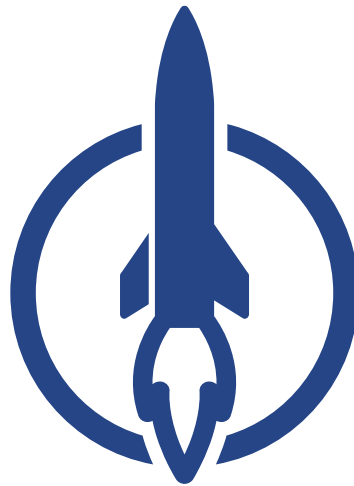


EUROPEAN ROCKETRY CHALLENGE

DESIGN, TEST & EVALUATION GUIDE



EUROC

EUROPEAN ROCKETRY CHALLENGE



INTERNAL APPROVAL

PREPARED BY:

Álvaro Lopes, Portuguese Space Agency
Inês d'Ávila, Portuguese Space Agency
Manuel Wilhelm, Portuguese Space Agency
Paulo Quental, Portuguese Space Agency
Jacob Larsen, Copenhagen Suborbitals

Signature:

Inês Sales d'Ávila
Manuel Wilhelm
Paulo Quental
Jacob Larsen

Date: 07/02/2022

VERIFIED BY:

Marta Gonçalves, Portuguese Space Agency

Signature:

Date: 07/02/2022

APPROVED BY:

Ricardo Conde, Portuguese Space Agency

Signature:

Date: 07/02/2022



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LIST OF REVISIONS

REVISION	DATE	DESCRIPTION
Version 01	20/07/2020	Original edition.
Version 02	03/03/2021	Second version, major revisions for EuRoC 2021.
Version 03	04/02/2022	Third version, major revision for EuRoC 2022.



1. INTRODUCTION

1.1. BACKGROUND

The Portuguese Space Agency – Portugal Space promotes the EuRoC – European Rocketry Challenge, hosted in the Municipality of Ponte de Sor, a competition that seeks to stimulate university level 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.

EuRoC 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.

Since EuRoC's first edition, in 2020, where 100 students were present to 2021, with 400 students participating, the growth of the competition within Europe is visible, and especially within Portugal, with an increasing number of interested teams applying to the competition. For the future, it is Portugal Space's goal to continue to foster the exchange of knowledge and international interaction inherent to the event, allowing more students to gain from the Challenge and, at the same time, contribute to it.

This document defines the rules and requirements governing participation in EuRoC. 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 (Table 1) are either applicable to the extent specified herein or contain reference information useful in the application of this document.

Table 1: Documents file location.

DOCUMENT	FILE LOCATION
EuRoC Rules & Requirements	http://www.euroc.pt
EuRoC Design, Test & Evaluation Guide	http://www.euroc.pt
EuRoC Launch Operations	http://www.euroc.pt
EuRoC Entry Form	http://www.euroc.pt
EuRoC Academic Institution Letter Template	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 Temporary Admission Guide	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. SOLID MOTORS



Only COTS solid motors from the official EuRoC motor list (issued separately) are permitted at EuRoC. The motors must be ordered via the official EuRoC pyrotechnics. Teams should refrain from contacting any other pyrotechnics suppliers on their own.

2.3. IGNITION SYSTEMS FOR SOLID MOTORS

For all solid motors (COTS and SRAD), the use of the electronic ignition system provided by the EuRoC organisers is mandatory.

2.4. 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.

2.4.1. 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.

2.4.2. 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.



2.4.3. CLUSTERED PROPULSION

Partial ignition may occur in clustered propulsion systems, leading to an increased probability of incident occurrence, mainly by three potential consequences:

1. The thrust force is lower than expected, thus acceleration on the launch rail and resulting launch rail take-off velocity too low, leading to an unstable flight.
2. The thrust force asymmetric, leading to a sideways momentum on the rocket off the launch rail, thus to an unstable flight, and potentially a structural failure.
3. Incompletely ignited propulsion systems separate from the vehicle, ignite in the air, or ignite from the top, and burning parts impact the ground.

To ensure stable flight, all clustered vehicles shall have a launch release system ensuring lift-off only occurs if a minimum threshold force is met. This can be done for example by implementing a breakaway coupling, a structural fuse, or a rope with defined breaking force.

An electromechanical alternative to a structural fuse is to measure the thrust of the restrained flight vehicle and then open a quick release mechanism if certain conditions are fulfilled. For example, as the vehicle throttles up, a squib/pyro actuated quick release latch can be electrically fired (i.e., Sweeny quick release latch) when the thrust has continuously exceeded a minimum threshold for perhaps 200 milliseconds (jerk and noise suppression).



*Figure 1: Example of a Sweeny quick release latch.
(Source: Matt Sweeney SPFX Inc.)*

To measure the thrust, a strain gauge could be used, or alternatively piezo-electric pressure sensors can be applied to measure the combustion pressure inside a thrust chamber, verifying that nominal thrust has been achieved before the quick release squib is fired. If the latter method with pressure sensors is used, the sensor/transducer shall be of stainless-steel and mounted in a way so that it remains protected from hot combustion gases by means of an oil trap.



Furthermore, all clustered vehicles shall provide an engineering proof (e.g., analysis and/or simulation) that stable flight is ensured for a lift-off force above the threshold force, even if the propulsion system fires asymmetrically (if applicable).

For vehicles with a “main” and several “secondary” propulsion systems, the arming function of the secondary propulsion systems shall be armed by launch detection (i.e., air-start), preventing ground arming of the clustered propulsion in event of misfire.

2.5. 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.

2.6. SRAD PROPULSION SYSTEMS

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.

2.6.1. 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.

2.6.2. HYBRID AND LIQUID PROPULSION FILLING SYSTEMS

Team shall demonstrate that the filling/loading/unloading of the liquid fuels can be done to be ready for the launch window (maximum 90 minutes for liquid propellant loading, including pressurization).

Teams utilising liquid propellants with low boiling point are also strongly encouraged to consider abandoning the use of “passive” or “self-pressurization” of propellants and adopt active external or internal pressurization (nitrogen or helium). Besides removing the significant propellant density uncertainties of two-phase flows (a volatile and somewhat arbitrary mixture of gas bubbles and liquid) in injectors, the flight vehicle can be pressurized in typically less than 15 seconds, at any point in time after having been loaded on the launch rail.



If teams utilise any kind of remote-controlled loading mechanism for gases or liquid propellants, the loading mechanism shall feature a clearly marked and labelled, single action, hand actuated, “Emergency Release Mechanism”, just in case a remote-controlled release mechanism jams and requires manual LCO assistance.

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, teams should account for a “failed” launch and subsequent unloading in launch preparation, thus teams should ensure the availability of additional propellants, igniters, and any other parts that might need replacement or adjustment in case a second launch attempt would be possible.

2.6.3. 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.

2.6.4. HYBRID/LIQUID VENTING

For hybrid and liquid motors, it is imperative that teams can facilitate oxidizer tank venting to prevent over-pressure situations. Teams will only be able to launch in specific time slots, so pressure relief measures must be implemented to account for rockets potentially sitting a long time in waiting on the launch rail. At no time oxidizer tanks must become safety liabilities.

2.6.5. 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.



2.6.6. 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 9.1. 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.).

3.4. ON-BOARD POWER SYSTEMS AND RAIL STANDBY TIME

Loss of launch slots have been experienced on multiple occasions as onboard batteries are typically located in inaccessible positions. Despite the requirement of at least six hours of battery life on the launch rail, an unsuccessful launch attempt typically results in the teams deciding to:

- Disarm any energetic pyrotechnics;
- Take the flight vehicle off the launch rail;
- Haul the rocket back to the team's preparation area;
- Use tools to perform medium to extensive disassembly of the flight vehicle to extract batteries;
- Spend one to several hours recharging the batteries, if charged spares are not readily available;
- Perform the whole operation in reverse and return to the launch rail many hours later, to perform an additional launch attempt, if the possibility is given.

This is a critically inefficient use of valuable and limited launch campaign time.

Teams should adopt one of the following two strategies:

- Implement an on-board charging and charge level maintenance system using an umbilical connection and cable;
- Place all rechargeable or replaceable batteries conveniently under service panels accessible from ground level, without resorting to ladders or lowering the launch rail, having several spare sets of charged batteries ready at any time.

The implementation of an on-board charging and charge level maintenance system, based on a vehicle-wide charging bus and an umbilical cable (featuring friction-based pull-release), connected to a ground-based power supply, should be designed/implemented as follows:

- A "charging bus" should run along the entire length of the flight vehicle, interfacing to all batteries to facilitate charging and continuous charging and subsequent maintenance trickle-charging;
 - Use mating connectors at every structural joint;



- Largely all benefits of the system are lost if even a single battery is left out of the umbilical charging bus system.
- Each tap-off from the on-board charging bus to individual battery subsystems shall be reverse current flow protected by a suitably rated diode;
- All on-board batteries should feature the same nominal voltage, as far as possible;
 - If bus voltage step-down is required for batteries with lower nominal voltage, adequately heat-dissipated linear regulators are strongly recommended and placed upstream of the mandatory cell balancing circuits;
 - Switch-mode regulation or onboard battery chargers are strongly discouraged due to generated EMI and electrical noise;
 - LiPo battery cell balancing circuits shall protect each individual battery pack;
 - LiPo battery cell balancing circuits of up to 12S cell count are widely available as pre-assembled PCBs for a low price, complete with built-in undervoltage-cut-off, overcurrent-protection and overcharging cut-off;
 - Flight vehicle batteries could all be considered “permanently” installed, not requiring removal past initial installation during on-site preparation. The ground-based power supply should simply be outputting the battery trickle charge voltage, plus a diode drop, for easiest implementation.

