Team 125 Project Technical Report for the 2023 IREC

Gerhardus J. Olde Loohuis[1] Peyton W. Gnadinger[2] Andrew A. Archibald[3] Branden A. Shay[4] Timothy K. Keetron[5] Garrett L. Murrell[6] Patrick W. Spencer[7] Alex A. Martinez[8]

River City Rocketry - University of Louisville, Louisville, KY, 40205, United States

An overview of the design, analysis, manufacturing, and testing of systems motivated by the Spaceport America Cup are presented. These systems, specifically the Ascent and Recovery System (ARS), the Fin Retainment System (FRS), the Steerable Parachute System (SPS), and the Avionics Vehicle Package (AVP) address the major technical challenges of the 2023 Spaceport America Cup and Space Dynamics Laboratory (SDL) Challenge: flight to a precise altitude target, development of a payload that performs a relevant function, and recording of relevant flight performance data for later analysis and the provision of valuable learning opportunities.

I. Nomenclature

A	=	amplitude of oscillation
a	=	cylinder diameter
C_p	=	pressure coefficient
Cx	=	force coefficient in the x direction
Cy	=	force coefficient in the y direction
c	=	chord
dt	=	time step
Fx	=	X component of the resultant pressure force acting on the vehicle
Fy	=	Y component of the resultant pressure force acting on the vehicle
f, g	=	generic functions
h	=	height
i	=	time index during navigation
j	=	waypoint index
K	=	trailing-edge (TE) nondimensional angular deflection rate

[1] Systems Engineer, River City Rocketry, 1960 S Arthur St, Louisville Ky, 40208
[2] Captain, River City Rocketry, 1960 S Arthur St, Louisville Ky, 40208
[3] Vehicle Lead, River City Rocketry, 1960 S Arthur St, Louisville Ky, 40208
[4] Payload Mechanical Lead, River City Rocketry, 1960 S Arthur St, Louisville Ky, 40208
[5] Payload Electrical Lead, River City Rocketry, 1960 S Arthur St, Louisville Ky, 40208
[6] Avionics Lead, River City Rocketry, 1960 S Arthur St, Louisville Ky, 40208
[7] Propulsion Lead, River City Rocketry, 1960 S Arthur St, Louisville Ky, 40208
[8] Payload Member, River City Rocketry, 1960 S Arthur St, Louisville Ky, 40208

II. Introduction

A. Document Description

This document serves as a comprehensive design description for River City Rocketry's launch vehicle, payload, and additional auxiliary systems that will be used to compete in the prestigious Spaceport America Cup Intercollegiate Rocket Engineering Competition (IREC). In this report, we will delve into the various design features that our team selected as well as the testing and validation performed. This document will be scored for the competition and serve as a reference for future team members from the 2023 Spaceport Team. For any future member reading this document, we wish that this document will serve you well and wish you luck in your current mission.

B. 2023 Endeavors

The 2022-2023 team has aimed to build an autonomous steerable parachute payload, develop a pressure-fed kerosene-liquid oxygen rocket engine, create a multi-system condition monitoring and tracking telemetry system, develop an L2 rocket flight vehicle for low-cost subsystem test flights, and develop a full-scale rocket flight vehicle for the 2023 Spaceport America Cup competition. The telemetry system, steerable parachute system, and full-scale rocket flight vehicle will be showcased during competition in the 2023 Spaceport America Cup. The liquid engine will serve as a development platform that the team can expand on going into the future, and the L2 test vehicle will remain available for flight tests of complete future subsystems.

C. Team Organization

The team's design for the Spaceport America Cup is the result of effective team organization and collaboration. We boast a multidisciplinary team which consists of passionate individuals from various fields of study including mechanical engineering, electrical engineering, computer science engineering, and communications. The team structure consists of members in team leadership, an avionics sub-team, a payload sub-team, an aerostructures sub-team, and propulsion sub-team. By fostering an organized and collaborative team structure, we have been able to capitalize on each team member's strengths and expertise, resulting in a cohesive and efficient design process. Our vision for excellence, and effective teamwork have been integral to the development of a competitive rocket design for the Spaceport America Cup Competition. The 2023 team organization is shown below in Figure 1.

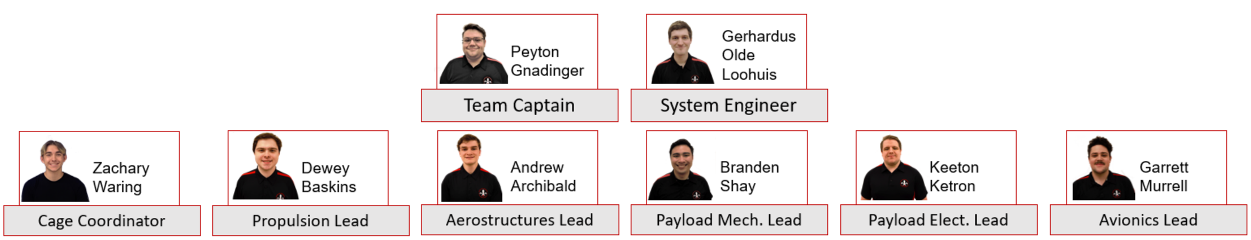

Fig. 1 Leadership Org Chart

III. System Architecture Overview

The presented work consists of four subsystems which are assembled to achieve the competition goals. Starting from the aft of the flight vehicle and referencing the subsystems shown in Figure 2, the vehicle consists of the COTS propulsion system, the Fin Retainment System (FRS), the Ascent and Recovery System (ARS), the Avionics Vehicle Package (AVP), and the Steerable Parachute System (SPS). The COTS propulsion system provides the energy necessary to launch the vehicle to its target altitude. The

Fin Retainment System provides a rigid fixture to mount the fins and transmit aerodynamic loads from the fins into the aft of the flight vehicle. This system also allows the fins to be easily removed for transport and replaced between flights if damage occurs. The Ascent and Recovery System both provides the support structure which contains all other subsystems, and a single bay dual deployment parachute system to safely recover the flight vehicle after flight. The Avionics Vehicle Package records information about the states of other subsystems and transmits that information to the ground crew, allowing informed GO/NO-GO decisions on the pad and remote monitoring of battery levels during waiting periods on the pad. The Steerable Parachute System is the primary competition payload and is deployed in flight before guiding itself to a GPS coordinate on the ground by adjusting the lengths of the cords attaching it to a cruciform parachute.

