Era of Small Satellites: Pico, Nano and Micro Satellites (PNM Sat)-An Over View Frugal Way to Access Low Earth Orbit

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Abstract
Every nation small or big is aspire to launch their own satellite to space and wish to provide an opportunity to their scientists/students in such a way to encourage them to continue the space research. For majority of the nations and academic institutions including leading research universities, it is still a distance dream! Including former Yugoslavian Countries (Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Serbia (including the regions of Kosovo and Vojvodina) and Slovenia). Committee for Space Programme Development (CSPD), Serbia has striving hard to provide an opportunity for building and launching of satellites for former Yugoslavian countries. In continuation of their sustained efforts of last two years, CSPD has succeeded in establishing a working relationship with India and paved the way for Indo-Serbian Collaborative Research leading to the realisation of launching of satellites of small nations. This paper highlights the opportunities opened up globally during the Space 2.0 era and need for the Pico, Nano and Micro Satellites (PNM Sat) as a frugal way to access the space and sustain space research by academic institutions and small nations in a frugal way!

Keywords: Pico, Nano and Micro Satellites (PNM Sat), CanSat, PocketQube, CubeSat, UNITYsat

ACRONYMS AND ABBREVIATIONS

Al	*Aluminium*
AA	*Aluminium alloy*
AOCS	*Attitude and orbit control subsystem*
ASD	*Acceleration spectral density*
ATOX	*Atomic oxygen*
CAD	*Computer-aided design*
COM	*Communication subsystem*
CoG	*Center of gravity*
CoM	*Center of mass*
EO	*Earth observation*
EPS	*Electric power subsystem*
E-sail	*Electric solar wind sail*
EMC	*Electromagnetic compatibility*
ESD	*Electrostatic discharge*
EM	*Engineering model*
ESA	*European Space Agency*
FEA	*Finite element analysis*
FPGA	*Field-programmable gate array*
FH	*Flight hardware*
GEO	*Geosynchronous orbit*
CG	*Gold gas*
HW	*Hardware*
HS	*High-level sine*
HSCOM	*High-speed communication*
IFA	*Inverted-F antenna*
LV	*Launch vehicle*
LEO	*Low Earth orbit*
MoS	*Margin of safety*
MEO	*Medium Earth orbit*
OBCS	*On-board computer subsystem*
PSD	*Power spectral density*
PCB	*Printed circuit board*
PDF	*Probability density function*
PNMSat	*PicoSat, NanoSat and Micro Sat*
PR	*Public relations*
RF	*Radio frequency*
RW	*Reaction wheel*
SDOF	*Single-degree-of freedom*
SPL	*Sound pressure level*
SS	*Stainless steel*
ST	*Star tracker*
STR	*Structure subsystem*
Ti	*Titanium*
UHF	*Ultra-high frequency*
VHF	*Very high frequency*

Introduction

The first man-made object that was launched into space was the Sputnik-1 satellite [1] in 1957. That was fascinating and appealing for all humankind and escalated the Space Race [2], consequently developing technologies and bringing attention to space science around the globe. Space become more accessible and open not just for governmental space agencies and huge companies, but for universities and other educational institutions in recent years. Technologies and devices have a tendency of becoming smaller in size and more powerful in performance (an ideal example is the Smartphone industry). A similar development has occurred in small satellite design, they have decreased in size as well as becoming more standard in their build-up. This trend was introduced by the California Polytechnic State University and Stanford University as CubeSat in 1999.

> ***CubeSat** concept introduced by Bob Twiggs and Jordi Puig-Suari in 1999*
> - *small (10x10x10 cm, 1 kg – Picosatellite)*
> - *low cost*
> - *short development time*
> - *ideal for education*
> - *involvement in all phases of Space project*

Cube Satellite (CubeSat)
It is a cubic-shape satellite identified by the number of units. One unit, more commonly known as 1U, is a cube with a volume equivalent to the one litre and a side-length of 10 cm. By merging a few cubes on top of each other, the variety of sizes increases (1U, 2U, 3U, 6U…). Satellites can be categorised by their mass. The one with a mass below 1 kg is a picosatellite, which is very often a 1U CubeSat (by default the mass of each unit should not exceed 1.33 kg), or a PocketQube (0.25U). The majority of launched or built CubeSats consist of nanosatellites with a mass of 1-10 kg, shown in Figure 1, as per March 14th 2017 [3].

Majority of 3U CubeSats mentioned in Figure 1, below, with a nominal mass limitation equivalent to 4 kg, however depending on the deployer (mechanical interface between the CubeSat and the launch vehicle (LV)) the mass can be higher. As in the case of ISIPOD, the maximum allowable mass for 3U is 6 kg [4]. A spacecraft with a mass range from 10 to 100 kg is a microsatellite, below 1 kg a picosatellite, and below 0.1 kg a femtosatellite. The smallest publicly-known femtosatellite is KickSat, a 3.5 by 3.5 cm single printed circuit board (PCB) with microprocessor, gyroscope, magnetometer, radio with antennas, and solar cells [5].

As with any piece of hardware (HW), a satellite needs a structure for holding it together or deploying into the orbit as per case of KickSat. Moreover, the development process for space structures is somewhat similar to the ground-application one with much more strict requirements and constraints.

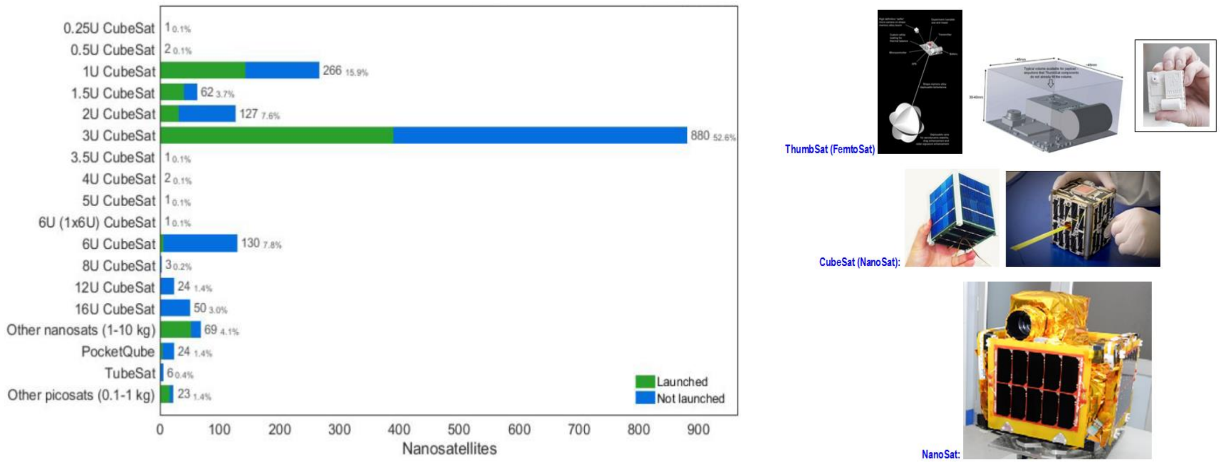


Figure 1. Nanosatellites by type

Development process initiates with the list of requirements and ends up with the product delivering for LV integration; it consists of designing, verification, manufacturing, and testing. Design means developing requirements, identifying options, doing analysis and trade studies, and defining a product in enough detail so one can build it [7, p.1]. For the ground applications, one also considers the outer look (how it looks like and how it feels like), however, for the space mission the main target in designing is functionality under certain requirements (some exceptions exists for public relations (PR) purposes). Hence, the structure has to be cost-effective which means obtaining high performance, reliability, and confidence for spent money, considering not only knowns but also variables and uncertainties [7, p.1].

