Spaceport America Cup

Intercollegiate Rocket Engineering Competition Design, Test, & Evaluation Guide

REVISION	DESCRIPTION	DATE
Baseline	Rev 1.0 Draft	Sep 2021
2022 V1.1	1. Initial edit for the 2022 Cup. 2. Edits to the 2021 version throughout for clarity and grammar 3. Moved section on requirement for Level 3 certified student or mentor to be present for critical activities from 3.2 to 3.1 4. Re-arranged bullets in 5.6 for clarity and added new bullet clarifying requirements for complex systems 5. Specified the JLCR is not permitted (6.1) and removed reference in 6.3 6. Clarified heading on 6.11 to apply to Recovery Systems 7. Added requirement for additional analysis to establish sufficient launch stability without flight test in 10.2 8. Format changes throughout for consistency	
V1.2	1. Baseline version for 2022 SA Cup. 2. Revised and clarified wording in 3.1 specifying that all solid launches require a Level 3 certified Flyer of Record, either TRA or NAR (COTS only), revised procedure for international teams to locate an L3 mentor. 3. Reworded last bullet of 4.10 to make it clear that frequency hopping / spread spectrum transmitters are only permitted if the MCC can receive them. 4. Reworded 8.3 to make it clear that the prohibition against stainless steel applies to airframe and engine components only. 5. Removed prohibition against stainless steel eye bolts, etc. in 8.4 6. Added size / weight limits and requirement for fly-away rail guides to be flight tested in 8.6 7. Re-worded 10.2 to make it clear that flight testing is the preferable way to show stability between 50-100 fps off the rail. If simulation is used, added requirement to show stability under a variety of launch conditions and that a single simulation run is not sufficient for this analysis. 8. Minor grammar and format changes throughout.	30 Sep 2021

1. Introduction

Introduction - The Experimental Sounding Rocket Association (ESRA) and the New Mexico Spaceport Authority (aka Spaceport America; NMSA) have partnered to host and support the Spaceport America Cup (SA Cup), a week-long series of events which will set the background and provide structure for the world's largest university rocket engineering competition. This new host-event continues the Intercollegiate Rocket Engineering Competition's (IREC) legacy of inspiring student design teams from across the country and around the world.

1.1. Background

Background - The “smoke and fire,” noise, high speeds, and sleek aerodynamics of rocketry encourage students to pursue science, technology, and mathematics-based careers. They have "Rocket Fever!", and competition motivates them to extend themselves beyond the classroom to design and build the rockets themselves. These students also learn to work as a team, solving real world problems under the same pressures they'll experience in their future careers.

ESRA held the first annual IREC in 2006. The competition achieved international status in 2011 when Canadian and Brazilian universities threw their hats in the ring. These schools have since been joined by others from every continent except Antarctica. In fact, the competition has roughly doubled in size every year since 2013, becoming the largest known collegiate level rocket engineering competition in the world in 2014. Attendance in 2016 included as many as 600 participants – including faculty, family, and friends of students from over 50 colleges and universities. The next year marked the start of a new era with the inaugural SA Cup. Over 1,100 students and representatives from 22 industry partners participated in an academic conference, rocket and payload engineering competitions, and non-competing demonstration flight tests. The cup continues to grow with over 150 teams competing in 2022.

1.2. Purpose and Scope

Purpose and Scope - This document defines the minimum design, test, and evaluation criteria the event organizers expect IREC teams to meet before launching at the SA Cup. The event organizers use these criteria to promote flight safety. Departures from the guidance this document provides may negatively impact an offending team’s score and flight status, depending on the degree of severity. The foundational, qualifying criteria for the IREC are contained in the IREC Rules & Requirement Document.

This document incorporates the Tripoli Rocketry Association (TRA) Safety Code, the National Fire Protection Association (NFPA) Code for High Power Rocketry (NFPA 1127), and ESRA’s observations on student launch initiatives. Although NFPA 1127, Section 1.3.3 exempts colleges and universities from its contents, and ESRA has no formal affiliation with the TRA, these documents remain excellent supplemental resources for student researchers to learn more about best practices adopted by the amateur high-power rocketry community.

If any IREC team is unclear about competition rules and requirements, or has a situation not specifically addressed by the rules, they should contact ESRA with questions or concerns regarding their project plans’ alignment with the spirit and intent of this IREC Design, Test, & Evaluation Guide (DTEG).

1.3. Convention and Notation

Convention and Notation - The following definitions differentiate between requirements and other statements. The degree to which a team satisfies the spirit and intent of these statements will guide the competition officials’ decisions on a project’s overall score in the IREC and flight status at the SA Cup.

- **Shall:** This is the only verb used to denote mandatory requirements. Failure to satisfy the spirit and intent of a mandatory requirement will always affect a project’s score and flight status.

- **Should:** This verb is used for stating non-mandatory goals. Failure to satisfy the spirit and intent of a non-mandatory goal may affect a project's score and flight status, depending on design implementation and the team's ability to provide thorough documentary evidence of their due diligence on-demand
- **Will:** This verb is used for stating facts and declarations of purpose. The authors' use these statements to clarify the spirit and intent of requirements and goals.

1.4. **Flight Status -** refers to the granting of permission to attempt flight, and the provisions under which that permission remains valid. A project's flight status may be either nominal, provisional, or denied.

- **Nominal** - A project assigned nominal flight status meets or exceeds the minimum expectations of this document and reveals no obvious flight safety concerns during flight safety review at the SA Cup.
- **Provisional** - A project assigned provisional flight status generally meets the minimum expectations of this document, but reveals flight safety concerns during flight safety review at the SA Cup which may be mitigated by field modification or by adjusting launch environment constraints. Launch may occur only when the prescribed provisions are met.
- **Denied** - Competition officials reserve the right to deny flight status to any project which fails to meet the minimum expectations of this document, or reveals un-mitigatable flight safety concerns during flight safety review at the SA Cup.

1.5. **Launch Vehicle versus Payload** - An effort is made throughout this document to differentiate between launch vehicle and payload associated systems. Unless otherwise stated, requirements referring only to the launch vehicle do not apply to payloads and vice versa.

1.6. **Revision** - The IREC DTEG may require revision from one competition to the next, based on the lessons learned by both host organizations and the participants.

- Major revisions will be accomplished by complete document reissue. "Real world events" may require smaller revisions to this document in the months leading up to a competition.
- Such revisions will be reflected in updates to the document's effective date. The authority to issue revised versions of this document rests with ESRA and NMSA.
- Revisions will be approved either by ESRA, NMSA, or jointly by both organizations as appropriate.

2. **Reference Documentation -** The following documents include standards, guidelines, schedules, or required standard forms. The documents listed in this section are either applicable to the extent specified in this document, or contain reference information useful in the application of this document.

DOCUMENT	FILE LOCATION
IREC Rules & Requirements Document	http://www.soundingrocket.org/sa-cup-documents--forms.html
SA Cup Integrated Master Schedule Document	http://www.soundingrocket.org/sa-cup-documents--forms.html
SA Cup Range Standard Operating Procedures	http://www.soundingrocket.org/sa-cup-documents--forms.html
IREC Entry Form & Progress Update	http://www.soundingrocket.org/sa-cup-documents--forms.html
TRA Safety Code	http://www.tripoli.org/SafetyCode
NFPA 1127: Code for High-Power Rocketry	https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1127
14 CFR, Part 1, 1.1 General Definitions	http://www.ecfr.gov/cgi-bin/text-idx?SID=795aaa37494b6c99641135267af8161e&mc=true&node=se14.1.1_11&rgn=div8
14 CFR, Part 101, Subpart C, 101.22 Definitions	http://www.ecfr.gov/cgi-bin/text-idx?SID=795aaa37494b6c99641135267af8161e&mc=true&node=se14.2.101_122&rgn=div8

3. High Power Certified Flyer of Record

High Power Certified Flyer of Record - Spaceport America, the Experimental Sounding Rocket Association (ESRA), and the Tripoli Rocketry Association (TRA) have signed an agreement to work together to continue to improve overall flight safety and efficient flight operations at the Spaceport America Cup (SA Cup).

- This new partnership will improve participant's access to TRA mentors, certifications, and launch sites. Student teams flying in the Commercial Off the Shelf (COTS) and Student Research and Design Solid (SRAD Solid) categories are required to fly under TRA flight code.

3.1. Tripoli Flight Requirements for COTS and SRAD Solid Categories

- A certified Level 3 Flyer of Record shall be required for COTS and SRAD solids and must be present for launch preparation, pad loading and recovery activities. There are three options to satisfy the requirement for a Level 3 certified Flyer of Record.
- HIGHLY Recommended - each team will secure a Level 3 certified TRA or NAR (COTS Only) Senior mentor who works closely with the team and is present as the Flyer of Record for the launch preparation, pad loading and recovery activities. Student teams ARE HIGHLY RECOMMENDED to subsidize the travel expenses of their Flyer of Record or mentor, both to and from the event.
- Recommended - team will have a TRA or NAR (COTS Only) Level 3 certified student member onsite for the launch preparation, pad loading and recovery activities. The student L3 member will be the Flyer of Record and must be onsite with the team for all aspects of launch.
- Last option (only for international teams who do not have access to TRA prefectures). International teams will first work with either TRA or NAR (COTS only) to locate an L3 senior member, who will virtually mentor the team throughout the year. If teams are unable to find a suitable mentor, ESRA Range Safety team members, who are Level 3 certified TRA or NAR (COTS Only) Senior members will act as mentors.
- In either case, senior mentors will virtually mentor the international team throughout the year and will be present as the Flyer of Record for the final flight safety inspections, launch preparation, pad operations, and recovery.

3.2. TRA (or NAR) Student Membership

- TRA Student membership is $10 per year per student. NAR (COTS Only) is $25 per year. This is a requirement for ANY student who will be on the range, at the pads or dealing with energetics.
- A maximum of 5 additional team members who are TRA or NAR (COTS only) student members may be on the pad loading team, recovery team, or working with the energetics (motor, ejection charges). These student team members do not have to be HPR certified but must be TRA or NAR (COTS only) student members. All students are highly recommended to secure HPR certification.
- Link to the TRA Student Membership application: **TRA Membership**.

