# Fostering space education in Azerbaijan through small satellite design program for undergraduate students

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- *The formulation of the initial framework for the teaching methodology and syllabus for "Introduction to Small Satellites Design 1 and 2"*
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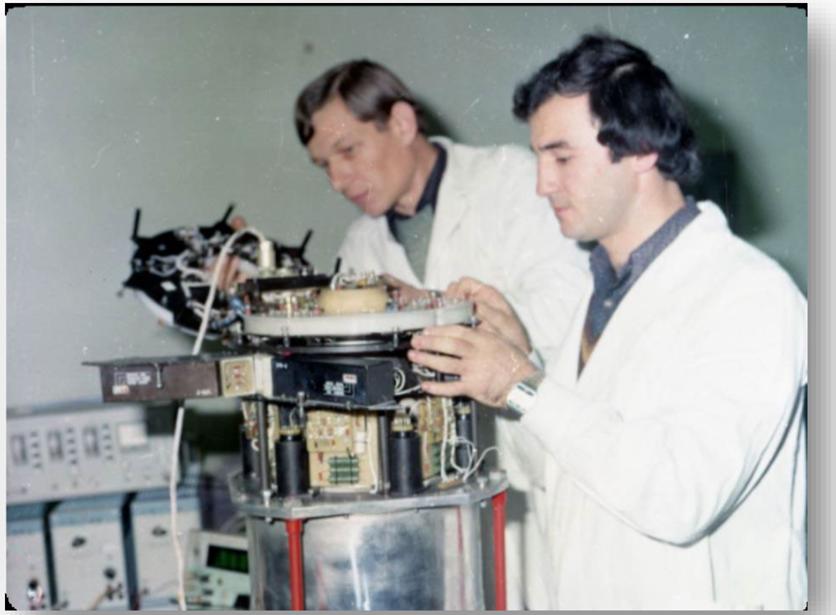
# Introduction

# Overview

*The primary catalyst for the ongoing growth in the nation's capacity for technological sector production and utilization is the establishment of a domestic workforce aligned with global market dynamics.*

**SPACE INDUSTRY**



Leading engineers from the Space Research Institute of the Academy of Sciences of the Azerbaijan SSR are in the process of preparing space equipment for an upcoming flight on October 6, 1984 [1].

*References:* 1. https://azercosmos.az/en/about-us/space-legacy,
2. https://en.wikipedia.org/wiki/Azerbaijan%27s_space_program

The first space agency of independent country [2].

2010

2011

2013

2014

2018

2021

# Overview


Practical showcasing of local students' enthusiasm for space technologies, particularly satellites, through regional CANSAT competitions [1].

There are 46 universities in total, comprising 35 public universities and 11 private institutions [2].

*While Azerbaijani universities may not be included in the list, the preliminary syllabus for the course "Fundamentals of Designing Small Satellites" at the Bachelor's level includes the subject headings of the methodical teaching tool, as well as other necessary exams, tasks, and activities to be conducted during the course.*

*References:* 1. https://cansat.space.az/,
2. https://en.wikipedia.org/wiki/List_of_universities_in_Azerbaijan

# *Survey of local space education and international small satellite design courses*

# Aerospace speciality in local Universities

**In the direction of aerospace mechanics**

- fundamental knowledge of higher mathematics and physics
- calculation and numerical methods
- mechanics of fluids, materials and aerospace structures
- theory of machines and machine parts
- hydraulics, thermodynamics and heat transfer
- aerodynamics, flight dynamics, ballistics and motion theory
- construction, dynamics and stability of flying machines
- design of aircraft, gas-turbine and rocket engines, power units and systems
- composite structures
- CAD/CAE/CAM in the aerospace industry
- production and testing technologies and other disciplines

**In the direction of aerospace electronics**

- fundamental knowledge of higher mathematics and physics
- calculation and numerical methods
- programming
- electrical engineering and electronics, electrical machines and apparatus
- digital systems and microprocessors
- radar equipment, power electronics and transmissions
- power plants
- aircraft electrical and instrumentation systems
- designing on-board microelectronic and microprocessor devices
- avionics systems, information networks and their software
- electronics of modern aircraft and other subjects

