nanosatellites launches



Nanosatellites types



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CubeSats stabilization types

Active:

- reaction wheels
- magnetorquers
- micropulsed plasma thrusters

Passive:

- gravitational
- aerodynamic

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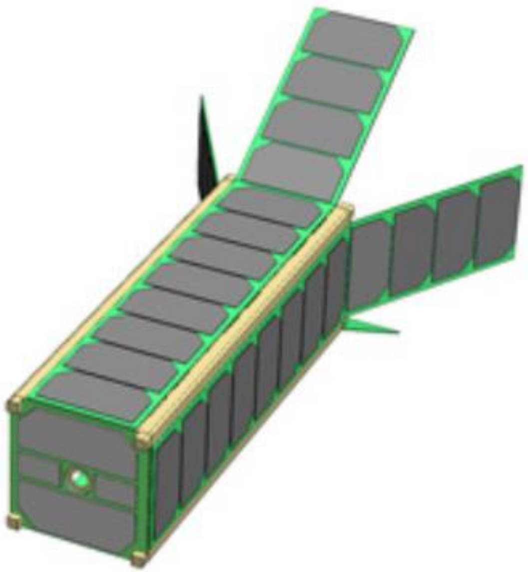
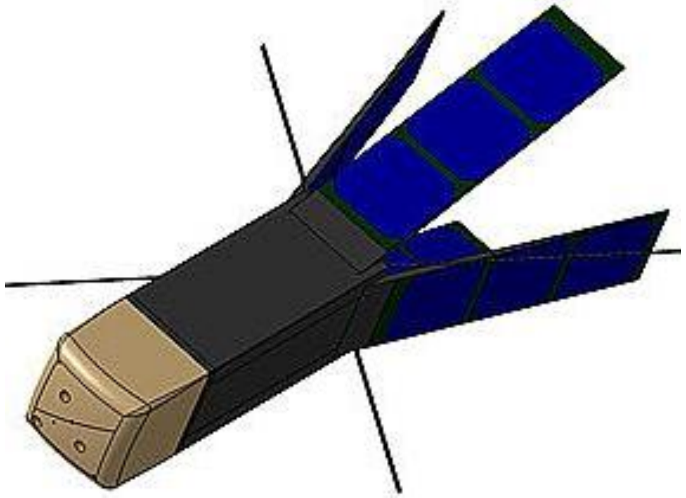
Aerodynamical stabilization

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

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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

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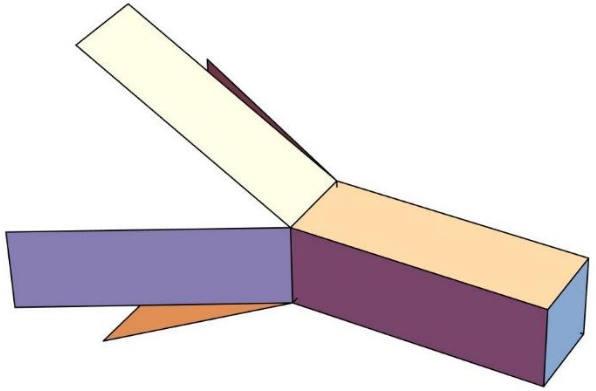
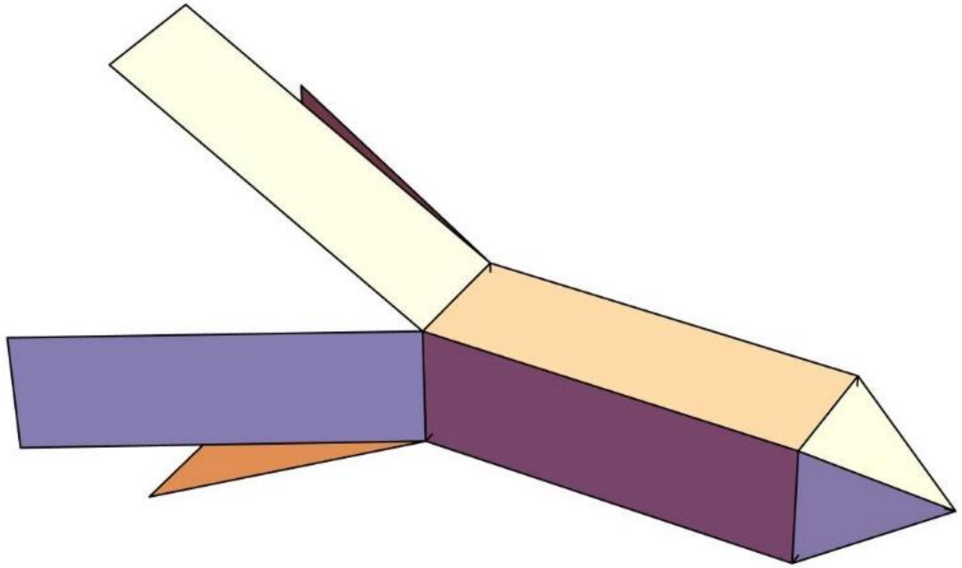
Main idea: use of a pyramidal nose