Nanosatellites (NanoSat)

- *First CubeSats launched in early 2000*
- *By now: > 800 nanosatellites launched*
- *Record in 2017: 104 on a single PSLV launcher*
- *Exponential increase in recent years*
- *Standard deployers important*
- *XPOD, P-POD, ISIPOD, Nanoracks (from ISS)*
- *Standardized launcher interfaces*
- *Initially mostly 1U, 2U, 3U CubeSats*
- *Trend to larger nanosatellites 6U, 8U, 12U*
- *Nanosatellite classification 1…10 kg mass*

In the particular case the satellite consists of payloads (which conduct scientific and technologic demonstration and performance) and subsystems or satellite bus (which operates the spacecraft). The structure supports the payload and spacecraft subsystems with enough strength and stiffness to preclude any failure (rupture, collapse, or detrimental deformation) that may keep them from working successfully [7, p.23]. Key requirements consist of functional (what must be done), operational (how well it must be done), and constraints (limit the available sources, schedule, or physical characteristics) [7, p.26]. The risk has to be evaluated and if the elimination is not feasible due to constraints in terms of time, cost, or schedule shift, than one has to accept the certain probability of failure or damage. In addition, the level of risk has to be evaluated with its influence on the entire mission – will it cause full mission failure or just minor element deformation that does not affect the mission success. Any risk evaluation starts with the estimation of failure probability and resolving consequence of that failure.

Space Mission Habitat

After the satellite reaches required orbit it will be exposed to other harmful habitats in the near-Earth space environment. The list consists of, but is not limited to, vacuum, thermal radiation, charged-particles radiation, neutral atomic and molecular particles, micrometeorites and space debris, magnetic fields, and gravitational fields [7, p.61].

Various sources are influencing the man-made objects as a function of orbit (Figure 2), where LEO is a low Earth orbit (160-2000 km), MEO is a medium Earth orbit (2000-35000 km), and GEO is a geosynchronous orbit (35876 km).

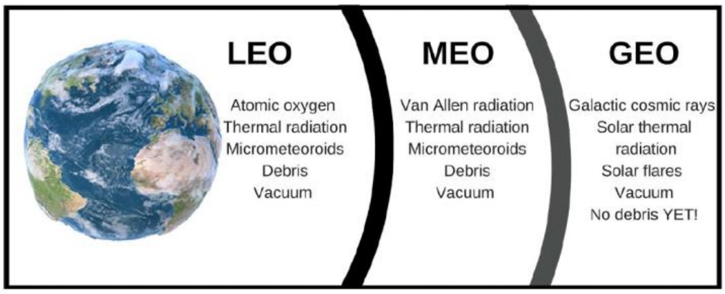


Figure 2. Space environment as the function of altitude

The term **vacuum** describes extremely low pressure in space. A vacuum has various effects on the structure. In vacuum, polymer-based materials (thermal insulators, adhesives, and the matrices for advanced composites) release substances in a gaseous form [7, p.63]. The substance is one of an organic origin or absorbed nitrogen, oxygen, and carbon dioxide on the ground. Moreover, the material has issues with water desorption that was absorbed by the material during on-ground processes. The aforementioned effects may degrade certain properties of material and might cause condensation on critical surfaces (lenses, mirrors, and sensors). Another effect is the internal pressure of sealed structures that was assembled at the ambient Earth pressure.

Thermal radiation is mainly a reference to direct solar flux (1309-1400 W/m^2) which means intensity of radiation, planetary albedo (global annual average is 0.3) which originates from the reflected solar flux, planetary emission flux (189-262 W/m^2), and the satellite electronics' infrared thermal emission. This results in a non-uniform heating of spacecraft which causes materials (especially with various thermal expansion coefficients) to expand differently, resulting in structural stresses. In addition, certain components require a precise operation temperature range (e.g. batteries, propellant tanks). The solution is to implement an active (requires power) and/or a passive (materials and coatings) thermal control system.

Charged-particle radiation is a high flux of energetic particles. The major sources are *trapped radiation* (Van Allen belt) which contains electrons and protons in the MEO, *galactic cosmic radiation* which contains 90% of protons and 10% of helium nuclei in the GEO and further, and solar radiation which is largely continuous solar wind (electrons, protons, and helium nuclei low in energy) and solar flares (high energetic protons and heavy ions) [7, p.69]. The radiation has a negative effect on the electronics and may cause damages or failure. There is no way to predict or to be protected against galactic cosmic radiation, thus electronics have to tolerate it.

Classification/Category of Satellites (Based on Weight)

a) Minisatellite (100–500 kg)
b) Microsatellite (10–100 kg)
c) Nanosatellites (1 -10 kg)
d) Picosatellites (100 gm-1 kg)
e) Femtosatellites (10-100 gm)

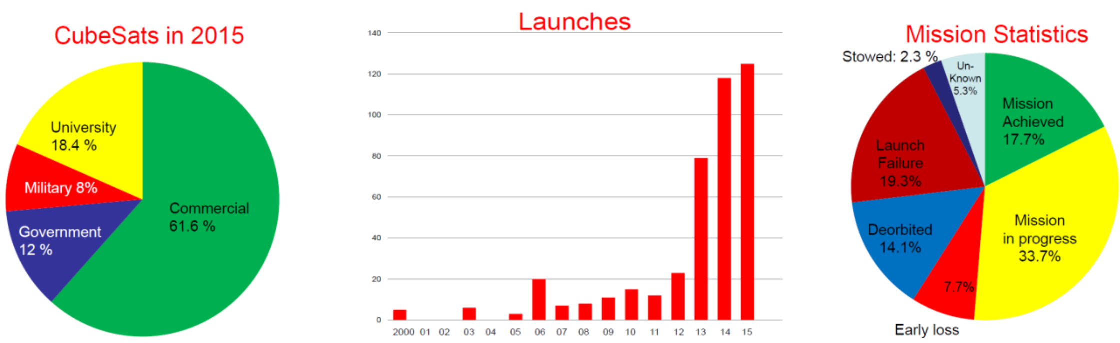


Figure 3. NanoSats Launched till 2015 *Source: M.Swartwout*

LEO contains relatively stable atomic and molecular particles. When the spacecraft moves at orbital hypervelocity, its surface is struck by particles that cause material recession. The most damaging is atomic oxygen (ATOX) [8]; among other impactors are *N_2, O_2, Ar, He, H*. The erosion process and rates rely on the material's composition. The most damaging are polymer based materials, while the impact on metals is not that significant, especially on aluminium (Al) which is commonly used for space structures due to its low density, radiation shielding capabilities, and manufacturability. For instance, an exposed Al surface to ATOX at an altitude of 500 km has an erosion rate of 7.6e-6 mm/year, however the same parameters applied to silver results in the erosion rate of 0.22 mm/year [9].

