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The Kentucky Re-entry Universal Payload System (KRUPS): Sub-orbital Flights

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James Devin Sparks, Student

Dr. Alexandre Martin, Major Professor

Dr. Alexandre Martin, Director of Graduate Studies

The Kentucky Re-entry Universal Payload System (KRUPS): Sub-orbital Flights

THESIS

A thesis submitted in partial
fulfillment of the requirements for
the degree of Master of Science in
Mechanical Engineering in the
College of Engineering at the
University of Kentucky

By
J. Devin Sparks
Lexington, Kentucky

Director: Dr. Alexandre Martin, Professor of Mechanical Engineering
Lexington, Kentucky 2018

ABSTRACT OF THESIS

The Kentucky Re-entry Universal Payload System (KRUPS): Sub-orbital Flights

The Kentucky Re-entry Universal Payload System (KRUPS) is an adaptable testbed for atmosphere entry science experiments, with an initial application to thermal protection systems (TPS). Because of the uniqueness of atmospheric entry conditions that ground testing is unable to replicate, scientists principally rely on numerical models for predicting entry conditions. The KRUPS spacecraft, developed at the University of Kentucky, provides an inexpensive means of obtaining validation data to verify and improve these models.

To increase the technology readiness level (TRL) of the spacecraft, two sub-orbital missions were developed. The first mission, KUDOS, launched August 13th, 2017 on a Terrier-Improved Malamute rocket to an altitude of ~150 km. The second mission, KOREVET, launched on March 25th, 2018 on the same type of rocket to an altitude of ~170 km. The chief purpose of both missions was to validate the spacecraft design, ejection mechanism, on-board power, data transmission, and data collection. After both missions, the overall TRL improved from 4 to 5 by validating most subsystems in a relevant environment. Both of these missions were invaluable preparation for the project's ultimate goal of releasing multiple experimental testbeds from the ISS.

KEYWORDS: Thermal Protection System (TPS), Sounding Rocket, International Space Station (ISS), Re-entry Vehicle

Author's signature: J. Devin Sparks

Date: October 15, 2018

The Kentucky Re-entry Universal Payload System (KRUPS): Sub-orbital Flights

By
J. Devin Sparks

Director of Thesis: Alexandre Martin

Director of Graduate Studies: Alexandre Martin

Date: October 15, 2018

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Chapter 1 Introduction

1.1 Overview and Background

Exploring beyond Earth and learning more about the universe has been a top interest in the space sciences. Recently, missions have been developed to obtain data from other planets, as well as from our own planet. The range of these missions can vary from collecting ground samples from a nearby planet to collecting data from micro-gravity experiments on the International Space Station (ISS). One of the most challenging tasks associated with these missions is ensuring that the vehicle survives planetary entry. To enter an atmosphere, the vehicle has to balance between deceleration, heating, and accuracy of landing[8]. The vehicle enters the atmosphere at hypersonic velocities, and needs to decelerate to ensure that the payload is safe. The vehicle decelerates as the kinetic energy is dissipated in the form of heat. Most of the heat is convected away in the atmosphere, but some of it still reaches the surface of the vehicle. This small fraction of heat is sufficient to cause major damage to the vehicle and the instruments inside. Therefore, a Thermal Protection System (TPS) is required to prevent the high heat flux from reaching the payload.

There are numerous types of TPS that have been used, but ablative TPS are most widely used for space exploration.[9] Ablation is the loss of surface material through several mass-removal mechanisms. The phenomenon can be classified into pyrolysis, thermo-chemical ablation, and thermo-mechanical ablation. Figure 1.1 shows the different mechanisms taking place in the ablative TPS material when subjected to high heat loads. Pyrolysis is a phenomenon in which the material is heated until it reaches a temperature where it decomposes (pyrolyzes) to carbonaceous residue and release gas. Thermo-chemical ablation is a mechanism in which the material reacts with the chemical species in the flow, thus causing material-recession. The char formed on the material is very weak and brittle, and is subjected to mechanical shear and internal pressure stresses, which also cause material recession. This mass removal caused by spallation is part of the thermo-mechanical ablation[10].

Ablative TPS are lightweight, relatively simple, and reliable. The high heat flux is mitigated by undergoing chemical and physical processes, including subliming, oxidizing, melting-vaporizing, and charring. Charring ablators are the material of choice for high enthalpy entry conditions. These materials include thermosetting resins such as phenolics, epoxies, and silicones, usually reinforced with materials like carbon fibers,

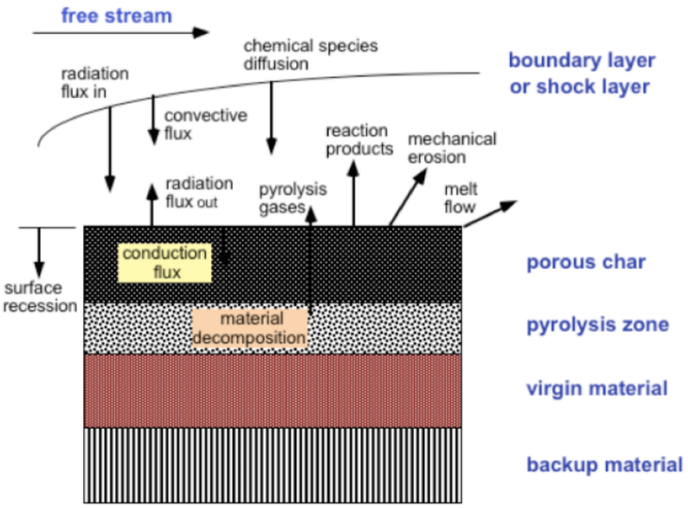


Figure 1.1: The behavior of ablative materials (Image taken from Ref.[1])

Nylon or refractories. Thus, a variety of charring ablator materials have been used for space missions. A few examples include Carbon Phenolic, Phenolic Impregnated Carbon Ablator (PICA), Avcoat, Advanced Carbon-Carbon (ACC), Super Lightweight Ablator (SLA), Norcoat Liège, Asterm, Monolithic Ablator (MonA), and Silicone Impregnated Reusable Ceramic Ablator (SIRCA)[10].

As these materials are being developed with improved material properties, they need to be properly tested. Currently, extensive ground tests are mainly performed using arc-jet and hypersonic wind tunnels to reach the final stage of design. Figure 1.2 illustrates an arc-jet test used to determine how an ablators sample ejects particles. Ground tests can give a relatively good representation of the environment that an entry vehicle is expected to encounter, but the costs of these tests are extremely high. Moreover, they cannot test all the relevant conditions at the same time. Finally, measuring and calibrating ground test facilities can be a challenge on its own.

Numerical modeling becomes an appealing approach, since the cost of high-performance computation has dropped significantly over the last few years. Moreover, during that same period, the computational power has increased. Modeling phenomena in hypersonic regime relies on the understanding of physics, and building suitable mathematical governing equations to match the environment. To do so, computer codes that model the flow field, the TPS, and the surface between both domaines are needed. The flow field can be modeled with Computational Fluid Dynamics (CFD) codes or the Direct Simulation Monte Carlo (DSMC). The TPS can be modeled through the use of Material Response (MR) codes[11, 12, 13, 14, 15, 16, 17, 18,

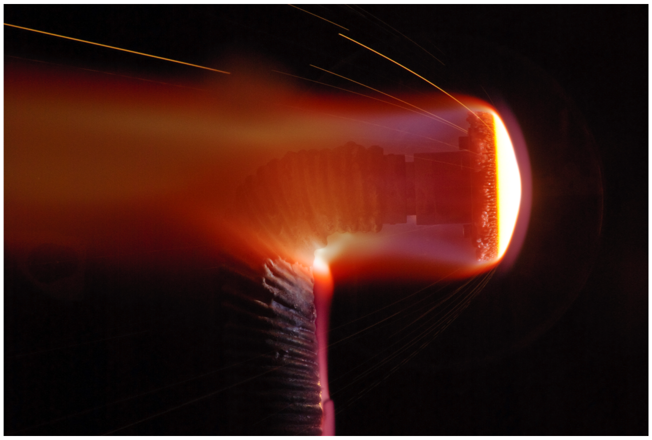


Figure 1.2: Arc-Jet test on an ablative material (Image taken from Ref.[2])

19, 20, 21, 22, 23, 24, 25], surface re-radiation, or steady-state ablation. As for the surface, it can be modeled using the surface thermo-chemistry data, chemistry model in the flow, or chemistry model in the material response[26]. These codes are currently used to predict the thickness of the heat shield required to protect the vehicle from the entry heat rates[27]. However, they need to be validated with actual flight data to ensure all physical phenomena are captured. Thus, to improve numerical modeling, and hence improve TPS materials, it is necessary to obtain more flight data[28, 29, 30, 31]. A new method of obtaining more flight data is to use small capsules [32, 6, 33, 34, 7, 35, 36], such as the KRUPS capsule, developed at the University of Kentucky.

The KRUPS project includes two flight missions — KUDOS and KOREVET. These two missions were necessary steps towards the main goal of the project, which is to provide an experiment testbed that launches from the ISS. A TRL timeline of the KRUPS project can be seen in Fig. 1.3. Both flight missions involved designing, analyzing, manufacturing, and testing an atmosphere entry spacecraft that has an on-board data acquisition system for data recovery. This data was transmitted to the ground station via the Iridium Network, during and post flight, for further analysis.

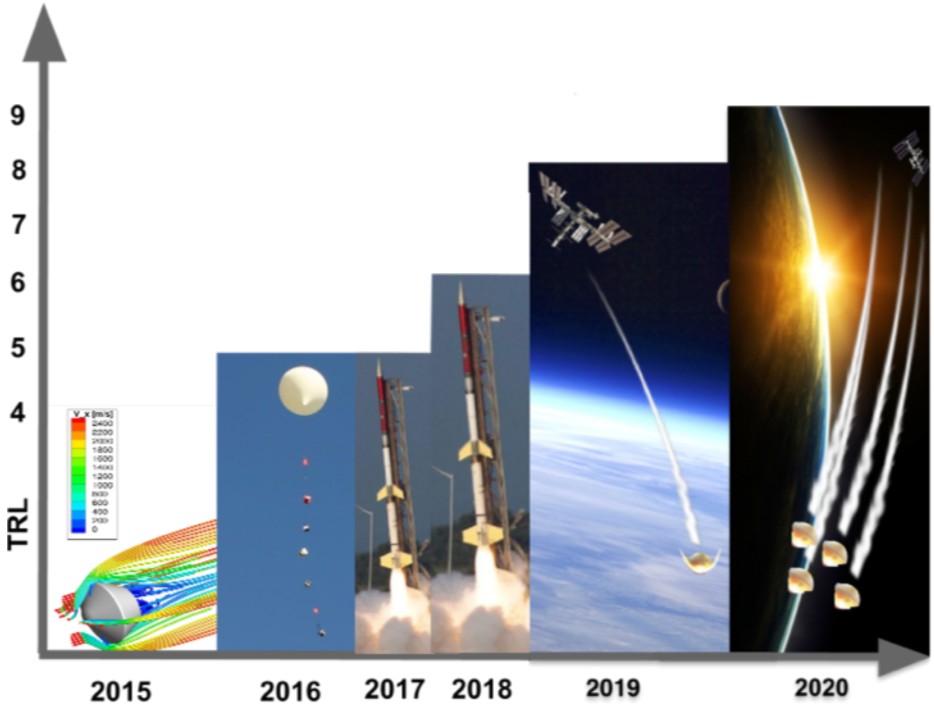


Figure 1.3: The Technology Readiness Level (TRL) overview of the KRUPS project

Chapter 2 Literature Review

The KRUPS project has the main goal of measuring flight data as the vehicle enters the atmosphere. This task has been done in the past through several missions. Each mission has had their own unique goal that they set out for themselves, but each have built off the lessons learned from previously flown vehicles. The KRUPS project has done the same thing by learning from missions that date as far back as 1971, with the Planetary Atmosphere Experiments Test vehicle (PAET). Without the knowledge that was learned from previous missions, the KRUPS project would not have been able to have advanced as quickly as it did. By learning from previous missions, the KRUPS project is able to have a higher chance at success. Therefore, there were four missions studied in-depth, which include the PAET vehicle, Mars Microprobe mission, Re-entry Breakup Recorder, and RED-Data2 (which is part of the commercial Re-Entry Device family development).

2.1 PAET

On June 20, 1971, a Planetary Atmosphere Experiments Test vehicle (PAET) entered the atmosphere at 6.6 km/s near Bermuda. The vehicle carried experiments designed to determine the composition and structural characteristics of the atmosphere. The vehicle measured the composition of the atmosphere via a mass spectrometer and a spectral radiometer, measured the duration and directional dependence of the communications blackout, determined the performance of the heat shield, and monitored the dynamics of the vehicle. The main objective of the vehicle was to evaluate and provide flight experiments, with instruments and measurement techniques, for use in different atmospheres.

The PAET vehicle was launched from Wallops Island by a NASA four-stage Scout launch vehicle. The first two Scout stages achieved an apogee of about 377 km, then the third stage ignited. The third stage guided the vehicle to an attitude of about -60° to the flight path. The fourth stage ignited, and sent the vehicle to an attitude of about -30° to the flight path. After the de-spin system reduced the spin rate, the PAET entry vehicle was released, at an altitude of 162 km. The vehicle entered the atmosphere at 93 km with a velocity of 6.6 km/sec. There was a communications blackout region from the altitude range of 80 km to 36 km. This communications blackout was due to shock heating and ionization of the gas flowing around the vehicle.

At 36 km, the vehicle slowed down to a velocity of 3.8 km/s. The vehicle impacted the ocean 896.53 seconds after the Scout launch vehicle lift-off. A better visual of the mission profile can be seen in Fig 2.1.

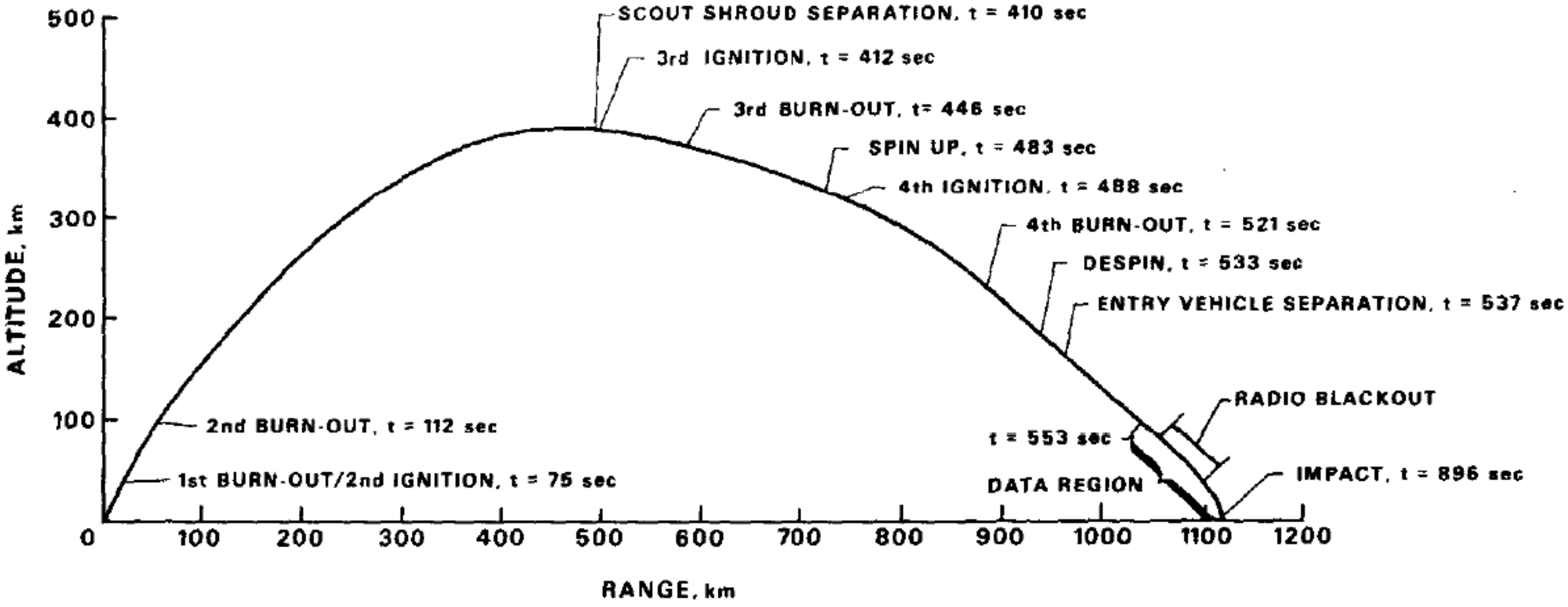


Figure 2.1: PAET's mission profile (Image taken from Ref.[3])

After the PAET entry vehicle impacted, it floated in the water for almost 1.5 hours. The telemetry transmission was received for 1 hour, and the vehicle was located by a low altitude search aircraft. However, the vehicle was not recovered because it sank 15 minutes prior to the arrival of the ship. Even though the vehicle was not retrieved, the telemetry data were received by multiple stations with excellent quality.

The PAET spacecraft consisted of the entry vehicle and its separation system, which can be viewed in Fig. 2.2. The entry vehicle geometric design was a spherically blunted 55° half-angle cone, with a hemi-spherical after-body (see Fig. 2.3). The diameter was 0.914 m, with a nose radius of 0.457 m. The center of gravity (CG) was located 0.185 m behind the stagnation point. Selecting the hemi-spherical after-body was proven to give the best vehicle dynamics. The after-body carried all of the antennas. The remainder of the equipment was mounted on the back face of the fore-body structure.

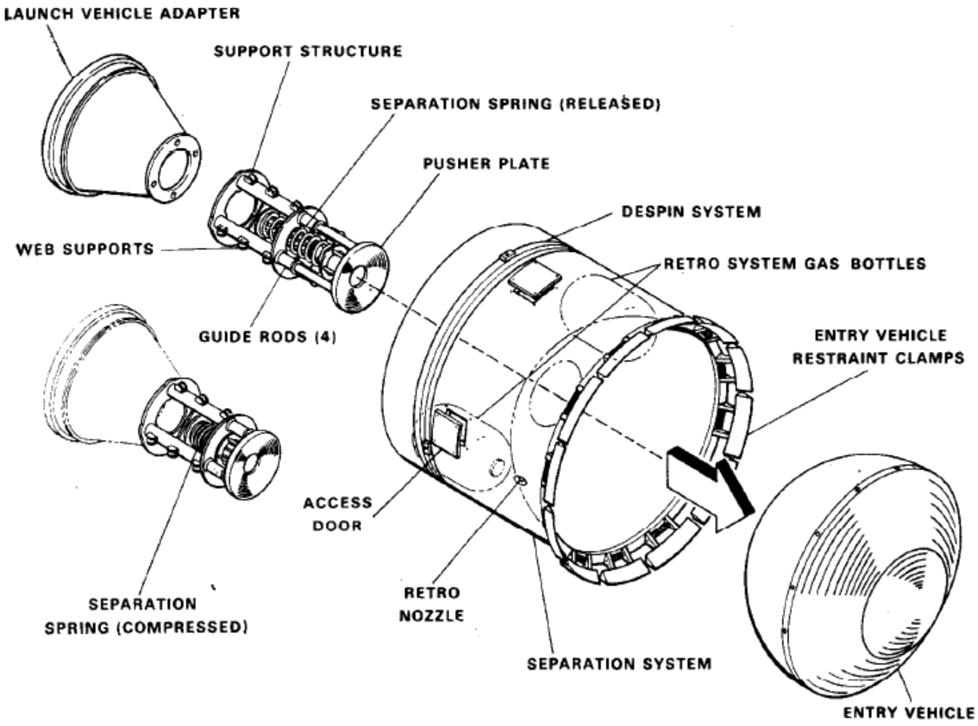


Figure 2.2: Exploded view of the PAET spacecraft (Image taken from Ref.[3])

The entry vehicle had a total weight of 62.1 kg, with the weight distribution listed in Table 2.1. The fore-body of the vehicle used a low density silicone elastomer ablator. The after-body used a light fiberglass honeycomb, covered with a very low density silicone elastomer ablator. The after-body was required to be radio transparent since all of the antennas were to transmit through that section.