**In the direction of flight control systems**

- fundamental knowledge of higher mathematics and physics
- programming
- management theory
- mechanics, electrical circuits
- gyroscopes, transmitters and transducers
- digital systems and microprocessors
- flight control, information-measuring systems and devices
- inertial navigation, on-board control computers and complexes
- aviation devices
- design of automatic control systems of aircraft and other subjects

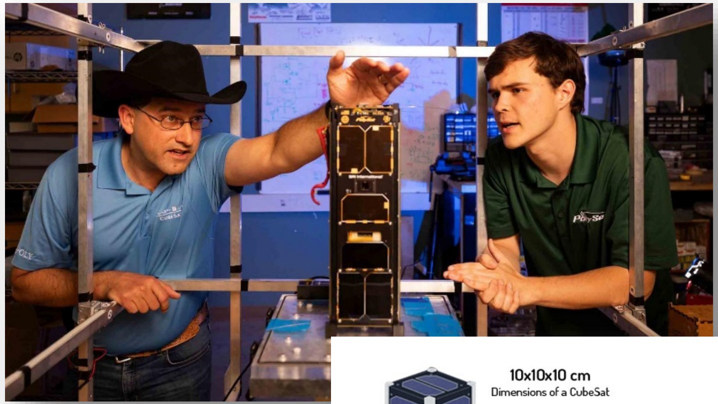
*Aerospace engineering specialty provides specialist training in the design, production, and technical operation of modern aviation and rocket-space equipment. Under this specialty, bachelor's training is conducted in 3 directions -aerospace mechanics, electronics, and control systems [2].*

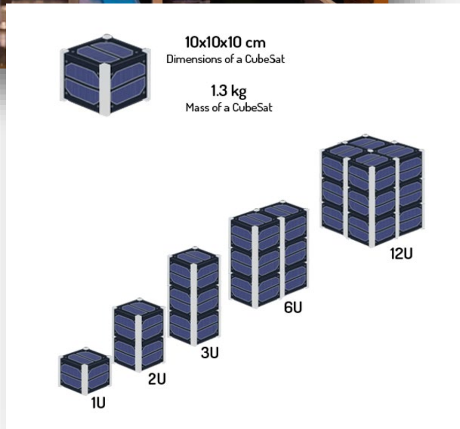
*Whereas the Department of radio electronic and Aerospace Systems is for the purpose of training highly qualified engineers for military purposes within the Faculty of Special Engineering and Technology [1].*

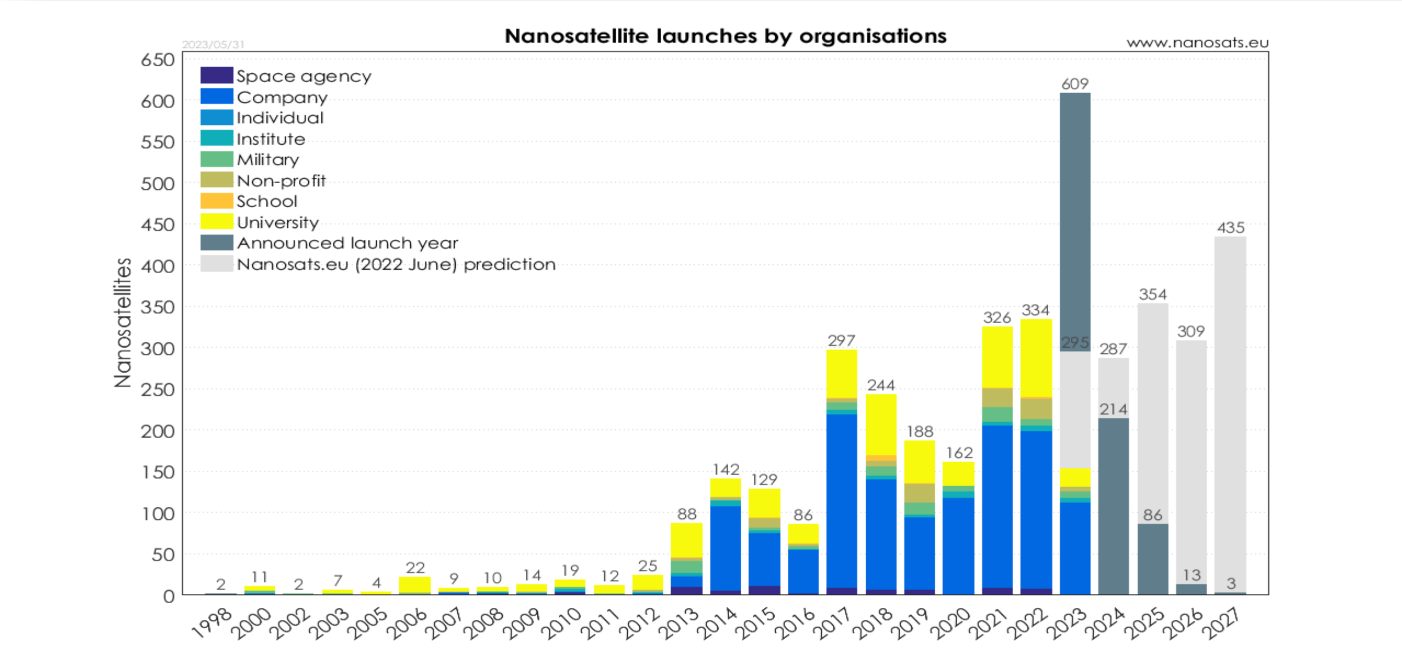
*References:* 1. https://www.aztu.edu.az/sub_site/az/radioelektron-ve-aerokosmik-sistemler-kafedrasi-62,
2. https://naa.edu.az/en/faculties/aerospace-faculty/

