2016中俄大学生小卫星创新设计大赛
Sino-Russian University Students Satellite Innovation Design Contest 2016

Nanosatellite aerobrake maneuvering device

Team: SunPulse

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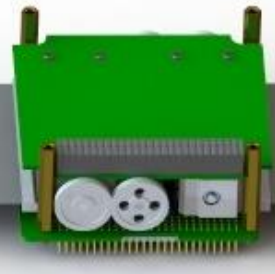
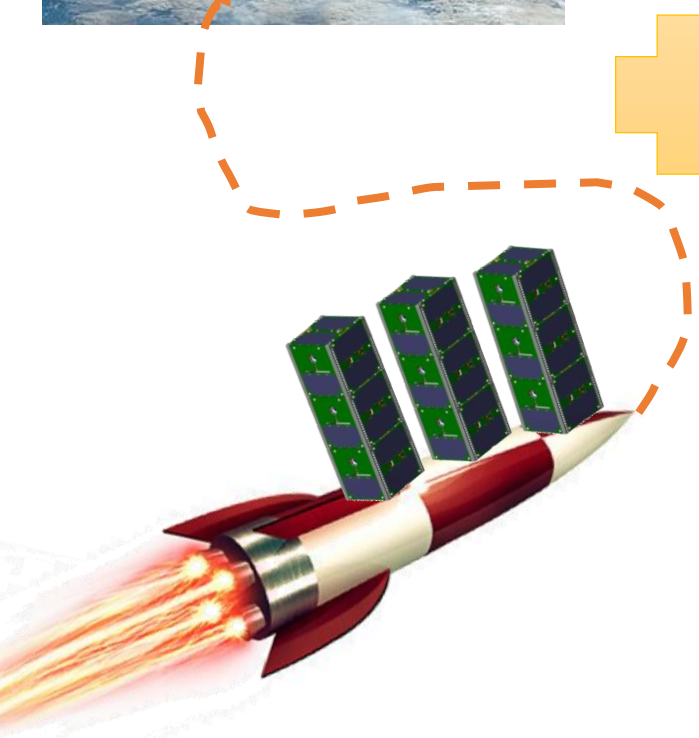
Problem