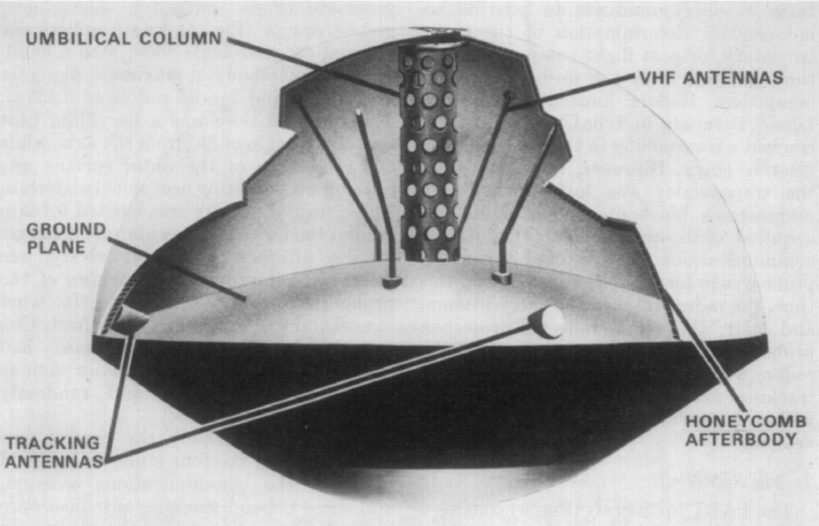


Figure 2.3: PAET's entry vehicle with the after-body cut away (Image taken from Ref.[3])

Table 2.1: PAET's weight distribution

Sub-systems	Weight (kg)
Instruments	14.0
Data handling and communications	6.9
Power and cabling	7.9
Structure	15.3
Heat Shield	10.7
Miscllaneous	7.3
Total	62.1

The instruments used in the PAET experiment include an accelerometer, two pressure sensors, and two temperature sensors. The temperature sensors and their deployment system were developed at Ames Research Center for the PAET. The sensors were 0.127 mm diameter butt-welded chromel-alumel thermocouples. However, they were placed outside the vehicle boundary layer to measure airstream recovery temperature. Two identical sensor heads were located at symmetrical locations. There was a third thermocouple used as a redundant source, just in case two were broken, data would still be returned. Figure 2.4 shows the data that was collected from the temperature sensor 2.

In conclusion, the PAET vehicle was considered a success. The vehicle met most of the objectives, and demonstrated that it had the capability of collecting atmospheric measurements during high speed entry. The temperature profile obtained from the temperature sensors proved to give accurate results, by reproducing the major and the

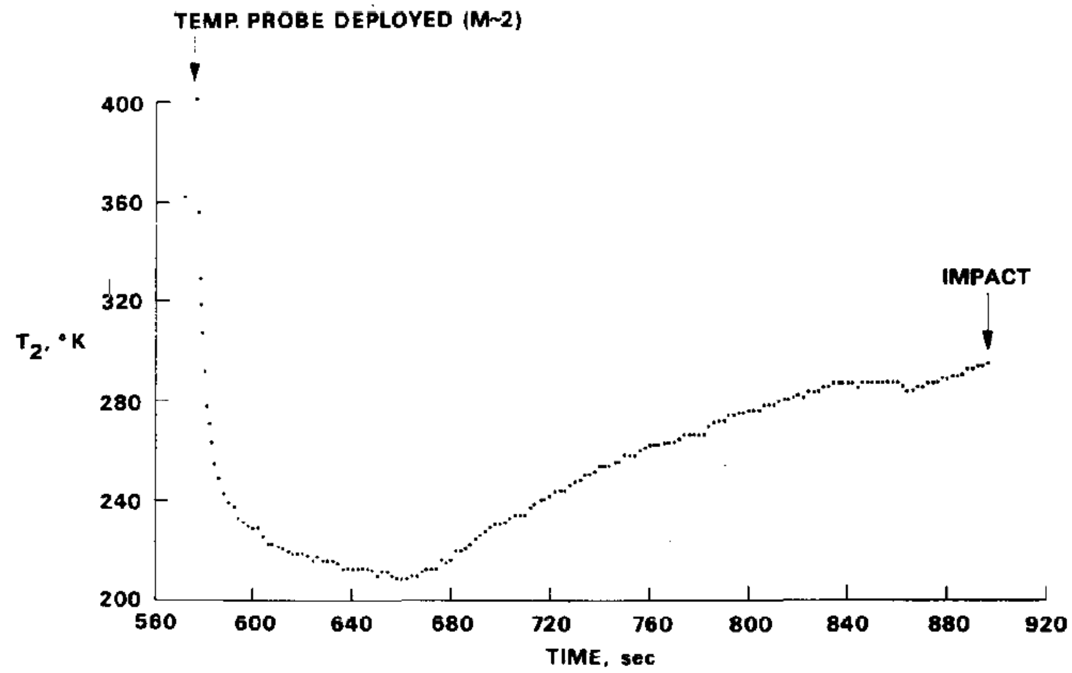


Figure 2.4: PAET's temperature data from the sensor 2 (Image taken from Ref.[3])

detailed features of the temperature structure of the atmosphere. PAET concluded that experiments can be performed during atmosphere entry, and can lead to a better survey of the atmospheres of other planets.

2.2 Mars Microprobe

The Mars Microprobe mission had objectives of providing sub-surface measurements near the south pole of Mars. The second mission was called Deep Space Two (DS-2), and involved the design of two small Mars entry probes. DS-2 is usually referred to as the Mars Microprobe mission. These two small entry probes were attached to the Mars 98 Surveyor Lander, and were launched using a Delta II rocket. Each probe was designed to penetrate through the surface of Mars, perform soil sampling, and detect water. The data collected was relayed to Earth through a link with the Mars Global Surveyor orbiter.

The design of the DS-2 probes were analyzed and tested extensively by Jet Propulsion Laboratory and NASA Langley Research Center. The vehicles needed to have enough stability to achieve passive re-orientation prior to the peak heating stage. Since the vehicle had to be stable at impact, the supersonic and transonic dynamic stability issues had to be addressed. Finally, the vehicles had to be protected from the harsh aero thermodynamic environment of a 7 km/s Mars entry.

To meet those requirements, a 45° half-angle cone with a rounded nose and shoulders was selected for the fore-body. The after-body was hemi-spherical, centered at the center of gravity (CG). In the past, blunted 45° sphere-cones were used for successful missions. When choosing the cone angle, there had to be a compromise among drag, stability, and packaging. A blunter nose increases the drag, while a sharper cone increases the stability. For the Microprobe, having a nose radius half the vehicle's overall base radius was an acceptable compromise among the stability and drag. Rounding the shoulder of the vehicle helped decrease local heating. The selection of using a hemi-spherical after-body was based on the PAET probe. It is possible that the vehicle could enter the atmosphere backward. The hemi-spherical after-body allows the vehicle to rotate such that it enters in the correct orientation. Also, this after-body design has been shown to decrease the instability issues observed in a blunt vehicle traveling through a transonic flight regime.

The final geometry of the Mars Microprobe aeroshell can be seen in Fig. 2.5. The figure shows the 45° sphere-cone with a nose radius of 0.0875 m, shoulder radius of 0.00875 m, and a maximum radius of 0.175 m. The figure shows the after-body having a hemi-spherical shape with a radius of 0.183 m centered about the CG. The CG is located 0.0902 m from the nose of the vehicle, along the symmetry axis.

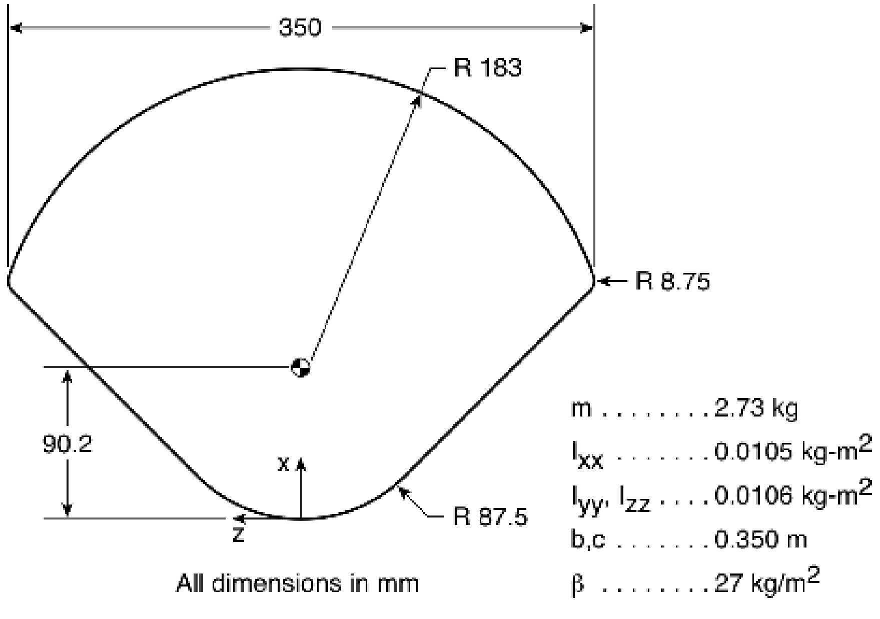


Figure 2.5: Mars Microprobe aero-shell geometry (Image taken from Ref.[4])

The database for the aerodynamics of the Mars Microprobe was derived from multiple CFD calculations and ground-based test data. To characterize the rarefied and transitional flow regimes, free molecular and Direct Simulation Monte Carlo (DSMC) computations were performed. Langley Aero-thermodynamic Upwind Relaxation Algorithm (LAURA) used thermo-chemical non-equilibrium computational fluid dynamic calculations to look at the continuum hypersonic flow regime. The Pioneer-Venus wind tunnel data was used in the supersonic, transonic, and subsonic regimes. The Thin-Layer Navier-Stokes 3-Dimensional program assisted with the validation and extrapolation process.

The analysis of the DS-2 design proved that the geometry was self-stabilizing. Figure 2.6 shows the angle of attack of the vehicle, as it starts on its side (90°). Looking at the figure, it is apparent that the geometry self-stabilizes. It reaches a 0° angle of attack, with a ± 10° wobble. All in all, Mars Microprobe was able to perform enough analysis to show that their geometry is self-stabilizing, had enough drag, and could withstand the intense aero thermodynamic heating.

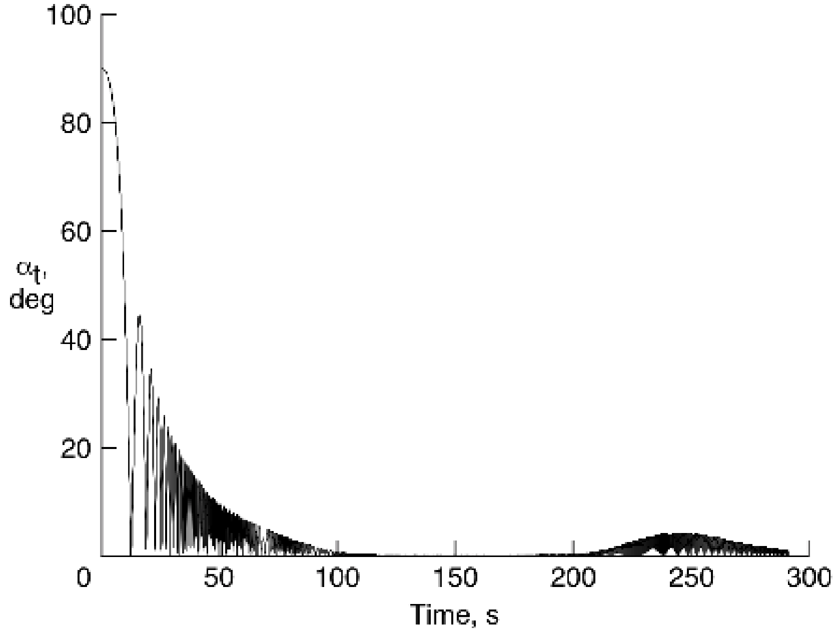


Figure 2.6: Mars Microprobe angle of attack profile (Image taken from Ref.[4])

2.3 REBR

There has been much interest in the design of a device that would collect data during atmospheric entry and breakup of satellites or other debris. This became a topic of discussion after measurements showed that it is possible for large enough debris to survive atmospheric entry and cause damage to people. In 1997, a farmer had a

570-pound stainless steel propellant tank land near his house in Texas. A picture of the debris is shown in Fig. 2.7. After this incident, efforts to learn more about objects as they enter the atmosphere increased.

Figure 2.7: Fallen space debris (Image taken from Ref.[5])

In the early 2000s, The Aerospace Corporation set out to design a new device and named it Re-entry Breakup Recorder (REBR). The design was complete and ready for flight testing in 2011. The device included a heat shield, an internal structure to allow equipment inside the device, power capabilities, electronics, communication system, and a housing dome. The exploded view of the design can be shown in Fig. 2.8.

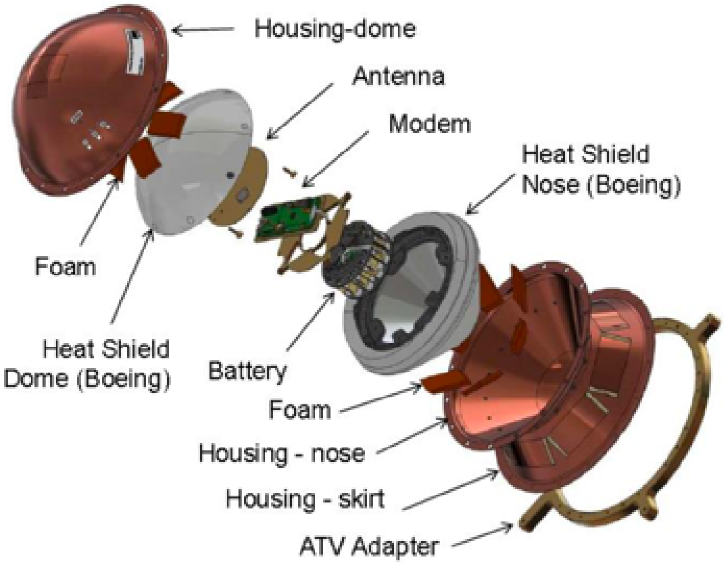


Figure 2.8: Exploded view of REBR (Image taken from Ref.[6])

The geometry was designed so that it would be aerodynamic. The fore-body angle is 45° and the radius of curvature of the nose is 25 percent of the maximum diameter. In order for REBR to be self-righting and statically stable, the center of mass had to have proper placement. It was determined that the center of mass had to be 44 percent of the maximum diameter in order to maintain stability during hypersonic, supersonic, transonic, and subsonic flight. Figure 2.9 shows the aerodynamic configuration in more detail.

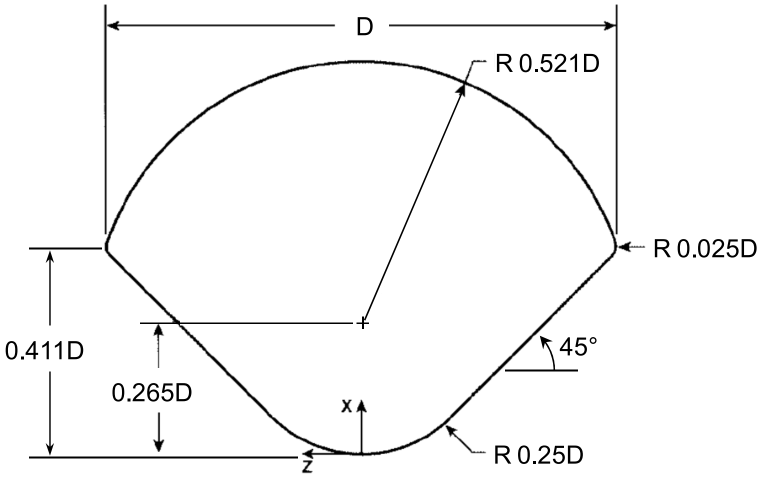


Figure 2.9: REBR dimensions (Image taken from Ref.[6])

It was determined that the device needed to have a heat shield to protect the instruments from the severe entry environments. The heat shield was designed and fabricated by The Boeing Company. Boeing provided a design using BLA-20 material with UltraFlex Honeycomb Core for the acreage TPS, and Dow Corning 93-104 material for the nose region TPS. The heat shield was radio-frequency (RF) transparent such that the satellite modem could send data to the ground station.

The REBR instruments, electronics, and batteries were mounted to a chassis, made of 6061-T6 aluminum for the aft section and Delrin 150 for the forward section. The assembly of the chassis, equipment, electronics, and batteries combined to weigh about 2.1 pounds. The entire structure was designed to sustain 100-G loading, which was much higher than the expected loading of 30-Gs. This provided a margin to account for the unknown environment during the breakup. REBR was contained in a two-piece external housing for attachment to the host vehicle and initial protection during breakup. The external housing was made out of copper and weighed about 9.9 pounds. Between the external housing and the TPS, silicone foam inserts were used to provide vibration damping. The two housing halves were held together by sixteen fasteners around the perimeter of the assembly.

To power the equipment inside the housing, REBR used two 18 V lithium primary batteries, composed of 24 Energizer L91 Ultimate Lithium AA cells. The batteries were tested to sustain the temperature range of -40 to 76°C. Since REBR was temporarily stored on the ISS, it had different settings for power saving mode and atmosphere entry detecting mode. All sensors were activated by flight software to execute the data collection.

For the electronics, REBR used a flight computer modem board, an inertial measuring unit, and a temperature sensor board. The flight computer modem board interacted with the Iridium modem and received data from the GPS receiver. The inertial measuring unit interacted with an accelerometer, gyro sensors, and eight thermocouples. During the atmosphere entry phase, the Iridium modem activated and attempted to establish connection to the Iridium system when REBR reached terminal velocity. Once the device had connected with the Iridium system, data was sent to the ground station until the device hit the ground or water. The Iridium used a frequency band of 1616-1625.5 MHz, while the GPS receiver operated at 1575.42 MHz.

REBR has been released from the ISS four times as of today. The first one was attached to a supply vehicle called Hypersonic Transfer Vehicle 2 (HTV-2), while the second was attached to Automated Transfer Vehicle 2 (ATV-2). The first REBR, which was attached to HTV2, was released from the ISS on March 28, 2011. During the flight, the vehicle surrounding REBR disintegrated as planned. At about 66.6 km, REBR was able to travel at about Mach 23. The software dialed up the Iridium system as intended and was able to transmit data to the ground system. This was the first successful recording of an unprotected atmosphere entry device. The second REBR, attached to ATV-2, ran into technical difficulties and it was unable to communicate with the ground system. However, there were two other REBRs successfully used for the HTV3 and ATV-3 reentry in 2012. All in all, the REBR missions were able to provide information regarding the satellite breakup. The re-entry breakup events that occurred among 66 and 84 kilometers compared well with what was computed in the Vehicle Atmospheric Survivability Project (VASP) and Vehicle Atmospheric Survivability Test (VAST) models.

2.4 RED-Data2

The main focus of RED-Data2 was to mature a smaller, lighter, and more operationally flexible system based on REBR. The concept of operations was very similar to REBR. Having a host housing structure separate during entry, like what is seen in Fig. 2.8, was replicated. The design methodology followed an inside-out approach. This is where the internal electronics were packed together as compact as possible, and the capsule was built to encapsulate it. The largest instruments drove the overall size of the capsule, which was the Iridium modem and batteries. After minimizing the capsule as much as possible, the RED-Data2 capsule took the size of a softball in comparison to the size of a basketball. Also, the mass of the capsule reduced more than 50%. A comparison of the RED-Data2 and REBR capsule can be seen in Fig. 2.10.

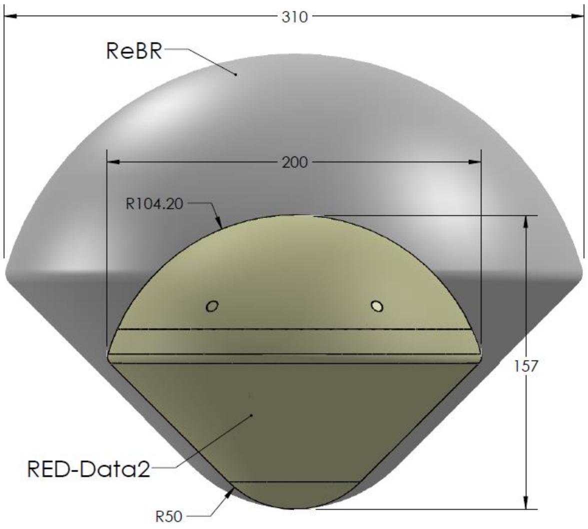


Figure 2.10: Capsule comparison among RED-Data2 and REBR capsule (in mm) (Image taken from Ref.[7])

RED-Data2 completed the design and construction of three capsules. They were sent to the ISS during April 2017. The expected heat flux from the atmosphere entry peaks at approximately 244 W/cm^2. The data recovered during the flights will be compared to CFD models to help NASA understand the performance of various TPS materials.

KRUPS is another project that has a goal to help NASA learn more about TPS materials. Even though the main objective of KRUPS is to provide an experimental testbed for multiple types of experiments, KRUPS expects to recover thermocouple data that will help the development of TPS materials. Flight data is necessary because there are only a few entry experiments that have been performed to this day. These experiments were costly and used TPS materials that were not flight proven. TPS materials are currently extensively tested by performing ground tests at arc-jet and hypersonic tunnel facilities. Even though these tests give a good estimate of the entry conditions, no ground tests can exactly replicate all conditions. Therefore, projects like RED-Data2 and KRUPS are needed so that there is a low-cost testbed to evaluate TPS materials in real flight scenario, and provide flight data to validate CFD models.