# History behind Small satellite educational programs

*The Cal Poly CubeSat Lab is a student run, multidisciplinary independent research lab and the main CubeSat development team at Cal Poly. The CubeSat standard was created by Cal Poly and Stanford University's Space Systems Development Lab in 1999 to facilitate access to space research for university students. Since then the standard has been adopted by hundreds of organizations worldwide. Students in lab get an opportunity to design and develop CubeSats and work on various missions [1].*






*The number of CubeSats launched by universities during 2021-2022 increased from 76 to 84 with an increase of 10.53% [2].*

*References:* 1. https://aero.calpoly.edu/cubesat-and-polysat/ ,
2. https://www.nanosats.eu/

# Survey of Small Satellite programs

| | | |
|---|---|---|
| Phase A | DESIGN AND DEVELOPMENT | Select ~10 programs |
| | | Fund universities through AFOSR |
| | | Emphasize design process from system concept to critical design review maturity |
| | | Conduct 6 design reviews |
| | | Facilitate satellite development workshops and telecoms |
| | | Select missions for Phase B |
| Phase B | INTEGRATION AND TESTING | Support satellite assembly, integration, and testing |
| | | Meet regularly with university teams |
| | | Facilitate hands-on satellite fabrication workshops |
| | | Conduct 3 testing and integration reviews |
| | | Support final testing of integrated satellite and completion of UNP test metrics |
| Phase C | ENVIRONMENTAL TEST | Provide environmental testing capabilities including bake out, thermal cycling, vacuum, and vibration testing |
| | | Enable student participation during the test campaign via the AFRL Space Scholar's Program |
| | | Finalize launch preparation with STP & Launch Vehicle (LV) |
| Phase D | MISSION OPERATIONS | University teams operate spacecraft |
| | | AFRL serves and advises in operations and data transfer |

*The University Nanosatellite Program (UNP) stands as a pioneering initiative in the domain of extensive CubeSat design and launch programs. Since its inception, UNP has drawn the active involvement of nearly 5,000 students representing 38 universities across the United States. This program has played a pivotal role in nurturing student talent and facilitating hands-on experience in spacecraft design and development.*

*Reference:* 1. https://universitynanosat.org/resources/

# *The formulation of the initial framework for the teaching methodology and syllabus for "Introduction to Small Satellites Design 1 and 2"*