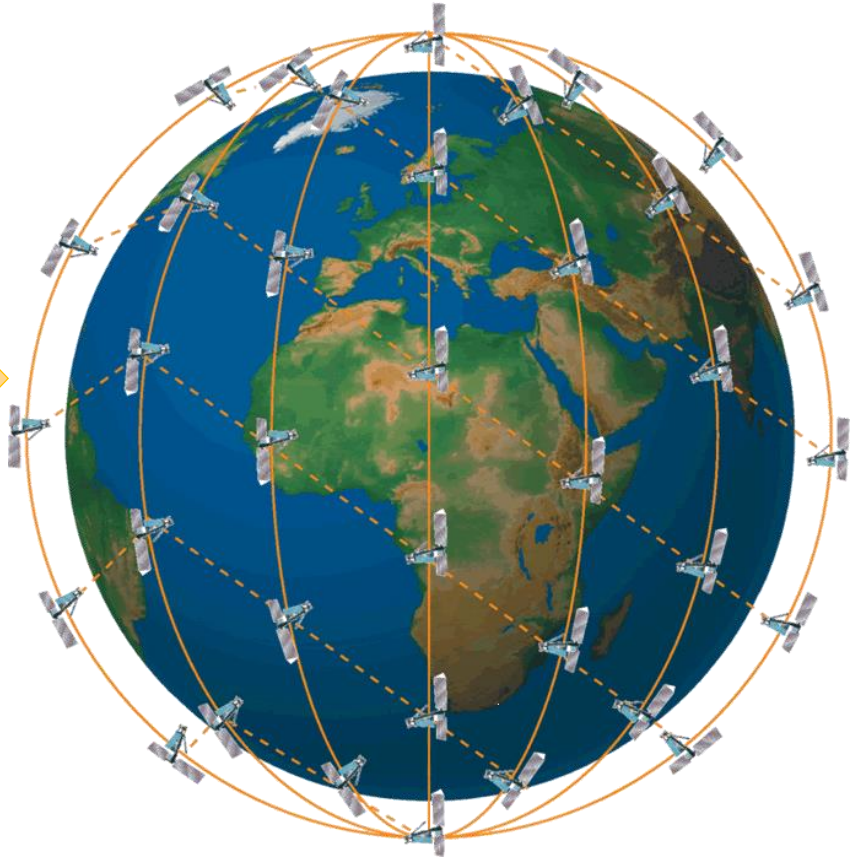


CubeSats are in one point

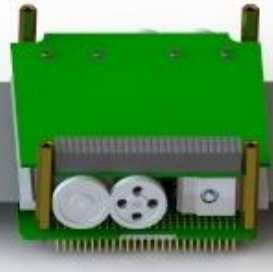


Propulsion system

CubeSats form a constellation

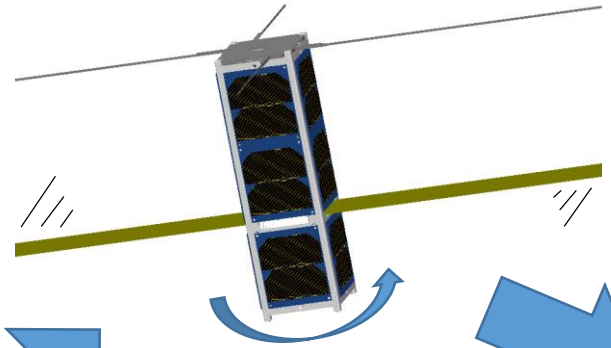


Innovative solution

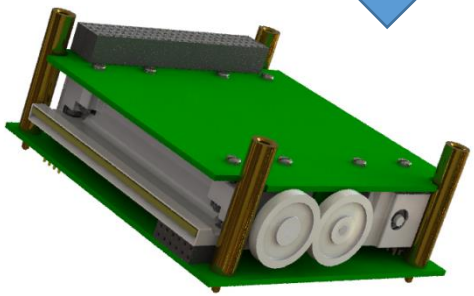


Two bladed rotary Solar Sail

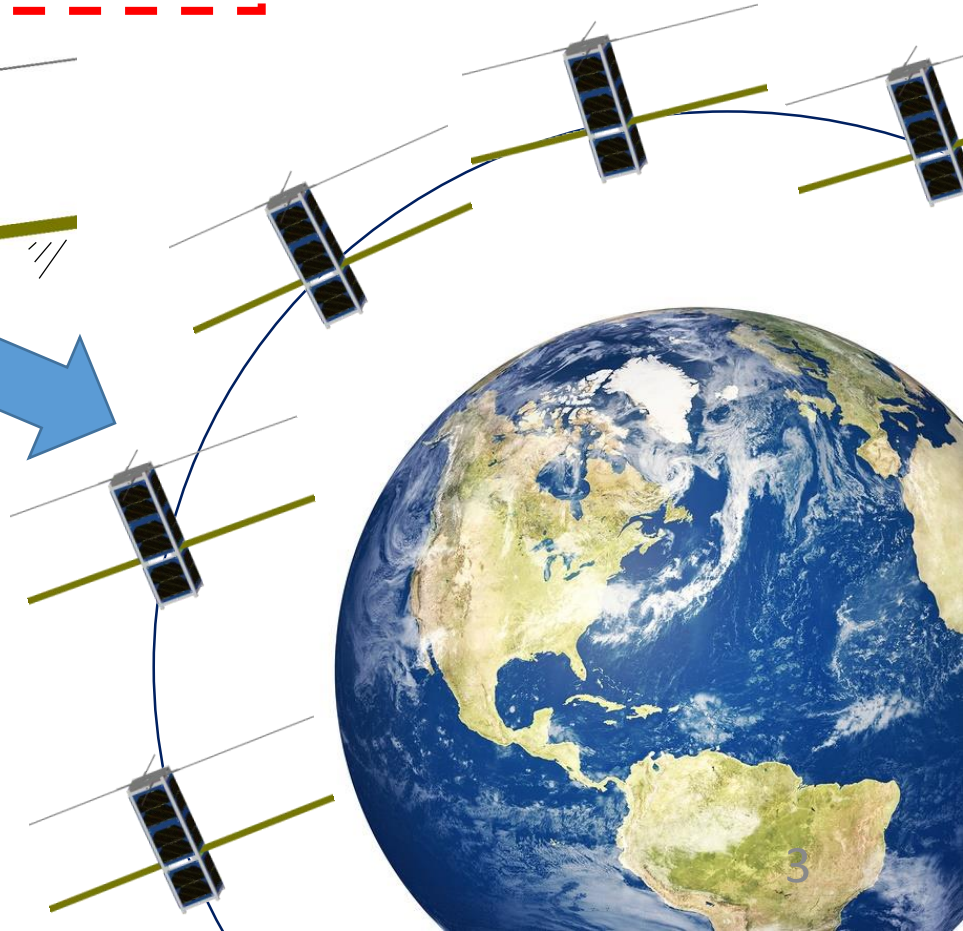
CubeSats form a constellation



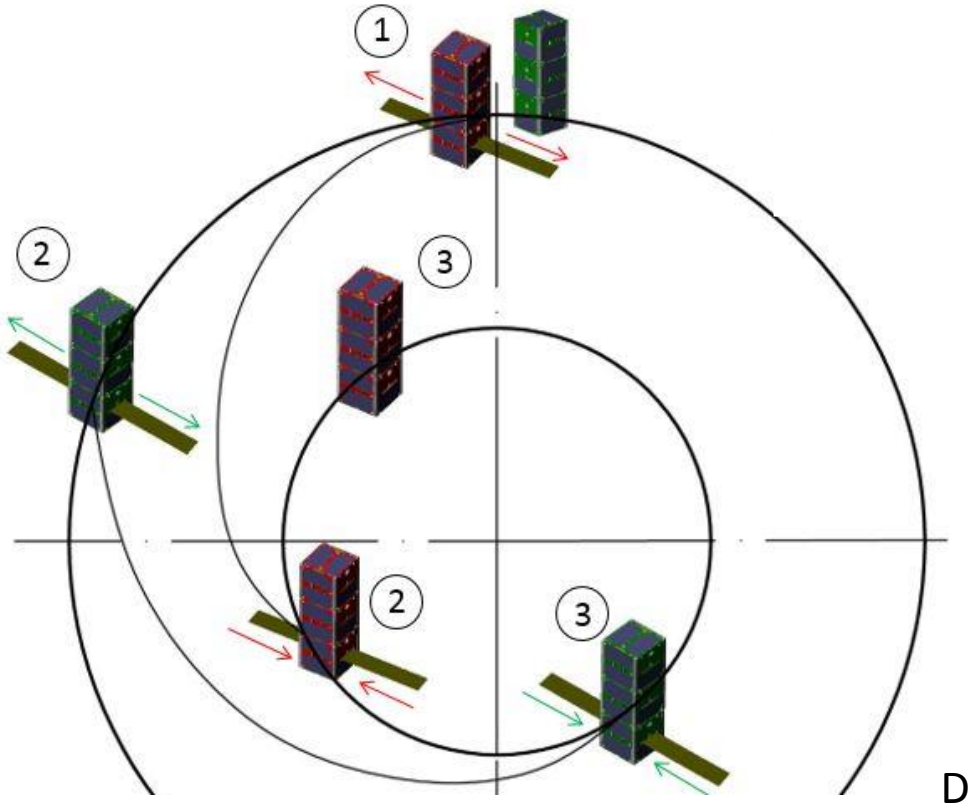
CubeSats with our unit



Our unit



Operation principle



The algorithm to form a constellation

1 - step

← → - sail deploying

→ ← - sail folding

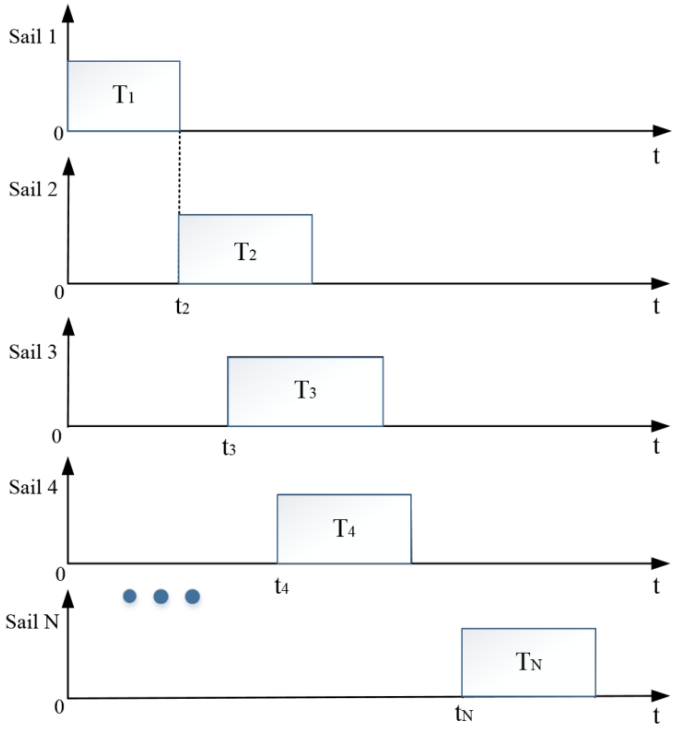


Diagram of Solar Sails deploying and folding

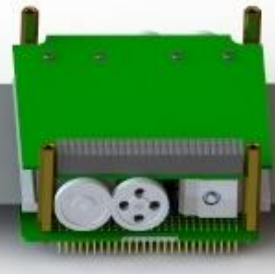
N – serial number of CubeSat

t – Time of deploying start for each sail