4. GPS Tracking Requirements for all IREC Rocket Flights

4. GPS Tracking Requirements for all IREC Rocket Flights - All rockets are required to have a GPS tracking solution on their rockets.

- Teams are required to prove their tracking solutions are functioning during Team Check-In on Monday and again at the final safety checks before proceeding to the launch pads.

4.1. Frequency Management - The MCC will begin coordinating the assignment of frequencies to teams in the months leading up to the Cup.

- MCC management will ensure that each team has a frequency that does not conflict with any other team.
- Teams should be able to quickly change frequencies on their transmitting and receiving stations if needed onsite.
- Teams will test their transmitter in coordination with the MCC prior to launch to ensure the MCC is receiving GPS telemetry.
- Any team that is transmitting on a frequency not assigned to them will be penalized.

4.2. GPS Redundancy - Students may have multiple GPS Tracking solutions within their rocket. One of these solutions should meet the requirements highlighted in this section.

- All transmitting devices on the rocket must be documented in your interim and final reports. Frequencies for all devices must be coordinated with MCC.

4.3. MCC Recommended COTS GPS Trackers - Approved COTS GPS solutions for high power rocketry are easy to use and available for a few hundred dollars.

Vendor	Product		Website
Altus Metrum	TeleGPS, TeleMega, etc.	70cm, APRS	Click Here
Big Red Bee	Beeline GPS	70cm, APRS	Click Here
Featherweight	Featherweight GPS	900MHz	Click Here

4.4. GPS Trackers options

- Frequency Ranges – 900MHz – Does not require a HAM license, good option for international teams who cannot acquire necessary certifications. MCC has a very limited number of 900MHz receivers so you may experience delays launching if you utilize this frequency range.
- 70cm – To avoid significant delays in potentially launching, teams should utilize 70cm/APRS systems for their GPS tracking systems. Requires a HAM license, or a similar international licensing.

4.5. Multi-stage Rocket GPS Systems - Teams with multiple stages or deployables are encouraged to use the Big Red Bee 70cm GPS units in each of the rocket stages and/or deployables. The Big Red Bee 70cm GPS unit has built in GPS timeslot capability.

4.6. APRS Support - For 70cm GPS solutions, APRS solutions are HIGHLY RECOMMENDED.

4.7. SRAD GPS Tracking systems - SRAD GPS solutions are approved but require significant additional documentation and testing. Here are additional requirements for SRAD developed GPS Tracking systems:

- Must be able to easily and rapidly change frequency as needed even on the range.
- APRS protocol is HIGHLY RECOMMENDED for SRAD GPS Tracking. The protocol utilizes 1200baud AFSK and the APRS packet format. See http://www.aprs.org/doc/APRS101.PDF
- Transmit rep must be set to 2sec. Transmissions on the same frequency from different stages(transmitters) must be shifted using GPS timeslotting.
- Solution should be thoroughly and successfully tested out to:
  - For 10k' flights - 2 miles (line of sight on the ground)
  - For 30k' or higher flights - 3 miles (line of sight on the ground).
- Videos of GPS Tracking testing should be included on your social media feeds and links in your final report.

4.8. FCC HAM Licensing - All student teams are HIGHLY recommended to work towards getting their HAM license (or similar for International teams).

- The 70cm APRS GPS Tracking solutions require a minimum of the primary user to be licensed at the Technician level or higher. Again, this certification is relatively easy to attain and looks great to future employers.
- Teams outside of the US should make every attempt to get licensed in their own region where possible.
- Most countries have reciprocal HAM licensing with the US. If you have a HAM license from outside of the US, make sure to bring a copy of the license printed in English with you.
- All others, make sure you know your callsign and are using it on your tracking solution.

4.9. International Teams who cannot secure a HAM License - Many international teams have confirmed that they will be unable to secure appropriate licensing for a HAM frequency.

- Teams needing an exception like this should attempt to utilize a 900MHz Featherweight GPS tracking system
- International teams should post their exception request on the HeroX GPS Tracking forums. Davinci staff are monitoring this forum and will work with you to find a workable resolution.

4.10. Assignment of Frequency - All teams will be assigned a frequency by MCC staff prior to arriving in Las Cruces.

- Failure to utilize this assigned frequency will cause significant delays in approving your project for flight and may cause your rocket to be grounded.
- Assignments will be provided to the teams via HeroX messaging and web forms.
- The MCC will maintain the team database of frequencies in order to ensure teams do not conflict with other team's frequencies.
- Frequency Hopping/Spread Spectrum transmitters are only permitted if they can be received

by the MCC, which lacks current capability to do so. As such, these transmitters are not recommended.

4.11. GPS Tracking Solution Safety Inspections - The GPS tracking information, configurations and system will be reviewed on each of the interim reports and will be physically inspected during the RANGE SAFETY CHECKOUT at the Tuesday conference session.

- Inspectors will ensure:
  - Team is utilizing their assigned frequency
  - All teams should label their rockets with team name, number and GPS frequency.
  - This label should be duplicated on each part of the rocket which could separate either as designed or accidentally.
  - Members have appropriate HAM licensing (if needed)
  - Transmitter and receivers are properly prepared.

4.12. Final GPS Tracking Systems Checkout - At the pads, teams will be instructed by the pad managers to turn on all electronics and confirm flight systems and GPS tracking systems are functioning properly.

- The team must be able to communicate with their receiving station and confirm that GPS signals are acquired and functioning properly.
- Pad managers will then call in the pad assignments and confirm that the MCC is receiving GPS telemetry successfully.
- Teams who cannot confirm GPS Tracking signal either through their team receivers or through the MCC will not be allowed to launch until the issue is resolved. Teams will not be allowed to delay launch operations and may have to return their rocket to the prep area.

4.13. MCC Coordination with tracking - The MCC has a large 30' radio tower with antenna arrays and stronger receivers. This system will be able to pick up signals at a significant further distance than handheld antennas.

- Teams attempting to recover their rocket who cannot lock onto its location should contact the MCC via their recovery backpack radio.
- They should then provide Team Identification Number. The MCC will provide the most recent updated coordinates received.

4.14. Recovery Team Training and GPS System Review at Team Registration - Students teams, upon initial arrival in Las Cruces on Monday will register/check-in at the Las Cruces Convention center.

- During the check-in process, recovery teams will be trained on utilization of the recovery backpack systems and GPS tracking systems will be reviewed and tested.

5. Propulsion systems

5.1. COTS Motors - Commercial of The Self Motors (COTS) is defined as a motor that has been certified by both the Tripoli and NAR associations. A list for all approved motors can be found on the NAR website:

http://www.nar.org/SandT/pdf/CombinedMotorsByImpulse.pdf

5.2. SRAD Motors - Student Research and Developed Motors (SRAD) – defined as any student built solid motor utilizing Non-Toxic ingredients as defined in Section 5.5. This includes all modified COTS solid motors. SRAD motors shall be static fired and well characterized before arrival to the competition. No second party motors are permitted under any circumstances.

5.3. Liquid Engine - A SRAD liquid engine is a student research and designed engine with stored fuel and stored oxidizer in the liquid state. All liquid propellants must be Non-Toxic as defined in Section 5.5. All liquid engines shall be static fired, well characterized, and tested as per section 5.18

5.4. Hybrid Engine - A hybrid engine is a student research and designed engine with a combination of solid and liquid or gaseous propellants. All hybrid propellants must be Non-Toxic as defined in Section 5.5. All hybrid engines shall be static fired, well characterized, and tested as per section 5.18

5.5. Non-Toxic Propellants - Launch vehicles entered in the IREC shall use non-toxic propellants. Ammonium perchlorate composite propellant (APCP), potassium nitrate and sugar (aka "rocket candy"), nitrous oxide, liquid oxygen (LOX), hydrogen peroxide, kerosene, propane, alcohol, and similar substances, are all considered non-toxic. Toxic propellants are defined as those requiring breathing apparatus, unique storage and transport infrastructure, extensive personal protective equipment (PPE).

5.6. Propulsion System Safing and Arming - A propulsion system is considered armed if only one action (e.g., an ignition signal) must occur for the propellant(s) to ignite.

- The "arming action" is usually something (i.e., a switch in series) that enables an ignition signal to ignite the propellant(s). The ESRA provided launch control system described in Section 11.2 of this document provides sufficient propulsion system arming functionality for almost all launch vehicles using single stage, solid rocket propulsion systems.
- For more complex systems, such as multi-stage, cluster, or hybrid, teams need to take extra care to ensure their rocket is properly safed.
- For example, a software-based control circuit that automatically cycles through an "arm function" and an "ignition function" does not, in fact, implement arming.

- In this case, the software's arm function does not prevent a single action (e.g., starting the launch software) from causing unauthorized ignition.
- This problem may be avoided by including a manual interrupt in the software program.
- Therefore, these requirements generally concern more complex propulsion systems (i.e., hybrid, liquid, and multistage systems) and all team-provided launch control systems.
- Additional requirements for team-provided launch control systems are defined in Section 11.3 of this document.

5.7. **Ground-start Ignition Circuit Arming** - All ground-started propulsion system ignition circuits/sequences shall not be "armed" until all personnel are at least 50 ft (15 m) away from the launch vehicle.

- The ESRA provided launch control system satisfies this requirement by implementing a remote “Pad HOT” sequence initiated from LCO.

5.8. **Air-start/Staged Ignition Circuit Arming** - All upper-stage (i.e., air-starts) propulsion systems shall be designed to prevent motor ignition during arming on the ground, inhibit motor ignition in the event of a non-nominal flight, and be capable of being disarmed in the event the rocket is not launched.

5.9. **Propellant Offloading After Launch Abort** - Hybrid and liquid propulsion systems shall implement a means for remotely controlled venting or offloading of all liquid and gaseous propellants in the event of a launch abort.