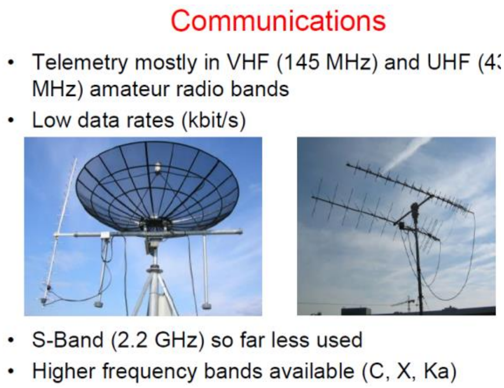
Space Debris

- *Increasing number of nanosatellites imposes a space debris risk*
- *LEO orbit crowded*
- *Orbit to comply with < 25 year orbital life-time*
- *Or: Active De-orbiting Mechanisms*
  - *Deployable sails/structures*
  - *Drag mechanisms*
  - *Propulsion (e.g. micro arc-jets)*

Against trapped and solar radiations, shieldings are implemented. The structure of the satellite can act as a radiation shield as well. For instance, in order to keep the total radiation dose below 10e4 rads per year at 4000 km, the required thickness of aluminium is 9 mm [7, p.71].

Micrometeoroids and Space Debris can have a fatal impact on the spacecraft structure at the orbital hypervelocity due to impacts (if the size of impactor is large enough). One can implement shielding against smaller objects. In addition, thermal blankets decrease the impact of small objects [10, p.10-11].

The **plasma brake** (Figure 4a) is an end-of-life disposal technique for objects in the LEO. The infamous space debris issue was regulated with a limit in the orbital post-mission lifetime of 25 years or 30 years after launch for all satellites in the LEO [11]. The problems behind already existing debris are upcoming large constellations shown in Figure 4b. The probable collisions at orbital hyper-velocities (over 3 km/s) will cause defragmentation which will consequently result in an enormous escalation of small objects, better known as the Kessler syndrome, which will disable access to LEO if the escalated problem is ignored.



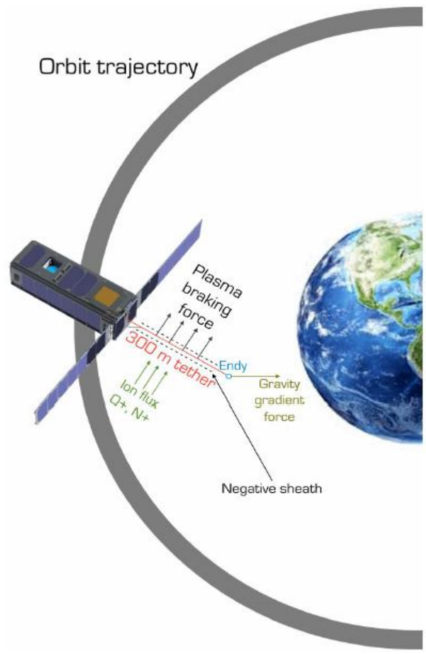


Figure 4a. Plasma brake concept for the gravity-stabilised tether

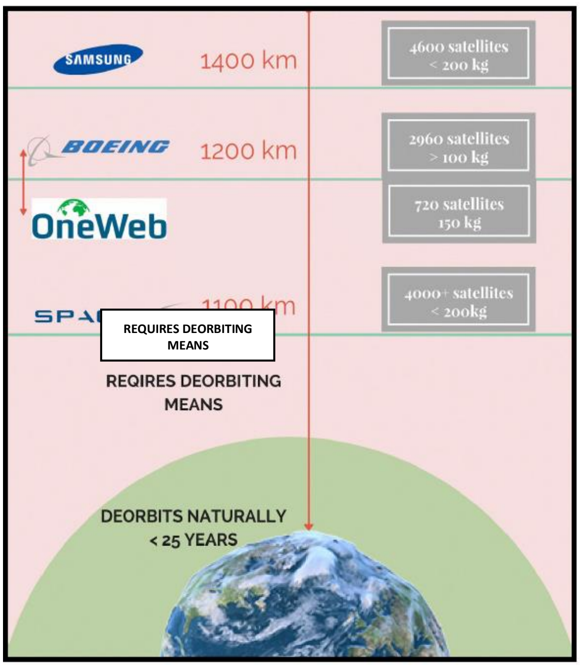


Figure 4b. Upcoming large constellations

Space Missions with Few Examples

- Astrobiology
- Astronomy
  - BRITE
  - CANIVAL-X (NASA): formation flying, virtual telescope
- Atmospheric Science
- Biology
- Pharmaceutical Research
- Earth Observation
  - Planet Labs (commercial)
- Space Weather
- Telecommunications
  - AIS (UTIAS, SPIRE- commercial)
  - ADS-B monitoring
  - Messaging
  - Amateur Radio
- Material Science
- Technology (OPS-SAT)

Major Components of Satellite Programmes

Space: Antenna systems, Attitude Control Systems, Communication Systems, Command Data Handling Systems, CubeSat Structures, Solar Panels,

Launch: CubeSat Deployers,

Ground: Ground Stations, Ground Support Equipment, Generic Engineering Model

a) Size & Objectives : CubeSat and Nanosat/Picosat Missions
b) CubeSat Platforms
c) Payload Development and Integration
d) Launch Services
e) Ground Stations
f) Commissioning and Operations Support

<table>
<tr><th>Work Group</th><th>Major Team/Core Activities</th></tr>
<tr><td>Antenna Systems</td><td rowspan="6">Selection of Payload (Novelty)</td></tr>
<tr><td>Attitude Control Systems</td></tr>
<tr><td>Communication Systems</td></tr>
<tr><td>Command Data Handling Systems</td></tr>
<tr><td>CubeSat Structures</td></tr>
<tr><td>Solar Panels</td></tr>
<tr><td>CubeSat Platforms</td><td rowspan="2">Payload Design and Development</td></tr>
<tr><td>Payload Identification/Development</td></tr>
<tr><td>System Integration</td><td>Payload Integration</td></tr>
<tr><td>Software Programming</td><td>Mission Software Development (Programming)</td></tr>
<tr><td>Launch Service</td><td>Launch Logistics</td></tr>
<tr><td>Ground Control Station</td><td>GCS</td></tr>
<tr><td>Commissioning and Operations Support</td><td>Observation</td></tr>
<tr><td>Review of Literature/Case Studies</td><td>Documentation</td></tr>
<tr><td>Testing and Analysis/ Failure Analysis</td><td>System-Level Testing</td></tr>
</table>

Applications of Satellite Programmes:

ISISpace has been working on training next generation scientists and engineers, performing small scale science missions or planning a novel application using a globe-spanning constellation etc. Potential space applications are listed below *(but not limited to the following)*:

1. ***Earth Sciences:*** *Nanosatellites for better understanding of our own planet*
2. ***Ship Tracking Services:*** *Near real time vessel tracking using satellite-AIS*
3. ***Aircraft Tracking:*** *Keeping track of aircraft on a global scale using ADS-B*
4. ***Space Research:*** *Small scale astronomy and exploration missions*
5. ***Climate Monitoring:*** *Network of satellites to monitor climate change*
6. ***Earth Observation:*** *Provide real-time imaging capability with satellite swarms*
7. ***Agriculture Monitoring:*** *Improve crop production using remote sensing data*
8. ***Microgravity Research:*** *Use the space environment to gain new insights*

9. ***Pipeline Monitoring:*** *Monitor critical infrastructure using satellites*
10. ***Signal Intelligence:*** *Use small satellites to ensure the security of our nation*
11. ***Education and Training:*** *Train the next generation scientists & engineers*
12. ***Telecommunications:*** *Provide global connectivity using small satellites*
13. ***Technology Validation:*** *Test your latest technologies onboard a small satellite*

Various Successful Strategies to Nurture Interest and Mobilize Passionate Workgroups/Team

What is a CanSat?
A CanSat is a simulation of a real satellite. All components are housed inside a can up to 350 ml. CanSat provides an affordable way to gain basic knowledge and skills in Space engineering for teachers and students, as well as experience engineering challenges when designing Satellites. Students are able to design and build a small electronic payload that can fit into the cans to 350 ml. CanSat is launched by Rocket, Balloon, Plane or Drone and delivered in apogee. With the Parachute, the CanSat slowly descends to the ground and carries out its mission during descent (for example: measures air pressure and temperature and sends telemetry). By analyzing the data collected by CanSat, students will explore the reasons for the success or failure of its mission. It is an affordable process and keep engaged the passionate students and in the process the team acquires adequate fundamentals/knowledge of system engineering along with necessary systems and subsystems to build their CubeSat!