T – Sail operation time

Simulation software developed by our team

Ballistics



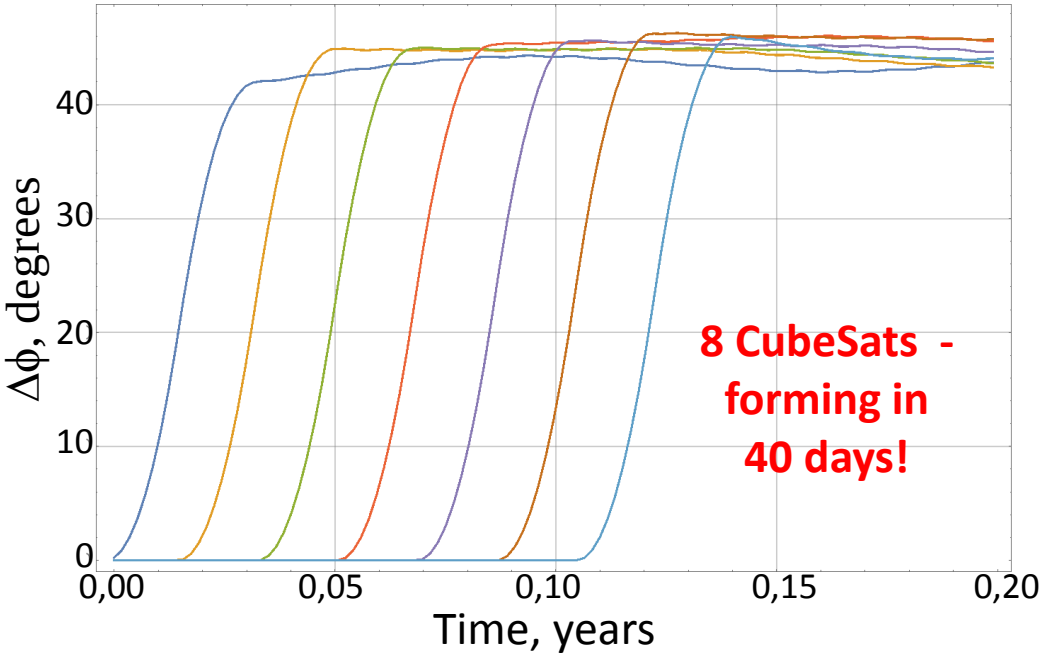
$$\mathbf{X}''(t)=\mathbf{F}/m$$

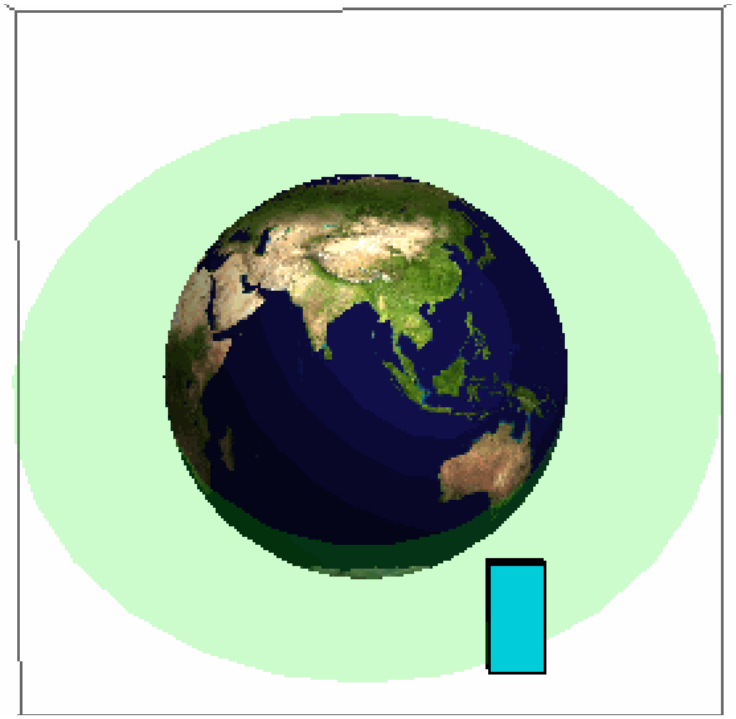
where **X** – coordinates vector; m – mass of CubeSat; **F=Fg+Fa+Fs** – net force vector, consist of:

Fg – gravity force of the Earth vector (compression of the Earth were taken into account - the second zonal harmonic),

Fa – atmospheric drag force (state standard specification GOST R 25645.166-2004, $F_{10,7}$ = 100 sfu),

Fs – solar radiation force.



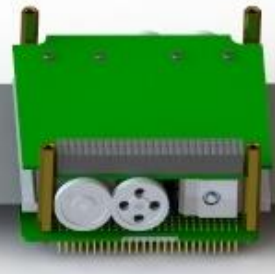


Evolution in time of the angles between 8 spacecrafts with the height of the orbit 450 km and sail area – 1 m^2

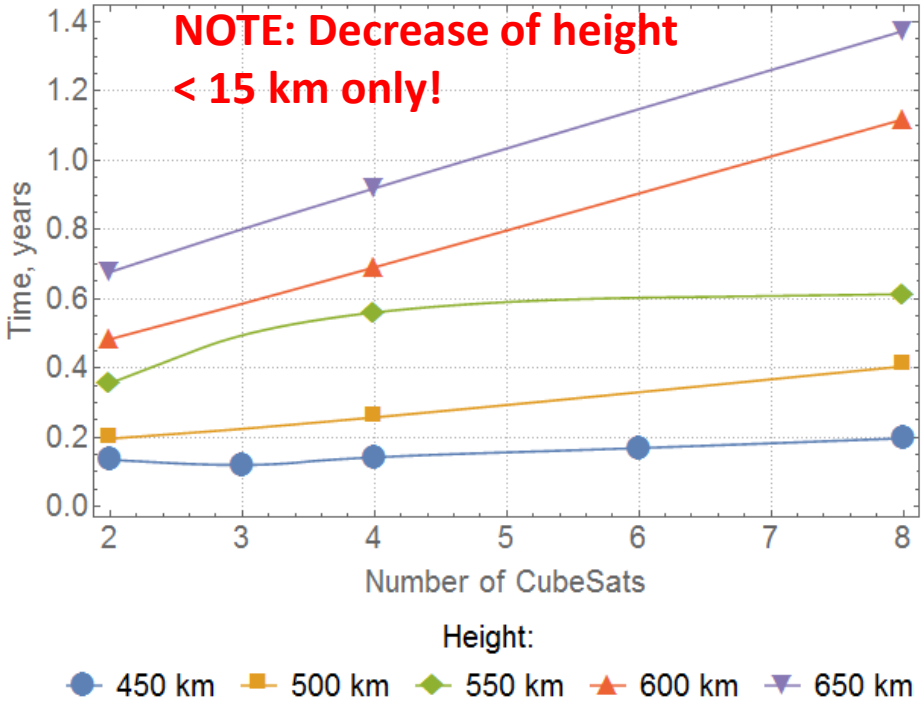
(machine time – 12 hours)

