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Final Bachelor Thesis Terms of Reference

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

Universitat Politècnica de Catalunya

Aerospace Vehicles Bachelor Degree

DESIGN OF A REUSABLE ROCKET MODEL WITH DEVICES ALLOWING SAFE SEA LANDING

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Delivery date: 22/06/2021

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Chapter 1

European Rocketry Challenge - Design, Test and Evaluation Guide

The Terms of Reference of this project have been the Design, Test and Evaluation Guide of the European Rocketry Challenge (EuRoC) [1].

EUROPEAN ROCKETRY CHALLENGE

DESIGN, TEST & EVALUATION GUIDE

EuRoC

EUROPEAN ROCKETRY CHALLENGE

PORTUGAL SPACE

MUNICÍPIO PONTE DE SOR

INTERNAL APPROVAL	
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LIST OF REVISIONS

REVISION	DATE	DESCRIPTION
Original	20/07/2020	Original edition.
Version 02	03/03/2021	Second version, major revisions for EuRoC 2021.

1. INTRODUCTION

1.1. BACKGROUND

The Portuguese Space Agency – Portugal Space, and the Municipality of Ponte de Sor have partnered to host the EuRoC – European Rocketry Challenge, a competition that seeks to stimulate university level engineering students to fly sounding rockets, by designing and building the rockets themselves.

It is widely recognized that such competitions foster innovation and motivate students to extend themselves beyond the classroom, while learning to work as a team, solving real world problems under the same pressures they will experience in their future careers.

The EuRoC competition is fully aligned with the strategic goals of Portugal Space, namely the development and evolution of the cultural/educational internationalization frameworks capable of boosting the development of the Space sector in Portugal. The Municipality of Ponte de Sor is home to one of the fastest growing aerospace regional clusters in Portugal, including the assemblance process of the first national satellite.

The EuRoC competition builds on the legacy of the joint ESRA – Experimental Sounding Rocket Association and Spaceport America since their first annual IREC – Intercollegiate Rocket Engineering Competition back in 2006, now known as the Spaceport America Cup. Due to COVID-19, the 2020 edition of SA Cup was cancelled, and several European university student teams reached out in order to implement a similar competition in Europe, inexistent so far. Thus EuRoC, the first European university rocket competition was born, with its first edition successfully implemented in Portugal, in 2020. The EuRoC organisers would like to take this moment and thank ESRA and the Spaceport America Cup for their groundbreaking work in the making of the Spaceport America Cup competition.

This document defines the design, test and evaluation guide governing participation in the EuRoC, based on the ruleset documentation of Spaceport America Cup. Major revisions of this document will be accomplished by complete document reissue. Smaller revisions will be reflected in updates to the document's effective date and marked by the revision number. The authority to approve and issue revised versions of this document rests with Portugal Space.

1.2. PURPOSE

This document defines the minimum design, test and evaluation criteria that teams must meet before launching at the competition. These criteria main goal is to promote flight safety. Departures from the guidance this document provides may negatively impact a team's score and flight status, depending on the degree of severity. The foundational, qualifying criteria for EuRoC are contained in the EuRoC Rules & Requirements document.

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 EuRoC and flight status at the competition.

Shall

Denotes mandatory requirements.

Failure to satisfy the spirit and intent of a mandatory requirement will always affect a project's score and flight status negatively.

Should

Denotes 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.

Compliance to recommended goals and requirements may impact a team's score and flight status in a positive way, as demonstrating additional commitment and diligence to implement (often safety and reliability related guidelines) is commendable.

Will

States facts and declarations of purpose.

These statements are used to clarify the spirit and intent of requirements and goals.

Flight status

Refers to the granting of permission to attempt a launch and the provisions under which that permission remains valid.

A project's flight status may be either nominal, provisional, or denied. The default flight status of any team is from the project onset "denied", until project deliverables, and ultimately a successful Flight Readiness Review and Flight Safety Review, convinces the technical jury to upgrade the flight status of teams.

1) 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 competition.
2) 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 competition which may be mitigated by field modification or by adjusting launch

environment constraints. Launch may occur only when the prescribed provisions are met.

3) 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 competition.

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.

1.3. 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 herein or contain reference information useful in the application of this document.

Document	File Location
EuRoC Rules & Requirements	http://www.euroc.pt
EuRoC Design, Test & Evaluation Guide	http://www.euroc.pt
EuRoC Entry Form	http://www.euroc.pt
EuRoC Academic Institution Letter	http://www.euroc.pt
EuRoC Motors List	http://www.euroc.pt (Teams' Reserved Area)
EuRoC Technical Questionnaire	http://www.euroc.pt (Teams' Reserved Area)
EuRoC Waiver and Release of Liability Form	http://www.euroc.pt (Teams' Reserved Area)
EuRoC Flight Card and Postflight Record	http://www.euroc.pt (Teams' Reserved Area)
EuRoC Master Schedule	http://www.euroc.pt (Teams' Reserved Area)

2. PROPULSION SYSTEMS

2.1. Non-toxic Propellants

Launch vehicles entering EuRoC shall use non-toxic propellants. Ammonium perchlorate composite propellant (APCP), potassium nitrate and sugar (also known as "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), etc. Home-made propellant mixtures containing any fraction of toxic propellants are also prohibited.

2.2. 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). 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.

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 10 of this document.

2.2.1. Ground-start Ignition Circuit Arming

All ground-started propulsion system ignition circuits/sequences shall not be "armed" until all personnel are at least 15 m away from the launch vehicle. The provided launch control system satisfies this requirement by implementing a removable "safety jumper" in series with the pad relay box's power supply. The removal of this single jumper prevents firing current from being sent to any of the launch rails associated with that pad relay box. Furthermore, access to the socket allowing insertion of the jumper is controlled via multiple physical locks to ensure that all parties have positive control of their own safety.

2.2.2. Air-start Ignition Circuit Arming

All upper stage (i.e., air-start) propulsion systems shall be armed by launch detection (e.g., accelerometers, zero separation force [ZSF] electrical shunt connections, break-wires, or other similar methods). Regardless of implementation, this arming function will prevent the upper stage from arming in the event of a misfire.

2.2.3. 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.

2.3. Air-start Ignition Circuit Electronics

All upper stage ignition systems shall comply with same requirements and goals for "redundant electronics" and "safety critical wiring" as recovery systems — understanding that in this case "initiation" refers to upper stage ignition rather than a recovery event. These requirements and goals are defined in Sections 3.3 and 3.4 respectively.

2.4. 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.

2.4.1. 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 4.2. Note that combustion chambers are exempted from the requirement for a relief device.

2.4.2. Hybrid and Liquid Propulsion System Tanking Testing

SRAD and modified COTS propulsion systems using liquid propellant(s) shall successfully (without significant anomalies) have completed a propellant loading and off-loading test in "launch-configuration", prior to the rocket being brought to the competition. This test may be conducted using either actual propellant(s) or suitable proxy fluids, with the test results to be considered a mandatory deliverable and an annex to the Technical Report, in the form of a loading and off-loading checklist, complete with dates, signatures (at least three) and a statement of a successful test. Referring to Section 2.4.3, it is highly recommended to perform this test multiple times as a part of the "all-up static engine test" configuration, described in that section.

The described annex may be amended to the Technical Report, as results become available, up to the day final deadline for delivery of the Technical Report. Failure to deliver this annex will automatically result in a "denied" flight status.

