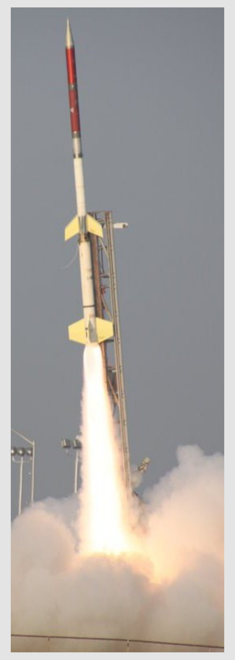
Rocket SAT

UNC Physics has become involved with a project called Rocket SAT-X, an outreach program funded by the Colorado Space Grant Consortium (COSGC). This program challenges students to design and fabricate an experimental payload that will be launched on a Terrier-Orion sounding rocket, provided and launched by NASA's Wallops Flight Facility in Virginia. The rocket flight will launch the payloads approximately 120km into space, where the rocket will then shed its fairing, exposing the student payloads to the space environment, as shown in **Figure 1**.



University *of* Northern Colorado

Reentry Experiment SAT-X

Abstract

The University of Northern Colorado Reentry Experiment SAT-X (ReX) project is designed to shed light on the challenging process of atmospheric reentry. The experiment will be conducted using a small reentry capsule, jettisoned at apogee from a sounding rocket. The flight will test the capability of the capsule as a platform for future reentry experiments.

Mission

"To provide a method for institutions to utilize a deployable and recoverable payload for future Rocket SAT-X missions. By providing this, we can greatly increase the amount of data recovered by eliminating the need to transmit restricted amounts of data to the ground."

ReX aims to characterize the process of reentry via data collected from a pair of capsules ejected from a sounding rocket at apogee. Inertial data will be used to reconstruct the actual trajectory, as well as to profile the drag force. Thermal data will be used to map the heat distribution over the capsule surface. In the absence of the actual data, a mathematical model (outlined in ***Theory and Scientific Concepts***) was constructed to inform the initial capsule design. Data collected from the flight will be used to optimize the model, thereby facilitating further refinement of the capsule design. Some aerospace missions tend to over-engineer flight hardware, designing components to standards that are well beyond what is necessary. By optimizing the payload design, fewer resources may be used in payload fabrication, saving time and money. Finally, the revised platform can be used by future reentry experiments.

1. Launch
2. Ascent: Onboard electronics initialize
3. Apogee: Fairing deployment; ReX capsules deployed
4. Descent: ReX capsules collect reentry data; Data transmitted to rocket
5. Splashdown