The advantages of implementing such a system are in most cases worth the efforts. Most significantly, the launch vehicle rail standby time changes to “infinite” and the launch vehicle is always launched with 100% peak charged batteries.

3.4.1. 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.

The interconnection redundancy of the nominal and redundant recovery electronics and recovery systems should be implemented as illustrated in Figure 2.

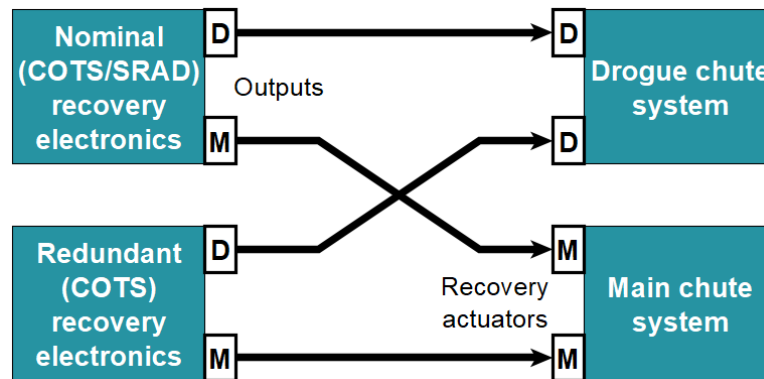


Figure 2: Interconnection redundancy implementation. (Source: Jacob Larsen)

3.4.2. 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.

3.4.3. RECOVERY ELECTRONICS ACCESS

As for all electronics, it is highly recommended to ensure easy and quick access to switches/connectors via an access panel on the airframe. Access panels should be positioned so they are reachable from ground level, ideally without ladders. Access panels shall be secured for flight.

3.5. OFFICIAL ALTITUDE LOGGING AND TRACKING SYSTEM

Single-stage flight vehicles and upper-most stages of flight vehicles shall feature a mandatory operational Eggtimer TRS Flight Computer for official altitude logging and GPS tracking. For more details see <http://eggtimerrocketry.com/>.

The competition achieved apogee will be determined from this device.

Note: Deployable payloads and lower stages also require a mandatory Eggfinder GPS tracking device, but this need not be the TRS Flight Computer.

More technical details on the Eggtimer TRS Flight Computer along with recommendations and lessons learned can be found in Appendix C.

The Eggtimer TRS Flight Computer system serves two purposes:

- Providing the EuRoC evaluation board with the means to easily determine and record the apogee altitude in a fast, efficient, and consistent way. Since the flight vehicle apogee is a



fundamental part of the competition, the method of determining it must be equally fair (hence identical) for all teams;

- Provide the student/recovery teams an efficient means of quickly tracking down the location of all landed flight vehicles (and any other tracked payload/components), to quickly clear the launch range.

The Eggtimer TRS Flight Computer System was chosen to impose the least amount of inconvenience to the teams:

- Low weight and volume transmitter, to not impede flight vehicle design or performance;
- Being cheap and imposing the smallest financial burden possible.

3.5.1. TRS FLIGHT COMPUTER AS COTS FLIGHT COMPUTER FOR RECOVERY

The Eggtimer TRS Flight Computer may be used as the COTS flight computers to comply with the requirements for redundant COTS Recovery Electronics according to section 3.3., or it may be used as an additional, independent standalone system.

The Eggtimer system was NOT chosen because it provides the best overall performance or versatility. It is however the cheapest system which fulfil the EuRoC organisation minimum functional requirements with regards to apogee logging and GPS tracking. It is therefore recommended that teams evaluate the specifications and functionality of the system before they decide between implementing it as their main flight computer or leaving it as a stand-alone “payload”.

3.5.2. TRS FLIGHT COMPUTER FREQUENCIES

EuRoC will make specific frequencies available for tracking system use, without the need for specific radio amateur licenses. Eggtimer Ham-frequency equipment can thus legally be used during EuRoC without a license. This means that all mandatory TRS Flight Computers must be purchased in the US “Ham” frequency range.

While the “EU” license free version of the TRS sounds like a compelling option, there is a major drawback in the fact, that the EU license free band contains only three separate channels/frequencies, and TRS systems cannot share the same frequency.

This is a major problem since multiple flight vehicles might be on the launch rails at the opening of a launch window. These vehicles will (when propulsive technology permits) be launched successively, as soon as the previous flight vehicle is believed landed, with no time for additional pre-flight preparations in between launches.

Therefore, purchasing the “EU” version of the TRS Flight Computer is highly discouraged, despite being legal to use.



3.5.3. TRS FLIGHT COMPUTER OPERATING FREQUENCY ALLOCATION

The EuRoC organisation intends to allocate unique TRS Flight Computer operating frequencies to teams, at the latest shortly after the FRR. This includes the frequency for the upper-most stage of the flight vehicle, as well as any other frequencies for lower stages and/or deployable payloads.

Teams shall however be capable of (and prepared to) re-program their operating frequencies of Eggtimer/finder equipment at short notice in case launch schedule reshuffling requires it so.

3.5.4. TRS FLIGHT COMPUTER FIRMWARE UPDATE

Teams must ensure that the TRS Flight Computer is running a custom version of the firmware for the 70 cm Ham frequency band, having a channel selection resolution of 25 kHz. This is necessary in order to be able to select the frequencies allotted to EuRoC.

Please note that firmware updates can be done at any time by participating teams, as long as the hardware has been procured.

3.5.5. TRS COMPATIBLE RECEIVER(S)

While teams are not required to procure one or more receivers for the Eggfinder “Ham-version” TRS Flight Computer, according to the EuRoC Rules and Requirements, teams shall procure the “full kit package”, as it includes the LCD GPS receiver.

3.5.6. TRS ELECTRONICS ACCESS

As for all electronics, it is highly recommended to ensure easy and quick access to switches/connectors via an access panel on the airframe. Access panels should be positioned so they are reachable from ground level, ideally without ladders. Access panels shall be secured for flight.

3.6. 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.

3.6.1. 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.

3.6.2. 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.

3.6.3. CRYO-COMPATIBLE WIRE INSULATION

In case of propellants with a boiling point of less than -50°C any wiring or harness passing within 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.).

3.7. 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.

3.8. RECOVERY SYSTEM TESTING

Recovery system testing has proven to be one of the most critical and at the same time underestimated tasks. Teams are strongly encouraged to test the system back-to-back as good as they can and implement standard procedures that they can fall back onto even during the most stressful of launch days.

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.

3.8.1. 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”.

3.8.2. 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”.

3.8.3. OPTIONAL FLIGHT ELECTRONICS DEMONSTRATION

Teams are encouraged to have a setup to demonstrate the electronics and recovery system working routine in the FRR, either by a software routine that actuates the outputs of the flight computer and using LED indicators or buzzers or by a self-developed setup. This step is not mandatory, it is instead a recommendation for teams to detect some possible bugs and defects in their system.



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.

Table 2: Overviews and configurations of stored-energy devices.

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 2.4.1. 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 locking 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 isotropic 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-isotropic 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 6000 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. 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.

As for all electronics, it is highly recommended to ensure easy and quick access to switches/connectors via an access panel on the airframe. Access panels should be positioned so they are reachable from ground level, ideally without ladders. Access panels shall be secured for flight.

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 (1D) on either side of the joint — measured from the separation plane. This rule applies both for "half" couplings (e.g., nosecone – body tube/coupling tube) as well as for "full" couplings (e.g., body tube – coupling tube – body tube). See example in Figure 3 for clarity. Regardless of implementation (e.g., RADAX or other join types) airframe joints need to be "stiff" (i.e., prevent bending).

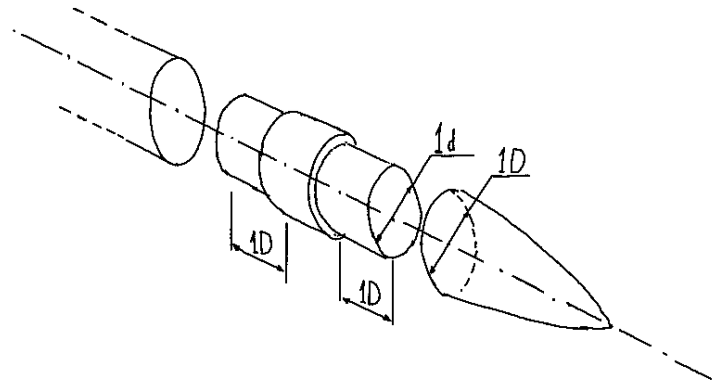


Figure 3: Examples for coupling tubes.

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.

6.3. 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 through 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.

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 nearly a 360° radiation pattern from a single antenna without significant dead-zones. This is true at any point in time, except when the rocket engine is



active. The ionized exhaust gas from the engine is highly disruptive to RF signals, so degradation or loss of link is to be expected.

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 RF dead zones, meaning that at least two antennas on opposite sides of the airframe are advisable.

RF antennas shall be kept as far away as possible from wiring and metallic structural elements. Numerous examples of poor installation practice have at a great extent ruined telemetry and link performances. Teams are highly advised to follow best RF-practices.

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 3.8..

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 Section 3.5. of this document.