Chapter 3 First Mission: KUDOS

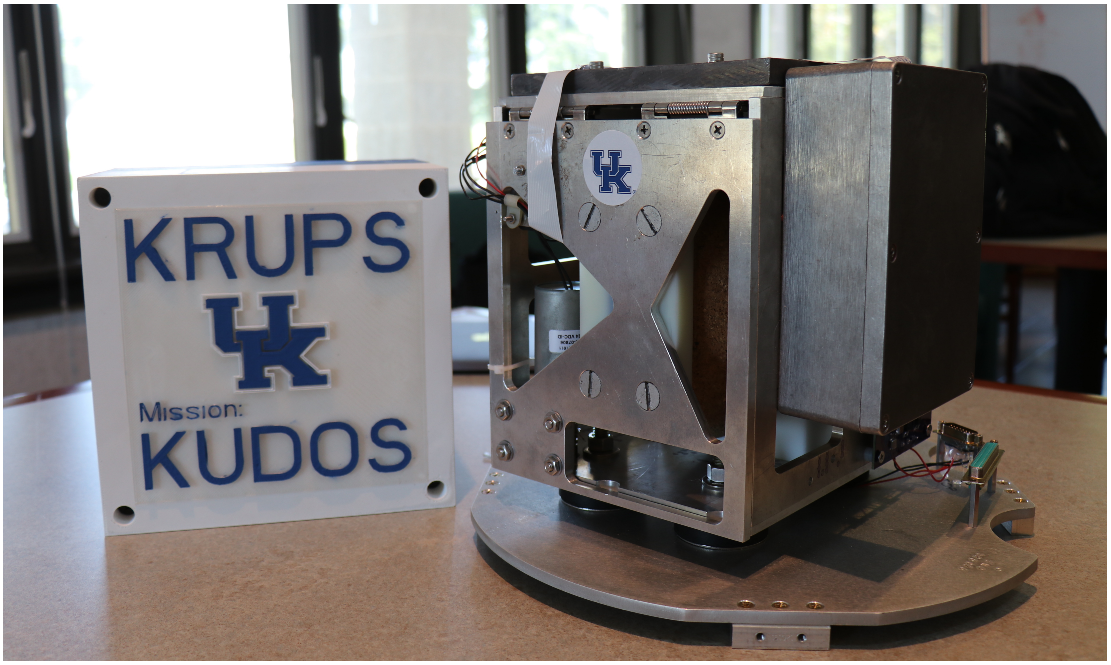


Figure 3.1: KUDOS payload before integrating on the rocket

3.1 Introduction

As a first step toward demonstrating the feasibility of releasing multiple experimental testbeds from the ISS, a sounding rocket experiment took flight on August 13th, 2017 as part of the RockSat-X program. RockSat-X is a program funded by the NASA Space Grant, that provides access to space for university developed experiments[37]. For the 2017 launch, a total of 8 teams participated in the program. Each team performed their own experiment, which included a variety of deployable and stationary devices.

The mission name of this first flight of the KRUPS spacecraft was dubbed KUDOS, short for the KRUPS Deployment and Communication System. For this flight, a subscale version of the KRUPS spacecraft was released at an altitude of ∼150 km, with the assistance of the Terrier-Improved Malemute sounding rocket. Even though the heat flux did not reach the magnitude of an orbital entry, this initial step aimed at testing the ejection mechanism, the data storage and the data recovery system. The spacecraft for KUDOS was scaled down to a diameter of 7.5-inches, and used a TPS made of high density cork. The experiment mounted on the rocket's payload shelf can be seen in Fig. 3.1. Because of the low heat flux, the high density cork was deemed more than sufficient for sub-orbital flights. At the end of this first flight, the overall TRL of the project was expected to go from TRL 4 to TRL 5.

3.2 Mission Requirements and Description

This mission aimed to launch a small (7.5-inch diameter) atmosphere entry vehicle out of the sounding rocket. During the entry phase, the on-board circuitry records the data of thermocouples, accelerometers, a gyrometer and magnometer. The main focus of the mission was to record thermocouple measurements at different depths of the TPS. Successfully recording thermocouple data inside the TPS would help provide flight data for numerical models validations. Because of the small size of the capsule and because it landed in the Atlantic Ocean, recovery was not possible. Therefore, the data needed to be transmitted to the ground station via Iridium satellites. An overview of the mission can be seen in Fig. 3.2, with the Concept of the mission Operation (ConOps).

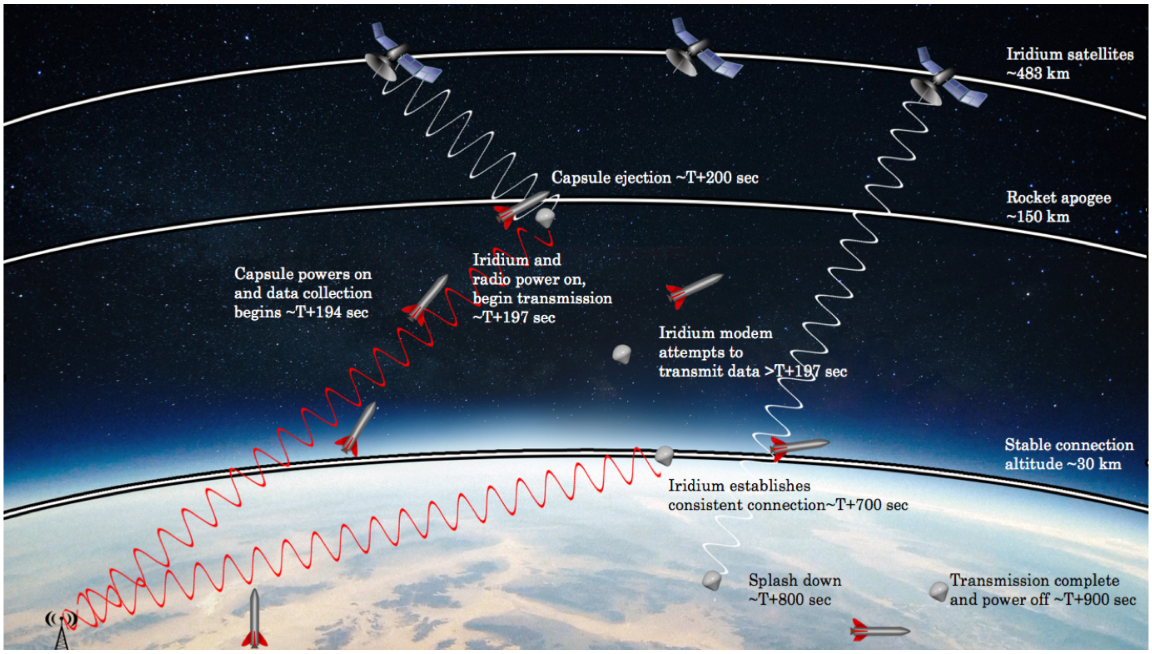


Figure 3.2: Concept of operations for KUDOS mission

As seen in the figure, the capsule was transported by the sounding rocket to apogee. Six seconds prior to the capsule ejection, the capsule power was turned on. Three seconds later, the transmission began. At t+200 seconds, the rocket reached apogee (~150 km) and the capsule was ejected. The capsule separated from the rocket, and both fell back through Earth's atmosphere. During the entry and descent phase, the capsule recorded and transmitted the scientific data using the Iridium satellites. Around 30 km, the connection was expected to become stable, and the bulk of the transmission would begin. Splashdown was expected around 800 seconds after the launch. Since the capsule was expected to survive splashdown, transmission was expected to continue until all the data was transmitted.

For the mission to succeed in validating the whole system, the following requirements needed to be met:

- The capsule shall have the maximum allowed size to eject through the longerons
- The capsule shall fit inside a release mechanism (KREM) so that there is no damage caused to the capsule
- The KREM (with the capsule inside) shall be 30 ± 1 lbs
- The KREM shall eject the capsule so that the capsule is undamaged
- All communication and electrical components shall fit inside the 7.5-inch diameter capsule
- The capsule shall be ejected close to rocket apogee
- The capsule shall be radio transparent to transmit the data
- The capsule shall have a center of gravity so that it is self-stabilizing
- The TPS shall be able to mitigate the heat enough to protect the electronics inside the capsule
- The capsule shall be able to withstand the impact forces of splashdown
- The KREM shall protect the capsule from the high vibrations and forces during launch
- The communication system shall transmit data to the Iridium satellite system after ejection

3.3 Manufacturing Phase

The first sub-system of interest was the KRUPS capsule. The capsule for the KUDOS mission was the sub-scale model, at 7.5-inch diameter. The geometry of the vehicle was based off the DeepSpace2 vehicles, itself based on the PAET entry vehicle[38]. The vehicle geometry had a 45° fore-body, a hemi-spherical after-body, and was based off the outer diameter of the vehicle D. In order for the vehicle to be self-stabilizing, the CG had to be $\pm\ 0.01D$ from the centerline and was limited to be $0.44D$ from the from the nose.

The KRUPS capsule consisted of high density cork TPS, a 3D-printed Nylon internal housing, and various electronics components for power, data acquisition, data storage, and data transmission. Figure 3.3 shows a deconstructed view of the KRUPS capsule, illustrating all of the sub-systems. Figure 3.4 shows the final assembly of the KRUPS capsule used for the KUDOS mission.

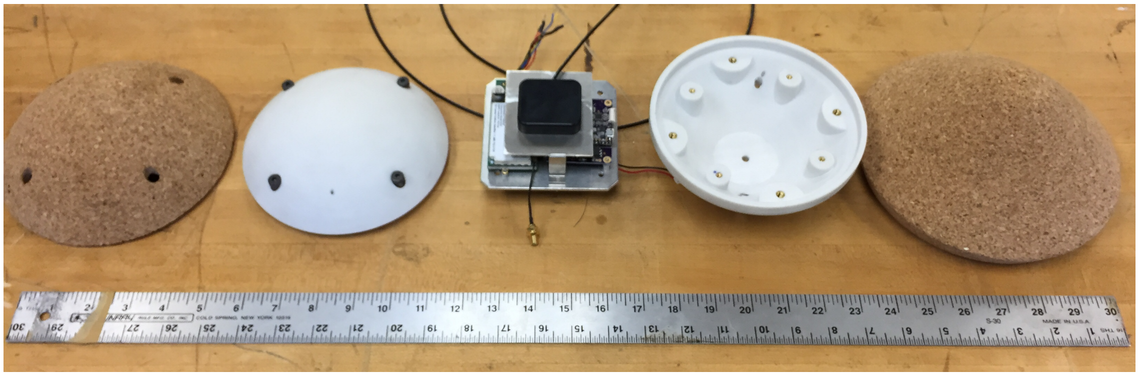


Figure 3.3: Exploded view of the KRUPS capsule for the KUDOS mission

Figure 3.4: Final assembly of the KRUPS capsule for the KUDOS mission

The TPS was made made of high density cork, which was shipped in as a solid block. The solid block was then machined, via CNC milling, in-house at the University of Kentucky. The 3D CAD model of the TPS profile was based off the geometry seen in Fig. 2.9. Cork is very brittle and can be deformed easily if the machining process is not carefully approached. Supports for the cork, seen in Fig 3.5, had to be made such that the shape of the TPS did not deform during the machining process. The material of the supports consisted of bondo putty and hardener, which were machined to match the negative of the TPS profile. After the supports were made for the fore-body and after-body, the cork was machined.

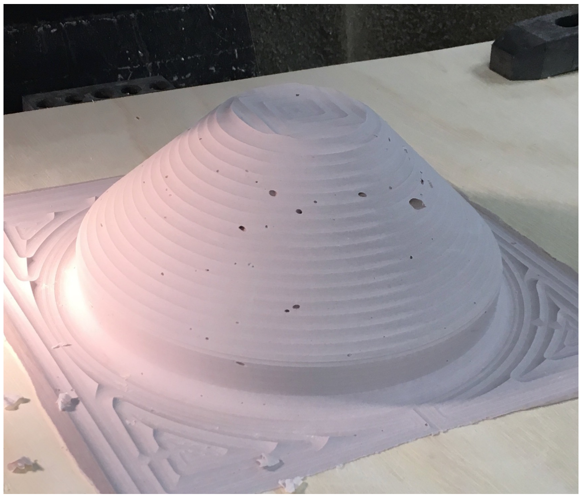
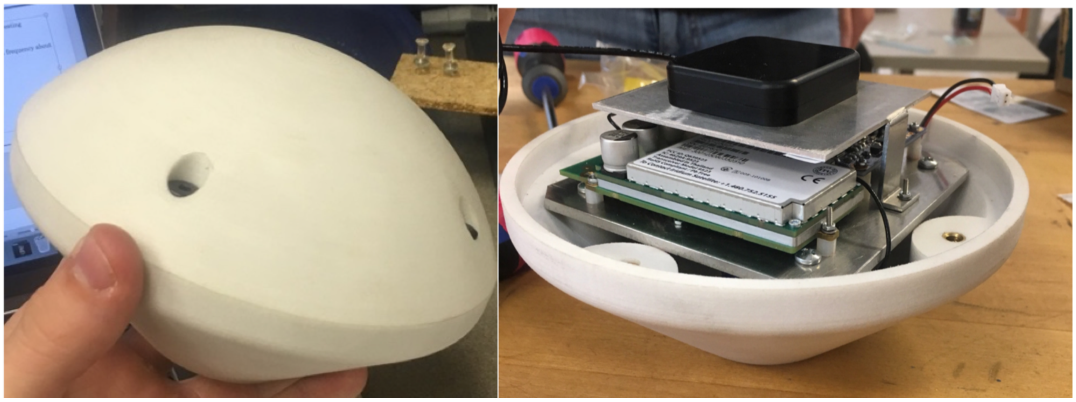


Figure 3.5: One of the supports used for KUDOS TPS machining process

RTV-577 was used to connect the cork TPS to the internal housing. This specific RTV was chosen because of its radio-transparency, which was an important feature since it surrounds the internal housing. Data transmission is a key factor in the mission. The internal housing was picked such that the housing could meet the heat, stress, and radio transparency requirements associated with the mission. The housing was 3D printed from Proto Labs, using a DuraForm HST (Mineral Fiber Filled Nylon-12) material. The housing served as a platform for the electronics, and assisted in maintaining the geometry of the capsule. This configuration can be seen in Fig. 3.6a and Fig. 3.6b, respectively. The four shoulder bolts located on the top piece allowed the capsule to be opened and closed with little impact to the vehicle.

Figure 3.6b shows that the electronics were mounted to an aluminum plate. This aluminum plate was bolted to the bottom piece of the internal housing. The electronics consisted of an Iridium modem, a custom-made electronic board, lithium ion batteries, and an antenna. Due to the small vehicle size, the amount of electronics



(a) Outside view of the internal housing used for the KUDOS mission (b) Inside view of the internal housing used for the KUDOS mission

Figure 3.6: Internal housing used for the KUDOS mission

were limited. The electronic board, seen in Fig. 3.7, was designed and built specifically for this project. The purpose of this electronic board was to collect, store, and transmit the data. In terms of sensors, the board had two accelerometers, a magnometer, a gyrometer, and twelve thermocouple ports. The data collected by the board were compressed before being transmitted through the Iridium satellites. This compression allows for more data to be sent in a shorter amount of time. The data is then sent to a ground station in the form of data packets, which were then sent to an email account. A closer look at the custom-made electronic board can be seen in Fig. 3.7.

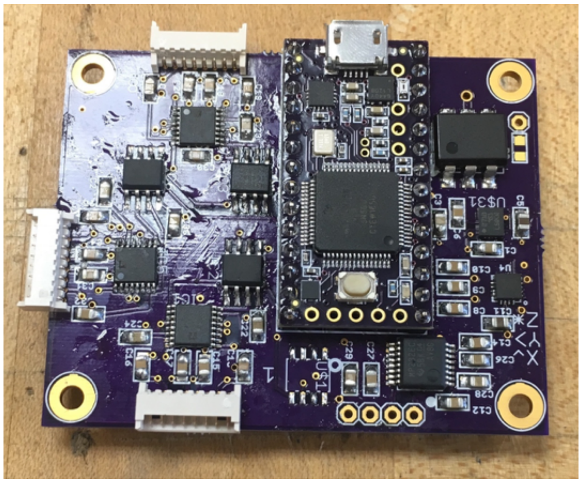
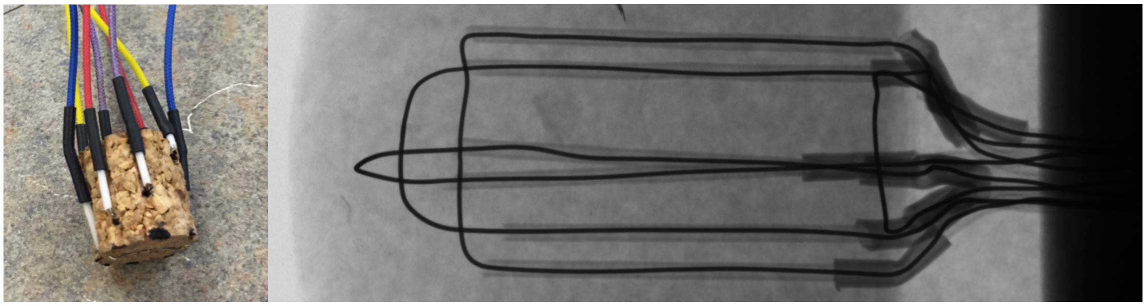


Figure 3.7: KRUPS electronic board used for the KUDOS mission

As mentioned earlier, the KRUPS project focuses on acquiring thermal response data during the experiment maturation stage. Temperature measurements of the heat-shield were obtained using three heat-shield thermal plugs. These three thermal plugs each included four thermocouples, placed at different depths within the cork (respectively 0.1, 0.2, 0.3-inches from the surface of the TPS, and 0.1-inch from the internal housing). The thermocouples were insulated using ceramic insulation along the sides of the plug, followed by insulation sleeves. A photograph of one of the thermal plugs used for the KUDOS mission can be seen in Fig. 3.8a.

The thermal plugs were inserted into holes, which were machined from the inside of the TPS. Contrary to the thermal plugs used on MSL, these holes were not drilled from the outside of the TPS[22]. The holes were drilled such that the surface of the thermal plugs were located 0.1-inch from the surface of the TPS. To facilitate the numerical reconstruction of the heat flux and material response of the heat shield, the KRUPS capsule was scanned using X-ray computed tomography. As an example, a 2D scan of the stagnation point thermal plug is shown in Fig. 3.8b. The bottom of the thermal plug is shown inside of the cork TPS. The dark area at the top is the internal housing. The scan indicates that the thermocouples were located at the correct distances and that they were in a straight orientation.

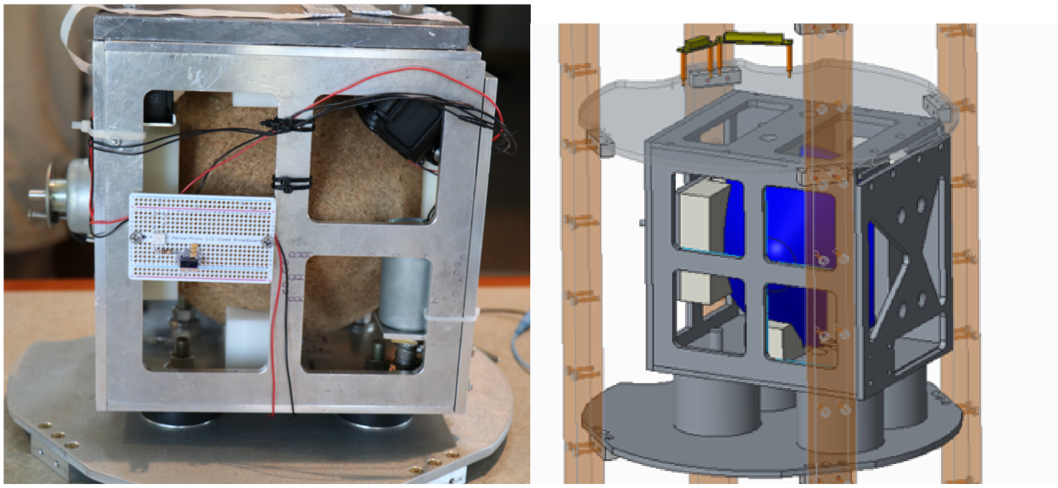


(a) Side cork thermal plug

(b) X-ray scan of the thermocouples at the stagnation point of the KRUPS capsule

Figure 3.8: Thermal plug used in the KRUPS capsule of the KUDOS mission

To protect and deploy the KRUPS capsule, the KREM sub-system was developed, and can be seen in Fig. 3.9a. The KREM included 4 vibration isolators and was attached to the payload shelf of the rocket. The KRUPS capsule was held within KREM by Nylon filler material machined to the outer profile of the capsule. At apogee, the KREM received a signal to eject the KRUPS capsule by the means of two solenoids. The first solenoid – a pull solenoid – was attached to the lid of the KREM. The lid opened, once the pull solenoid was activated, via two spring-loaded hinges. The second solenoid – a push solenoid – pushed the capsule out of the KREM once activated. KREM also had two cameras (GoPro sessions) mounted inside the mechanism, one camera was mounted in the back corner, and the other camera was mounted to the lid. The video footage was stored on a memory card, which was located inside an insulated and waterproof box, with the help of extension cables.



(a) Final assembly of KREM

(b) Orientation of KREM

Figure 3.9: KRUPS Rocket Ejection Mechanism (KREM)

The KREM was placed on the top shelf of the sounding rocket payload section, as can be seen in Fig. 3.9b. The capsule was released between the longerons of the rocket, which are spaced 8.2-inches apart. This distance between the longerons was the main reason why a sub-scale version of the KRUPS capsule had to be used for the mission.