5.10. **Air-Start/Staged Ignition Circuit Electronics** - All upper-stage ignition systems shall comply with the same requirements and goals for “safety critical wiring” as recovery systems.

- Staged flights shall have a minimum thrust-to-weight ratio of 8 on the boost.
- The sustainer shall have a minimum thrust-to-weight ratio of 3.
- Clustered rockets shall have a minimum thrust-to-weight ratio of 6 on any motor that is ignited on the pad (i.e., the rocket must be able to fly safely if only one of the multiple motors lights).

5.11. **Air-Start/Staged Flight Computer Requirements** - Ignition of air-start motors shall be accomplished using a COTS flight computer that has the capability of performing an “altitude check” that can inhibit air-start ignition below a pre-selected altitude. Currently available flight computers that have this capability include, but are not limited to:

- Featherweight Raven
- Altus Metrum Telemega, EasyMega and EasyTimer
- MARSA Systems MARSA 54 or MARSA 33

- Student built, non-commercial flight computers are not allowed for the purpose of igniting air-start motors.
- Redundant flight computers can be used for air-start ignition, but are neither required nor recommended.
- Simple timers are prohibited except when used in combination with altitude or tilt lockout.
- Flight computers that inhibit air-start motor ignition using angle from vertical (tilt) are encouraged. Currently available flight computers that have this capability include, but are not limited to:
  - Altus Metrum TeleMega, EasyMega and EasyTimer
  - MARSA Systems Tilt Module & Interface with either the MARSA 54 or MARSA 33 flight computers
  - Multitronix Kate 2
- Projects using tilt-inhibit may be allowed to launch at an elevation of 87°+1°, rather than at 84°+1°, at the discretion of launch officials.
- “Demonstration” high altitude projects that are projected to fly in excess of 30,000 feet must utilize tilt inhibition (in addition to altitude lockout).

5.12. **Air-Start/Staged Flights – Arming Procedures** - All projects must have provisions capable of preventing air-start motor ignition on the ground.

- A provision to open the circuit between the flight computer and the initiator during power-up of the flight computer is mandatory.
- Shunts are recommended but are not required. Examples of recommended switch designs are provided in Appendix D.
- Flight computers shall not be armed until the rocket is in a vertical position.
- The electronics configuration shall be designed such that the provision used to open the circuit to the initiator can be used to again open the circuit to the initiator in the event that the rocket is not launched.

5.13. **Air-Start/Staged Flights – Motor Inhibit During Flight** - The flight computer controlling air-start motor ignition shall be configured to inhibit ignition of the air-start motor unless booster burnout has been detected and the rocket has reached an altitude of at least 80% of the simulated altitude at the time when initiator firing is desired.

- The flight computer shall be configured to prevent the air-start motor from firing at a later time if the altitude threshold was not achieved.

5.14. **Air-Start/Staged Flights – Additional Information Requirements** - Teams shall provide additional information in progress update reports specifically related to air-start flights.

- The information specified below will be provided as part of the 2nd Progress Update .
- Updated information, including a response to ESRA comments is applicable, shall be included in the 3rd Progress Update.

- The required information includes the following:
  - Schematic diagram of the electronics configuration to be used for air-start motor ignition and recovery
  - A graph illustrating flight simulation profile, to include altitude, velocity and acceleration as a function of time to the expected apogee time
  - An explanation of strategy for the flight based on the above flight profile (i.e., what is the rationale behind the selection of staging times, coast times, etc.)
  - A description of specific procedures that will be used to prevent air-start motor ignition on the ground
  - A description of specific procedures that will be used to inhibit air-start motor ignition in the event of a non-nominal flight
  - Drawing & description of the interstage coupler.

5.15. **SRAD Propulsion System Testing** - Teams shall comply with all rules, regulations, and best practices imposed by the authorities at their chosen test location(s).

- The following requirements concern verification testing of student researched and developed (SRAD) and modified commercial-off-the-shelf (COTS) propulsion systems.
- ESRA recommends teams complete these tests by April 1st of the competition year.

5.16. **Combustion Chamber Pressure Testing -** SRAD and modified COTS propulsion system combustion chambers shall be designed and tested according to the SRAD pressure vessel requirements defined in Section 6.2 of this document. Note that combustion chambers are exempted from the requirement for a relief device.

5.17. **Hybrid and Liquid Propulsion System Tanking Testing -** SRAD and modified COTS propulsion systems using liquid propellant(s) shall successfully (without significant anomalies) complete a propellant loading and off-loading test in "launch-configuration".

- This test may be conducted using either actual propellant(s) or suitable proxy fluids.
- Links to videos and testing data should be posted in your final report.

5.18. **Static Hot-Fire Testing** - SRAD propulsion systems shall successfully (without significant anomalies) complete an instrumented (chamber pressure and/or thrust), full scale (including system working time) static hot-fire test prior to the IREC.

- SRAD Solid teams must provide a BurnSim file of their intended SRAD motor along with static test data and that includes a graph of the pressure & thrust over time.
- A link to a video of successful testing must be included in your 3rd progress report.
- All SRAD motors must be designed and manufactured by the team.
- The flight motor must represent the static test motor in all respects.
- Any changes to the SRAD flight motor must be tested and resubmitted. No Exceptions.

5.19 Minimum Thrust-to-Weight Ratio

- Except as noted in section 5.10, the minimum thrust-to-weight ratio for all competition launches shall be 5:1
- Thrust-to-weight ratio will be calculated based on either initial thrust of the motor or the average thrust of the motor (whichever is greater), divided by the takeoff weight (launch vehicle plus payload) of the rocket.

6. Recovery Systems and Avionics

6.1. Dual-Event Parachute and Parafoil Recovery

Dual-Event Parachute and Parafoil Recovery - Each independently recovered launch vehicle body anticipated to reach an apogee above 1,500 ft (457 m) above ground level (AGL) shall follow a "dual-event" recovery operations concept (CONOPS).

- Dual Event recovery involves an initial deployment event with a drogue parachute deployment (or a reefed main parachute) at or near apogee followed by a main deployment event at a much lower altitude.
- Independently recovered bodies (payloads) whose apogee is not anticipated to exceed 1,500 ft (457 m) AGL are exempted from dual deployment and may feature only a single/main deployment event.
- Note: the Jolly Logic Chute Release (JLCR) is not permitted for any recovery purposes
- Tender Descender and other "Cable-Cutter" systems that are appropriately rated for large parachutes are acceptable as long as they have been thoroughly tested.

6.2. Initial Deployment Event - The initial deployment event shall occur at or near apogee to stabilize the vehicle's attitude to prevent or eliminate ballistic re-entry.

- The drogue chute is also utilized to reduce the rocket's descent rate enough to permit a successful main deployment event yet not so much as to exacerbate wind drift.
- Appropriate descent speeds under drogue should be between 75 and 150 ft/s (23-46 m/s).

6.3. Main Deployment Event - The main deployment event for any recovery method shall occur at an altitude no higher than 1,500 ft (457 m) AGL and reduce the vehicle's descent rate sufficiently to prevent excessive damage upon impact with ground (< 30 ft/s or 9 m/s).

6.4. Ejection Gas Protection - The recovery system shall implement adequate protection (e.g., fire resistant material, pistons, baffles etc...) to prevent hot ejection gases (if implemented) from causing burn damage to retaining chords, parachutes, and other vital components as the specific design demands.

6.5. Parachute Swivel Links - The recovery system rigging (e.g., parachute lines, risers, shock chords, etc.) shall implement appropriately rated swivel links at connections to relieve twist/torsion as the specific design demands.

- This will mitigate the risk of torque loads unthreading bolted connections during recovery

6.6. Parachute Coloration and markings - When separate parachutes are used for the initial and main deployment events, these parachutes should be highly dissimilar from one another visually.

- This is typically achieved by using parachutes whose primary colors contrast those of the other chute.

- This will enable ground-based observers to more easily characterize deployment events with high-power optics.

6.7. **Non-parachute/Parafoil Recovery Systems** - Teams exploring other (i.e., non-parachute or parafoil based) recovery methods shall notify ESRA of their intentions at the earliest possible opportunity, and keep ESRA apprised of the situation as their work progresses.

- ESRA may make additional requests for information and draft unique requirements depending on the team's specific design implementation.
- Range Safety personnel can deem the design as unsafe if they feel there is a possibility the recovery could depart the recovery area

6.8. **Redundant Electronics** - Launch vehicles shall implement completely independent and redundant recovery systems to include: arming switch, sensors/flight computers, power supply, energetics, and "electric initiators".

- At least one of the systems shall include a COTS flight computer.
- The systems shall be designed such that if the primary system fails the backup system will ensure a safe recovery of the launch vehicle.
- In this context, electric initiator is the device energized by the sensor electronics, which then initiates some other mechanical or chemical energy release to deploy its portion of the recovery system (i.e., electric matches, nichrome wire, etc.).

6.9. **Redundant COTS Recovery Electronics** - At least one redundant recovery system electronics subsystem shall implement a COTS flight computer (e.g., StratoLogger, G-Wiz, Raven, Parrot, AIM, EasyMini, TeleMetrum, RRC3, etc.).

- This flight computer may also serve as the official altitude logging system specified in Section 2.5 of the IREC Rules & Requirements Document.
- The COTS flight computer shall also fire either the primary or backup energetic system.
- To be considered COTS, the flight computer (including flight software) must have been developed and validated by a commercial third party.
- Commercially designed flight computer “kits” (e.g., the Eggtimer or similar) are not permitted as COTS.
- Flight computer “kits” may be used as secondary or tertiary electronics. Any student developed flight computer assembled from separate COTS components will not be considered a COTS system.
- Similarly, any COTS microcontroller running student developed flight software will not be considered a COTS system.
- Student modifications to the base software or hardware of a COTS flight controller will be considered an SRAD upgrade. As such, the flight computer will no longer be considered COTS.

