EUROPEAN ROCKETRY CHALLENGE

DESIGN, TEST & EVALUATION GUIDE

EuRoC
EUROPEAN ROCKETRY CHALLENGE

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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 revisions for EuRoC 2022.
Version 04	20/02/2023	Fourth version, overall revisions for EuRoC 2023. Important revisions in Sections: 2.2; 3.4; 3.5; 5; 8.2; Appendix B.
Version 4.1	06/03/2023	Fourth version, revision 1: clarifications on Section 3.4 and references update.
Version 05	25/03/2024	Fifth revision, overall revisions for EuRoC 2024. Important revisions in Sections 2.6.2; 2.6.5; 3.1.5; 4.2.2; 4.2.4; 4.2.5 and 8.2. Addition of Sections 2.6.3; 4.2.1; Appendix C and Appendix D.

1. INTRODUCTION

1.1. BACKGROUND

The Portuguese Space Agency – organizes the EuRoC – European Rocketry Challenge, 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 Portuguese Space Agency, 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, 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 the Portuguese Space Agency'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.

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 Portuguese Space Agency. The Portuguese Space Agency reserves the right to change the EuRoC criteria and procedures at its discretion and at any time, including during the event.

1.2. PURPOSE

This document defines the minimum design, test, and evaluation criteria the event organizers expect teams to meet before launching at the competition. The organizers use these criteria to promote flight safety. Deviations from the guidance this document provides may negatively impact an offending team's score and flight status, depending on the degree of severity. The foundational, qualifying criteria for 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.

EuRoC reserves the right to remove projects and/or teams from the competition at any point (starting from the moment of application) due to safety concerns.

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 recommendations.

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 EuRoC officials 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 Entry Form	http://www.euroc.pt
EuRoC Academic Institution Participation Letter	http://www.euroc.pt
EuRoC Motors List	http://www.euroc.pt
EuRoC COTS Motors Acquisition Guide	http://www.euroc.pt (Teams’ Reserved Area)
EuRoC Technical Questionnaire	http://www.euroc.pt (Teams’ Reserved Area)
EuRoC Launch Operations 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)

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. COTS SOLID MOTORS

Only COTS solid motors from the official EuRoC Motors List, compiled in conjunction with European suppliers, are permitted at EuRoC. More information on the motor acquisition process can be found in the EuRoC COTS Motors Acquisition Guide, which will be made available before the event, in due time.

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, a rope with defined breaking force, slightly tilting the motors outward or air starting.

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., Sweeney 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 Sweeney quick release latch.
(Source: Matt Sweeney SPFX Inc.)

To measure the thrust, a strain gauge could be used, or alternatively piezoelectric 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 can be of stainless-steel and mounted in a way so that it remains protected from hot combustion gases by means of an oil trap, or the use of Inconel diaphragm in which case an oil trap may not be needed.

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 the 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 3.6 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. Due to the requirement to proof test combustion chambers, these shall be designed allowing to be closed off in a leak-tight manner for testing at any section between the throat and the exit section of the nozzle. Note that combustion chambers are exempted from the requirement for a relief device.

2.6.2. HYBRID AND LIQUID PROPULSION FILLING SYSTEMS

Teams 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 strongly encouraged to consider abandoning the use of "passive" or "self-pressurization" of propellants, due to the safety risks associated, 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.

To further mitigate safety hazards, disconnection of all loading lines shall happen *before* any propellant tank pressurization is initiated. If a remote-controlled loading line disconnection fails, and a hands-on manual disconnection is required, propellant tank pressures will still be at the low levels fit for ground operations near the flight vehicle.

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”, in case a remote-controlled release mechanism jams and requires manual LCO (Launch Control Officer) 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. DISSIMILAR CONNECTIONS

All loading lines, whether for pressurization gases or propellants, are mandatory to feature dissimilar connectors, preventing inadvertent misconnections, as far as possible. The safety hazards of such mix-ups are extreme and must be prevented at any level of design, manufacturing, integration, and test.

2.6.4. 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 2.6.7, it is highly recommended to perform this test multiple times as 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.

2.6.5. 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 shall be implemented to account for rockets potentially sitting a long time in waiting on the launch rail. All isolated sections of pressurized lines (including pressure vessels) shall incorporate a passive pressure relief device (PRD) with an opening set point below the maximum tested pressure of the line section. All pressure relief devices shall have a discharge coefficient equal to or higher than any other fluid interface on the respective pressurized section in which they are installed. At no time must oxidizer tanks become safety liabilities.