To use the release mechanism appropriately, two electronic boards were designed to send signals to different components on KREM. One board was made specifically for the cameras, while the other board sent power to the capsule and solenoids. A functional block diagram (FBD) of the experiment is shown in Fig. 3.10. The diagram shows how signals were relayed to different components. It also shows that the rocket's Timer Events 1, 2, and 3 (TE-1, TE-2, and TE-3) were used. The order of the timer events are misleading since the order in which they occur are TE-3, then TE-1, and finally TE-2. TE-3 was the first timer event to activate, at t+180 seconds. This timer event sent a signal to the GoPro board, which then started the videos. TE-1 was the next timer event line to activate, at t+194 seconds. This timer event sent a signal to the KREM board, which sent a signal to the door solenoid and turned the capsule power on. TE-2 was the last timer event line to activate, at t+200 seconds. This timer event sent a signal to the KREM board, which sent a signal to the back solenoid.

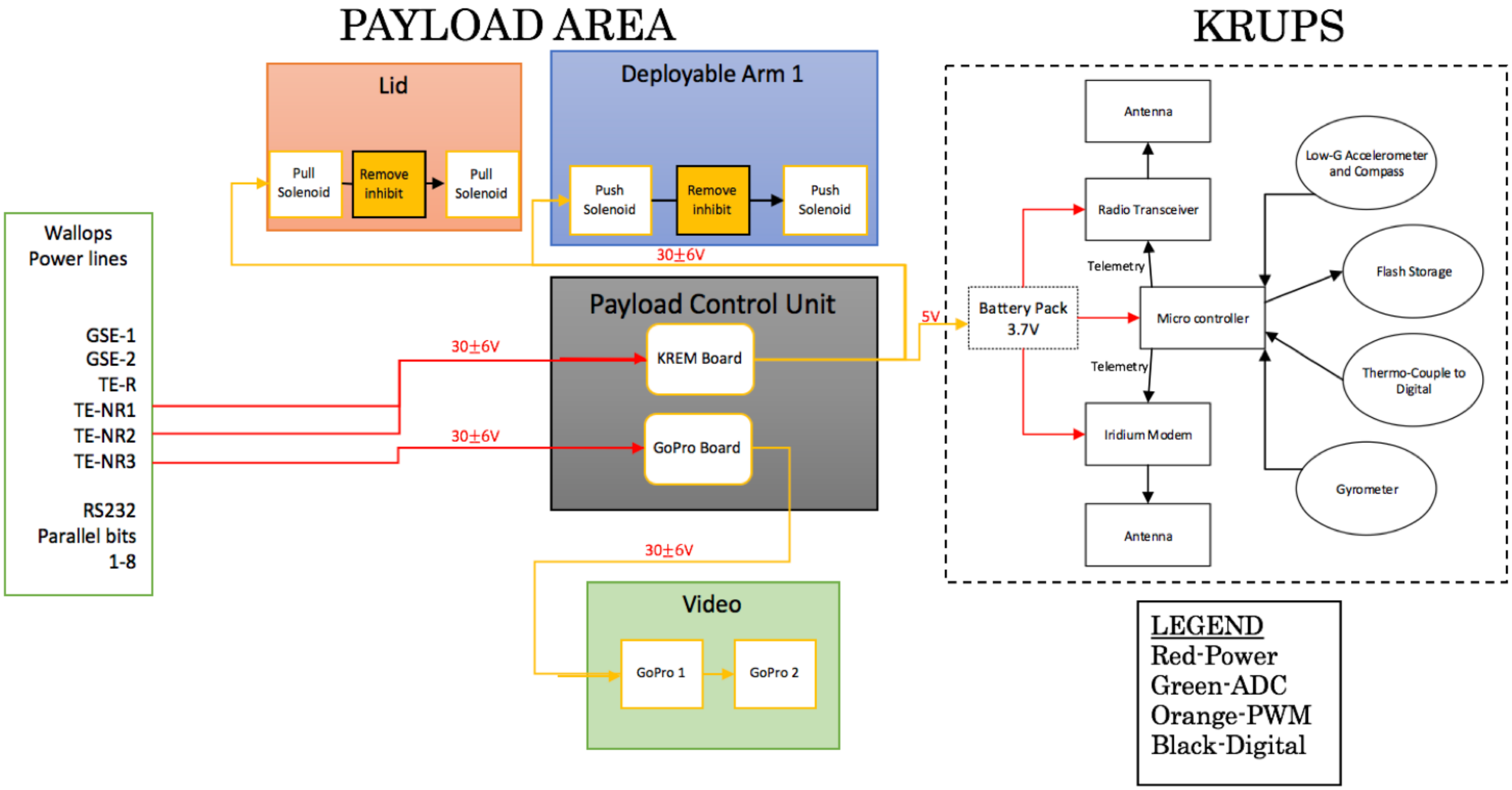


Figure 3.10: KUDOS functional block diagram

The battery pack inside the capsule was activated using the incoming voltage supplied by TE-1. There were two wires that connected from the KREM board and inserted into the capsule's ports. This power connection for the capsule can be seen in Fig. 3.11 After the activation of the capsule, the electronics only used the power supplied by the battery pack. As can be seen in Fig. 3.11, the wires were not appropriately secured, and the capsule had the possibility of rotating. If the capsule were to rotate during the intense vibrations of launch, the power activation wires could disconnect before the capsule was turned on. Therefore, extensive tests were performed before launch to ensure that the capsule would not rotate.

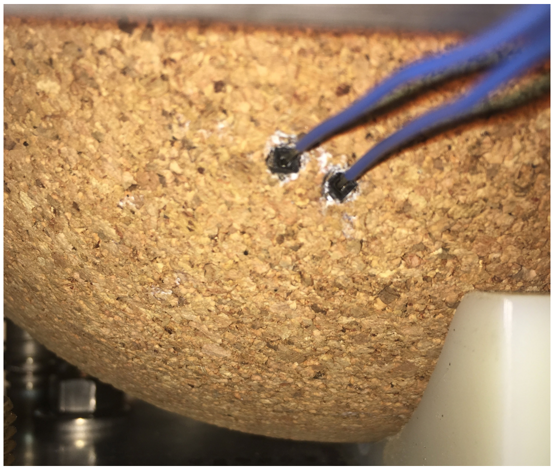


Figure 3.11: Power activation used to power the spacecraft

3.4 Analysis

Trajectory estimates

The data gathered by the capsule during the KUDOS mission was intended to be compared to CFD results obtained using the KATS CFD code[39, 40, 41, 42]. To understand the flight conditions that the capsule would experience during the atmosphere entry, the expected trajectory was calculated using the in-house KTMP code[43]. Through these simulations, it was possible to roughly estimate the expected stagnation point heat flux for different flight scenarios, using the Sutton-Graves empirical relation. Based on the rocket trajectory, a velocity of 315 m/s was used as an initial condition at apogee. The model projects that the heat flux expected for a flight from the ISS is approximately 170 W/cm^2. For the KUDOS launch, the trajectory code projected that the capsule would experience a heat flux of approximately 17.9

W/cm^2. Results for the KUDOS mission are shown in Fig. 3.12, obtained for various apogees using KTMP.

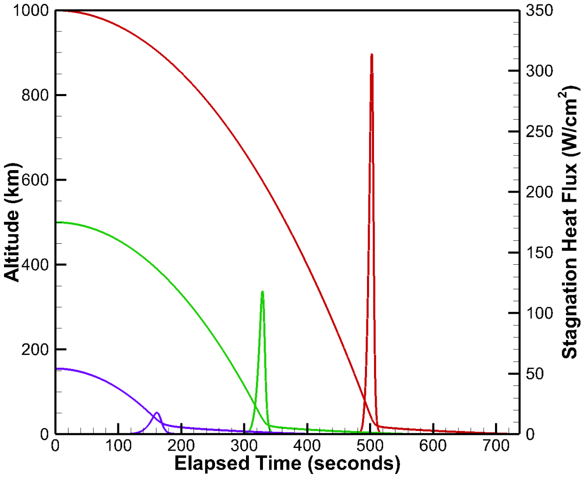
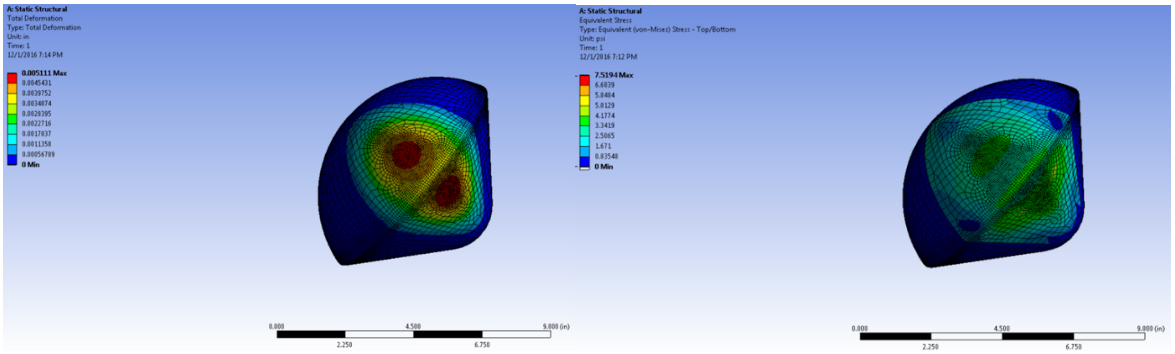


Figure 3.12: Trajectory and heat flux for the KUDOS mission, at various entry altitudes, obtained using the in-house trajectory code KTMP

The purple lines correspond to what was predicted for the KUDOS mission. The other lines shown in the figure show a comparison of what would be expected if the KRUPS capsule were to be pushed off a sounding rocket that had higher altitudes, 500 km and 1000 km. The two purple lines show an altitude vs time and a heat flux vs time comparison. This shows that the capsule was expected to have a peak heat flux (17.9 W/cm^2) at 30 km. Performing this trajectory analysis provided expected velocities, heat fluxes, and provided data necessary to design a TPS that would allow the capsule to survive the atmospheric entry environment.

ANSYS Analysis

The cork TPS was fragile and could be deformed with little stress. Since collecting thermal response data located inside the TPS was the main experimental goal, making sure the TPS was not damaged was important. To verify that the impact of the solenoid pushing the capsule out of the release mechanism did not damage the TPS, a finite element analysis was performed. The analysis modeled the stress and deformation of the TPS once the solenoid was activated and pushed the capsule out of KREM. The highest stress was expected to occur as soon as the solenoid touched the capsule, which is due to the static friction from the top and bottom filler materials. It was estimated that the KRUPS capsule would be ejected at a velocity of 1 in/sec, which would require a maximum force of 20 lbf. A pressure of 0.92 psi was estimated by measuring the contact surface of the filler material and capsule. The cork material was added into the ANSYS material database, with a Young's Modulus of Elasticity of 18.6 MPa and a Poisson ratio of 0.0. It was assumed that the filler material would hold the capsule in a fixed position. Therefore, a fixed boundary condition was applied to the surfaces where the filler material came into contact with the capsule.



(a) Total deformation of the capsule

(b) Von-Mises stress of the capsule

Figure 3.13: ANSYS results regarding the pressure exerted on the capsule

Figure 3.13b shows that the maximum stress expected was 7.52 psi and it occurs on the surface of the TPS, where it contacts the filler material. Figure 3.13a shows that the total deformation expected was roughly 0.0051-inches occurring on the surface of the TPS, where the maximum pressure is to be exerted. Therefore, very low stress and deformation is expected with the release of the capsule from the release mechanism. It was concluded that KREM would not damage the TPS upon ejection, thus allowing the experiment to work as intended.

3.5 Testing Phase

Several tests were conducted on the sub-systems to prepare for the launch. These included ejection tests in simulated micro-gravity, vibration tests, vacuum tests, communication tests, and atmospheric balloon flights. The ejection test in simulated micro-gravity focused on determining the flight path of the capsule and verifying that the capsule was able to clear the KREM without getting lodged inside. Figure 3.14 shows the setup of the ejection test.

The KREM was propped up on boards and had the lid open. The fact that the capsule was counter-weighted via fishing line and pulley system is not visible in the figure. A slight force applied to the capsule sent it out of the KREM, which *almost* replicated the expected conditions in micro-gravity. The test was repeated

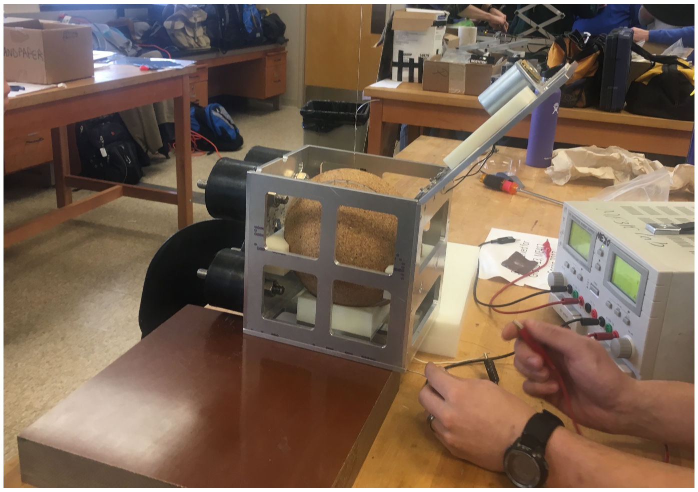


Figure 3.14: Setup of the ejection testing, performed in-house

several times to help determine the tolerance of the filler material and the appropriate amount of rubber to be placed on the surface of the filler material.

The vibration test focused on the durability of KREM and verified that the capsule did not rotate. The KREM, with the capsule inside, was attached to a support structure, which was then attached to a shaker table. This support structure was needed so that the KREM could interface with the mounting bolts of the shaker table. A photograph of the setup is presented in Fig. 3.15. Several vibration profiles were tested to verify the experiment was ready for launch. The profiles consisted of a Sine Test and a Random Test, and were based off the conditions suggested by the RockSat-X program[37]. The tests were performed from 20-2000 Hz, only in the longitudinal direction, due to the limitations of the shaker table. This was determined to not be a problem since the most violent conditions were expected in the longitudinal axis, the axis of the rocket. This test helped determine that a rubber liner was needed on the filler material. Without the extra friction and compression given by the rubber, the capsule would have rotated during the test.

The vacuum tests focused on verifying that the electronics did not outgas once activated. Individual parts were all tested. The main components on the KREM that needed testing were the two solenoids. Each solenoid was connected to the power supply in a vacuum chamber. The chamber was depressurized to the pressure expected at 150 km, 3.73×10^{-6} Torr. After depressurization, the solenoids were activated for a period longer than the expected actual time. During and after the test, a visual inspection of the glass window was performed. If the solenoids outgassed during the test, a noticeable amount of gas would have collected on the window of

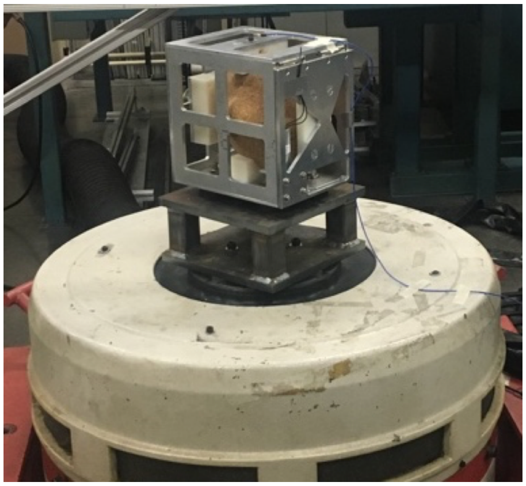
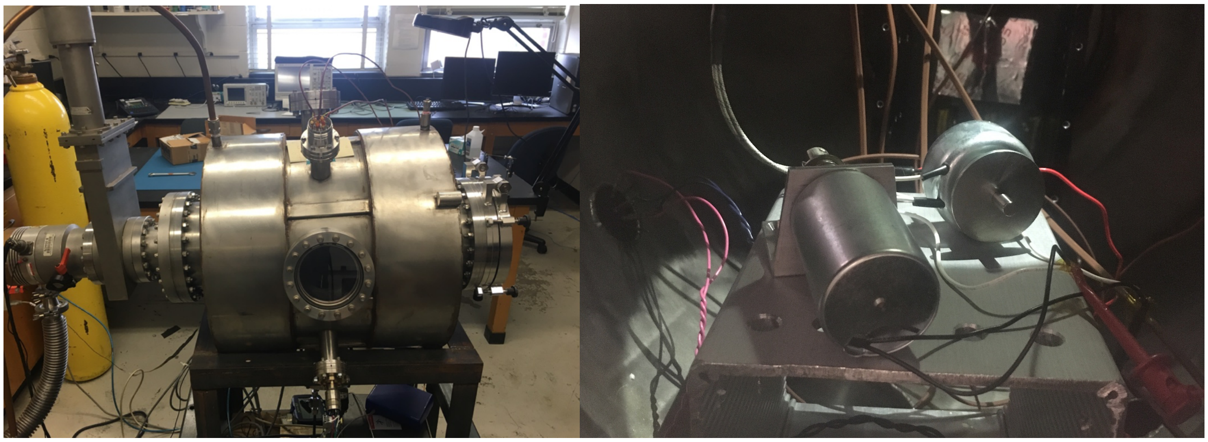


Figure 3.15: Setup of the vibration testing, performed at Yokohama (Versailles, KY)

the chamber. Figure 3.16 shows the inside and outside of the vacuum chamber.



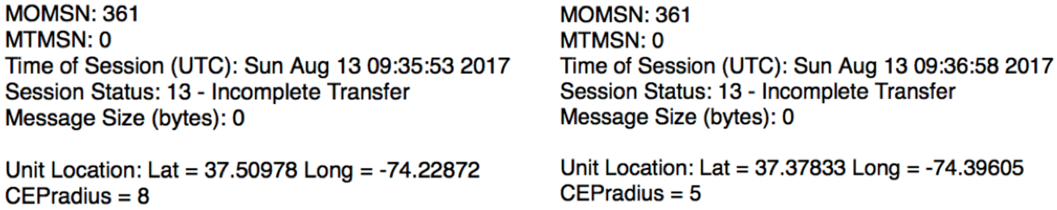
(a) Outside view of the vacuum chamber (b) Inside set-up of the vacuum chamber

Figure 3.16: Vacuum chamber testing performed at the University of Kentucky

Both the communication and atmospheric balloon flight tests focused on verifying that the Iridium modem was able to connect with the satellites and send data packets. The main communication test involved taking the capsule outside to a clear area and testing the connection. This verified that the TPS, RTV, and internal housing were radio transparent. This test was conducted several times to verify the system was ready. The balloon flight test verified the same elements, but at higher altitude. These tests helped verify that the communications system was ready for the actual flight.

3.6 Results

The success of the KUDOS mission relied on the ability to transmit the data to the ground station. Unfortunately, for this mission, no data packets were received. However, a connection was established, and two "incomplete transfer" emails were received (see Fig. 3.17). These emails confirmed that the capsule was powered, and was able to connect to the Iridium satellites. The "incomplete transfer" statement means that the connection was interrupted before the data transfer was completed.



```
MOMSN: 361
MTMSN: 0
Time of Session (UTC): Sun Aug 13 09:35:53 2017
Session Status: 13 - Incomplete Transfer
Message Size (bytes): 0

Unit Location: Lat = 37.50978 Long = -74.22872
CEPradius = 8
```

(a) First email received

```
MOMSN: 361
MTMSN: 0
Time of Session (UTC): Sun Aug 13 09:36:58 2017
Session Status: 13 - Incomplete Transfer
Message Size (bytes): 0

Unit Location: Lat = 37.37833 Long = -74.39605
CEPradius = 5
```

(b) Second email received

Figure 3.17: Incomplete transfer emails received a few minutes after launch

Even though no data packets were obtained from the KUDOS mission, two cameras were mounted inside the KREM to document the ejection phase. Since the rocket was recovered after splashdown, the data from the two cameras was also retrieved. The cameras started recording ten seconds before capsule ejection, and continued until the cameras melted during the atmospheric entry phase. The data from the cameras was stored inside a thermally insulated box on the payload shelf through the use of cable extensions. Figure 3.18 shows a snapshot of the KRUPS capsule being released at 150 km[44, 45]. These videos were able to confirm that the lid opened at the appropriate time without any resistance. Five seconds after the lid opened, the capsule was pushed out without getting jammed inside the the KREM. The functionality of the KREM was then deemed a success.