Loading and unloading of liquid propellants must be a well-drilled, safe and efficient operation at the competition launch rails.

It is strongly recommended that the flight vehicle is designed such that any filling/loading/unloading connections for fluid propellants are readily accessible from the ground. No propellant loading procedure should necessitate ladders or other elevation devices. Furthermore, the teams should account for a "failed" launch and subsequent unloading in launch preparation, if they want to keep the possibility to be provided a second launch attempt, e.g., be ensure the availability of additional propellants, igniters, and any other parts that might need replacement or adjustment.

2.4.3. 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 EuRoC. In the case of solid rocket motors, this test needs not to be performed with the same motor casing and/or nozzle components intended for use at the EuRoC (i.e., teams must verify their casing design, but are not forced to design reloadable/reusable motor cases).

The test shall, to the extent possible, be conducted as an “all-up static engine test”, which means that the completed flight vehicle, rigidly fastened to a suitable test stand in an upright position, should be tested for a full duration burn under the most realistic settings possible. Test results from horizontal tests, using flight components is less optimum, whereas test results from test benches (not using flight components) do not qualify.

The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and an annex to the Technical Report.

The described annex may be amended to the Technical Report, as results become available, up to the day final deadline for delivery of the Technical Report. Failure to deliver this annex will automatically result in a “denied” flight status.

“Test as you fly – Fly as you test”. This test-mentality significantly increases the chances of a lift-off and a nominal flight.

3. RECOVERY SYSTEMS AND AVIONICS

3.1. Dual-event Parachute and Parafoil Recovery

Each independently recovered launch vehicle body, anticipated to reach an apogee above 450 m above ground level (AGL), shall follow a "dual-event" recovery operations concept, including an initial deployment event (e.g., a drogue parachute deployment; reefed main parachute deployment or similar) and a main deployment event (e.g., a main parachute deployment; main parachute un-reefing or similar). Independently recovered bodies, whose apogee is not anticipated to exceed 450 m AGL, are exempt and may feature only a single/main deployment event.

3.1.1. Initial Deployment Event

The initial deployment event shall occur at or near apogee, stabilize the vehicle's attitude (i.e., prevent or eliminate tumbling), and reduce its descent rate sufficiently to permit the main deployment event, yet not so much as to exacerbate wind drift. Any part, assembly or device, featuring an initial deployment event, shall result in a descent velocity of said item of 23-46 m/s.

3.1.2. Main Deployment Event

The main deployment event shall occur at an altitude no higher than 450 m AGL and reduce the vehicle's descent rate sufficiently to prevent excessive damage upon impact with ground. Any part, assembly or device, featuring a main deployment event, shall result in a descent velocity of said item of less than 9 m/s.

3.1.3. 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.

3.1.4. Parachute Swivel Links

The recovery system rigging (e.g., parachute lines, risers, shock chords, etc.) shall implement swivel links at connections to relieve torsion, as the specific design demands. This will mitigate the risk of torque loads unthreading bolted connections during recovery as well as parachute lines twisting up.

3.1.5. Parachute Coloration and Markings

When separate parachutes are used for the initial and main deployment events, these parachutes should be visually highly dissimilar from one another. This is typically achieved by using parachutes whose primary colours contrast those of the other chute. This will enable ground-based observers to characterize deployment events more easily with high-power optics.

Utilised parachutes should use colours providing a clear contrast to a blue sky and a grey/white cloud cover.

3.2. Non-parachute/Parafoil Recovery Systems

Teams exploring other recovery methods (i.e., non-parachute or parafoil based) shall mention them in the dedicated field of the Technical Questionnaire (see Section 9.2 of the EuRoC Rules & Requirements document). The organisers may make additional requests for information and draft unique requirements depending on the team's specific design implementation.

3.3. Redundant Electronics

Launch vehicles shall implement redundant recovery system electronics, including sensors/flight computers and "electric initiators" — assuring initiation by a backup system, with a separate power supply (i.e., battery), if the primary system fails. In this context, electric initiators are the devices 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, flash bulbs, etc.).

3.3.1. 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, Eggtimer, AIM, EasyMini, TeleMetrum, RRC3, etc.).

To be considered COTS, the flight computer (including flight software) must have been developed and validated by a commercial third party. While commercially designed flight computer "kits" (e.g., the Eggtimer) are permitted and considered COTS, 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.

3.3.2. Official Altitude Logging and Tracking System

EuRoC will require teams to implement a common mandatory altitude logging and GPS tracking device in all rocket systems to be specified in more detail in the *Official Altitude Logging and Tracking Addendum* in due time before the event on the website (e.g. COTS "Eggtimer" system or similar). This device serves three purposes:

- Provide the apogee reached for official altitude logging and scoring
- Enable the event officials to attempt to track the vehicle during flight
- Enable easy and quick location of the vehicle for recovery

3.3.3. Dissimilar Redundant Recovery Electronics

There is no requirement that the redundant/backup system be dissimilar to the primary; however, there are advantages to using dissimilar primary and backup systems. Such configurations are less vulnerable to any inherent environmental sensitivities, design, or production flaws affecting a particular component.

3.4. Safety Critical Wiring

For the purposes of this document, safety critical wiring is defined as electrical wiring associated with recovery system deployment events and any "air started" rocket motors.

3.4.1. 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.

3.4.2. Secure Connections

All safety critical wiring/cable connections shall be sufficiently secure as to prevent de-mating 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.

3.4.3. Cryo-compatible Wire Insulation

In case of propellants with a boiling point of less than -50°C any wiring or harness passing within the close proximity of a cryogenic device (e.g., valve, piping, etc.) or a cryogenic tank (e.g., a cable tunnel next to a LOX tank) shall utilize safety critical wiring with cryo-compatible insulation (i.e., Teflon, PTFE, etc.).

3.5. Recovery System Energetic Devices

All stored-energy devices (i.e., energetics) used in recovery systems shall comply with the energetic device requirements defined in Section 4 of this document.

3.6. 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.

3.6.1. Ground Test Demonstration

All recovery system mechanisms shall be successfully (without significant anomalies) tested prior to EuRoC, 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.

The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and annex to the Technical Report.

The described annex may be amended to the Technical Report, as results become available, up to the day final deadline for delivery of the Technical Report. Failure to deliver this annex will automatically result in a "denied" flight status.

Correct, reliable and repeatable recovery system performance is absolute top priority from a safety point of view. Statistical data also concludes that namely recovery system failures are the major cause of abnormal "landings".

3.6.2. Optional Flight Test Demonstration

All recovery system mechanisms shall be successfully (without significant anomalies) tested prior to EuRoC, either by flight testing, or through one or more ground tests of key subsystems. 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 EuRoC (i.e., a surrogate booster may be used).

The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and annex to the Technical Report.

The described annex may be amended to the Technical Report, as results become available, up to the day final deadline for delivery of the Technical Report. Failure to deliver this annex will automatically result in a "denied" flight status.

Correct, reliable and repeatable recovery system performance is absolute top priority from a safety point of view. Statistical data also concludes that namely recovery system failures are the major cause of abnormal "landings".

4. STORED-ENERGY DEVICES

4.1. 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 of the system. An energetic device is considered armed when only one event is necessary to release the energy. For the purpose of this document, 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 and in which configurations 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 provided in Section 2 of this document, 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 2.2.1 requires propulsion systems to 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.

4.1.1. 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.

4.1.2. 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.

