KRUPS Deployment and Communication System
(KUDOS)
Preliminary Design Review

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University of Kentucky
November 1, 2016
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Mission Overview: Mission Statement

• Increase the TRL of a small entry spacecraft to TRL 8 by demonstrating data acquisition, communication, and TPS designs

Mission Objectives

• Test and demonstrate communication system, release mechanism, and TPS design for application in future research
• Obtain data for the TPS, which will be used to help ongoing scientific investigations on protection for entry conditions
• A rocket is a cost effective way to collect data at high altitude and high speed in order to test the TPS
Mission Overview: Success Criteria

• Test the communication system at high altitude and velocities
  – >50% of data collected by sensors shall be received for analysis
• Release mechanism reliability in space environment
  – Mechanism shall eject KRUPS from rocket, without damaging KRUPS or striking longerons
• Test the sensors for thermocouple data acquisition
  – >50% of data retrieved from the thermocouple sensors shall be stored on KRUPS
Mission Overview: Theory and Concepts

• Ablative Thermal Protection Systems (TPS)
  – Used/Developed from 1950’s - (e.g. AVCOAT on Apollo missions)
• Significant advances have been made in the last 15 years
  – Development of low-density materials such as PICA, used on MSL, Stardust and Dragon
• Many improvements due to high-fidelity numerical methods

Micro-CT scan of FiberForm
Mission Overview: Theory and Concepts

• Ablative TPS relies on the phase-change of the material to mitigate high heat flux
  – Phenolic resin and carbon matrix

Micrographs of PICA at different magnifications. (Agrawal et al., 2013)
Mission Overview: Theory and Concepts

- No ground facility can reproduce atmospheric entry flows
- TPS designed using numerical modeling tools and ground test campaigns
- Problems validating models
  - Limited flight data
  - MSL and Orion EFT-1 have provided data
- Similar concepts are being developed in:
  - Belgium
  - Germany
  - Private Sector
Mission Overview: Expected Results

Thermocouple trace of the MISP 1 instrument over the Mars entry of MSL

a) Location of the MEADS sensors that measure pressure at the surface of the heat shield—the contours illustrate heating (image from Bose with permission)

Location of the instruments on MSL
ConOps
2.0 System Overview
System Overview: Science Design

- Extract material, chemical and transport properties at the micro-scale level.
- Model material response and gas surface interactions at the macro-scale level.
- Application to atmospheric entry spacecraft.
System Overview: Science Design

- The mission will result in a better understanding of material, chemical and transport properties.
- Heat flux is the main measurement that is modeled in computational research.
- Placement and design of thermocouples are key factors in the design of KRUPS.

3D material response modeling
System Overview: Science Design

Thermocouples

- 12 total thermocouples integrated with KRUPS.
  - Via three (3) thermo-plugs embedded in heat shield
- Thermocouples are spaced 0.1, 0.2, 0.45, and 0.7-inches from heat shield surface
System Overview: Science Design

- Thermo plug locations
System Overview: Engineering Design

- KRUPS is structured similarly to REBR
  - REBR - A data re-entry breakup recorder designed by Aerospace Corp.,
  - 3 successful mission in re-supply vehicles (HTV, ATV, etc.)
- The computational research data will be compared with data recorded from:
  - Thermocouples
  - Accelerometers
  - Gyrometers
  - Pressure gauges
- Iridium Satellite Network will receive data from KRUPS
  - Global satellite coverage
- Release mechanism in development
System Overview: Payload Layout

- Electrical Board
- Ejection Mechanism
- Bottom Mount

Dimensions:
- Width: 10.75
### Table 1. Top Level Requirements

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<tr>
<th>Requirement</th>
<th>Verification Method</th>
<th>Description</th>
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<tbody>
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<td>Minimum of 50% of all data transmissions shall be received by radio transceiver or via Iridium network</td>
<td>Test</td>
<td>Iridium and ISM band radio will be tested on a balloon launch</td>
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<tr>
<td>Payload and all subsystems shall withstand three-axis loading at 25 G, and longitudinal impulse loading of 50 G for 200 seconds</td>
<td>Test</td>
<td>The payload and all subsystems will be subjected to these vibration loads in our vibration testing</td>
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<tr>
<td>The combined structure shall have a center of gravity (CG) that is within 1 inch square in the plane of the RockSat-X deck in a latitudinal direction</td>
<td>Test</td>
<td>The CG of each subsystem will be collected, then the subsystems will be placed on the payload to get the correct overall CG.</td>
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Functional Block Diagram