The cameras were able to show that the capsule stayed in place on the way to apogee. However, it was noted that the capsule jarred and became misaligned when the lid opened. The displacement was not severe enough to prevent ejection. The video captured from the back of KREM also showed that the capsule hit the inside wall, which induced a rotation. It is likely that this was caused by the slight shift resulting from the opening of the door. The TPS appeared to be unharmed. However, the rotation might have caused the capsule to take more time to stabilize, which, in

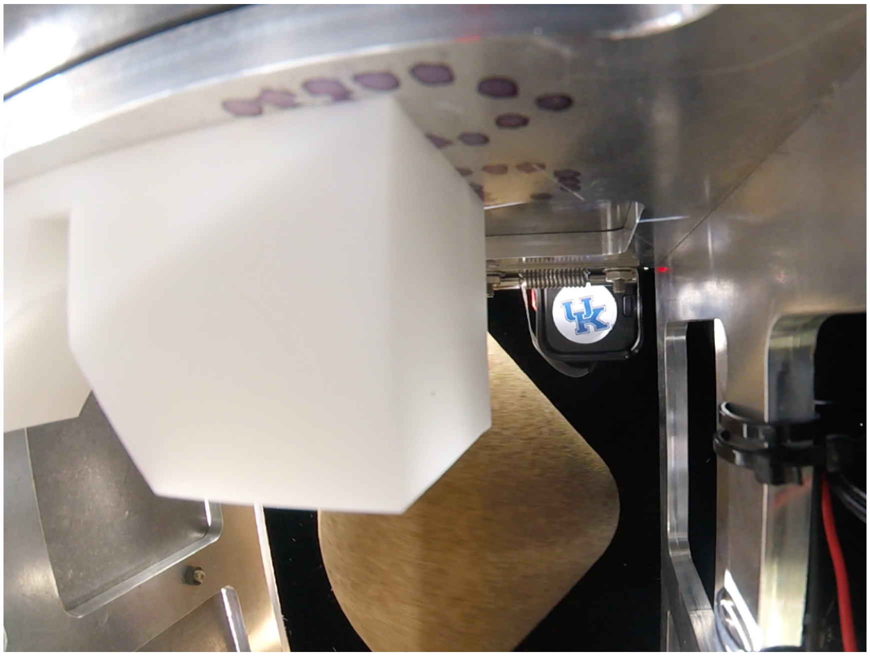


Figure 3.18: Video screenshot as the capsule is being ejected from KREM at rocket apogee (150 km)

turn, might explain the interruption in the data transfer. These results were used to improve the system for the KOREVET launch.

3.7 Conclusion

The KUDOS mission launched in August 2017, and the first KRUPS capsule was successfully ejected at 150 km of altitude. During that mission, several subsystems were tested, and the technology readiness level of the project was raised to level 5. The KREM sub-system was determined to be a reliable method of powering the capsule, and releasing it from the rocket. The capsule successfully connected to the Iridium satellites, but no data packets was received. Nevertheless, the mission was deemed a success, and paved the way for the next flight, this time using a full size capsule[46]. It is expected that the knowledge gathered and lessons learned from both of these flights will results in multiple orbital missions, to be launched in the near future. The success of such missions would result in a low-cost validation approach for entry experiments and instruments.

Chapter 4 Second Mission: KOREVET

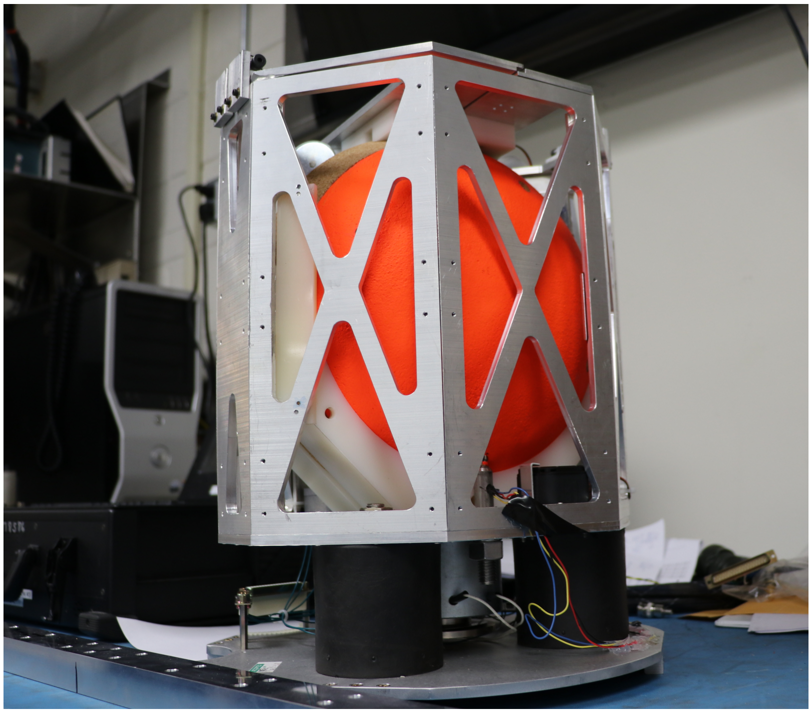


Figure 4.1: KOREVET payload before integrating on the rocket

4.1 Introduction

As another step towards releasing multiple experimental testbeds from the ISS, a second sounding rocket took flight on March 25th, 2018 as part of the NASA Undergraduate Student Instrument Project (USIP) Student Flight Research Opportunity (SFRO) program. USIP SFRO is a program that provides hands-on flight project experience to enhance the science, technical, leadership, and project skills for undergraduate student teams and allows students to understand NASA goals with sub-orbital flights. Like the RockSat-X mission, each team performed their own experiment, which included stationary devices, with the exception of our experiment.

This mission was named KOREVET, short for KRUPS Operational Re-entry Experimental Vehicle for Extensive Testing. This second mission was on a similar flight as the first, but a full-scale 11-inch KRUPS spacecraft was released, instead of the 7.5-inch diameter spacecraft. The experiment was attached to the Terrior-Improved Malemute sounding rocket, but the apogee for this flight was at 170 km, since there was less weight on the rocket. Once again, the heat flux was not expected to reach the high heat flux of an orbital entry. This mission aimed to validate the sub-systems at full-scale, with the expectation of correcting the communication malfunction from the previous launch. The spacecraft for KOREVET also used high density cork as the TPS since the heat flux was projected to be low. The experiment mounted on the rocket's payload shelf can be seed in Fig. 4.1. At the end of this second flight, the overall TRL of the project was expected to stay at TRL 5 since the goal was to test the full-scale sub-systems. If the communications were to work in this mission, the overall TRL was expected to change to TRL 6.

4.2 Mission Requirements and Description

This mission aimed to launch a full-size atmosphere entry vehicle out of a sounding rocket. During the entry phase of the mission, the electronics inside the vehicle recorded the data of thermocouples, accelerometers, a gyrometer, GPS unit, and magnometer. The main focus of this mission was similar to the first mission, to record thermocouple measurements at different depths of the TPS. Recording the thermocouple data at the stagnation point was the most important location, and would help provide flight data for numerical model validation. After the vehicle landed in the Atlantic ocean, a side task was to retrieve the capsule. Since the capsule was bigger in this mission, a stronger GPS unit was integrated inside the capsule. Also, painting the after-body hemi-sphere bright orange increased the chance of recovery. The primary source of data collection relied on transmission via Iridium satellites. The overview of the flight is similar to what was shown for the KUDOS mission, with the main difference being the altitude the capsule is released from. This ConOps can be seen in Fig. 4.2.

Five seconds prior to the capsule ejection, the capsule was to be powered on. Three seconds later, the capsule was to attempt to collect data and transmit. At t+255 seconds, the rocket should be approximately at apogee ($\sim$170 km) and the capsule ejected. From this point on, the capsule records and transmits the data using the Iridium satellites. A communications blackout was expected until about 30 km, thus most of the data was to be transmitted below this altitude. Splashdown was to occur shortly after, and the capsule was expected to continue transmitting data until all data was collected. Also, the capsule would be transmitting GPS coordinates to assist the recovery team with the retrieval process.

For this mission to succeed, the following requirements needed to be met:

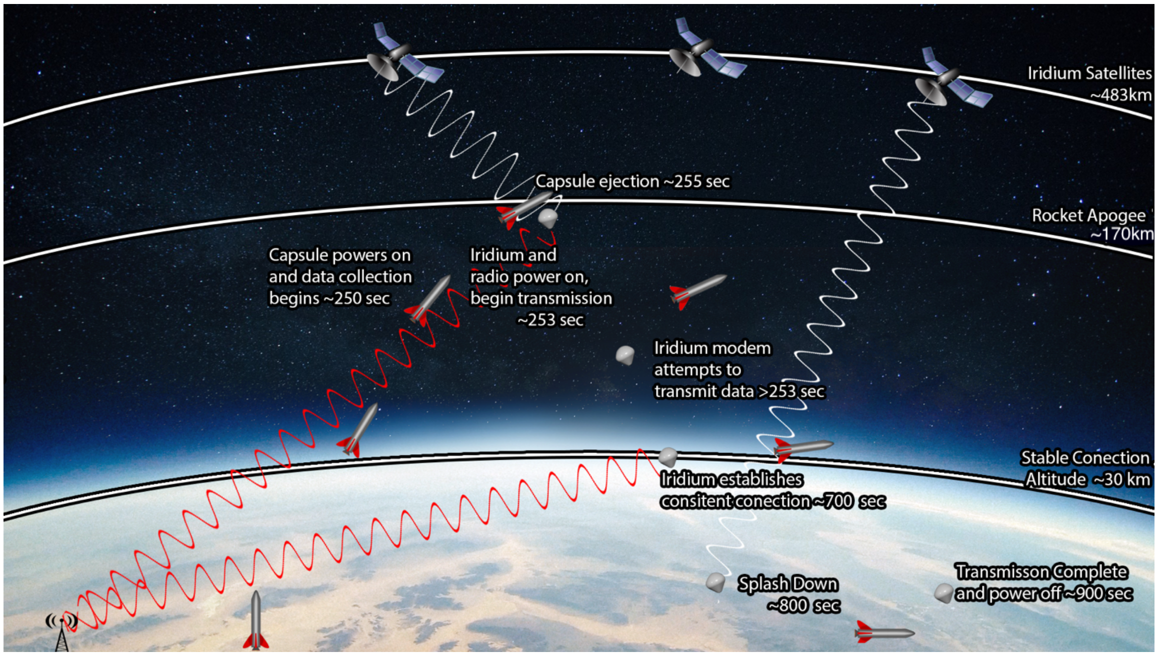


Figure 4.2: Concept of operations for KOREVET mission

- The capsule size shall match the size that will be used for orbital flights
- The capsule shall fit inside a release mechanism (KREM) so that there is no damage caused to the capsule
- The experiment payload shall weigh 35±5 lbs
- The KREM shall eject the capsule so the capsule is undamaged
- The KREM shall eject the capsule so the capsule has a slow spin rate
- All communication and electrical components (including GPS) shall fit inside the 11-inch diameter capsule
- The capsule shall be ejected close to rocket apogee
- The capsule after-body shall be radio transparent to transmit the data
- The capsule shall have a self-stabilizing geometry
- The TPS shall mitigate enough heat to protect the electronics inside the capsule
- The capsule shall be able to survive the impact forces of splashdown
- The KREM shall protect the capsule from excessive vibrations and forces during launch

- The communication system shall transmit data to the Iridium satellite system after ejection

- The capsule shall include enough recovery features to increase the chances of collecting the capsule after impact

4.3 Manufacturing Phase

As mentioned earlier, the spacecraft for the KOREVET mission was the full-scale model, 11-inch diameter. The vehicle's geometry was similar to the first mission. The geometry (based on D), derived from the DeepSpace2 vehicles, can be seen in Fig. 2.9[6]. There have been multiple missions that were successful in utilizing the self-stabilizing design of the vehicle. The vehicle geometry included a 45° fore-body and a hemi-spherical after-body. The vehicle is self-stabilizing when the CG is $\pm 0.01D$ from the centerline and is limited to $0.44D$ from the nose.

The KOREVET capsule was similar to what was used for the KUDOS mission. The capsule was made of high density cork TPS, the same 3D-printed Nylon internal housing, and various electronic components for power, data acquisition, data storage, and data transmission. The deconstructed view of the capsule is similar to what is shown in Fig. 3.3. The main difference was that everything was scaled up in size, and the electronic stack-up was changed. A comparison of the capsules can be seen in Fig. 4.3.

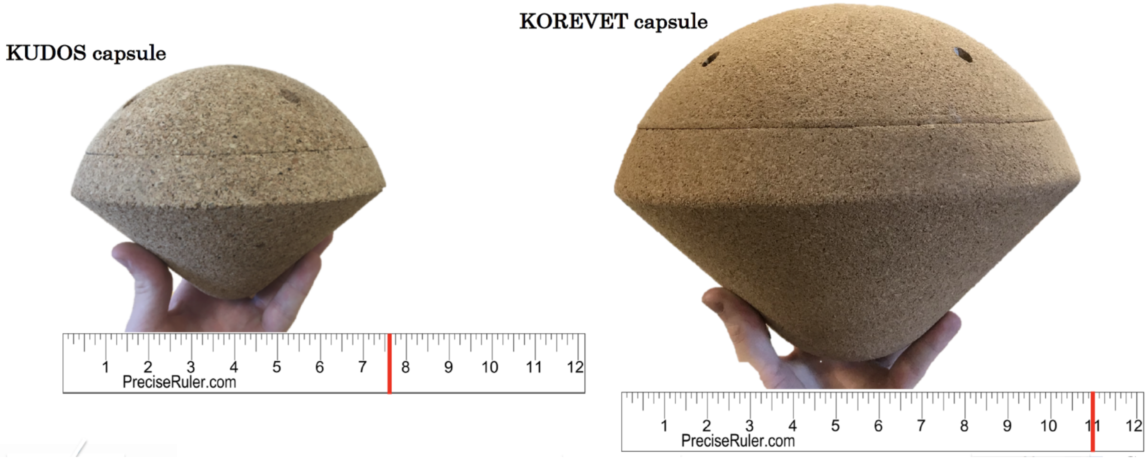


Figure 4.3: Comparison of the capsules used in KUDOS vs KOREVET

The TPS was made of high density cork, the same as was used for KUDOS. The block of cork was machined to the geometry shown in Fig. 2.9, using a CNC mill.

Supports had to be machined again since the size of the TPS had changed and this time, MDF was used as the support material. This material was more sturdy, gave more dampening, and had a smoother finish. This support can be seen in Fig. 4.4.

Figure 4.4: KOREVET support (made out of MDF) used to stabilize cork as it was machined

After the supports were made, two complete TPS were machined. One was used for testing, while the other was used for the actual launch. Each vehicle took about three to four days to be machined. The machining process of the capsule can be seen in Fig. 4.5. Once the TPS was CNC machined, the capsule was ready to be put together.

Figure 4.5: KOREVET TPS bottom shell during the machining process

The same type of RTV (RTV-577) was used to connect the cork TPS to the internal housing, since this was a proven method. The RTV was verified as a radio-transparent adhesive that was strong enough to hold the capsule together. The internal housing also stayed consistent to what was used for KUDOS. The housing was 3D-printed from Proto Labs, using Duraform HST (Mineral Fiber Filled Nylon-12) material. The internal housing can be seen in Fig. 4.6a, while Fig. 4.6b shows the bottom half of the housing. The main differences to notice are that a location slot was added to the lip and rubber sealants were used in five locations. The location slot was used so that the bottom and top piece would line up easier. The rubber sealants were used to help prevent water from leaking into the capsule. All of the other features were similar to those seen in the KUDOS internal housing.

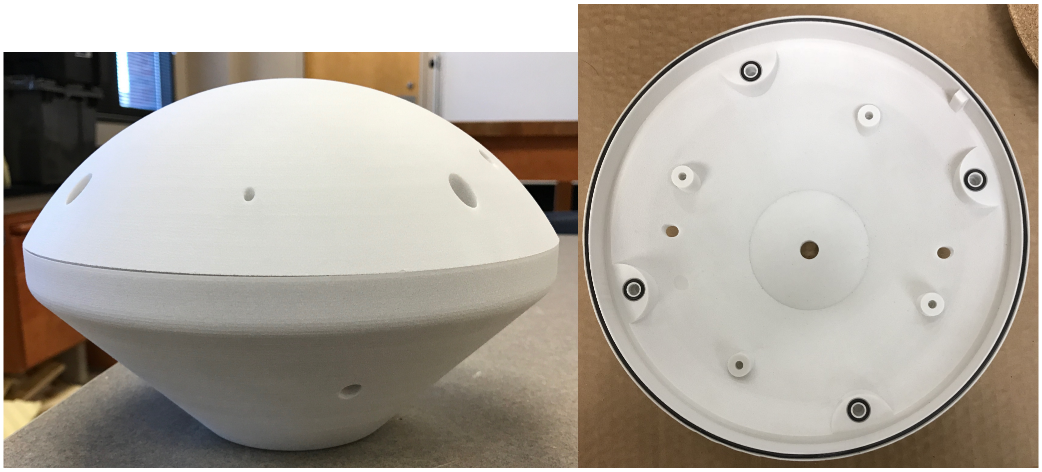

(a) Outside view of the internal housing (b) Bottom half of the housing

Figure 4.6: Internal housing used for the KOREVET mission

The electronics were mounted to an aluminum plate. Since the vehicle was scaled up, the volume inside the capsule also increased. This allowed the electronics to fit inside the capsule easily. The electronics consisted of an Iridium modem, a custom-made electronic board stack-up, lithium ion batteries, GPS, and an antenna. This setup can be seen in Fig. 4.7. As you can see from the figure, the electronics are a lot less compact on the aluminum plate in comparison to the KUDOS mission. Also, a platform was not needed to mount the antenna.

The custom-made electronic board stack-up, seen in Fig. 4.8, was modified from the previous mission. Instead of having all of the sensors and components on the same board, two separate boards were made. The bottom board was the "motherboard", which had the main components needed for functionality. The top board included the sensors (thermocouple ports) that were of interest for the mission. This improvement was made to address the *universal* portion of KRUPS. Since KRUPS will eventually be used for different experiments, this improvement allows other sensors to be plugged

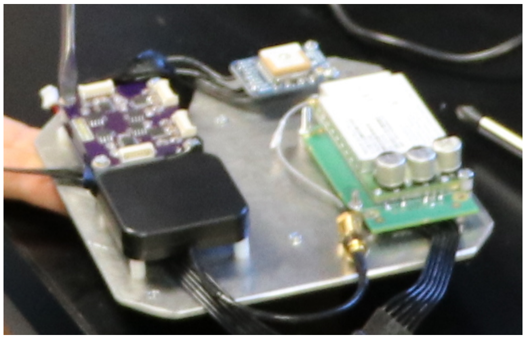


Figure 4.7: Electronic setup for KOREVET mission

into the “motherboard” in future flights.

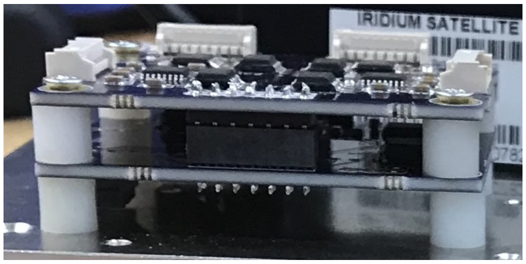


Figure 4.8: Double-layer sensor-board stack used to collect and store data

For the KOREVET mission, three heat-shield thermal plugs were used to collect temperature measurements. One thermal plug was located at the stagnation point, while the other two were located on the side profile of the 45° fore-body (spaced 180° from each other). This can be seen in Fig. 4.9. The main thermal plug is the stagnation point, while the other two plugs are used to help determine the angle of attack the vehicle enters at. The two thermal plugs on the side included four thermocouples, while the stagnation plug had 8 thermocouples. All of the thermocouples were spaced 0.1-inch from each other, except for the one thermocouple that was placed 0.1-inch from the internal housing. The other thermocouples were placed such that the first thermocouple was 0.1-inch from the TPS surface. A picture of the stagnation thermal plug can be seen in Fig. 4.10a. These thermal plugs were inserted using the same method used in KUDOS. To ensure the location of the thermocouples were accurate, 360° x-ray scans of the plugs were taken. One view of the stagnation plug is shown in Fig. 4.10b. The x-ray scan shows the electrical tape, located at the top and in the middle of the plug. A cork stand was used to hold the thermal plug during the scans. Even though the cork plug blends in with the cork stand, the thermocouple locations were still visible.