Furthermore, it is highly recommended that the arming mechanism is accessible from ground level, without the use of ladders or other elevation devices, when the rocket is at a vertical orientation on the launch rail. If this requirement is considered early in the design process, implementing the arming devices in the lower section of the rocket is easy, while also mitigating the need for risky or hazardous arming procedures at a height.

4.2. 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.

4.2.1. 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.

4.2.2. 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.

4.2.3. Designed Burst Pressure for Composite Pressure Vessels

All SRAD and modified COTS pressure vessels either constructed entirely from non-isentropic materials (e.g., fibre reinforced plastics; FRP; composites) or implementing composite overwrap of a metallic vessel (i.e., 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.

4.2.4. 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.

4.2.4.1. Proof Pressure Testing

SRAD and modified COTS pressure vessels shall be proof pressure tested successfully (without significant anomalies) 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 EuRoC). 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.

The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered mandatory deliverable and annexed to the Technical Report.

The described annex may be amended to the Technical Report, as results become available, up to the day final deadline for delivery of the Technical Report. Failure to deliver this annex will automatically result in a “denied” flight status.

The pressure testing is an important factor in instilling confidence in the structural strength and integrity of the flown pressure vessels. Since liquid propellant loading onto hybrid or bi-liquid propelled flight vehicles will in the majority of cases involve manual loading, there will be times where ground personnel will be in close proximity with pressurized systems. It is crucial that ground personnel safety is heightened by the use of proof pressure tested pressure vessels.

4.2.4.2. 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 favourably; however, this will not be considered an alternative to proof pressure testing of the intended flight article.

5. ACTIVE FLIGHT CONTROL SYSTEMS

5.1. 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 EuRoC be actively guided towards a designated spatial target. The organisers may make additional requests for information and draft unique requirements depending on the team's specific design implementation.

5.2. 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 8.3 of this document. The organisers may make additional requests for information and draft unique requirements depending on the team's specific design implementation.

5.3. 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.).

5.4. Boost Phase Dormancy

CAS shall mechanically lock in a neutral state 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 (i.e., max Q) in its trajectory, or the launch vehicle has reached an altitude of 6.000 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.).

Since all flight vehicles with Control Actuator Systems (guidance systems) are to be designed inherently passively stable at lift-off, CAS are not needed until somewhat into the flight, performing minor course corrections thereafter. In enforcing a boost dormancy phase, any unexpected, erratic, or faulty CAS system behaviour will take place far from the launch rail, minimizing the chances of putting EuRoC participants at risk near the launch rail.

5.5. 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 CAS commanding rather than a recovery event. These requirements and goals are defined in Sections 3.3 (except Section 3.3.1) and Section 3.4 respectively of this document. 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.

5.6. Active Flight Control System Energetics

All stored-energy devices used in an active flight control system (i.e., energetics) shall comply with the energetic device requirements defined in Section 4 of this document.

6. AIRFRAME STRUCTURES

6.1. 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 3 mm to 5 mm hole is drilled in the booster section just behind the nosecone or payload shoulder area, and through the hull or bulkhead of any similarly isolated compartment/bay.

6.2. Overall Structural Integrity

Launch vehicles will be constructed to withstand the operating stress 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, analysing and mitigating their design's unique load set.

6.2.1. Material Selection

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

6.2.2. Load Bearing Eyebolts and U-bolts

All load bearing eyebolts shall be of the closed-eye, forged type — NOT of the open eye, bent wire type. Furthermore, all load bearing eyebolts and U-Bolts shall be steel or stainless steel. This requirement extends to any bolt and eye-nut assembly used in place of an eyebolt.

6.2.3. Implementing Coupling Tubes

Airframe joints which implement "coupling tubes" should be designed such that the coupling tube extends no less than one body calibre 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).

6.2.4. Launch Lug Mechanical Attachment

Launch lugs (i.e., 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.

The aft most launch lug shall support the launch vehicle's fully loaded launch weight while vertical.

At EuRoC, 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. This test needs to be completed successfully before the admittance of the team to Launch Readiness Review.

6.2.5. Launch Rail Fit Check

All teams shall perform a “launch rail fit check” as a part of the flight preparations (the Launch Readiness Review), before going to the launch range. This requirement is particularly important if a team is not bringing their own launch rail, but instead relying on EuRoC provided launch rails.

Arriving at the launch rails, only then discovering that a team's launch lugs does not fit the launch rail, will be considered gross negligence by Mission Control and the EuRoC jury. The launch rail fit check will ensure that such surprises are not encountered on the launch rails, causing delays and loss of lunch opportunities.

6.3. RF Transparency

Any internally mounted RF transmitter, receiver or transceiver, not having the applicable antenna or antennas mounted externally on the airframe, shall employ “RF windows" in the airframe shell plating (typically glass fibre panels), enabling RF devices with antennas mounted inside the airframe, to transmit the signal though the airframe shell.

RF windows in the flight vehicle shell shall be a 360° circumference and be at least two body diameters in length. The internally mounted RF antenna(s) shall be placed at the midpoint of the RF window section, facilitating maximizing the azimuth radiation pattern.

RF transmitter, receivers or transceivers are not allowed to be mounted externally. Externally mounted antennas are allowed, but only if at least two antennas are mounted on opposite sides of the airframe, thus retaining circumferential symmetry and covering sufficient transmission area, transmitting or receiving identical signals.

This scheme is implemented to prevent a metal or carbon fibre body from shielding antennas from line-of-sight, creating RF “shadow” or “dead/blind-zones", with subsequent loss of signal.

More exotic externally mounted antennas or antenna arrays (wrap-around patch antenna arrays or similar) are allowed but must still exhibit horizontal 360° radiation pattern.

Please note, that even though a single downward facing antenna mounted on a stabilization fin near the engine seems like a good way to provide a 360° radiation pattern without significant dead-zones, this is still a bad idea. The ionized exhaust gas from the engine is highly disruptive to RF signals, so this strategy is highly discouraged.

As popular as carbon fibre is for the construction of strong and lightweight airframes, it is also conductive and will significantly shield and/or degrade RF signals, which is unacceptable. Externally mounted antennas often provide a more powerful and uniform radiation pattern but finds the flight vehicle body providing large RF dead zones, meaning that at least two antennas on opposite sides of the airframe is necessary.

Although the result of this pilot program may have some inherent utility to recovery, it DOES NOT exempt affected teams from the requirement for team provided recovery tracking beacon(s) defined in Section 8.2. of EuRoC Rules & Requirements Document.

6.4. Identifying Markings

The team's Team ID (a number assigned by EuRoC prior to the competition event), project name, and academic affiliation(s) shall be clearly identified on the launch vehicle airframe. 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 EuRoC.

6.5. Other Markings

There are no requirements for airframe coloration or markings beyond those specified in Section 6.4 of this document. However, EuRoC offers the following recommendations to student teams: mostly white or lighter tinted colour (e.g., yellow, red, orange, etc.) airframes are especially conducive to mitigating some of the solar heating experienced in the EuRoC launch environment. Furthermore, 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 track and record the launch vehicle’s trajectory with high-power optics more easily.

7. PAYLOAD

7.1. 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 9 m/s before it descends through an altitude of 450 m AGL.

All types of deployable payloads must be authorized by the EuRoC Technical Evaluation Board prior to the EuRoC. Deployable payloads without two-stage recovery systems (drogue and main chute, like the rockets) will be subjective to considerable drift during descent.