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 $84^{\circ} \pm 1^{\circ}$ 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 stability margin of at least 1.5 calibres throughout the whole flight phase (upon leaving the launch rail), 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).

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

9.1. LAUNCH RAILS

EuRoC will provide standardised launch rails for the teams that do not intend to bring their own launch rail. One of the EuRoC Launch rails which will generally be near the paddock during Flight Readiness Reviews for the Launch Rail Fit Check, while three will be at the Launch Site. The vehicle is guided by a 50 mm x 50 mm cross-section aluminium rail by Kanya (see Figure 4 for details) The launch rail length is 12 m and the launch rail inclination usually $84\pm 1^\circ$ to vertical, which may be lowered on a case-by-case basis if the EuRoC officials deem it necessary. For details on the launch lugs, please see Section 6.2.4..

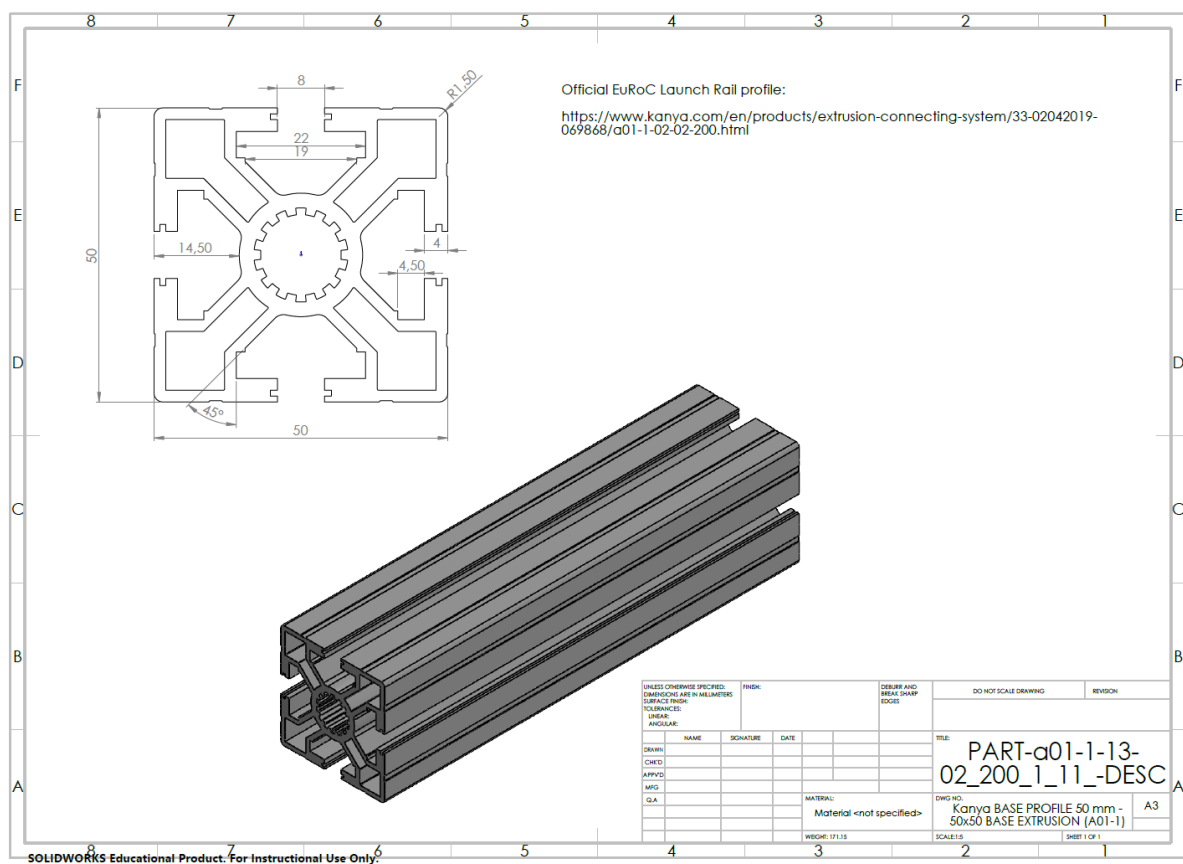


Figure 4: EuRoC launch rail profile.

9.1.1. LAUNCH RAIL FIT CHECK

All teams shall perform a “launch rail fit check” as a part of the flight preparations (the Flight 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. Teams shall provide their own bottom “spacer” to define their vehicles’ vertical position on the rail.



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 evaluation board. The launch rail fit check will ensure that such surprises are not encountered on the launch rails, causing delays and loss of launch opportunities.

Note: The launch rail fit check can only be done in the presence of EuRoC officials. Teams cannot use the EuRoC launch rails without permission, any launch rail related activity shall be duly authorised by EuRoC officials.

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 650 metres from the launch rail. 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. Appendix B: 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.



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

B.1. 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.

B.2. 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.

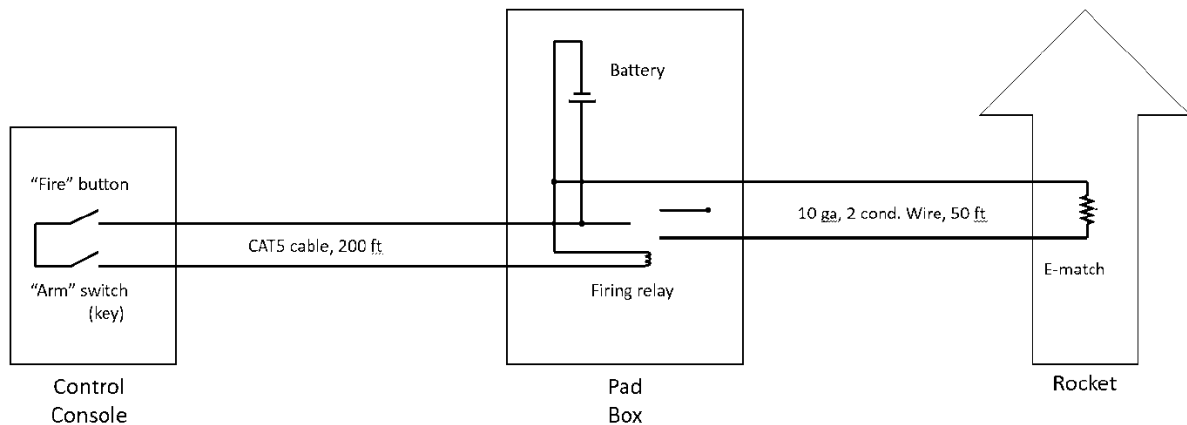


Figure 5: A simple high current fire control system.

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 6). 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).

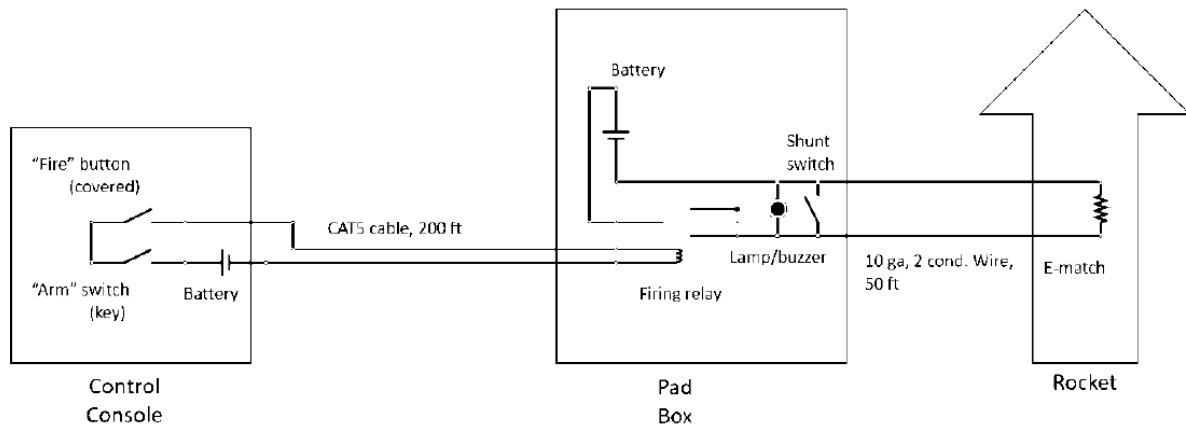


Figure 6: An improved high current fire control system.

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: OFFICIAL ALTITUDE LOGGING AND TRACKING SYSTEM

C.1. INTRODUCTION

This appendix contains mandatory provisions for flight vehicles partaking in the EuRoC competition.

C.1.1. SCOPE

EuRoC calls for a specific system for rocket (flight vehicle) apogee tracking and subsequent location/recovery of landed vehicles, which this appendix focuses on.

The specific system tested and approved for these tasks is described in further detail in the technical sections, along with recommendations and lessons learned from the test campaign at the end.

C.1.2. BACKGROUND

The fast growth in number of teams attending the EuRoC competition calls for some careful considerations on how to complete the following two tasks in the most efficient and expedient way:

- Providing the EuRoC jury with the means to easily determine and record the apogee altitude in a fast, efficient, and consistent way. Since the flight vehicle apogee is a fundamental part of the competition, the method of determining it must be equally fair (hence identical) for all teams;
- Provide the student/recovery teams an efficient means of quickly tracking down the location of all landed flight vehicles (and any other tracked payload/components), to quickly clear the launch range.

After careful consideration of what a future-proof solution to the above could look like, EuRoC requires students to fly a mandatory system for altitude logging and recovery tracking.