Simulation software developed by our team

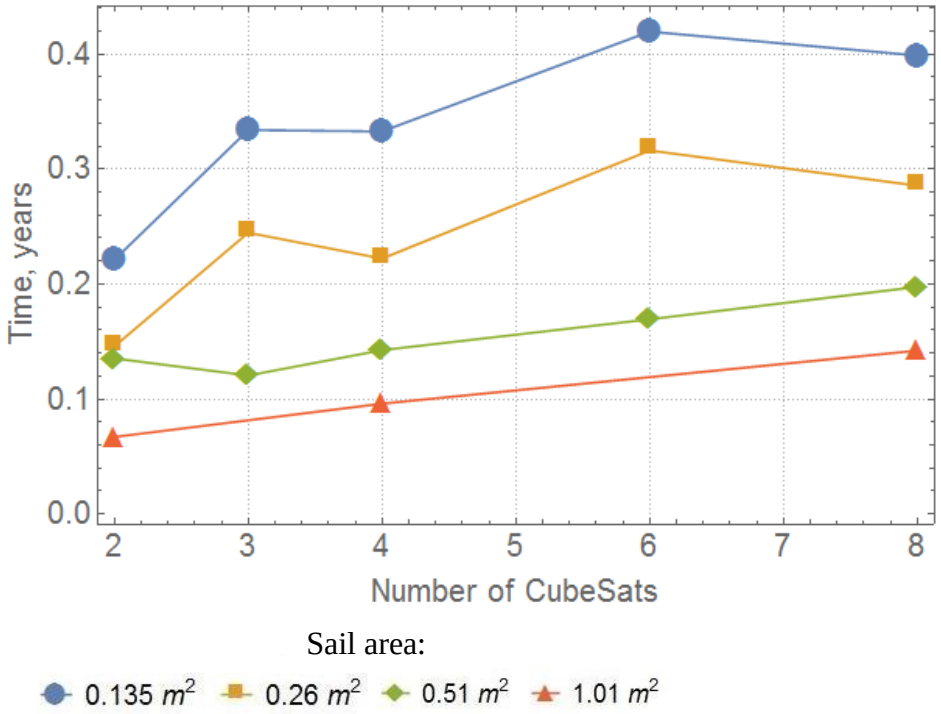
Ballistics



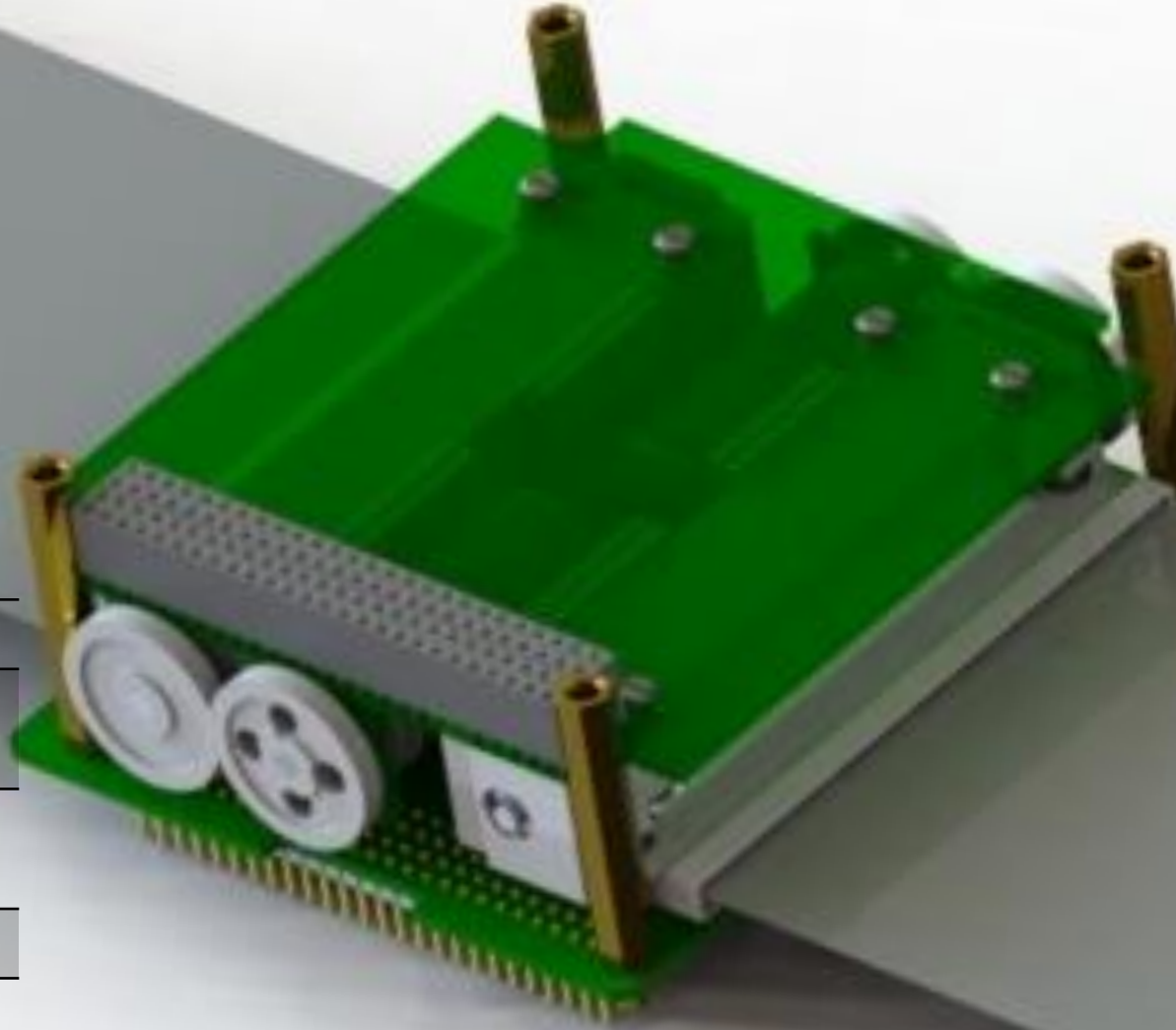
Influence of orbit height
for the period of deploying
(sail area – 0,5 m^2)



Influence of the sail area
for the period of deploying
(height – 450 km)

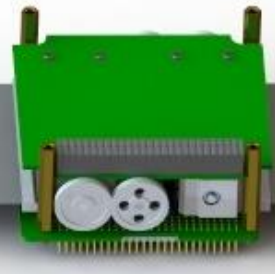


Technical features

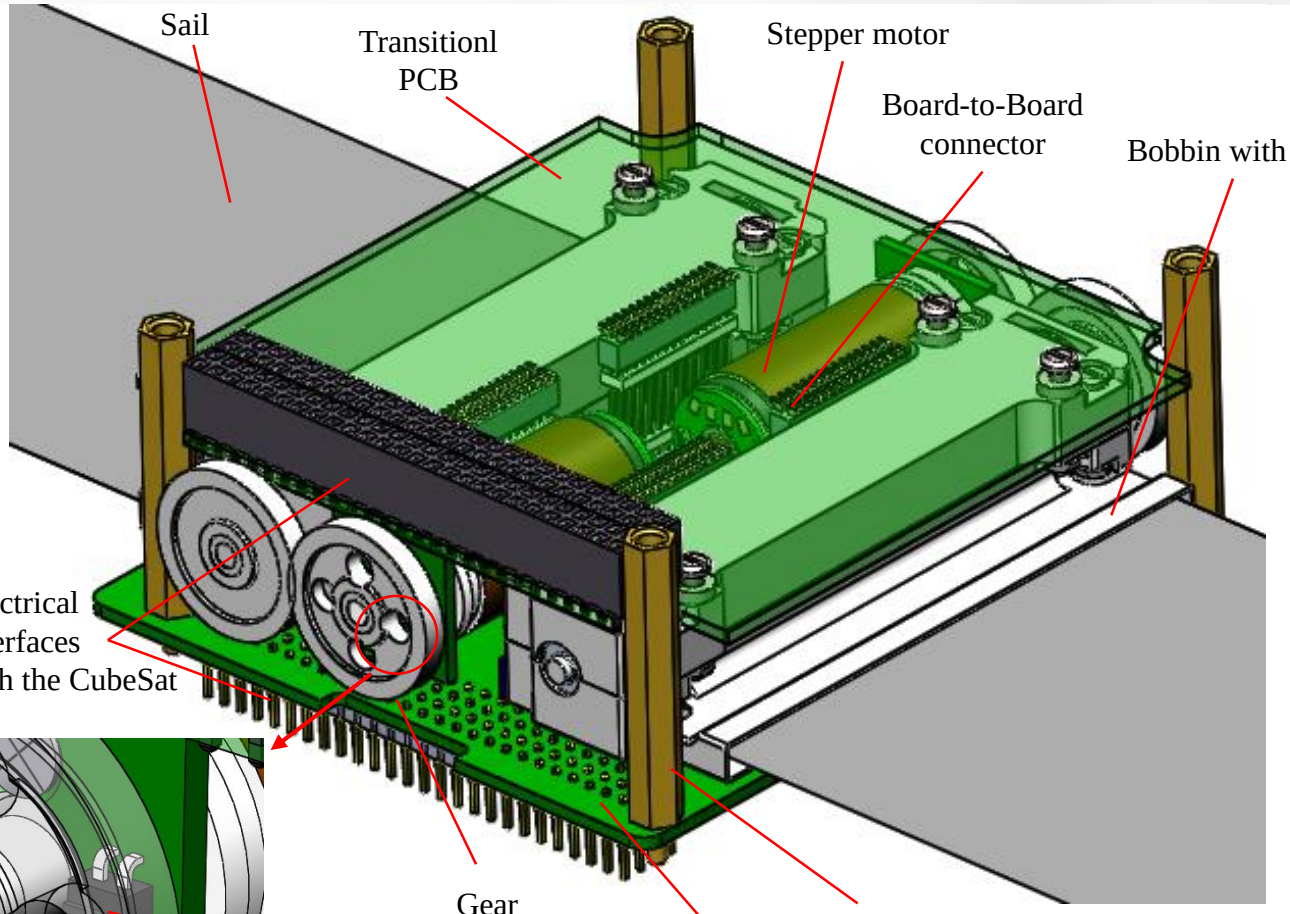


Mass, kg	0,30
Dimensions, mm (sail is folded)	90 x 96 x 38
Sail max length, m (two blades total)	20
Sail max width, mm	76
Average energy consumption	0
Energy consumption during sail deploying/folding	1,2 W (up to 15 min)