Space engineering learning, based on the CanSat/Rocketry concept, enables students to gain hands-on experience through a specific interdisciplinary project. Since this is a Space engineering project, teachers and students will gain experience from mission defining, conceptual design, through integration and testing, to launching and actual system operation, ie experience from the whole Space project cycle and then participate in the CanSat/Rocketry competition with its peers at home country and abroad. One of the main advantages of the CanSat/Rocketry concept is its interdisciplinary: combination of mathematics, physics, informatics/ programming, mechatronics, telecommunications, aviation and rocketry, mechanics, etc.. CanSat is a simulation of a real, large, Satellite and contains all the components as a real Satellite, but with limited complexity. Whenever the CanSat/Rocketry Teams Win-Lose the Competitions, they have enough lessons learned in the process to cement their unity with the project and dos and don’ts as well! It helps the team members to get motivated and sustain their interest for learning and doing continuously till they launch their CubeSat to LEO!

Benefits of CanSat/Rocketry Based Education:
CanSat/Rocketry is an effective educational tool for:

- Learning by doing;
- Involving students in technology and engineering as a practical complement to other, fundamental, subjects they study, such as mathematics and physics;
- Emphasizing teamwork where each student has a specific task/role that creates a sense of responsibility for him/her;
- Students gain experience of the complete process: defining the mission, design, development/ constructing, programming, testing, launching and analysis;
- Simple conducting experiments with balloon/rocket/plane/drone;
- Learning methods can be adapted to the age level of students, or to their needs and abilities;
- Students are able to analyze the reasons for success or failure after descending CanSat and Rocket to the ground;
- Acquired knowledge and experience can be applied to other projects as this concept enables obtaining of ideas and stimulates students' thinking;
- Useful for a further education/career guidance process;

Today, almost every country in the higher education system has a CanSat program, so the initiative to establish CanSat/Rocketry Championship at the Global level is additionally justified.

Facts as of 2020 January 1 *(Nanosatellite Database by Erik: https://www.nanosats.eu/)*
Nanosats launched: 1307
CubeSats launched: 1200
Interplanetary CubeSats: 2
Nanosats destroyed on launch: 87
Most nanosats on a rocket: 103
Countries with nanosats: 65
Companies in database: 467
Forecast: over 2500 nanosats to launch in 6 years

Design and Development of Indo-Serbian PocketQube, CanSat and UNITYsat:

TSC PocketQube V1(50 mm x 50 mm x 50 mm) :

Power Specifications

- Total unit works at 3.3V.
- Battery Specs (planned to use): Li-po 3.6V @ 1240mAh.

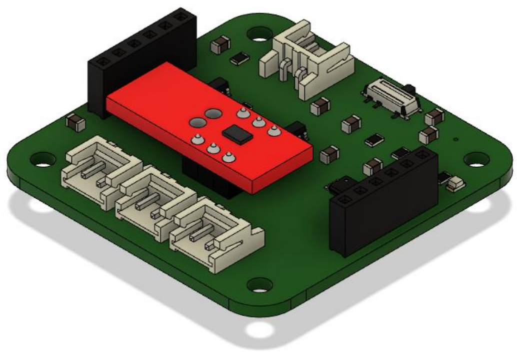
Board Specifications

- Per board: 44.45mm (L) x 44.45mm (W) x 8.5mm (header height) + desired board thickness
- Available Board thickness 0.4, 0.6, 0.8, 1, 1.2, 1.6, 2.0 in mm
- 2 Layer Board.
- 4 M3 Mounting Holes.
- All Boards are interconnected in two rail configurations using Stack headers.

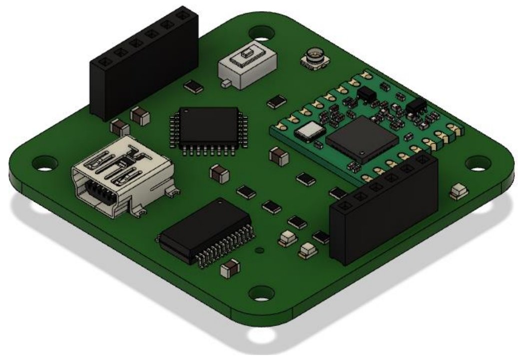
Board Description

EPS

- Can plug 3no of 2V @ 150mA solar cells (Dimension 5cm x 5cm x 4mm).
- Discharge Protection Circuit.
- 3V3 Voltage regulator.
- LiPo Fuel gauge (to monitor battery).
- Power Switch.



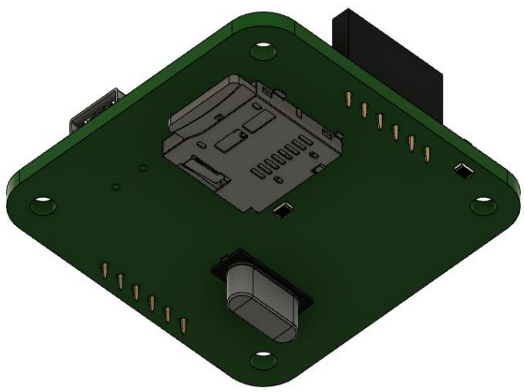
Snapshot of EPS v1



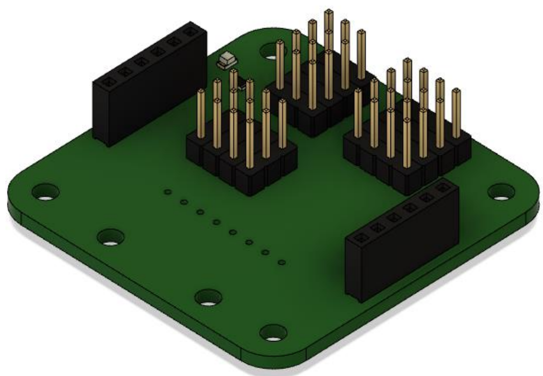
Snapshot of OBC (Isometric Top View)

OBC (with COM)

- Has On-board USB Interface for uploading and serial monitoring.
- Uses 8-bit AVR RISC-based microcontroller combines 32kB Flash, 2KB SRAM
- Uses SX1268 433/868 MHz **LoRa** Module. (http://www.dorji.com/products-detail.php?ProId=64)
- Can plug in 16GB micro SD Card for Data storage.
- Contains UFL Male Connector for antenna extension.