6.10. **SRAD Recovery Electronics** - Teams are encouraged to develop their own flight computers, however SRAD flight computers must be well documented and provide proof of function.

- This should include ground testing as well as flight testing before the competition.

6.11. **Safety Critical Wiring for Recovery Systems and Air-Start Motors** - Safety critical wiring is defined as electrical wiring associated with recovery system deployment events and any "air started" rocket motors.

- In addition to the following requirement statements, all safety critical wiring should follow the safety critical wiring guidelines described in Appendix B of this document.

6.12. **Cable Management** - All safety critical wiring shall implement a cable management solution (e.g., wire ties, wiring, harnesses, cable raceways) which will prevent tangling and excessive free movement of significant wiring/cable lengths due to expected launch loads.

- This requirement is not intended to negate the small amount of slack necessary at all connections/terminals to prevent unintentional de-mating due to expected launch loads transferred into wiring/cables at physical interfaces.

6.13. **Secure Wiring Connections** - All safety critical wiring/cable connections shall be sufficiently secure as to prevent disconnecting due to expected launch loads.

- This will be evaluated by a "tug test", in which the connection is gently but firmly "tugged" by hand to verify it is unlikely to break free in flight.

6.14. **Recovery System Energetic Devices** - All stored-energy devices (aka energetics) used in recovery systems shall comply with the energetic device requirements defined in Section 6.18 of this document.

6.15. **Recovery system Testing** - Teams shall comply with all rules, regulations, and best practices imposed by the authorities at their chosen test location(s).

- The following requirements concern verification testing of all recovery systems. ESRA recommends teams complete these tests by 01 April.
- While not a requirement, this date is recommended to assure teams are prepared for the IREC.

6.16. **Ground test demonstration** - All recovery system mechanisms shall be successfully (without significant anomalies) tested prior to the IREC, either by flight testing, or through one or more ground tests of key subsystems.

- In the case of such ground tests, sensor electronics will be functionally included in the demonstration by simulating the environmental conditions under which their deployment function is triggered.

- A link to all videos of the testing cycle(s) should be included in the final report.

6.17. **Optional Flight Test Demonstration** - While not required, a flight test demonstration may be used in place of ground testing.

- In the case of such a flight test, the recovery system flown will verify the intended design by implementing the same major subsystem components (e.g., flight computers and parachutes) as will be integrated into the launch vehicle intended for the IREC (i.e., a surrogate booster may be used).
- A link to a video of the test flight should be included in the final report.

6.18. **Stored-energy Devices - Energetic Device Safing and Arming** - All energetics shall be safed until the rocket is in the launch position, at which point they may be "armed".

- An energetic device is considered safed when two separate events are necessary to release the energy.
- An energetic device is considered armed when only one event is necessary to release the energy.
- Energetics are defined as all stored-energy devices, other than propulsion systems, that have reasonable potential to cause bodily injury upon energy release.
- The following table lists some common types of stored-energy devices and overviews in what configuration they are considered non-energetic, safed, or armed.

DEVICE CLASS	NON-ENERGETIC	SAFED	ARMED
Igniters/Squibs	Small igniters/squibs, nichrome, wire or similar	Large igniters with leads shunted	Large igniters with no-shunted leads
Pyrogens (e.g., black powder)	Very small quantities contained in non-shrapnel producing devices (e.g., pyro-cutters or pyro-valves)	Large quantities with no igniter, shunted igniter leads, or igniter(s) connected to unpowered avionics	Large quantities with non-shunted igniter or igniter(s) connected to powered avionics
Mechanical Devices (e.g., powerful springs)	De-energized/relaxed state, small devices, or captured devices (i.e., no jettisoned parts)	Mechanically locked and not releasable by a single event	Unlocked and releasable by a single event
Pressure Vessels	Non-charged pressure vessels	Charged vessels with two events required to open main valve	Charged vessels with one event required to open main valve

- Although these definitions are consistent with the propulsion system arming definition, this requirement is directed mainly at the energetics used by recovery systems and extends to all other energetics used in experiments, control systems, etc.

- Note that while Section 5.6 requires propulsion systems be armed only after the launch rail area is evacuated to a specified distance, this requirement permits personnel to arm other stored-energy devices at the launch rail.
- Teams should not bring excessive amounts of pyrogenic materials to the event. If your rocket requires a total of 12g of BP or Pyrogen, please do not transport a large container (~1lbs) to the event. A smaller plastic container (<40g) would be most appropriate.

6.19. **Arming Device Access** - All energetic device arming features shall be externally accessible/controllable. This does not preclude the limited use of access panels which may be secured for flight while the vehicle is in the launch position

6.20. **Arming Device Location** - All energetic device arming features shall be located on the airframe such that any inadvertent energy release by these devices will not impact personnel arming them.

- For example, the arming key switch for an energetic device used to deploy a hatch panel shall not be located at the same airframe clocking position as the hatch panel deployed by that charge.

6.21. **SRAD Pressure Vessels** - The following requirements concern design and verification testing of SRAD and modified COTS pressure vessels. Unmodified COTS pressure vessels utilized for other than their advertised specifications will be considered modified, and subject to these requirements. SRAD (including modified COTS) rocket motor propulsion system combustion chambers are included as well but are exempted from the relief device requirement.

6.22. **Relief Device** - SRAD pressure vessels shall implement a relief device, set to open at no greater than the proof pressure specified in the following requirements. SRAD (including modified COTS) rocket motor propulsion system combustion chambers are exempted from this requirement.

6.23. **Designed burst Pressure for Metallic Pressure Vessels** - SRAD and modified COTS pressure vessels constructed entirely from isentropic materials (e.g., metals) shall be designed to a burst pressure no less than 2 times the maximum expected operating pressure, where the maximum operating pressure is the maximum pressure expected during pre-launch, flight, and recovery operations

6.24. **Designed Burst Pressure for Composite Pressure Vessels** - All SRAD and modified COTS pressure vessels either constructed entirely from non-isentropic materials (e.g., fiber reinforced plastics; FRP; aka composites), or implementing composite overwrap of a metallic vessel (aka composite overwrapped pressure vessels; COPV), shall be designed to a burst pressure no less than 3 times the maximum expected operating pressure, where the maximum operating pressure is the maximum pressure expected during pre-launch, flight, and recovery operations.

6.25. **SRAD Pressure Vessel Testing** - Teams shall comply with all rules, regulations, and best practices imposed by the authorities at their chosen test location(s). The following requirements concern design and verification testing of SRAD and modified COTS pressure vessels. Unmodified COTS pressure vessels utilized for other than their advertised specifications will be considered modified, and subject to these requirements. SRAD (including modified COTS) rocket motor propulsion system combustion chambers are included as well. ESRA recommends teams complete these tests by 01 April. While not a requirement, this date is recommended to assure teams are prepared for the IREC.

- Proof Pressure Testing - SRAD and modified COTS pressure vessels shall be proof pressure tested successfully (without significant anomalies) tested to 1.5 times the maximum expected operating pressure for no less than twice the maximum expected system working time, using the intended flight article(s) (e.g., the pressure vessel(s) used in proof testing must be the same one(s) flown at the IREC).
- The maximum system working time is defined as the maximum uninterrupted time duration the vessel will remain pressurized during pre-launch, flight, and recovery operations.
- Optional Burst Pressure Testing - Although there is no requirement for burst pressure testing, a rigorous verification & validation test plan typically includes a series of both non-destructive (i.e., proof pressure) and destructive (i.e., burst pressure) tests.
- A series of burst pressure tests performed on the intended design will be viewed favorably; however, this will not be considered an alternative to proof pressure testing of the intended flight article.

7. Active Flight Control Systems

7.1. Restricted Control Functionality - Launch vehicle active flight control systems shall be optionally implemented strictly for pitch and/or roll stability augmentation, or for aerodynamic "braking".

- Under no circumstances will a launch vehicle entered in the IREC be actively guided towards a designated spatial target.
- ESRA may make additional requests for information and draft unique requirements depending on the team's specific design implementation.

7.2. Unnecessary for Stable Flight - Launch vehicles implementing active flight controls shall be naturally stable without these controls being implemented (e.g., the launch vehicle may be flown with the control actuator system [CAS] – including any control surfaces – either removed or rendered inert and mechanically locked, without becoming unstable during ascent).

- Attitude control systems (ACS) will serve only to mitigate the small perturbations which affect the trajectory of a stable rocket that implements only fixed aerodynamic surfaces for stability.
- Stability is defined in Section 10.2 of this document. ESRA may make additional requests for information and draft unique requirements depending on the team's specific design implementation.

7.3. Designed to fail Safe - Control actuator systems (CAS) shall mechanically lock in a neutral state whenever either an abort signal is received for any reason, primary system power is lost, or the launch vehicle's attitude exceeds 30° from its launch elevation.

- Any one of these conditions being met will trigger the fail safe, neutral system state. A neutral state is defined as one which does not apply any moments to the launch vehicle (e.g., aerodynamic surfaces trimmed or retracted, gas jets off, etc.).

7.4. Boost Phase Dormancy - CAS shall mechanically lock in a neutral state – defined in Section 7.3 of this document – until either the mission's boost phase has ended (i.e., all propulsive stages have ceased producing thrust), the launch vehicle has crossed the point of maximum aerodynamic pressure (aka max Q) in its trajectory, or the launch vehicle has reached an altitude of 20,000 ft (6,096 m) AGL.

- Any one of these conditions being met will permit the active system state.
- A neutral state is defined as one which does not apply any moments to the launch vehicle (e.g., aerodynamic surfaces trimmed or retracted, gas jets off, etc.).

7.5. **Active Flight Control System Electronics** - Wherever possible, all active control systems should comply with requirements and goals for "redundant electronics" and "safety critical wiring" as recovery systems—understanding that in this case "initiation" refers to CAS commanding rather than a recovery event.

- Flight control systems are exempt from the requirement for COTS redundancy, given that such components are generally unavailable as COTS to the amateur high-power rocketry community.

