AN INTEGRATED DESIGN COMPETITION USING MODEL ROCKETS

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Abstract

The principle objective of this design competition is to provide upper-level students with an opportunity to integrate the use of engineering measurements and analytical modeling techniques to accurately predict *a priori* the performance of a miniature rocket system. A secondary objective is to provide these students an opportunity practice and improve communication, leadership, and technical skills while grouped in small competing teams. Each engineering team is challenged to predict the performance of a miniature rocket by developing an analytical model of the rocket trajectory using engineering principles and laboratory measurements. The student teams also participate in the hands-on activity of building and launching the prototype rocket system. This prototype is ultimately used to test the predictions of the analytical model. It is launched for the first, and last, time as the concluding event of this design competition. To add realism to the activity, the student teams are given imitation money that is used to buy the materials (e.g. the rocket) and services (e.g. wind tunnel time). Points are awarded based on the analytical model, the results from the component testing, the aesthetics of the rocket, the weight of the finished rocket, the costs of the project, and finally, the performance of the rocket. This design competition provides the students with an open-ended design problem that emphasized the importance of employing the engineering design process in the development of a functioning prototype.

Introduction

The genesis of this design challenge for the upper level engineering students is rooted in the first flight of the McDonnell Douglas F18 E/F fighter plane. The F18 E/F is a significant upgrade of the F18 C/D. The E/F featured a stretched fuselage, new more powerful engines, new low-observable inlets, new wings, and new flight control software. The E/F was essentially a new airplane. Yet the first flight for this plane originated at Lambert International Airport located in the center of the St. Louis metropolitan area. The decision to take-off and land at Lambert with a new airplane might at first be considered a somewhat reckless disregard for public safety. However, after considering the preparation and engineering activities leading up to the first flight, the decision was based on confidence in a thorough engineering development program that had determined the airplane performance *a priori*. The F18 E/F successfully departed and returned to Lambert with minimal deviation from the flight plan. The first flight was a success.

The engineering development program had produced a detailed understanding of the aircraft's performance prior to the first flight. The airplane design was developed with over 15,000 hours of wind-tunnel testing. The flow field bounding the airplane was calculated in detail using computational fluid dynamic techniques. The engines were thoroughly tested in ground based test programs. The flight control system was developed and refined through thousands of hours

in a flight simulator. Full-scale mock-ups were built for testing the structural integrity of the airframe. The performance of the plane was modeled and predicted during a careful engineering development program prior to the first flight.

Our objective in developing this rocket design challenge for our students is to provide the students with a similar engineering development project on a scale compatible with an undergraduate laboratory course. The students experience the fundamental design process while being challenged to model and predict the performance of a small-scale rocket prior to its first flight. The process requires the students use the laws of motion and experimental results from ground based testing to develop a predictive numerical model describing the flight of the rocket. The experiments that provide the data for this model require the students to plan appropriate tests, obtain calibration data for the testing equipment, post-process the experimental data, and incorporate the data into their model. One advantage to this approach is that many of the laboratory activities and most of the equipment are the same as those used in the same course during previous semesters. The rocket theme unifies these lab activities into a complete design project.

The design challenge is organized as an intra-class competition. Each team's relative performance is measured based on six metrics: reporting scores, rigor of the analytical model, rocket performance, rocket weight, rocket aesthetics, and project cost. The class is divided into teams each consisting of four students. Each student team is responsible for developing a prototype rocket that satisfies mission requirements. These requirements provide the design constraints. The prototype is built from the parts provided in an Estes Alpha III model rocket kit and the rocket motor is specified (e.g. an Estes B4-4 model rocket motor).

In an effort to simulate a realistic development program with both time and monetary constraints, each team starts with deadlines and a budget consisting of $250 "Bradley Bucks". Using this budget, each team is required to purchase all of the materials (including the rocket kits and motors), occupancy hours for the test facilities, and hourly wages for support personnel. Each team has the freedom to spend their budget as needed with the understanding that the lowest cost will result in the highest budgeting score.

Technical Approach:

Building and launching an Estes rocket kit is a relatively simple endeavor for most college level students. The performance of these kits and motors is well documented by Estes[4] and in published literature. For example, an Alpha III rocket with a B4-4 rocket will reach an altitude of 600-800 feet upon launch. The students are asked to modify the basic rocket kit so that the prototype would launch to some other peak height, for this example an altitude of 100 feet. The students are also asked to make the prototype lightweight and stable. They are also asked to make the rocket aesthetically pleasing to a casual observer. The most significant challenge to the students is that the rocket performance is measured on the first launch of the rocket. Any indication of a prior launch, which is relatively easy to detect on these models, will disqualify a team from the competition and result in a score of zero. This last constraint requires the students to develop an accurate analytical model of their rocket's performance based on the laws of motion and ground based component testing. The deadlines imposed for the project are

predominantly for reporting these test results and delivery of the model predictions. The overall team scores are also heavily weighted towards the quality of the reports and the analytical model.

