

Rochester Institute of Technology

## RIT Digital Institutional Repository

---

Presentations and other scholarship

Faculty & Staff Scholarship

---

2006

### The Design of a small satellite launch system - a multidisciplinary capstone experience

Dorin Patru

Jeffrey Kozak

Robert Bowman

Follow this and additional works at: <https://repository.rit.edu/other>

---

#### Recommended Citation

Patru, Dorin; Kozak, Jeffrey; and Bowman, Robert, "The Design of a small satellite launch system - a multidisciplinary capstone experience" (2006). Accessed from <https://repository.rit.edu/other/630>

This Conference Paper is brought to you for free and open access by the RIT Libraries. For more information, please contact [repository@rit.edu](mailto:repository@rit.edu).

# The Design of a Small Satellite Launch System – A Multidisciplinary Capstone Experience

Dorin Patru<sup>1</sup>, Jeffrey D. Kozak<sup>2</sup>, Robert J. Bowman<sup>3</sup>

**Abstract** - Three years ago the Electrical and Mechanical Engineering Departments at Rochester Institute of Technology (RIT), initiated the Design of a Small Satellite Launch System, a long-term, multidisciplinary project. Its main objective is to offer students a unique and stimulating capstone design experience. A high altitude balloon will lift an instrumentation platform, a four stage 200kg rocket, and a 1kg satellite to ~30km. At this altitude the rocket will fire and after a brief powered flight it will place the satellite in Low Earth Orbit. The balloon bursts and the instrumentation platform descends using a parachute. Among other advantages, starting the powered flight at this altitude eliminates the need for ground infrastructure and allows the optimization of the engine nozzles. Two teams have designed, tested, successfully flown and recovered an instrumentation platform. A third team is complementing its functionality with attitude control. A fourth team is designing and ground testing the upper stage of the rocket. The project has engaged 22 students so far, co-advised by a faculty member from each department. The paper describes the organization and aim of the project. It is shown how its multi-disciplinary character enhances the capstone experience of the students. A faculty perspective on advising and student perspectives on working in multi-disciplinary teams are provided. The lessons learned in the past three years are analyzed and the next development phases are outlined.

**Index Terms** – Multidisciplinary, Capstone, Senior Design, Satellite, Launch.

## INTRODUCTION

The capstone or senior design project represents the first real design experience for undergraduate students enrolled in engineering majors. While design is trained in certain laboratory and/or project assignments associated with a specific course, by their nature, intent and time constrains these exercises are usually limited in scope. Furthermore, the capstone or senior design projects involve a team of student designers. Based on “customer” requirements, they develop the design specifications, generate and evaluate different alternative concepts and then design and implement the prototype. This organization tries to make the student training

scenario as similar as possible to what students will encounter after graduation at their workplace.

Traditionally, the students in a team would all be majoring in the same discipline. However, most industry designs require multidisciplinary expertise, i.e. engineers from different disciplines. To be successful, they not only need to be experts in their own fields, but also need to be able to communicate effectively across discipline borders. Although this requirement is common knowledge, the traditional capstone or senior design experience does not specifically address it.

Five years ago the College of Engineering at the Rochester Institute of Technology, started a college-wide, multidisciplinary approach to senior design [1]. The teams include students from Mechanical, Electrical and Industrial Engineering Departments. They collectively work on a design which requires expertise from all disciplines. The number and type of students is determined from the scope of the project. The teams are co-advised by faculties from each department.

Aligned to this initiative, the authors have proposed and started three years ago a multi-year, multidisciplinary project which goal is to design, implement and subsequently improve a small satellite launch system [2]. While student groups at many universities have designed, built and operated small satellites for more than two decades, a complete launch system has never been attempted within academia. Furthermore, the challenge of developing technology for space exploration is a strong and appealing motive for students.

The paper describes first the organization and aim of the project. Second, it outlines the instructional objectives. Third, it analyses the impact on students with different learning styles. Fourth, it provides some student and faculty perspectives on working in and with these multidisciplinary teams, and the lessons learned over the past three years. Finally, it outlines future development phases of the project.