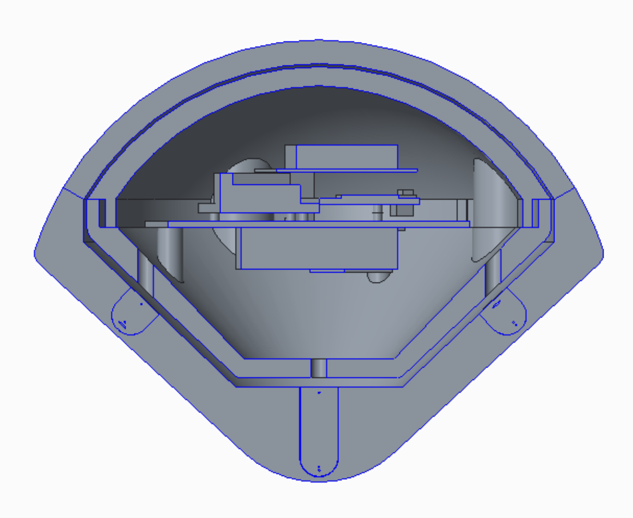
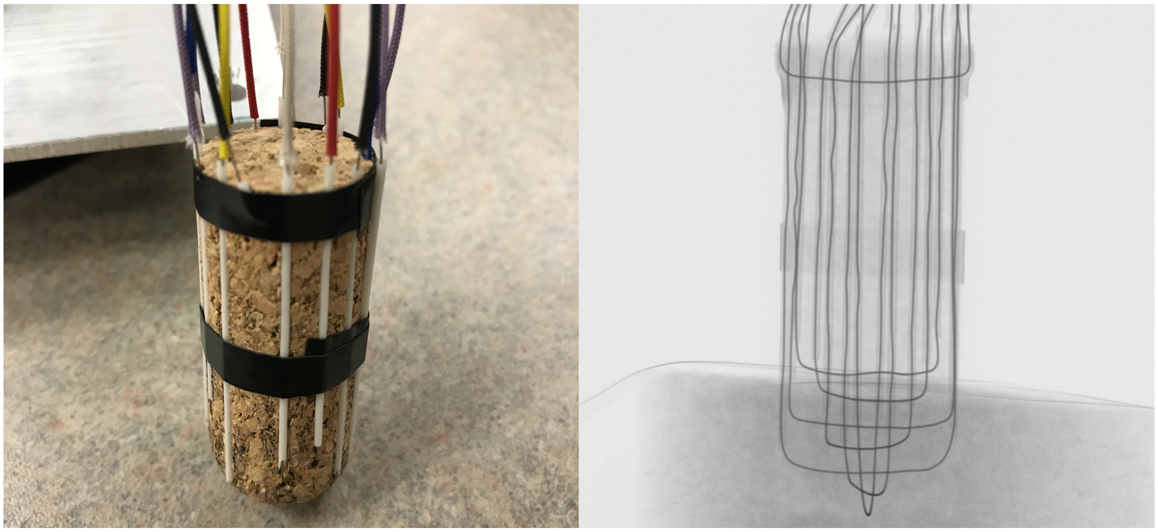


Figure 4.9: Internal (CAD) view of the KOREVET capsule



(a) Stagnation cork thermal plug with 8 thermocouples

(b) X-ray scan of the stagnation plug

Figure 4.10: Stagnation thermal plug used for the KOREVET mission

To protect the capsule during launch and deploy it at the appropriate altitude, a new KREM was developed. The KREM was based off what was used in the KUDOS launch. Originally, it was preferred that we keep the same design, but since the same rocket was used for KOREVET, the same size constraints were given. This time, instead of being placed at the top of the experiment deck, the KRUPS payload was situated at the bottom of the deck. This allowed the capsule to eject along the axis of the rocket, as can be visualized in Fig. 4.11 With this new location, the size of the capsule was not restrained by the longerons, allowing the capsule to be full-scale. Due to the increased capsule and same payload constraints of mounting on a 12-inch diameter shelf, the KREM had to be re-designed, keeping the solenoids as the main mechanism.

(a) Doors closed (b) Doors opened (c) Spacecraft ejected

Figure 4.11: KOREVET experiment layout snapshots during the timeline of the experiment

A comparison among the two release mechanism designs can be seen in Fig. 4.12. KOREVET's KREM used 3 vibration isolators to attach to the rocket's payload shelf. The shape of the KREM also changed; the shape for KUDOS resembled a cube box, while the shape for KOREVET resembled an octagon box. This shape was symmetric and was designed to maximize the size in the 12-inch diameter payload shelf. The KRUPS was held inside by filler material machined to KRUPS outer profile. Instead of having filler material on the sides of the KREM, only three Nylon pieces were used, with no side pieces. Two pieces were attached to the doors, while the other piece was attached to the push solenoid rod. As shown in Fig. 4.12, the filler material attached to the solenoid rod was much larger in size, where the white Nylon covers almost half of the capsule. This design change was made to ensure that the capsule stayed in place as the door opened.

Two doors were assembled on the KREM to allow the door to be distributed on both sides, and thus be smaller. With both doors opening at the same time, the chances of the capsule shifting due to the doors were expected to be lower than the KUDOS launch. Twenty-four 135° custom-made brackets were used to connect all of the side plates together. Four Nylon internal side panels were used to help guide the filler material so the capsule would eject in a straight line. Two cameras (GoPro sessions) were used on this mission. One was attached to the inside of the door, and the other attached to the back corner of the KREM. The memory cards were stored in a small waterproof and insulated box, which was attached to the bottom of the KREM.

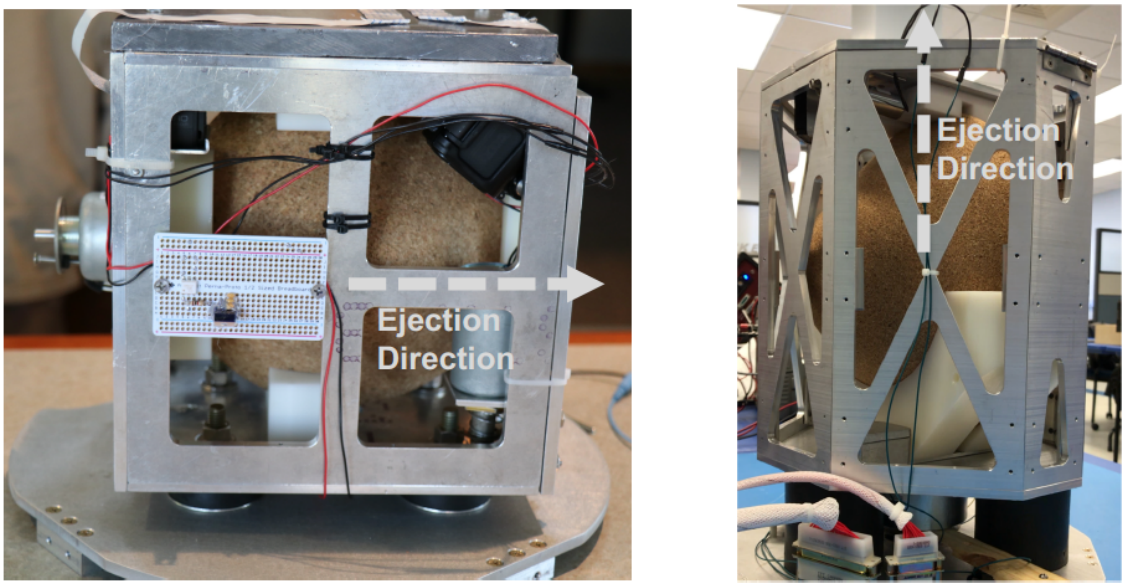


Figure 4.12: KREM comparison among the KUDOS and KOREVET missions

The release mechanism was controlled using the same methods used for KUDOS, seen in Fig. 3.10. Timer Events 1, 2, and 3 provided by the sounding rocket were used to trigger our experiment. The order of the timer events were TE-1, TE-2, and TE-3, which was changed from KUDOS. TE-1 activated at t+235 seconds, which sent signal to the Camera board to turn on the cameras. TE-2 activated at t+245 seconds, which sent a signal to the KREM board to activate the pull solenoid on the door. This timer event signal also sent a signal to the capsule, to turn on the capsule electronics. TE-3 activated at t+250 seconds, which sent a signal to the KREM board to activate the push solenoid.

The battery pack inside the capsule was activated using the signal provided by TE-2. The design of the power activation was changed for this mission. Instead of having two wires feed into the capsule, a 3.5 mm headphone jack was used. Figure 4.13 shows the new design of the power connection. This design was implemented to give a solid connection with the capsule prior to ejection. The connector helped prevent the capsule from rotating during launch, therefore power disconnection was not an issue. Even though the connector helped prevent rotation, the KREM was designed to have the capsule as tight as possible while the doors were closed. To enable a smooth ejection, the tip of the connector was sanded down to a smaller diameter, so the jack had minimal friction with the walls of the port during the ejection process.

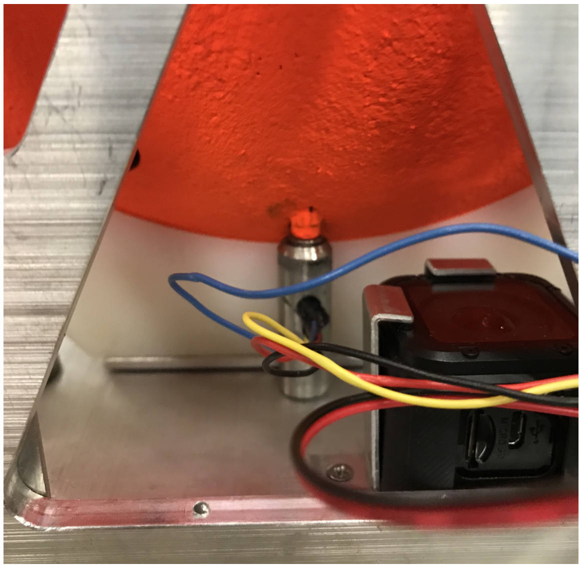


Figure 4.13: Connection port used to activate the capsule's electronics

4.4 Analysis

Trajectory Estimates

The data gathered by the spacecraft during the KOREVET mission was expected to be compared to CFD results obtained by the KATS CFD code[39]. As the initial step, the expected trajectory was calculated using the in-house trajectory code[43]. These simulations predicted the heat flux and velocity that the spacecraft would experience. The model used Sutton-Graves empirical relation, and a velocity of 480 m/s was used at apogee, which is the expected velocity of the sounding rocket. For the KOREVET launch, the spacecraft was expected to experience a heat flux of approximately 8 W/cm^2. A visual representation of the expected heat flux is shown in Fig. 4.14.

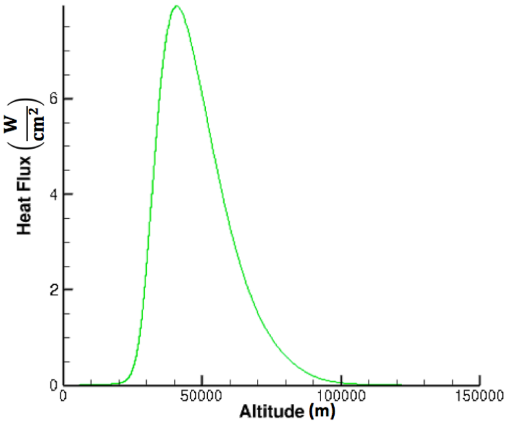
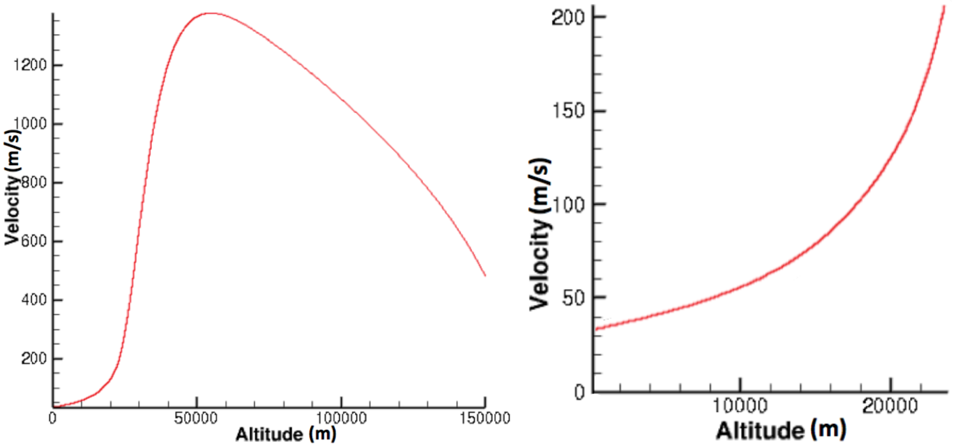


Figure 4.14: Heat flux expected for the KOREVET mission

To determine if the spacecraft for the KOREVET launch would survive the splashdown impact, the velocity of the vehicle was required. Using the KTMP code, the velocity of the vehicle was estimated, and can be seen in Fig. 4.15. The graphs shown in Fig. 4.15 estimated that the spacecraft would reach a velocity of more than 1,200 m/s, which puts the vehicle in supersonic conditions. The velocity was expected to peak at approximately 55 km. As the vehicle falls lower than 55 km, the vehicle was expected to decelerate dramatically, causing the spacecraft to slow down to a velocity of 33.5 m/s at impact. This 33.5 m/s was the velocity that was used for impact testing.



(a) Overall estimated velocity profile

(b) Zoomed-in velocity profile

Figure 4.15: KOREVET velocity results using the KTMP code

ANSYS Analysis

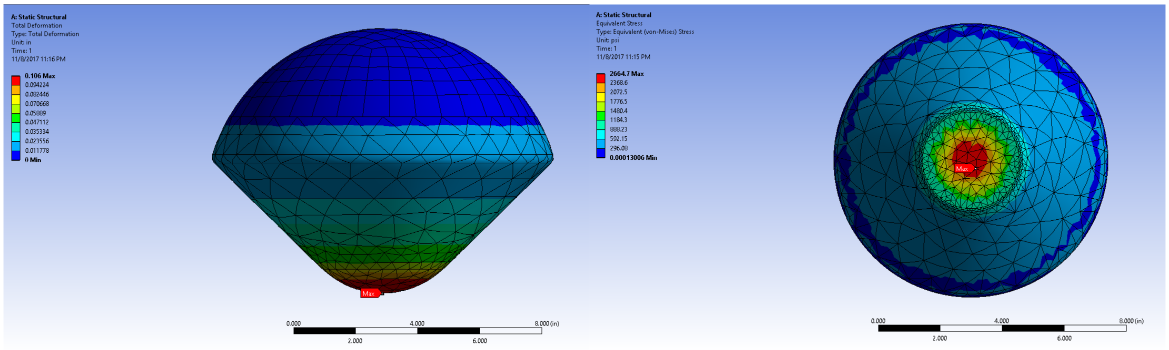
One concern raised from the KUDOS flight was the ability of the spacecraft to survive splashdown. For that flight, data packets were expected to be received after splashdown, but it was not the case. One of the reasons for this failure might have been that the vehicle did not survive. For the KUDOS flight, no analysis was performed prior to the flight to determine if the spacecraft would survive the impact forces caused by the vehicle hitting the water. This was tested for the KOREVET flight. It was decided that an impact test would be performed, but first an analysis was needed to calculate the test conditions.

The geometry of the Nylon internal housing and the cork TPS was modeled in ANSYS Workbench 18.2. The mesh was refined at the bottom surface of the TPS and internal housing structure. A fixed support was constrained to the top portion of the TPS and internal housing, while the impact force was applied to the bottom surface of the TPS. To determine the impact force, the following equation had to be considered:

$$F = \frac{mv^2}{2d}. \tag{4.1}$$

This equation was derived from the work equation ($W = Fd$). To provide the worst case scenario, the following inputs were used. Since the spacecraft was not expected to exceed 10 lbs, the mass (m) was set at 4.5 kg. The KTMP code projected the spacecraft to travel with a velocity of 33.5 m/s at splashdown, but the velocity (v) was set at 50 m/s. It was expected that the spacecraft would travel approximately 3 m into the ocean before floating back to the surface, so the displacement (d) was set at 1 m to make sure the team determined the highest expected impact force (F). With the approximate values implemented, the impact force was expected to be approximately 1,265 lbs. After setting the constraints of the model, ANSYS was set to output the deformation and the von Mises stress of the spacecraft. The results can be seen in Fig. 4.16.

Figure 4.16(a) shows the maximum deformation on the spacecraft occurs on the cork material on the fore-body. This location was where the maximum deformation was expected to take place. The figure also shows that the maximum deformation was approximately 0.106-inches, considered to be acceptable. Figure 4.16(b) shows the maximum von-mises stress occurs on the bottom surface of the internal housing structure. The impact force causes the Nylon material to experience a stress up to 2,700 psi. Nylon is easily able to withstand these conditions. Both of these results were based off worst case scenario calculations, and therefore show that the spacecraft



(a) Deformation of the TPS (b) Von-mises stress of the internal housing

Figure 4.16: ANSYS results regarding the capsule surviving splashdown

should withstand splashdown.

Another concern raised from the KUDOS flight was the ability of the spacecraft to self-stabilize. The CG for the KUDOS mission was calculated using the Creo Parametric software, but was not measured. For KOREVET, the CG was placed in the correct location by using the Creo Parametric software to stack the electronics in the capsule such that there were no interferences. After applying the appropriate densities to the items associated with the spacecraft, an estimate of the CG was obtained. The CG results can be visualized in Fig. 4.17. The cross lines located near the center of the spacecraft represents the CG location measured. The results showed that the CG in the x, y, and z axes, respectively, are 2.16×10^{-2}, 4.74, and 7.88×10^{-2} inches. These results follow the DeepSpace2 CG requirements. The y-axis CG location measured at $0.43D$, which was lower than the $0.44D$ requirement. After the theoretical CG was calculated, its location was measured as explained in the following section.

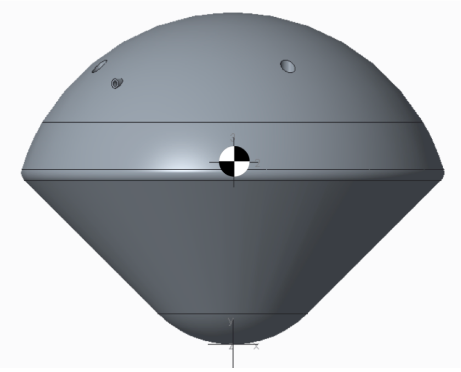


Figure 4.17: Visualization of the KOREVET spacecraft's CG

4.5 Testing Phase

Several tests, similar to the tests performed for the KUDOS mission, were conducted for the KOREVET mission. These tests included vibration tests, thermal-vacuum tests, communication tests, and full simulation tests[47]. The micro-gravity simulated test was excluded for this mission since it forced the capsule to be ejected along the straight line, and could not exactly replicate the actual environment. The tests that were added for the KOREVET mission included waterproof test, impact test, and spacecraft CG test.

The waterproof test was executed using the test spacecraft. This test involved the cork TPS, connected to the Nylon internal housing, floating in a pool of water for over 15 minutes. To determine if the inside of the spacecraft would become wet, humidity indicators were placed along the inside of the spacecraft and inspected afterwords. These humidity indicators change colors in a range that specifies the humidity level of the surrounding air. These were tested before the actual test to make sure they worked as expected. Figure 4.18 shows the capsule during the test, performed at the Aquatics Center at the University of Kentucky. During the test, multiple pictures were taken at different viewing angles. These pictures were sent to NASA Wallops Flight Facility so that they would know what to expect during the search for the capsule. The test ended up being a success, since it proved that the capsule was able to float in the water for the necessary duration of time without allowing moisture inside.

The impact test was also executed using the test spacecraft. This test involved the spacecraft being dropped from the top diving board height of the Aquatic Center. The top diving board was 10 meters from the water, which allowed the capsule to travel at a terminal velocity of almost half of that expected for the actual flight. This allowed the results of the test to give a reasonable expectation of what would happen during the actual flight. The distance traveled after splashdown and the ability of the spacecraft to stay waterproof and float were inspected with this test. A snapshot of the capsule hitting the water can be seen in Fig. 4.19. The test showed that the capsule traveled about half a meter through the water. Then, the capsule floated back to the surface of the water shortly after. The test also showed that the capsule was able to survive the impact forces, and it stayed waterproof post impact. Although this test was performed at half the expected velocity, it was reasonable to assume the capsule would perform similarly at full velocity.

The spacecraft's CG was measured using the flight spacecraft. This test involved

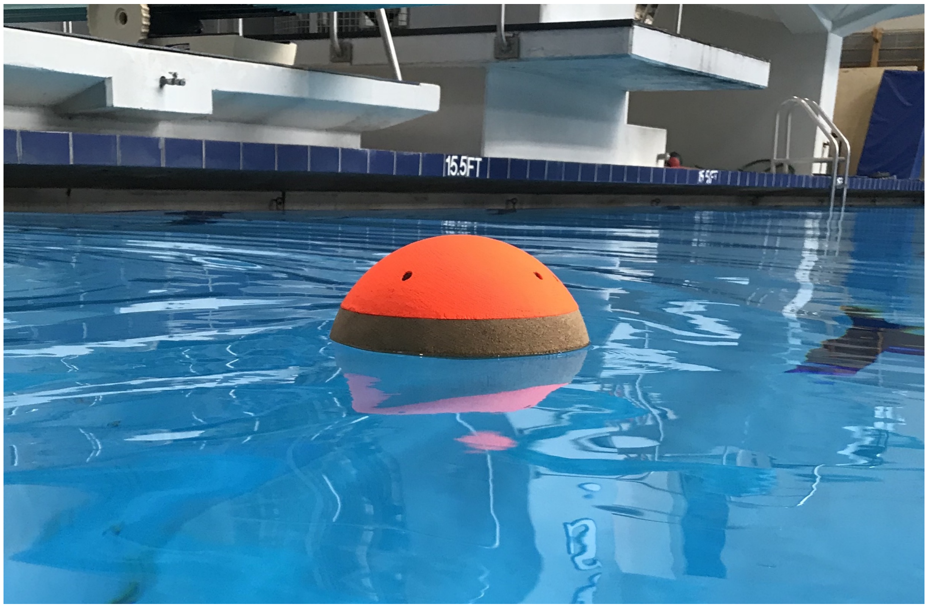


Figure 4.18: A picture taken during the waterproof test

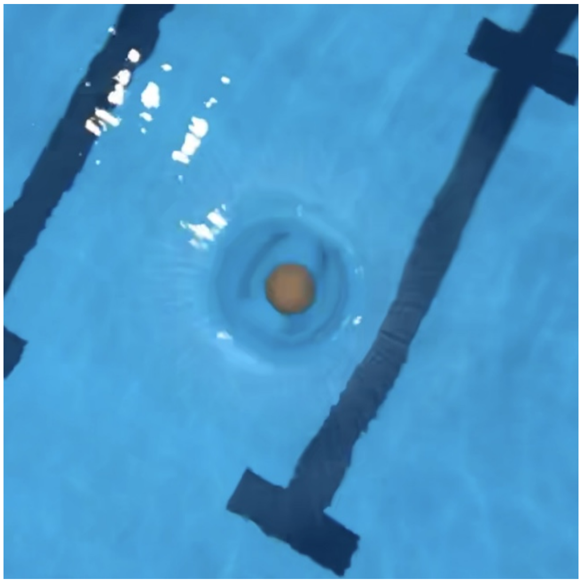


Figure 4.19: A snapshot taken during the impact test

having the spacecraft, with all electronics inside, inside a uniformly distributed box. Before the CG of the spacecraft was measured, the CG of the 12 × 12 × 12" box had to be measured. The material of the box used for this test was Medium Density Fiberboard (MDF). The box was machined such that the profile of the capsule was CNC milled out from the center of the box. Then, the CG of the box was measured using a 90° angle-iron. All three axes were balanced and measured on the angle-iron. Since it is very difficult to exactly balance the box on the edge of the angle-iron, the "balanced" position was measured at the point where it tilted one direction initially, then after barely moving the box, it would move the opposite direction. This method gave results that were deemed reasonable. After the CG of the box was measured, the weight of the box was measured. Then, the capsule was inserted in the box and the CG was measured again using the same methods. The weight was also measured again. This data was sufficient to calculate the CG location of the capsule. The data collected can be seen in Table 4.1. The middle (capsule) column of the table was calculated using the results from the other two columns. The results of this test showed that the CG of the capsule was $0.23D$, which is lower than the $0.44D$ maximum requirement. The CG analysis and test gave different results of $0.43D$ and $0.23D$ because adjustments were made to the internal housing, which caused the CG to drop. A picture of the CG test can be seen in Fig. 4.20.