Fig. 2 Section view of flight assembly showing each subsystem

A. Propulsion Subsystem

The team will use a Cesaroni N5600 commercial reload in a Cesaroni Pro98 6G casing, with a double-headed igniter from AMW used for ignition. A custom plate below the motor is used for motor retainment. This motor was chosen because it was already owned by the team. The same reload was used in the team's 2022 season. This year, the vehicle is smaller and lighter and using a much smaller motor would have been preferable if one was available, but this motor was already owned by the team, and with no other planned projects requiring an N motor, the on-hand, zero-cost option was the clear choice. Because of this motor choice, significant extra weight was required in the vehicle design to reach the desired apogee of 10,000 ft. According to thrustcurve.org, the motor has an impulse of 13,628 N*s, a maximum thrust of 6789 N, a burn time of 2.4s, and zero reported failures in the Malfunctioning Engine Statistical Survey. Because of the relatively high maximum thrust, care was taken on the thrust structure of the rocket to ensure proper transfer of thrust to the entire vehicle. These efforts are detailed in the Aero-structures Subsystem below.

B. Aero-Structures and recovery Subsystem

i. Vehicle subsystem

Forward pass is a 6-inch diameter rocket with a total length of 164 inches, a wet mass of 103 lbs, and a dry mass of 78.1 lbs. Initial open rocket models showed that a high weight was necessary for reaching the apogee goal of 10,000 ft with the selected motor. Forward pass consists of 4 sub-assemblies. These sub-assemblies are the booster section, recovery section, upper section, and the payload nosecone. All airframe components (body tubes, coupler tubes, shoulders, etc.) are made from G12 fiberglass purchased from Wildman Rocketry [] or an equivalent source. Fiberglass was chosen for its strength, weight, and RF transparency. These tubes were proven to be effective at handling the forces of the same motor and similar deployment conditions in both spaceport 2022 on and a prior test launch. The 6-inch inner diameter was chosen to give workable clearances for inside components.

Booster section

The booster section of the rocket is comprised of a welded fin retainment and thrust plate system, replaceable fins, a 50-inch body tube, and coupler containing a sand ballast system. Separated from the rest of the vehicle, the booster section has a total height of 58 inches and a dry mass of 40.6 lbs.

In previous vehicles, it was decided to design the fins to be replaceable instead of epoxying them directly to the body tube. This allows for the booster body to be salvaged if any damage occurs to the fins upon landing. Previous systems included exterior mounting brackets that added drag and instability, or many internal machined parts that were found to be cumbersome and inconvenient to assemble. To subvert these problems, Forward passes replaceable fin system is designed to be fully internal and welded, both to add rigidity and ease the assembly process. The fin retainment system also constrains the motor and transmits the thrust to the rest of the vehicle. Located at the aft of the booster section, the welded fin retainment system includes the thrust plate, angles, the inner ring angle mount, and the fore ring.

All components are made from Hot rolled steel for ease of welding, availability, and added mass. The motor slides into the innermost hole of the thrust plate and through the rest of the assembly, with the thrust plate, inner ring angle mount, and fore ring all acting as centering rings. Located at the aft of the fin retainment system, the thrust plate transmits the force of the motor to the rest of the structure through the contact interference between it and the aft closure of the motor. To appropriately fit up the angle pieces, the thrust plate has cuts that the angles slot into during welding. There are also 3 ¼-20 tapped holes to bolt a motor retainment plate that clamps the motor down so it doesn't slide out after burn. Additional cuts are made to save weight at the aft of the rocket and shift the center of gravity further up.

The angles are used to clamp down on the fin tabs and hold the fins in place during launch. The faces of the angles are spaced out ¼" using the same material the fins are made from, then welded to the thrust plate as a base to achieve as tight of a fit as possible. The angle pieces have 4 ¼" clearance holes, with one angle piece having nuts welded on the outside of the holes. ¼" bolts will pass through the angle and fin holes,

(Andrew: Fully describe the vehicle, its design, include renderings of components/subassemblies, include FEA analysis of critical components, and outline design rationale, assumptions, tradeoffs, etc.)

ii. Recovery subsystem

(Andrew: Fully describe the recovery system, discuss the design choices made, and include schematic diagrams or similar of its layout. Discuss some of the tradeoffs made, and potentially find renderings/images of the chutes from previous team documentation)

C. Payload Subsystem

River City Rocketry has chosen to answer the 2022-2023 Space Dynamic Laboratory Payload challenge by designing and building a payload capable of altering its trajectory after being deployed from the rocket called the Steerable Parachute System (SPS for short). The payload will be falling under a custom-made cruciform parachute that is actuated using two DC servo motors to change the angle of attack of the parachute. Each motor can affect the parachute and move the descending payload in its respective orthogonal axis to navigate the payload to a predetermined location.

Overview picture of the assembly here

The SPS is housed in the nosecone section of the rocket with the shroud lines connecting the SPS to the parachute going through the bulk plate. The parachute is stored in a parachute bag, which is attached to a pusher cup aft of the nose cone and parachute. To ensure the payload parachute inflates a safe distance from the rocket, a 86 ft nylon cord is used to connect the pusher cup to the body of the rocket which will act as a hard stop to pull the parachute bag off the parachute. This pusher cup also allows the SPS and parachute to deploy consistently.

i. Payload Mechanical Overview

The SPS is comprised of four major sections: the pusher cup, the cord routing system, the control gear system, and the electronics as seen on figure #.

