Helping students fly high: how to teach physics (and a whole lot more) using high-power rockets

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Main Idea: teach physics (mechanics) and other important skills to students in an engaging, hands-on, fun way, by using rockets as a context. Let them play and learn at the same time. Keep them engaged with interesting, real-life applications.

Inspiration: High power rocketry video lessons offered by James Flaten.

[mn-space-grant] Remote high-power rocketry lessons - last call to confirm (or sign up) a student team for this fall

Inbox ×

James Flaten <flate001@umn.edu> Aug 28, 2017, 11:49 AM

to MN, Nyla, Daniel

Hi all!

As I mentioned at our affiliate meeting last spring - see attached slide - this fall I'm planning to offer high-power rocketry lessons by videocon (not necessarily by Skype) to schools who aren't yet involved in high-power rocketry. This fall I'm open to

About Macalester College:

- Private liberal arts college
- About 2000 students
- Only undergraduate programs
- Small class sizes: varies from about 35 in introductory physics courses to about a dozen in advanced physics courses

About me:

- Theoretical elementary particle physicist
- 16 years at Macalester College
- Introductory physics courses: mechanics, electricity and magnetism
- Advanced core physics courses: classical mechanics, quantum mechanics
- Advanced elective courses: advanced quantum, radiation
- Special topics courses: elementary particle physics, general relativity

PHYS194 Rocket Science

- First year students only
- Enrollment: 17 students
- Quantitative reasoning requirement designation: Q3
- Writing requirement designation: WA
- Distribution requirement designation: natural sciences
- Equivalent to PHYS226, Principles of Physics I, intro calc-based physics

- Students have some high school calculus background
- Students have some high school physics background

- Residential requirement: student live on same floor in dorm
- Additional goals: create community, make students familiar with campus services

From the syllabus:

"Rocket Science is a rocketry themed calculus-based introductory physics course for first-year students only. The course covers standard material such as Newton's laws, conservation of energy, linear momentum, and angular momentum, oscillations and orbital dynamics, but with a strong focus on applying these basic physics principles to rocket propulsion and flight dynamics. Instead of a conventional lab, the course includes a hands-on semester-long project where students design, simulate, build, and fly their own high-power rockets. Apart from the rocket building project, evaluation will take the form of regular problem sets, exams, short papers, and a research paper."

- Homework: 15%
- Rocket building project: 25% (modeled after James Flaten's video lessons project, rocketry competitions)
- Writing assignments: 25% (scaffolded approach, theme: crewed mission to Mars)
- 2 Midterm exams: 10% each
- Final exam: 15%
- Bonus credit opportunities: 5% (attending physics seminars, public observation nights, etc)

Lecture topics:

- Newton’s laws
- Projectile motion (high power rockets)
- Drag (high power rockets, parachutes)
- Conservation of energy
- Conservation of momentum (rocket engines)
- Torque, moment of inertia
- Conservation of angular momentum (rocket rotation)
- Gravity (orbital dynamics, Hohmann transfer, sling shot effect, Oberth effect)
- Oscillation

- Textbook (Halliday and Resnick) only as a back-up
- Application and examples as much as possible related to rocketry and space exploration.
- Watched a lot footage of launches in class (Saturn V, space shuttle, Ariane 5, etc)

Sample homework question: conservation of mechanical energy and angular momentum

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PHYS 194 – Rocket Science

Homework 6 is due in class on Wednesday, November 7, 2018.

Design a yo-yo de-spin mechanism for a rotating payload module. The module, not including the components of the de-spin mechanism, has moment of inertia I. The yo-yo de-spin mechanism consists of two weights attached two equal lengths ropes that are initially wound around a circular cross-section of the module of radius R and attached to it at diametrically opposed points. The initial angular velocity of the module before deployment of the yo-yo mechanism is anticipated to be ω. Once the de-spin mechanism is deployed, the weights will swing out and the ropes are released just when they are completely unwound and make a right angle with the surface of the module. Find the relation that the length of the ropes and the mass of the weights must satisfy to optimally de-spin the module. The mass of the ropes may be neglected. If you are using any conservation laws in your analysis, please carefully explain why they apply.