Table 4.1: KOREVET CG results

	MDF	**Capsule**	**Both**
x axis (in)	5.967	5.612	5.910
y axis (in)	5.967	5.239	5.850
z axis (in)	5.470	2.744	5.032
weight (lbs)	27.32	5.23	32.55

4.6 Results

The success of the KOREVET mission relied on the ability to transmit the data to the Iridium satellites or retrieve the capsule. Unfortunately, no data packets were received. Unlike the KUDOS mission, the capsule did not try to connect with the Iridium satellites. The GPS coordinates were reliant on the fact that packets were going to be sent. Since there were no GPS coordinates transmitted, the capsule was never found. Even with the capsule after-body being painted bright orange, the

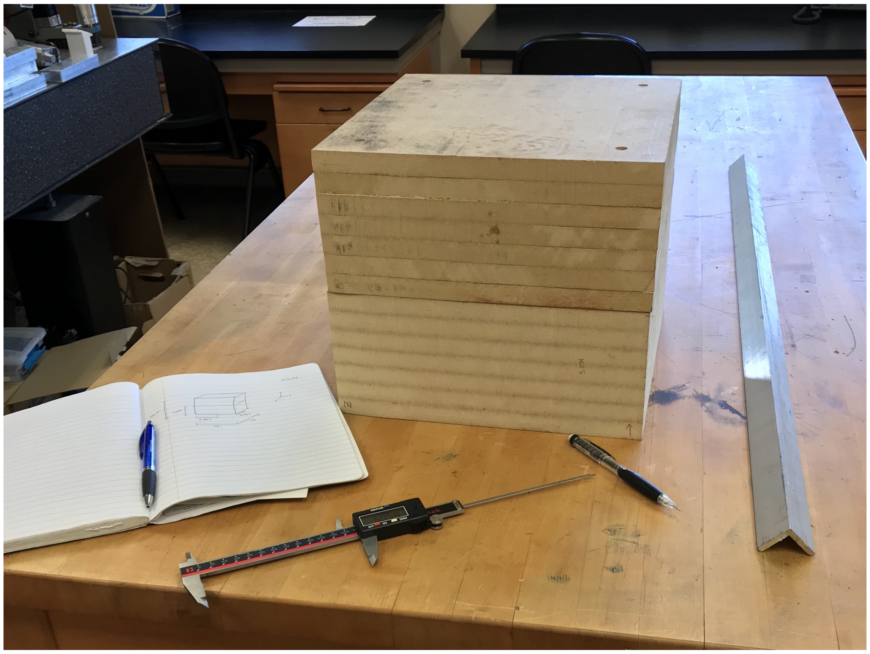


Figure 4.20: The setup used to measure the CG of the capsule

recovery team was unable to locate it in the ocean. This was due to there being much debris in the ocean that had the same color as the capsule's after-body.

Even though there were no data packets received with this mission, there were two cameras on-board to help determine how the other sub-systems performed. The experiment deck inside the rocket was recovered by NASA Wallops, allowing the video footage to be recovered from the cameras[48, 49]. The water and heat proof box used for this launch worked as expected. The memory cards were retrieved and after decrypting the file, the footage from both cameras were restored. The footage was corrupted when the camera was damaged during the descent. A code was created to decrypt and restore the video footage. Unfortunately, only 7 seconds of video was recovered by both cameras. It appears that there was a wiring issue on the GoPro board that sent current to the cameras when TE-2 was activated. This caused the cameras to ultimately turn back off 2 seconds after the TE-2 was activated. However, these 7 seconds of footage gave important information regarding the sub-systems. The videos were able to provide enough information to verify that the KREM was a successful design. A snapshot of the KOREVET experiment at 170 km (pre-ejection) can be seen in Fig. 4.21.

The main concern heading into the launch was the possibility that the doors would not open. During one of the full simulation tests performed at Wallops, the doors did not open when TE-2 was activated. This raised some concern, but adjustments were

Figure 4.21: Video screenshot before the capsule was ejected from KREM at rocket apogee (170 km)

made to the solenoid rod location to increase the chances of the doors opening. The doors not opening may have been a rocket power supply issue, or the capsule could have been pressing the doors too tight, which would cause the solenoid to be too weak to pull. Fortunately, the video verified that the doors opened as expected. The video also showed that the adjustments that were made to ensure that the capsule would stay in place were a success. The video captured by the back camera verified that the capsule did not shift as the doors were opening. Even though the cameras did not capture the ejection of the capsule, the updates that were made to the KREM showed to be successful updates. The 7 seconds of camera footage were able to discharge the main worries. Therefore, the full-scale KREM design can be used again for similar sounding rocket flights with a high level of confidence. Only small changes need to be made to the KREM moving forward.

4.7 Conclusion

The KOREVET mission was launched in March 2018. Adjustments learned from the KUDOS mission were made to the sub-systems to allow a better chance of obtaining data. All sub-systems were scaled up since the size of the capsule changed from 7.5-inch diameter to 11-inch diameter. Since the same rocket was used for this mission, size constraints played a significant role in the design of KREM. After adjustments were made, a well-tested full-scale KREM was ready for flight. This second mission had the KRUPS capsule ejected at an altitude of ∼170 km. This mission verified the full-scale design for most sub-systems. However, no data packets were received with this mission. This caused the TRL of the project to stay at level 5, since the whole system was not verified. Even though the overall TRL of the project did not improve with this mission, a lot of the individual sub-systems were improved. This mission allowed the full-scale KRUPS experiment to be tested, which proved to be a bigger achievement than originally thought.

Chapter 5 Conclusion

The KRUPS project has performed two sub-orbital flights (KUDOS and KOREVET) to develop, test, and improve the technology testbed. KRUPS is expected to become a low-cost experimental testbed, validating atmospheric entry experiments[50, 51, 52, 53, 54, 55, 56] and instruments[57, 58, 59], and providing flight validation data. With these flights, the KRUPS project was able to improve from Technology Readiness Level (TRL) 4 to TRL 5. The project is close to getting to TRL 6, which can be achieved by successfully testing the entire system in a micro-gravity environment. During these flights, collecting thermocouple data was the main experiment on-board.

The KUDOS mission, which was launched in August 2017, was the first attempt to test the experiment in a micro-gravity environment. The first KRUPS capsule, 7.5-inch diameter, was ejected at an altitude of ∼150 km. During this mission, several sub-systems were tested, and the TRL of the project was raised to level 5. The KREM sub-system was determined to be a reliable method of powering and releasing the capsule. The capsule momentarily connected to the Iridium satellites, but no data packets were received. Nevertheless, the KUDOS mission was deemed a success, and paved the way for the next flight[46]. This mission ultimately acted as a mitigation flight for the full-scale mission – KOREVET.

The KOREVET mission was launched in March 2018. Adjustments, learned from the KUDOS mission, were made to the sub-systems to allow a better chance of obtaining data. All sub-systems had to be scaled up since the size of the capsule changed from 7.5-inch diameter to 11-inch diameter. Since the same rocket was used for this mission, size constraints played a significant role in the design of KREM. After adjustments were made, a well-tested full-scale KREM was ready for flight. The second KRUPS capsule was ejected at an altitude of ∼170 km. This mission verified the full-scale design for most sub-systems. However, no data packets were received with this mission. This caused the TRL of the project to stay at level 5, since the whole system was not verified. Even though the overall TRL of the project did not improve with this mission, a lot of the individual sub-systems were improved. This mission allowed the full-scale KRUPS experiment to be tested, which proved to be a bigger achievement than originally thought.

Moving forward, the students involved with KRUPS can build from what was accomplished with the KOREVET mission. Scaling and re-designing sub-systems will no longer be a troubling task for upcoming missions. These two missions were necessary and played a pivotal role in getting to the ultimate goal. It is expected that the lessons learned from both of these flights will result in multiple orbital missions (to be launched in the near future). The success of such missions would result in a low-cost validation approach for atmosphere entry experiments and instruments.

5.1 Original contribution

A list of original contributions to the KRUPS project is outlined in this section.

1. **The KRUPS Rocket Ejection Mechanism (KREM) was designed and built for both missions.** There were no existing release mechanisms that could safely hold the KRUPS vehicle in place during launch and eject once the experiment reached apogee. For KUDOS, six concepts were designed and narrowed down such that the best design was implemented into the system. There was constant improvement to KREM as testing was done, such as weight reduction in the side panels and replacing vibration isolation dampers with smaller dampers. The increase vehicle size and the lessons learned from KUDOS called for a new design for KOREVET's KREM. Significant improvements were made to KREM, such as the taller filler material being added and a more sturdy connection from KREM to the vehicle.

2. **Analysis was computed for both missions to ensure the vehicle would survive the entire mission.** There was research conducted previously to get an estimate on the heat flux expected with sub-orbital flights. However, there were no tests done with the exact profile (vehicle and mission) that correlated to KUDOS and KOREVET. The updated Kentucky Trajectory Modeling Program (KTMP) provided estimated heat flux and velocity results, which played a pivotal role in the determination of TPS material.

   Since there were no existing release mechanisms designed for a vehicle like KRUPS, ANSYS simulations provided results to confirm that the KREM and KRUPS would survive the violent conditions of launch, and that KRUPS would survive splashdown. There were ANSYS simulations to verify that KREM would not buckle during launch, KREM and KRUPS could survive the stress expected with launch, KRUPS would not be damaged due to the impact of the solenoid, and ensure that KRUPS would remain intact after splashdown.

3. **Led an undergraduate multi-disciplinary engineering team for both missions.** KRUPS included disciplines other than just mechanical engineering. KRUPS balanced between mechanical engineering, computer engineering, and computer science. Mechanical engineering students focused on producing KREM and the KRUPS vehicle. The computer engineering student focused on producing the KREM electronic board, as well as producing the on-board electronics that fit inside the vehicle. The computer science student focused on programming the vehicle in such a way that it could transmit data packets through the Iridium satellites at a fast rate. In order for a complex system to move together as one, a System's Engineering approach was used. The System's Engineering approach allowed for each discipline to give an update as goals are met. Knowing the progress of each discipline allowed all disciplines to converge together smoothly when the sub-systems were combined into a single system.

4. **NASA reviews were composed and presented to gain feedback from professionals.** NASA review meetings are part of the System's Engineering approach. The reviews started from concept development and ended just before launch week. The reviews consisted of PowerPoint slides that gave in-depth details of the progress up to certain points. Each set of slides built off of one another as the project moved forward. The reviews were presented to a NASA panel once every month or two to show progress of the experiment. Most of the time, the reviews were given via teleconference, but the Critical Design Review (CDR) for KOREVET was given in front of a NASA panel at ILC Dover. Each review was helpful and necessary because questions and concerns were addressed such that improvements could be made to the system.

5.2 Future work

The initial plan for the KRUPS project was to perform two sub-orbital missions (KUDOS and KOREVET) to prepare for an orbital flight, released from the International Space Station (ISS). This was the scenario if KRUPS was successfully tested in a micro-gravity environment, changing the TRL to TRL 6. Instead, the two sub-orbital flights were able to successfully test most of our sub-systems, but not all. The two flights allowed the TRL of the project to advance to TRL 5. The KRUPS project is therefore not entirely ready for the orbital flight missions.

The RockSat-X program was the program used for the KUDOS mission. If there is room available, KRUPS would require about 16-inches of height. KRUPS would require to be on the bottom of the experiment deck, similar to the layout of the KOREVET flight. This is a necessary requirement to perform another full-scale test. During this next mission, adjustments can be made to the individual sub-systems to improve the quality of the experiment. With this being said, the main focus of the next experiment is to make sure the communications system sends data packets. This has been the key sub-system that has not been successful.

With the other sub-systems verified, a lot of focus can be put into the communications system. There are a few methods that need to be taken to make sure that this problem gets fixed. The first method that is currently being pursued, is to talk to the Iridium experts at NASA Wallops. It was explained that during their first 3-4 missions using Iridium, they were unable to connect with the Network (same as us). After adjusting the system, they were able to get reliable connection with Iridium ever since. Therefore, it is key to get more information from them on ways that we could adjust our system to give us the best chance of data transmission. Another step that needs to be taken for the next mission is to recruit more electrical/computer engineering and computer science students. During both of these missions, there were only 2-3 students working on the communications system. Having more students involved in this part of the experiment would mean that more hours would be put into the system, thus giving a higher chance of success. Another step that would help the project succeed is to recruit a communications mentor for the students. It is preferred that this mentor has experience with transmitting via satellites (possibly with cube-sats). The mentors and the students could set up a weekly or bi-weekly meeting to go over designs, analysis, and tests. With this being said, recruiting a mechanical mentor would be helpful as well. This mentor could assist with verifying that the capsule is being designed as intended and the KREM design is ready for space.

After the next sub-orbital mission is deemed successful, the project would be at TRL 6. This completely successful mission would allow the experiment to be considered for a deployment from the ISS. A successful mission from the ISS would allow for more KRUPS capsules to be tested. With multiple successful missions from the ISS, the KRUPS project would attempt to implement other experiments instead of collecting only thermocouple data. The capsule would be ready to test other sensors and perform other experiments. An updated TRL timeline of the KRUPS project can be seen in Fig. 5.1.

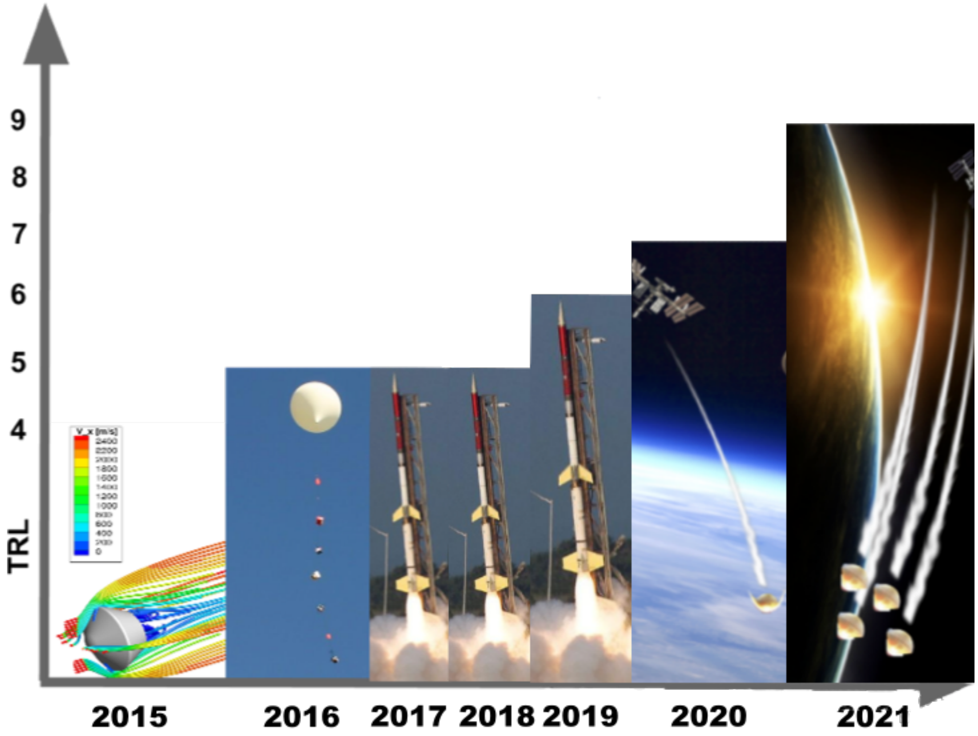


Figure 5.1: The updated TRL overview of the KRUPS project

Bibliography

[1] Laub, B. and Venkatapathy, E., "Thermal protection system technology and facility needs for demanding future planetary missions," *Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science*, edited by A. Wilson, Vol. 544 of *ESA Special Publication*, Feb. 2004, pp. 239–247.

[2] Dunbar, B., "NASA Ames Helps Re-enter the Dragon," .

[3] Seiff, A., Reese, D. E., Sommer, S. C., Kirk, D. B., Whiting, E. E., and Niemann, H. B., "PAET, an entry probe experiment in the Earth's atmosphere," *Icarus*, Vol. 18, No. 4, 1973, pp. 525 – 563.
doi:https://doi.org/10.1016/0019-1035(73)90058-4

[4] Braun, R. D., Mitcheltree, R. A., and Cheatwood, F. M., "Mars Microprobe entry analysis," *1997 IEEE Aerospace Conference*, Vol. 1, Feb 1997, pp. 247–262 vol.1.
doi:10.1109/AERO.1997.574416

[5] "Debris landed in Texas," .

[6] Weaver, M. A. and Ailor, W. H., "Reentry Breakup Recorder: Concept, Testing, Moving Forward," *AIAA Space 2012 Conference and Exposition*, AIAA Paper 2012-5271, Pasadena, CA, Sep 2012.
doi:10.2514/6.2012-5271

[7] Sidor, A. T., Braun, R. D., and DePasquale, D., "RED-Data2 Commercial Reentry Recorder: Size Reduction and Improved Electronics Design," *AIAA Atmospheric Flight Mechanics Conference*, AIAA Paper 2014-1231, National Harbor, MD, January 2014 2014.
doi:102514/6.2014-1231

[8] "Returning from Space: Re-entry," .

[9] Bowman, W. H. and Lawrence, R. M., "Ablative materials for high-temperature thermal protection of space vehicles," *Journal of Chemical Education*, Vol. 48, No. 10, October 1971, pp. 690–691.
doi:10.1021/ed048p690

[10] Davuluri, R. S. C., *Modeling of Spallation Phenomenon in an arc-jet environment*, M.Sc. Thesis, University of Kentucky, Lexington, KY, May 2015.