SPS assembly here

One of the critical issues the team identified as a hazard for the SPS was the potential for its parachute to be tangled with the body of the rocket immediately after deployment. To address this issue, the team designed a pusher cup system to delay the opening of the SPS's parachute unit it was at least 86 ft away from the main body of the rocket. This length of shock cord was chosen as it is the distance between the lowermost point of the payload body tube and the lowermost section of the booster +10 ft as seen on figure ##.

Deployment picture

The pusher cup is made from a 6-inch-long coupler with a G10 Fiber glass bulkhead attached to the aft section. The aft side of the bulkhead has a U-bolt with a 86 ft section of braded Kevlar rope rated for 800 lbs of force. The fore section of the bulkhead has a brace in which the parachute bag is secured. The parachute bag is undersized for the parachute to prevent smaller forces from prematurely deploying the parachute as it is falling.

Drawing for Pusher cup

The cord routing system is comprised of a top aluminum bulk plate, a plexiglass blast shield, and a custom-made mount (cord route mount) used to hold a camera and the key switch. The cord route mount also guides the shroud line to prevent harsh bending angles against sharp edges of the aluminum plate. The mount also serves to hold the fore GPS antenna required for section ##.

Drawing for the Custom Mount

The bulk plate and blast shields were chosen to be made from aluminum and plexiglass respectively due to the high force generated by the black powder and aluminum being easy to machine with.

Calculate the Force acting on the BP, pusher cup and bulk plate

Cord routing system

The cord routing system

SPS Gears

The payloads movement is controlled by two sets of gears that manipulate the lateral and longitudinal movements of the parachute. The sets of gears are separated into an upper and lower section separated by a divider plate. The lower set of gears controls the lateral movement while the upper set controls the longitudinal. Each set of gears has their own custom cord routing system which routes the cords along the circumference of the disks twice before fixing one end to the corresponding aluminum plate. This creates a loop for the gear to actuate as seen in figure ##.

Cord routing system

This cord routing creates a moveable pulley system where an aluminum dowel acts as the pulley such that the cord length moves twice the distance compared to the angular rotation of the gear. This was chosen to maximize the range of useable cord length to give the payload more control authority.

Show the angle difference between the double routed vs singular routed

The cord routes are custom resin printed pieces with a slit cut out of the top cord route. This was to prevent a pinch point where the gear would have to put more force to pull the cord. (clarify)

Image of the cord routes

The gears used are two sets of identical gear sizes with the driven gear being 68 teeth and the pinion gear being 16 teeth. The diametral pitch is a custom value determined by the distance between the center of the driving motor to the center of the rotating shaft. This method was chosen to minimize the distance between the edge of the motor to the edge of the plate the motor is mounted on.

Show assembly of the gears meshing

The diametral pitch was found using:

Equation to find DP

And was taken up to 5 significant figures of accuracy.

The tooth count of the pinion and driven gear are constrained by the root chord thickness and the projected output torque of the driven gear. The maximum tooth count was determined to comply with waterjet accuracy guidelines which prevented a minimum geometric feature of 1/8th of an inch. Using

The maximum allowable tooth count was calculated to be: ##teeth

On the other hand, the minimum tooth count was determined to ensure the resulting torque output on the driven gear was at least three times greater than the expected torque to prevent back-driving of the motor. This guideline was recommended by *THE NASA THINGY.*

The torque acting on the gear was calculated using the force generated by a cruciform parachute carrying an 11 lb weight descending at 20ft/s. This force was multiplied by the radial distance between the pivot point and the center of the gear to get the expected torque of the shroud lines.

Stress analysis for Tooth loads

The team chose to water jet the gear due to the unique nonstandard diametral pitch needed to main the maximum distance between the gear sets. The water jet also enabled the gears to have a more custom profile to tailor itself to the limit switch integration and cord mounting. The driven gear was split into two identical ¼", 6061 aluminum plates which were press together via aluminum dowels and a hydraulic press as seen in figure ##. The drive gear was manufactured in two pieces to avoid material tapering. This was deemed necessary as we found material tapering in a solid ½" plate.

Gear Assembly

Gear Drawings

To reduce the friction between the Mild Steel Hot rolled center shaft and the gears, Koyo R16-2RS sealed ball bearing were pressed into the ID of the drive gears.

Ball Bearing drawing

The centering shaft acts as the main form of mounting the payload. Apart from acting as the axis in which the drive gears rotate, it also acts as the main attachment point between the nosecone and the SPS. To minimize drag, three low-profile bolts are mounted though the shoulder of the nosecone and into the centering shaft. The centering shaft also accommodates three all-thread to axially lock the control system plates. The centering shaft is made of a hollow 1" diameter pipe welded to a ½" water jetted plate. This design allows the payload electronics wires to connect motors without snagging or tangling issues with the gears.

Center Shaft drawing

(Branden: Fully describe the mechanical design of the Payload, include renderings of components/subassemblies, include FEA analysis of critical components, and outline the design rationale, assumptions, tradeoffs, etc.)

ii. Payload Electrical Overview

(Keeton & Alex)

(Keeton and Alex: Fully describe the electrical design of the Payload and the Avionics battery pack, include circuit schematics, board layouts, and renderings of the battery design, discuss the control code, outline the rationale behind design choices, sensor selection, assumptions made, design tradeoffs, etc.)

The payload electrical system oversaw the power of the whole rocket during pre-flight. We decided to do this via 2 batteries, 1 in the body of the rocket for general power, and another attached to the payload to power it post deployment. The battery chemistry for both is LiFePo4 because it is known for its high stability in a wide range of temperature as well as its high impact resistance.

The large battery in the body of the rocket is a 5s6p meaning its 5 cells in series for a total voltage of 16V and 6 sets in parallel for longer life. This gives us about 13.5-amp hours of battery life (2.3Ah/cell *6cells). With our system drawing .25 for payload and an estimate of 1.25 amps for the rest of the vehicle on average. This battery can power the rocket for a total of 9 hours after arming which was deemed necessary after conservative estimates based on previous launches delays and scrubs.