Snapshot of OBC (Isometric Bottom View)

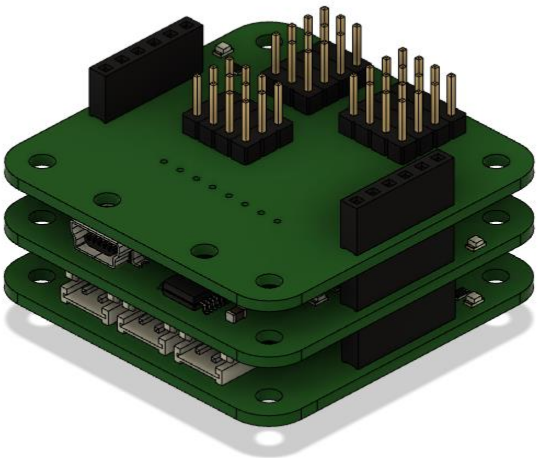


Snapshot of Sensor Breakout Board (Isometric Top View)

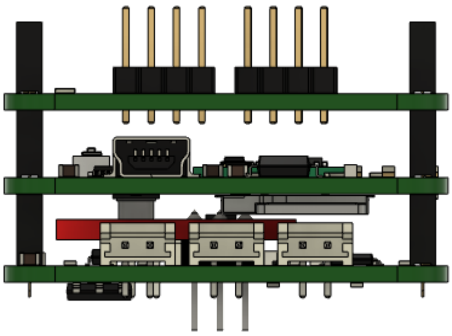
Sensor Breakout

- Holds Temperature and 9-DOF (BMP280 + MPU9250) Sensors On-Board
- 4 I2C Ports.
- 4 Analog Pinouts
- 4 Digital Pinouts. (1 PWM).

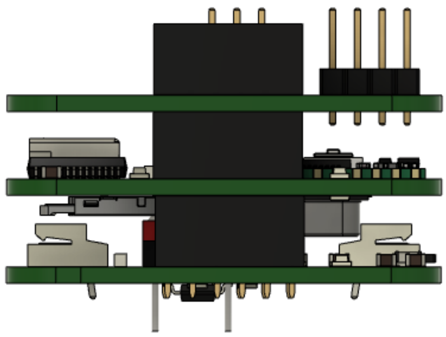
Complete PocketQube View



ISOMETRIC VIEW

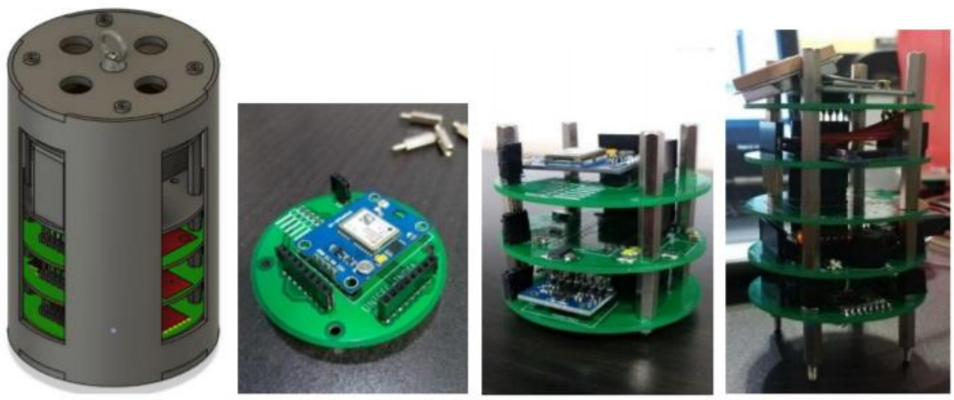


FRONT VIEW

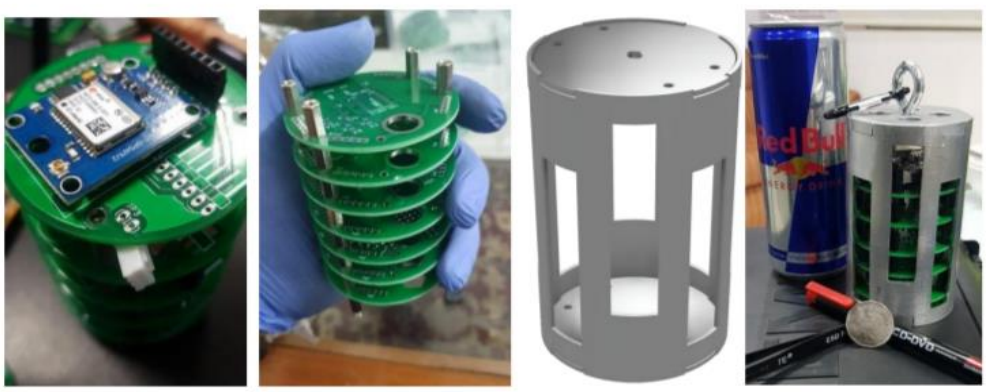


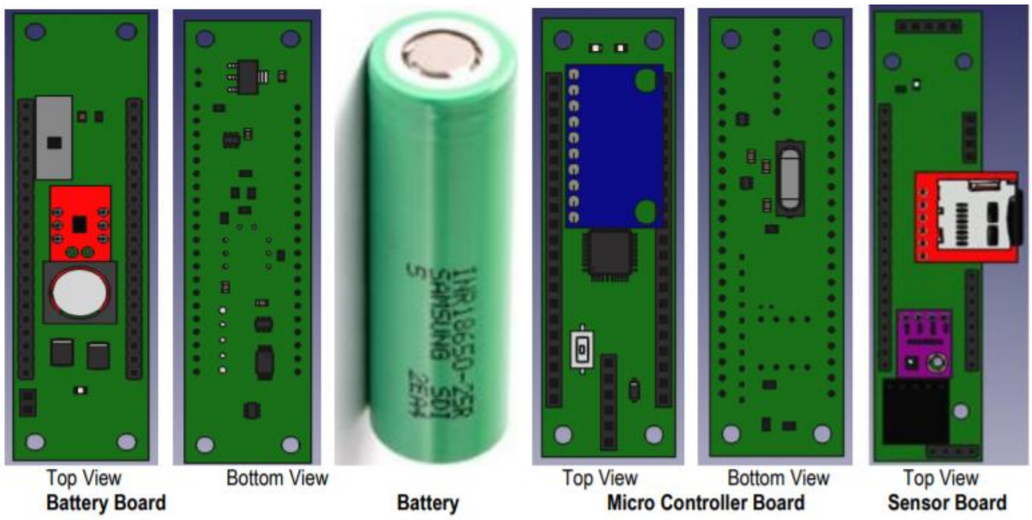
RIGHT VIEW

Indo-Serbian CanSat:

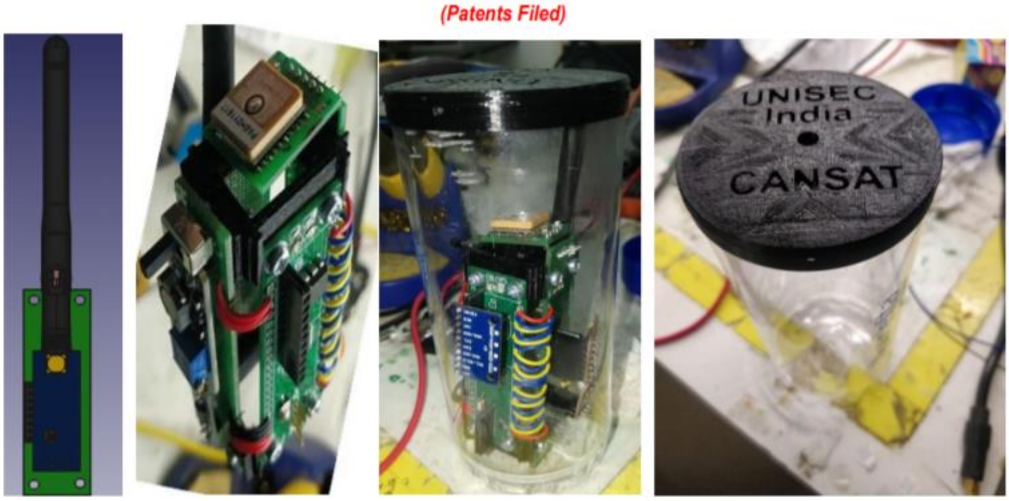


Views of Final Assembly of CanSat Built during above Workshops *(Patents Filed)*





(Patents Filed)