Note that deployable payloads implementing a parachute or parafoil based recovery system are not required to comply with the dual-event requirements described in Section 3.1 of this document, being allowed to utilize a single-stage 8-9m/s descent rate from apogee recovery system, subject to case-by-case EuRoC approval (the intent being to accommodate certain science/engineering packages requiring extended airborne mission time).

7.1.1. 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 3.3 and 3.4 respectively.

7.1.2. 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 3.6.

7.1.3. Deployable payload GPS Tracking Required

It must be noted that deployable payloads are equivalent to flight vehicle bodies and sections, in that they can be difficult to locate after landing. All deployable payloads shall feature the same mandatory GPS tracking system as all rockets and rocket stages as specified in the *Official Altitude Logging and Tracking Addendum* to be published in due time before the event.

The GPS locator ID must differ from the ID of the launch vehicle.

7.2. Payload Energetic Devices

All stored-energy devices (i.e., energetics) used in payload systems shall comply with the energetic device requirements defined in Section 4 of this document.

8. LAUNCH AND ASCENT TRAJECTORY REQUIREMENTS

8.1. 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 EuRoC. Competition officials reserve the right to require certain vehicles' launch elevation be as low as 70°, if flight safety issues are identified during pre-launch activities.

The tolerance expressed within the nominal launch azimuth is intended as nothing more than an expression of acceptable human error by the operator setting the launch rail elevation prior to launch.

8.2. Launch Stability

Launch vehicles shall have sufficient velocity upon "departing the launch rail" to ensure they will follow predictable flight paths. In lieu of detailed analysis, a rail departure velocity of at least 30 m/s is generally acceptable. Alternatively, the team may use detailed analysis to prove stability is achieved at a lower rail departure velocity 20 m/s either theoretically (e.g., computer simulation) or empirically (e.g., flight testing).

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 centre of gravity (CG) separates from the launch rail.

The requirements for team provided launch rails are defined in Section 10 of this document.

8.3. 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 calibres, regardless of CG movement due to depleting consumables and shifting centre of pressure (CP) location due to wave drag effects (which may become significant as low as 0.5 Mach). Not falling below 2 body calibres will be considered nominal, while falling below 1.5 body calibres will be considered a loss of stability.

8.4. Over-stability

All launch vehicles should avoid becoming "over-stable" during their ascent. A launch vehicle may be considered over-stable with a static margin significantly greater than 2 body calibres (e.g., greater than 6 body calibres).

9. EUROC LAUNCH SUPPORT EQUIPMENT

EuRoC will provide a basic launch support "equipment" during the EuRoC 2021 event:

At the launch rails:

- 3-phase 400VAC IEC 60309 (16A) sockets, powered from a >6kW diesel generator.
- 1-phase 230VAC CEE 7/3 "Schuko" sockets, powered from the above-mentioned diesel generator.

A main "junction box" will be available within 10 meters of each launch rail, but teams must bring their own extension cables and socket rails/cable drums, etc.

At mission control:

- 1-phase 230VAC CEE 7/3 "Schuko" sockets, powered from a low-power generator (maximum 2kW available for all of mission control).

- A main "junction box" with a limited number of sockets will be available in Mission Control. Teams must bring their own extension cables and socket rails/cable drums, etc., if the team intends to utilize equipment beyond a few sockets.

9.1. Launch Rails

EuRoC will provide a number of standardised launch rails. They will generally be of the "extruded aluminium profile" type, with exact launch rail lengths and aluminium cavity profiles to be made available in the reserved teams' area of the EuRoC website in due time prior to the event.

9.2. EuRoC-provided Launch Control System

EuRoC will provide a Launch Control System. The system will be a Wilson F/X Wireless Launch Control System or equivalent.

The Wilson F/X wireless Launch Control System with one LCU-64x launch control unit and two PBU-8w encrypted 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).

10. TEAM-PROVIDED LAUNCH SUPPORT EQUIPMENT

10.1. Equipment Portability

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

10.2. Launch Rail Elevation

Team provided launch rails shall implement the nominal launch elevation specified in Section 8.1 of this document and, if adjustable, not permit launch at angles either greater than the nominal elevation or lower than 70°.

10.3. Operational Range

All team provided launch control systems shall be electronically operated and have a maximum operational range of no less than 400 metres from the launch rail. A 600-metre operational range is preferred. The maximum operational range is defined as the range at which launch may be commanded reliably.

10.4. 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. Fire Control System Design Guidelines of this document provides general guidance on assuring fault tolerance in amateur high-power rocketry launch control systems.

10.5. Safety Critical Switches

All team provided launch control systems shall implement ignition switches of the momentary, normally open (also known as "dead man") 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.

11. EQUIPMENT

11.1. Communication Equipment

All teams are encouraged to obtain a number of decent quality license-free PMR radios for internal team communication, communication with EuRoC staff/mission control, ad-hoc coordination, etc. A suitable supply of expendable spare batteries or battery chargers is highly recommended.

11.2. Personal Protection Equipment

All teams must bring any Personal Protection Equipment (PPE) required for all preparation and launch activities. EuRoC does not have a supply of spare PPE. PPE includes, but is not limited to, safety goggles, gloves, safety shoes, hardhats, ear protection, cryo-protection, etc.

11.3. Field Equipment

All teams are encouraged to provide each participating team member with a suitable "field/day pack", which is kept close at hand (or worn) during launch days. Due to the possibility of strong sunlight and high temperatures even in October, some of these provisions are intended to get students through a hot and dry day in the field, while other provisions are intended to enable student teams to continue efficient operation after loss of daylight after a quick sun-down and a resulting sudden and significant drop in ambient temperature.

While most days start out as sunny "t-shirt and shorts weather", it is a very unpleasant experience ending a day, stuck in the dark with nothing but a mobile phone, and freezing due to lack of clothing.

- Sunscreen, wide brimmed hat and sunglasses
  - You will look like you are on a well-prepared holiday (avoiding sunburn too).
- Practical footwear for both dirty and muddy conditions
  - It can get *really* messy in the field!
- At least a litre of drinking water
  - No accessible water at the launch rails, nor mission control.
- Snacks, biscuits and other non-perishable energy supplements.
  - Food trucks might be far away, and low blood sugar is a party killer.
- Headlamp/head-torch
  - Having only one hand free for working after dusk makes people look unprofessional.
- Backup clothing, covering exposed arms and legs.
  - Freezing students are just miserable. Save yourself the experience and stay warm!

