High-Power Rocketry for Freshmen – Both Educational and Exciting

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Abstract

"High-power rocketry" is essentially the adult analog of Estes-style "model rocketry" that many people have enjoyed, sometimes starting as young children. Model rocket motors are classified with letters like A, B, and C, whereas high-power rocketry begins with H-class motors. Considering the fact that the total impulse doubles for every letter, an H-class motor is over 100 times more energetic than a basic A motor, and provides a lot of excitement for all ages when used to power a 4-foot (or taller) rocket thousands of feet into the air.

Students from across multiple departments in the College of Science and Engineering at the University of Minnesota – Twin Cities participate in designing, building, and flying high-power rockets, both for classes and for extra-curricular projects, often related to high-power rocketry national competitions. Although I have served as a faculty adviser for extra-curricular high-power rocket builds, competition high-power rocketry teams, and aerospace engineering senior design high-power rocketry projects, I particularly like teaching high-power rocketry to freshmen. And to ALL freshmen who are interested, not just to those planning to major in engineering or physical science fields.

Freshman seminars on high-power rocketry, with no prerequisites, have been taught at the U of MN – Twin Cities for the past five years. These hands-on classes teach a multitude of valuable skills (at an introductory level) including, but not limited to, (a) using simulation software to predict the performance of various rocket shapes, (b) using CAD software to draw components then fabricate them with machine shop tools, 3D printers, laser cutters, and/or water-jet cutters, (c) airframe construction using epoxy, hand tools, and basic power tools, (d) avionics bay (av-bay) assembly, which includes basic wiring, soldering, and altimeter programming, (e) collection and spreadsheet analysis of flight sensor data plus on-board video footage, and more! High-power rocketry freshman seminars are very popular among students, many of whom proceed into more-complicated extracurricular activities (some involving rocketry; some not) earlier than they normally would have in their college career. Class members are more likely to select engineering or physical science majors than non-class members. And even students who end up pursuing other majors come away with a much deeper appreciation of rocketry (all types), in particular, and of aerospace/mechanical/electrical engineering, in general.

A high-power rocketry class does require a certified mentor to sign off on the student rockets (preferably the class instructor will get certified), as well as coordination with a high-power rocketry club to conduct and oversee launches, including filing FAA waivers. Fortunately, there are Tripoli High-Power Rocketry clubs and NAR (National Association of Rocketry) clubs all around the country, so it is usually not too hard to find certified mentors to help train faculty (and students too, if need be) and to provide launch opportunities at specific launch fields away from metropolitan centers. The Tripoli Minnesota High-Power Rocketry Club that the U of MN – Twin Cities works with conducts their launches on sod farms near North Branch, MN, about a one-hour drive north of the Minneapolis campus. Freshman seminar class launches are scheduled for weekends, to avoid taking students away from campus on regular class days.

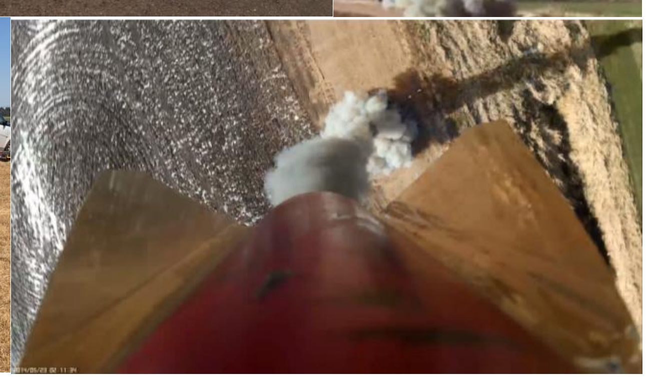
Introduction

Building and flying toy rockets is a perennial favorite activity of young and old alike, and "high-power" rocketry is a step up in size, power, and complexity, beyond Estes-style "model" rocketry with which many people are familiar. This makes it an engaging past-time for adults and high-power rocketry clubs organize rocket launches (which require FAA waivers), often on weekends, always outside of metro areas, at flying fields all around the country. Both Tripoli http://www.tripoli.org/, which does mostly high-power, and NAR (National Association of Rocketry) http://www.nar.org/, which does mostly model rocketry but some high-power, have active clubs in many communities. The best way to learn, and to get involved, is to find a local club and attend a public rocket launch event (often held monthly, at least during the summer).