PAYLOAD AREA

- Wallops Power lines
- GSE-1
- GSE-2
- TE-R
- TE-NR1
- TE-NR2
- TE-NR3
- RS232 Parallel bits 1-8

DC to DC 28V to 5V Converter

Payload Control Unit

- computer
- Controller 2
- Remove connector
- Controller 1
- Launch sensor

Deployable Arm 1

- Solenoid
- Remove pin
- Solenoid

KRUPS

- Antenna
- Radio Transceiver
- Battery Pack
- micro-controller
- In-drum Modem
- Thermo Couple to Digital
- micro-SD

LEGEND
- Red: Power
- Green: ADC
- Orange: PWM
- Black: Digital
System Overview: Special Requests

- Transmit Frequencies:
  - Iridium network on 1616-1625Mhz
  - Transmit to ground station frequencies TBD
- Place below all payloads with extendable arms or similar
## User Guide Compliance: Summary

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<th>Requirement</th>
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<th>Comments</th>
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<td>Final design in progress</td>
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<tr>
<td>Weight 30.0+/ - 1.0 lbs.</td>
<td>Yes</td>
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<td>Max Height &lt; 10.75” (5.13”)</td>
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<td>Bottom of deck has flush mount hardware?</td>
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<td>Within Keep-Out Zone</td>
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<td>Using &lt; 10 A/D Lines</td>
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<td>Using X Redundant Power Lines (TE-R)</td>
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<td>Using &lt; 1 Ah</td>
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<td>Using &lt;= 28 V</td>
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<td>Using RF (If yes, list frequency and TX Power)</td>
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<td>Frequency/power TBD. Only TX on ejected capsule!</td>
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<tr>
<td>Using deployable?</td>
<td>Yes</td>
<td>The whole capsule is ejected</td>
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<td>Whole team consists of US Persons</td>
<td>No</td>
<td>Non-US persons are part of the senior design teams, but <strong>will not</strong> be on site at Wallops</td>
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<td>Using ITAR and/or Export Controlled hardware</td>
<td>No</td>
<td>There is a possibility to get an ITAR restricted heat-shield, but it would add too many constraints</td>
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3.0 Subsystem Design

Presenter: Courtney Montague
Subsystem Design

- Thermal Protection System
  - Location of thermocouples
  - Shape / Dimensions
- Release Mechanism
  - KRUPS pre-ejection restraint and deployment
- Communication
  - Iridium network & KRUPS transmissions
- Embedded Control
  - Data collection & storage
- Electrical
  - Capsule power system
Subsystem Design: Thermal Protection System

- Weight not to exceed 1 lb.
- Material options:
  - Cork
  - Airbus heat shield
Subsystem Design: Release Mechanism

- Weight not to exceed 15 lbs
- Power: Wallops supplied 28V stepped down to 5V
- Solenoid controlled ejector
Subsystem Design: Communication

- Weight to not exceed 1.5 lbs
- Power: 4.5V
- NAL Research Iridium Modem
- Custom designed radio transceiver in ISM band
Subsystem Design: Embedded Control

- Weight to not exceed .5 lbs
- PJRC Teensy 3.2 micro-controller
- Custom designed instrument board
  - High and Low G Accelerometer
  - Gyroscope, and Magnetic Compass
  - Thermocouple to Digital Converter
  - Surface Pressure Sensor
  - Micro-SD card
Subsystem Design: Electrical

- Weight: ~0.3-0.46 lbs
- Power: 4.5V nominal
  - Arranged in a series-parallel connection
- Power source: 9 AA batteries
- Yields 7-9Ah of capacity
4.0 Risk Matrices

Presenter: Gabriel Myers
Risk Matrix: Thermal Protection System

1. TPS.RSK.1; Consequence: 5; Likelihood: 3
   Thermal Protection System failure IF the release mechanism penetrates the TPS outer layer

2. TPS.RSK.2; Consequence: 5; Likelihood: 3
   Thermal Protection System failure IF the outer layer of the TPS gets damaged during the shipping processes
Risk Matrix: Release Mechanism