C.1.3. RATIONALE

While the prime intentions behind instigating a specific mandatory altitude and logging system are clear, the EuRoC organisation has also put some emphasis on trying to find a solution which will impose the least amount of inconvenience (in general) on teams.

An example of trying to impose a least amount of inconvenience, for requiring the installation of a distinct mandatory altitude logging and tracking system is, for example:

- Low weight and volume transmitter, to not impede flight vehicle design or performance;
- Being cheap and imposing the smallest financial burden possible.



It is the EuRoC organisation main objective to seek out a universally fair and transparent method of determining apogee, where teams may be separated by only a few meters at apogee.

Furthermore, the EuRoC organisation also focuses on finding a field-rated solution for tracking and recovering the flight vehicles in the most efficient and expedient manner, minimising at the most the efforts of, and time spent in the field, trying to locate and recover landed rockets.

C.2. ALTITUDE LOGGING AND TRACKING SYSTEM FUNCTIONAL REQUIREMENTS

C.2.1. ALTITUDE AND APOGEE REQUIREMENTS

- 1) The system shall be able to log and store the flight apogee in a non-volatile memory.
 - Apogee and flight data may still be recoverable after various “unforeseen events”, such as power-outs or even crashes.
- 2) The system shall be able to allow the EuRoC Jury to extract the apogee and flight data, using one fast, efficient, and standardized way, without necessarily requiring student team assistance.
 - This means one common system across all flight vehicles, to which the Jury can extract the needed flight data with one single tool.
- 3) The system should be able to provide real-time altitude read-outs during flight.
 - If this data or data stream is captured and logged, it should be possible to reconstruct the altitude curve and the apogee, in case of a total loss of flight vehicle/data.
- 4) The system should be able to provide the teams and Jury with a preliminary apogee figure for quick measure, later to be backed up by detailed recorded flight data.

C.2.2. TRACKING AND RECOVERY REQUIREMENTS

- 1) The system shall consist of a transmitter and a receiver, and the transmitter shall record it's position by means of GPS and transmit its location to the receiver.
 - Both the transmitter and receiver can be transceivers;
 - More than one transmitter can be employed when the Rules and Regulations call for it, as required for each stage of multi-stage flight vehicles, as well as for deployable payloads;
 - More than one receiver can be employed for various purposes.



- 2) The system shall as efficiently and directly as possible direct the operator of the receiver to the landing coordinates of the flight vehicle. This is achieved by the receiver being aware of the transmitters position (or last known position), as well as the receiver's own current position, through GPS receivers in both devices.
 - The receiver shall be mobile and transportable (in the operational state) by a single person, without support.

C.2.3. GENERAL REQUIREMENTS

1. The transmitter shall be as small and light as possible, facilitating easy integration into the flight vehicle and exhibit the least possible mass penalty for flight vehicle mass budgets.
2. The system shall be a commercially available solution, with a history of adequate and reliable operation, to which EuRoC can acquire and use the organisation's own receivers.
 - Teams can fly additional high-end tracking solutions as they please, but EuRoC recovery crews shall be able to utilize one single type of standardized and field-programmable system receiver to track and recover all flight vehicles launched.
3. The system shall be field-programmable with regards to RF operating frequency.
 - Unexpected launch slot re-shuffling may suddenly necessitate a likewise re-shuffling of GPS tracking system operating frequencies;
 - "Field-programmable" may include the use of additional equipment, such as a laptop, to accomplish the task of changing frequencies.
4. The transmitter shall be mounted internally in the flight vehicle, at the location of an "RF-transparent" section, unless the transmitter features an externally mounted antenna.
 - No external mounting allowed.
5. The system should be capable of performing its function without the support of other services, such as mobile cell networks, online web-services, or online apps.
 - A self-reliant, enclosed, stand-alone system is well suited for field operations, with intermittent or lacking mobile services (where delicate laptops, wired breakout boards, and web-based apps are not).
6. The receiver display should be clearly readable in bright sunlight.
 - Backlit screens and displays can be difficult to read under clear skies and full sun conditions.
7. The receiver should, to the extent possible, be ruggedized for extended periods of field use.
 - The receiver and its operator may likely experience a bumpy and dusty cross-country excursion, while conducting the recovery effort;



- The receiver should be able to operate continuously throughout a day.
8. The system should be cheap and affordable to the extent possible, where it does not impact reliability or function.
- Affordable and adequate performance is favoured over fancy and expensive alternatives.

C.3. MANDATORY ALTITUDE LOGGING AND TRACKING SYSTEM

C.3.1. EGGTIMER TRS FLIGHT COMPUTER

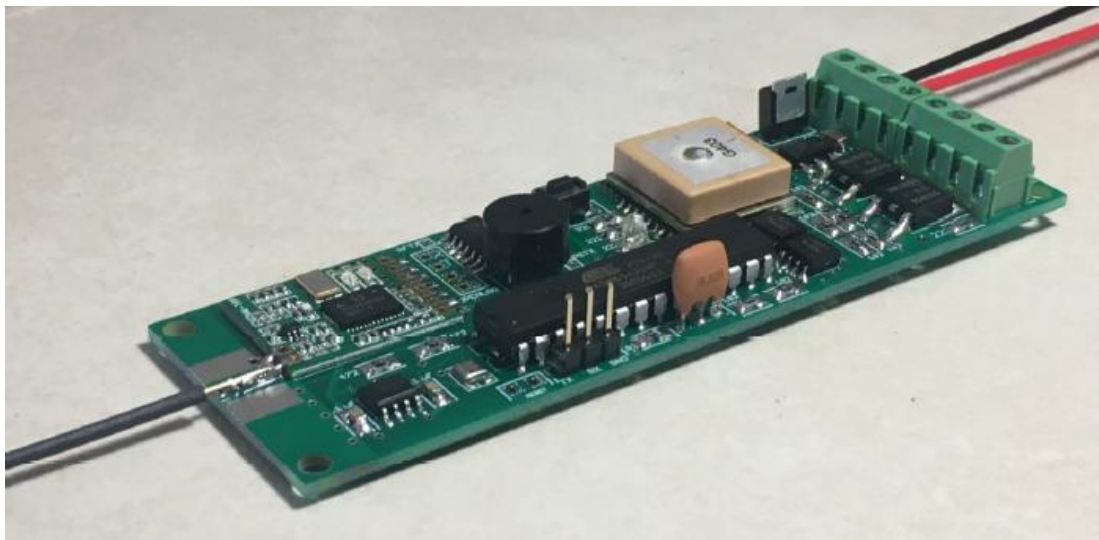


Figure 7: Eggtimer TRS Flight Computer (assembled). (Source: Eggtimer)

Single-stage flight vehicles and upper-most stages of flight vehicles shall feature an operational Eggtimer TRS Flight Computer for official altitude logging and GPS tracking.

The competition achieved apogee will be determined from this device.

Note: Deployable payloads and lower stages also require a mandatory Eggtimer GPS tracking device, but this need not be the TRS Flight Computer. See section C.4.5. for details.

The Eggtimer TRS (Total Recovery System) Flight Computer combines several useful systems in one device, fulfilling the requirements outlined in section C.2.:

- A COTS dual-channel deployment computer;
- Barometric pressure sensor for apogee determination and recovery systems deployment;
- A non-volatile memory for recording flight data (including altitude) over the full flight duration.

GPS tracking functionality and a tracking transmitter.



The TRS Flight Computer comes as a kit (PCB, components and some sub-assemblies) and requires component mounting and testing.

C.3.1.1. TRS FLIGHT COMPUTER FIRMWARE UPDATE

Teams must ensure that the TRS Flight Computer is running a custom version of the firmware for the 70 cm Ham frequency band, having a channel selection resolution of 25 kHz. This is necessary in order to be able to select the frequencies allotted to EuRoC.

Please note that firmware updates can be done at any time by participating teams, as long as the hardware has been procured.

See section C.4. for further details on firmware.

C.3.1.2. THE TRS FLIGHT COMPUTER IS ELIGIBLE AS THE REDUNDANT COTS DEPLOYMENT ELECTRONICS

As per the “Redundant COTS Recovery Electronics” section in the EuRoC Design Guide, the TRS Flight Computer fulfils this requirement and can be used as the redundant recovery system electronics sub-system.

C.3.1.3. TRS FLIGHT COMPUTER OPERATING FREQUENCY ALLOCATION

The EuRoC organisation will allocate TRS Flight Computer operating frequencies to teams no less than 24 hours prior to the Flight Readiness Review. This includes the frequency for the upper-most stage of the flight vehicle, as well as any other frequencies for lower stages and/or deployable payloads.

Teams must however be capable of (and prepared to) re-program their operating frequencies of Eggfinder/finder equipment at short notice in case launch schedule reshuffling requires it so.

C.3.1.4. EUROC MISSION CONTROL EGGFINDER LCD HANDHELD RECEIVERS

The EuRoC organisation will field a selection of fully upgraded Eggfinder LCD handheld receivers, to be placed at Mission Control for the duration of the launch campaign:

- Four units of Ham-version LCD handheld receivers with LCD-GPS and custom field-use enclosure upgrade;
- One unit of EU license free version LCD handheld receiver with LCD-GPS and custom field-use enclosure upgrade.

Up to five of these LCD handheld receivers will be tuned to the individual TRS Flight Computer transmission frequencies of the flight vehicles scheduled for launch, at each launch slot.



