Astronomy as a Tool for Training the Next Generation Technical Workforce

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Abstract

A major challenge for today's institutes of higher learning is training the next generation of scientists, engineers, and optical specialists to be proficient in the latest technologies they will encounter when they enter the workforce. Although research facilities can offer excellent hands-on instructional opportunities, integrating such experiential learning into academic coursework without disrupting normal operations at such facilities can be difficult. Also, motivating students to increase their skill levels by undertaking and successfully completing difficult coursework can require more creative instructional approaches, including fostering a fun, non-threatening environment for enhancing basic abilities. Astronomy is a universally appealing subject area, and can be very effective as a foundation for cultivating advanced competencies. Therefore, an experiment to achieve the above goals using an astronomy-based concept was implemented at the New Mexico Institute of Mining and Technology in the Spring 2009 academic semester.

1. INTRODUCTION

We report on a project initiated at the New Mexico Institute of Mining and Technology (NM Tech), a science and engineering school in Socorro, NM, to incorporate a state-of-the-art optical telescope and explosive experiments into an entry-level course in basic engineering. Students enrolled in an explosive engineering course were given a topical problem in Planetary Astronomy: they were asked to explore a method to energetically mitigate a potentially hazardous impact between our planet and a Near-Earth asteroid to occur sometime in the future. They were first exposed to basic engineering training in the areas of fracture and material response to failure under different environmental conditions through lectures and traditional laboratory exercises. The students were then given access to NM Tech's Magdalena Ridge Observatory's (MRO) 2.4-meter telescope (see Fig. 1) to collect physical characterization data, (specifically shape information) on two potentially hazardous asteroids (one roughly spherical, the other an elongated ellipsoid). Finally, the students used NM Tech's Energetic Materials Research and Testing Center (EMRTC) to perform explosive experiments to discern how an object's shape affects outcome, and what must be factored into explosive charge placement to attain the desired result of complete destruction of the object. The scientific findings (details below) derived by the students were valuable, and the students benefited from this non-traditional teaching approach such that they acquired a superior appreciation for research and experimentation, and exited the course with an increased motivation to continue their engineering training.

Fig. 1. The Magdalena Ridge Observatory's 2.4-meter fast-tracking telescope facility.

2. COURSE OBJECTIVES AND IMPLEMENTATION

Basic Engineering

The parent course was one offered through the Explosives Engineering Department at New Mexico Tech, entitled "Introduction to Pyrotechnics and Explosives". This course was designed as a hands-on introduction to the field of explosives engineering, through which many basic principles of explosives were demonstrated by making pyrotechnic compounds in a laboratory setting, with an emphasis on laboratory and pyrotechnics safety. Throughout the course, students explored concepts such as combustion chemistry, oxygen balance, and physical effects including confinement and particle size/shape and their effects on the performance of energetic materials. Students also ran small-scale experiments to compare the performance of different pyrotechnic compounds by modifying common explosive tests (the Trazul test, the plate dent test and the Eglin heave test, among others). The final, large scale tests were conducted at the Energetic Materials Research and Testing Center, and are detailed below.

Observational Astronomy

To best assess and plan for mitigation of a potential asteroid impact with the Earth, a better understanding of the physical parameters (impact strength, size, spin rate, shape) that characterize the near-Earth population of objects is required. Specifically, the object's shape poses significant challenges in terms of developing a plan to fragment and disrupt it, in order to render it harmless if it were headed toward the Earth. Therefore, a laboratory exercise was developed to introduce students to this concept, and to provide a framework for additional training in mathematical interpretation. For this exercise, the students worked with photometric data that they collected themselves (see Fig. 2) on an asteroid using the Magdalena Ridge Observatory's 2.4-meter telescope [1] to determine the asteroid's rotation period and approximate shape (i.e., whether the object was elongated or roughly spherical).

Asteroids generally are irregularly shaped so that as they rotate, their effective cross sectional area changes as viewed from the Earth. That means that the light reflected back to an observer also changes, and that light variation over time is called a "lightcurve". By observing the light curve as the asteroid rotates, its rotational period (or how fast it's spinning on its axis) can be determined. Typical rotational periods for asteroids in the main asteroid belt between Mars and Jupiter are 5 - 15 hours, but near-Earth objects have been observed to rotate with spin rates as fast as 42 seconds. Further, the amplitude of the lightcurve (i.e., the magnitude at a peak in the variation subtracted from the magnitude at a trough) can be used to estimate its rough shape—the larger the amplitude, the more likely the asteroid is elongated.