Constructing a high-power rocket then flying it (under the supervision of a certified club member at a high-power club launch, if you aren't certified yourself) is both highly educational and exciting – an ideal activity for students just starting college. Indeed, one needs to be at least 18 to get certified to fly high-power rockets, so this really is a post-high-school hobby. At the U of MN – Twin Cities undergraduates of various ages in a wide variety of majors participate in high-power rocketry projects. I offer high-power rocketry freshman seminars for credit, but there is also an extra-curricular Rocket Team which also brings new many students to this hobby every year. Students often start by building a "kit-rocket" but many then proceed to designing their own "scratch-built" rockets, sometimes customized to accomplish specific goals for rocketry competitions. The images in this paper all come from U of MN – Twin Cities freshman seminars.







Curriculum

There are a wide variety of lessons that can be taught in a rocketry class (or in a rocketry module embedded within a class). These range from basic physics to systems engineering to programming to wiring and electronics to computer-aided design and simulation to construction techniques to documentation to project management to teamwork and communication skills. When teaching freshman seminars, I also include discussions about how to succeed in college.

The two books used in my classes are *Modern High-Power Rocketry 2* by Mark Canepa (required) and *Model Rocket Design and Construction, 3rd ed.* by Timothy S. Van Milligan (recommended). Students read the entire first book and skim (and occasionally consult) the second book. Van Milligan is the more-technical book of the two, though it talks only about model rocketry. A solid background in model rocketry would be useful for a high-power rocketry course, but too few students have that to make it a formal prerequisite. So we talk about rocketry from scratch and then usually skim (or even skip) model rocketry and just dive right in to high-power rocketry. Only about half the students in my classes report having experience building and flying model rockets. But not having rocketry experience does not seem to hinder them, assuming instruction takes that into consideration.

My freshman seminars meet for one 2-hour time block once a week. They also have a dedicated "lab" space for construction, so teams don't have to be continually taking out then putting away their rockets. Indeed, epoxy-drying steps in the construction process require the rocket not to be moved for multiple 6-hour stints, so being able to assign each 3-4 person team of a table or lab bench on which they can build for the entire semester very helpful. When taught in the fall, we typically start by building kit-rockets – all different, so students see the variety in designs – and fly those in early October. The rest of the semester is spent designing and scratch-building a "Round 2" rocket, launched in late November or early December, sometimes even after there is snow on the ground. Teams are assigned to teams at the start of the class and teams are maintained for the whole semester. Teams produce a mix of in-class oral presentations and written reports: Preliminary Design Reviews about the design and anticipated performance, Flight Readiness Reviews about the actual construction, and Post-Flight Reviews about how the rocket flew with comments about discrepancies from predicted performance (of which there always are some). I sometimes assign students to make short "educational videos" as well, to show during their end-of-semester public exhibit, along with their hardware.

When teaching freshmen without any particular prerequisites such as physics or calculus, hand-calculations requested are quite modest. We talk about how to calculate center of mass and center of pressure and then do so one time "by hand" (actually, using an Excel spreadsheet which students help code). We also talk about why it is hard to apply Newton's Laws of Motion to rocketry – thrust is non-constant, drag depends on speed, mass keeps changing, etc. – and then do some basic physics calculations as well. But such exercises are mostly to help them appreciate what the simulation software (discussed below) is doing for them and to better-understand why changes to parameters in the simulations have the impact that they do on rocket performance. Students also calculate the amount of Pyrodex (a gunpowder substitute) is required to pressurize and "break open" the rocket at the points in the flight when parachutes are called for.

Simulation software is quite central to designing model and high-power rockets because it allows students to explore likely performance of a wide range of rocket designs before actually building anything. Construction using epoxy is permanent, so you only get to build something once. Simulation software helps ensure in advance that it has a good chance of working.