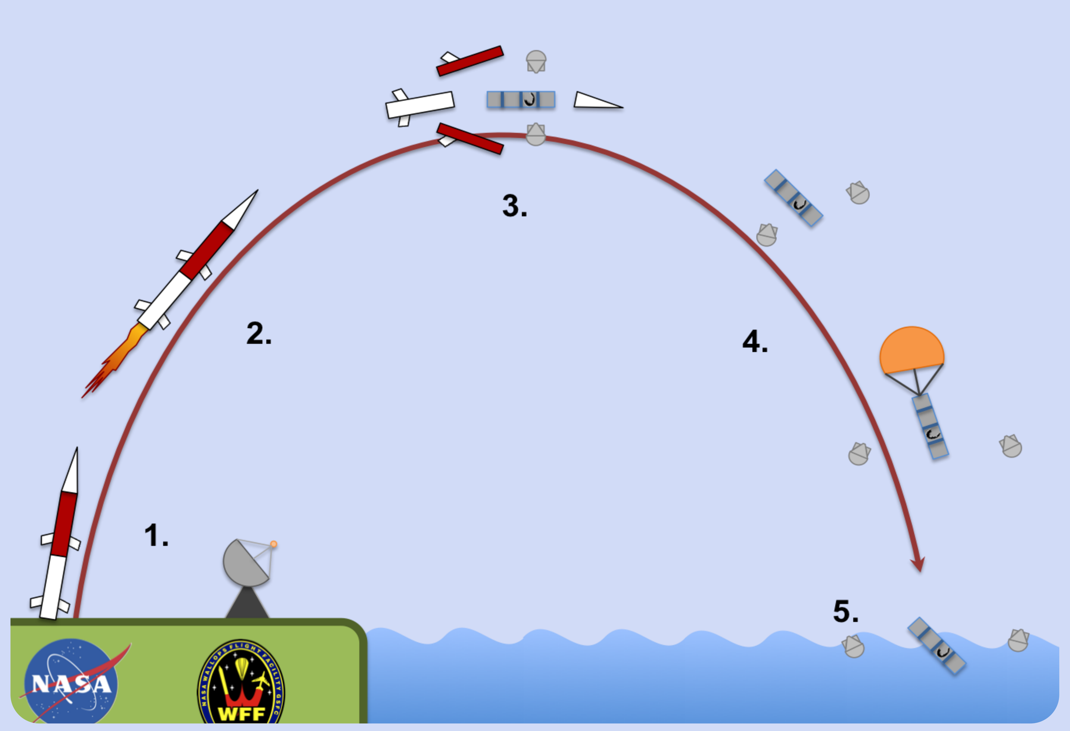


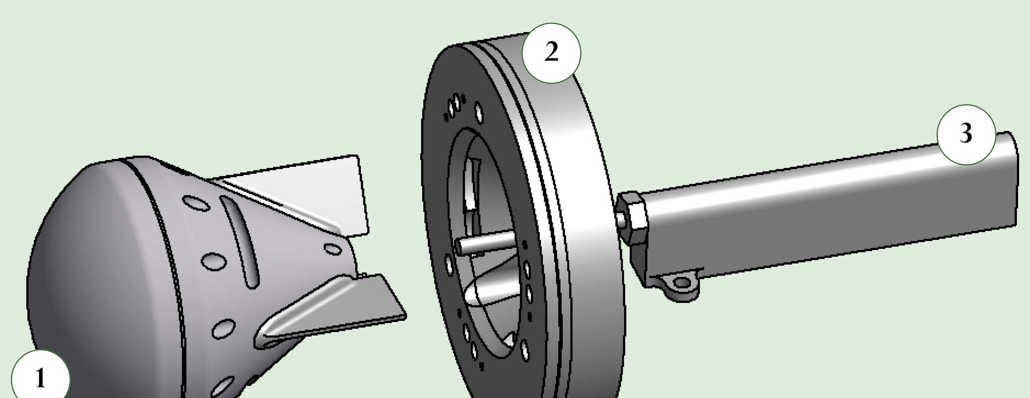
Figure 1

Design — Reentry Capsule Shell & Base Station

"Bomb" Model | Sphere Model | Apollo Capsule | Streamlined Model

Each of the above models was constructed and evaluated for: aerodynamic stability, self-orienting characteristics, structural integrity, internal storage space for electronics, and drag coefficient. The evaluation was carried out by conducting several short-range drop tests and using a CAD simulation and the mathematical model. With this, the streamline shaped model proved to be the most suitable candidate for an effective reentry vehicle.

Figure 2 shows the entire ReX payload. The capsule contains two electronics and sensor boards and radio antennae are embedded in the tail fins. A harness/lock holds the capsule in place until an external timing signal triggers the unlocking sequence. The capsule is then ejected by a spring loaded plunger. An HD camera is used to record the capsule launch. All of these subsystems are integrated on the rocket-mounted deck plate.



1. Reentry Capsule
2. Capsule Harness/Lock
3. Accelerator (Spring/Plunger)
4. "Go Pro" HD Camera Housing
5. Rocket-Mounted Deck Plate

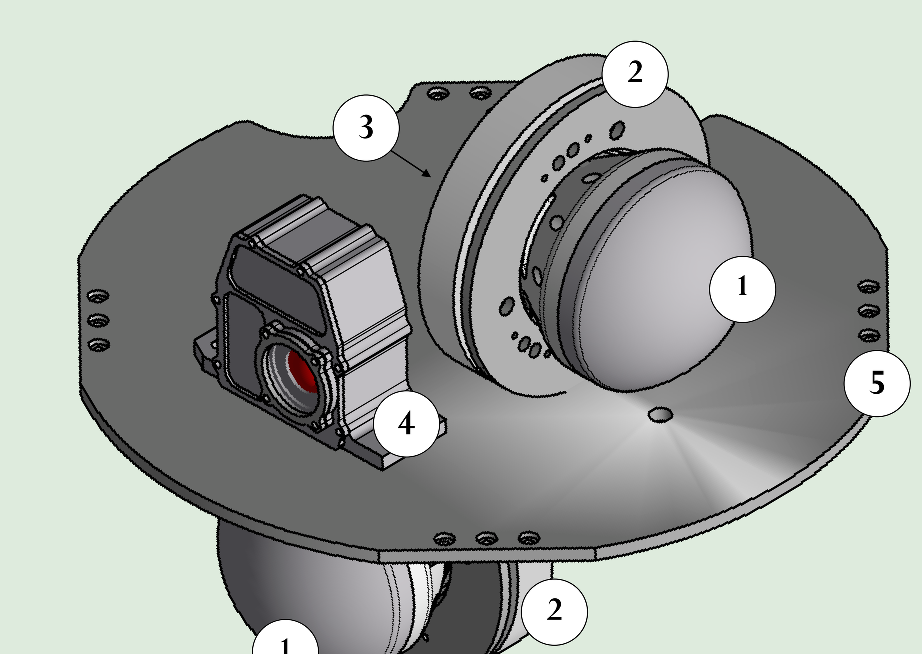


Figure 2

Theory and Scientific Concepts

The analytical model estimates the force of impact and the effects of heat during reentry. It is used to refine the shape of the capsule (**Figure 2**) and to interpret the flight data.