The students are required to develop an analytical model based on Newton's Second Law of Motion:

$$\Sigma \mathbf{F} = (1/g_c)(m * \mathbf{a}). \tag{1}$$

The mass is the instantaneous mass of the rocket and the forces are the thrust of the rocket motor, **T**, the weight of the rocket, **W**, and the aerodynamic drag, **D**.[1,2] The instantaneous acceleration, **a**, of the rocket is a function of forces acting on the rocket, the mass of the rocket, and time, t.

$$\Sigma \, \mathbf{F} = m*\mathbf{a} \; = \mathbf{T} - \mathbf{W} - \mathbf{D} \tag{2}$$

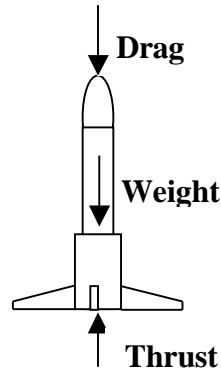$$\mathbf{a}(t) = \frac{\mathbf{T}\,(t) - \mathbf{W}(t) - \mathbf{D}(t)}{m(t)} \tag{3}$$

Figure 1: Forces acting on the rocket

The acceleration is also the derivative of the velocity,

$$\mathbf{a}(t) = d\mathbf{V}/dt \tag{4}$$

$$\frac{d\mathbf{V}(t)}{dt} = \frac{\mathbf{T}\,(t) - \mathbf{W}(t) - \mathbf{D}(t)}{m(t)} \tag{5}$$

The acceleration is numerically integrated to evaluate the instantaneous velocity of the rocket,

$$\mathbf{V}(t) = \int_0^t \frac{\mathbf{T}(t) - \mathbf{W}(t) - \mathbf{D}(t)}{m(t)} \, dt \; . \tag{6}$$

The velocity is then numerically integrated to evaluate the instantaneous displacement of the rocket, **Y**,

$$\mathbf{Y}(t) = \int_0^t [\mathbf{V}(t)] dt \, dt \quad . \tag{7}$$

The results from these numerical integrations include the instantaneous acceleration, velocity, and displacement of the rocket.

Clearly, the reliability of the analytical model is linked to the understanding of the of the thrust, the drag, and the mass (and thereby weight) as a function of time from the instant of launch. The ground based component testing is primarily directed at measuring the thrust and drag forces and the mass of the rocket.

The thrust forces generated by the rocket motors are measured using a rocket thrust stand shown in Figure 2. The rocket motor is mounted inverted and attached to a load cell. The output of the load cell is measured using a computer controlled analog-to-digital (A/D) converter. The sampling rate of the A/D is selected by the individual teams with a maximum possible rate of 10,000 samples per second. A lab assistant is available to operate the test stand and to deliver the raw data. The students are informed that they should expect variability in the thrust output between rocket motors and this variability could effect the agreement between their predictions and the actual rocket performance. They are encouraged to test more than one rocket motor. However, it should be noted that the teams are required to use their budget to pay for all of the rocket motors that they used. In addition, their budget is charged for the time that they use the thrust test stand.
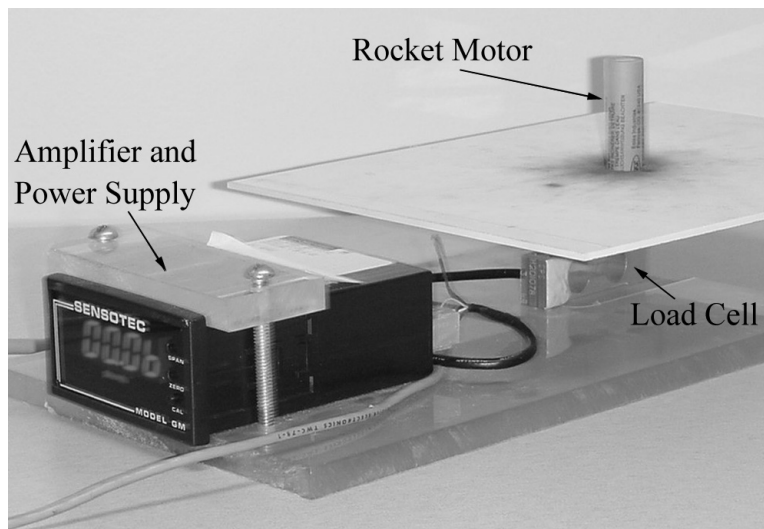

Figure 2: Rocket motor thrust stand

The drag forces on the rocket are measured using a subsonic wind tunnel. Rocket model concepts are mounted on a wind tunnel sting that is instrumented with lift and drag load cells. Figure 3 shows a rocket model mounted in the subsonic wind tunnel. The maximum velocity of the wind tunnel is about 120 mph (176 ft/s), higher than the expected peak velocities for the rockets. The students are required to specify the operating velocities for the test points and are allowed the freedom to change and/or modify the rocket model during the testing. A technician is available to conduct the tests as prescribed by the students and to deliver the raw data. Again

it should be noted that the team budget is charged for wind tunnel occupancy hours. The students are encouraged to represent their data in terms of the dimensionless parameters: Reynolds' Number, Re, and drag coefficient, C_d.[3]