7.6. **Active Flight Control System Energetics -** All stored-energy devices used in an active flight control system (aka energetics) shall comply with the energetic device requirements defined in Section 6.18 of this document.

8. Airframe structures

8.1. Adequate Venting - Launch vehicles shall be adequately vented to prevent unintended internal pressures developed during flight from causing either damage to the airframe or any other unplanned configuration changes.

- Typically, a 1/8 to 3/16 inch (0.318 to 0.476 cm) hole is drilled in the booster section just behind the nose cone or payload shoulder area, and through the hull or bulkhead of any similarly isolated compartment/bay.

8.2. Overall Structural Integrity - Launch vehicles will be constructed to withstand the operating stresses and retain structural integrity under the conditions encountered during handling as well as rocket flight.

- The following requirements address some key points applicable to almost all amateur high power rockets, but are not exhaustive of the conditions affecting each unique design.
- Student teams are ultimately responsible for thoroughly understanding, analyzing, and mitigating their design's unique load set.

8.3. Material Selection - PVC (and similar low-temperature polymers), Public Missiles Ltd. (PML) Quantum Tube, and stainless steel components shall not be used in any structural (i.e., load bearing) capacity, most notably as launch vehicle airframes, or solid propulsion system combustion chambers.

8.4. Load Bearing EyeBolts And U-Bolts - All load bearing eye bolts shall be of the closed-eye, forged type – NOT of the open eye, bent wire type.

- All load bearing eye bolts and U-Bolts shall be steel.
- This requirement extends to any bolt and eye-nut assembly used in place of an eyebolt.

8.5. Implementing Coupling Tubes - Airframe joints which implement "coupling tubes" should be designed such that the coupling tube extends no less than one body caliber on either side of the joint – measured from the separation plane.

- Regardless of implementation (e.g., RADAX or other join types) airframe joints will be "stiff" (i.e., prevent bending).

8.6. Rail Guides Mechanical Attachment - Rail guides should implement "hard points" for mechanical attachment to the launch vehicle airframe.

- These hardened/reinforced areas on the vehicle airframe, such as a block of wood installed on the airframe interior surface where each launch lug attaches, will assist in mitigating lug "tear outs" during operations.

- At the IREC, competition officials will require teams to lift their launch vehicles by the rail guides and/or demonstrate that the bottom guide can hold the vehicle's weight when vertical before permitting them to proceed with launch preparations.

- Fly-away rail guides are not permitted for rockets greater than 98mm diameter, or weighing more than 50 lbs.

- Subject to the above size and weight restrictions, fly-away rail guides are permitted as long as they are launch-tested on a rocket of similar size, weight, and thrust.

8.7. **Aft Most Launch Rail Guide -** The aft most launch rail button shall support the launch vehicle's fully loaded launch weight while vertical.

- At the IREC, Range Safety Officers will require teams to lift their launch vehicles by the rail guides and/or demonstrate that the bottom guide can hold the vehicle's weight when vertical before permitting them to proceed with launch preparations.

8.8. **Identifying Markings** - The team's Team ID (a number assigned by ESRA prior to the IREC), project name, and academic affiliation(s) shall be clearly identified on the launch vehicle airframe, nose cone and other locations where possible.

- The Team ID especially, will be prominently displayed (preferably visible on all four quadrants of the vehicle, as well as fore and aft), assisting competition officials to positively identify the project hardware with its respective team throughout the IREC.
- ESRA does not provide any guarantee that lost rockets may be recovered or returned to the teams after the competition has ended. If a rocket is found with identifying markings, every effort will be made to return the components to the team at the team’s expense.

8.9. **Other Markings -** There are no requirements for airframe coloration or markings beyond those specified in Section 8.8 of this document; however, ESRA offers the following recommendations to student teams.

- Mostly white or lighter tinted color (e.g., yellow, red, orange, etc.) airframes are especially conducive to mitigating some of the solar heating experienced in the IREC launch environment.
- High-visibility schemes (e.g., high-contrast black, orange, red, etc.) and roll patterns (e.g., contrasting stripes, “V” or “Z” marks, etc..) may allow ground-based observers to more easily track and record the launch vehicle’s trajectory with high-power optics.
- Any form of green or brown or colors associated with camouflage patterns is highly discouraged.

9. Payload

9.1. Payload Recovery - Payloads may be deployable or remain attached to the launch vehicle throughout the flight.

- Deployable payloads shall incorporate an independent recovery system, reducing the payload's descent velocity to less than 30 ft/s (9 m/s) before it descends through an altitude of 1,500 ft AGL.
- Note that while deployable payloads implementing a drone, glider, parachute or parafoil based recovery system are not required to comply with the dual-event requirements (the intent being to accommodate certain science/engineering packages requiring extended mission time).
- Teams are advised that any hardware drifting outside the safe recovery area or onto White Sands Missile Range (WSMR) must be either abandoned or recovered at the team's own expense.
- WSMR is located approximately 10 miles (16 km) East from the NMSA Vertical Launch Area (VLA). No teams are allowed to enter WSMR lands.

9.2. Payload Recovery System Electronics and Safety Critical Wiring - Payloads implementing independent recovery systems shall comply with the same requirements and goals as the launch vehicle for "redundant electronics" and "safety critical wiring".

- These requirements and goals are defined in Sections 6.8 and 6.13 respectively of this document.

9.3. Payload Recovery System Testing - Payloads implementing independent recovery systems shall comply with the same requirements and goals as the launch vehicle for "recovery system testing".

- These requirements and goals are defined in Section 6.15 of this document.

9.4. Payload Energetic Devices - Payloads MAY NOT include any form of pyrotechnics. These include but are not limited to: rocket motors, exploding bolts, or other energetics.

10. Launch and Ascent Trajectory Requirements

10.1. Launch Azimuth and Elevation - Launch vehicles shall nominally launch at an elevation angle of 84° ±1° and a launch azimuth defined by competition officials at the IREC.

- Range Safety Officers reserve the right to require certain vehicles' launch elevation be lower if possible flight safety issues are identified during pre-launch activities.
- Competition officials may allow staged flights to launch at 87°+1° if the rocket is using “tilt” to inhibit air-start motor ignition.

10.2. Launch Stability - Launch vehicles shall have sufficient velocity upon departing the launch rail to assure they will follow predictable flight paths.

- A rail departure velocity of at least 100 ft/s (30.5 m/s) is generally acceptable.
- Teams unable to meet this velocity requirement may use detailed analysis to prove stability is achieved at a lower rail departure velocity (greater than 50 ft/s [15.24 m/s]), preferably via flight testing. Alternatively, computer simulation can be used, but must evaluate stability under a variety of launch conditions --- a single simulation run is not sufficient.
- Teams shall comply with all rules, regulations and best practices imposed by the authorities at their chosen test location(s).
- Departing the launch rail is defined as the first instant in which the launch vehicle becomes free to move about the pitch, yaw, or roll axis.
- This generally occurs at the instant the last rail guide forward of the vehicle's center of gravity (CG) separates from the launch rail.
- Note that ESRA will provide teams with launch rails measuring 17 ft (5.2 m) in length.
- Teams whose designs anticipate requiring a longer launch rail to achieve stability during launch must provide their own.

10.3. Ascent Stability - Launch vehicles shall remain "stable" for the entire ascent.

- Stable is defined as maintaining a static margin of at least 1.5 to 2 body calibers, regardless of CG movement due to depleting consumables and shifting center of pressure (CP) location due to wave drag effects (which may become significant as low as 0.5 M).
- Stability shall not fall below 1.5 body calibers to be considered nominal, while falling below 1.5 body calibers will be considered a loss of stability.

10.4. Over-Stability - Launch vehicles will not be "over-stable" during their ascent.

- A launch vehicle may be considered over-stable when it has a static margin significantly greater than 2 body calibers (e.g., greater than 6 body calibers at liftoff.
- Over-stable rockets are particularly vulnerable to crosswind or wind shear effects, which often occur in New Mexico.

11. ESRA Provided Launch Support Equipment

ESRA Provided Launch Support Equipment - All teams competing in the COTS or SRAD solid categories will be required to use ESRA supplied launch rails and launch control systems.

11.1. ESRA-provided Launch Rails

ESRA-provided Launch Rails - ESRA will provide launch rails that feature 17 ft (5.2 m) long, 1.5" x 1.5" (aka 1515) aluminum guide rails of the 80/20® type.

- More details on 80/20® rail profiles may be located on the 80/20® Inc. website: https://8020.net/).
- These rails will accommodate almost any rocket body diameter and fin length.
- On these rails, the rocket is loaded horizontally on top of the guide rail and then the rail is erected to the required launch elevation. All launch vehicles shall attach to these launch rails via at least two rail guides (lugs/buttons/etc...) which, together, support the vehicle's fully loaded launch weight if suspended horizontally.
- Once erected, the launch vehicle will be supported vertically by a submerged mechanical stop in the rail - whose position may be adjusted.
- At the IREC, Competition officials will require teams to lift their launch vehicles by the rail guides and/or demonstrate that the bottom guide can hold the vehicle's weight when vertical before permitting them to proceed with launch preparations.

11.2. ESRA-Provided Launch Control System

ESRA-Provided Launch Control System - ESRA utilizes a Wilson F/X Wireless Launch Control System consisting of one LCU-64x launch control unit and up to four PBU-8w encrypted wireless pad relay boxes

- More details on Wilson F/X Digital Launch Control Systems may be found on the Wilson F/X website: www.wilsonfx.com).
- Each pad relay box may connect and relay a launch command to as many as eight independent launch pads, enabling the launch control unit to command as many as 32 independent launch pads when fully configured.
- Connection wires are run from the pad relay box to each launch pad.
- These wires are connected to the motor igniter(s) utilizing alligator clips.
- Fault tolerance, including propulsion system arming functionality is provided for simple/non-complex, single stage solid propellant rockets by signal encryption and physical arming keys located on the pad relay boxes and launch control unit.