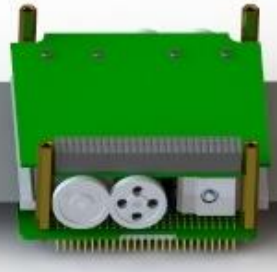
Sail unit internal design

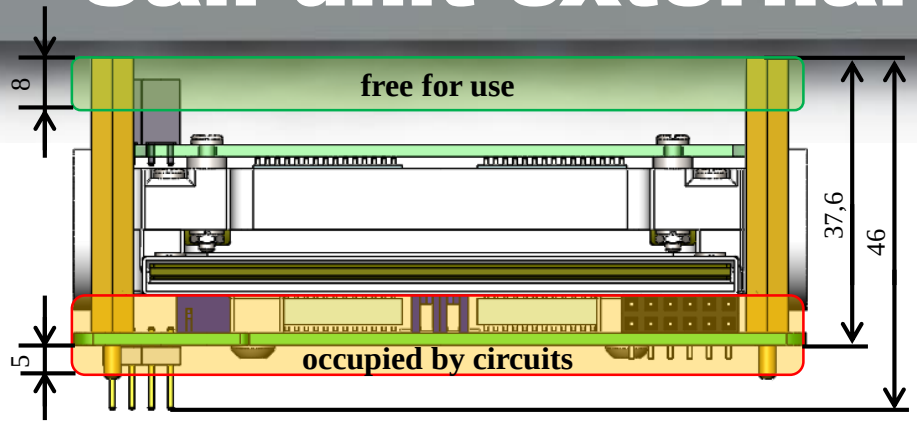


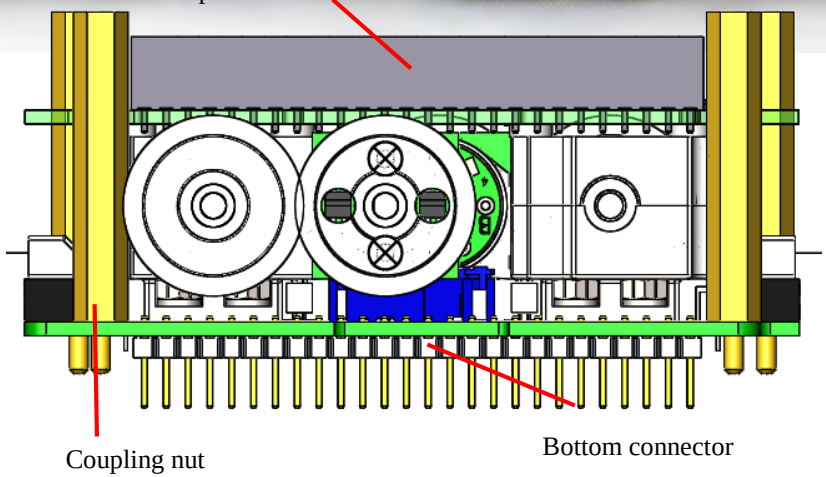
- Solar Sail Unit
  - Bobbins with sail
  - Motor drives
  - Avionics
  - Structure

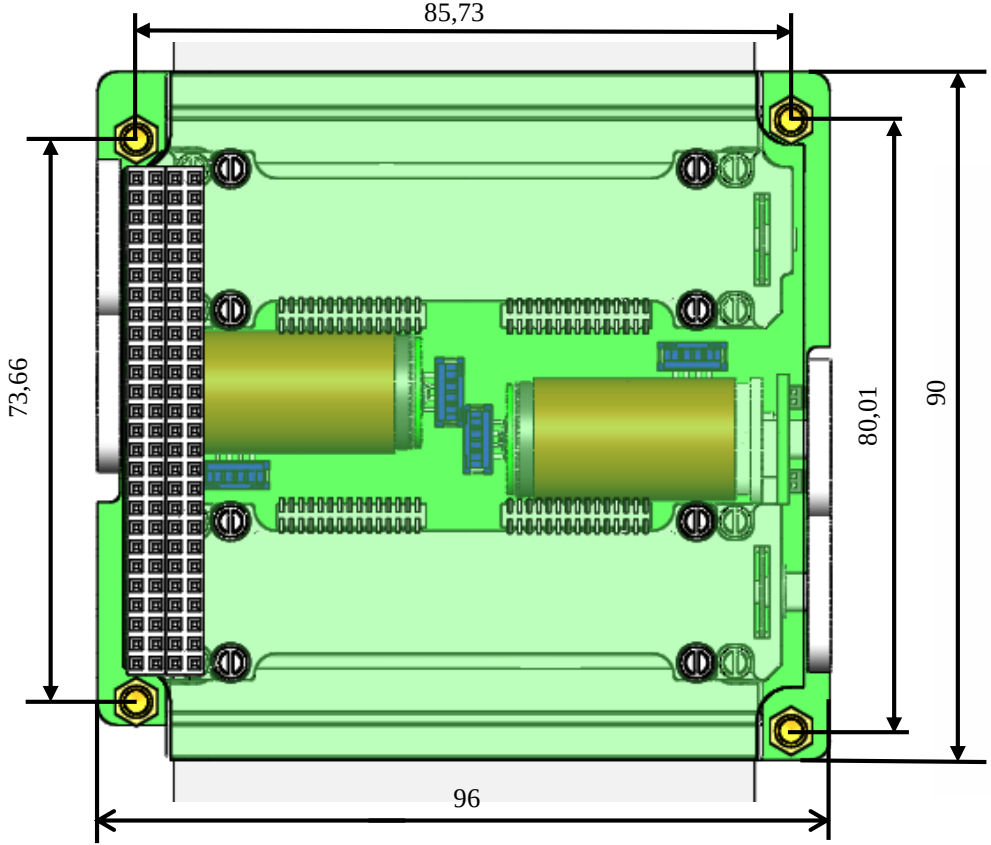


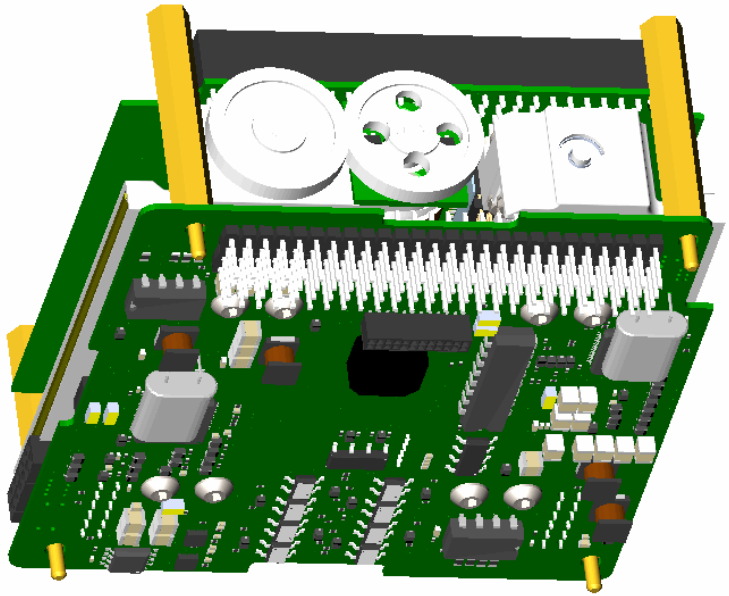
Sail unit external design





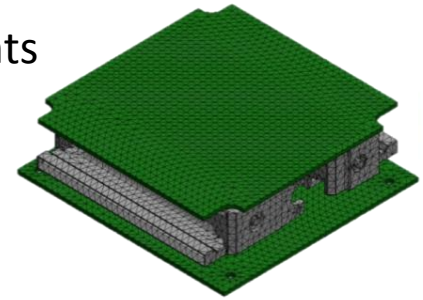




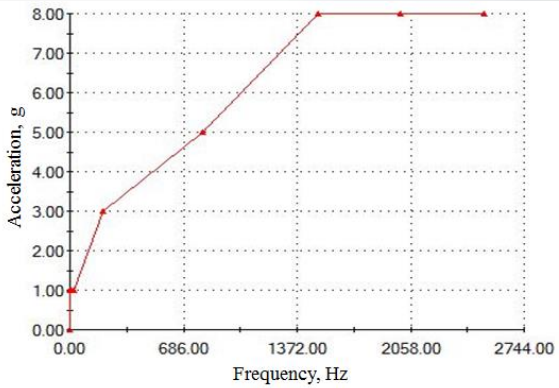


Strength analysis

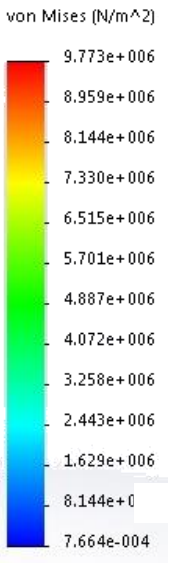
Design environment: SolidWorks Simulation
Static load: 10 g acceleration
FEM mesh: 42908 Tet10 elements
Safety factor: > 4.0