The mass of the rocket includes the fixed mass of the rocket body and the variable mass of the rocket motor propellant. The students are able to measure the mass of the rocket motor before and after firing on the thrust stand. Three different scales are made available to the students with different full-scale ranges and resolutions. They are allowed to dissect one rocket motor and measure the mass of the components. They are also allowed to mount the rocket thrust stand vertically so that a rocket motor could be fired horizontally and eliminate the contribution of gravity. Based on these data, the students develop an empirical model that predicts the variable mass of the propellant as a function of time. This empirical model of the mass is inserted into the rocket performance model to predict the overall mass and weight of the rocket.
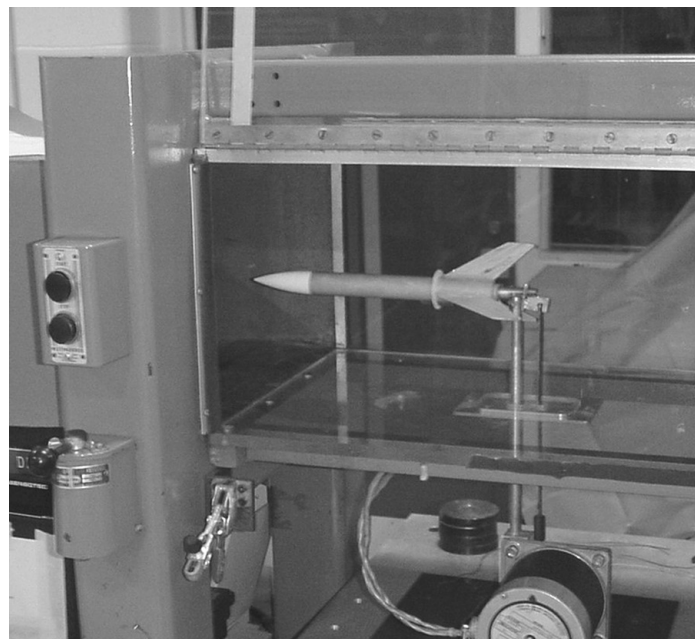

Figure 2: Model rocket mounted in the subsonic wind tunnel

The analytical model of the rocket performance is based on the discrete integration of Newton's second law (see equations 1 through 7). The recommended approach uses a predictor/corrector iteration scheme and the students are encouraged to use the Engineering Equation Solver software for the integration[4]. The students determine both the time step for the integration and the convergence criteria predictor/corrector approach. The initial conditions are approximated as zero height, velocity, and acceleration. At each time step, the instantaneous forces are calculated based on the previous time step. The instantaneous acceleration is then calculated from the forces. The acceleration is used to evaluate a new velocity and the velocity is used to evaluate the displacement. The new velocity is used to calculate a new estimate of the aerodynamic drag, which changes the forces acting on the rocket. The calculations are repeated for the acceleration, the velocity, and the displacement, which results in a new value for the aerodynamic drag. This process is repeated at each time step until the solution converges. The peak altitude occurs when the velocity reaches a value of zero.

Design Competition Description

As noted previously, the key objective of this competition was for the students to formulate a model of the rocket's performance before they launch it. The objectives, the deadlines, the rules, and the metrics were provided to the students in writing and orally early in the semester. A sample listing of the schedule and project deadlines is provided in Table 1 below. The students are given two coaching sessions during class periods for discussions covering the appropriate governing equations and approaches to model the rocket's acceleration, velocity, displacement and stability. During these coaching sessions the students were introduced to the testing facilities that they would be using to acquire their data. The students were required to use one of two different software packages that allowed them to perform the necessary integrations and data processing.

Table 1: Competition Schedule
09/06/01 – Accept the challenge and begin model development
09/13/01 – Receive rocket kits
10/04/01 – Preliminary Analytical Model Report (Memo Report by Close of Business,COB)
10/18/01 – Deliver the Aerodynamic Drag Report (Memo Report by COB)
11/15/01 – Deliver the Rocket Thrust Report (Memo Report by Close of Business, COB)
11/15/01 – Deliver the Final Analytical Model (Memo Report by COB)
12/06/01 – Launch rockets (rain/snow date 12/12/01)
12/12/01 – Deliver Final Technical Report (By COB)

Testing

The test facilities for measuring thrust, weight and aerodynamic drag described above and were made available to the teams during two regularly scheduled lab periods. All the teams did their testing of the initial rocket designs during these regularly scheduled lab periods. The teams were required to reserve a time for their tests on a first-come-first-serve basis. For times outside of the scheduled lab periods, the teams were allowed to continue testing for successive design iterations based on the lab assistant and lab's availability. This was not an administrative nightmare because the cost constraints not only prevented teams from performing multiple tests but also motivated them to put more thought into the scheduled testing.

The students were expected to arrive at their reserved time prepared with a test plan. The lab assistant was to serve as a technician only and was instructed not to give the team any engineering advice. The teams specified the data they needed, the levels required for the independent variables, and the sampling rate for the data. The technician only delivered the data that was requested. For example if calibration information was not requested, the calibration data was not delivered. The calibration data was collected prior to testing and was provided to the teams upon request for a charge against their budget.