Indo-Serbian Collaboration has paved the way for Conducting Capacity Building CanSat Workshops in Eastern Europe along with CSPD, Serbia! Also planned to Organize Continental and Global CanSat/Rocketry Competitions 2020/2021 at Serbia and Other Host Countries by the end of 2020 onwards and Global Finals will be held at Serbia! Students' Exchange/Higher Education/Joint Development of Satellites for Former Yugoslavia Regions also have been planned.

UNITYsat:

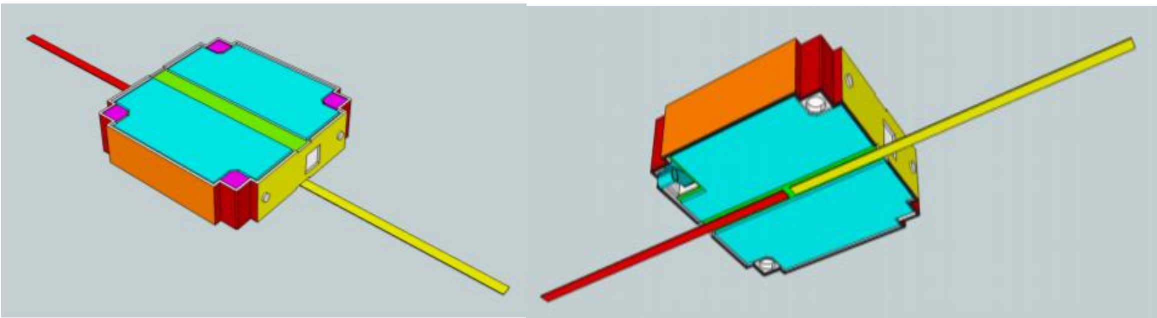
The *Unity program* (originally conceived by CSPD, Serbia has been evolved into Indo-Serbian Collaboration) represents a response to the increasing need of individuals and groups for easier access to Space, in order to achieve sustainable progress in their work and development of this area. The concept itself emerged in the post-conflict region as an attempt to re-establish the cooperation of the people in the region, but this time in a completely different way, which in itself goes beyond the current mode of thinking and demands a new approach in international relations, whereby independence in creation of each participant is not jeopardized, and on the other hand there is a constant presence of the necessity of cooperation among the participants. In this way, everyone achieves both individual and group goals, and progress is inevitable. Technically, the *Unity program* is based on CubeSat standards (http://www.cubesat.org/), primarily by dimensions and basic characteristics. The 3U POD deployer carries several small satellites (UNITYsat) which will be delivered in Orbit. The main characteristics of the UNITYsat are as follows:

- **a)** The chassis of every UNITYsat is made by combining of anodized aluminium and 3D printed filament;
- **b)** Basic dimensions of every UNITYsat are 10.0cm x 10.0cm x 2.5cm;
- **c)** User/developer defines payload of its own UNITYsat with respect of the standards defined in this document;

The price is formed on the one UNITYsat: development kit + launch service. Although the volume of the one UNITYsat is 250 cm^3, the same rules (rights and obligations) are valid as for large satellites. The user/developer can put all the basic subsystems and payload in its own UNITYsat if meets the defined standards. Testing of each UNITYsat before the launching process is mandatory and this is also defined by mentioned standards.

- Each UNITYsat is sorted one on the other.
- The Remove Before Flight (RBF) must be on designated side of the UNITYsat (yellow side) in the form of switch, that must not exceed the external dimension of the designated side, i.e. it must be in the same plane.
- RBF is a mandatory part of each UNITYsat regardless of whether the user/developer has chosen to power its own UNITYsat only from batteries or uses and the Solar Cells.
- Batteries may be full charged during launching, but the user/developer must provide a place (port) on a designated (yellow surface in UNITY.skp) side of UNITYsat for external battery charging and diagnostics if desired. External battery charging and diagnostics will not be allowed after placing UNITYsat in 3U POD deployer!

The *Unity program* is an Open source program, which means that all components except the external structure can be designed and standardized by third parties, under a condition that everything complies with the standards defined in program document. This is one of the reasons why this program is called *Unity*.



UNITYsat Assembly

Defined Standards for UNITYsat

a) General Requirements

- All parts shall remain attached to the UNITYsat during launch, ejection and operation. No additional space debris shall be created.
- Pyrotechnics shall not be permitted.
- No pressure vessels shall be permitted.
- No hazardous materials shall be used on a UNITYsat. If you are not sure if a material is considered hazardous contact us.
- UNITYsat materials shall satisfy the following low out-gassing criterion to prevent contamination of other spacecraft during integration, testing, and launch. *(Note : A list of NASA approved low out-gassing materials can be found at: http://outgassing.nasa.gov)*
- The latest revision of the UNITYsat Define Standards shall be the official version (http://2comnet.info/komsat/en/unity-program/), which all UNITYsat users/developers shall adhere to.

b) UNITYsat Mechanical Requirements

The UNITYsat configuration and physical dimensions shall be per UNITY.skp mentioned in Program Document *(which will be shared among interested Teams/Countries after signing NDA).*

- The UNITYsat shall be 109.0+0.1 mm wide (X dimensions per UNITY.skp).
- The UNITYsat shall be 109.0+0.1 mm wide (Y dimensions per UNITY.skp).
- A single UNITYsat (basic dimension) shall be maximum 25.0 mm tall (Z dimension per UNITY.skp), including antennas and Solar cells (if exist). *(Note: Users/developers should keep in mind that external structure (Anodized aluminium) of the UNITYsat will be delivered to each user/developer after additional purchase of structure. It is a prerequisite for participation in the program! In this way deviations in the external dimensions will be prevented. The internal/core structure which holds electronics can be 3D printed (ABS filament). User/developer can design the internal/core structure as it likes, but with respect of the Defined Standards in this document. In the UNITY.skp is given only an example of internal/core structure and changes are allowed!)*
- **Mass:** Each single UNITYsat (basic dimension) shall not exceed 220g mass; Two UNITYsat shall not exceed 440g mass and Three UNITYsat shall not exceed 660g mass etc.
- **Materials:** For external structure material is Anodized aluminium. For internal/core structure material ABS (3D printing filament) shall be used.

- The UNITYsat shall use separation springs with characteristics defined in Table 1 on the designated place *(white holes at the Bottom side in UNITY.sk*p). Separation springs with characteristics can be found using McMaster Carr P/N 84985A76. The separation springs provide relative separation between UNITYsats after deployment from the 3U POD Deployer.