APPENDIX A: ACRONYMS, ABBREVIATIONS & TERMS

AA	Actual Apogee
AGL	Above Ground Level
APCP	Ammonium Perchlorate Composite Propellant
APRS	Automatic Packet Reporting System
ANAC	Portugal´s National Civil Aviation Authority
CONOPS	Concept of Operations
COTS	Commercial of-the-shelf
DTEG	Design, Test and Evaluation Guide
EuRoC	European Rocketry Challenge
ESRA	Experimental Sounding Rocket Association
FRR	Flight Readiness Review
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
H	Hybrid
HPR	High Power Rocket
IREC	Intercollegiate Rocket Engineering Competition
L	Liquid
LRR	Launch Readiness Review
LOX	Liquid Oxygen
P	Points
RF	Radio Frequency
S	Solid
SAC	Spaceport America Cup
SRAD	Student Researched & Developed
TA	Target Apogee
TBD	To be determined or defined
TBR	To be resolved
TBC	To be confirmed

TEB	Technical Evaluation Board
U	Unit, as in Cube-Sat unit
ACS	Attitude Control Systems
AGL	Above Ground Level
APCP	Ammonium Perchlorate Composite Propellant
APRS	Automatic Packet Reporting System
ANAC	Portugal´s National Civil Aviation Authority
CAS	Control Actuator System
CONOPS	Concept of Operations
COPV	Composite Overwrapped Pressure Vessels
COTS	Commercial of-the-shelf
DTEG	Design, Test and Evaluation Guide
EuRoC	European Rocketry Challenge
ESRA	Experimental Sounding Rocket Association
FRP	Fibre Reinforced Plastics
GPS	Global Positioning System
HPR	High Power Rocket
IREC	Intercollegiate Rocket Engineering Competition
LOX	Liquid Oxygen
PPE	Personal Protective Equipment
SRAD	Student Researched & Developed
TBD	To be determined or defined
TBR	To be resolved

APPENDIX B: 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 have 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.

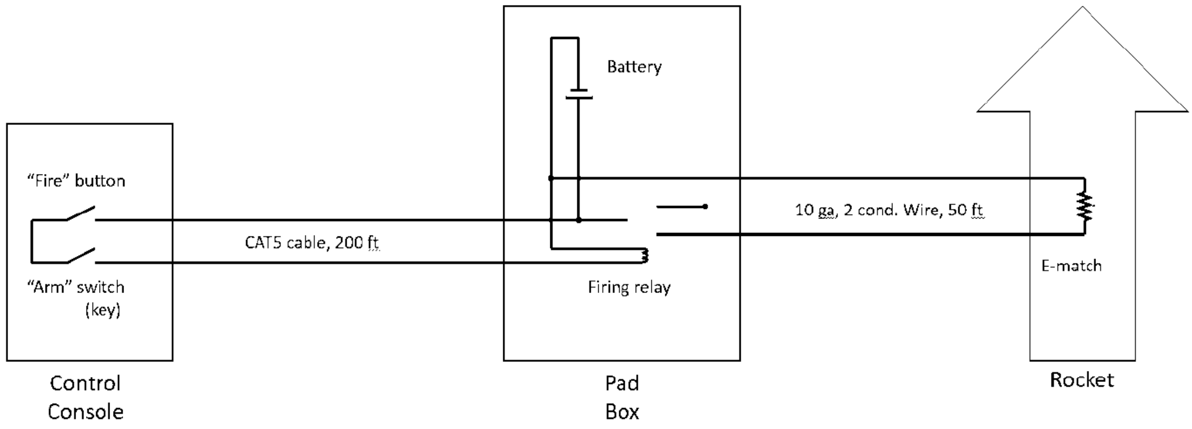

Figure 1: A simple high current fire control system

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 hook up (pad personnel should turn the shunt switch ON anytime they approach the rocket).

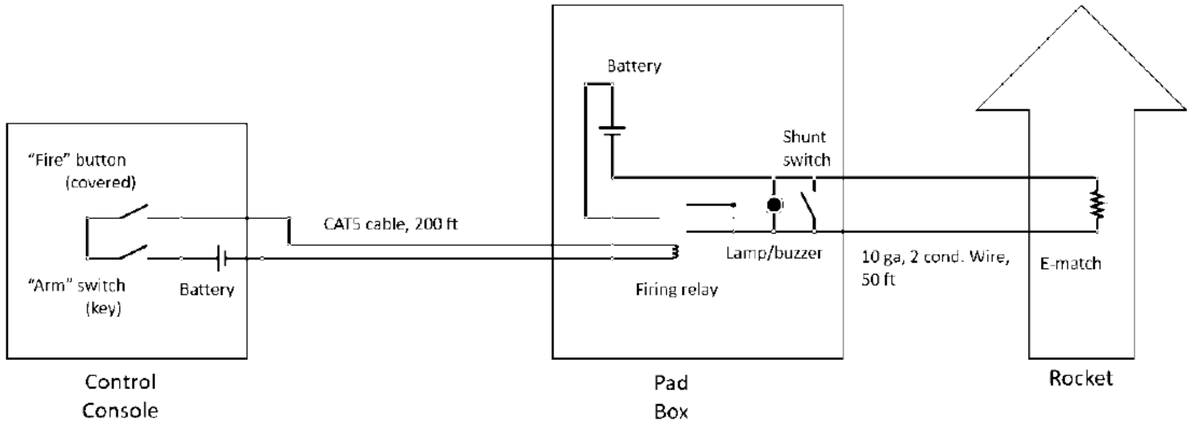

Figure 2: An improved high current fire control system

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 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 fuelling 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.

Hopefully the reader is getting the gist: 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 analysed 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 C: FLIGHT READINESS REVIEW CHECKLIST

Table 1: Flight Readiness Review checklist

Section	Description	Actions to be taken
PROPULSION SYSTEMS		
Checklist	Upon request, the flier should provide the inspector with hardcopy checklist procedures for the propulsion system's safe handling, assembly, disassembly, and operation (both nominal and off-nominal/contingency flows) – including self-inspection/verification steps which make individual team members accountable to one another for having completed the preceding process(es).	Simple confirmation Inspection on site
Non-toxic Propellants	Launch vehicles entering EuRoC shall use non-toxic propellants. Ammonium perchlorate composite propellant (APCP), potassium nitrate and sugar (also known as "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), etc. Home-made propellant mixtures containing any fraction of toxic propellants are also prohibited.	Simple confirmation
Total Impulse	The sum of all rocket stages' impulse must either not exceed 40,960 newton-seconds, or the Flier must have previously consulted with EuRoC on provisions for launching a larger rocket.	Simple confirmation
Motor Retention	The design must provide for positive retention of the propulsion system within the airframe - leaving no possibility for the propulsion system to shift from its retaining device(s) and jettison itself.	Inspection on site Proof by reasoned argumentation
Thrust Structure	A "structural chain" that transfers the propulsion system thrust to various points on the rocket structure must exist and it must be capable of withstand these loads.	Inspection on site Proof by reasoned argumentation
Thrust Curve	Upon request, the flier must provide the inspector with hardcopy thrust curve data for each individual rocket motor or engine implemented.	Proof by calculation
PROPULSION SYSTEM SAFING AND ARMING		

Pre-flight and Countdown Procedure	Upon request, the flier should provide the inspector with hardcopy checklist procedures for any of the propulsion system's unique final on-pad preparations, pre-flight, and launch (both nominal and off-nominal/abort/mishap flows) - including self-inspection/verification steps which make individual team members accountable to one another for having completed the preceding process(es).	Simple confirmation Inspection on site
Ground-start Ignition Circuit Arming	All ground-started propulsion system ignition circuits/sequences shall not be "armed" until all personnel are at least 15 m away from the launch vehicle. The provided launch control system satisfies this requirement by implementing a removable "safety jumper" in series with the pad relay box's power supply. The removal of this single jumper prevents firing current from being sent to any of the launch rails associated with that pad relay box. Furthermore, access to the socket allowing insertion of the jumper is controlled via multiple physical locks to ensure that all parties have positive control of their own safety.	Simple check
Air-start Ignition Circuit Arming	All upper stage (i.e., air-start) propulsion systems shall be armed by launch detection (e.g., accelerometers, zero separation force [ZSF] electrical shunt connections, break-wires, or other similar methods). Regardless of implementation, this arming function will prevent the upper stage from arming in the event of a misfire.	Proof by reasoned argumentation Inspection on site
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.	Proof by reasoned argumentation
Air-start Ignition Circuit Electronics	All upper stage ignition systems shall comply with same requirements and goals for "redundant electronics" and "safety critical wiring" as recovery systems — understanding that in this case "initiation" refers to upper stage ignition rather than a recovery event.	Simple confirmation Inspection on site
Staging Ignition Commit Criteria	The electronics controlling the various staging events must inhibit staging if the rockets' flight profile deviates from predicted nominal behaviour.	Proof by reasoned argumentation