Standard design with blunt nose



Proposed design with pyramidal nose

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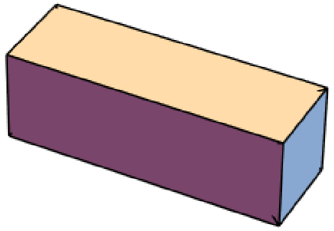
Deployment process animation



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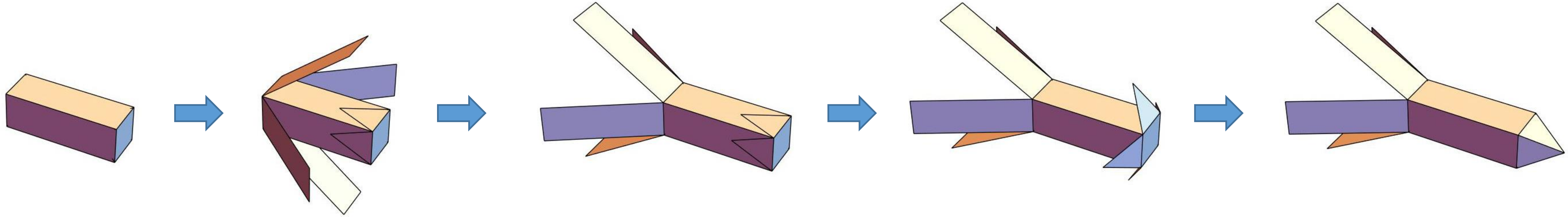
Deployment process



Initial state

Stabilizing panels deployment…

Panels deployed

Nose section deployment…

Fully deployed

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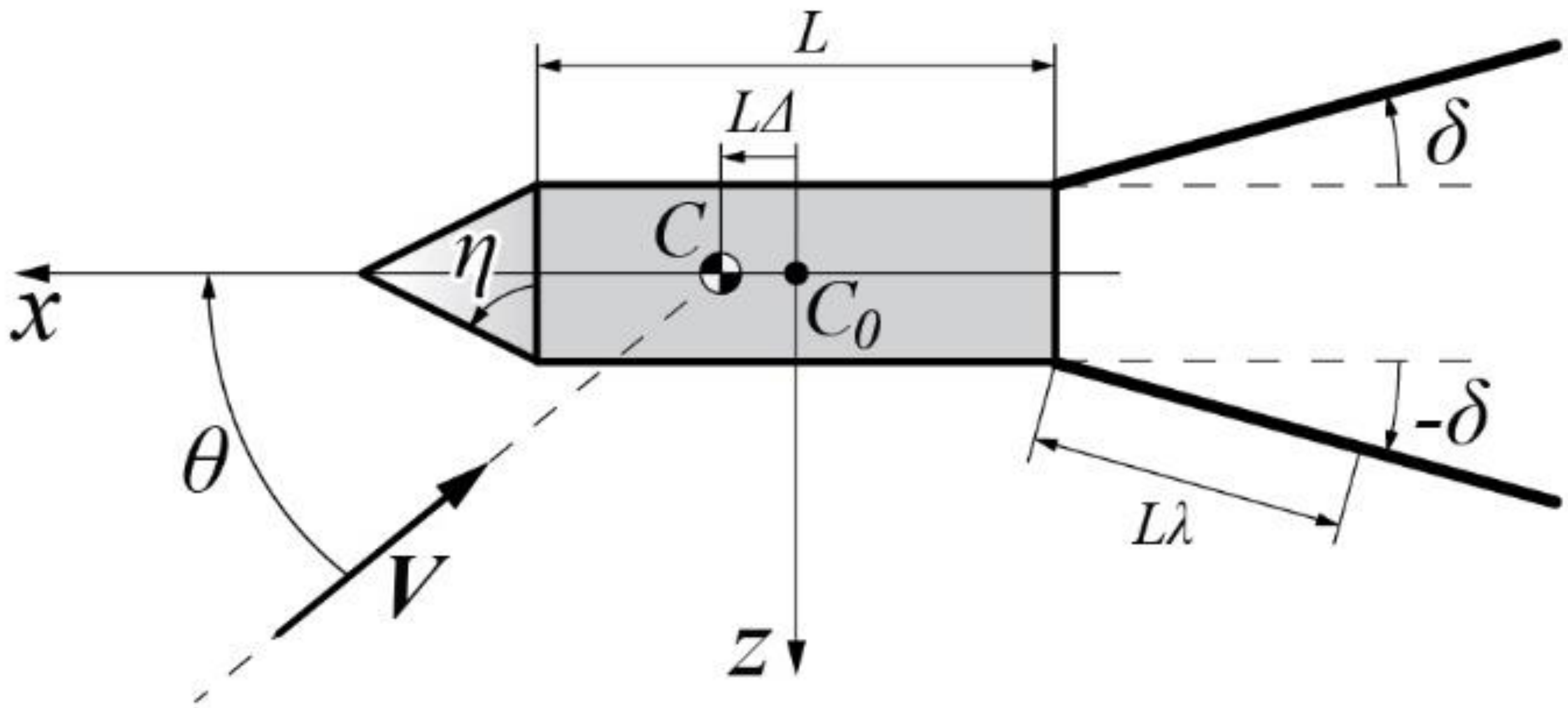
Geometry of CubeSat with panels and pyramidal nose