11.3. Team-Provided Launch Support Equipment

- **Equipment Portability -** If possible/practical, teams should make their launch support equipment man-portable over a short distance (a few hundred feet).
- Environmental considerations at the launch site permit only limited vehicle use beyond designated roadways, campgrounds, and basecamp areas.

11.4. **Launch Rail Elevation** - Team provided launch rails shall be set to an appropriate angle that is provided and confirmed by the range safety officer.

11.5. **Operational Range -** All team provided launch control systems shall be electronically operated and have a minimum operational range of no less than 1,500 ft from the launch rail.

- A 2,000 ft operational range is preferred.
- The maximum operational range is defined as the range at which launch may be commanded reliably.

11.6. **Fault Tolerance and Arming -** All team provided launch control systems shall be at least single fault tolerant by implementing a removable safety interlock (i.e. a jumper or key to be kept in possession of the arming crew during arming) in series with the launch switch.

- Appendix C of this document provides general guidance on assuring fault tolerance in amateur high power rocketry launch control systems.

11.7. **Safety Critical Switches** - All team provided launch control systems shall implement ignition switches of the momentary, normally open (aka "deadman") type so that they will remove the signal when released.

- Mercury or "pressure roller" switches are not permitted anywhere in team provided launch control systems.

APPENDIX A: ACRONYMS, ABBREVIATIONS, AND TERMS

ACRONYMS & ABBREVIATIONS	
ACS	Attitude Control System
AGL	Above Ground Level
APCP	Ammonium Perchlorate Composite Propellant
CAS	Control Actuator System
CFR	Code of Federal Regulations
CG	Center of Gravity
CONOPS	Concept of Operations
COPV	Composite Overwrapped Pressure Vessel
COTS	Commercial Off-the-Shelf
CP	Center of Pressure
ESRA	Experimental Sounding Rocket Association
FRP	Fiber Reinforced Plastic
IREC	Intercollegiate Rocket Engineering Competition
LOX	Liquid Oxygen
NFPA	National Fire Protection Association
NMSA	New Mexico Spaceport Authority; aka Spaceport America
SAC	Spaceport America Cup
SRAD	Student Researched & Developed
TBD	To Be Determined
TBR	To Be Resolved
TRA	Tripoli Rocketry Association
VLA	Spaceport America Vertical Launch Area
WSMR	White Sands Missile Range
ZSF	Zero Separation Force

TERMS

Amateur Rocket	14 CFR, Part 1, 1.1 defines an amateur rocket as an unmanned rocket that is "propelled by a motor, or motors having a combined total impulse of 889,600 Newton-seconds (200,000 pound-seconds) or less, and cannot reach an altitude greater than 150 kilometers (93.2 statute miles) above the earth's surface".
Body Caliber	A unit of measure equivalent to the diameter of the launch vehicle airframe in question.
Excessive Damage	Excessive damage is defined as any damage to the point that, if the systems intended consumables were replenished, it could not be launched again safely. Intended Consumables refers to those items which are - within reason - expected to be serviced/replaced following a nominal mission (e.g., propellants, pressurizing gasses, energetic devices), and may be extended to include replacement of damaged fins specifically designed for easy, rapid replacement.
FAA Class 2 Amateur Rocket	14 CFR, Part 101, Subpart C, 101.22 defines a Class 2 Amateur Rocket (aka High Power Rocket) as "an amateur rocket other than a model rocket that is propelled by a motor or motors having a combined total impulse of 40,960 Newton-seconds (9,208 pound-seconds) or less."
Non-toxic Propellants	For the purposes of the Spaceport America Cup: IREC, the event organizers consider ammonium perchlorate composite propellant (APCP), potassium nitrate and sugar (aka "rocket candy"), nitrous oxide, liquid oxygen (LOX), hydrogen peroxide, kerosene, propane and similar, as non-toxic propellants. Toxic propellants are defined as requiring breathing apparatus, special storage and transport infrastructure, extensive personal protective equipment, etc.

Appendix B: Safety Critical Wiring Guidelines

Introduction

- With the aim of supporting recovery reliability and overall safety, this white paper sets out guidelines for all safety critical wiring. This is defined as wiring associated with drogue (or other drag device) deployment, main parachute deployment, and any air-start rocket motors.
- The wiring techniques described here are optimized for inspection and ease of field repair. All non-critical wiring is outside the scope of this white paper.

Wiring Guidelines

- All wire should be stranded, insulated, 22 AWG or larger. Strands should be copper, plated with either silver or tin (entire wire, not just the ends).
- When an off-the-shelf component includes flying leads, those leads may be used unmodified. For example, an E-match may contain solid wire, a battery connector may integrate 26 AWG wire, etc.
- Stranded wire of sizes smaller than 22 AWG may be used only when needed by an off-the-shelf component. For example, if the terminal block on an altimeter is sized to accept 24 AWG wires then that is the size of wire that should be used for that portion of the circuit.
- Wire strands should never be removed in order to allow a wire to fit into a smaller hole or terminal. Use smaller wire for this purpose.
- Wire should be stripped only with a wire stripping tool of the correct gauge. Any severed strands should be cause for rejection.
- Each end of a wire should be terminated in one of the following approved methods, with exceptions in Paragraphs 4 and 5 below:
    - Crimped into a crimp terminal (preferred). This includes crimp terminals on multi-conductor connectors such as 9-pin D-sub connectors (see table below).
    - Screwed into a binding screw terminal (acceptable).
    - Wires should be terminated into a terminal block, only if a piece of off-the-shelf equipment (i.e., an altimeter) has built-in terminal blocks and so there is no other choice. Two-piece terminal blocks must be positively secured together – friction fit is insufficient.
- Wires should be terminated by soldering, only if a piece of off-the-shelf equipment (i.e., an arming key switch) has built-in solder terminals and so there is no other choice.
- The reliability of solder joints cannot be established by visual inspection alone.
- All crimp operations should be performed with the correct tooling, using crimp terminals sized for the appropriate wire gauge.
- Where multiple wires are crimped into a single terminal, calculate the effective gauge (for example, two 22 AWG are effectively 19 AWG).
- Terminals with insulated plastic sleeves (usually color-coded to indicate barrel size) should not be crimped.
- If a terminal is supplied with an insulated plastic sleeve, it should be removed prior to use. It may be necessary to adjust the crimp tooling to get a tighter squeeze.
- The crimp quality of insulated terminals is difficult to inspect.

- There is normally no need for insulation when terminals are mounted properly in barrier blocks. If insulation is needed, add clear heat-shrink tubing.
- When a bare wire is held down by a binding screw terminal the wire should make a 180 degree hook, and strands must be visible exiting the screw head. Only one wire should be permitted per screw.
- The wire bend should be clockwise, so that it will tighten as the screw is torqued.
- When ring or spade terminals are held down by binding screw terminals, a maximum of two terminals are allowed per screw.
- A maximum of three wires should be crimped into a single terminal barrel. Butt-splice terminals are considered to have separate barrels in each end.
- If two or more wires must be joined, one of the following approved methods should be used:
    - Crimp a ring terminal onto each wire, and then screw them into a barrier block. Add approved barrier block jumper pieces if many wires must be joined.
    - Screw bare wires under binding head screws in a barrier block. Add approved barrier block jumper pieces if many wires must be joined.
    - Crimp the wires into an uninsulated butt-splice terminal, and then insulate with clear heat-shrink tubing.
    - Any wire-twisting splice method (including wire nuts) is explicitly forbidden. Forget everything you know about household wiring. Houses don't see launch vibration!
- All insulating tubing (usually heat-shrink) should be transparent. This allows inspection of the underlying hardware.
- No tape, glue or RTV should be used to insulate or bundle any element of the wire harness.
- The following rules apply to connectors:
    - They should use crimp contacts, as soldering has been forbidden.
    - They should use a positive locking mechanism to keep the two halves mated under vibration and tension. Friction fit alone is not acceptable.
    - Plastic connector latches should not be used (such as found on automotive applications), but circular connectors with plastic coupling nuts are acceptable.
- Individual wires should be bundled together to make a harness (factory multi-conductor wiring in a common outer jacket is also acceptable).
- The safety critical harness should be kept separate from the payload harness (if any).
- Bundling should be accomplished by:
    - A light twist (for mechanical reasons only, no EMC mitigation is intended).
    - Short (1 cm) lengths of clear heat-shrink tubing or zip-ties every 5 cm.
    - Wire mesh sleeving, provided it allows for inspection of the wiring inside.
- The harness should be supported by plastic P-clamps. It should not be permitted to touch any sharp edge or screw thread.
- All items that are connected by the harness (barrier blocks, sensors, batteries, actuators, switches, etc.) should be rigidly fixed to the rocket structure so that they cannot move.
- Rigid fixing implies attachment with threaded fasteners or a solid glue bond. Cable ties and/or tape are not acceptable examples of rigid fixing.

- No wire should be tight. All wire must have some slack, demonstrated by a curve at its termination.
- Batteries should be connected appropriately:
  - 9V transistor batteries should be secured in clips, and connected using proper snap terminals.
  - Gel-cell batteries should be secured with clamps, and connected using "faston" crimp terminals.
  - Cylindrical batteries (AAA, AA, C, D, etc.) should be mounted into commercial holders. The holders should be rigidly secured to the structure, and the batteries should then be strapped into the holders.

Circuit Board Guidelines

- All heavy components should be staked.
- All IC sockets and press-fit contacts should be positively restrained so that they cannot disconnect under vibration.
- Provided they are done right, wire wrap, through-hole solder, and surface-mount solder are all acceptable fabrication methods.
- Solderless breadboards (aka plug-in breadboards) should not be used.
- Any commercial board for the high-power rocketry market should be considered to be of sufficient quality, provided it is in an undamaged factory state.

Recommended Parts

- Here are some recommended components that can be bought from Digikey, Mouser, Omron, and Amazon that will help to satisfy the wiring guidelines.
- These are recommendations only, and you are free to choose other parts and buy from other suppliers.
- Look up the catalog pages associated with each Digikey or Mouser number to find similar parts of different sizes.