Table 1: UNITYsat Separation Spring Characteristics

Characteristics	Value
Plunger Material	Stainless Steel
End Force Initial/Final	0.5 lbs./1.5 lbs.
Throw Length	0.05 inches minimum above the standoff surface


Spring Plunger

c) UNITYsat Electrical Requirements

Electronic systems shall be designed with the following safety features:

- No electronics shall be active during launch to prevent any electrical or RF interference with the launch vehicle and primary payloads. UNITYsat with batteries shall be fully deactivated during launch or launch with discharged batteries.
- The UNITYsat shall include deployment switch on the designated place (Blue switch on the Bottom side in UNITY.skp) to completely turn off satellite power once actuated. In the actuated state, the deployment switch shall be centered at the level of the bottom side of external structure (black surface in UNITY.skp).
  - All systems shall be turned off, including real time clocks.
  - The UNITYsat diagnostics and battery charging after the UNITYsat have been integrated into the 3U POD Deployer are not allowed. Note: All diagnostics and battery charging shall be done while the UNITYsat deployment switch is depressed.
- The UNITYsat shall include a Remove Before Flight (RBF) switch. The RBF switch shall be ON after UNITYsat integration into the 3U POD Deployer.
  - The RBF switch shall be accessible from the Access Port location (yellow surface in UNITY.skp).
  - The RBF switch shall cut all power to the UNITYsat once it is OFF.
- Batteries may be full charged during launching, but the user/developer must provide a place (port) on a designated (yellow surface in UNITY.skp) side of UNITYsat for external battery charging and diagnostics if desired. External battery charging and diagnostics will not be allowed after placing UNITYsat in 3U POD Deployer!
- An example of setting the Antenna and bending method will be performed live through the Workshop during the development process (example of dipole antenna 17.3cm x 2). This example is extremely important because based on it must be set up and bend and the Antenna(s) with other dimensions. The contact between the Antenna and the interior side of the 3U POD Deployer is NOT allowed!
- Deploying of Antennas and/or Solar cells etc. are allowed only by using Timer Switch (e.g. NiChrome timer switch) which countdown is triggered by separation of UNITYsats after ejection from the 3U POD Deployer in Orbit. The Timer countdown must last at least 15 minutes before deploying of Antennas and/or Solar cells.

d) Operational Requirements

UNITYsats shall meet certain requirements pertaining to integration and operation to meet legal obligations and ensure safety of other UNITYsats.

- Deploying of Antennas and/or Solar cells etc. are allowed only by using Timer Switch (e.g. NiChrome timer switch) which countdown is triggered by separation of UNITYsats after ejection from the 3U POD Deployer in Orbit. The Timer countdown must last at least 15 minutes before deploying of Antennas and/or Solar cells.
- Users/developers shall obtain and provide documentation of proper licenses for use of frequencies.
  - For amateur frequency use, this requires proof of frequency coordination by the International Amateur Radio Union (IARU). Applications can be found at www.iaru.org.

- Instead of using of UNITYsat Acceptance Checklist (UNITYsat AC) CSPD&ITCA shall conduct a minimum of one fit check in which user/developer hardware shall be inspected. A final fit check shall be conducted prior to launch.

e) Testing Requirements

Testing shall be performed to meet all requirements deemed necessary to ensure the safety of the UNITYsats and the 3U POD Deployer. Test plans that are not generated by the CSPD, Serbia & ITCA/TSC, India are considered to be unofficial. Requirements derived in this document may be superseded by launch provider requirements. All flight hardware shall undergo protoflight and acceptance testing. At the very minimum, all ***UNITYsats shall undergo the following tests.***

- Random Vibration Random vibration testing shall be performed as defined by CSPD & ITCA/TSC and/or LV provider, or if unknown, GSFC-STD-7000.
- Thermal Vacuum Bakeout Thermal vacuum bakeout shall be performed to ensure proper outgassing of components. The test cycle and duration will be outlined by CSPD & ITCA/TSC and/or LV provider, or if unknown, GSFC-STD-7000.
- Visual Inspection Visual inspection of the UNITYsat and measurement of critical areas shall be performed both by user/developer and by CSPD & ITCA/TSC.
- Qualification UNITYsats may be required to survive qualification testing as outlined by the CSPD & ITCA/TSC and/or LV provider. If are unknown, GSFC-STD-7000 (NASA GEVS). Qualification testing will be performed at developer facilities. In some circumstances, CSPD & ITCA/TSC can assist developers in finding testing facilities or provide testing for the developers. Additional testing may be required if modifications or changes are made to the UNITYsats after qualification testing.
- Protoflight All UNITYsats shall survive protoflight testing as outlined by the CSPD & ITCA/TSC and/or LV provider. If are unknown, GSFC-STD-7000. Protoflight testing will be performed at developer facilities. In some circumstances, CSPD & ITCA/TSC can assist developers in finding testing facilities or provide testing for the developers. UNITYsats SHALL NOT be disassembled or modified after protoflight testing. Additional testing shall be required if modifications or changes are made to the UNITYsats after protoflight testing.
- Acceptance (depends in first place of LV provider / could be subject of changes) After delivery and integration of the UNITYsats into the 3U POD Deployer, additional testing shall be performed with the integrated system. This test ensures proper integration of the UNITYsats into the 3U POD Deployer. Additionally, any unknown, harmful interactions between UNITYsats may be discovered during acceptance testing. The 3U POD Deployer Integrator shall coordinate and perform acceptance testing. After acceptance testing, the UNITYsats will be removed from 3U POD Deployer to perform diagnostics through the designated UNITYsat diagnostic ports and then again integrated into the 3U POD Deployer to repeat the process one more time. Visual inspection of the system shall be performed by the 3U POD Deployer Integrator. The 3U POD Deployer SHALL NOT be disintegrated at this point.

f) Responsibilities

CSPD & ITCA/TSC responsibilities are to deliver purchased development kit to users/developers, to enable launch (through its LV provider partner) at a contracted price once capacity of 3U POD Deployer is full, to integrate the users/developers UNITYsats with 3U POD 7 Deployer, to ensure the safety of the 3U POD Deployer and protect the launch vehicle (LV), primary payload, and other Satellites. Responsibility for deploying UNITYsats in Orbit is on LV provider. Responsibility for functionality of the UNITYsats is on users/developers.

g) Applicable Documents

The following documents form a part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document shall take precedence.

- Cal Poly CubeSat Design Specifications Document (www.cubesat.org)
- LSP Program Level P-POD and CubeSat Requirements Document (LSP-REQ-317.01)
- General Environmental Verification Standard for GSFC Flight Programs and Projects (GSFC-STD-7000)
- Procedural Requirements for Limiting Orbital Debris (NPR 8715.6)

Frugal Way to Access Low Earth Orbit (LEO)

Problems Identified by Space Enthusiasts to Access LEO:
Limited knowledge, insufficient experience, Money for launch / cheaper launch, Time in general, Period of time to launch

Tools Available to Access LEO:

Acquired knowledge, Technology, Collaboration / Teamwork, Motivation

Let's start with the problems of Limited Knowledge and Insufficient Experience using the Tool at our disposal. Due to the interdisciplinary nature of Space Engineering, Acquired Knowledge allows you to be aware of what you do not know and thus save you time and direct you. Collaboration/Teamwork makes up for time and knowledge because not everyone knows everything, so teams are made up of people from many fields. Technology speeds up the process and helps you gain experience because it allows you to make mistakes that you can easily correct.

Motivation is, of course, the basis of everything and is constantly present.