Once the rocket vehicle is completely assembled and armed, the batteries will be operating until launch. Due to the high temperatures of the surrounding environment along with the heat produced by the batteries, the possibility of system failure due to overheating was investigated. As a result, the implementation of an active cooling system was chosen. The current design includes two F.D.M. printed parts which will serve to constrain and organize the battery cells. This system will be further isolated inside an airtight capsule to ensure no pressure differences influence nearby altimeters. This is critical due to the sensitivity of the altimeters. Failure to take this into account may give rise to the parachutes of the vehicle deploying too early or late.

This system will be controlled with a fan talking to the avionics system in section ## [GARRETT]

The payload battery is a 4s4p providing 12v to the payload. This voltage was chosen to be large enough to power the motors, then the larger battery was chosen to be 1 cell larger to create a voltage differential. This voltage differential is used with a diode to allow an amazingly simple system to stop the payload battery from being used until the main battery is disconnected, see figure #. Then as many parallel as could fit in 1 layer of the rocket for a longer life during flight and on pad in case of main battery failures.

Battery management fig

Battery charging procedure: SELF NOTE FOR KEETON SO I KNOW THIS ISNT A FIGURE AND ACTUALLY A PARAGPACH I NEED TO WRITE ABOUT BATTERY STUFF.

The rest of the payload electronics are in the electrical bay of the payload, See figure #. There is 4 main parts. PCB, motor controllers, Antenna, IMU. The PCB includes multiple sensors and the raspberry pi. There are 2 motor controllers on the second level along with an antenna for the GPS. Finally at the top level there is an IMU.

Payload cross section figure

The PCB can be broken down into 5 more sub parts. i. GPS and antenna switch, ii. Sensors, iii. Pi, iv. Motor, V. power. A full picture of the schematic is provided below with these 5 sections clearly defined, see figure #.

Full schematic figure

i. The first section is the GPS. This consists of the GPS module and an IC to control the switching of antennas. In our system, we have 2 antennas. The first is used to get a GPS fix as the rocket ascends. Then after the rocket reaches apogee it flips, and the second antenna is used. We deemed this necessary after some preliminary testing and decided that the large metal mass that is the payload blocks most signals from going through it. See figure # for the schematic of the switch.

GPS circuit and switch fig

ii. Sensors, there are 3 devices in this section, the BNO, BMP, and transceiver. The BNO, or IMU, is a 9-axis orientation unit. This sensor allows us to get a relative and absolute heading of the payload. This device allows us to direct toward the ending point. Next is the BMP, this device gives us the height of the payload, so we know our altitude allowing us to decide how aggressive we want to steer. Lastly the transceiver is to allow for recovery as we broadcast our position to the ground station and allow communication during flight of all system.

iii. The raspberry Pi section contains the 40-pin header of the raspberry pi along with all the pulldown/pullup resistors for each GPIO pin. All the GPIO pins used for reading motor inputs as well as output from the pi that are not standardized (i.e., not i2C, UART, or SPI) are pulled down. Then the i2C bus is pulled high. Lastly there is also a voltage divider coming in from the main 16V battery to detect when the main battery as been disconnected indicating deployment to the pi, see figure # for the pi circuit.

Pi Fig

iv. The motor section of the PCB consists of only headers. There are 8 headers in total. 2 for encoders, 4 for limit switches, and 2 for the PWM signal going to the motor controller. Due to the high-power requirement of motors the power running to the motors is done directly from the battery, check figure # for a diagram.

Motor fig.

v. Lastly is the power section. This takes in both batteries. They both immediately feed into a diode so that the 16V can back feed the 12V stopping it from turning on until the 16V is disconnected. The diode then feeds into a 5V regulator. This regulator has an EMC circuit. This is to stop any interference from the power system affecting the other sensors and antennas. The whole board runs on either this 5V power or the 3.3V provided by the Pi. See fig # for the full power circuit including the EMC circuit.

Power fig

POLOAD CODE EXPLINATION START

D. Avionics Subsystem

(Garrett: Fully describe the design and implementation of the Avionics, include circuit schematics, board layouts, and renderings of components as applicable, discuss software implementation and the ground station, including assumptions made, design tradeoffs, system capabilities and limitations, etc.)

IV. Mission Concept of Operations Overview

(Gerhardus)

V. Conclusions and Lessons Learned

In the course of developing the systems for this year's Spaceport America Cup competition, the team faced multiple organizational and project management challenges and generated several valuable lessons learned. By comparison, the technical challenges were relatively minor, but valuable takeaways were still found. The organizational lessons-learned have been subdivided into team management insights and knowledge transfer strategies.

During the previous competition year, one of the primary team management challenges faced by the team was a lack of centralized decision-making authority. We had two co-captains with equal authority and no division between administrative and technical responsibilities. This system resulted in numerous communication failures, problems with leadership members countermanding each other, a lack of a cohesive systems-level vision for the competition hardware, and a failure to create and follow a coherent schedule, among other issues. Considering this, during this year, we implemented a more centralized system consisting of a single team captain responsible for all administrative and financial tasks and a systems engineer responsible for all technical planning and technical executive decision-making. This new system greatly improved the efficacy of our communications and established singular roles which would make the final call if an impasse occurred between technical sub-teams. Unfortunately, since this organizational system was new to us, there wasn't a previous legacy of how things should be done, and multiple challenges were discovered and resolved.