2.6.6. 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.

2.6.7. 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. In addition, the usage of colours dissimilar from those of ground vegetation (i.e. avoiding certain shades of green and brown, as well as black) is recommended to ease the location of the vehicle during recovery operations.

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

Lithium-Polymer (LiPo) batteries are not allowed due to the increased flammability and thus an increased fire hazard. Teams shall implement less flammable on-board power systems. Below teams can find the battery general prioritisation, and allowed characteristics, according to toxicity, flammability, environmental hazards, etc).

1. LiFePO4 chemistry cells are allowed in any form factor and in any casing (plastic or metallic).
2. NiMH (Nickel-Metalhydride) chemistry cells are allowed in metal casing and any form factor.
3. Alkaline chemistry (non-rechargeable) cells are allowed in metal casing and any form factor. External power may be provided to a rocket via umbilical cable, to avoid draining alkaline (non-rechargeable) batteries while sitting on the launch rail.
4. Other Li-Ion chemistry cells are allowed, but shall be of metallic casing cylindrical form factor, which provides increased ruggedness against mechanical damage. Li-Ion cells in rectangular form factor and/or plastic casing are prohibited.

LiPo cells are prohibited, regardless of encapsulation or form factor. These cells have negligible mechanical resilience, low ignition temperature and an exothermic decomposition nature. Lithium chemistry (non-rechargeable) cells are prohibited, regardless of encapsulation or form factor, due to the high probability of metallic Lithium, REACH concerns or toxicity/environmental impact.

Note: This requirement only applies to the on-board systems, off-board systems are exempt of such requirement.

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 recommended and placed upstream of the mandatory cell balancing circuits, since they bypass any EMI issues inherent to switching DC-DC converters;
    - Switch-mode regulation or onboard battery chargers require acute attention to generated EMI and electrical noise;

  - 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, CATS, 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. Any SRAD hardware implemented between a COTS flight computer and any recovery system actuator (e.g., servo, e-match, thermal knife, solenoid valve, nicrome wire, or similar) violates the redundant COTS recovery electronics requirement, resulting in a denied flight status.

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

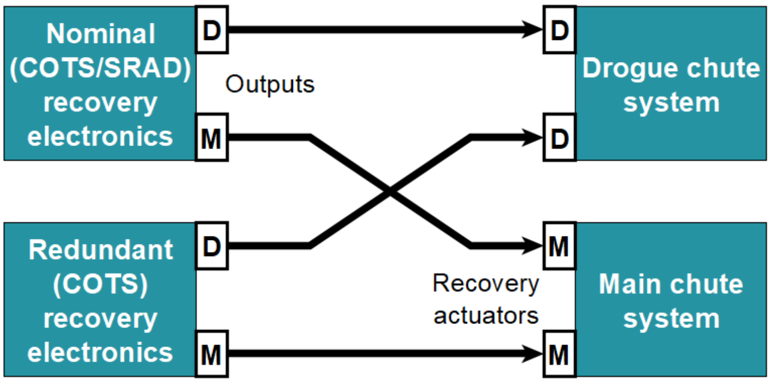


Figure 2: Interconnection redundancy implementation. (Source: Jacob Larsen)

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.

3.4.4. ELECTRONICS RELIABILITY, STRESS TESTING AND OVER-HEATING

Experience from prior EuRoC events reveal that electronics problems account for an estimated 70% of cases where teams experience unreliable electronics, loss of telemetry, loss of control or other anomalies, which often leads to scrubbed launches or even loss of the flight vehicle.

One clear trend is that teams fail to take action on conducting proper thermal testing of their electronics and/or adding suitable cooling or venting provisions.

While electronics tend to work well in a temperature-controlled laboratory environment, with open electronics compartments due to integration and testing, it must be taken into account that the flight vehicle may stay on a launch rail for several hours exposed to direct sun and high temperatures, with closed electronics compartments. In addition, when teams use black coloration, it results in maximum thermal absorption. Sudden rain showers are also possible at the launch site, it is therefore recommended that teams treat their electronics and systems in such a way that the rocket can sit on the rail in case of heavy rainfall. Particularly, any equipment or electronics operating on 230 V main power needs to be protected from rain, due to the risk of short circuits and electric shock.

It is strongly recommended that teams thermally test their electronics to know the reliable operational temperature range, implement cooling or venting provisions and monitor at least one temperature sensor representative of the electronics temperature.