But OK you all knew this, let's see specifically. We want to make a satellite, and we have the problems and tools listed. We decided to start gradually, from the beginning. We adapted the CanSat concept to elementary school age and started learning the same way as making a real satellite because CanSat is a replica of a real satellite and contains everything that has a real satellite, but with limited complexity. We made teams, shared tasks and everyone was given their own scope of work and responsibility. All participants are equally important.

Then we raised everything to a higher level, high school and started studying Rockets. Both Rocket Engine Rockets and Water Rockets, constantly applying the acquired knowledge of fundamental subjects. We put together CanSat and Rocket and launch CanSat as a true satellite. Then things got even more interesting. Then the study at University came, we asked ourselves, what now ... it's not a problem to raise CanSat and Rockets to an even higher level, and even accredit Space engineering programs, but what's the point if we can't reach the goal because we are so small, how do we continue to improve ourselves? How can we contribute to development now? Do we have to wait for employment in some big Aerospace company or Agency?

History has taught us that no one should be underestimated and everyone should be given a chance if possible, if the goal is justified/correct.

These issues occur even at the very beginning and therefore we again applied engineering approach and again start with thinking and thinking... then we realized that we are constantly going around in circles, because new problem that has not been present has now appeared. And that problem is money for the launch / the launch must be cheaper. OK now we have the knowledge and we have some experience, but how to apply it completely, how to go further during study period. (Digression: The cheapest launch is € 25,000 for PQ, which is unrealistic for many institutions / organizations, especially individuals).

Then we applied a tool that has been used all the time, but in the process of learning, and that is collaboration.

India and Serbia have found solution that big players made possible for small players and beginners (you). The UNITY Program was created, these big players are from ISRO. India and Serbia have proposed a new approach in the educational process in which students have the opportunity to apply their theoretical knowledge through the creation of a real satellite during their studies and to motivate one another through competition with their colleagues/students from other institutions and automatically promote this program, which is actually common goal. This is UNITY because you cannot reach the goal easily (and cheaply), you need 13. You are all independent in your work and will be independent in Orbit, but only together you can achieve that goal.

Consider the breadth (wideness) of this Program and how much UNITYs we actually have here and whether it may be a symbolic representation of humanity.

Finally, remember the price of € 25,000 for PQ, OUR/YOUR UNITY has allowed you to get twice as much (in satellite capacity) for € 12,000, and the whole Program applying the Open Source principle of development (which means you can make money, too). Cost effective launch opportunities have been studied extensively by Indo-Serbia Collaborative Team and they wish to share such knowledge to interested workgroups and teams of various countries!

All this is very important because The future of Space Science depends on our ability to attract and engage students into Science, Technology, Engineering and Mathematics (STEM) fields.

Reaching students earlier in their educational development cycle is critical in the development of a workforce for all countries so that they may remain competitive in the global marketplace. Teachers in K-12 education must engage students in STEM curriculum earlier to generate interest, develop skills and provide the educational foundation for students to build upon. The CanSat/Rocketry Program is made for this purpose and UNITY is a logical continuation for the common good." Collaborative opportunities are always open for interested teams from any countries!

Summary

- Nanosatellites and CubeSats have matured from pure educational projects to in-orbit demonstrators
- Proof that demanding scientific and technological missions can be carried out with small satellites at low cost and within short timescales
- Industry and Space agencies are increasingly using nanosatellite technology
- Commercial services are already in place using constellations
- Reliability increased: professional implementation
- Tailored PA/QA standards introduced
- Next astronomy mission can make use of recent developments in processors and communication subsystems
- Coordinated frequency bands should be used instead of traditional amateur radio bands to avoid interference and to provide higher data throughput
- Large number of spacecraft require strict adherence to existing rules and procedures to avoid harmful interference and space-debris problems
    - Authorisation, Registration, Frequency coordination and Compliance with “Code of conduct”

Turn-key CubeSat and nanosat/picosat missions are possible with the help of Innovative Solutions from Consortium of Space Scientists, MSMEs in Space Programmes under the initiative of ITCA. ISISpace engineers were responsible for the integration of 101 CubeSats onto the PSLV launch vehicle of ISRO, a true world record has been created with a launch of 104 Satellites (3 more by ISRO)! Among these 101 satellites, there are 3 satellites where ISISpace, Netherlands played a major role in the design, development and implementation of the spacecraft. They are able to deliver small satellites ready for launch in 6 to 18 months. They also have ample experience with working with a broad range of standardized CubeSat and nanosat parts from various vendors and if needed, customized solutions will be implemented. Customers for satellite missions include government agencies, research institutes, universities and commercial companies. Good numbers of start-ups are working in the area of small satellites and building CanSats, CubeSats and PocketQubes!

Conclusion

The future of Space Science depends on our ability to attract and engage students into Science, Technology, Engineering and Mathematics (STEM) fields. Authentic, hands-on experience with space applications enhances engagement and learning in the STEM disciplines and can help to attract students to STEM careers [17]. The goal of the UNITY program is to provide interested students and small nations the opportunity to lead and participate in the development of a spacecraft payload through its life cycle in a frugal way. The learning experience will be enhanced with CanSat/Rocketry Competitions and development of PocketQube/CubeSat by the team through learning by doing and creating their own “satellite” (highest in RBT Level of learning pedagogy) right from manufacturing, environmental testing, satellite integration, spaceport, launch vehicle, range and spacecraft operations etc. The UNITYsat Program of Serbia will provide a unique and important STEM opportunity for students/researchers in small countries to develop critical skills in systems engineering and space science that will complement their existing programs and initiatives. It is a cost effective, short-term program that provides students/researchers in small countries with an exciting opportunity to conduct valuable scientific space-based research.

Indo-Serbian Collaboration have paved the way for Global Competitions, starting at Continent Level to International Levels along with various knowledge Conferences, Workshops and exclusive Sensitization Seminar “Capacity Building for Student Satellites and Rocketry” has been planned with the help of International experts, which will cover and provide overall bird’s eye view of the above major components of Satellite Programmes. Indian Technology Congress Association (ITCA) has also agreed to network with Global leaders to get various opportunities for funding the entire projects on affordable terms and conditions. ITCA has also initiated 75 Students’ Satellites Programme: Mission 2022 which has envisaged to launch 75 Students built Satellites to LEO to celebrate India’s Freedom 75 Years (1947-2022) in India! Good amount of Academic Institutions and Universities have shown interest and started their own space projects at their campuses enthusiastically.

Lead Agencies for 75 Students’ Satellites Programme: Mission 2022:

Israel: *The Herzliya*

Science Center and Tel Aviv University

India: *Indian Technology Congress Association (ITCA)*

Opportunities for Launch Support and Technical Collaborations: Identified Agencies:

1. Indian Space Research Organization , ISRO
2. Israel Space Agency and Israel Aerospace Industry

3. French National Space Research Center, CNES
4. United Nations Space Office – UNOOSA
5. GK Launch Services (GK) is an operator of Soyuz-2 Commercial Launches from the Russian Spaceports (Vostochny, Plesetsk) and the Republic of Kazakhstan (Baikonur)
6. World Federation of Engineering Organizations (WFEO)-ICT
7. BRICS Federation of Engineering Organisations
8. World Academy of Engineers
9. CANEUS Small Satellite Sector Consortium, Canada/USA
10. University Space Engineering Consortium (UNISEC)–Global, Japan; UNISEC-Serbia, India, Samara, Italy

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