## PROJECT DESCRIPTION AND ORGANIZATION

### *I. Present Launch Options for Pico-Satellites*

A satellite with a weight of 1 kg or less is arbitrarily called a pico-satellite [3], [4]. Such a satellite can incorporate a beacon transmitter, or a transponder, and/or a video camera, or any other miniaturized scientific instrument, which would fit

<sup>1</sup> Dorin Patru, Assistant Professor, Rochester Institute of Technology, dxpeee@rit.edu

<sup>2</sup> Jeffrey D. Kozak, Assistant Professor, Rochester Institute of Technology, jdkeme@rit.edu

<sup>3</sup> Robert J. Bowman, Professor, Rochester Institute of Technology, rjbeee@rit.edu

within the specified weight limit. With current and future advances in Micro-Electro-Mechanical Systems (MEMS), it is expected that more such low-weight and low-volume instruments will be created and used in future spacecrafts.

Current launch vehicles are designed to launch payloads with weights of 100 to 6000 kg. On the light end, Orbital Sciences Inc., offers Pegasus for launching payloads of a minimum 285 kg in polar (97°), low earth orbit (400 km) [5]. On the heavy end, Sea-Lunch launches up to 6000 kg in Geosynchronous Transfer Orbit [6].

Amateur Radio Groups, usually members of the Amateur Radio Satellite Corporation – AMSAT, have designed and built satellites with weights of 10 to 100 kg. Similar satellites have been designed and build by groups of students in universities. These were launched as secondary, piggyback payloads. In a few rare instances, e.g. during a launch vehicle test flight, the ride to orbit was free. Except for these cases, the cost of a launch was usually between \$100k and a few million dollars.

To decrease the cost of a launch, one solution at hand is to decrease the weight of the satellite, which is certainly possible with today’s technologies. However, current launch vehicles are designed to launch larger and heavier satellites. Consequently, these launch vehicles are not cost-effective to launch individual pico-patellites.

The project Cubesat [7], lead by CalPoly and Stanford Universities, uses a mother-satellite to carry several pico satellites into orbit. After the former is placed in orbit, the individual pico-satellites are individually expelled / deployed, and from that point on function independently. Although one pico- satellite weighs less than 1 kg, the current cost for the launch of each one is \$80,000. Furthermore, launch opportunities come only every 3-5 years, and then the launch is predicated by the completion of each small satellite. It is worth to note that, more than 40 high school and university student teams worldwide are building satellites following the cubesat standard. In-depth coverage of small satellites can be found at [4].

*II. Balloon Based, Pico-Satellite Launch System*

Airborne launch has commercially materialized in the early 1990’s, with Orbital Sciences’ first aircraft-launched Pegasus rocket [4]. In the 1950’s, Dr. Van Allen’s group at the University of Iowa, has used such a system for high altitude research. Since then, numerous other attempts have been made with increasingly large rockets. These latter attempts have been less successful, due to the fact that the combined rocket and payload weight was several thousand kg. However, a 200 kg rocket is similar to what Dr. Van Allen’s group has successfully launched several times, and therefore the authors believe it is a feasible approach.

Current balloons can rise above 30,000 m, and float for extended periods of time, from hours to days, with payloads as heavy as 1000 kg [8]. At that altitude, atmospheric pressure and density are less than 1 % that at sea level. Thus, it is safe to assume that external forces on the balloon and platform will be virtually zero. Once floating, the balloon payload will

passively stabilize translation in the z-axis, i.e. the direction of the gravitational force, and tilt in the xy-plane, i.e. parallel to Earth’s surface.

The proposed launch system is shown, not to scale, in Fig.1. The instrumentation platform is attached to the balloon via a parachute, which in case of an uncontrolled balloon burst would land the entire balloon payload safely on the ground. In normal operation, it would land the instrumentation platform after the rocket is launched. The instrumentation platform contains sensors and video cameras which are used to supervise and control the rocket launch remotely. The rocket or launch vehicle is attached to the instrumentation platform. In the current concept, all four stages of the latter are envisioned to use hybrid propellant and to be able to place a payload of under 1 kg into low earth orbit.