Reporting

Two types of written reports were required of the students. The first and most common report was the memo report. These reports were to summarize the results of each of the tests (drag and thrust) and the analytical modeling. These reports were based on the premise that all of the

participants, including the reviewers, were aware of the test equipment, procedures, and the project objectives. This report was intended to simulate a report that might be used in a corporate internal communication between collaborating teams and was based on an industry model. At the end of the semester, a comprehensive lab report was required. This second type of lab report was based on the premise that the reader had no previous knowledge of the design project. The students were required to provide all pertinent information and were allowed to incorporate the previous memo reports into the final report. The students were given the format for this report at the beginning of the semester, which was the same as the format required for the other lab exercises performed for the course.

Budgeting and Fee Structure

A fundamental goal of this activity was to simulate realistic working conditions in the execution of this design activity. In any profitable enterprise cost is an important factor in the design process. Therefore, we introduced expenses into the exercise and made them an important factor in the final scoring. With the development of any engineering system there are costs associated with the purchase of materials, support personnel wages, and lab facility fees. All of the activities of this project were assigned relative costs. We printed an artificial currency for this project and the principle denomination was called a "Bradley Buck". Each team was given $250 Bradley Bucks at the beginning of the project. A fee structure for materials and services was established as shown in Table 2.

Table 2: Costs and fees (all costs are in $Bradley Bucks$)

Materials	Rate:	Minimum Charge:
1) Rocket Kit	$20/rocket	$20
2) Rocket Motor	$10/motor	$10
Facility Fees		
1) Wind Tunnel Fees	$40/hour	$10
2) Thrust Stand Fees	$10/data set	$10
3) Scale Fees	$40/hour	$10
4) Launch Fees	$10/launch	$10
5) Calibration Fees	$10/Instrument	$10
6) PC Laboratory	No Charge	
7) Software Licensing Fees	No Charge	
Consulting Fees		
1) Professor	$80/hour	$20
2) Teaching Assistant	$20/hour	$10
3) Fellow Student	$10/hour	$10

When a team required any material or service, that team was required to sign some of their currency and "pay" the lab assistant. This money was accumulated throughout the semester and totaled at the end of the project to determine the team's cost score.

One unexpected result from imposing and tracking expenditures was the cooperation among the competing teams to collect common data. Some of the required data could be shared between the teams without compromising the competitive nature of the project. For example, all of the teams pooled money to buy a statistically significant number of rocket motors to test the variability in the rocket motor thrust. Since all the teams were required to use the same model

rocket engine they collaborated to perform common thrust tests and then shared the results. This collaboration allowed the teams to reduce the costs for acquiring thrust data without detracting from the independent nature of the project.

This collaborative structure evolved organically for this project and similar collaborative efforts can be seen clearly in industry as competitive companies pool resources for pre-competitive research (e.g. automotive companies formed USCAR to develop a high efficiency vehicle, Society of Automotive Engineers, etc.) and post-competitive testing (e.g., mileage ratings of vehicles, efficiency ratings consumer appliances, etc.)

Aesthetics

The last criterion upon which the rockets were judged was the aesthetics. This feature of the competition provided the students with an opportunity to introduce some non-technical creativity to the prototype. Photographs of the rockets were collected and then distributed to one of the freshman classes for an unbiased, independent evaluation. The freshmen were allowed to vote for the best looking rocket and the votes were tabulated.

Student Teams

As technological problems in today's world become more complex the need for teams of specialists becomes greater. At Bradley University we are striving to integrate team projects into as many courses as possible. This rocket project is ideal for providing experience working in teams. First, the requirements for the project are bigger than one individual can accomplish in one semester. The activities are comprehensive enough to allow for specialization. The rocket fabrication required manual dexterity; some students are better than others. The computer model required someone with better analytical skills capable of concentrating on the programming and data analysis. The reporting requirements required someone with good communication skills. Finally, the aesthetic component of the competition required someone with artistic skill capable of producing a visually appealing rocket. We survey the students at the beginning of the semester to assess their strengths and assign balanced teams. We have tried to prevent friends from participating on the same team. By doing so, the opportunity for the students to learn the skill of working on a team with people that they don't necessarily know or like has been preserved.

Scoring and Grading

Our intentions were to weight the theoretical model heavily to emphasize the importance of using engineering tools during the design process to simulate performance and enhance a design prior to hardware development. Our original goal was to simulate realistic budget pressures on the engineering teams as they decided which expenses to incur while delivering an acceptable design. Our plan was to represent a company where management places importance on both cost and long-term profitability. As it turned out, our choice of the relative weighting for the budget (15%) versus performance (5%) simulated a condition in industry where management placed too great importance on cost with little regard for performance. As an example, some teams chose not to perform additional testing even if it might lead to significantly improved rocket

performance because the points gained from saving money would more than offset the points deducted from missing the target altitude.

The scoring is based on several criteria as outlined in Table II.