The model requires a knowledge of the forces exerted on the reentry vehicle. The dominant force is air resistance. Assuming a purely vertical descent, the resultant acceleration due to air drag and gravity results in the following equation:

$$a_{resultant} = g(h) - \frac{\rho(h) \cdot v_{object}^2 \cdot A \cdot C_d}{2 \cdot m},$$

where g(h) is Earth's gravitational acceleration with respect to altitude, ρ(h) is the air density with respect to altitude, v_{object} is the capsule's speed, A and m are the capsule's cross-sectional area and mass, respectively, and C_d is the geometry-dependent drag coefficient.

Using this equation, the capsule's velocity versus altitude can be plotted. This is the blue curve in **Figure 3.**

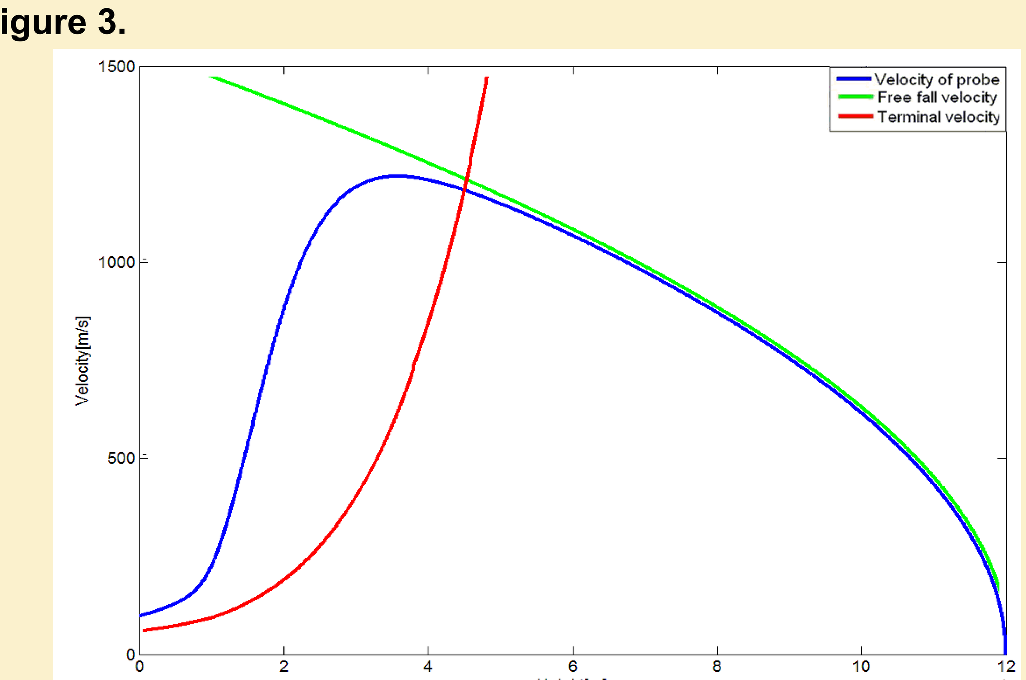


Figure 3. Reentry vehicle dropped from 120km

The green curve describes the motion of a freely falling object. The red curve is the altitude-dependent terminal velocity. At higher altitudes, where there is virtually no drag, the object is effectively freely falling as indicated by the convergence of the blue and green curves.

At the point where the terminal velocity and free fall curves cross, the capsule experiences a significant change in velocity. The change is abrupt, as illustrated by the velocity and acceleration profiles in **Figure 4**. This phenomenon can be compared to that of an object hitting a "wall of atmosphere". The impact causes the reentry object to experience a large impulse and heat buildup due to air friction. Both effects could prove hazardous to the capsule.