As each rocket launches, each of the EuRoC operated tuned LCD receivers may be connected to a tripod with high gain directional antennas at mission control. The aim is to receive live telemetry and altitude data even at 9 km altitude and track the flight vehicle until loss of line-of-sight at very low altitude. The procedure is predicted to be as follows:

- Mission Control will know the flight vehicle assigned operating frequency (or frequencies) and program the EuRoC operated LCD receivers during launch preparations;
- The reception of valid TRS Flight Computer telemetry will be verified prior to (or during) the Launch Readiness Review, performed at the launch rail;
- Mission Control will track the TRS Flight Computer of each flight vehicle during the entire flight, using high gain antennas at Mission Control, until potential loss of signal, due to loss of line-of-sight at very low altitude;
- Mission control will record the last known GPS coordinates at mission control for reference;
- All EuRoC LCD handheld receivers will stay powered while recovery operations are running;
- Teams shall each have at least one tracking receiver. Several can be advantageous for more efficient tracking and recovery;
- Recovery teams will change LCD handheld receiver operating frequencies in the field, as necessary to recover all jettisoned stages and/or deployable payloads;
- Teams may leave their TRS Flight Computer powered during recovery and transportation back to Mission Control, provided that any recovery systems are brought back into a safe state, where actuation of recovery systems (regardless of status) is prevented;
- A representative of the EuRoC organisation will inspect the recovered flight vehicles at Mission Control and extract flight data and apogee from the TRS Flight Computer, as possible.

C.3.1.5. OTHER ALTITUDE LOGGING AND GPS TRACKING SYSTEMS

Teams are welcome to operate and fly one or more of their own altitude logging and/or GPS tracking solutions, in addition to the mandatory systems, described in this addendum.

Such systems may have superior performance or range compared to the selected mandatory EggTimer systems, but this does not exempt teams from implementing the mandatory systems.

Again, the EuRoC organisation is firm on testing and validating a system and procedures for the fair, equal and transparent recording of apogees, and the implementation of efficient tracking and recovery operations.



C.3.2. EUROC TESTING OF THE EGGTIMER TRS FLIGHT COMPUTER

The EuRoC organisation conducted both GPS tracking field tests as well as simulated flight tests, using a vacuum chamber. A short summary of the tests used to evaluate and approve the Eggtimer TRS Flight Computer (and other Eggfinder products) is outlined as follows.

Note: The testing was performed using the EU license free frequency version of the Eggtimer product line (869 MHz range), hence the expected range of the 433 MHz range Ham-version products is expected to be roughly double of what is described below.

The entire Eggfinder range of GPS tracking solutions, as well as the TRS Flight Computer, utilizes the same half-duplex RF module for telemetry. As expected, range performance has been found to be similar for all products.

C.3.2.1. ON-GROUND GPS TRACKING TESTS

Two cases of worst-case scenario testing were carried out:

- An Eggfinder TX was placed in a wet crop field, 10 cm off the ground (line of sight), with the aim of having the wet vegetation attenuating the RF link as much as possible;
- An Eggfinder TX was placed at a tree stub in a rugged and heavily forested area.



*Figure 8: Eggfinder TX placed in wet crop field at a distance of 530 meters (heavy digital zoom; red arrow marks TX location).
(Source: Jacob Larsen)*



Figure 9: Another worst-case scenario: A rugged and heavily forested test area. (Source: Jacob Larsen)

While the crop field test illustrated in Figure 8 did feature line-of-sight between TX transmitter and LCD handheld receiver, ground effects and wet vegetation should provide a challenging test setup.

Test results indicated that the RF-link range was about 500 meters with a wire antenna on the TX and an Eggtimer supplied 3 dB stub antenna, as illustrated in Figure 10.

The forest test range limitation was primarily governed by loss of line-of-sight, due to bumpy terrain, while wet tree trunks were also identified as efficient signal attenuators.

Circling the transmitter in the forest revealed a consistent RF-link range of about 300 meters, regardless of terrain and foliage.

It can thus be concluded, that at the absolute worst-case scenario of an 869 MHz EU licence free version in a forest, an LCD handheld receiver will pick up the RF-link signal at a minimum distance of 300 meters, regardless of conditions.

If getting within 300 meters of a GPS transmitter, the LCD handheld receiver will pick up the tracking signal, no matter what terrain it is in.

433 MHz “Ham” versions are expected to exhibit about twice the range of the above.



*Figure 10: LCD handheld receiver detects GPS transmitter at a distance of 530 meters.
(custom enclosure, 3dB stub antenna, SMA board connector options) (Source: Jacob Larsen)*

C.3.2.2. AIR-TO-GROUND GPS TRACKING TESTS

No air-to-ground GPS tracking tests have been conducted as of time of writing. The manufacturer indicates about 15 km of line-of-sight aerial range with the Ham-version and a stub antenna. About half that with the EU license free 869 MHz version.

Based on the above, lack of range of the Eggfinder equipment is not currently a concern.

C.3.2.3. TRS FLIGHT COMPUTER SIMULATED FLIGHT TEST

In the interest of testing and validating the performance of the TRS Flight Computer, a simulated flight test case was devised, using a vacuum chamber to simulate the ambient pressure drop experienced during ascent.

The test objectives were as follows:

- To simulate a trajectory the TRS Flight Computer would interpret as a real launch;
- To record flight and altitude data onboard the TRS non-volatile memory;
- To rehearse and gain experience with the TRS Flight Computer arming sequence;



- To rehearse the interpretation of downlink telemetry and flight events displayed at the LCD handheld receiver;
- To rehearse downloading and visualizing the flight data stored in the TRS Flight Computer non-volatile memory.

The test consisted of quickly drawing a vacuum to simulate ascent and then gradually opening a manual bleed valve to simulate apogee and descent.

The flight data is easily downloaded from the TRS Flight Computer, using a laptop and the USB/TTL UART data cable. The data is downloaded and saved into a log file as comma separated ascii values, using a terminal program.

Figure 11 illustrates the flight data imported into an excel spreadsheet and displayed in a suitable graph format.

There are two things to note in Figure 11:

- All altitudes and velocity data from the TRS Flight Computer are displayed and logged in units of feet and feet/sec. The TRS Flight Computer is not capable of transmitting and/or recording flight data in metric units.
 - This is in stark contrast to the GPS and tracking data downrange displayed on the LCD handheld receiver, which can be switched between feet and meters.
- The drogue deployment is delayed, contrary to supposed to happen at “nose-over”, due to an artifact of the test setup. The apogee is a discontinuous kink in the pressure profile, in contrast to the continuous inverted parabola expected. The flight computer waits for one second of vertical velocity below 100 ft/sec, before it arms and fires the drogue pyro channel. This is why the drogue deployment event does not happen at nose-over in the below test.
 - The TRS Flight Computer deployment channels work as advertised. It is the test setup which is not capable of generating a smooth simulated apogee.

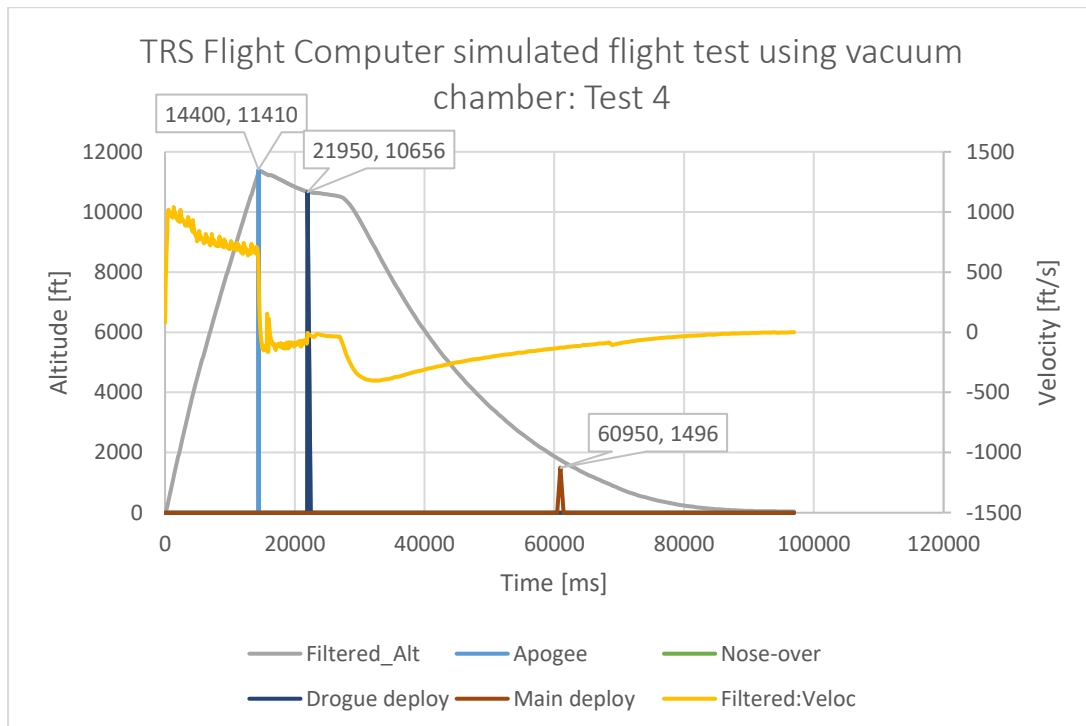


Figure 11: TRS downloaded flight data visualization from vacuum chamber test #4, 1500 feet main deployment set (delayed drogue deployment event is an artifact of having too sharp a kink at apogee). (Source: Jacob Larsen)



C.4. MANDATORY SYSTEM KEYPOINTS, RECOMMENDATIONS AND REQUIREMENTS SUMMARY

C.4.1. MANDATORY ALTITUDE LOGGING AND GPS TRACKING SYSTEM

For single-stage flight vehicles (and upper-most stage vehicles), the mandatory Official Altitude Logging and Tracking device to be installed is the Eggtimer TRS Flight Computer.