One of the major early systems engineering challenges was a tendency to overcomplicate the flight systems. Most individual team members had their own specific interests, and would get to add features, add desired capabilities, or otherwise put their own touch on their subteams' systems. Each individual additional feature was manageable and therefore approved, but the cumulative impact of the added features was an unrealistic degree of complexity. As a consequence of this complexity, the team started the Fall semester with a 30,000 foot COTS architecture including a variable airbrake system, a CO2 cold gas thruster system for apogee adjustment at low speeds, a vehicle-wide serial communication, power management, and telemetry system, and a deployable steerable parachute system capable of aiming for a specific landing location. As the semester progressed, it started becoming clear that some systems would not reach completion before the June competition. In response, the cold gas thruster system was deleted. Shortly following this, financial pressure due to unforeseen changes with one of our sponsors forced a descope to a cheaper 10,000 foot COTS architecture. In the early Spring semester, the airbrake system was also deleted, and substantial ballast mass was added to the vehicle to bring the simulated apogee down to 10,000 feet. Since both the airbrake and cold gas thruster systems had been removed, a simple reaction wheel for roll control was added to the aft ballast compartment which previously housed the airbrake system. This system gave the people who were displaced from the airbrakes and cold gas thrusters something interesting to work on but was ultimately also removed a few months later when it started experiencing excessive schedule slip. The consequence of this drawn-out progressive descoping, modification, and partial rescoping of the system was considerable wasted time, resources, and energy. Additionally, deleting people's systems after they slipped a few times has a significant negative impact on team morale, which both causes people to reallocate more of their energy to classes and other obligations, and causes burnout which reduces each person's productive output

The technical challenges faced by the team were minor compared to the organizational challenges

Deadline leapfrogging – The more deadlines are missed, the less weight future ones carry.

Insurance costs

Recruiting, knowledge transfer and retention – professionalism

Divide organizational lessons-learned and technical lessons-learned

- Organizational lessons-learned
    - Team management lessons-learned
        - Try-fail-try-fail-repeat leapfrog strategy
        - Professionalism and planning strategy
        - Preemptive scope reduction strategy
        - Documentation only works if it is used
    - Knowledge transfer strategies
        - Subsystem ownership – importance of passion – importance of interest catching activities
        - Instructional/teaching sessions
        - Retraction to advisory roles before departure
        - Increase carry-over of information and documentation from previous years
    - Documentation only works if it is used
- Technical lessons-learned
    - Composites manufacturing
-

(Gerhardus)

Appendix

A. System Weights, Measures, and Performance Data

(Andrew, Branden, Keeton, Garrett: List your system info sections here)

B. Project Test Reports

(Andrew, Branden, Keeton, Garrett: Describe any tests you have conducted and the results of those tests)

C. Hazard Analyses

(Gerhardus: Do generalized and operations hazard analyses)

D. Risk and Failure Mode Analyses

(Andrew, Branden, Keeton, Garrett, Patrick: Do analyses for your subsystems)

Propulsion Risk Assessment Matrix

Hazard	Possible Causes	Mitigation Approach	Risk Level After Mitigation
Fragmentation of motor components from explosion during flight	Voids or cracks present in propellant grains	Grains will be inspected by team members and Flyer of Record to ensure high quality of grains.	Low
	Motor assembled incorrectly – closures not sealed correctly, etc	Motor will be assembled with the help of Flyer of Record to ensure correct assembly.	Low
	Defect in casing or closure manufacturing	Casing and closures will be inspected prior to motor assembly by both a team member and Flyer of Record.	Low
Failure to ignite motor	E-match not inserted into grain core properly	Wait a minimum of 60 seconds before approaching rocket to ensure motor does not ignite. Once at rocket, immediately disconnect igniter from launch control electronics. Only essential, fully trained, and certified personnel go to pad to inspect and replace (as necessary) E-match.	Low
Motor ignition occurs prematurely	Igniter was installed prematurely	Proper procedure and necessary checklists will be followed precisely during launch operations. This includes not installing the igniter into the motor until necessary, and paying attention to competition staff at all times.	Low

(Gerhardus: Do analyses for operations and multiple-system failure modes)

E. Procedures and Checklists

(Andrew, Branden, Keeton, Garrett, Patrick: Put all of your procedures and checklists here)

Propulsion Procedure Only initial step when it is fully completed and last step is also fully initialed. If any part of step is incomplete do not initial. Positive and negative consequences ultimately fall on initial. If previously completed step is realized or caused to be incomplete, restart checklist from top. DO NOT initial for any steps not checked personally by initialer. DO NOT initial any others than your own.	
Step **DO NOT INSTALL IGNITER OR CLOSURES UNTIL INSTRUCTED!**	**Initial**
At lodging: Assemble motor according to provided instructions up to, but no further than, grain-liner gluing step. Store liner on end in place where it cannot fall over.	
Before driving to launch site: Confirm completion of packing checklist. Insulate liner with blanket.	
After arriving at launch site: Continue motor assembly according to provided instructions, including installation of forward closure.	
Prepare igniter: Pull igniter leads through hole in plastic nozzle cap. Twist igniter around igniter dowel. Do not install igniter into motor.	
When vehicle is ready for launch: Install aft closure. Install motor into vehicle.	
Install motor retainment ring. Confirm secure installation of retainment ring.	
Find and bring to launch site plastic nozzle cap, igniter, and this checklist. Pull igniter leads through hole in plastic nozzle cap.	
When vehicle is fully armed and OK given from Spaceport staff to install igniter: Install igniter into motor. Ensure igniter reaches near forward closure. Install plastic nozzle cap onto nozzle.	
Clack ignition system clips together before attaching to igniter leads, confirming lack of sparks. Connect ignition system clips to igniter leads, gripping lead in clip then twisting lead around clip.	
Ensure ignition system clips are spaced apart from each other and from any metal objects before retreating from vehicle.	
If vehicle must be disarmed: Disconnect igniter leads from ignition system clips. Remove plastic nozzle cap. Remove igniter from motor.	

Item Number	PROPULSION	Initial	Box # / Car	Note if applicable
1	CTI Pro98 wrench tool or other method/tools			
2	Polyurethane glue			
3	Bucket / washing container			
4	Dish soap			
5	Rags			
6	Casing			
7	Forward closure			
8	2x Retaining ring (min)			
9	Liner (per)			
10	Forward disk insulator (per)			
11	Igniter dowel (per)			
12	Double-headed igniter (per)			
13	Nozzle cap (per)			
14	Nozzle (per)			
15	O-rings (per)			
16	Motor kit (per)			
17	Motor instructions			
18	Scrubby thing			
19	Motor Retainer (or under vehicle)			
20	Broomstick/wood dowel			
21	IPA			
22	Blankets for motor box vibration insulation			
23	Disposable gloves			
24	3x Procedure sheet			

F. Engineering Drawings

(Andrew, Branden, Keeton, Garrett, Peyton, Alex: Put all component drawings here)

References

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END OF REPORT, REFERENCE FORMATTING INFO BELOW

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VI. Procedure for Spaceport America Cup Technical Report Submission

On or before the date specified in the Integrated Master Schedule prior to the event, teams shall submit a single digital PDF copy of their Project Technical Report. Technical reports exceeding 50 Megabytes in size may need to be uploaded to a cloud server as long as the permissions allow the judges unrestricted access to the document.