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Table II: Scoring

1) Final Technical Report	15	pnts
2) Theoretical Model	20	pnts
3) Aerodynamic Drag Report (Memo)	15	pnts
4) Rocket Motor Thrust Report (Memo)	15	pnts
5) Performance (Closest to 100 ft = high score)	5	pnts
6) Weight (minimum weight = highest score)	5	pnts
7) Aesthetics (class vote)	5	pnts
8) Soft landing	5	pnts
9) Cost (minimum cost = highest score)	15	pnts

Total: 100 pnts

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Based on our observations of the class behavior, it is clear that the balance of points awarded for the budget and performance can be adjusted to simulate a variety of industrial environments. This balance could be adjusted to reflect an environment where great emphasis is placed on minimizing cost, like a manufacturer of consumer products. In contrast, the balance could be adjusted to reflect an environment where great emphasis is placed on extremely reliable performance regardless of cost, for example a company developing a system to land men on the moon or place an expensive satellite in an orbit of Mars. The next time we challenge the students with this design competition, we plan to strike a different balance between the two factors.

Results

Figure 4 demonstrates a typical model output for a prototype rocket design. The original diameter of the unmodified rocket is 1 inch. One approach to increasing the aerodynamic drag and reducing the peak altitude is to increase the frontal area. Another approach to decreasing the peak height is to increase the weight of the rocket. For this case, increasing the frontal area required more material being added to the rocket, which also increased the weight. The increased weight also affected the rocket performance. Balancing the increased weight and increased aerodynamic drag in the analytical model lead to a design for which the rocket traveled to a peak height of 100 feet. The model showed that by increasing the diameter of rocket body to 1.585 inches the peak altitude was decreased to achieve the mission objective.

It should be noted that this mission objective could have been met by only increasing the weight of the rocket. However for this reason, a second design goal was to minimize the weight of the rocket. If a team were to choose to only increase the weight of the rocket the team would be penalized in the weight criteria and experience shows that increased weights additionally leads to sacrificing points for a soft landing.
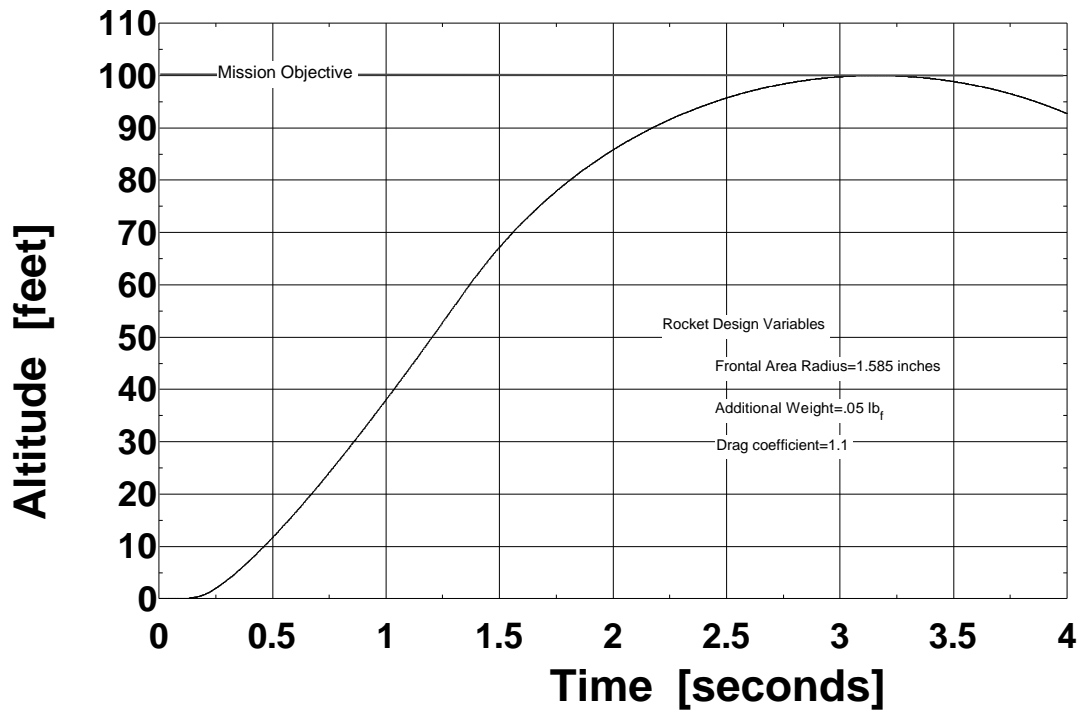
Figure 4. Predicted altitude for a typical modified rocket

Most teams used the analytical models to calculate a prediction of the performance of the design prototypes they had developed through testing rather than to use the model as a predictive design tool. The students were given enough information on the first day of class to develop an analytical model. They were shown references and data about drag coeficients[3]. They were given manufacturer's information about the rocket motor performance[4]. Yet, most of the teams started wind tunnel testing without completing the analytical model. They deduced they needed to increase the frontal area of the rocket to increase drag. During the wind tunnel experiments these teams changed the rocket geometry and measured the corresponding drag. Once the analytical model was completed these drag coefficients were inserted to make a prediction for the peak altitude. If the peak altitude was too high, the analytical model was used to predict a required increase in weight. Weight was added to the model to achieve the target height.

The students could have used the analytical model as a predictive design tool by evaluating a target drag coefficient prior to wind tunnel testing. Then the wind tunnel tests could be used to develop a model that produced the appropriate drag results keeping the weight to a minimum. A future improvement to this design challenge will be to require a preliminary analytical model capable of predicting performance prior to any testing. This is already reflected in the sample competition schedule seen in Table 1. The students will be asked to identify a target drag coefficient for the models prior to the wind tunnel tests.