- The TRS (Total Recovery System) device combines:
 - A COTS dual-channel deployment computer;
 - Barometric pressure sensor for apogee determination and recovery systems deployment;
 - A non-volatile memory for recording flight data over the full flight duration;
 - GPS tracking and recovery transmitter.

C.4.2. TRS FLIGHT COMPUTER FREQUENCY RANGE

EuRoC will make specific frequencies available for tracking system use, without the need for specific radio amateur licenses. Eggtimer Ham-frequency equipment can thus legally be used during EuRoC without a license. This means that all mandatory TRS Flight Computers MUST be purchased in the US “Ham” frequency range.

- The recommended package to buy is (approximately \$200):
 - The “Eggtimer TRS/LCD Starter set, 70cm Ham versions” (includes data cable + terminal blocks + external antennas) at \$168 (2021 price).
 - The “Eggfinder LCD-GPS module kit” at \$40 (2021 price).

C.4.3. “EU” TRS FLIGHT COMPUTER VERSIONS

While the “EU” license free version of the TRS sounds like a compelling option, there is a major drawback in the fact, that the EU license free band contains only three separate channels/frequencies (and TRS systems cannot share the same frequency).

This is a major problem since multiple flight vehicles will be sitting on the launch rails at the opening of a launch window. These vehicles will (when engine technology permits) be launched successively, as soon as the previous flight vehicle is believed landed, with no time for additional pre-flight preparations in between launches.

- Therefore purchasing the “EU” version of the TRS Flight Computer is highly discouraged, despite being legal to use;



- However, for teams or flight vehicles already having an “EU”-frequency versions of Eggtimer products, these “EU” frequency systems can be flown at EuRoC as a replacement for the “HAM” frequency version. The EuRoC organization only has one “EU” compatible receiver, limiting its use.

C.4.4. PROCUREMENT OF TRS COMPATIBLE RECEIVER(S)

While teams are not required to procure one or more receivers for the Eggfinder “Ham-version” TRS Flight Computer, according to the EuRoC Rules and Requirements, teams are strongly encouraged to procure the above “full kit package”.

- The TRS Flight Computer is best programmed wirelessly from the LCD receiver while firmware updating, and flight data download happens via the USB-serial adaptor data cable (included in package).
- The LCD receiver has several test functions (including deployment channel testing) which are very useful.
- Having an LCD receiver allows teams to train both programming of the TRS Flight Computer as well as GPS tracking.
- It is difficult to underscore how much easier the GPS tracking and location becomes with the LCD-GPS module kit addition to the LCD receiver. Don’t forget to order it.
- It is not encouraged to add the Bluetooth option, as the LCD-GPS programming port is much more useful in the wired configuration. An openlogger module can alternatively be installed to capture and store all received telemetry. This is very useful for post-flight analysis, especially if the vehicle is lost.

C.4.5. MANDATORY GPS TRACKING SYSTEMS FOR DEPLOYABLE PAYLOADS OR STAGES

While the upper-most stage of any multi-stage flight vehicle, as well as any single-stage flight vehicle, must feature the mandatory Eggfinder TRS Flight Computer for official altitude recording and GPS tracking, this is not the case for deployable payloads or stages.

It is still mandatory to implement a Eggfinder GPS tracking device for lower stages and deployable payloads, as the EuRoC operated LCD handheld receivers (or student operated LCD receivers) can be reprogrammed in the field to track each flight vehicle component.

While the Eggtimer TRS Flight Computer can be utilized in all stages and deployable payloads, there are some simpler, smaller and cheaper compatible alternatives for lower stages and deployable payloads:

- The Eggfinder TX and TX-mini GPS tracking transmitters are fully eligible for tracking and location any lower stages or deployable payloads.



- The Eggfinder TX and TX-mini transmitters enable EuRoC recovery teams to track and locate lower stages and deployable payloads, using already available LCD handheld receivers, while the flight data and apogee of such stages and payloads are not relevant to team scoring.
- The Eggfinder LCD receivers are fully compatible with the TX and TX-mini and can be used to easily program the RF frequency of these transmitters.

C.4.6. UP-TIME REQUIREMENTS OF TRANSMITTERS

The following requirements pertain to the mandatory Eggtimer TRS Flight Computer, TX, TX-mini and LCD receivers:

- The battery capacity of the various Eggtimer/finder transmitters must be sufficient to keep the GPS tracking systems running continually for at least 12 hours.

C.4.7. UPDATING FIRMWARE TO THE CUSTOM 25 KHZ CHANNEL STEP VERSION

Due to the differences of EU and the US, the frequencies allotted by the Portuguese authorities, channel centre frequencies may lie at frequencies “odd” to the US Ham system. Consequently, students will have to update the firmware of the TRS Flight Computer (and any LCD-GPS receivers) with a special firmware version capable of 25 kHz channel selection.

The TRS firmware update is described in the “How to update the Eggtimer TRS firmware” document at the Eggtimer support web page.

Direct link: http://eggtimerrocketry.com/wp-content/uploads/2018/06/Eggtimer_TRS_Flash_Update_Instructions1.pdf

Likewise, there is a document for updating the LCD-GPS firmware: <http://eggtimerrocketry.com/wp-content/uploads/2020/04/Eggfinder-LCD-Flash-Update-Instructions-1.pdf>

Both firmware updates were performed as a part of testing the system, since both devices were delivered with outdated firmware. The flashing procedure uses the USB data cable and should not present a challenge to student teams.

C.4.8. TRS FLIGHT COMPUTER SAMPLE FILE

A sample file captured from a TRS Flight Computer illustrates the recorded data (GPS location and some NMEA sentences deleted or redacted for clarity). Worthwhile noting, besides the standard NMEA sentences:

- **{DM}** is deployment status
 - D for undeployed drogue chute



- d for deployed drogue chute
- M for undeployed main chute
- m for deployed main chute
- <2>, <-6> (or other varying number) is the barometric altitude in feet at any time.
- <1015>, <1015> (repeated) is the achieved apogee
- This achieved apogee term is however not broadcasted before the TLS Flight Computer has determined that the rocket has landed. A landing event is determined as an altitude of less than 30 feet above ground level for 5 seconds, or alternately when the TRS runs out of flight memory.

@JSL EggTimer@

```
$GPGGA,211127.000,XXXX.7710,N,0XXXX.4560,E,1,05,3.7,23.1,M,41.8,M,,0000*6C
```

```
$GPGSA,A,3,13,15,05,23,18,,,,,,4.8,3.7,3.1*33
```

```
$GPRMC,211127.000,A,XXXX.7710,N,0XXXX.4560,E,0.42,222.64,140821,,,A*6A
```

```
{DM}
```

```
<2>
```

@JSL EggTimer@

```
$GPGGA,211128.000,XXXX.7709,N,0XXXX.4569,E,1,05,3.7,23.1,M,41.8,M,,0000*62
```

```
$GPGSA,A,3,13,15,05,23,18,,,,,,4.8,3.7,3.1*33
```

```
$GPRMC,211128.000,A,XXXX.7709,N,0XXXX.4569,E,0.30,222.64,140821,,,A*61
```

```
{dm}
```

```
<-6>
```

@JSL EggTimer@

```
$GPGGA,211131.000,XXXX.7709,N,0XXXX.4571,E,1,05,3.7,23.0,M,41.8,M,,0000*62
```

```
$GPGSA,A,3,13,15,05,23,18,,,,,,4.8,3.7,3.1*33
```

```
$GPRMC,211131.000,A,XXXX.7709,N,0XXXX.4571,E,0.00,222.64,140821,,,A*63
```

```
{dm}
```

```
<1015>
```

@JSL EggTimer@

```
$GPGGA,211134.000,XXXX.7709,N,0XXXX.4571,E,1,05,3.7,23.0,M,41.8,M,,0000*67
```

```
$GPGSA,A,3,13,15,05,23,18,,,,,,4.8,3.7,3.1*33
```

```
$GPRMC,211134.000,A,XXXX.7709,N,0XXXX.4571,E,0.00,222.64,140821,,,A*66
```

```
{dm}
```

```
<1015>
```



C.4.9. LCD HANDHELD RECEIVER



Figure 12: LCD handheld receiver with backlight and custom 3D printed enclosure. (Source: Jacob Larsen)

The LCD handheld receiver is well described in this document, thus this section focuses only on observations and specific characteristics of the device.

- It is necessary to wipe the EEPROM flight memory before use, according to the LCD receiver user guide.
- As illustrated in Figure 12, the backlight option in the LCD handheld receiver is very useful after dark, if it is not excessively bright. An 86 Ohm series resistor had to be fitted on the leads going to the backlight, which also brings the back light current consumption down to about 20 mA.

Without this series resistor, the backlight acts like a blinding flood light, gulping up about 200 mA in the process.

- The programming port on the rear face of the LCD handheld receiver PCB can be used to log downlink telemetry data from the TRS Flight Computer, using a USB/TTL UART data cable, although less elegant than the RX receiver solution outlined in section C.7.. Another recommended solution is to install an openlog breakout board for telemetry capture.