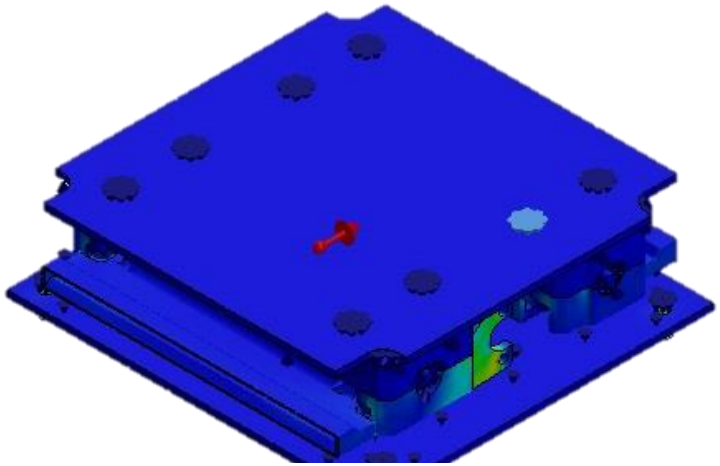


Dynamic load profile



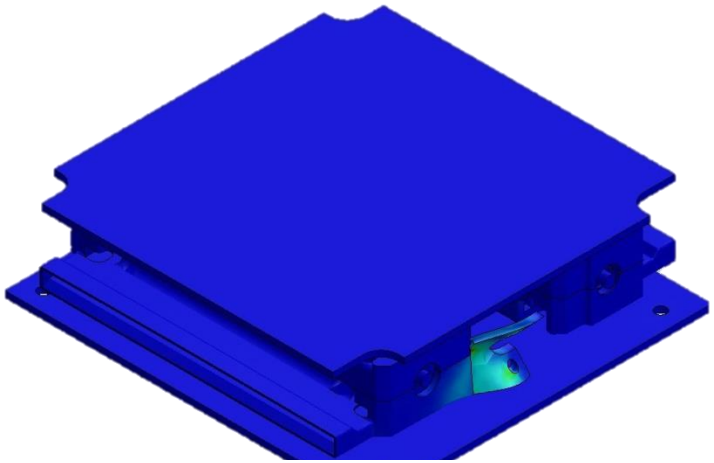
Results of the static strength analysis:

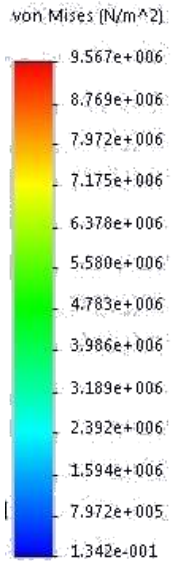




Maximum stress (Z – axis) ≈ 10 MPa

Results of the dynamic strength analysis (Q=10):

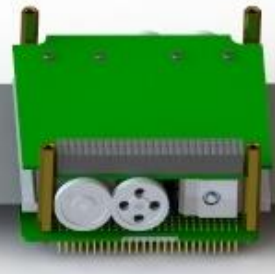




Maximum stress (X – axis) ≈ 10 MPa

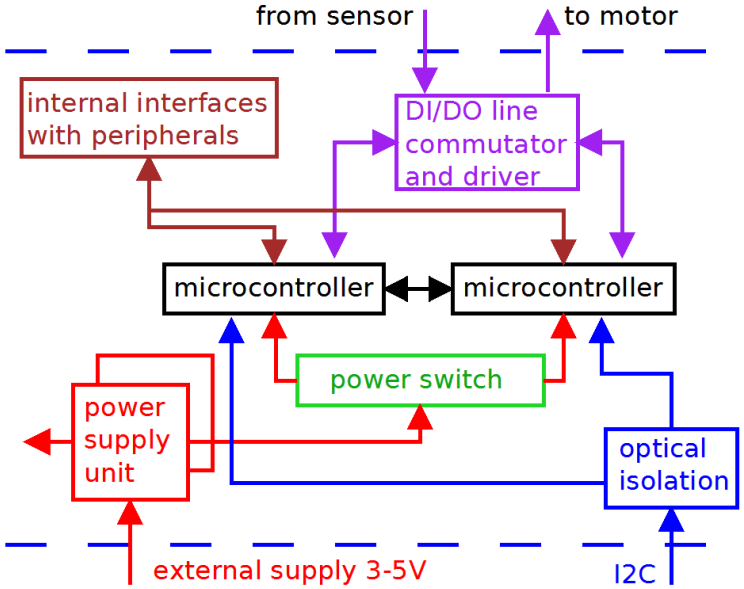
The unit withstand static and dynamic loads during a launch with safety factor >4

Avionics

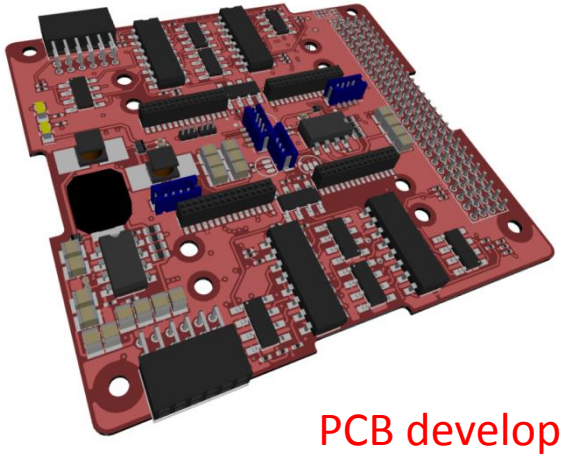


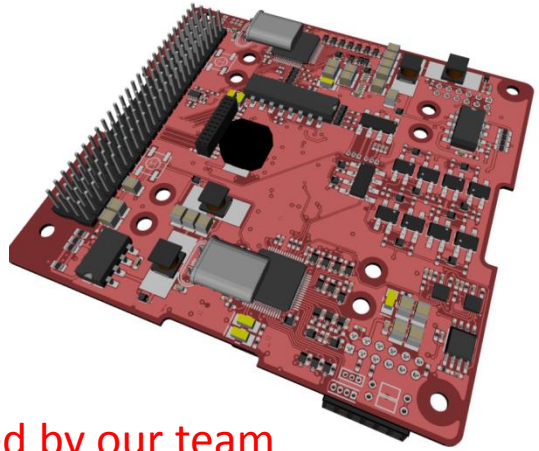
Specifications :

- Regulated power(3,3; 5,0 V) for internal circuits
- Control of all operating modes of a sail
- Full-redundancy
- One failure in any component tolerance
- Unit control by I2C bus
- Telemetry/sail status by I2C bus
- Sail deploying/folding is done by commands from groundstations throw CubeSat radio