Teams shall submit their Project Technical reports using the HeroX website: (https://www.herox.com/SpaceportAmericaCup2022).

Teams should bring a limited number of hardcopies to the Spaceport America Cup so members of the judging panel and other competition officials may consult the contents at will during interactions with the team.

VII. General Guidelines and Required Elements

The following section outlines general (non-formatting) guidelines to follow. Technical reports will contain all elements identified in Section 2.7.2 of the IREC Rules and Requirements document, which is available for download on the ESRA website (http://www.soundingrocket.org/sa-cup-documents--forms.html). Missing or incomplete elements will result in loss of points. The following required items are provided for quick reference and teams should consult the Rules and Requirements for detailed guidance. Teams are permitted to add other technical elements at their discretion. No table of contents is required, although teams will not be penalized for including one.

D. Report Body

1) Abstract
2) Introduction
3) System Architecture Review
4) Mission Concept of Operations Overview
5) Conclusion and Lessons Learned

E. Required Report Appendices

1) System Weights, Measures and Performance Data
2) Project Test Reports
3) Hazard Analysis
4) Risk Assessment
5) Assembly, Preflight, Launch, and Recovery Checklists
6) Engineering Drawings

F. List of References

References are required and must follow the format under "References" at the end of this document.

VIII.Detailed Formatting Instructions

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> Extended quotes, such as this example, are to be used when material being cited is longer than a few sentences, or the standard quotation format is not practical. In this Word template, the appropriate style is "Extended Quote" from the drop-down menu. Extended quotes are to be in Times New Roman, 9-point font, indented 0.4" and full justified.

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The abstract should appear at the beginning of your paper. It should be one paragraph long (not an introduction) and complete in itself (no reference numbers). It should indicate subjects dealt with in the paper and state the objectives of the investigation. Newly observed facts and conclusions of the experiment or argument discussed in the paper must be stated in summary form; readers should not have to read the paper to understand the abstract. The abstract should be bold, indented 3 picas (1/2") on each side, and separated from the rest of the document by - blank lines above and below the abstract text.

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Papers with many symbols may benefit from a nomenclature list that defines all symbols with units, inserted between the abstract and the introduction. If one is used, it must contain all the symbology used in the manuscript, and the definitions should not be repeated in the text. In all cases, identify the symbols used if they are not widely recognized in the profession. Define acronyms in the text, not in the nomenclature.

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Footnotes, where they appear, should be placed above the 1" margin at the bottom of the page. To insert footnotes into the template, use the Insert>Footnote feature from the main menu as necessary. Numbered footnotes as formatted automatically in the template are acceptable, but superscript symbols are the preferred AIAA style, in the sequence, *, †, ‡, §, ¶, #, **. ††, ‡‡, §§, etc.

List and number all references at the end of the paper. Corresponding bracketed numbers are used to cite references in the text [1], unless the citation is an integral part of the sentence (e.g., "It is shown in Ref. [2] that…") or follows a mathematical expression: "$A^2 + B = C$ (Ref. [3])." For multiple citations, separate reference numbers with commas [4, 5], or use a dash to show a range [6-8]. Reference citations in the text should be in numerical order.

In the reference list, give all authors' names; do not use "et al." unless there are more than 10 authors. Papers that have not been published should be cited as "unpublished"; papers that have been submitted or accepted for publication should be cited as "submitted for publication." Private communications and personal website should appear as footnotes rather than in the reference list.

References should be cited according to the standard publication reference style (for examples, see the "References" section of this template). Never edit titles in references to conform to AIAA style of spellings, abbreviations, etc. Names and locations of publishers should be listed; month and year should be included for reports and papers. For papers published in translation journals, please give the English citation first, followed by the original foreign language citation.

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All artwork, captions, figures, graphs, and tables will be reproduced exactly as submitted. Be sure to position any figures, tables, graphs, or pictures as you want them printed.

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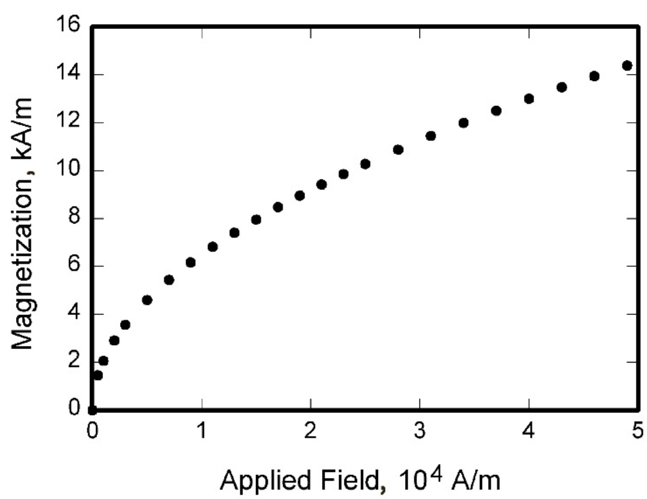

Fig. 1 Magnetization as a function of applied fields.

Place figure captions below all figures; place table titles above the tables. If your figure has multiple parts, include the labels "a)," "b)," etc. below and to the left of each part, above the figure caption. Please verify that the figures and tables you mention in the text actually exist. *Please do not include captions as part of the figures, and do not put captions in separate text boxes linked to the figures*. When citing a figure in the text, use the abbreviation "Fig." except at the beginning of a sentence. Do not abbreviate "Table." Number each different type of illustration (i.e., figures, tables, images) sequentially with relation to other illustrations of the same type.