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Considered CubeSats parameters

Parameter	Value
Satellite body length	0.3 m
Satellite body cross-section area	0.01 m^2
Panel length	0.3 m
Panel deployment angle	30°
Nose section deployment angle	0 (blunt), 63.5° (pyramidal)
Principal moments of inertia of the satellite with deployed nose section and panels transverse longitudinal	 0.025 kg·m^2 0.005 kg·m^2

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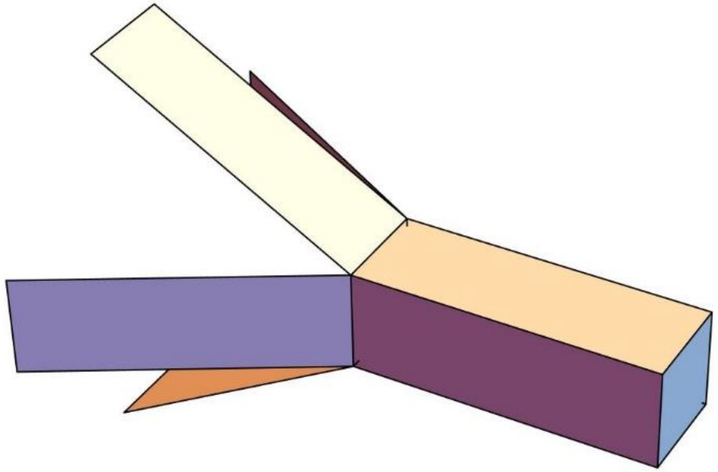
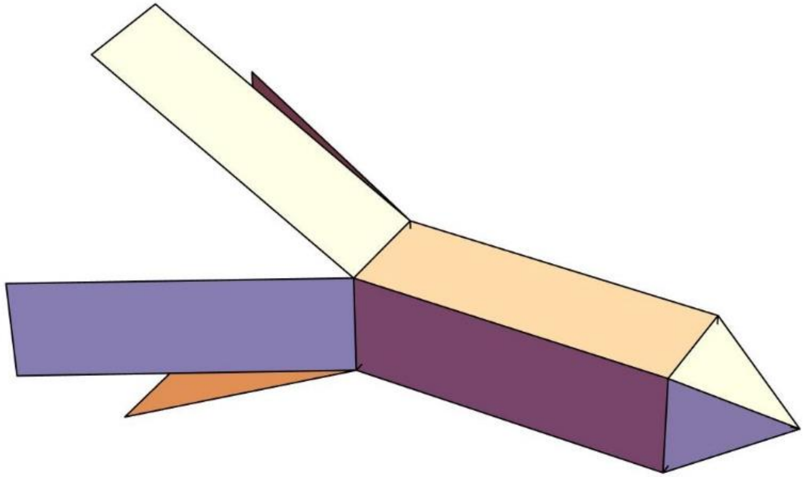
Pyramidal nose decreases aerodynamic drag by the factor of 1.5!