# Survey of Small Satellite programs

In the context of the "Introduction to Small Satellites Design 1 and 2" subjects, students are expected to have a strong foundational knowledge in several key areas. *These include "Physics," "Mathematics," "Introduction to Aerospace Engineering," "Flight Dynamics," "Programming," "Electrical Engineering and Electronics," "Avionics Systems Design," "Rocket and Spacecraft Design," "Orbital Mechanics," "Engineering Graphics," and "Informatics" at a proficient level. Emphasis is placed on proficiency in Electrical-Electronics, Mechanics, Programming, and Space-Aerodynamic theory as these form the core basis of the subject.*

| No | Type of attestation | Time | Maximum points collected |
|---|---|---|---|
| 1. | Midterm exams | 5, 10, 15 weeks | 10 |
| 2. | Laboratory work | Throughout the semester | 10 |
| 3. | Class attendance | Throughout the semester | 10 |
| 4. | Course work | Throughout the semester | 10 |
| 5. | Abstract | Throughout the semester | 10 |
| 6. | Final exam | End of semester | 50 |
| TOTAL | | | 100 points |
| A student who scores 51 points and above in the final evaluation gets the specified credit for the subject. During the exam, the student must score at least 17 points. | | | |

Distribution of points and assessment of attestations

*The subject aims to achieve the following:*

- Understand space environment and orbital mechanics,
- Learn about new space and satellite technologies,
- Gain in-depth knowledge of CubeSat satellite platforms and their design fundamentals,
- Undertake theoretical and practical tasks related to project management in satellite projects,
- Conduct satellite mission and system-level simulations and analyses using computer tools,
- Participate in hands-on work involving satellite assembly, integration, and standardization in laboratory settings,
- Perform essential tests, verification, and validation processes on the assembled CubeSat kit platform.

# Initial Syllabus content of "Introduction to Small Satellites Design 1 and 2". P: 1&2

| Weeks | Lectures | Lecture topics | Lecture hours | Laboratories | Laboratory topics | Laboratory hours |
|---|---|---|---|---|---|---|
| 1 – S1 | Introduction to Small Satellites | Meet the spaceflight; Introduction to Small Satellites; Introduction to Small Satellite Concepts; Satellite Form Factors; Satellite Subsystems and Components; | 2 | Lab, CubeSat kit and electronic material orientation and safety | Introduction to CubeSat kit; Introduction to all course budget templates and calculations; Team division for CubeSat kit assembly and mission determinations; Introduction to Conceptual design documendation; | 2 |
| 2 – S1 | Space Systems Engineering | Introduction to Space Systems Engineering; Mission Design Basics; Mission Analysis; Developing CONOPS; Project Constraints & High-level Mission analysis; STK Fundamentals; | 2 | | | |
| 3 – S1 | Orbital Mechanics and Orbits | Payload and CubeSat applications; CubeSat Configuration; The Space Environment; Orbits; Orbit Design; Orbital Mechanics; Multisatellites missions; | 2 | Mission design and satellite system analises | Project constraints, requirement determination, mission analises, system level STK scenerio design; Trade study, lifetime, communication, power STK analises; | 2 |
| 4 – S1 | On-board Systems | Overview of on-board systems; On-Board Data Handling OBC&CDH subsystem; Data Budget; On-Board Software; | 2 | | | |
| 5 – S1 | Satellite Design and Structures | Mechanical Design; Mechanical and thermal design; Spacecraft Structures; | 2 | Course budget template based calculations and analises | Determination of all: Data Budget; Link Budget; Mass Budget; Pointing Budget; Power and Energy Budgets; Requirements Verification Matrix (RVM); | 2 |
| 6 – S1 | Propulsion and Attitude Control | Rocket Performance Equations, Solid and Liquid Propellant Engines; Attitude Determination Control, ADCS subsystem; Propulsion; Sensors and mechanisms guidance and control; | 2 | | | |
| 7 – S1 | Budgets and Development Phases | Volume and Mass Budgets; Development phases; Small satellite design; Lifecycle of a CubeSat; | 2 | On-Board computer data handling and processing | Ground and Board Software Development; On-Board PCB assembly and test; | 2 |