Sample exam question: projectile motion

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Physics 194 - Rocket Science

Mid-term exam 1, Wednesday, October 17, 2018, from 2.20 to 3.20 pm.

This is a closed book exam. The use of a calculator is allowed. Please show all your calculations and provide clear explanations.

The Ariane 5 is a European heavy-lift launch vehicle. It consists of a main stage liquid fuel engine, two strap-on solid state rocket boosters, and a second stage. The boosters are jettisoned at burn-out, approximately 130 seconds after lift-off, when the vehicle has reached a height of approximately 67 km and its speed is approximately 2020 m/s.

1. (40 pts) The boosters are disposable and not used again for other launches. They are allowed to fall into the Atlantic ocean after they are jettisoned.
a. Calculate the gravitational acceleration at the altitude of booster burn-out. For the remainder of this problem, assume that the gravitational acceleration during the fall of the boosters is approximately equal to the gravitational acceleration at the surface of the Earth.
b. Ignoring drag, what is the highest elevation the boosters reach?
c. Again ignoring drag, how long after burn-out do the boosters plunge into the ocean?

Rocket Build project

- Not possible without the support of James Flaten (mentoring, quality control, certification) and MnSGC (materials)
- Students worked in groups of four or five
- Rocket was essentially the same as the one introduced by James Flaten during video lessons
- James Cannon, president of the Macalester High Power Rocketry team, conducted the lab
- Eight week build schedule
- One common hour with whole class each week to set goals
- 10 hours with lab assistant available in lab
- Students had free access to lab to work
- Students used Open Rocket simulation tool
- Students wrote a pre-flight report, and post-flight analysis report

Developed skill set, apart from physics:

- Working in a team
- Planning and scheduling
- Working with tools
- Testing components
- Integrating components
- Using simulation tools
- Documenting progress
- Acquiring sensor data
- Data analysis
- Etc

- Long hours working together created a great opportunity for students to bond

- All four teams successfully launched their rocket, resulting in a great sense of accomplishment.

The PHYS194 class during the November 2018 launch event in North Branch, Minnesota


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Writing instruction

- Scaffolded approach: five assignments of increasing complexity: summary of an original research paper, comparison of two research papers, mini-literature review on a topic, cumulating into a twenty page research paper.
- Theme: crewed mission to Mars; broad enough to let students explore their interests: psychological effects of long term isolation, biological radiation damage, physiological effects due to micro-gravity, rocket propulsions systems, gender bias in crew selection, etc.
- Teaching assistant: Macalester High Power Rocketry Team member Maya Wills provided invaluable help
- Multiple rounds of peer review: fellow students, writing assistant, instructor
- Student learned to write professionally in their own voice
- Students learned how to do literature research
- Students learned how to appropriately cite the work of others
- Students were trained in evaluating the work of others
- Students learned to professionally respond to criticism

Example of the title page of one of the research papers

Run GNC: Guidance, Navigation, and Control for a Manned Mission to Mars

Jason E. Beal
Student Author
Macalester College, Saint Paul, MN 55105

Abstract

Since the first successful Mars landing, Viking 1, in 1976, the goals for the exploration of Mars have only increased. It is clear that we are on the verge of a new generation of Mars exploration, one that will be able to place landers on Mars with unprecedented payload masses, at high altitudes, and with extreme accuracy. However, it is also apparent that we do not currently have the entry, descent, and landing architecture nor guidance, navigation, and control technology required for such missions. Furthermore, with the prospect of manned missions to Mars on the horizon, the necessary advances must be developed. This excerpt from the paper "Run GNC: Guidance, Navigation, and Control for Manned Mission to Mars" will explore the current status of this problem and discuss what advances are being made.

- Conclusions

- End of the semester evaluations showed that students really enjoyed the course. The consensus sentiment was that they were challenged, had to work hard, learned a lot and had fun.

- My own impression, based on student performance on homework assignments and exams, is that teaching physics within the context of rocketry and space exploration is highly effective.

- In my opinion the various elements of the course can be successfully replicated at other institutions.

- Please contact me for more detailed discussion if you would like to learn more: terveldhuis@Macalester.edu, 651-696-6838