Positive State Indication	Each independent set of electronics controlling staging events must provide sensory (i.e., visual or auditory) indication of its activation.	Simple confirmation Inspection on site
Special Consideration for "Drag Separation"	The electronics controlling stage ignition in design's implementing "drag-separation" must not be located in the separating stage - where premature separation could prevent ignition of the following stage.	Simple confirmation Inspection on site
SRAD Propulsion System Testing		
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 4.2. Note that combustion chambers are exempted from the requirement for a relief device.	Proof by previous testing
Hybrid and Liquid Propulsion System Tanking Testing	SRAD and modified COTS propulsion systems using liquid propellant(s) shall successfully (without significant anomalies) have completed a propellant loading and off-loading test in "launch-configuration", prior to the rocket being brought to the competition. This test may be conducted using either actual propellant(s) or suitable proxy fluids, with the test results to be considered a mandatory deliverable and an annex to the Technical Report, in the form of a loading and off-loading checklist, complete with dates, signatures (at least three) and a statement of a successful test. Failure to deliver this annex will automatically result in a “denied” flight status. Loading and unloading of liquid propellants must be a well-drilled, safe and efficient operation at the competition launch rails.	Proof by previous testing
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 EuRoC. In the case of solid rocket motors, this test needs not to be performed with the same motor casing and/or nozzle components intended for use at the EuRoC (i.e., teams must verify their casing design, but are not forced to design reloadable/reusable motor cases). The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and an annex to the Technical Report. Failure to deliver this annex will	Proof by previous testing

	automatically result in a "denied" flight status. See Section 2.4.3. for more information.	
RECOVERY SYSTEMS AND AVIONICS		
Checklist	Upon request, the flier must provide the inspector with hardcopy checklist procedures for the recovery system's safe handling, assembly, disassembly, and operation (both nominal and off-nominal/contingency flows) - including self-inspection/verification steps which make individual team members accountable to one another for having completed the preceding process(es).	Simple confirmation Inspection on site
Pre-flight and Countdown Procedure	Upon request, the flier must provide the inspector with hardcopy checklist procedures for any of the recovery system's unique final on-pad preparations, pre-flight, and launch (both nominal and off-nominal/abort/mishap flows) - including self-inspection/verification steps which make individual team members accountable to one another for having completed the preceding process(es).	Simple confirmation Inspection on site
Dual-event Parachute and Parafoil Recovery	Each independently recovered launch vehicle body, anticipated to reach an apogee above 450 m above ground level (AGL), shall follow a "dual-event" recovery operations concept, including an initial deployment event (e.g., a drogue parachute deployment; reefed main parachute deployment or similar) and a main deployment event (e.g., a main parachute deployment; main parachute un-reefing or similar). Independently recovered bodies, whose apogee is not anticipated to exceed 450 m AGL, are exempt and may feature only a single/main deployment event.	Proof by calculation Proof by reasoned argumentation
Inspect for Damage	If previously flown, any used parachutes, shock chords, and suspension lines must not exhibit signs of damage which threatens the safe recovery of the rocket.	Simple Confirmation Inspection on site
Initial Deployment Event	The initial deployment event shall occur at or near apogee, stabilize the vehicle's attitude (i.e., prevent or eliminate tumbling), and reduce its descent rate sufficiently to permit the main deployment event, yet not so much as to exacerbate wind drift. Any part, assembly or device, featuring an initial	Proof by reasoned argument (Deployment event) Proof by calculation (Descent rate) Proof by previous

	deployment event, shall result in a descent velocity of said item of 23-46 m/s.	testing (Descent rate)
Main Deployment Event	The main deployment event shall occur at an altitude no higher than 450 m AGL and reduce the vehicle's descent rate sufficiently to prevent excessive damage upon impact with ground. Any part, assembly or device, featuring a main deployment event, shall result in a descent velocity of said item of less than 9 m/s.	Proof by reasoned argumentation (Deployment event) Proof by calculation (Descent rate) Proof by previous testing (Descent rate)
Parachutes and Parafoils	Any parachutes or parafoils used must be rated for the weight of the vehicle and the expected conditions at deployment.	Proof by calculation
Safe Descent rate	Parachutes or parafoils intended for the final descent phase to the ground must not allow a descent rate that would represent a safety hazard.	Proof by calculation Proof by reasoned argumentation Proof by previous testing
Personal Safety	The arming/disarming process must not place the operator in the predicted path of hot gases, ejecta, or deployable devices which might result from an unintentional triggering event	Simple check
Activation Devices	The electronics controlling recovery events must be activated by externally accessible switches, and do not require any disassembly of the rocket to either activate or de-activate.	Simple confirmation
Positive State Indication	Each independent set of electronics controlling recovering events must provide sensory (i.e., visual or auditory) indication of its activation.	Simple confirmation Inspection on site
Acceleration Effects on Electronics	Heavy items - most notably batteries - must be adequately supported to prevent them becoming dislodged under anticipated flight loads.	Simple confirmation
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.	Simple confirmation Inspection on site
Parachute Swivel Links	The recovery system rigging (e.g., parachute lines, risers, shock chords, etc.) shall implement swivel links at connections to relieve torsion, as the specific design demands. This will mitigate the risk of torque	Simple confirmation Inspection on site

	loads unthreading bolted connections during recovery as well as parachute lines twisting up.	
Parachute Coloration and Markings	When separate parachutes are used for the initial and main deployment events, these parachutes should be visually highly dissimilar from one another. This is typically achieved by using parachutes whose primary colours contrast those of the other chute. This will enable ground-based observers to characterize deployment events more easily with high-power optics. Utilised parachutes should use colours providing a clear contrast to a blue sky and a grey/white cloud cover.	Simple confirmation
Non-parachute/Parafoil Recovery Systems	Teams exploring other recovery methods (i.e., non-parachute or parafoil based) shall mention them in the dedicated field of the Technical Questionnaire. The organisers may make additional requests for information and draft unique requirements depending on the team's specific design implementation.	Simple confirmation Inspection on site Proof by reasoned argumentation In-depth proofing needed
REDUNDANT ELECTRONICS		
Redundant COTS Recovery Electronics	At least one redundant recovery system electronics subsystem shall implement a COTS flight computer. This flight computer may also serve as the official altitude logging system specified in Section 2.5 of the EuRoC Rules & Requirements document, and further detailed in the Official Altitude Logging and Tracking Addendum that will be published in due time prior to the event. See section 3.3.1 for more information.	Simple confirmation
Mandatory Official GPS Tracking and Tracking Systems	EuRoC will require teams to implement a common mandatory GPS tracking and locating device in all rocket systems featuring a dual-event deployment and recovery system, to be specified in more detail in the *Official Altitude Logging and Tracking Addendum.*	Simple confirmation
Dissimilar Redundant Recovery Electronics	There is no requirement that the redundant/backup system be dissimilar to the primary; however, there are advantages to using dissimilar primary and backup systems. Such configurations are less vulnerable to any inherent environmental sensitivities, design, or production flaws affecting a particular component.	No action necessary