The curve in **Figure 5** is generated by calculating the power as a function of time using the drag force and capsule's velocity. The area under the curve is potentially the heat

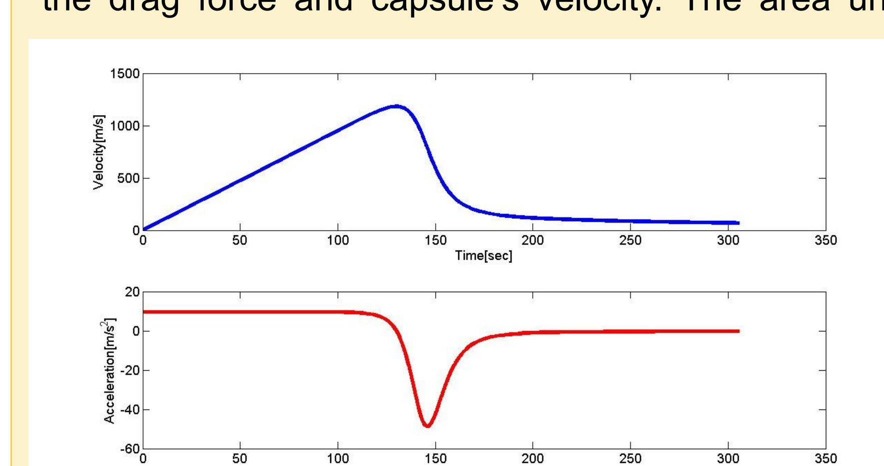


Figure 4. Reentry vehicle dropped from 120km

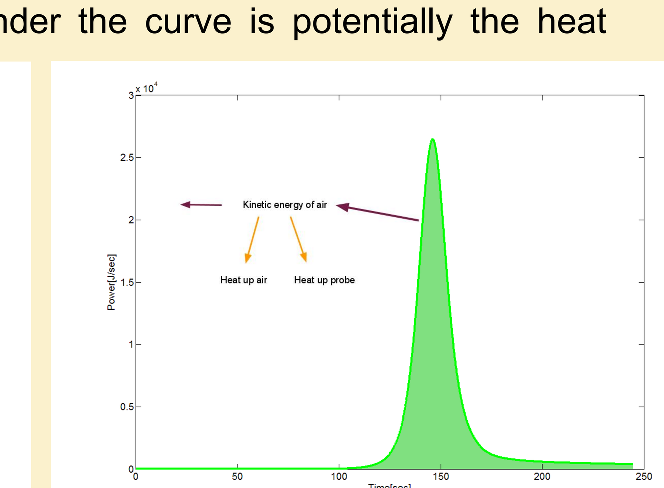


Figure 5. Heat Energy of Reentry

Design — Heat Shield and Data Recovery

The mathematical model makes two design issues apparent:

- The capsule may not survive the extreme force of impact at splashdown
- Heat buildup due to air friction may cause breakup or melting

Unfortunately, accounting for one amplifies the other, i.e., reducing the drag decreases the total heat buildup yet increases the capsule's impact velocity. This conflict was addressed by adding a heat shield. The carbon fiber heat shield protects the heat-sensitive aluminum. By leaving the capsule shape intact, the drag coefficient is unaffected and the impact velocity is unchanged.

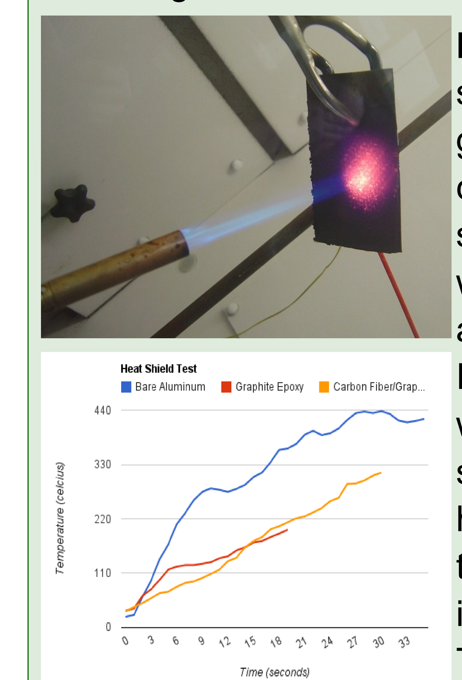


Figure 6

Figure 6 (left) shows a test of a heat shield in which aluminum is coated with graphite epoxy and overlaid with carbon-fiber. It is then heated over a set period of time. Two other samples were tested - bare aluminum and aluminum coated in graphite epoxy. Initially, the rate of temperature change was least for the carbon fiber coated sample. The math model shows that heat acquisition occurs over a short time, so it's adequate to consider the initial behavior of the temperature. Therefore, the best heat shield is the carbon-fiber/graphite epoxy coating.