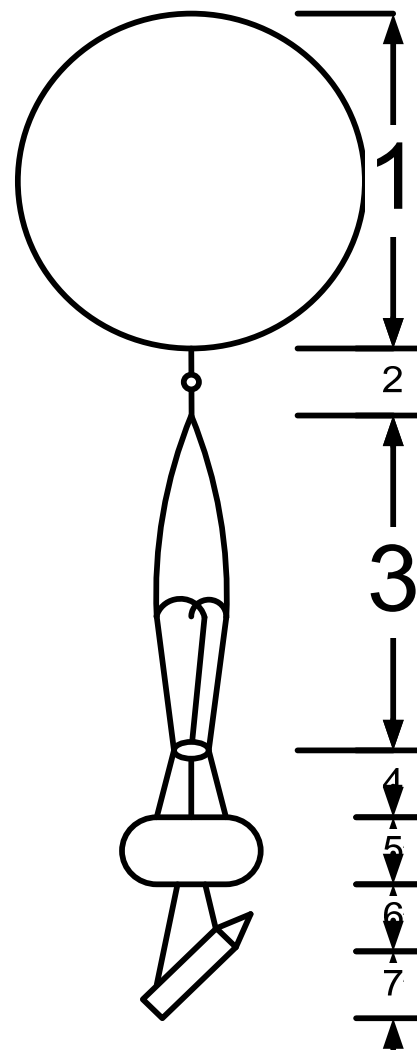


FIGURE 1  
LAUNCH SYSTEM BLOCK DIAGRAM. (1) BALLOON, (2) TETHER, (3) PARACHUTE, (4) STABILIZATION TETHERS, (5) INSTRUMENTATION PLATFORM, (6) ROCKET SUSPENSION LINES, AND (7) ROCKET WITH PICO-SATELLITE PAYLOAD.