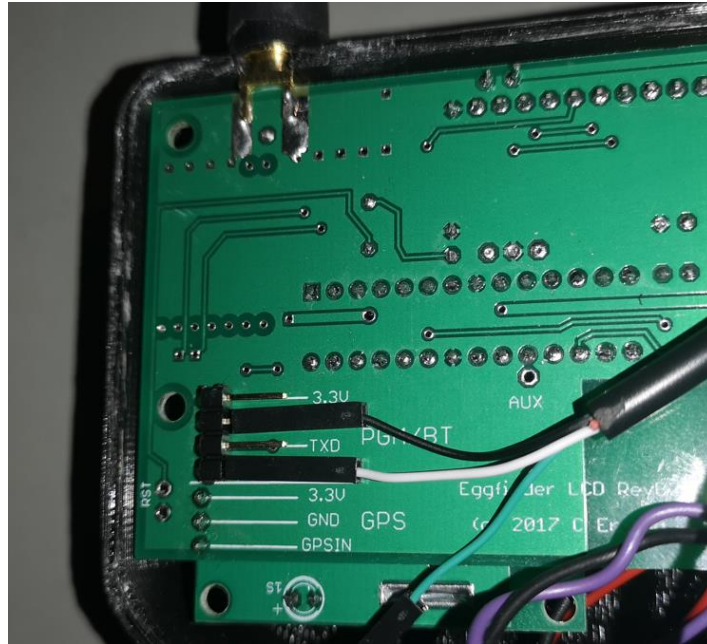


Figure 13: A USB/TTL UART data cable can be used to record TRS Flight Computer downlink data to a laptop.
(Source: Jacob Larsen)

C.5. EGGTIMER TRS ALTITUDE LOGGING AND GPS TRACKING SYSTEM LESSONS LEARNED

Based on previous editions of EuRoC a number of findings, advantages, disadvantages, and risks for the mandatory (Eggtimer TRS based) altitude logging and GPS tracking system have been compiled below (in no particular order):

- When properly implemented, the GPS tracing performance is excellent. A rocket which unintentionally deployed its main chute at an altitude of 9593 meters was continuously tracked until horizon dependent loss of line-of-sight, at a downrange of 27 kilometers, using a cheap type 5-element Yagi antenna.
- The biggest drawback of the Eggtimer system is that the quality control is left up to the students assembling and testing the correct performance and tracking range of the system. This responsibility of inspecting own work and validating performance cannot be overstated.
- In some of the worst cases seen, GPS tracking telemetry was lost a little over 100 meters past the Mission Control tent, which corresponds to the RF-module output not being electrically connected to the transmitter antenna trace (or very bad installation and RF practices). Such serious issues will be discovered with rudimentary range testing and performance



assessment;

- The Eggtimer TRS documentation quality is lacking. The EuRoC organization will require a significant improvement of the documentation from the manufacturer, or as a minimum interact with the manufacturer until all functionality is understood, such that it can be clearly communicated to teams;
- The Eggtimer TRS system requires training and accumulation of experience to realize its full potential, which is considerable, once full system understanding is achieved. It is a cheap field-programmable, 2-channel deployment computer, with position and altitude downlink, deployment test features, e-match continuity checking, stand-alone GPS tracking receiver and flight data recorder;
- Print a rugged case for the LCD tracking receiver and let that one have the experience of constant exposure to fine flying dust and rattling around in the bottom of an army truck going off-road in the attempts of recovering a stray rocket, instead of your mint condition Macbook. Link to free printable LCD tracking receiver enclosure: <https://www.dropbox.com/sh/i1p1tfhbfjeivvw/AAD5kwoKUdgcNXBqD6kyJ7W4a?dl=0>
- Appoint a dedicated GPS tracking and recovery responsible team member along with 3-4 recovery team members. Field-train and drill the recovery team in quickly and efficiently tracking down the rocket, by having team members (not part of the recovery team) place the rocket in unknown locations and have the recovery team do a series of increasingly challenging tracking challenges;
- Re-acquiring a GPS tracking signal given only an approximate heading and a 3-5 kilometer downrange is quite challenging. Finding a rocket in thick vegetation without a functional GPS tracking signal and a handheld tracking receiver is close to impossible. Both scenarios have proved to be surprisingly common at EuRoC;
- It is highly recommended to integrate an openlogger breakout board in the back of the Eggtimer LCD receiver. This means that the human readable ASCII telemetry downlink data stream can be captured for post-flight analysis, even in the event of an in-flight failure leading to a total loss of the vehicle. Besides GPS NMEA sentences, the TRS data downlink barometric altitude and recovery system deployment events.
- A cheap and widely available directional 5-element Yagi antenna with UHF-SMA adaptor cable does wonders for the tracking range.



Figure 14: Yagi 5-element high gain antenna.

C.6. CUSTOM 3D PRINTED LCD RECEIVER ENCLOSURE

A convenient custom enclosure was developed and refined as a part of the Eggtimer/Eggfinder test campaign, in order to ruggedize the LCD handheld receiver for field use.

The manufacturer's plastic enclosure and installation of the LCD receiver in an odd-sized rectangular box called for something more refined.

The stl-files are for free printing and use, as well as a step-file model of the enclosure design being available for reference. The latest version files can also be retrieved from the following Dropbox link, until further notice:

<https://www.dropbox.com/sh/i1p1tfhbfjeivvw/AAD5kwoKUdgcNXBqD6kyJ7W4a?dl=0>



Figure 15: Updated ruggedized custom enclosure for the LCD handheld receiver. (Source: Jacob Larsen)

Relevant details, in no particular order:

- This enclosure design is free for printing and use;
- The “CS” is a reference to Copenhagen Suborbitals (www.copsub.com);
- The red pushbutton is included in the Eggfinder LCD handheld receiver kit;
- A double pole, double throw switch, switches power and backlight on and off simultaneously;
- The design consists of three parts:
 - Front section;
 - Rear section;
 - Battery cap (snaps into place).
- The rear section contains an opening, providing access to the programming port, which is used to program TX, Mini or RX operating frequencies;
- Put a piece of tape over the opening when not in use. It keeps the dirt out of the unit.

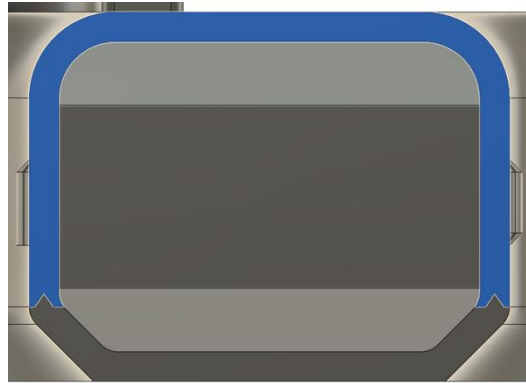


Figure 1: Blue recess and dark grey notch mating scheme. (Source: Jacob Larsen)

- The front and rear enclosure mates accurately using a notch-and-recess fit. Put a few drops of glue in there, if you want to assemble the enclosure permanently;
- The GPS-LCD module add-on is conveniently soldered to the LCD receiver PCB using a 3-pin header.

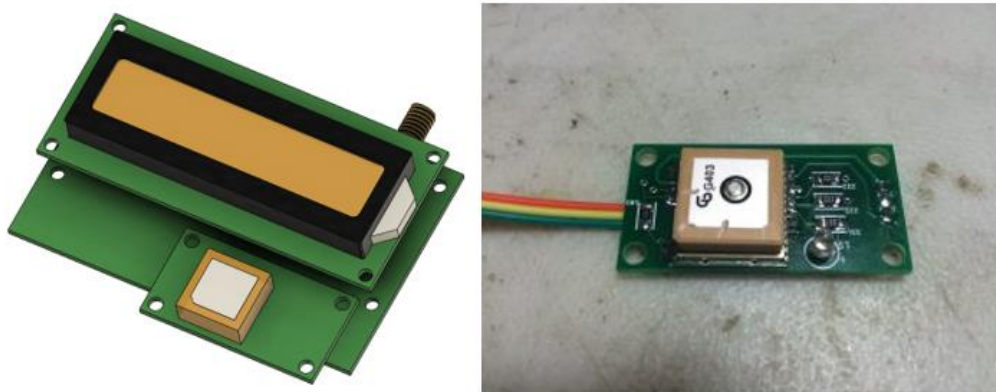


Figure 18: Crude CAD model of LCD receiver PCBs, with LCD-GPS module add-on soldered in place.
(Source: Jacob Larsen and Eggtimer)

- Eight PCB mounting points are integrated into the front and rear enclosures. Tap M3 threading in all eight and fit each of the two LCD receiver PCBs in their respective enclosure segments, using countersunk M3x6mm countersunk screws with reduced head.

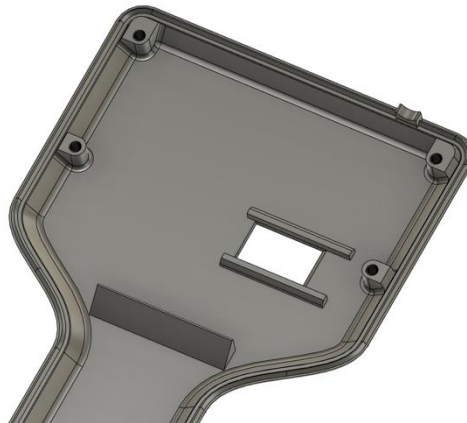


Figure 19: Rear section illustrating the programming port opening and where to tap M3 threading.
(Source: Jacob Larsen)

- The battery compartment fits a 2S 1900 mAh LiPo battery with measures 115 x 34 x 18 mm, which should provide about 18 hours of operation per charge. The printed battery compartment cap clicks nicely into position.