Fig. 2. Students taking data using the MRO 2.4m telescope.

Two asteroids (of different shapes) were used as the 40 or so students cycled through collecting data with the telescope. Using the photometric dataset they acquired, the students measured the brightness of the asteroid as it varied with respect to two comparison stars in the image field (this is differential photometry). They solved for the rotation period by analyzing the lightcurve, and derived the amplitude. A sample of the data from one of the student groups is shown in Fig. 3 for Near-Earth asteroid 1997 XF11. The students were then instructed that to a first approximation, the amount of light reflected from the asteroid can be estimated as proportional to its cross sectional area. They derived a relationship linking cross sectional area to brightness variation, assumed that the object could be modeled as a triaxial ellipsoid, and estimated the asteroid's axial ratio implied by the amplitude of their measured lightcurve. Some of the student groups measured asteroids that deviated only slightly from being spherical, and others found that their asteroid was nearly cigar-shaped. The basic objective was accomplished, however: to introduce the students to complication of asteroid shape variations that would set the stage for the next stage of the course: threat mitigation (see next section).

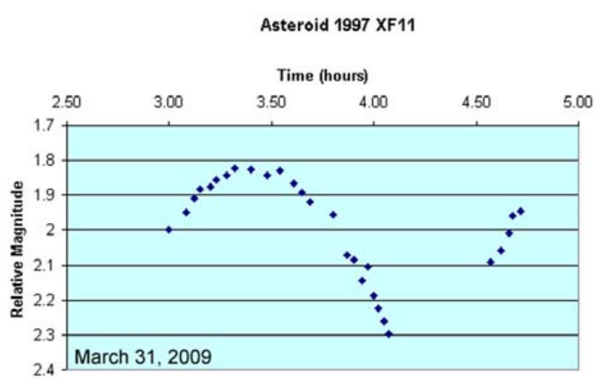

Fig. 3. Partial lightcurve data on asteroid 1997 XF11 taken by the students.

Impact Experiments

The goal of this pilot project was to lead the students through the basic steps necessary to prepare them to address the problem of how to destroy a potentially hazardous asteroid on a collision course with the Earth. They were given in-class laboratory training, exposure to computer usage, mathematics practice, and hands-on training collecting and analyzing observational data on the asteroids themselves. The final stage would be for the students to perform laboratory impact experiments to simulate an asteroid target and try to fragment it such that it would be rendered harmless as an impactor. To accomplish this, the students were given access to NM Tech's Energetic Materials Research and Testing Center (EMRTC) and were asked to perform 4 impact experiments using the facility's powder gun and 4 targets of differing sizes and shapes.

To implement this approach, it is necessary to be confident of the energy required to completely destroy and disperse the object in question, which in turn is dependent on composition, internal structure, size, and shape. The laboratory impact experiments for this project were designed to explore the effect of both size and shape on collisional outcome. This ability to physically characterize the hazardous object enhances our predictive capabilities and better ensures that the desired end result will be achieved.

The "model" asteroid targets were made of a mixture of cement and silica sand (#30), which is a good material analog to real asteroids, and the projectiles were 1018 steel, seated in a polylux sabot. The projectile mass (~1 kg) and type was held constant for all of the impact shots. Target sizes and types were varied: a 1-foot, 2-foot, and 3-foot diameter cube were used, as well as a 3-foot long (1-foot diameter) cylinder. Table 1 summarizes the initial impact conditions and outcomes for the 4 impact shots.

Target Type (cement/silica sand)	**3' cube**	**2' cube**	**1' cube**	**3' cylinder**
Target Mass (kg)	1763	523	66	346
Projectile (1018 steel) Mass (kg)	1.091	1.104	1.095	1.098
Powder type	HC33FS	IMR 3031	IMR 3031	HC33FS
Powder wt. (lbs)	1.85	0.56	0.0115	1.85
Impact Velocity (km/sec)	1.164	0.626	0.272	1.063
KE/Target Mass (erg/g)	4.19×10^6	4.14×10^6	6.14×10^6	1.79×10^7
Largest Fragment Mass/Target Mass	0.125	0.153	0.080	0.047

Table 1. Impact experiment initial conditions for a 1-foot, 2-foot, and 3-foot diameter cement/sand cube, and a 3-foot long cement/sand cylinder. The projectile material was steel.

Fig.'s 4, 5, 6, and 7 depict the targets before and after impact. The students collected the fragments post-impact for each test, and measured the fragment masses to derive a mass distribution.