$$C_D = 5.0$$



$$C_D = 3.4$$

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

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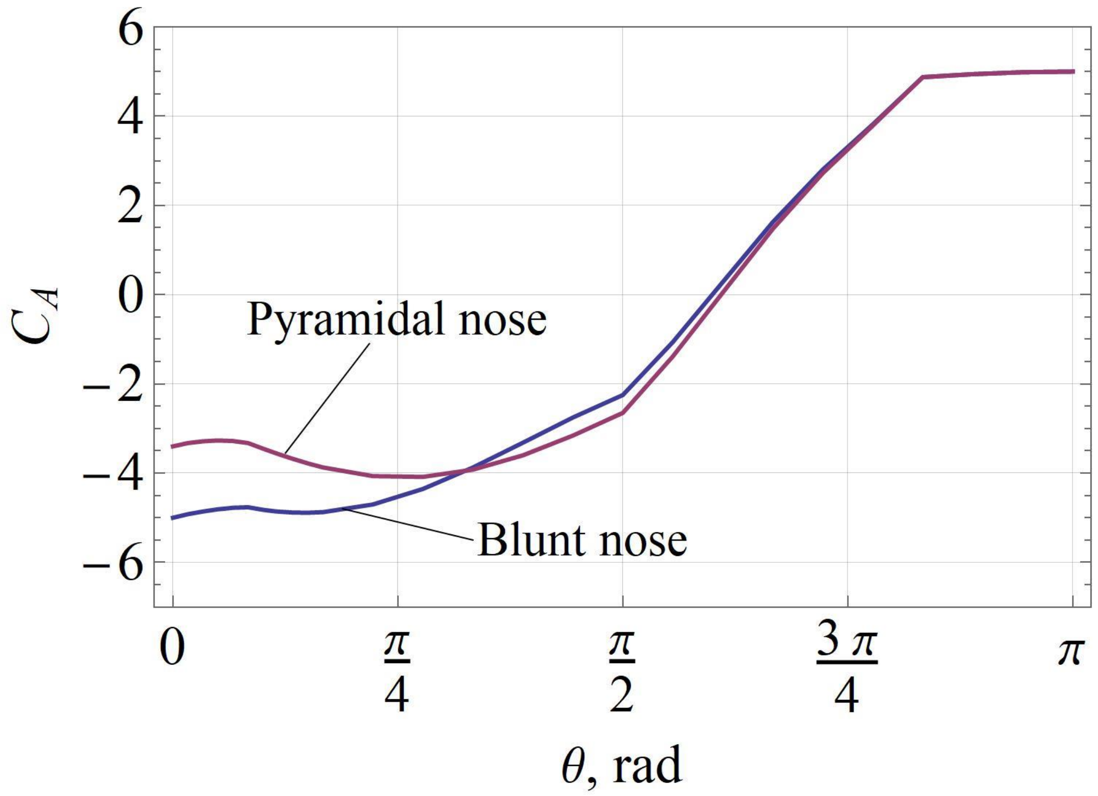
Axial force coefficient



$$C_D = C_A\big|_{\theta=0}$$

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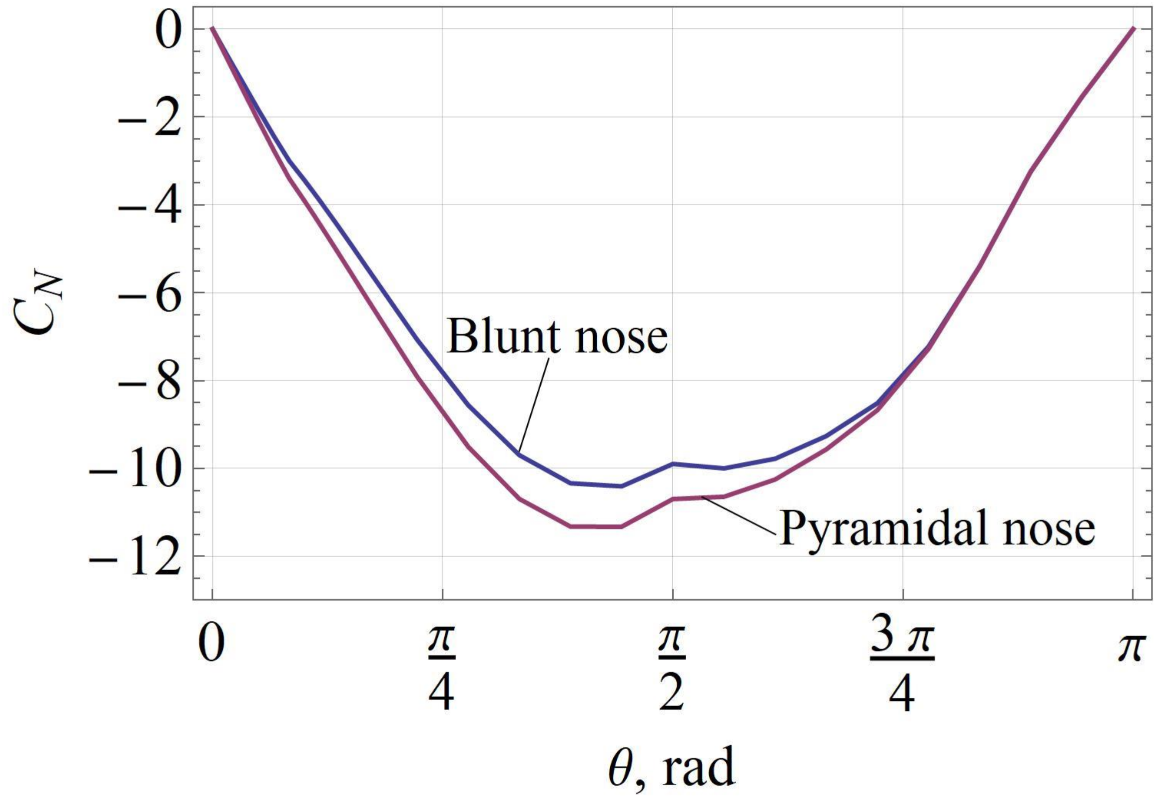
Normal force coefficient