Figure axis labels are often a source of confusion. Use words rather than symbols. As in the example to the right, write the quantity "Magnetization" rather than just "M." Do not enclose units in parenthesis, but rather separate them from the preceding text by commas. Do not label axes only with units. As in Fig. 1, for example, write "Magnetization, kA/m" not just "kA/m." Do not label axes with a ratio of quantities and units. For example, write "Temperature, K," not "Temperature/K."

Multipliers can be especially confusing. Write "Magnetization, kA/m" or "Magnetization, 10^3 A/m." Do not write "Magnetization (A/m) x 1000" because the reader would not then know whether the top axis label in Fig. 1 meant 16000 A/m or 0.016 A/m. Figure labels must be legible, and all text within figures should be uniform in style and size, no smaller than 8-point type.

G. Equations, Numbers, Symbols, and Abbreviations

Equations are centered and numbered consecutively, with equation numbers in parentheses flush right, as in Eq. (1). Insert a blank line above and below the equation. First use the equation editor to create the equation. If you are using Microsoft Word, use either the Microsoft Equation Editor or the MathType add-on (http://www.mathtype.com) for equations in your paper, use the function (Insert>Object>Create New>Microsoft Equation *or* MathType Equation) to insert it into the document. Please note that "Float over text" should *not* be selected. To insert the equation into the document:

1) Select the "Equation" style from the pull-down formatting menu and hit "tab" once.
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3) Enter the equation number in parentheses.

A sample equation is included here, formatted using the preceding instructions. To make your equation more compact, you can use the solidus (/), the exp function, or appropriate exponents. Use parentheses to avoid ambiguities in denominators.

$$\int_0^{r_2} F(r,\varphi)\,dr\,d\varphi = [\sigma r_2/(2\mu_0)] \cdot \int_0^{\infty} \exp(-\lambda|z_j - z_i|)\lambda^{-1} J_1(\lambda r_2) J_0(\lambda r_i)\,d\lambda \tag{1}$$

Be sure that the symbols in your equation are defined before the equation appears, or immediately following. Italicize symbols (*T* might refer to temperature, but T is the unit tesla). Refer to "Eq. (1)," not "(1)" or "equation (1)" except at the beginning of a sentence: "Equation (1) is…" Equations can be labeled other than "Eq." should they represent inequalities, matrices, or boundary conditions. If what is represented is really more than one equation, the abbreviation "Eqs." can be used.

Define abbreviations and acronyms the first time they are used in the text, even after they have already been defined in the abstract. Very common abbreviations such as AIAA, SI, ac, and dc do not have to be defined. Abbreviations that incorporate periods should not have spaces: write "P.R.," not "P. R." Delete periods between initials if the abbreviation has three or more initials; e.g., U.N. but ESA. Do not use abbreviations in the title unless they are unavoidable (for instance, "AIAA" in the title of this article).

H. General Grammar and Preferred Usage

Use only one space after periods or colons. Hyphenate complex modifiers: "zero-field-cooled magnetization." Avoid dangling participles, such as, "Using Eq. (1), the potential was calculated." [It is not clear who or what used Eq. (1).] Write instead "The potential was calculated using Eq. (1)," or "Using Eq. (1), we calculated the potential."

Use a zero before decimal points: "0.25," not ".25." Use "cm^2," not "cc." Indicate sample dimensions as "0.1 cm x 0.2 cm," not "0.1 x 0.2 cm^2." The preferred abbreviation for "seconds" is "s," not "sec." Do not mix complete spellings and abbreviations of units: use "Wb/m^2" or "webers per square meter," not "$webers/m^2$." When expressing a range of values, write "7 to 9" or "7-9," not "7~9."

A parenthetical statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within parenthesis.) In American English, periods and commas are placed within quotation marks, like "this period." Other punctuation is "outside"! Avoid contractions; for example, write "do not" instead of "don't." The serial comma is preferred: "A, B, and C" instead of "A, B and C."

If you wish, you may write in the first person singular or plural and use the active voice ("I observed that…" or "We observed that…" instead of "It was observed that…"). Remember to check spelling. If your native language is not English, please ask a native English-speaking colleague to proofread your paper.

The word "data" is plural, not singular (i.e., "data are," not "data is"). The subscript for the permeability of vacuum μ_0 is zero, not a lowercase letter "o." The term for residual magnetization is "remanence"; the adjective is "remanent"; do not write "remnance" or "remnant." The word "micrometer" is preferred over "micron" when spelling out this unit of measure. A graph within a graph is an "inset," not an "insert." The word "alternatively" is preferred to the word "alternately" (unless you really mean something that alternates). Use the word "whereas" instead of "while" (unless you are referring to simultaneous events). Do not use the word "essentially" to mean "approximately" or "effectively." Do not use the word "issue" as a euphemism for "problem." When compositions are not specified, separate chemical symbols by en-dashes; for example, "NiMn" indicates the intermetallic compound $Ni_{0.5}Mn_{0.5}$ whereas "Ni–Mn" indicates an alloy of some composition Ni_xMn_{1-x}.

Be aware of the different meanings of the homophones "affect" (usually a verb) and "effect" (usually a noun), "complement" and "compliment," "discreet" and "discrete," "principal" (e.g., "principal investigator") and "principle" (e.g., "principle of measurement"). Do not confuse "imply" and "infer."

Prefixes such as "non," "sub," "micro," "multi," and ""ultra" are not independent words; they should be joined to the words they modify, usually without a hyphen. There is no period after the "et" in the abbreviation "et al." The abbreviation "i.e.," means "that is," and the abbreviation "e.g.," means "for example" (these abbreviations are not italicized).

IX. Conclusion

A conclusion section is required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions. *Note that the conclusion section is the last section of the paper that should be numbered. The appendix (if present), acknowledgment, and references should be listed without numbers.*

Appendix

Required appendices should appear before the acknowledgments.