Avionics architecture

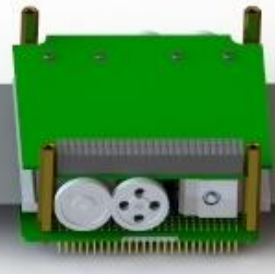




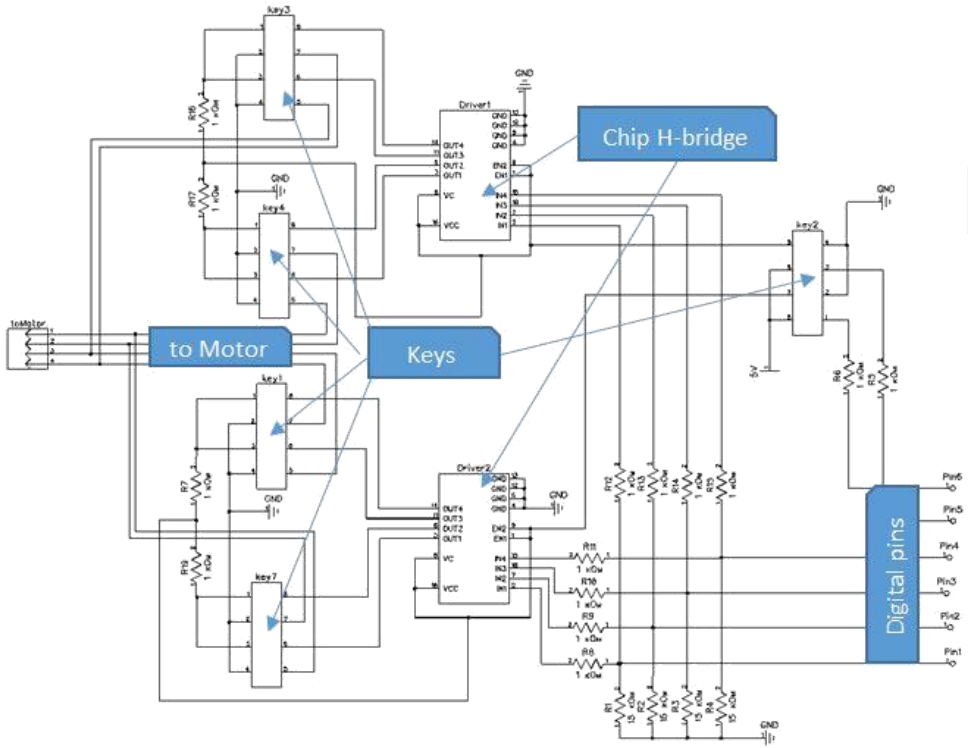
PCB developed by our team

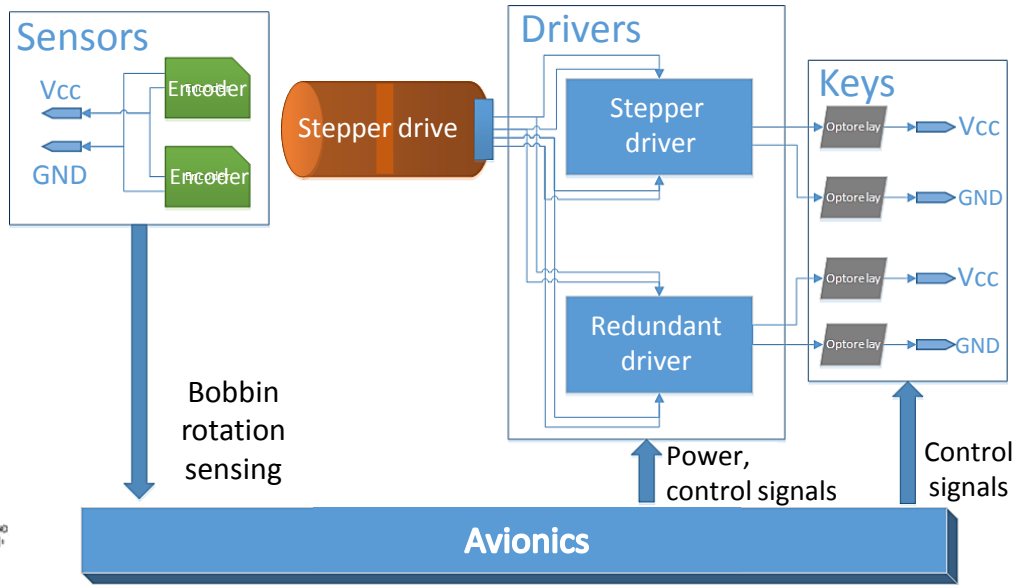
Primary Russian reliable electronic components

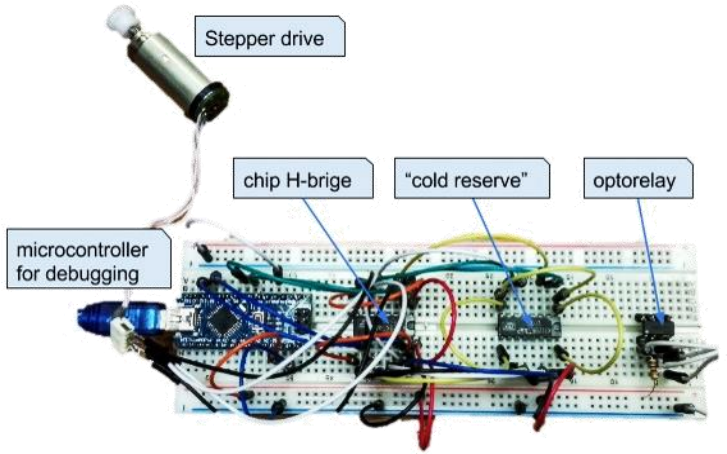
Motor drives



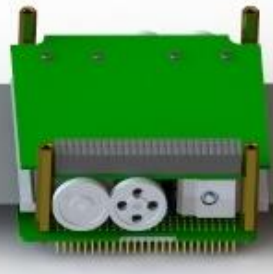
- Stepper bipolar motors are used for sail deploying/folding
- Typical H-bridge motors drivers realized, but cold redundant
- Fails are detected by sensing bobbins rotation