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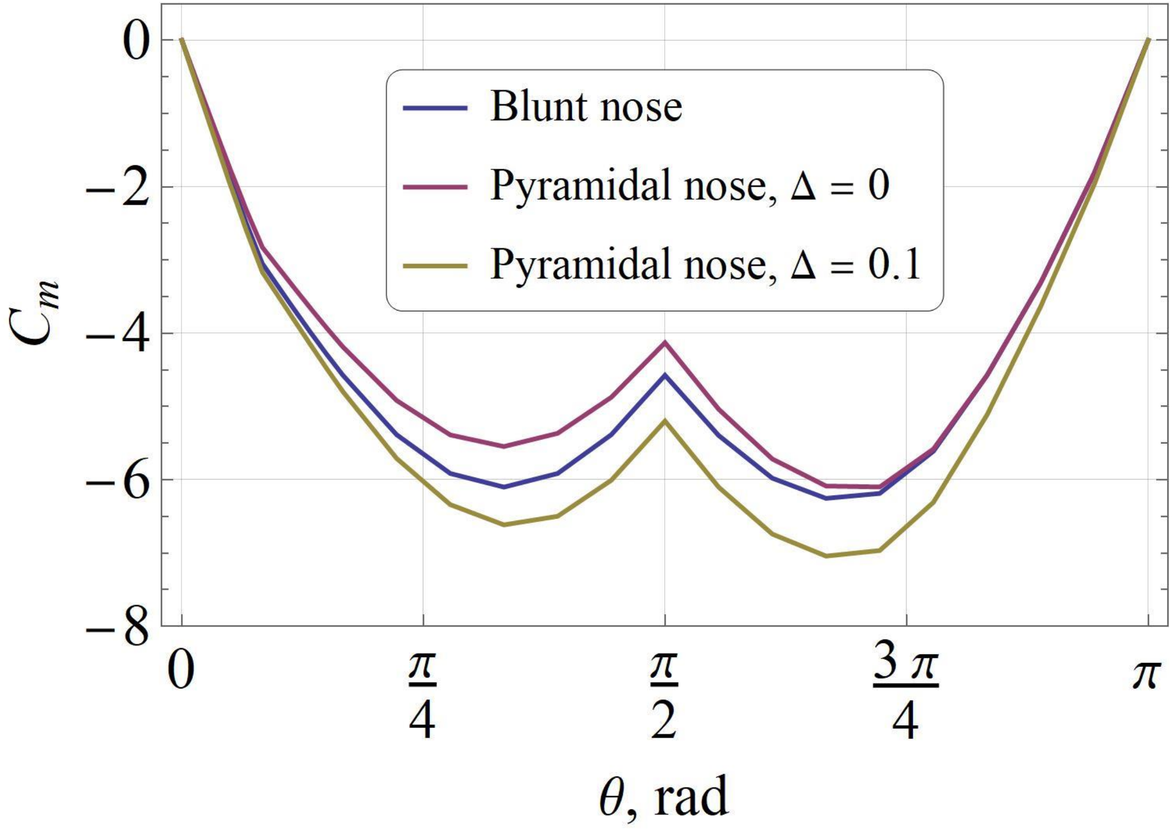
Restoring pitch torque coefficient



Here Δ is the dimensionless center of mass shift

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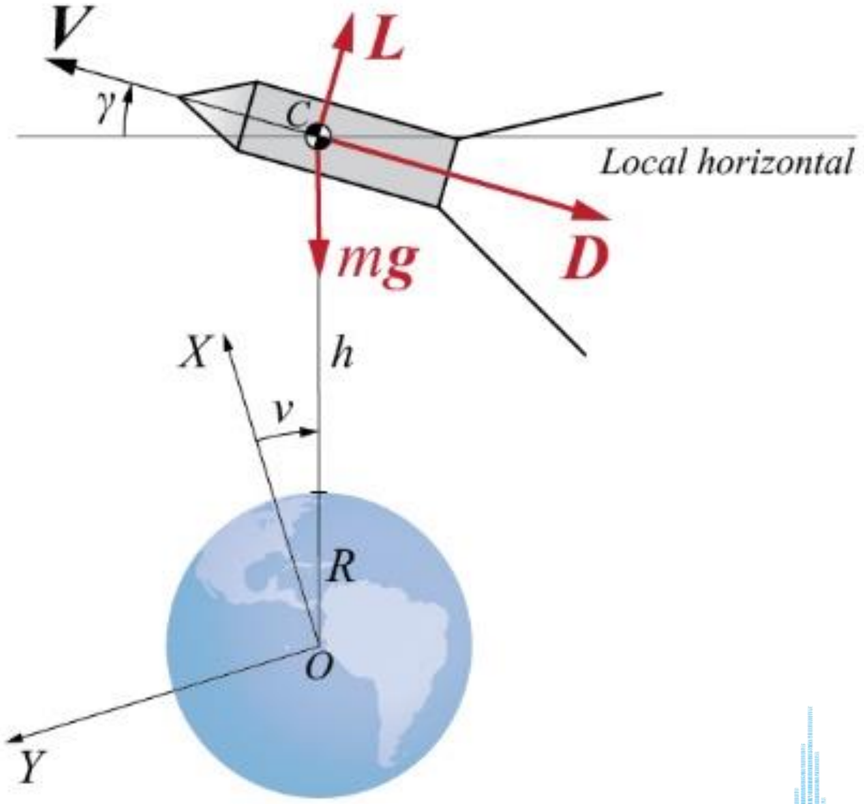
Re-entry equations