The students were also required to plot the acceleration and the velocity of the rocket through its trajectory to the peak altitude. Figures 5 and 6 show typical plots of the predicted acceleration and velocity respectively. The acceleration plot presented in Figure 5 is based on the raw, unfiltered thrust data from the thrust stand. Some teams chose to filter their data.
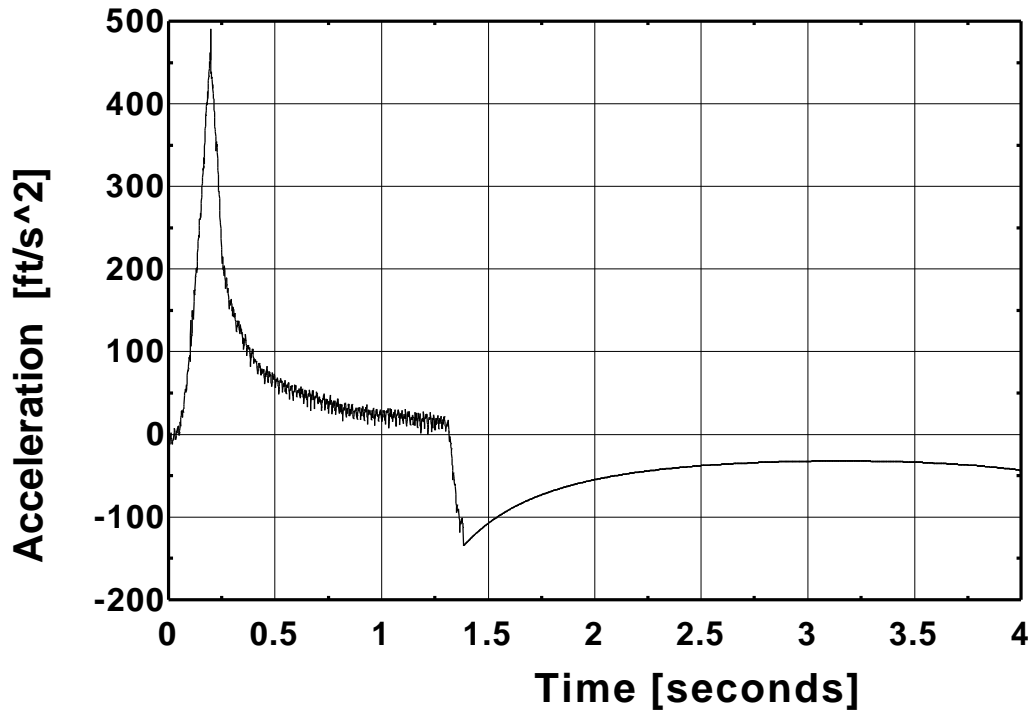
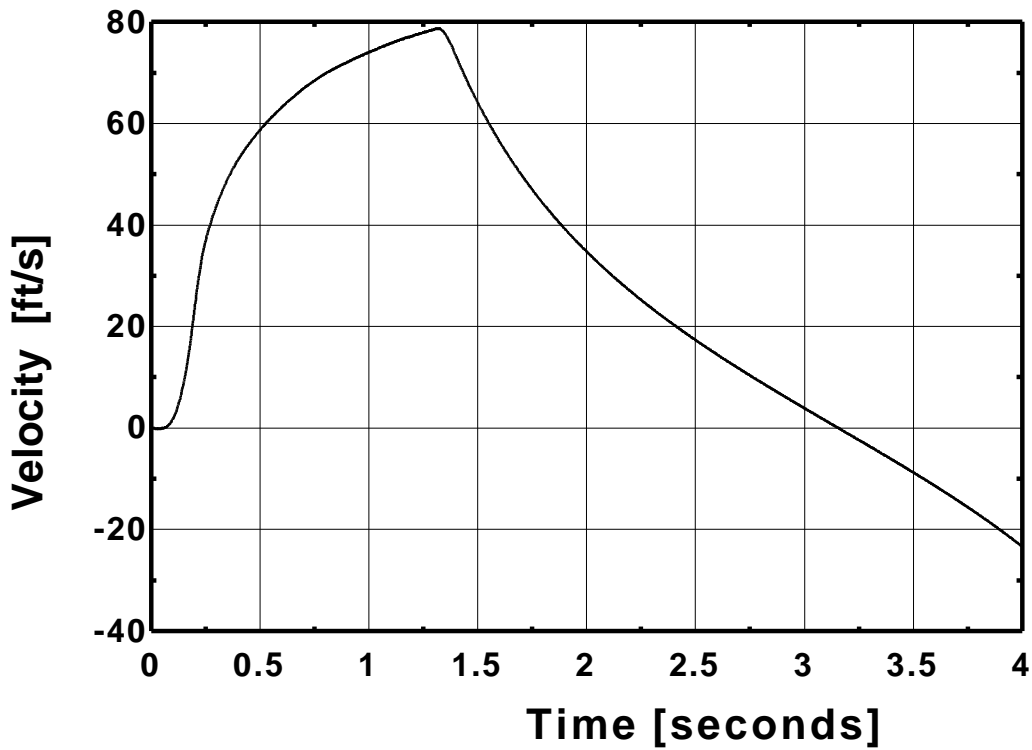Figure 5. Predicted acceleration for a typical modified rocket model