Safety Critical Wiring		
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.	Simple confirmation Inspection on site
Secure Connections	All safety critical wiring/cable connections shall be sufficiently secure as to prevent de-mating 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.	Inspection on site
Cryo-compatible Wire Insulation	In case of propellants with a boiling point of less than -50°C any wiring or harness passing within the close proximity of a cryogenic device (e.g., valve, piping, etc.) or a cryogenic tank (e.g., a cable tunnel next to a LOX tank) shall utilize safety critical wiring with cryo-compatible insulation (i.e., Teflon, PTFE, etc.).	Inspection on site
Recovery System Energetic Devices	All stored-energy devices (aka energetics) used in recovery systems shall comply with the energetic device requirements defined in Section 4 of this document.	Simple confirmation
Recovery System Testing		
Ground Test Demonstration	All recovery system mechanisms shall be successfully (without significant anomalies) tested prior to EuRoC, 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. The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and annex to the Technical Report. Failure to deliver this annex will automatically result in a “denied” flight status.	Proof by previous testing

Optional Flight Test Demonstration	All recovery system mechanisms shall be successfully (without significant anomalies) tested prior to EuRoC, either by flight testing, or through one or more ground tests of key subsystems. 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 EuRoC (i.e., a surrogate booster may be used). The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and annex to the Technical Report. Failure to deliver this annex will automatically result in a “denied” flight status.	No action necessary
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 of the system. An energetic device is considered armed when only one event is necessary to release the energy. For the purpose of this document, energetics are defined as all stored-energy devices – other than propulsion systems – that have reasonable potential to cause bodily injury upon energy release. See Section 4.1 for more information.	Simple check
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.	Simple confirmation Inspection on site
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. Furthermore, it is highly recommended that the arming mechanism is accessible from ground level, without the use of ladders or other elevation	Simple confirmation

	devices, when the rocket is at a vertical orientation on the launch rail.	
SRAD Pressure Vessels		
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.	Proof by previous testing
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.	Proof by calculation Proof by reasoned argumentation In-depth proofing needed
Designed Burst Pressure for Composite Pressure Vessels	All SRAD and modified COTS pressure vessels either constructed entirely from non-isentropic materials (e.g., fibre reinforced plastics; FRP; composites) or implementing composite overwrap of a metallic vessel (i.e., 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.	Proof by calculation Proof by reasoned argumentation In-depth proofing needed
SRAD Pressure Vessel Testing		
Proof Pressure Testing	SRAD and modified COTS pressure vessels shall be proof pressure tested successfully (without significant anomalies) 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 EuRoC). The maximum system working time is defined as the maximum uninterrupted time duration the vessel will remain pressurized during pre-launch, flight, and recovery	Proof by previous testing

	operations. The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered mandatory deliverable and annexed to the Technical Report. Failure to deliver this annex will automatically result in a "denied" flight status.	
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 favourably; however, this will not be considered an alternative to proof pressure testing of the intended flight article.	No action necessary
ACTIVE FLIGHT CONTROL SYSTEMS		
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 EuRoC be actively guided towards a designated spatial target. The organisers may make additional requests for information and draft unique requirements depending on the team's specific design implementation.	Simple confirmation
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. The organisers may make additional requests for information and draft unique requirements depending on the team's specific design implementation.	Proof by reasoned argumentation Inspection on site

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.).	Proof by reasoned argumentation Inspection on site
Boost Phase Dormancy	CAS shall mechanically lock in a neutral state 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 (i.e., max Q) in its trajectory, or the launch vehicle has reached an altitude of 6.000 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.).	Proof by reasoned argumentation Inspection on site
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 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.	Simple confirmation
Active Flight Control System Energetics	All stored-energy devices used in an active flight control system (i.e., energetics) shall comply with the energetic device requirements defined in Section 4 of this document.	Simple confirmation
AIRFRAME STRUCTURES		
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 3 mm to 5 mm hole is drilled in the booster section just behind the nosecone or payload shoulder area, and through the hull or bulkhead of any similarly isolated compartment/bay.	Simple confirmation Inspection on site

Overall Structural Integrity		
Checklist	Upon request, the flier should provide the inspector with hardcopy checklist procedures for the rocket's assembly and integration for flight - including self-inspection/verification steps which make individual team members accountable to one another for having completed the preceding process(es).	Simple confirmation Inspection on site
Material Selection	PVC (and similar low-temperature polymers), Public Missiles Ltd. (PML) Quantum Tube components shall not be used in any structural (i.e., load bearing) capacity, most notably as load bearing eyebolts, launch vehicle airframes, or propulsion system combustion chambers.	No action necessary (for stainless steel components) Simple confirmation
Load Bearing Eyebolts and U-bolts	All load bearing eyebolts shall be of the closed-eye, forged type — NOT of the open eye, bent wire type. Furthermore, all load bearing eyebolts and U-Bolts shall be steel or stainless steel. This requirement extends to any bolt and eye-nut assembly used in place of an eyebolt.	No action necessary (for stainless steel) Inspection on site
Implementing Coupling Tubes	Airframe joints which implement "coupling tubes" should be designed such that the coupling tube extends no less than one body calibre 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).	Simple confirmation Proof by reasoned argumentation
Launch Lug Mechanical Attachment	Launch lugs (i.e., 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. The aft most launch lug shall support the launch vehicle's fully loaded launch weight while vertical. At EuRoC, 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. This test needs to be completed successfully before the admittance of the team to Launch Readiness Review.	Inspection on site Proof by previous testing
Launch Rail Fit Check	All teams shall perform a “launch rail fit check” as a part of the flight preparations (the Launch Readiness Review), before going to the launch range. This	Inspection on site

	requirement is particularly important if a team is not bringing their own launch rail, but instead relying on EuRoC provided launch rails.	
Rail Guide Attachment	The rail guides must be firmly attached to the rocket without evidence of cracking in the joints, and the aft most guide attachment must be sufficient to bear the rocket's entire mass when erected.	Inspection on site
Slip-fit Joints	Joints intended to separate in flight cannot become separated when loaded by their own weight alone, and the Flier should demonstrate cognizance of shear pin design (if implemented).	Proof by reasoned argumentation
Joint Stiffness	All joints - both separating and non-separating in flight - must be "stiff", so as to eliminate any visible airframe bending.	Inspection on site
Fin Attachment	The fins must be firmly attached to the rocket without evidence of cracking in the joints. ("Hairline" cracks may be acceptable if the fins are not loose or, if the fins are mounted using the "through-the-wall" [TTW] construction technique.	Inspection on site
Fin Stiffness	The fins must exhibit no shifting and minimal deflection (i.e., bending) when handled.	Inspection on site
Fin "Warpage"	The fins must exhibit little-to-no indication of damage due to moisture penetration or excessive thermal cycling during storage or transport - leading to out of tolerance dimensional changes in the part.	Inspection on site
RF TRANSPARENCY		
RF Window Location	Any internally mounted RF transmitter, receiver or transceiver, not having the applicable antenna or antennas mounted externally on the airframe, shall employ “RF windows" in the airframe shell plating (typically glass fibre panels), enabling RF devices with antennas mounted inside the airframe, to transmit the signal though the airframe shell. RF windows in the flight vehicle shell shall be a 360° circumference and be at least two body diameters in length. The internally mounted RF antenna(s) shall be placed at the midpoint of the RF window section, facilitating maximizing the azimuth radiation pattern. RF transmitter, receivers or transceivers are not allowed to be mounted externally. Externally mounted antennas are allowed, but only if at least two antennas are mounted on opposite sides of the	Simple confirmation