1. MD.RSK.1; Consequence: 5; Likelihood: 3
   Mechanical Deployment failure IF thermal expansion differs from design expectations

2. MD.RSK.2; Consequence: 5; Likelihood: 3
   Mechanical Deployment failure IF vibration during launch engages the release mechanism early

3. MD.RSK.3; Consequence: 5; Likelihood: 3
   Mechanical Deployment failure IF temperature range exposed to the release mechanism differs from design expectations
Risk Matrix: Communication

RISKS

1. COM.RSK.1; Consequence:4; Likelihood: 4
Communication failure IF we can not receive more than 50% of data transmitted via Iridium or ISM band radio

2. COM.RSK.2; Consequence:4; Likelihood: 1
Communication failure IF the power source to KRUPS becomes disconnected during the launch

3. COM.RSK.3; Consequence:4; Likelihood: 2
Communication failure IF the power source to KRUPS does not activate from the preset timer.

4. COM.RSK.4; Consequence:3; Likelihood: 3
Communication failure IF the radio transceivers inside of KRUPS overheat due to TPS insulation
Risk Matrix: Electrical

1. ELE.RSK.1; Consequence: 5; Likelihood: 3
   Electrical failure IF the vibration during launch causes the wire connections to disconnect

2. ELE.RSK.2; Consequence: 5; Likelihood: 3
   Electrical failure IF wire insulation degrades in the temperature range during flight
5.0 Initial Test Plan
Test/Prototyping Plan

- Vibration shaker will test the communication system, release mechanism, and electrical system
  - Mitigates COM.RSK.2, MD.RSK.2, and ELE.RSK.1
- Thermo-Vacuum Chamber will test the electrical system
  - Mitigates ELE.RSK.2
- Balloon Launch will test the communication system
  - Mitigates COM.RSK.1 and COM.RSK.4
6.0 Management
## Management

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Management

- **Budget:** $34,000
  - Status of Deposit: Paid
- **Faculty:** Dr. A. Martin, & Dr. S.W. Smith

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### KUDOS/University of Kentucky

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<tr>
<th>Role</th>
<th>Name</th>
<th>Day Phone</th>
<th>Cell Phone</th>
<th>Receive Texts?</th>
<th>Email</th>
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<tbody>
<tr>
<td>Faculty Advisor</td>
<td>Alexandre Martin</td>
<td>859-317-9184</td>
<td>734-474-4383</td>
<td>Yes</td>
<td><a href="mailto:alexandre.martin@uky.edu">alexandre.martin@uky.edu</a></td>
<td>Canada/US Perm. Res.</td>
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<tr>
<td>Leadership Team (Undergraduate)</td>
<td>Evan Whitmer</td>
<td>270-977-5498</td>
<td>270-977-5498</td>
<td>Yes</td>
<td><a href="mailto:evancw@gmail.com">evancw@gmail.com</a></td>
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<tr>
<td>Leadership Team (Undergraduate)</td>
<td>Courtney Montague</td>
<td>859-753-0931</td>
<td>859-753-0931</td>
<td>Yes</td>
<td><a href="mailto:ccmontague@yahoo.com">ccmontague@yahoo.com</a></td>
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<tr>
<td>Leadership Team (Undergraduate)</td>
<td>Gabriel Myers</td>
<td>859-324-6191</td>
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<td><a href="mailto:gimy222@g.uky.edu">gimy222@g.uky.edu</a></td>
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<tr>
<td>Leadership Team (Undergraduate)</td>
<td>Devin Sparks</td>
<td>405-482-9680</td>
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<td><a href="mailto:devin.sparks@uky.edu">devin.sparks@uky.edu</a></td>
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Please Place priority levels for times you are available. This is done by simply typing a 1, 2, 3, or 4 in each clear box. Hashed boxes are not available.
Risks

• Communication failure
  – A balloon launch will test:
    • Antennas
    • Communication System at ~30.5km altitude
• Mechanical deployment failure
  – Vibration testing
  – Thermo-Vacuum chamber tests
• Electrical failure
  – Thermo-Vacuum chamber tests wire connections in high altitude conditions
Conclusion

• This mission is a cost effective method for validating computational models and experimental ground tests
  – Directly compare numerical models with flight data
  – Result in improved design of Thermal Protection Systems

• Next steps toward the CDR
  – Finalize designs
  – Engineering analysis completed
  – Drawings completed