$$\dot{h} = V \sin\gamma,$$

$$\dot{V} = -\frac{D}{m} - g\sin\gamma,$$

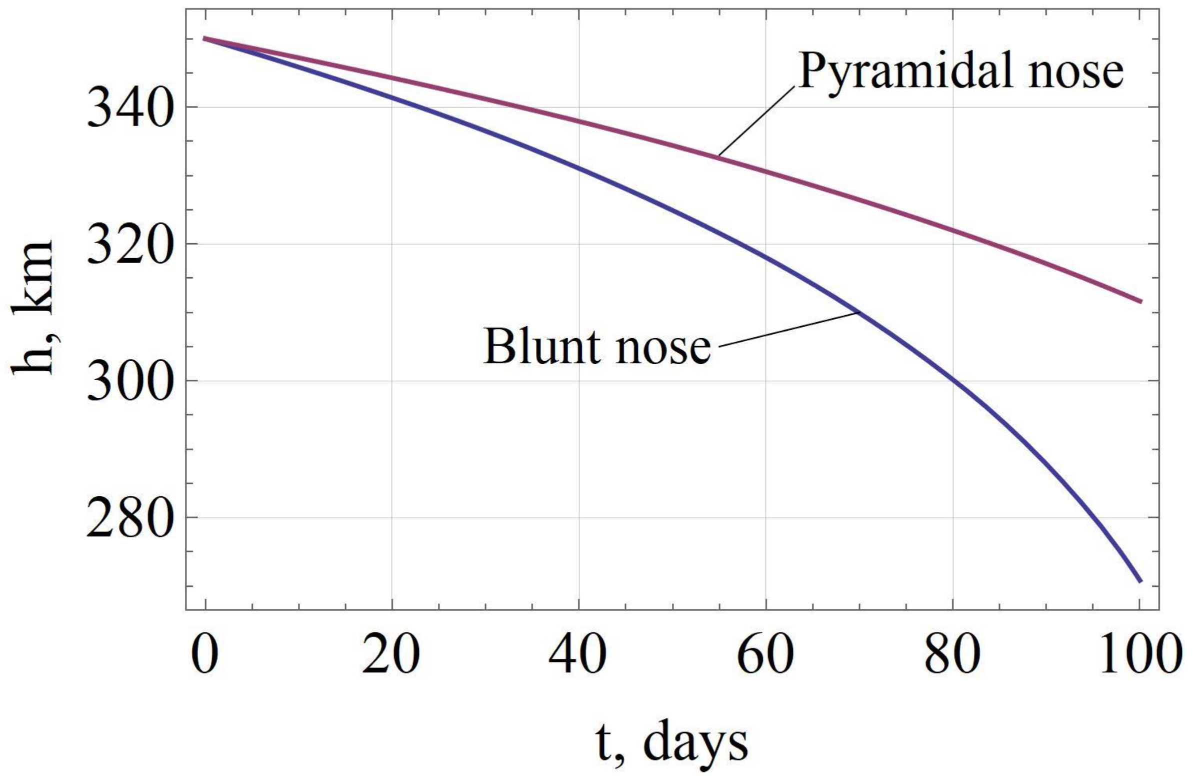
$$\dot{\gamma} = -\frac{\cos\gamma}{V}\left(g - \frac{V^2}{R+h}\right),$$



where

$$D = C_D \frac{1}{2}\rho(h)V^2 A$$ is the aerodynamic drag

Orbital altitude evolution



Altitude loss in 100 days is 40 km less!