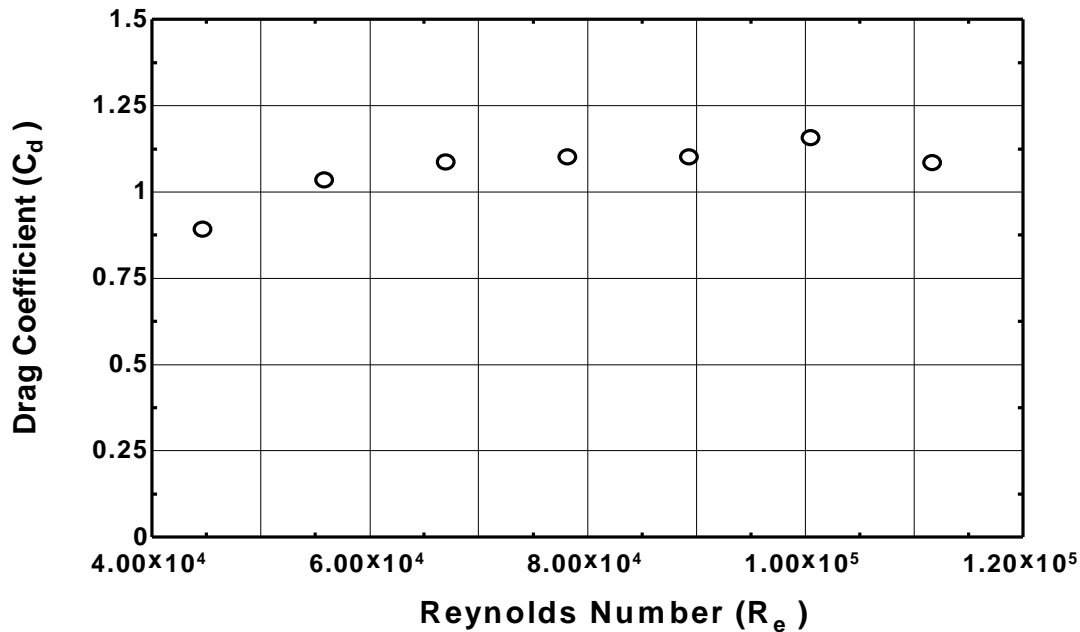Figure 6. Predicted velocity for a typical modified rocket model

Figure 7: The drag coefficient as a function of Reynolds number

Component Testing

As noted previously, the students were allowed (and required) to use a wind tunnel and thrust stand apparatus for a charge against their budget. The data that resulted from these experiments were used in the analytical models to predict the rocket performance. These data were also documented in the required reports. Figure 7 shows the results from the wind tunnel test of one team. This team chose to test their prototype rocket at seven different wind tunnel velocities. At each velocity they measured the drag force. They were required to represent the data in dimensionless form. From the experimental data, they were able to determine the drag coefficient as a function of Reynolds number. The Reynolds number is based on the diameter of the frontal area of a rocket that had a diameter of 1.5 inches. As one might expect, the Reynolds number is relatively constant over much of the velocity range. As a result, the students were able to extrapolate the drag coefficient to the entire range of flight velocities with reasonable confidence.

The rocket motor thrust is an important input to the analytical model. As noted above the thrust was measured using a thrust stand. The results from one of these experiments is shown in Figure 8. These data were sampled at a rate of 1000 samples/second. The data shown in this plot were unfiltered. The student teams were required to integrate this data to evaluate the total rocket motor impulse. They were given the freedom to filter the data as they deemed necessary for a satisfactory result. They also were encouraged to compare the results of several motors to evaluate an average thrust and impulse. The choices of the teams ranged from using raw data in their models to using filtered and averaged thrust curves. The students were also given the opportunity to use the measured variability in the rocket motor performance to broaden the target range for the peak altitude from 100 ± 0 ft to $100 \pm \delta$ ft. The allowable error, δ, was determined using the variability in the thrust of the rocket motors along with other sources of uncertainty.
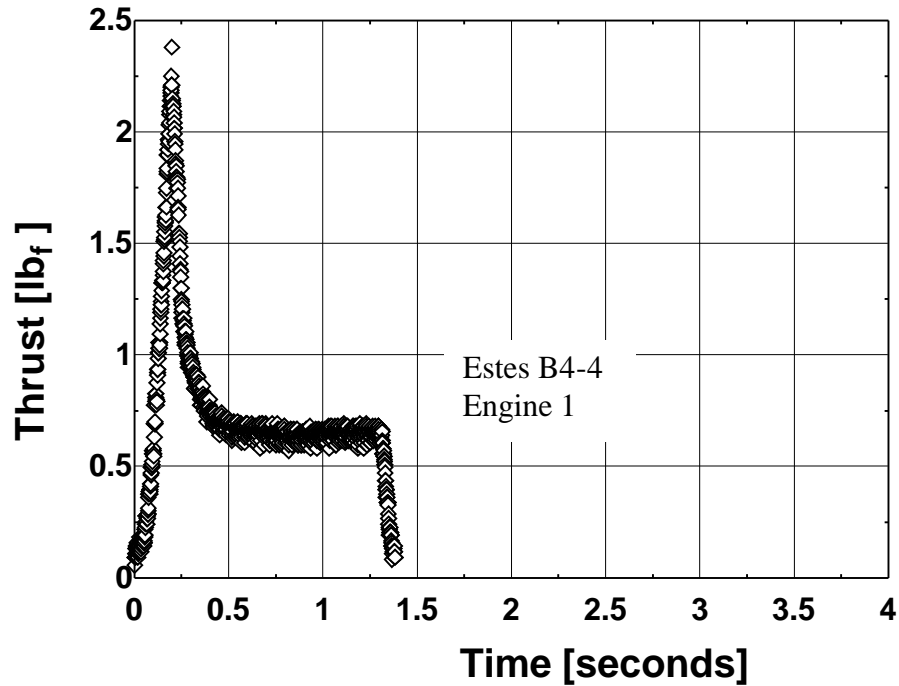
Figure 8. An example of the measured rocket motor thrust