Fig. 4. The 1-foot cube target is shown as the impact progresses. The project is impacting the target from the right in the images.

Fig. 5. The 2-foot cube target is shown as the impact progresses. The project is impacting the target from the right in the images.

Fig. 6. The 3-foot cube target is shown as the impact progresses. The project is impacting the target from the right in the images.

Fig. 7. The 3-foot cylinder target is shown as the impact progresses. The project is impacting the target from the right in the images.

The objective for these experiments was to hold the kinetic (impact) energy per unit mass of the target constant, and discern whether shape or size had an effect on collisional outcome. This was achieved for the 3-foot diameter and 2-foot diameter cubes, but considerably more energy (see Table 1) was delivered to the 1-foot cube and the 3-foot cylinder, so direct comparisons between all the target types could not be made. Clearly, however, the students could see that as the collisional energy per unit mass was increased, the mass of the largest fragment (normalized to the original target mass) remaining post impact decreased, with the greatest visible damage occurring for the case of the 3-foot cylinder which was impacted with the most energy. With respect to the 3-foot and 2-foot cubes, some effect of target size could be noticed (the larger target had a smaller post-impact largest fragment), but more data would be needed to make any statistically significant conclusions.

3. Results

The resulting cumulative fragment mass distribution for the 4 impact tests are shown in Fig. 8. The distributions follow a classic two-slope power law behavior, something often observed in the fragmentation of rock targets. There are more numerous smaller fragments, with a few large fragments defining the slope discontinuity. The mass distributions are quite similar for the 3 cubic targets, with a difference in the behavior of the cylinder, highlighting a potential shape effect.

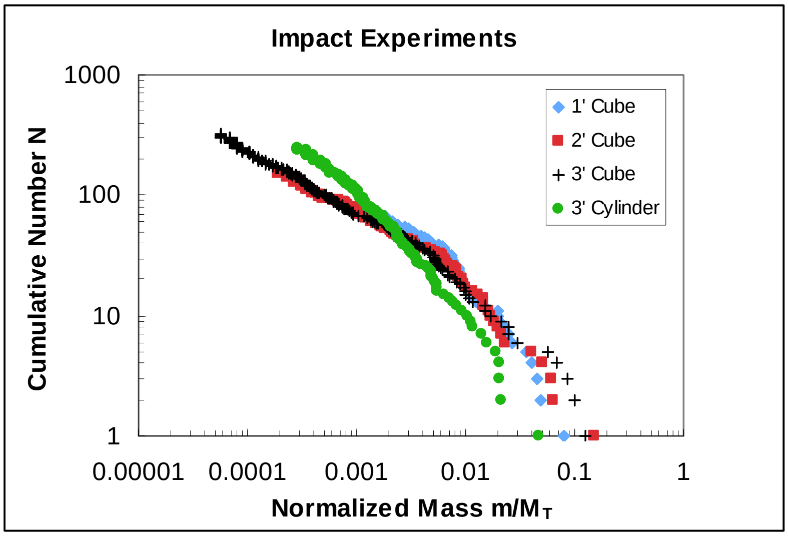

Fig. 8. Fragment mass distribution for all four impact experiments. The cumulative number N (representing the number of fragments having that mass or larger) versus the fragment mass (normalized to the original target mass) is shown.

The final assignment for the students in the course was to write a proposal to “save the Earth” from a potential killer asteroid. The students were required to incorporate data taken from the 2.4-meter telescope observations as well as the impact experiments. They were also required to make a cost estimate for the proposed activity. Numerous innovative solutions were generated which indicated that a good comprehension of the engineering problems was achieved. The students did, however, have problems developing credible cost estimates.

4. CONCLUSIONS

The student response to the course was outstanding. Student evaluations of the course indicated a strong appreciation of the “hands on” focus. It is expected that this course will continue to be offered to entering freshman. The impact experiments generated significant data, which can be used to better the understanding of asteroid fragmentation. The fragments from the cylinder were significantly different then the cubic target. With successive iterations of the course, additional target parameter initial conditions will be investigated. These parameters will include: different shapes, different impact locations and different target sizes. A database will be maintained from the multiple iterations of the course.

5. REFERENCES

1. Ryan, E. V., Ryan, W. H., and Romero, V. D. (2002). Magdalena Ridge Observatory (MRO) as a Tool for Asteroid Science, Proceedings of the 34th Meeting of the DPS, Birmingham, AL., *BAAS*, Vol. 34, No. 3.