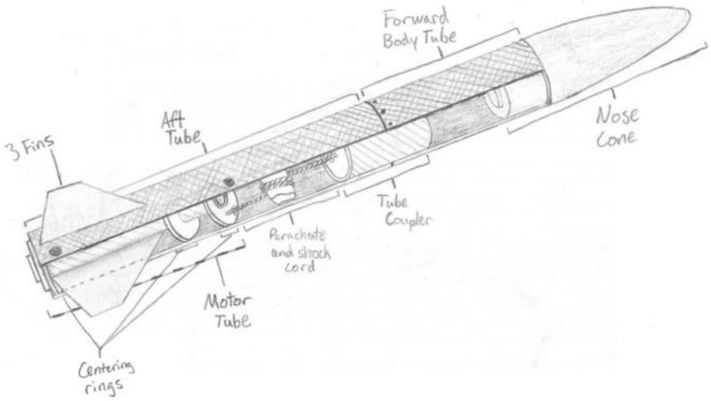
The two simulation software packages I've used in my classes are called RockSim 9 and OpenRocket. The former is slightly fancier, and even draws cute little animations of the rocket in flight. But the latter is free, making it the software of choice for most beginners. Both packages have libraries with electronic models of the most commonly-sold rocket kits and rocket motors, allowing immediate analysis. Both packages also allow one to "build" custom electronic models from individual parts too, allowing the students wide latitude in their scratch-build designs. As parts are added to an electronic model, the software will automatically calculate center of mass and center of pressure and hence predict static margin (AKA stability). When a motor is selected the software will calculate acceleration, velocity, and height for all times during the flight, especially just as the rocket leaves the launch rail (important for stability) and at the peak of the flight (AKA apogee) (see graph later in this paper). It is possible to simulate flights under various wind conditions as well, to get an idea of how far the rocket will drift down-wind on descent. Choosing different parachute sizes will change the descent speed. The software can also simulate "dual-deploy" in which a small "drogue" parachute is deployed at apogee and a larger "main" parachute is deployed shortly before the rocket lands, minimizing drift. Note: Rocket motors usually come with built-in "motor eject" charges which go off near apogee (if you time things right) but implementing dual deploy requires the use of electronic altimeters that sense rocket motion and fire explosive "ejection" charges to get multiple parachutes out at different points during the flight. The software can even take into account the changes is surface friction, depending on whether or not the rocket is painted.

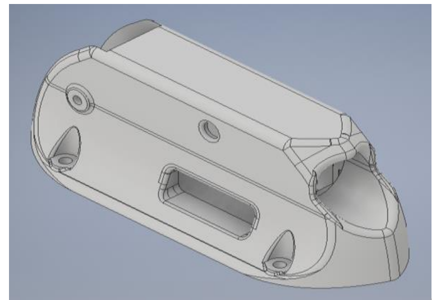
Besides building the airframe, using epoxy to attach fins (which the students have to fabricate from wood or fiberglass in the case of scratch-built rockets), the most complicated part of the rocket build is probably the payload/avionics bay (AKA the av-bay). The av-bay contains a programmable altimeter to fire explosive charges for parachute ejection events. Hence the altimeter needs to be very-solidly wired to ejection charges, a battery, and an externally-reachable switch to arm the altimeter after the rocket is sealed up and is on the launch rail. To test whether or not the ejection charges can actually break shear pins and separate the rocket – this depends in large part on whether the rocket is "tight" enough to hold the over-pressurization – students conduct pre-flight "ejection tests" during which they literally blow the rocket apart on the ground (see photos later in this this paper). Students use CAD software such as SolidWorks to help them plan how the contents of their av-bay will be organized and sometimes to 3D-print some parts such as av-bay sleds and camera pods (see figures later in this paper).

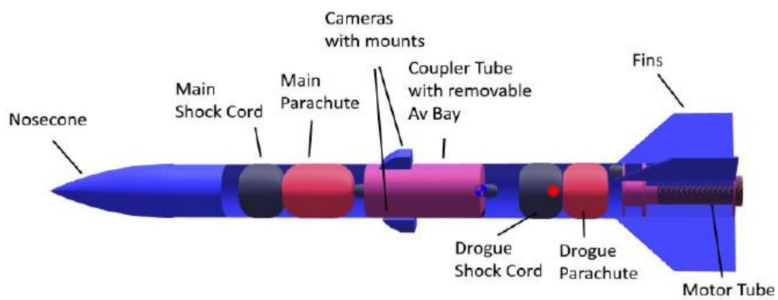
In addition to mini-lectures on rocketry basics and construction techniques, I also include presentations about "real" (i.e. historical and/or outer space) rocketry. We talk, albeit briefly, about systems engineering, especially as it relates to spacecraft. We watch episodes 1 and 5 from HBO's *From the Earth to the Moon* mini-series and the students do pair-peer-review of short essays on either (a) the impact of adding astronauts to a space program or (b) the ways in which science and engineering interact in a space program. We discuss trajectory design as well as Entry, Descent, and Landing (EDL) for missions to the Moon and to Mars, which are very different. And also we talk about the past, present, and future of human spaceflight. Students are always surprised to learn how many different countries have worked on, or are currently working on, trying to develop the ability to get their own citizens into outer space.