Part	Number	Notes
Wire	Digikey A5855W-100-ND	This is good 22-gauge, tinned, Teflon insulated wire. Cold-flow is a long-term consideration, but shouldn't be a problem for a short lifetime rocket.
Wire	Digikey C2016L-100-ND	22-gauge tinned PVC-insulated wire. Note that the “L” designates the insulation color (other colors are B,R,A,Y,N,W)
Wire	Digikey W120-100-ND Digikey W121-100-ND	2-conductor, 22-gauge 3-conductor, 22-gauge
Wire	Amazon “Tinned marine grade wire”	18-gauge, available in 35-ft or 100-ft rolls
Ring terminals, uninsulated	Digikey A27021-ND (#6 hole)	The Solistrand series is a high quality terminal. Various crimp tools are available. You get what you pay for – the expensive ones are very nice, but the basic ones will do in a pinch.
Butt-splice terminal	Digikey A09012-ND	Another Solistrand series terminal
“Faston” terminal	Digikey 298-10011-ND (check size)	These terminals are useful for connecting switches, gel cell batteries, and many automotive devices
9V battery holder, with solder terminals	Digikey 708-1409-ND	Screw this holder to your chassis, and then cable tie the battery in. Note: snap-on 9V battery connectors such as Digikey BS12I-ND are not acceptable.
4 AA battery holder	Digikey 708-1399-ND	This is a nice enclosed battery box for 4 AA cells

P-clamp	Digikey 7624K-ND (check size)	This particular unit is for a 0.25” dia. harness. Select the correct size.
Heat-shrink tubing	Digikey A014C-4-ND (check size) Mouser 650-RNF100 (check size)	Material is clear polyolefin with low shrink temperature. Shrink with hot-air gun or oven.
Barrier block (double row)	Digikey CBB206-ND Mouser 538-2140 or 4140 (0.375” pitch), 538-2141 or 4141 (0.438” pitch)	Available in a range of lengths. Can accept ring or spade terminals (preferred), or bare wire (acceptable).
Barrier block jumper	Digikey CBB314-ND	Connect adjacent strips when many wires need to be connected together
D-sub connectors (9 contact)	Digikey A31886-ND (male shell) Digikey A34104-ND (female shell) Digikey A1679-ND (male pins) Digikey A1680-ND (female pins)	The connectors and contacts are cheap, but the crimp tools are expensive.
D-sub fixing hardware	Digikey MDVS22-ND (screw) Digikey MDVS44-ND (socket)	These kits convert the D-sub friction fit into a proper positive lock.
MIL-C-38999 connectors	Digikey 956-1017-ND (13 pin panel mount receptacle with pins) Digikey 956-1020-ND (13 pin plug with sockets)	These connectors approach the style and quality used on orbital launch vehicles. Extremely robust, but very expensive!
Switch for pull-pin	Omron SS-5G	This switch is rated to 30G. Available direct or as part of some commercial pull-pin switches

Appendix C: Fire Control System Design Guidelines

Introduction

- The following white paper is written to illustrate safe fire control system design best practices and philosophy to student teams participating in the IREC. When it comes to firing (launch) systems for large amateur rockets, safety is paramount. This is a concept that everyone agrees with, but it is apparent that few truly appreciate what constitutes a "safe" firing system. Whether they've ever seen it codified or not, most rocketeers understand the basics:
    - The control console should be designed such that two deliberate actions are required to fire the system.
    - The system should include a power interrupt such that firing current cannot be sent to the firing leads while personnel are at the pad and this interrupt should be under the control of personnel at the pad.
    - These are good design concepts and if everything is working as it should they result in a perfectly safe firing system. But "everything is working as it should" is a dangerous assumption to make. Control consoles bounce around in the backs of trucks during transport. Cables get stepped on, tripped over, and run over. Switches get sand and grit in them. In other words, components fail. As such, there is one more concept that should be incorporated into the design of a firing system:
        - The failure of any single component should not compromise the safety of the firing system.

Proper Fire Control System Design Philosophy

- Let us examine a firing system that may at first glance appear to be simple, well designed, and safe (Figure 1). If everything is functioning as designed, this is a perfectly safe firing system, but let's examine the system for compliance with proper safe design practices.
- The control console should be designed such that two deliberate actions are required to launch the rocket. Check! There are actually three deliberate actions required at the control console: (1) insert the key, (2) turn the key to arm the system, (3) press the fire button.
- The system should include a power interrupt such that ignition current cannot be sent to the firing leads while personnel are at the pad and this interrupt should be under control of personnel at the pad. Check and check! The Firing relay effectively isolates the electric match from the firing power supply (battery) and as the operator at the pad should have the key in his pocket, there is no way that a person at the control console can accidentally fire the rocket.
- But all of this assumes that everything in the firing system is working as it should. Are there any single component failures that can cause a compromise in the safety of this system? Yes. In a system that only has five components beyond the firing lines and e-match, three of those components can fail with potentially lethal results.

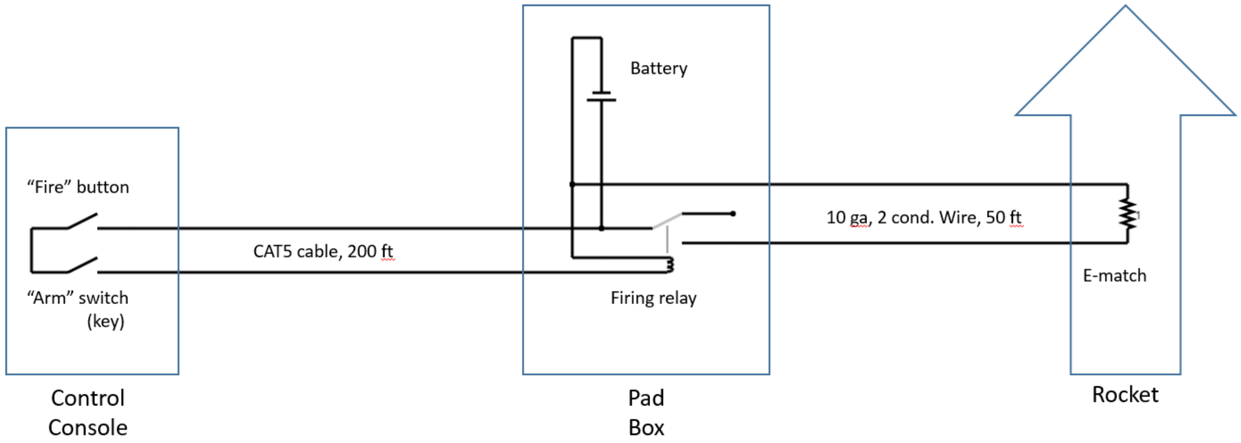


Figure 1: A simple high current fire control system.

Firing Relay

- If the firing relay was stuck in the ON position: The rocket would fire the moment it was hooked to the firing lines.
- This is a serious safety failure with potentially lethal consequences as the rocket would be igniting with pad personnel in immediate proximity.

Arming Switch

- If the arm key switch failed in the ON position simply pushing the fire button would result in a fired rocket whether intentional or not. This is particularly concerning as the launch key – intended as a safety measure controlled by pad personnel – becomes utterly meaningless.
- Assuming all procedures were followed, the launch would go off without a hitch. Regardless, this is a safety failure as only one action (pressing the fire button) would be required at the control console to launch the rocket. Such a button press could easily happen by accident.
- If personnel at the pad were near the rocket at the time we are again dealing with a potentially lethal outcome

CAT5 Cable

- If the CAT5 cable was damaged and had a short in it the firing relay would be closed and the rocket would fire the moment it was hooked to the firing lines. This too is a potentially lethal safety failure.

Notice that all three of these failures could result in the rocket being fired while there are still personnel in immediate proximity to the rocket. A properly designed firing system does not allow single component failures to have such drastic consequences. Fortunately, the system can be fixed with relative ease. Consider the revised system (Figure 2). It has four additional features built into it: (1) A separate battery to power the relay (as opposed to relying on the primary battery at the pad), (2) a flip cover over the fire button, (3) a lamp/buzzer in parallel with the firing leads (to provide a visual/auditory warning in the event that voltage is present at the firing lines), and (4)a switch to short out the firing leads during hookup (pad personnel should turn the shunt switch ON anytime they approach the rocket).

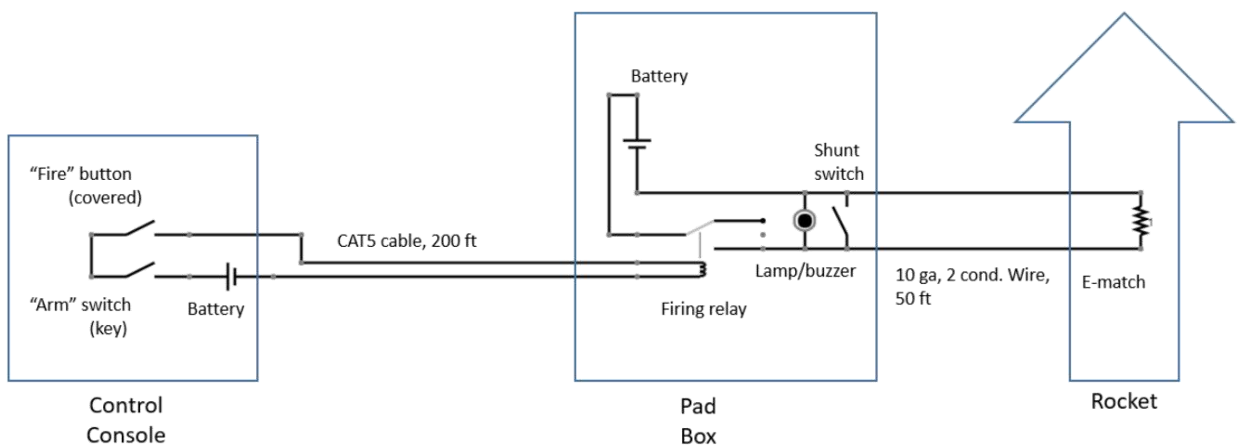


Figure 2: An improved high current fire control system.