| Weeks | Lectures | Lecture topics | Lecture hours | Laboratories | Laboratory topics | Laboratory hours |
|---|---|---|---|---|---|---|
| 8 – S1 | Communication Systems | Communication, TTC subssytem; Power, communication, and data handling systems; Link Budget Communication system and design; Ground Segment; | 2 | | | |
| 9 – S1 | Assembly, Integration, and Verification | Assembly, Integration and Verification; Manufacturing, verification and qualification; | 2 | Telecommunication and Telecommand processing | Ground equipment sytem design and configuration; Telecommunication PCB assembly and tests; | 2 |
| 10 – S1 | Space Operations and Platforms | Spacecraft Operations; Budgets; Complete Spacecraft Platforms; Dedicated Spacecraft Bus; | 2 | | | |
| 11 – S2 | Power Generation and Storage | Electrical power EPS susbsystem; Power Generation; Solar Cells; Solar Panels & Arrays; Multi-junction Solar Cells; Flexible Solar Cells; Organic Solar Cells; Energy Storage; Secondary Li-ion and Lipo Batteries; | 2 | Altitude Determination and Control system | Environmental Test procedures; ADCS PCB assembly and tests; | 2 |
| 12 – S2 | In-Space Propulsion | Overview of In-Space Propulsion Technology Types; Small Spacecraft Propulsion; In-Space Chemical Propulsion; In-Space Electric Propulsion; In-Space Propellant-less Propulsion; | 2 | | | |
| 13 – S2 | Guidance, Navigation, and Control (GNC) | GNC Subsystems; Integrated Units; Reaction Wheels; Magnetic Torquers; Thrusters; Star Trackers; Magnetometers; Sun Sensors; Horizon Sensors; Inertial Sensing; GPS Receivers; | 2 | Electrical power supply and system | Environmental Test procedures; EPS PCB assembly and tests; | 2 |
| 14 – S2 | Structural Design and Manufacturing | Primary Structures; CubeSat Structures; Mechanisms; | 2 | | | |

# Initial Syllabus content of "Introduction to Small Satellites Design 1 and 2". P: 3&4

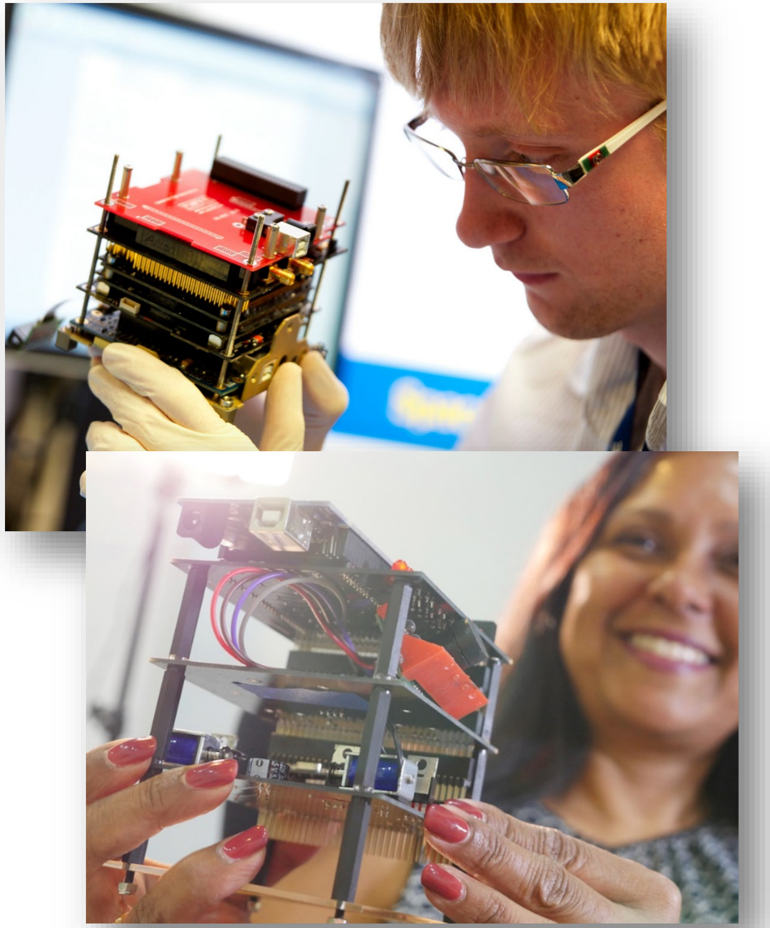
| Weeks | Lectures | Lecture topics | Lecture hours | Laboratories | Laboratory topics | Laboratory hours |
|---|---|---|---|---|---|---|
| 15 – S2 | Radiation Effects and Thermal Control | Radiation Effects and Mitigation Strategies; Shielding from the Space Environment; Inherent Mass Shielding; Ad Hoc Shielding; Passive Systems; Paints, Coatings, and Tapes; Multi-layer Insulation; Thermal Straps; Thermal Contact Conductance and Bolted Joint Conductance; Thermal Interface Materials and Conductive Gaskets; Sunshields; Thermal Louvers; Deployable Radiators; Heat Pipes; Phase Change Materials/ Thermal Storage Units; Thermal Switches; Multifunctional Thermal Structures; | 2 | Spacecraft structure and thermal analises, control | Structural minor designs and production through 3D printing and prior assembly; Structural and Thermal analysis; | 2 |
| 16 – S2 | Active Thermal Systems | Active Systems; Heaters; Cryocoolers; Thermoelectric Coolers (TEC); Fluid Loops; Active Thermal Architecture; | 2 | | | |
| 17 – S2 | Avionics and Software | Avionics Systems Platform and Mission Development Considerations; Highly Integrated Onboard Computing Products; Radiation-Hardened Processors; Memory, Electronic Function Blocks, and Components; Bus Electrical Interfaces; Flight Software; Implication of CDH Processors on FSW; Frameworks; Mission Operations and Ground Support Suites; Development Environment, Standards, and Tools; | 2 | CubeSat assembly and integration | CubeSat assembly and integration along with minor tests; Handling procedures over requirements; | 2 |