Do not print this enclosure using carbon fibre reinforced plastics, since the conductivity of the carbon fibre may negatively impact the internal GPS receiver sensitivity.

C.7. NOTES ON ADDITIONAL TESTED EGGFINDER DEVICES

This section lists some findings on tested Eggfinder equipments, other than the TRS Flight Computer.

C.7.1. EGGFINDER TX TRANSMITTER

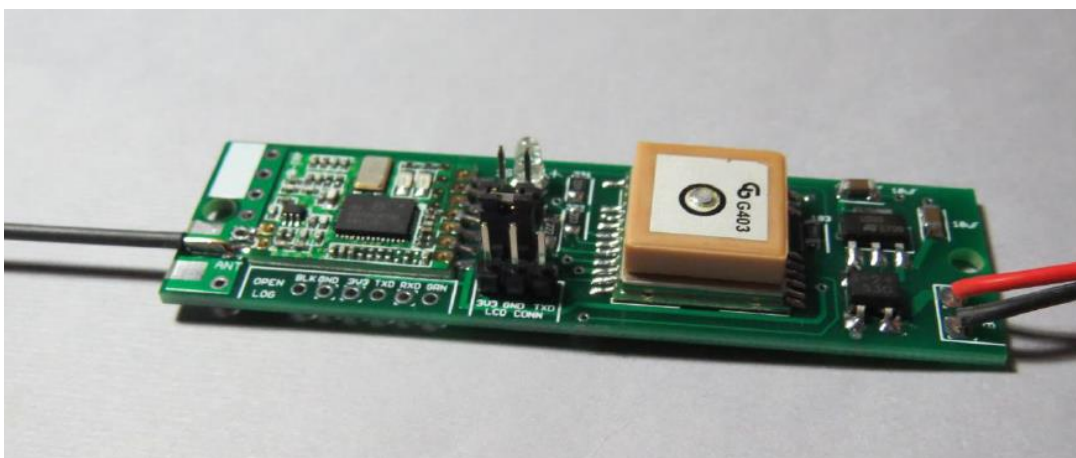


Figure 20: Eggfinder TX transmitter. (Source: Eggtimer)



The Eggfinder TX transmitter is a simple and useful GPS tracking transmitter. Some observations made during assembly and testing:

- The device is quite simple and just transmits the onboard GPS NMEA sentences at 9600 baud, to any receiver listening.
- It has the added advantage that it features PCB space for an Openlogger device, if one wants to log whatever is transmitted onboard. (Eggtimer stock Openloggers)
- The TX transmitter will accommodate a SMA PCB edge-connector, required for external antennas, contrary to the Mini transmitter. (Eggtimer stocks SMA PCB edge connectors).
- The RF module of the tested device would not transmit anything, until the RF module frequency was reprogrammed, using the LCD handheld receiver and the included 3-wire programming cable. It worked flawlessly since then.
- The TX transmitter has an included jumper for setting it into programming mode. This is contrary to the Mini transmitter, which utilizes inconvenient solder jumpers.

C.7.2. EGGFINDER TX-MINI TRANSMITTER

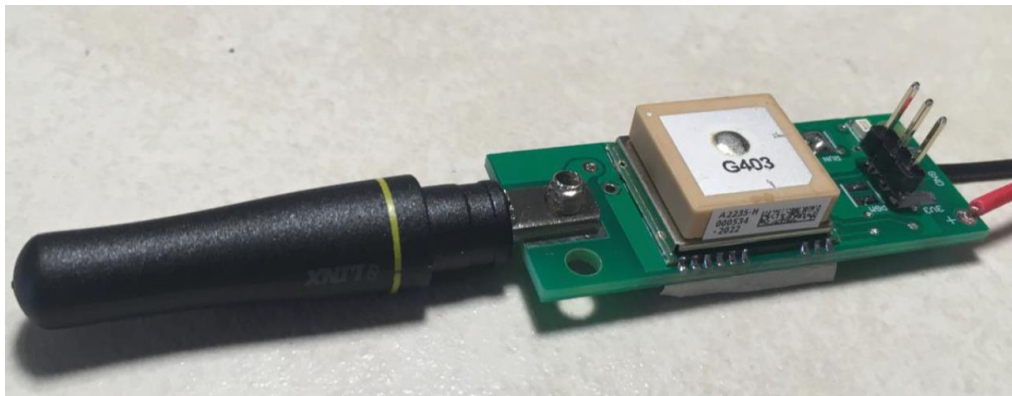


Figure 21: Eggfinder Mini transmitter. (Source: Eggtimer)

The Eggfinder Mini transmitter is a smaller version of the TX transmitter, intended for very small rockets. Some observations made during assembly and testing:

- The Mini transmitter uses solder jumpers for putting the device either in programming or running mode. This is inconvenient in the event of having to change the RF-link frequency in the field.
- This device cannot accommodate an SMA PCB edge connector. It is stuck with the little stub antenna.
- Some issues were encountered as difficulties with getting good solder joints between the PCB and the GPS module.



- The Mini transmitter, with its short stub antenna, had a very similar RF-link range, compared to the TX transmitter with a wire antenna.

C.7.3. EGGFINDER RX “DONGLE” RECEIVER

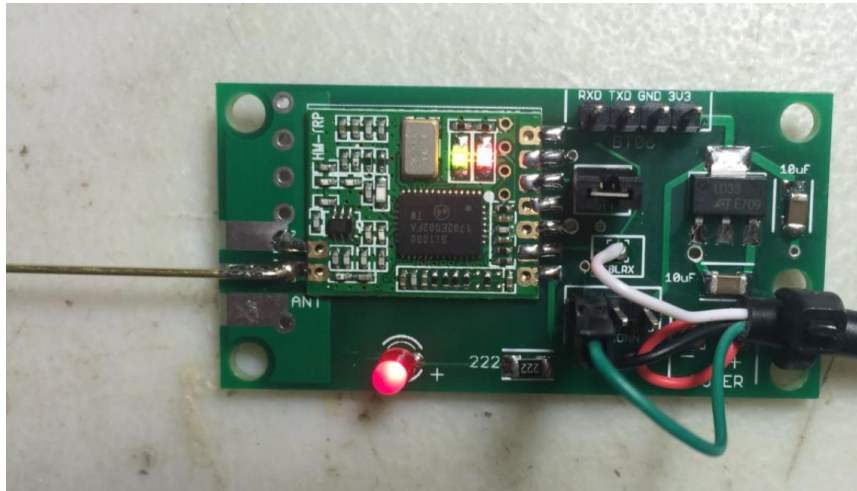


Figure 22: Eggfinder RX "dongle" receiver. (Source: Eggtimer)

The RX receiver is potentially a useful device, considering how inexpensive it is. Some observations made during assembly and testing:

- The RX receiver is very inexpensive due to the lack of a GPS receiver.
- The RX receiver is available in both a Bluetooth and a USB cable option, of which the latter seems more useful.
- The RX receiver frequency is easily programmed with an LCD handheld receiver and the included 3-wire programming cable.
- The “USB version” of the RX receiver can be powered directly from a laptop, if using a USB/TTL UART data cable (included). No other accessories required.

The RX receiver (USB cable version) and a laptop makes for an excellent TRS Flight Computer stand-alone telemetry backup data logger. While the TRS Flight Computer logs high-speed flight data to onboard non-volatile EEPROM, said EEPROM may in some unfortunate incidents disintegrate upon “landing”, taking the recorded flight data with it into oblivion.

If an RX receiver has logged the telemetry, which also includes the altitude reading from the TRS Flight Computer barometric pressure sensor, the trajectory and apogee may be reconstructed from these data, enabling the EuRoC Jury to award points for achieved apogee.



APPENDIX D: FLIGHT READINESS REVIEW CHECKLIST

Table 3: 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 automatically result in a "denied" flight status. See Section 2.6.6. for more information.	Proof by previous testing



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 deployment event, shall result in a descent velocity of said item of 23-46 m/s.	Proof by reasoned argument (Deployment event) Proof by calculation (Descent rate) Proof by previous 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 loads unthreading bolted connections during recovery as well as parachute lines twisting up.	Simple confirmation Inspection on site



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. To be considered COTS, the flight computer (including flight software) must have been developed and validated by a commercial third party.	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, specified in more detail in Appendix C.	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 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	Proof by previous testing



	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 joint 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 requirement is particularly important if a team is not bringing their own launch rail, but instead relying on EuRoC provided launch rails.	Inspection on site
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 through 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. 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.	Simple confirmation



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 systems (drogue and main chute, like the rockets) will be subjective to considerable drift during descent.	Proof by calculation Proof by reasoned argumentation Proof by previous testing
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 Appendix C: Official Altitude Logging and Tracking System. 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 $84^{\circ} \pm 1^{\circ}$ 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.	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., computer simulation) or empirically (e.g., flight testing).	Proof by calculation
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-degree-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 at angles either greater than the nominal elevation or lower than 70°.	Inspection on site
Operational Range	All team provided launch control systems shall be electronically operated and have a maximum operational range of no less than 650 metres from the launch rail. 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 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.	No action necessary

Table 4: 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 5: 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.”