3.5. OFFICIAL ALTITUDE LOGGING AND TRACKING SYSTEM

Single-stage flight vehicles and upper-most stages of flight vehicles shall feature a mandatory operational CATS Vega Flight Computer for official altitude logging and landing site tracking. For more details see https://catsystems.io.

The competition achieved apogee will be determined from this device.

Note: Deployable payloads and lower stages also require a mandatory CATS Vega flight computer for landing site tracking purposes.

More technical details on the CATS Vega Flight Computer along with recommendations can be found in the CATS User Manual, available on the EuRoC website.

The CATS Vega 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.

3.5.1. CATS VEGA FLIGHT COMPUTER AS COTS FLIGHT COMPUTER FOR RECOVERY

The CATS Vega 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 for altitude logging and/or tracking purposes only.

It is recommended that teams evaluate the specifications and functionality of the system before deciding between implementing it as the main flight computer, redundant flight computer or leaving it entirely as a passive standalone “payload” (cargo).

3.5.2. CATS VEGA FLIGHT COMPUTER FREQUENCIES

The CATS Vega system operates on the 2,4 GHz ISM band, with an EuRoC operating band allowed between 2400 and 2483,5 MHz and a maximum transmission power of 100 mW.

More information on the CATS system specifications can be found in the CATS User Manual, available on the EuRoC website.

3.5.3. CATS TRANSMITTER CALL-SIGN

Teams shall assign to each transmitter a “call-sign” (referred to in the CATS User Manual as the `tele_link_phrase` telecommand) respecting the following string format (case sensitive and no white-spaces allowed):

- Two-digit team number:
    - [xx]
- One underscore:
    - [_]
- Stage or (deployable) payload designation, depending on where the CATS device is mounted:
    - [**stage**] or [**payload**]

- Designation of stage or payload number, the first instance of each by default enumerated as ”1”:
    - [**y**]
- Designation of the mandatory CATS flight computer in each stage or payload (with mandated EuRoC firmware version) is by default [**m**] and any additional CATS flight computer in the same stage or payload [**a**]:
    - [**m**] or [**a**]

Mission Control and Recovery units will by default lock on to [**m**] call-signs for flight- and recovery telemetry.

Teams should expect to be required to functionally demonstrate all CATS flight computer → CATS Ground station telemetry links of their flight vehicle during the Flight Readiness Review, as well as observe the Technical Evaluation Board representatives verify functional telemetry reception with separate TEB Ground stations.

3.5.4. CATS TRANSMITTER CALL-SIGN EXAMPLES

The following example is the CATS system call-sign applicable to Team 04, having a simple single stage rocket (one mandatory CATS unit, one additional COTS Altimax flight computer, and an internal dummy mass payload):

- 04_stage1m

Next, Team 06, single-stage, mandatory CATS, additional SRAD flight computer, deployable payload with one mandatory CATS:

- 06_stage1m
- 06_payload1m

Team 20, single-stage, SRAD (primary recovery), mandatory CATS (flown as internal cargo), additional CATS (redundant recovery), deployable payload with mandatory CATS and additional CATS for deployable payload recovery redundancy:

- 20_stage1m
- 20_stage1a
- 20_payload1m
- 20_payload1a

Lastly, Team 22, having a two-stage rocket with two deployable payloads (both ejected from 2nd stage), constituting four mandatory and two additional CATS flight computers in total:

- 22_stage1m
- 22_stage1a

- 22_stage2m
- 22_stage2a
- 22_payload1m
- 22_payload2m

Please note that referring to Section 3.5 all stages and deployable payloads require one mandatory CATS flight computer each, for uppermost stage altitude logging and landing point tracking of all landed ejected or jettisoned parts, enabling flight vehicle and payload recovery operations requiring a single CATS ground station. Additional CATS units (or any other flight computer(s)) in stages or payloads are optional, as are additional CATS ground stations.

3.5.5. CATS VEGA FLIGHT COMPUTER FIRMWARE UPDATE

Information on the CATS Vega firmware update procedure can be found in the CATS User Manual, available on the EuRoC website.

While the CATS Vega system is open-source, teams will be required to fly a specific firmware version in each mandatory CATS flight computer, mandated by the EuRoC organization. The EuRoC firmware version requirement still applies to CATS flight computers, regardless of if flown as inert “cargo” (no interfaces to any part of the recovery system) or as the mandatory COTS flight computer.

CATS flight computers not featuring the mandated EuRoC firmware version will be considered SRAD flight computers.

3.5.6. CATS RECEIVER

The CATS Ground Station is the supplementary hardware to the CATS Vega flight computer. Information on the CATS Ground Station can be found in the CATS User Manual, available on the EuRoC website.