| Weeks | Lectures | Lecture topics | Lecture hours | Laboratories | Laboratory topics | Laboratory hours |
|---|---|---|---|---|---|---|
| 18 – S2 | RF and Optical Communications | Radio Frequency Communications; Frequency Bands; System Architecture; Major Components in Smallsat Communication Systems; Design Considerations; Policies and Licensing; Encryption; Antennas; | 2 | | | 2 |
| 19 – S2 | Launch and Deployment | Launch Integration Role; Launch Brokers and Services Providers; Dedicated Launches; Traditional Rideshare Launches; Deployment Methods; CubeSat Dispensers; SmallSat Separation Systems; Integration Hardware; Orbital Maneuvering / Transfer Vehicles; Deployment from ISS; | 2 | CubeSat integrated testings, verification and validation | CubeSat integrated testing – The Five Tests; Flight odel based assembly and test procedures; Full Functional Test Procedure and Report; On-Orbit Operational Requirement checkings; Evaluation and report finishing for CubeSat models; | |
| 20 – S2 | Ground Data and Supporting Systems | Types of Communication Infrastructures; Frequency Considerations; Frequency Selection: Link Budget; Frequency Licensing; Ground Segment Services; Ground Segment as a Service (GSaaS); Ground Stations Components; Ground Station Operation Component Hardware for Ground Systems (GS); Ground Software; Mission and Science Operations Centers; Software for Mission Operations; End-to-End Communications and Compatibility Testing; End-to-End Hardware for Ground Systems; Cyber Security Technologies; Scheduling and Mission Operations Software; | 2 | | | 2 |

# Survey of Small Satellite programs

*Discussion*

The course "Introduction to Small Satellites Design 1 and 2" is crucial for preparing aerospace engineering students in small satellite technology. Covering topics from space systems engineering to CubeSat design, it offers theoretical knowledge and hands-on labs. This course establishes a solid foundation for future aerospace engineers, enabling them to contribute to space exploration.



*Conclusion*

In summary, "Introduction to Small Satellites Design 1 and 2" is vital for aerospace education. The curriculum equips students with knowledge, practical skills, and problem-solving abilities. Graduates meet the demand for small satellite professionals, aligning with global trends. Offering this course in Azerbaijani institutions advances the nation's space technology and cultivates a skilled engineering workforce. It's an investment in Azerbaijan's space education, empowering students to excel in the global space industry.

# Thank You!