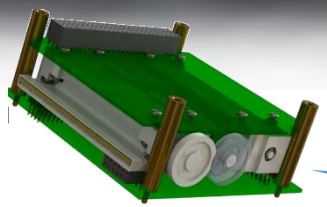






Integration into the CubeSat





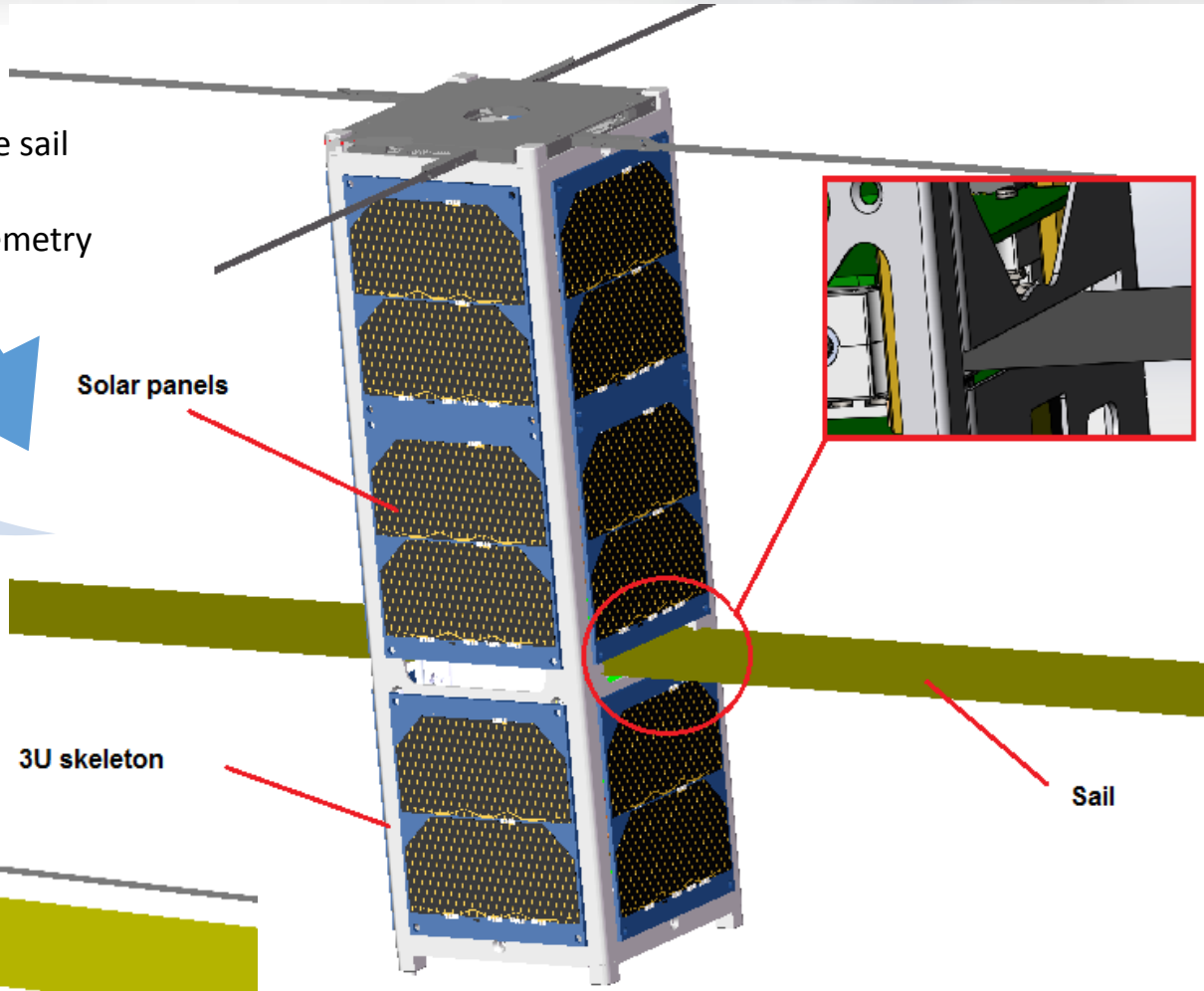
Operates the sail

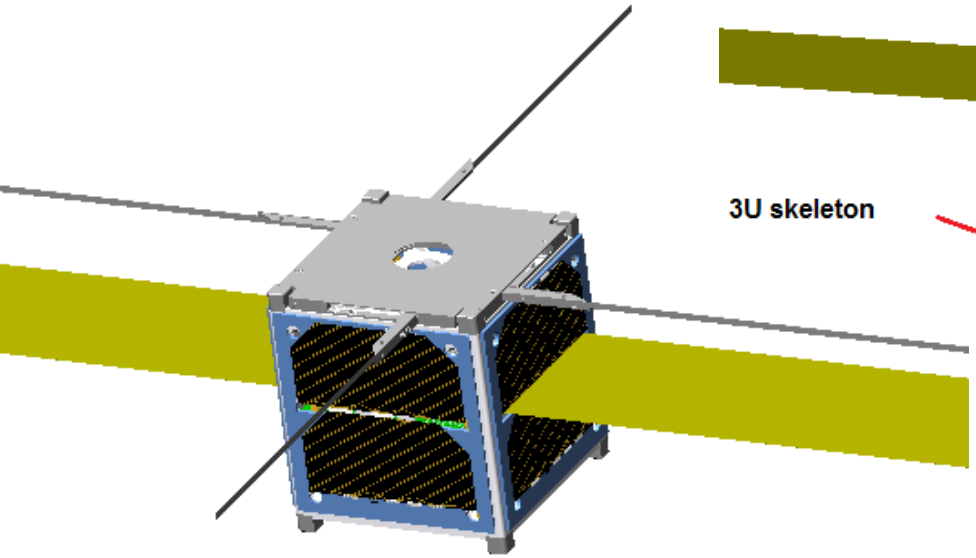
Telemetry

Spinning for Sail deploying

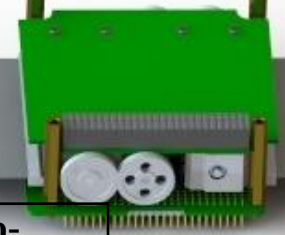
Commands from ground station

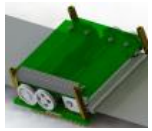
Power supply





Analogs and our advantages



Criteria for comparing	BMSTU Solar Sail Unit 	ClydeSpace Pulsed Plasma Thruster 	Micro-space micropro-pulsion system 
Technology	Thin-filmed construction	Electric pulse thrusters	MEMS cold gas thruster
Mass	0,30 kg	0,28 kg	0,30 kg
Energy consumption	Average: 0 During sail deploying: 1,5 W up to 15 min	2,7 W	2 W
Total Impulse	-	42 N*s	40 N*s
Delta V (for 3U CubeSat)	-	10,5 m/s	10,0 m/s
Operation features	Continuous micro thrust	$40x10^{-6}$ N*s impulses with 1Hz frequency	Continuous thrust
Cost	3 k$	15 k$	≈ 90 k$

Ability to deorbit the spacecraft in a fully passive mode

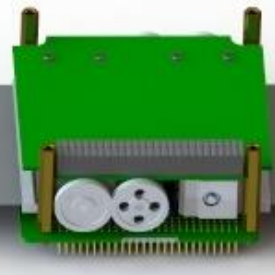
Low energy consumption

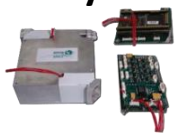
Low cost compared to conventional propulsion systems

And more over:

- Absence of consumable materials (fuel);
- Simple design and therefore higher reliability;
- Using primary Russian electronic components;
- Long-term benefits (Solar Sail technology).

Economic benefit



Cost part	BMSTU Solar Sail Unit	ClydeSpace Pulsed Plasma Thruster	Microspace micropropulsion system
			
Device cost	3 k$	15 k$	90 k$
Time of orbit phasing	0,18 year	0,055 year	≈ 0 year
Cost of satellite operation time losses	11,8 k$ [1]	3,6 k$	0 k$
Total Cost:	**14,8 k$**	**18,6 k$**	**90 k$**
Mission benefit	**75,2 k$** [1]	**71,4 k$**	**0 k$**

1) Conservative estimation. Really CubeSats payloads will be out of operation for only 1-2 weeks (only when Solar Sail is deployed). Operation time looses will decrease significantly

Satellite form factor	CubeSat 3U
Satellite mass	4 kg
Power	10 W
Number of satellites in constellation	4
Orbit	Sun synchronous orbit 500km
Satellites position in orbit	In orbit plane with phasing angles: 0°, 90°, 180°, 270°
Operating life	5 years
Launch type	Piggy back launch with main payload - Earth observation satellite

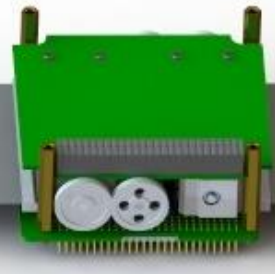
$$C_{TIME} = (C_{SAT} + C_{launch}) / T_{LIFE}$$

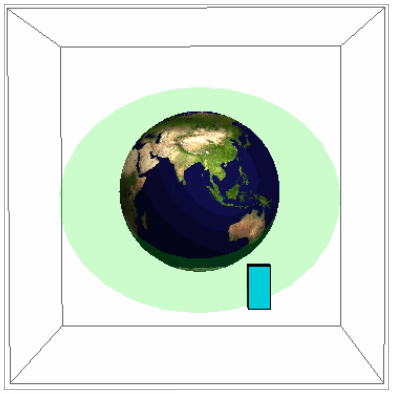
C_{SAT} = 200k$ – satellite development and production cost (BMSTU expert estimation)

C_{launch} = 130k$ - satellite launch cost (DNEPR rocket launch provider)

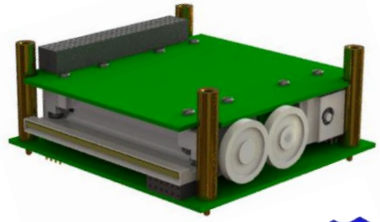
T_{LIFE} – satellite operation time

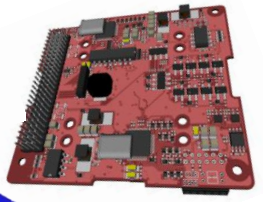
Conclusions

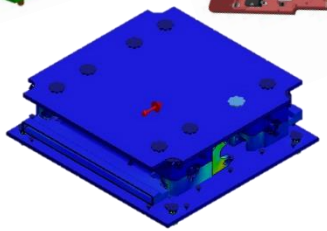




- The work proved the feasibility and technological competitive of forming a satellite constellation with solar sail
- The algorithm and mathematical model for ballistic simulation are developed
- The Solar Sail unit for CubeSats was developed, that can:
  - Form a constellation
  - Reduce the waste satellites

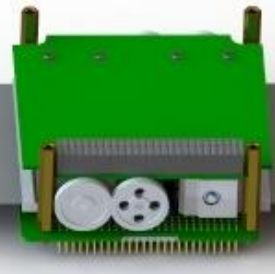






- Our Solar Sail Unit withstand static and dynamic loads during a launch on typical launch vehicle
- Economics estimates have shown that our solution for CubeSat orbit constellation forming can be competitive

Perspective

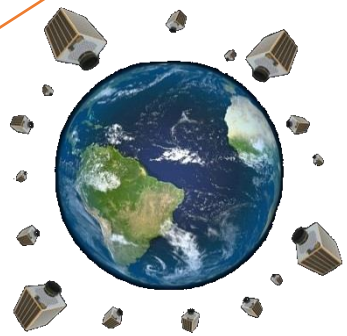


Mobile communication

Real time Earth observation

Space weather monitoring

Solar Sail Unit



- We made a mock-up and it’s testing is planned soon
- The next step for this technology is flight proving and demonstration
- We will be ready to flight in one year and started to find opportunity for a launch

Gratitude

Thanks to:
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And thanks everybody, who is here today, for your attention!