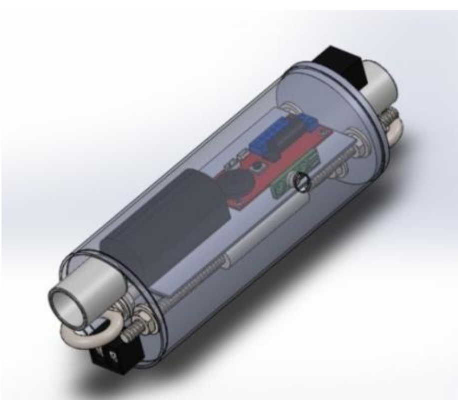
I have posted some documents from my high-power rocketry freshman seminars here:
http://www.aem.umn.edu/people/faculty/flaten/AEM1905RocketrySampleDocuments/
Please maintain attribution to me and to the U of MN – Twin Cities if you elect to modify/adopt any of them for your own use.

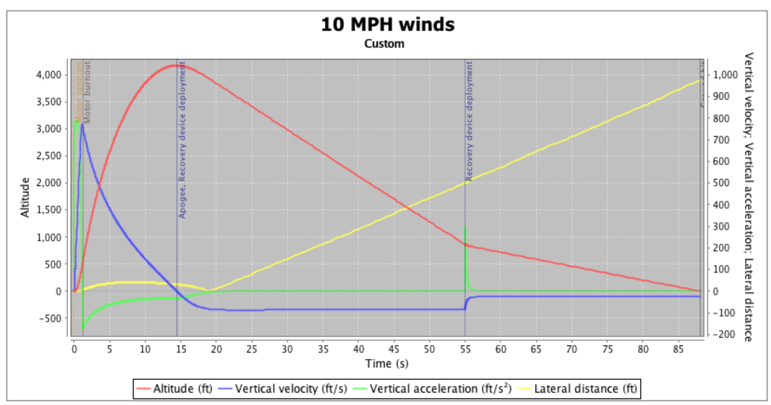
Some images from high-power rocketry oral and written reports produced in freshman seminars.











Challenges

Since the launching of high-power rockets is a regulated activity (by rocketry clubs who, in turn, seek FAA waivers), an important early step for getting involved in high-power rocketry learn is to about launch opportunities in your part of the country. If you want to incorporate high-power rocketry into your curricular offerings, you also need to explore how launch opportunities mesh with your academic school year and with student availability. The U of MN – Twin Cities works with the Tripoli Minnesota High-Power Rocketry Club http://www.tripolimn.org/ which conducts monthly club launches on sod farms near North Branch, Minnesota (about a one-hour drive from Minneapolis) from May through October. We attend those launches when we can, but we are fortunate that Gary Stroick of Tripoli Minnesota is willing to offer us additional launch dates, upon request. Fall classes typically launch kit-rockets at the Tripoli Minnesota October club launch then call for a "private" launch closer to the end of the semester, to launch "Round 2" rockets. Competition teams, on the other hand, tend to do a lot of designing and building during the fall and winter but often want to start doing test flights in March or April, requiring additional "private" launch dates.

Every high-power rocket launch must be sponsored and overseen by a certified rocketeer – typically a member of the club running the launch. It is best for the instructor of a high-power rocketry class to become certified since doing so will teach them a lot about rockets and make them a better instructor. Then they can oversee launches of rockets built by their own students. "Level 1" certification requires building, by yourself, a high-power rocket then flying and successfully recovering it on an H or I-class motor. There is no written test, nor a requirement that the rocket contain any electronics. Having Level 1 certification allows one to purchase and fly H and I-class motors. "Level 2" certification requires passing a multiple choice test and building, by yourself, a high-power rocket then flying and successfully recovering it on a J, K, or L-class motor. There is no requirement that the rocket contain electronics, but the launching club might have addition rules such as requiring electronic tracking on all rockets flying higher than 3000 feet. Although it is not required, building a rocket for a Level 2 certification attempt is a good opportunity to learn to install and operate an altimeter and possibly even use a dual-deploy (two-parachute) configuration. Having Level 2 certification allows one to purchase and fly J, K, and L-class motors. Typically certification also requires active paid-up membership in a high-power rocketry club. I am a member of the Tripoli Minnesota High-Power Rocketry Club.