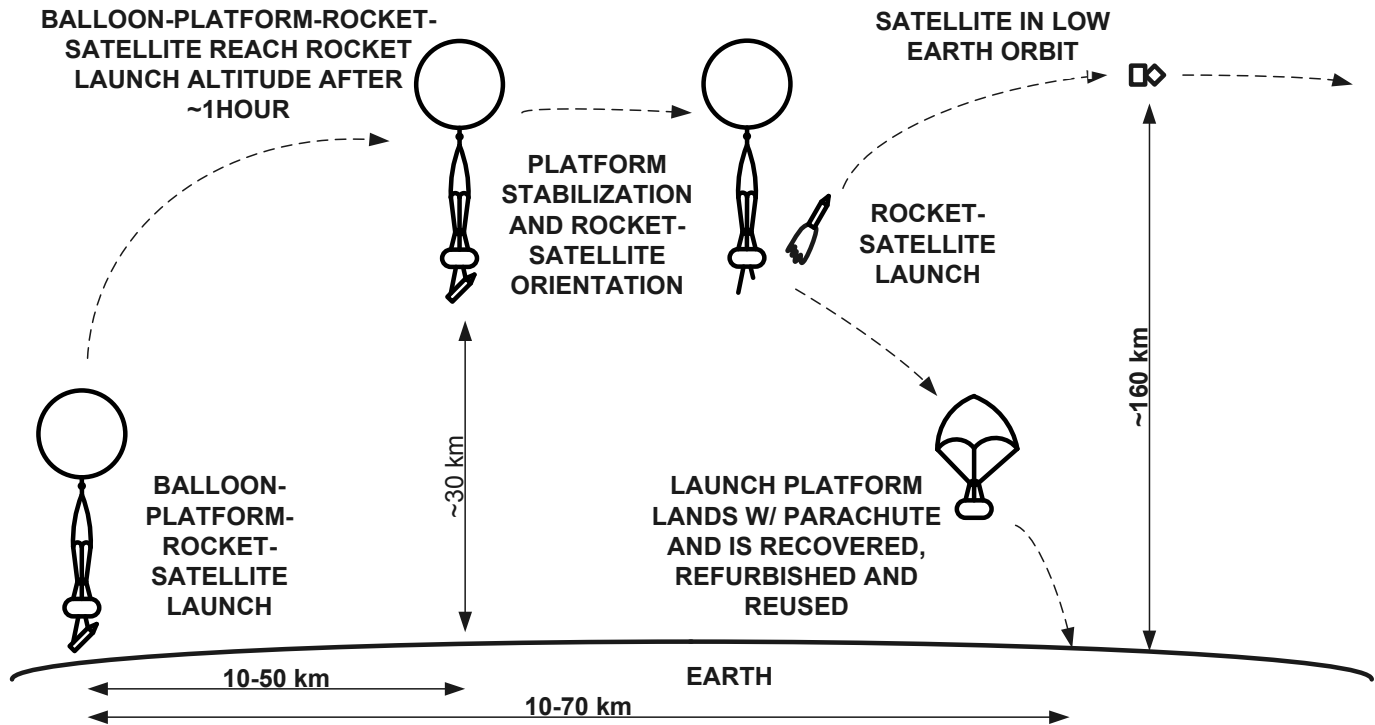


FIGURE 2  
TYPICAL MISSION PROFILE.

A generic mission profile is shown in Fig.2. The balloon and its payload are launched from the ground, and reach rocket launch altitude after approximately one hour. After the platform passively stabilizes, the rocket inertial navigation system is initialized and the rocket is released under an angle. After a few seconds of free fall, the first stage ignites. The powered flight phase continues under the control of the inertial navigation system, and completes with the release of the pico-satellite in low earth orbit. The platform is recoverable, but the rocket stages are expendable.

### III. Launch System Performance Analysis

The proposed launch system has the following advantages:

- No need for ground infrastructure, except for a seven-person mobile launch control, which can be located in a van. The equipment, e.g. power generator, antennas, portable computers and radio transceivers, can be carried by the controllers to any desired launch location.
- Launch location can be at any latitude. It is only restricted by the safety range requirements over populated areas.
- Atmospheric drag is virtually zero during the phase of powered flight to orbit.
- The value of the maximum dynamic pressure, or max-q, will be very low, resulting in a more relaxed structural design. The latter is further supported by lower launch

loads, e.g., vibrations, compared to a launch on a conventional vehicle;

- Weather conditions do not affect the phase of powered flight to orbit.
- Rocket motors operate in vacuum at all times. Thus, nozzle geometries can be optimized for highest efficiency under these conditions.
- Launch frequency can be as high as several times per year.

The proposed launch system raises the following concerns:

- Rocket launch location can be within 50 km from the balloon launch location.
- Preliminary studies show that the mechanical components of the rocket stages are scalable. However, weight limitation may result in a less accurate rocket attitude and guidance system. This could impact the accuracy of orbital insertion.
- Due to the tolerance in rocket orientation before ignition, and the tolerance of the rocket attitude and guidance system, the “customer”, i.e. owner of the satellite, might need to accept a lower probability of mission success; however, this would be compensated by: (1) the very low cost of a launch, (2) the possibility to launch a second, identical satellite within days, and (3) the very low cost of such a satellite.

We expect that in the course of the project these limitations and concerns will be addressed and resolved.

*IV. Project Organization*

The project organization is shown in Table I. As can be seen, the teams perform original design or improve upon prior design of different subsystems of the launch system.

The first team started with the design of the instrumentation platform. Their work was continued and improved by the second team, which has successfully launched the instrumentation platform twice, without a rocket attached to it. This year a third team is further customizing the instrumentation platform to lower its weight and volume. In parallel, a fourth team is designing a rocket engine test stand and the fourth stage of the rocket. Starting next academic year, there will be three multidisciplinary senior design teams associated with this project: one will continue the work on the instrumentation platform, one continuing the rocket design, and one designing the pico-satellite that will be used during the first launches.