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Attitude motion

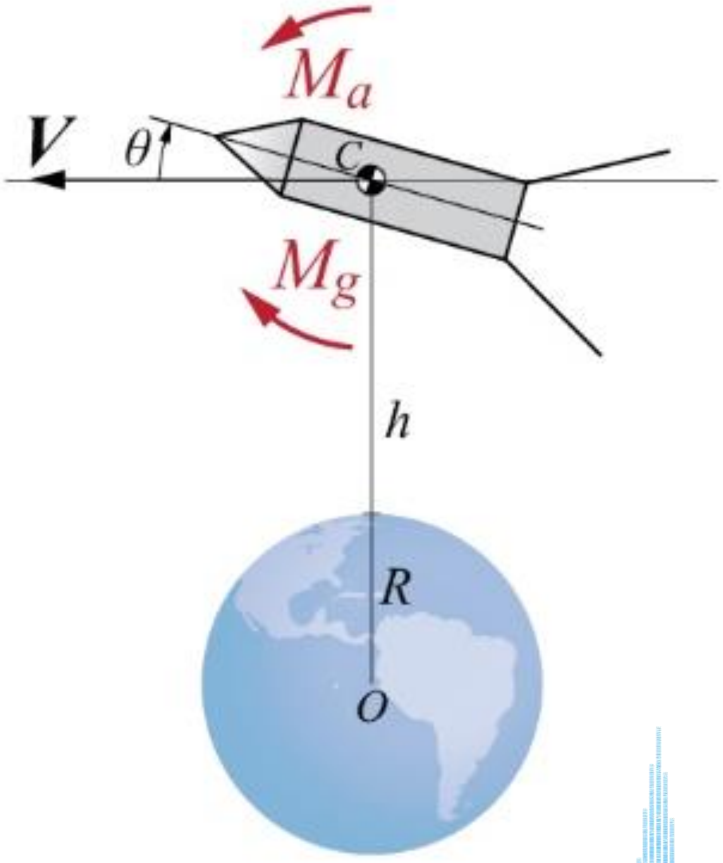
Gravity gradient torque

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

Aerodynamic restoring pitch torque

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

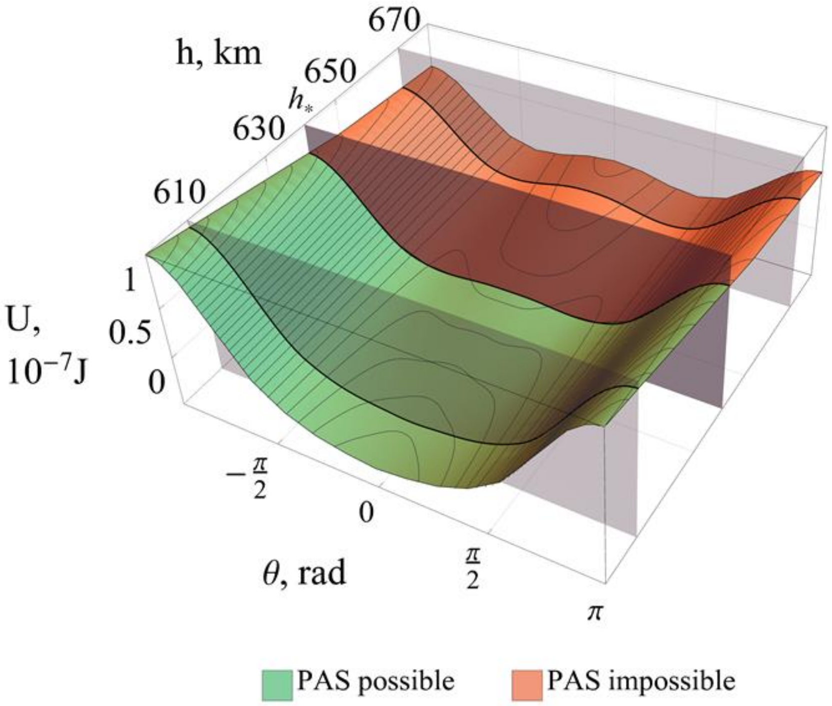
$$C_m = \sum_{j=1}^{k}(b_j + d_j\Delta)\sin j\theta$$

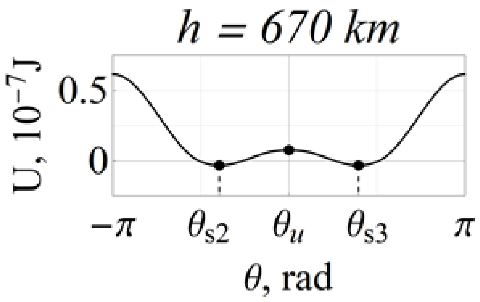


Potential energy of 3U CubeSat

$$U = -\int \left(M_a + M_g \right) d\theta =$$

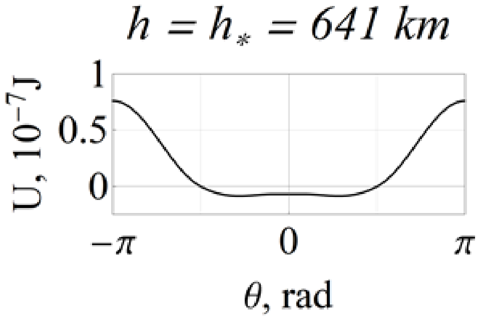
$$\frac{1}{2}\rho(h)V^2 Al \sum_{j=1}^{k} \frac{(b_j + d_j\Delta)}{j} \cos j\theta + \frac{3(J_z - J_x)\mu}{2(R+h)^3} \cos^2 \theta$$