Students cannot become certified based on what they do in my freshman seminars because they work in teams rather than individually to build their rockets. But I have them take the Level 2 certification test so upon completion of my class they are well-poised to earn both Level 1 and Level 2 certifications, if they want to take the time (and spend the money) to build additional rockets by themselves. Students on our Rocket Team regularly choose to become certified.

Cost can be an issue, of course, including transportation to launches. A modest-size high-power rocket kit might cost about $100, plus an additional $100 or so for the epoxy and other construction materials and an H-class or I-class motor on which to fly it (one time). A programmable altimeter (we use Raven3, Stratologger, and AIM USB altimeters) that sense where the rocket is during flight and fire ejection charges, as opposed to an "Altimeter Two" which is just a data logger, will cost another $60 to $160 but is not consumable – it can be used over and over, even switched between rockets if need be. We typically use Mobius ActionCam video cameras in 3D-printed external camera pods to capture the down-looking rocket-view of the flight. That costs another $100 (or slightly less), but is also a non-consumable expense.

Other Options

As mentioned above, high-power rocketry can be engaging for college students from a wide variety of majors and ages, not just freshmen. The extra-curricular Rocket Team at the U of MN – Twin Cities recruits broadly, not just from my freshman seminar classes, and works on a wide variety of build projects. During a typical year they simultaneously (a) build kit-rockets, to train new members who didn't take my freshman seminar, (b) design and test custom rockets for high-power rocketry competitions, including our own Midwest Space Grant High-Power Rocketry Competition hosted with Tripoli Minnesota every spring in North Branch, and (c) develop new features of interest to club members, such as active roll control devices or casting their own body tubes and motor propellant. Students teaching students – the Rocket Team has relatively little faculty oversight – is quite effective, but it is handy to have formal freshman rocketry classes to feed knowledgeable members into that team every year as well. Some Rocket Team projects are multi-year endeavors, with the lessons learned during one year serving as the jumping-off point for the next year's activities. The Rocket Team assigns its members to subteams – Simulation/ Design, Avionics, Airframe, Propellant, Recovery, etc. Students sometimes elect to move from one subteam to another, picking up additional valuable skills as they do so.

Here is a video showing several views, including a down-looking on-board video, of the launch of one competition rocket built by a group of U of MN – Twin Cities freshmen just after finishing taking my rocketry seminar. https://www.youtube.com/watch?v=Hxd-pOwUZMQ Several of these students then went on to become leaders on the extracurricular Rocket Team.

If limitations on high-power launch opportunities prove to be insurmountable, or you just want to ease into rocketry at first, remember that model rocketry also has lots to offer for both the college and especially the pre-college level. Basically all you need is an open area in which to launch and recover rockets – the larger the better – no FAA permission required. Small model rocket kits flying on A or B motors are easy to assemble, can fly hundreds of feet high, and (with a data logger like an Altimeter Two) can collect high-quality performance data. Larger/heavier model rockets, either kit-built or designed-and-scratch-built, can be flown on motors up to G-class without certification (though attempting to use motors beyond about D-class really could benefit from a solid background in rocketry – like what high-power experience would provide). An intermediate solution might be for the instructor to get high-power certification and experience, but then limit flights with students to (possibly-large) model rockets which are cheaper, quicker and easier to build (so they could possibly be just a module in an existing class on another topic), less restrictive to launch, yet can teach essentially all of the same lessons.

Conclusion

Despite implementation challenges, high-power rocketry is a very engaging activity for college-age students that teaches skills many valuable skills. These include using software packages to simulate performance and guide design, using CAD for fabrication of parts and documentation, learning high-reliability construction techniques (especially working with epoxy), learning to wire ejection-charge circuits and program altimeters, and learning to collect, analyze, and present flight data. Possibly even more important, rocketry requires effective teamwork, communication, and organization. A rocketry class, especially the field trip day(s) to launch the rockets, is a welcome change of pace from typical classroom or laboratory activities.

Teaching high-power rocketry, especially to freshman, has been very rewarding. I encourage you to explore rocketry options in your area then engage your students in age-appropriate rocketry activities, either curricular or extra-curricular. Your students will thank you!

Appendix

At the end of each freshman seminar class the students put on a public exhibit at which they display rockets, show slides and videos, and tell stories. Here is a flier for one such exhibit.