Performance

The rocket launch was the final activity of this competition. The design concepts for the rockets varied widely. Most tried in some way to increase the frontal area. Figure 9 shows the rockets.

Figure 9: A photograph of the rockets

All of the rockets were launched in sequence on the same day and under the same launch conditions. A support technician launched the rockets. The altitudes were measured using four inclinometers positioned equidistant around the launch site. The rockets from the five teams flew from a low of 53.6 feet to a high of 122.4 feet. The measure of performance was the difference between the peak altitude of the flight and the mission objective of 100 feet.
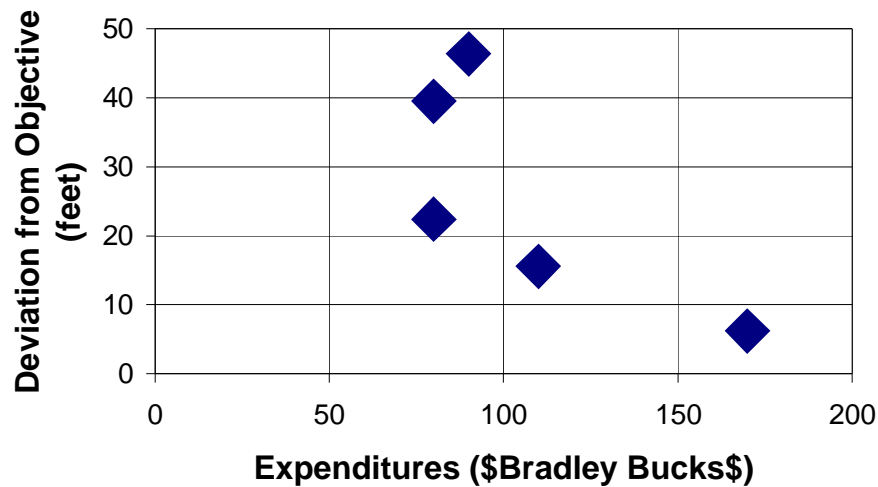

Figure 10: Influence of spending on rocket performance.

Figure 10 shows the absolute value of the deviation from the target height. From this figure, it is clear that the teams that spent the most money on development came closest to meeting the objective.

Conclusions

It was clear that the students enjoyed the design competition and were anxious to launch the rockets for the first time to test the performance of the analytical models. This competition has proven to be a comprehensive design exercise that has been successfully integrated into a laboratory course. The exercise uses many pieces of equipment that have been traditionally used in this lab but with a unifying theme. An emphasis was placed on modeling the performance of the rocket system prior to fabricating the functional prototype.

Introducing cost and budget constraints into the design process simulated realistic design pressures in industry and fostered more team collaboration coupled with a reduction in the amount of testing. The scoring algorithm for the competition introduced an opportunity for students to make design decisions that influenced both their team performance and their grades. The algorithm can be tailored to emphasize different factors governing the design process. The scoring algorithm can be used to simulate different economic environments and corporate cultures by the relative weighting of the budget and performance criteria.

Our observations and feedback from the students suggest that this design challenge was both fun and effective. We believe that we can improve the experience for the students by promoting the analytical model as a predictive design tool as opposed to only a predictive analysis performed

after testing. In the future, the students will be required to develop a functional analytical model prior to any component testing. The preliminary results from the model will be compiled into a preliminary report with an early deadline.

Bibliography

1. "Handbook of Model Rocketry", G. Harry Stine, March 1994, John Wiley & Sons; ISBN: 0471593613. 349 pages.
2. "Second Stage : Advanced Model Rocketry", by Michael Banks (Compiler), Tim Van Milligan (Compiler), William Coulter, Tim Van Milligan (Editor), 2nd edition, May 1998, Kalmbach Publishing Company; ISBN: 0890242127.
3. "Fluid Mechanics", Frank White, 4th Edition, 1999, McGraw-Hill, ISBN 0-07-069716-7
4. "Estes Technical Information Sheets," www.estesrocket.com/rocketry101
5. "Engineering Equation Solver," S.A. Klein, 2002, F-Chart Software

Biography

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