Acknowledgments

An Acknowledgments section, if used, **immediately precedes** the References. Sponsorship information and funding data are included here. The preferred spelling of the word "acknowledgment" in American English is without the "e" after the "g." Avoid expressions such as "One of us (S.B.A.) would like to thank…" Instead, write "F. A. Author thanks…"

References

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Periodicals

[1] Vatistas, G. H., Lin, S., and Kwok, C. K., "Reverse Flow Radius in Vortex Chambers," *AIAA Journal*, Vol. 24, No. 11, 1986, pp. 1872, 1873.
doi: 10.2514/3.13046

[2] Alyanak, E. J., and Pendleton, E., "Aeroelastic Tailoring and Active Aeroelastic Wing Impact on a Lambda Wing Configuration," Journal of Aircraft, published online 10 Nov. 2016.
doi: 10.2514/1.C033040

[3] Dornheim, M. A., "Planetary Flight Surge Faces Budget Realities," *Aviation Week and Space Technology*, Vol. 145, No. 24, 9 Dec. 1996, pp. 44–46.

[4] Terster, W., "NASA Considers Switch to Delta 2," *Space News*, Vol. 8, No. 2, 13–19 Jan. 1997, pp. 1, 18.

All of the preceding information is required. The journal issue number ("No. 11" in Ref. 1) is preferred, but the month (Nov.) can be substituted if the issue number is not available. Use the complete date for daily and weekly publications. Transactions follow the same style as other journals.

Books

[5] Peyret, R., and Taylor, T. D., *Computational Methods in Fluid Flow*, 2nd ed., Springer-Verlag, New York, 1983, Chaps. 7, 14.

[6] Oates, G. C. (ed.), *Aerothermodynamics of Gas Turbine and Rocket Propulsion*, AIAA Education Series, AIAA, New York, 1984, pp. 19, 136.

[7] Volpe, R., "Techniques for Collision Prevention, Impact Stability, and Force Control by Space Manipulators," *Teleoperation and Robotics in Space*, edited by S. B. Skaar and C. F. Ruoff, Progress in Astronautics and Aeronautics, AIAA, Washington, DC, 1994, pp. 175–212.

Publisher, place, and date of publication are required for all books. No state or country is required for major cities: New York, London, Moscow, etc. A differentiation must always be made between Cambridge, MA, and Cambridge, England, UK. Note that series titles are in Roman type.

Proceedings

[8] Thompson, C. M., "Spacecraft Thermal Control, Design, and Operation," *AIAA Guidance, Navigation, and Control Conference*, CP849, Vol. 1, AIAA, Washington, DC, 1989, pp. 103–115

[9] Chi, Y. (ed.), *Fluid Mechanics Proceedings*, NASA SP-255, 1993.

[10] Morris, J. D., "Convective Heat Transfer in Radially Rotating Ducts," *Proceedings of the Annual Heat Transfer Conference*, edited by B. Corbell, Vol. 1, Inst. of Mechanical Engineering, New York, 1992, pp. 227–234.

Reports, Theses, and Individual Papers

[11] Chapman, G. T., and Tobak, M., "Nonlinear Problems in Flight Dynamics," NASA TM-85940, 1984.

[12] Brandis, A. M., Johnston, C. O., and Cruden, B. A., "Nonequilibrium Radiation for Earth Entry," AIAA Paper 2016-3690, June 2016.

[13] Steger, J. L., Jr., Nietubicz, C. J., and Heavey, J. E., "A General Curvilinear Grid Generation Program for Projectile Configurations," U.S. Army Ballistic Research Lab., Rept. ARBRL-MR03142, Aberdeen Proving Ground, MD, Oct. 1981.

[14] Tseng, K., "Nonlinear Green's Function Method for Transonic Potential Flow," Ph.D. Dissertation, Aeronautics and Astronautics Dept., Boston Univ., Cambridge, MA, 1983.

Government agency reports do not require locations. For reports such as NASA TM-85940, neither insert nor delete dashes; leave them as provided. Place of publication *should* be given, although it is not mandatory, for military and company reports. Always include a city and state for universities. Papers need only the name of the sponsor; neither the sponsor's location nor the conference name and location is required. *Do not confuse proceedings references with conference papers*.

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Regularly issued electronic journals and other publications are permitted as references. Include the DOI if provided; otherwise provide the full URL. Archived data sets also may be referenced as long as the material is openly accessible, and the repository is committed to archiving the data indefinitely. References to electronic data available only from personal websites or commercial, academic, or government ones where there is no commitment to archiving the data are not permitted in the reference list.

[15] Atkins, C. P., and Scantelbury, J. D., "The Activity Coefficient of Sodium Chloride in a Simulated Pore Solution Environment," *Journal of Corrosion Science and Engineering* [online journal], Vol. 1, No. 1, Paper 2, URL: http://www.cp/umist.ac.uk/JCSE/vol1/vol1.html [retrieved 13 April 1998].

[16] Vickers, A., "10-110 mm/hr Hypodermic Gravity Design A," *Rainfall Simulation Database* [online database], URL: http://www.geog.le.ac.uk/bgrg/lab.htm [retrieved 15 March 2006].

Break website addresses after punctuation, and do not hyphenate at line breaks.

Computer Software

[17] TAPP, Thermochemical and Physical Properties, Software Package, Ver. 1.0, E. S. Microware, Hamilton, OH, 1992.

Include a version number and the company name and location of software packages.

Patents

Patents appear infrequently. Be sure to include the patent number and date.

[18] Scherrer, R., Overholster, D., and Watson, K., Lockheed Corp., Burbank, CA, U.S. Patent Application for a "Vehicle," Docket No. P-01-1532, filed 11 Feb. 1979.

Private Communications and Websites

References to private communications and personal website addresses are not permitted. They may, however, be incorporated into the main text of a manuscript or may appear in footnotes.

Unpublished Papers and Books

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[19] Doe, J., "Title of Paper," *Name of Journal* (to be published).
[20] Doe, J., "Title of Chapter," *Name of Book*, edited by…, Publisher's name and location (to be published).
[21] Doe, J., "Title of Work," Name of Archive, Univ. (or organization), City, State, Year (unpublished).

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