In theory, these simple modifications to the previous firing circuit have addressed all identified single point failures in the system. The system has 8 components excluding the firing lines and e-match (part of the rocket itself). Can the failure of any of these components cause an inadvertent firing? That is the question. Let us examine the consequences of the failure of each of these components.

Fire Button

- If the fire button fails in the ON position, there are still two deliberate actions at the control console required to fire the rocket. (1) The key must be inserted into the arming switch, and (2) the key must be rotated.
- The firing will be a bit of a surprise, but it will not result in a safety failure as all personnel should have been cleared by the time possession of the key is transferred to the Firing Officer.

Arm Switch

- If the arm switch were to fail in the ON position, there are still two deliberate actions at the control console required to fire the rocket. (1) The cover over the fire button would have to be removed, and (2) the fire button would have to be pushed.

- This is not an ideal situation as the system would appear to function flawlessly even though it is malfunctioning and the key in the possession of personnel at the launch pad adds nothing to the safety of the overall system.
- It is for this reason that the shunting switch should be used. Use of the shunting switch means that any firing current would be dumped through the shunting switch rather than the e-match until the pad personnel are clear of the rocket.
- Thus, personnel at the pad retain a measure of control even in the presence of a malfunctioning arming switch and grossly negligent use of the control console.

Batteries

- If either battery (control console or pad box) fails, firing current cannot get to the e-match either because the firing relay does not close or because no firing current is available.
- No fire means no safety violation.

CAT5 Cable

- If the CAT5 cable were to be damaged and shorted, the system would simply not work as the current intended to pull in the firing relay would simply travel through the short. No fire means no safety violation.

Firing Relay

- If the firing relay fails in the ON position the light/buzzer should alert the pad operator of the failure before he even approaches the pad to hook up the e-match.

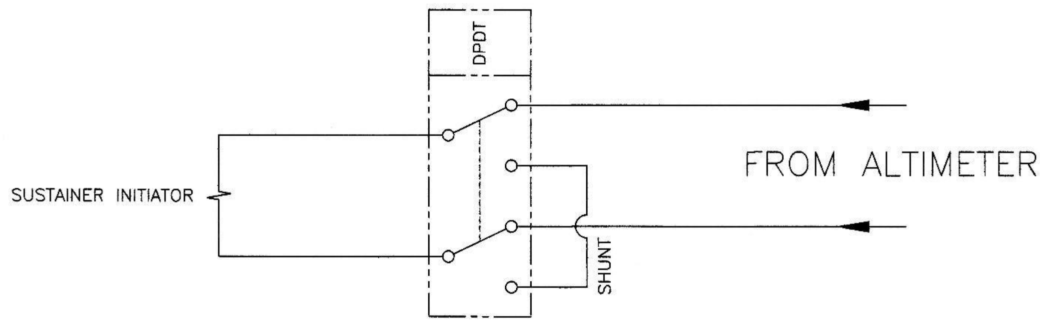
Shunt switch, Lamp/Buzzer

- These are all supplementary safety devices.
- They are intended as added layers of safety to protect and/or warn of failures of other system components.
- Their correct (or incorrect) function cannot cause an inadvertent firing.

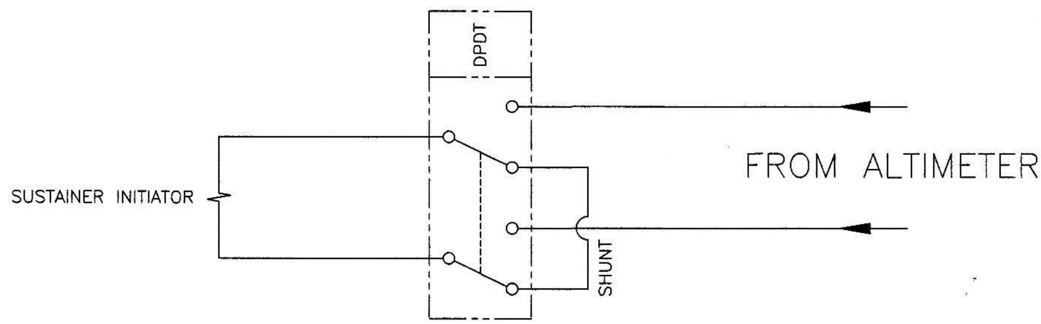
Is this a perfect firing system? No. There is always room for improvement. Lighted switches or similar features could be added to provide feedback on the health of all components. Support for firings at multiple launch pads could be included. Support for the fueling of hybrids and/or liquids could be required. A wireless data link could provide convenient and easy to set up communications at greater ranges. The list of desired features is going to be heavily situation dependent and is more likely to be limited by money than good ideas.

The circuit should be designed such that no single equipment failure can result in the inadvertent firing of the e-match and thus, the rocket motor. Whether or not a particular circuit is applicable to any given scenario is beside the larger point that in the event of any single failure a firing system should always fail-safe and never fail in a dangerous manner. No matter how complicated the system may be, it should be analyzed in depth and the failure of any single component should never result in the firing of a rocket during an unsafe range condition. Note that this is the bare minimum requirement; ideally, a firing system can handle multiple failures in a safe manner.

Appendix D: Airstart ignition wiring diagram



SUSTAINER INITIATOR ARMED



SUSTAINER INITIATOR SAFE

Appendix E: Spaceport America Cup and Tripoli Rocket Association Partnership

Summary

The Experimental Sounding Rocket Association (ESRA), Spaceport America, and the Tripoli Rocketry Association (TRA) are now formally working together to continue to improve overall flight safety and efficient flight operations at the annual Spaceport America Cup. In addition, student teams flying in the Commercial Off the Shelf (COTS) and Student Research and Design SOLID (SRAD SOLID) categories will begin flying under TRA flight code. Details of how this impacts competing teams are described below.

Background

TRA, Spaceport America, and ESRA all share common goals to create safe and exciting launch opportunities for the next generation of Aerospace engineers as they progress from hobby to industry environments. Our organizations are highly aligned: ESRA provides the educational framework and administration of the world's largest international collegiate rocketry event; TRA provides the safety/flight operations framework, incredible membership expertise and an amazing insurance program; and Spaceport America provides a world-class facility and support. Stated simply, we have assembled outstanding partners to build and safely operate the greatest rocketry competition in history.

The Spaceport America Cup has relied on the TRA safety code and membership expertise/guidance to create a safe launching environment for its event since 2017. The Cup's Range Safety and Launch Operations teams are filled with a significant number of Senior Level 3 high power rocketry experts (>30). A growing number of competing teams utilize TRA prefectures for mentorship, certification flights and test flights of their competition projects.

Benefits:

- **Student Team Liability Insurance** - In previous years, students were either insured by their university or through a 3rd party insurance provider. By becoming a TRA student member and following the TRA Safety code, the student is insured by TRA's insurance program. TRA insurance covers COTS and SRAD solid flights. TRA insurance DOES NOT cover SRAD hybrid and liquid teams or flights.
- Student teams will have improved access to TRA mentors, certifications, and launch sites - TRA has a growing list of US and international prefectures with active launch sites. Student teams are highly recommended to engage with their local TRA prefectures for mentoring, certification flights and additional launch experience.

Tripoli Flight Requirements for COTS and SRAD Solid Categories:

- **Certified Level 3 Flyer of Record (3 options)**
    - HIGHLY Recommended - each team will secure a Level 3 certified TRA or NAR (COTS Only) Senior mentor who works closely with the team and is present at the launch. Student teams ARE HIGHLY RECOMMENDED to subsidize the travel expenses of their mentor, to and from the event.
    - Recommended - team will have a TRA or NAR (COTS Only) Level 3 certified student member at the launch.
    - Last option (only for international teams who do not have access to TRA prefectures) - ESRA Range Safety team members, who are Level 3 certified TRA or NAR (COTS Only) Senior members, will virtually mentor the team throughout the year and will be present for the final flight safety inspections and launch.
- **TRA (or NAR) Student Membership**
    - TRA Student membership is $10 per year per student. NAR is $25.

- The HPR Level 3 certified student or mentor shall lead and supervise all launch preparation, pad loading and recovery activities.
- A maximum of 5 additional team members who are TRA or NAR (COTS only) student members may be on the pad loading team, recovery team, or working with the energetics (motor, ejection charges).
- These student team members do not have to be HPR certified but must be TRA or NAR (COTS only) student members.
- All students are highly recommended to secure HPR certification.
- Link to the TRA Student Membership application
  TRA Membership

Questions:

- **Why are we making this change?**
  - One of ESRA's primary goals is to foster a healthy engineering competition by conducting what has become the Spaceport America Cup.
  - Our desire is also to find ways to minimize costs to student teams.
  - Put simply, there has been no widely available and cost effective insurance solution for student teams.
  - Working with TRA and formally adopting the requirements above permits teams to be covered by the TRA insurance policy for COTS and SRAD SOLID rockets.
  - Hybrid and liquid teams must still work with their universities to find suitable insurance policies.

- **Why are hybrids and liquid rockets excluded from this policy change?**
  - TRA brings world-class expertise in the area of COTS and SRAD SOLID rocket motors.
  - The policies and rules for solid motors are well established with a robust system of mentors and specific certification levels.
  - Liquid and hybrid rockets are inherently more complex with dangers and risks that are substantially different from solid motors.
  - No hybrid/liquid rocket organization yet exists that has standardized on safety rules and established formal certifications based on levels of expertise and experience.
  - ESRA is committed to continuing to search for viable means to support the establishment of such an organization.

- **Is it acceptable if an international team (COTS or SRAD solid category) has identified a Level 3 certified Tripoli or NAR (COTS only) mentor who is not an ESRA Range Safety team member?**
  - ABSOLUTELY YES! As long as that the L3 certified mentor participates (virtually) throughout the design, manufacturing, testing of the project and attends (in person) the event with the team.