As can be inferred, the project can be continued indefinitely, as the continuous advances in technology provide for opportunities to build a better and cheaper system. Furthermore, a major milestone will be achieved once the first pico-satellite will be placed in orbit. From that point on, the teams of each year will be able to see their work flying, which will be an unmatched incentive to get their implementation done.

**GENERAL AND PROJECT SPECIFIC INSTRUCTIONAL OBJECTIVES**

Instructional objectives allow us to quantify the impact a particular educational activity will have on the students involved. By the end of this multidisciplinary capstone or senior design experience, students will be able to:

- List and Identify space environment specific conditions, such as high temperature fluctuations, vacuum, radiation, etc.
- List and identify the components of a small satellite launch system.
- Outline the countdown procedure for their particular subsystem.
- Explain the function of their subsystem.
- Formulate and describe possible alternative concepts for their design. Determine which of these are most suitable for the intended application through evaluation, selection and justification.
- Interpret the output of specific Computer Aided Design Software, used during the design.
- Apply discipline specific engineering design methods.
- Design a subsystem prototype to meet specific design requirements.
- Create original solutions to unconventional problems.
- Determine design specifications based on application requirements.
- Optimize the design of their subsystem in terms of: weight, volume, power consumption, efficiency and other criteria.
- Evaluate worst case scenarios for the operation of their subsystem.
- Formulate specifications to cross discipline boundaries.
- Acquire knowledge to communicate effectively across discipline boundaries.
- Manage time to meet design due dates.
- Design hardware that will actually fly, compared to only paper and pencil design.

TABLE I  
PROJECT ORGANIZATION

Phase	Activity	Objectives	Duration / Status	Students Involved
1	Instrumentation Platform design and testing.	Design, implementation and testing of a high altitude balloon tethered instrumentation platform for use in Phase 4.	Started in Fall 2003 – on going	Platform Team 1 – 7 Platform Team 2 – 2 Platform Team 3 – 5
2	Rocket design and testing.	Design, implementation and ground testing of a hybrid propellant rocket.	Started in Spring 2005 with the design of the 4 <sup>th</sup> stage, ~ 5 kg – on going	Rocket Team 1 – 8
3	Pico-Satellite design, construction and testing.	Design, implementation and ground testing of the Pico-Satellite, to include a radio beacon.	Started in Spring 2004 – on going	Satellite Team 1 – 4
4	Sub-orbital test flight of one rocket stage.	Test stage and guidance system	Summer 2007 – tentative date	
5	Complete Launch System testing.	The airborne testing of the complete launch system with the launch of an earth remote sensing Pico-Satellite.	Pending successful completion of previous stages	
6	Launch System improvements and upgrades / Pico-Satellite developments	Improve and upgrade the Launch System with state-of-the-art technologies / Develop Pico-Satellites tailored for scientific space experiments	Indefinitely	Platform Team ~ 6 Rocket Team ~ 6 Satellite Team ~6

Compared to a traditional senior design project, a multidisciplinary one adds the challenge of working with team members who cannot immediately follow one's line of thought, not because of lack of expertise in their discipline, but in the other. This means that more time will be necessary to share design information, and to arrive at design solutions which are acceptable from all points of view. However, the additional time spent is worthwhile, as this enhances their knowledge and communications skills beyond the boundaries of their own discipline.

### WILL ALL STUDENTS BENEFIT FROM THIS MULTIDISCIPLINARY EXPERIENCE?

In this section we try to answer this question, by analyzing the different types of students by the way they learn [9].

From a perception point of view, *learners* are classified into *sensing* or *intuitive*. *Sensing learners* are practical, like concrete thinking, hands-on work and are methodical. The project is practical because it targets a final physical implementation of hardware that has to fly, it is hands-on and students have to apply discipline specific design methodologies. *Intuitive learners* are imaginative, like abstract, model based thinking, and like variety. Students working on this project have to create innovative solutions to unconventional problems.