Data may not be retrievable because of burn-up on reentry, destruction on impact, or inability to recover the capsule. To ensure data capture, a set of 900MHz XBee radio transceivers continuously transmit information from the capsule to the ground via the base station on the rocket.

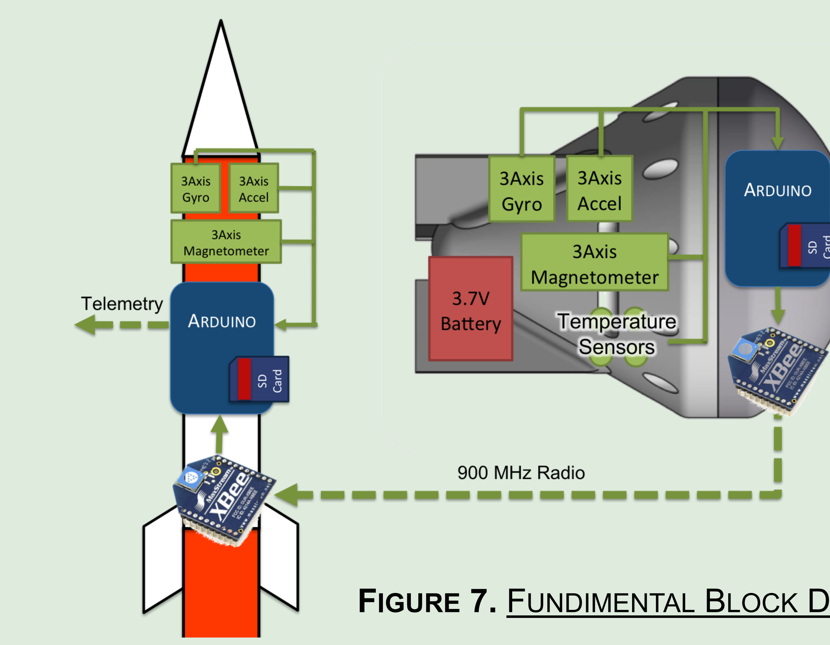


Figure 7. Fundimental Block Diagram

Manufacturing

The UNC team is fabricating the various capsule bodies and launchers and assembling the required electronics (**Figure 8**).

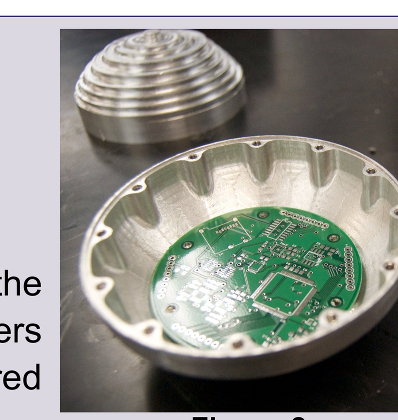


Figure 8

The mechanical elements, including the capsule, the capsule launcher/locking harness, the RS-X deck mounts, and the camera housing will be fabricated out of 6061 Aluminum, and will be machined using an automated CNC mill (**Figure 9**). A Rapid Prototyper plastic printing machine at *Road Narrows Robotics* was used to create a prototype model (**Figure 10**) of the capsule for preliminary testing.

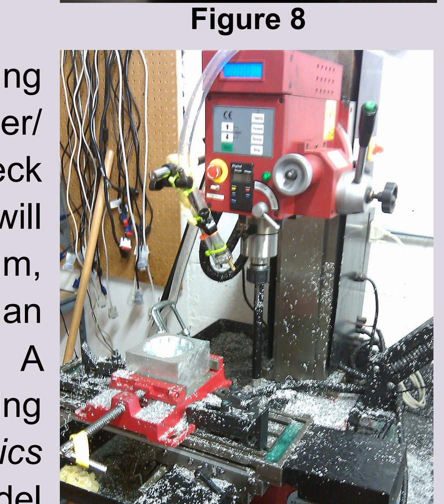


Figure 9

The payloads' custom electronics boards will be printed by *Advanced Circuits*. Once these are printed, the appropriate sensors, computers, and radios will be assembled on the boards, which will then be integrated into the reentry capsule shells.

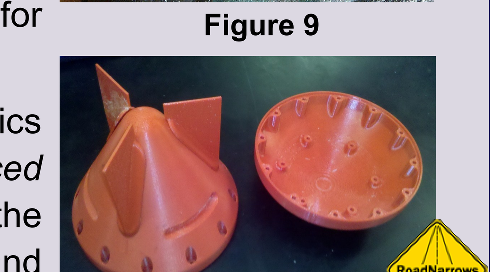


Figure 10

Road Narrows Robotics, Loveland, CO