	airframe, thus retaining circumferential symmetry and covering sufficient transmission area, transmitting or receiving identical signals. As popular as carbon fibre is for the construction of strong and lightweight airframes, it is also conductive and will significantly shield and/or degrade RF signals, which is unacceptable.	
Identifying Markings	The team's Team ID (a number assigned by EuRoC prior to the competition event), project name, and academic affiliation(s) shall be clearly identified on the launch vehicle airframe. 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 EuRoC.	No action necessary
Other Markings	There are no requirements for airframe coloration or markings beyond those specified in Section 6.4 of this document. However, EuRoC offers the following recommendations to student teams: mostly white or lighter tinted colour (e.g., yellow, red, orange, etc.) airframes are especially conducive to mitigating some of the solar heating experienced in the EuRoC launch environment. Furthermore, 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.	No action necessary
PAYLOAD		
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 9 m/s before it descends through an altitude of 450 m AGL. Deployable payloads without two-stage recovery	Proof by calculation Proof by reasoned argumentation Proof by previous testing

	systems (drogue and main chute, like the rockets) will be subjective to considerable drift during descent.	
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".	Inspection on site
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".	Simple confirmation
Deployable Payload GPS Tracking Required	It must be noted that deployable payloads are equivalent to flight vehicle bodies and sections, in that they can be difficult to locate after landing. All deployable payloads shall feature the same mandatory GPS tracking system as all rockets and rocket stages as specified in the Official Altitude Logging and Tracking Addendum to be published in due time before the event. The GPS locator ID must differ from the ID of the launch vehicle.	Simple confirmation
Payload Energetic Devices	All stored-energy devices (i.e., energetics) used in payload systems shall comply with the energetic device requirements defined in Section 4 of this document.	Simple confirmation
LAUNCH AND ASCENT TRAJECTORY REQUIREMENTS		
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 EuRoC. Competition officials reserve the right to require certain vehicles' launch elevation be as low a 70°, if flight safety issues are identified during pre-launch activities.	Simple check
Launch Stability	Launch vehicles shall have sufficient velocity upon "departing the launch rail" to ensure they will follow predictable flight paths. In lieu of detailed analysis, a rail departure velocity of at least 30 m/s is generally acceptable. Alternatively, the team may use detailed analysis to prove stability is achieved at a lower rail departure velocity 20 m/s either theoretically (e.g.,	Proof by calculation

	computer simulation) or empirically (e.g., flight testing).	
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 calibres, regardless of CG movement due to depleting consumables and shifting centre of pressure (CP) location due to wave drag effects (which may become significant as low as 0.5 Mach). Not falling below 2 body calibres will be considered nominal, while falling below 1.5 body calibres will be considered a loss of stability.	Proof by calculation
Over-stability	All launch vehicles should avoid becoming "over-stable" during their ascent. A launch vehicle may be considered over-stable with a static margin significantly greater than 2 body calibres (e.g., greater than 6 body calibres).	Proof by calculation
Flight Simulation	Upon request, the flier should either provide a hard copy, or demonstrate on a portable computer, a 3-degreee-of-freedom (3DoF) simulation (or better) of the rocket's nominal trajectory.	In-depth proofing needed
Fin Alignment	The fins should be mounted parallel to the roll axis of the rocket, or (if canted or otherwise roll inducing) the Flier must demonstrate cognizance of the predicted roll behaviour and its effects.	Inspection on site
Staging Event Sequence and Timing	Any delays implemented between staging events must not be so long as to significantly risk the rocket having "arced-over" into an unsafe orientation - typically by "gravity turn".	Proof by calculation
TEAM-PROVIDED LAUNCH SUPPORT EQUIPMENT		
Equipment Portability	If possible/practicable, teams should make their launch support equipment man-portable over a short distance (a few hundred metres). Environmental considerations at the launch site permit only limited vehicle use beyond designated roadways, campgrounds, and basecamp areas.	Simple confirmation
Launch Rail Elevation	Team provided launch rails shall implement the nominal launch elevation specified in Section 8.1 of this document and, if adjustable, not permit launch	Inspection on site

	at angles either greater than the nominal elevation or lower than 70°.	
Operational Range	All team provided launch control systems shall be electronically operated and have a maximum operational range of no less than 400 metres from the launch rail. A 600-metre operational range is preferred. The maximum operational range is defined as the range at which launch may be commanded reliably.	No action necessary
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.	Inspection on site
Safety Critical Switches	All team provided launch control systems shall implement ignition switches of the momentary, normally open (also known as "dead man") 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.	Simple confirmation
EQUIPMENT		
Communication Equipment	All teams must bring any Personal Protection Equipment (PPE) required for all preparation- and launch activities. EuRoC does not have a supply of spare PPE. PPE includes, but is not limited to, safety goggles, gloves, safety shoes, hardhats, ear protection, cryo-protection, etc.	No action necessary
Personal Protection Equipment	All teams must bring any Personal Protection Equipment (PPE) required for all preparation- and launch activities. EuRoC does not have a supply of spare PPE. PPE includes, but is not limited to, safety goggles, gloves, safety shoes, hardhats, ear protection, cryo-protection, etc.	Simple confirmation
Field Equipment	All teams are encouraged to provide each participating team member with a suitable “field/day pack”, which is kept close at hand (or worn) during launch days. Due to the possibility of strong sunlight and high temperatures even in October, some of these provisions are intended to get students through a hot and dry day in the field, while other provisions are intended to enable	No action necessary

	student teams to continue efficient operation after loss of daylight after a quick sun-down and a resulting sudden and significant drop in ambient temperature.	

Table 2: Legend for de-scoping FRR checklist

LEGEND FOR DE-SCOPING FEEDBACK
This requirement is very important
This requirement is important
This requirement is of lesser importance

Table 3: Legend for actions to be taken on the FRR checklist

ACTIONS TO BE TAKEN	
No action necessary	"I see you used stainless steel here. Okay, fine"
Simple confirmation	"Are you using non-toxic propellants?" – "Yes, we are"
Simple check	"Is everybody at least 15 m away when the ground-start ignition circuit is arming?" – "Okay now, yes"
Inspection on site	"Are all the critical wiring/cable connections sufficiently secured?" – "I will have a look, ah I see, yes"
Proof by reasoned argumentation	"Can you tell me about your process of offloading propellant in case of a launch abort?" – "Okay, sounds reasonable, this should work."
Proof by previous testing	"Have you tested the pressure vessels to 1.5 the maximum expected operating pressure?" – "Okay, I will have a look at the results and understand if everything has been tested appropriately."
Proof by calculation	"Regarding the launch stability, have you calculated the lower rail departure velocity? How did you do it? What is the result?" – "Okay, I see and understand the calculation, this will work then."
In-depth proofing needed	"How does this design feature work?" – "Okay, so you are not certain, and I do not understand on site, so let us go to the CAD model and check."

Bibliography

[1] EuRoC. *European Rocketry Challenge Design, Test, & Evaluation Guide*. Tech. rep. Version 2. 2021.