From an information representation point of view, *learners* are classified into *visual* or *verbal*. *Visual learners* like graphic input, such as the drawings, schematics and charts the students use in the designs associated with this project. *Verbal learners* like to operate with text based information. These will most likely engage in activities such as test, verification, evaluation and procedure generation.

From an information processing point of view, *learners* are classified into *active* or *reflective*. *Active learners* like to try out and work in groups, for which the project offers ample opportunities. *Reflective learners* like to think it thoroughly and work solo. The fact that each team gets one or just a few chances to try out their hardware, thorough design and verification is a must. The design of certain hardware blocks can be assigned to individual team members.

Finally, from an understanding point of view, *learners* are classified into *sequential* and *global*. *Sequential learners* can function/work with partial information, whereas *Global learners* need the big picture. There is a big picture which is constantly refined as the design progresses.

The activities associated with this project are not favoring any particular learning style, but give each *learner* the opportunity to benefit from completing them.

### STUDENT AND FACULTY PERSPECTIVES - LESSONS LEARNED

Students that have been and are involved in the project have indicated that during their Senior Design I, the biggest challenge they faced was to cross disciplinary boundaries. However, the concept development brainstorming sessions

have helped in establishing the proper communication channels.

During Senior Design II they faced another challenge: meeting design and manufacturing deadlines to allow other team members test their components. Though this design dependence is not limited to multidisciplinary projects, it is always present in these.

With the exception of one team which had only two members, all others had between four and eight students. We were initially afraid that a large team might not perform qualitatively as well as a smaller team. To our surprise, the performance of a team was not affected by its size, but rather by the efficiency of the student leader. However, we believe that for all practical purposes, a team's size should be capped at eight. Because students still take other classes, it becomes difficult to schedule meeting times for more than eight students and two or three faculty members.

The teams have been and are advised by at least a faculty member from each department. At the beginning, students are tempted to use their associated faculties to communicate across disciplinary boundaries. We intentionally discourage this, and they also soon realize that it is more efficient if they establish a dialog among themselves.

As faculties we have not found advising this project more difficult than other single-discipline projects we have advised before. While managing a multidisciplinary team of practicing engineers can be a challenge, we find managing these teams of multidisciplinary students even more challenging and exiting.

Probably the greatest challenge for us advisors and coordinators of this project is to ensure the safety of all students and third parties. Finding out about and adhering to local, national and international laws and regulations is a continuous work in progress for both students and advisors.

### FUTURE PLANS

Starting next academic year, we will run three student teams in parallel each year. The first one will continue the design and improvement of the instrumentation platform, the second one will use this year's ground testing experience and commence with the design and testing of the other three rocket stages, and the third one will continue the design and implementation of the first pico-satellite.

### ACKNOWLEDGMENT

The authors wish to acknowledge the continuous help and support provided by Dr. Edward Hensel, Dr. Elisabeth DeBartolo, James Stefano, Kenneth Snyder, Dave Hathaway, Robert Krynik and Dave Snyder. We also acknowledge the support of many unnamed Amateur Radio Operators who have assisted us during our two launches. Finally, we want to acknowledge RIT's financial support and the donations received from a large number of companies, which are listed on the project's website [2].

**REFERENCES**

- [1] <http://edge.rit.edu/>
- [2] <http://meteor.rit.edu/>
- [3] "Anthology of Radio Amateur Satellites", Published by The American Radio Relay League
- [4] <http://centaur.sstl.co.uk/SSHP/index.html>
- [5] "Pegasus User's Guide", Orbital Sciences Corporation, August 2000, available for download at <http://www.orbital.com/>
- [6] "Sea Launch User's Guide", at <http://www.sea-launch.com/>
- [7] "CubeSat Design Specification", at <http://cubesat.calpoly.edu/>
- [8] <http://www.aerostar.com/>
- [9] R.M. Felder and L.K. Silverman, "Learning and Teaching Styles in Engineering Education," *Engr. Education*, 78(7), 674-681 (1988)