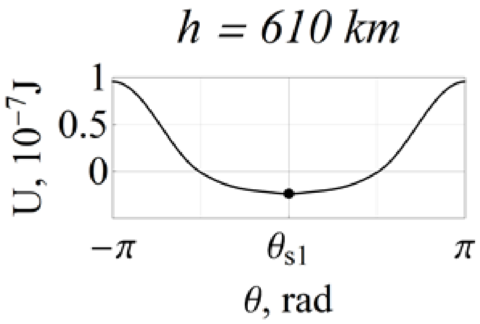




$h > h_*$:

$\theta = 0$ is **unstable**

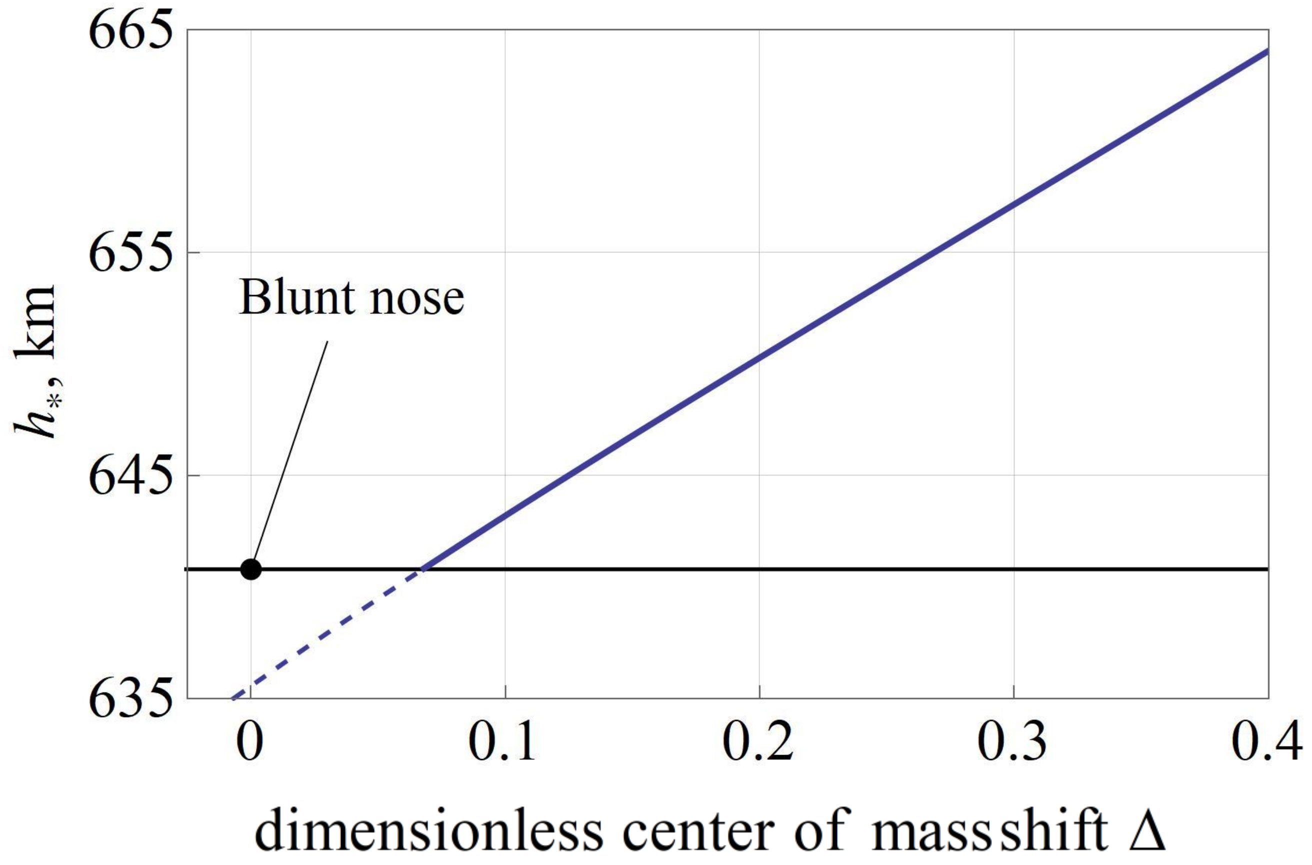




$h < h_*$:

$\theta = 0$ is **stable**

Critical altitude of 3U CubeSat with pyramidal nose



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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

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