[11] Martin, A. and Boyd, I. D., "Strongly coupled computation of material response and nonequilibrium flow for hypersonic ablation," *Journal of Spacecraft and Rockets*, Vol. 52, No. 1, Jan. 2015, pp. 89–104.
doi:10.2514/1.A32847

[12] Martin, A. and Boyd, I. D., "Non-Darcian behavior of pyrolysis gas in a thermal protection system," *Journal of Thermophysics and Heat Transfer*, Vol. 24, No. 1, Jan.–Mar. 2010, pp. 60–68.
doi:10.2514/1.44103

[13] Martin, A. and Boyd, I. D., "Modeling of heat transfer attenuation by ablative gases during the Stardust re-entry," *Journal of Thermophysics and Heat Transfer*, Vol. 29, No. 3, Jul. 2015, pp. 450–466.
doi:10.2514/1.T4202

[14] Martin, A., Cozmuta, I., Boyd, I. D., and Wright, M. J., "Kinetic rates for gas phase chemistry of phenolic based carbon ablator decomposition in atmospheric air," *Journal of Thermophysics and Heat Transfer*, Vol. 29, No. 2, Apr. 2015, pp. 222–240.
doi:10.2514/1.T4184

[15] Martin, A., Scalabrin, L. C., and Boyd, I. D., "High performance modeling of an atmospheric re-entry vehicles," *Journal of Physics: Conference Series*, Vol. 341, No. 1, Feb. 2012, Article 012002.
doi:10.1088/1742-6596/341/1/012002

[16] Boyd, I. D., Martin, A., Wiebenga, J. E., and Jenniskens, P., "Hypersonic Flow and Radiation Analysis of the Automated Transfer Vehicle "Jules Verne"," *Journal of Spacecraft and Rockets*, Vol. 50, No. 1, Jan.–Feb. 2013, pp. 124–136.
doi:10.2514/1.A32208

[17] Farbar, E. D., Boyd, I. D., and Martin, A., "Numerical Prediction of Hypersonic Flow Fields Including Effects of Electron Translational Nonequilibrium," *Journal of Thermophysics and Heat Transfer*, Vol. 27, No. 4, Oct.–Dec. 2013, pp. 593–606.
doi:10.2514/1.T3963

[18] Alkandry, H., Boyd, I. D., and Martin, A., "Comparison of Transport Properties Models for Flowfield Simulations of Ablative Heat Shields," *Journal of Thermophysics and Heat Transfer*, Vol. 28, No. 4, Oct. 2014, pp. 569–582.
doi:10.2514/1.T4233

[19] Fu, R., Weng, H., Wenk, J. F., , and Martin, A., "Thermo-mechanical coupling for charring ablators," *Journal of Thermophysics and Heat Transfer*, Vol. 32, No. 2, April 2018, pp. 369–379.
doi:10.2514/1.T5194

[20] Weng, H. and Martin, A., "Multidimensional modeling of pyrolysis gas transport inside charring ablative materials," *Journal of Thermophysics and Heat Transfer*, Vol. 28, No. 4, Oct.–Dec. 2014, pp. 583–597.
doi:10.2514/1.T4434

[21] Weng, H. and Martin, A., "Numerical Investigation of Thermal Response Using Orthotropic Charring Ablative Material," *Journal of Thermophysics and Heat Transfer*, Vol. 29, No. 3, July 2015, pp. 429–438.
doi:10.2514/1.T4576

[22] Omidy, A. D., Panerai, F., Lachaud, J. R., Mansour, N. N., and Martin, A., "Effects of water phase change on the material response of low density carbon phenolic ablators," *Journal of Thermophysics and Heat Transfer*, Vol. 30, No. 2, Apr. 2016, pp. 472–477.
doi:10.2514/1.T4814

[23] Martin, A., Bailey, S. C. C., Panerai, F., Davuluri, R. S. C., Vazsonyi, A. R., Zhang, H., Lippay, Z. S., Mansour, N. N., Inman, J. A., Bathel, B. F., Splinter, S. C., and Danehy, P. M., "Numerical and experimental analysis of spallation phenomena," *CEAS Space Journal*, Vol. 8, No. 3, Sep. 2016, pp. 229–236.
doi:10.1007/s12567-016-0118-4

[24] Nouri, N., Panerai, F., Tagavi, K. A., Mansour, N. N., and Martin, A., "Evaluation of the anisotropic radiative conductivity of a low-density carbon fiber material from realistic microscale imaging," *International Journal of Heat and Mass Transfer*, Vol. 95, Apr. 2016, pp. 535–539.
doi:10.1016/j.ijheatmasstransfer.2015.12.004

[25] Nouri, N. and Martin, A., "Three dimensional radiative heat transfer model for the evaluation of the anisotropic effective conductivity of fibrous materials,"

International Journal of Heat and Mass Transfer, Vol. 83, Apr. 2015, pp. 629–635.
doi:10.1016/j.ijheatmasstransfer.2014.12.041

[26] Zhang, H., *High Temperature Flow Solver for Aerothermodynamics Problems*, Ph.D. thesis, University of Kentcuky, 2015.

[27] *Survey of the Supporting Research and Technology for the Thermal Protection of the Galileo Probe*, American Institute of Aeronautics and Astronautics, 2018/07/16 1982, pp. 293–327.
doi:doi:10.2514/5.9781600865565.0293.0327

[28] Lee, D. B., "Apollo experience report: Aerothermodynamics evaluation," Technical Note NASA-TN-D-6843, NASA Johnson Space Center, 1972.
doi:2060/19720018273

[29] Mahzari, M., Braun, R. D., and White, T., "Reconstruction of Mars Pathfinder Aeroheating and Heat Shield Response Using Inverse Methods," *Journal of Spacecraft and Rockets*, Vol. 50, No. 6, November–December 2013, pp. 1171–1182.
doi:10.2514/1.A32462

[30] Bose, D., White, T., Mahzari, M., and Edquist, K., "Reconstruction of Aerothermal Environment and Heat Shield Response of Mars Science Laboratory," *Journal of Spacecraft and Rockets*, Vol. 51, No. 4, November–December 2014, pp. 1174–1184.
doi:10.2514/1.A32783

[31] Cichan, T., Norris, S. D., and Marshall, P., "Orion: EFT-1 Flight Test Results and EM-1/2 Status," *AIAA SPACE 2015 Conference and Exposition*, AIAA Paper 2015-4414, Pasadena, CA, Aug 2015.
doi:10.2514/6.2015-4414

[32] Weaver, M. A. and Ailor, W., "REBR: An Innovative, Cost-Effective System for Return of Reentry Data," *AIAA SPACE 2007 Conference and Exposition*, AIAA Paper 2007-6222, Long Beach, CA, September 2007.
doi:10.2514/6.2007-6222

[33] Empey, D., Swanson, G., Winter, M., Venkatapathy, E., Prabhu, D., Peterson, K., Agrawal, P., Skokova, K., Gorbunov, S., and Mangimi, N., "Small Probe

Reentry Investigation for TPS Engineering (SPRITE)," *50th AIAA Aerospace Sciences Meeting*, AIAA Paper 2012-0215, January 9-12 2012.
doi:10.2514/6.2012-215

[34] Prabhu, D., "Flowfield Analysis of a Small Entry Probe (SPRITE) Tested in an Arc Jet," *50th AIAA Aerospace Sciences Meeting*, AIAA Paper 2012-216, Nashville, TN, January 2012.
doi:10.2514/6.2012-216

[35] Sidor, A. T., Anderson, T. R., and Braun, R. D., "Small Probe Flight Testing of Thermal Protection Systems in Simulated Earth Entries," *54th AIAA Aerospace Sciences Meeting*, AIAA Paper 2016-2193, San Diego, CA, January 2016.
doi:10.2514/6.2016-2193

[36] Sakraker, I., *Aerothermodynamics of Pre-Flight and In-Flight Testing Methodologies for Atmospheric Entry Probes*, Phd thesis, Université de Liège and von Karman Institute for Fluid Dynamics, Liège, Belgium, February 2016.
doi:2268/194601

[37] Chris Koehler, G. R. J., *RockSat-X Users Guide*, Colorado Space Grant Consortium, Discovery Learning Center Room 270, Boulder, Colorado 80309, 8th ed., July 2016.

[38] Smrekar, S., Catling, D., Lorenz, R., Magalhães, J., Moersch, J., Morgan, P., Murray, B., Presley, M., Yen, A., Zent, A., et al., "Deep Space 2: The Mars Microprobe Mission," *Journal of Geophysical Research: Planets*, Vol. 104, No. E11, 1999, pp. 27013–27030.
doi:10.1029/1999JE001073

[39] Zhang, H., *High Temperature Flow Solver For Aerothermodynamics Problems*, Ph.D. Thesis, University of Kentucky, Lexington, KY, July 2015.

[40] Davuluri, R. S. C., Zhang, H., and Martin, A., "Numerical study of spallation phenomenon in an arc-jet environment," *Journal of Thermophysics and Heat Transfer*, Vol. 30, No. 1, Jan. 2016, pp. 32–41.
doi:10.2514/1.T4586

[41] Li, Z., Zhang, H., Bailey, S. C., Hoagg, J. B., and Martin, A., "A Data-Driven RANS k-w approach for modeling turbulent flows," *Journal of Computational*

Physics, Vol. 345, September 2017, pp. 111–131.
doi:10.1016/j.jcp.2017.05.009

[42] Duzel, U., Schroeder, O. M., and Martin, A., "Computational Prediction of NASA Langley HYMETS Arc Jet Flow with KATS," *56th AIAA Aerospace Sciences Meeting*, AIAA 2018-1719, Kissimmee, FL, Jan 2018.
doi:10.2514/6.2018-1719

[43] Cooper, J. M., Stieha, J. K., Fowler, A. M., Wright, N. A., and Martin, A., "Kentucky Re-entry Universal Payload System," *54th AIAA Aerospace Sciences Meeting*, AIAA Paper 2016-2192, San Diego, CA, January 2016.
doi:10.2514/6.2016-2192

[44] "Back camera space footage for University of Kentucky project," Aug 2017.

[45] "Door camera space footage for University of Kentucky project," Aug 2017.

[46] Sparks, J. D., Myers, G. I., Whitmer, E. C., Nichols, J. T., Dietz, C. J., Khouri, N., Smith, S. W., and Martin, A., "Overview of the second test-flight of the Kentucky Re-entry Universal Payload System (KRUPS)," *12th AIAA/ASME Joint Thermophysics and Heat Transfer Conference*, AIAA Paper 2018-3589, Atlanta, GA, June 2018.
doi:10.2514/6.2018-3589

[47] Sparks, J. D., Whitmer, E. C., Myers, G. I., Montague, C. C., Dietz, C. J., Khouri, N., Nichols, J. T., Smith, S. W., and Martin, A., "Overview of the first test-flight of the Kentucky Re-entry Universal Payload System (KRUPS)," *56th AIAA Aerospace Sciences Meeting*, AIAA Paper 2018-1720, Kissimmee, FL, Jan 2018.
doi:10.2514/6.2018-1720

[48] "Lid video footage for KRUPS second sub-orbital flight mission," May 2018.

[49] "Back view video footage for KRUPS second sub-orbital flight mission," May 2018.

[50] Ferguson, J. C., Panerai, F., Bailey, S. C. C., Lachaud, J. R., Martin, A., and Mansour, N. N., "Modeling the oxidation of low-density carbon fiber material based on micro-tomography," *Carbon*, Vol. 96, Jan. 2016, pp. 57–65.
doi:10.1016/j.carbon.2015.08.113

[51] Panerai, F., Ferguson, J. C., Lachaud, J. R., Martin, A., Gasch, M. J., and Mansour, N. N., “Analysis of rigid and flexible substrates for lightweight ablators based on X-ray micro-tomography,” *International Journal of Heat and Mass Transfer*, Vol. 108, Part A, May 2017, pp. 801–811.
doi:10.1016/j.ijheatmasstransfer.2016.12.048

[52] Panerai, F., White, J. D., Cochell, T. J., Schroeder, O. M., Mansour, N. N., Wright, M. J., and Martin, A., “Experimental measurements of the permeability of fibrous carbon at high temperature,” *International Journal of Heat and Mass Transfer*, Vol. 101, Oct. 2016, pp. 267–273.
doi:10.1016/j.ijheatmasstransfer.2016.05.016

[53] Panerai, F., Martin, A., Mansour, N. N., Sepka, S. A., and Lachaud, J., “Flow-Tube Oxidation Experiments on the Carbon Preform of a Phenolic-Impregnated Carbon Ablator,” *Journal of Thermophysics and Heat Transfer*, Vol. 27, No. 2, Apr. 2014, pp. 181–190.
doi:10.2514/1.T4265

[54] Bailey, S. C. C., Bauer, D., Panerai, F., Splinter, S. C., Danehy, P. M., Hardy, J. M., and Martin, A., “Experimental analysis of spallation particle trajectories in an arc-jet environment,” *Experimental Thermal and Fluid Science*, Vol. 93, May 2018, pp. 319–325.
doi:10.1016/j.expthermflusci.2018.01.005

[55] Miller, M. A., Martin, A., and Bailey, S. C. C., “Investigation of the scaling of roughness and blowing effects on turbulent channel flow.” *Experiments in Fluids*, Vol. 55, No. 2, Feb. 2014, pp. 1–11, Article 1675.
doi:10.1007/s00348-014-1675-y

[56] Borchetta, C. G., Martin, A., and Bailey, S. C. C., “Examination of the Effect of Blowing on the Near-Surface Flow Structure over a Dimpled Surface,” *Experiments in Fluids*, Vol. 59, No. 3, March 2017, pp. Article 36.
doi:10.1007/s00348-018-2498-z

[57] Gazaric, M., Wright, M., Little, A., Cheatwood, F. M., Herath, J., Munk, M., Novak, F., and Martinez, E., “Overview of the MEDLI Project,” *Aerospace Conference, 2008 IEEE*, No. IEEE Paper 2008-1510, Big Sky, MT, 3-10 March 2008, pp. 1–12.
doi:10.1109/AERO.2008.4526285

[58] Brandis, A. M., Johnston, C. O., and Cruden, B. A., “Non-equilibrium Radiation for Earth Entry,” *46th AIAA Thermophysics Conference*, AIAA Paper 2016-3690, Washington, D.C., June 2016.
doi:10.2514/6.2016-3690

[59] Cruden, B. A., Brandis, A. M., and Johnston, C. O., “Development of a Radiative Heating Margin Policy for Lunar Return Missions,” *55th AIAA Aerospace Sciences Meeting*, AIAA Paper 2017-1370, Grapevine, TX, January 2017.
doi:10.2514/6.2017-1370

Vita

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Education

University of Kentucky	Lexington, KY
Master of Science in Mechanical Engineering/Systems Engineering	Aug 2017 – Present

- Outstanding Masters Student — GPA: 3.83

University of Kentucky	Lexington, KY
Bachelor of Science in Mechanical Engineering	Aug 2015 – May 2017

- Magna Cum Laude — GPA: 3.86

Morehead State University	Morehead, KY
Bachelor of Science in Physics	Aug 2012 – May 2017

- Magna Cum Laude — GPA: 3.80

Honors & Awards

Dean's List	University of Kentucky: 2015 – 2017

- The award is awarded to students that earn a grade point average of 3.6 or higher while taking 12 credits or more in that semester.

University Scholars Program (USP) Student	University of Kentucky: 2016

- USP is a single continuous program culminating in both a baccalaureate and a masters degree.

Cummins Award	University of Kentucky: 2017

- The award is awarded to the best Mechanical Engineering Senior Design Group at the end of the year.

Publications

Archival Journal Papers

[1] Sparks, J. D., Whitmer, E. C., Myers, G. I., Montague, C. C., Dietz, C. J., Khouri, N., Nichols, J. T., Smith, S. W., and Martin, A., "Overview of the first test-flight of

the Kentucky Re-entry Universal Payload System (KRUPS)," *Journal of Spacecraft and Rockets*, 2018, In preparation.

Archival Conference Papers

[1] Sparks, J. D., Myers, G. I., Whitmer, E. C., Nichols, J. T., Dietz, C. J., Khouri, N., Smith, S. W., and Martin, A., "Overview of the second test-flight of the Kentucky Re-entry Universal Payload System (KRUPS)," *12th AIAA/ASME Joint Thermophysics and Heat Transfer Conference*, AIAA Paper 2018- xxxx, Atlanta, GA, June 2018, Accepted.

[2] Sparks, J. D., Whitmer, E. C., Myers, G. I., Montague, C., Dietz, C. J., Khouri, N., Nichols, J. T., Smith, S. W., and Martin, A., "Overview of the first test-flight of the Kentucky Re-entry Universal Payload System (KRUPS)," *56th AIAA Aerospace Sciences Meeting*, AIAA Paper 2018-1720, Kissimmee, FL, Jan 2018.

Referred Conference Abstracts

[1] Setters, C. E., Sparks, J. D., Schroeder, O. M., Cooper, J. M., and Martin, A., "CFD Modeling for KRUPS's KOREVET Launch," *43rd AIAA Dayton-Cincinnati Aerospace Sciences Symposium (DCASS)*, No. 43DCASS-120, Dayton, OH, Feb 2018.

[2] Sparks, J. D., Myers, G. I., Setters, C. E., Smith, S. W., and Martin, A., "The Kentucky Re-entry Universal Payload System (KRUPS): The Experimental Testbed," *43rd AIAA Dayton-Cincinnati Aerospace Sciences Symposium (DCASS)*, No. 43DCASS-133, Dayton, OH, Feb 2018.

[3] Setters, C. E., Sparks, J. D., Schroeder, O. M., Cooper, J. M., and Martin, A., "Validation of KATS CFD with Flight Data from KRUPS's KUDOS Launch," *Book of Abstracts - 9th Ablation Workshop*, Bozeman, MT, Aug 2017.

[4] Sparks, J. D., Whitmer, E. C., Setters, C. E., Myers, G. I., Cooper, J. M., Martin, A., and Smith, S. W., "The Kentucky Re-entry Spacecraft (KRUPS) for TPS Testing: Overview of SRF-1," *Book of Abstracts - 9th Ablation Workshop*, Bozeman, MT, Aug 2017.

[5] Sparks, J. D., Whitmer, E., Myers, G., Montague, C., Smith, S. W., and Martin, A., "Process of Providing a Small-Payload Return from International Space Station," *42nd Dayton-Cincinnati Aerospace Sciences Symposium*, No. 42DCASS-085, Dayton, OH, Mar 2017.

Conference Presentations

[1] Sparks†, J. D., Myers, G. I., Nichols, J. T., Whitmer, E. C., Khouri, N., Dietz, C. J., Smith, S. W., and Martin, A., "Kentucky Re-entry Universal Payload System (KRUPS): Sub-orbital Flights," *15th International Planetary Probe Workshop*, Boulder, CO, June 2018.

[2] Myers†, G. I., Sparks†, J. D., Khouri, N., Nichols, J. T., Whitmer, E. C., Smith, S. W., and Martin, A., “Technology Development for the Kentucky Re-entry Universal Payload System,” *National Council of Space Grant Director’s conference*, Washington, D.C., Mar 2018.

[3] Setters†, C. E., Sparks, J. D., Schroeder, O. M., Cooper, J. M., and Martin, A., “CFD Modeling for KRUPS’s KOREVET Launch,” *43rd AIAA Dayton-Cincinnati Aerospace Sciences Symposium (DCASS)*, No. 43DCASS-120, Dayton, OH, Feb 2018.

[4] Sparks†, J. D., Myers, G. I., Setters, C. E., Smith, S. W., and Martin, A., “The Kentucky Re-entry Universal Payload System (KRUPS): The Experimental Testbed,” *43rd AIAA Dayton-Cincinnati Aerospace Sciences Symposium (DCASS)*, No. 43DCASS-133, Dayton, OH, Feb 2018.

[5] Sparks, J. D., Whitmer, E. C., Myers, G. I., Montague, C. C., Dietz, C. J., Khouri, N., Nichols, J. T., Smith, S. W., and Martin, A., “Overview of the first test-flight of the Kentucky Re-entry Universal Payload System (KRUPS),” *56th AIAA Aerospace Sciences Meeting*, AIAA Paper 2018-1720, Kissimmee, FL, Jan 2018, Presented by Olivia M. Schroeder†.

[6] Sparks†, J. D., Whitmer, E. C., Setters, C. E., Myers, G. I., Cooper, J. M., Martin, A., and Smith, S. W., “The Kentucky Re-entry Spacecraft (KRUPS) for TPS Testing: Overview of SRF-1,” *9th Ablation Workshop*, Bozeman, MT, Aug 2017.

[7] Sparks†, J. D., Whitmer, E., Myers, G., Montague, C., Smith, S. W., and Martin, A., “Process of Providing a Small-Payload Return from International Space Station,” *42nd Dayton-Cincinnati Aerospace Sciences Symposium*, No. 42DCASS-085, Dayton, OH, Mar 2017.

Posters

[1] Myers, G. I., Sparks, J. D., Khouri, N., Nichols, J. T., Whitmer, E. C., Smith, S. W., and Martin, A., “Technology Development for the Kentucky Re-entry Universal Payload System,” poster, *National Council of Space Grant Director’s conference*, Washington, D.C., Mar 2018.

[2] Setters, C. E., Sparks, J. D., Schroeder, O. M., Cooper, J. M., and Martin, A., “Validation of KATS CFD with Flight Data from KRUPS’s KUDOS Launch,” poster, *9th Ablation Workshop*, Bozeman, MT, Aug 2017.

[3] Sparks, J. D., Cooper, J. M., Schroeder, O. M., Owen, J., Meek, C., Setters, C. E., Whitmer, E., “The Kentucky Re-entry Spacecraft (KRUPS) for TPS Testing: Overview of SRF-1,” poster, *14th International Planetary Probe Workshop*, The Hague, Netherlands, June 2017.

[4] Sparks, J. D., Whitmer, E., Myers, G., Montague, C., Smith, S. W., and Martin, A., “Process of Providing a Small-Payload Return from International Space Station,” poster,

University of Kentucky Mechanical Engineering Graduate Poster Competition, Lexington, KY, Mar 2017.

Experience

University of Kentucky — Lexington, KY
System Engineer Graduate Student — Aug. 2016 – May 2018
Project: Kentucky Re-entry Universal Payload System (KRUPS)

- Implemented the Systems Engineering approach to a NASA project by preparing the Concept Design Review (CoDR), Preliminary Design Review (PDR), Critical Design Review (CDR), and other reviews necessary for a successful mission.

Spurlock Power Station — Maysville, KY
Student Mechanical Engineer — May 2014 – Jan. 2016

- Managed project scope, schedule, and cost for a $500,000 project.

Involvement

KREM — University of Kentucky
Member — Aug. 2016 – May 2017

- Obtained teamwork experience by working in a group of five mechanical engineering students.
- Contributed to the design and build of a release mechanism that would push a capsule out of a sounding rocket.
- Arranged tests to verify the system would hold up in violent conditions.

KUDOS — University of Kentucky
Undergraduate Team Lead — Aug. 2016 – Aug. 2017

- Gained team lead experience by managing a large group of undergraduate students from a variety of major disciplines.
- Participated in multiple sub-system designs and integration.
- Successfully ejected a re-entry vehicle out of a sounding rocket in micro-gravity conditions.

KOREVET — University of Kentucky
Graduate Advisor — May 2017 – May 2018

- Wrote papers and presented about KRUPS and the two flight missions.
- Gained a more in depth knowledge in the ablation field and re-entry conditions.
- Increased designing, machining, and testing background by contributing to most subsystems involved in the project.