3.5.7. CATS ELECTRONICS ACCESS

As for all electronics, it is highly recommended to ensure easy and quick access to switches/connectors to on-board CATS devices via an access panel in the airframe. Access panels should ideally be positioned so they are reachable from ground level, 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-variants, 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 well as they can and implement standard procedures that they can fall back onto even during the most stressful 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 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

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.

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 non-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 or physically disconnected (i.e. mechanical switch or connector) 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 4 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 clocking position as the hatch panel deployed by that charge.

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

4.2. SRAD PRESSURE VESSELS

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

4.2.1. BURST DISCS

Each SRAD pressure vessel and every propellant tank shall implement an over-pressure safety measure, in the form of a (replaceable) burst disc, with a diaphragm orifice diameter of no less than 6 millimeters. The burst (or rupture) disc solution can be either COTS or SRAD.

Given the scarcity of COTS burst disc options and the coarse and limited range of burst pressures available, SRAD burst discs are equally viable and reliable, provided that proper care is taken to design, manufacture, test, and document it. Teams can find in Appendix C practical examples of manufacturing, burst pressure tailoring and testing.

Burst discs (COTS or SRAD) shall be selected or calibrated to rupture at a pressure no higher than 1,25 times the nominal tank pressure, leaving adequate margin up to the 1,50 times proof pressure (see section 4.2.4.1). Teams are recommended to select (or calibrate) for a rupture pressure in the range of 1,15 to 1,20 of the nominal tank pressure.

Burst disc orifices (the body which determines the rupture pressure) shall be clearly and permanently marked with the average rupture pressure determined by testing, along with a unique identifier, tracing each burst disc orifice to an associated test report. Punching, engraving, grinding, etching, etc. counts as permanent marking. Various permanent markers based on ink or paint do not.

Individual test reports are required for each SRAD burst disc orifice, tied to its unique identifier or serial number. Each burst disc orifice test report must contain a minimum of five consecutive rupture tests, preferably using a data logging system and a pressure transducer for optimum rupture pressure documentation. The burst disc sheet metal must also be specified in detail. The rupture pressure to be marked on the burst disc orifice is the average of five consecutive rupture tests. The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and annexed to the Technical Report.

It is mandatory that all burst discs come from the same stock material sheet, both for flight, testing and rupture pressure characterization. Teams are recommended to pick out a sheet of material sufficiently large to cover all burst disc needs. Using the same sheet material everywhere eliminates risk incurred by accidentally mixing up burst discs of different material thickness.

Two noticeable exceptions for fitting of mandatory burst discs (and relief devices) are combustion chambers (of any type) and COTS composite overwrapped pressure vessels (COPV), with a nominal operating pressure of 300 bar/4500 psi or above. The burst pressures safety factor is a factor of 3 for such COPVs, resulting in burst pressures well outside the capabilities/range of the compressor systems and/or COTS gas supplier bottles.

4.2.2. RELIEF DEVICE

It is recommended that SRAD pressure vessels implement an additional relief device, set to open in the range of 1,10 to 1,20 times the nominal operating pressure.

4.2.3. ENGINE START-UP SINGLE-FAULT PREVENTION

In order to prevent a single-fault (operator fault, SW fault, EMI fault, etc.), initiating an unscheduled engine start-up sequence from potentially resulting in unintended propellant mixing (with or without an electrically connected engine igniter), a second-level protection feature is recommended on hybrid and bi-liquid rockets in order to mitigate the risk.

Oxidizer soaking of hybrid grains or mixing of bi-liquid propellants will result in a very volatile mixture, which may on occasion self-initiate. The protection feature should take the form of a manual switch (pull-plug, key-switch, reed-switch, or similar), which is capable of disconnecting the propellant valve(s) from their power source. If a propellant valve has a separate control/actuator interface and a separate power interface, then the interruption functionality must still be applied to the power interface line. If the power and control/actuator interfaces are joined (a solenoid valve, for example), that single interface is to be interrupted. If implemented on a bi-liquid, both the fuel-side and oxidizer-side propellant valves shall feature the valve disabling safety switches. If the propellant valves are pyro- or pneumatically actuated, a suitable short circuit shunt or pneumatic valve shall be used to achieve the same effect.

A single interruption in the hot/force line is sufficient if the propellant valve(s) are electrically powered. There is no requirement for galvanically isolating the power circuit of the valve. It is not recommended to add the safety switch in the return line.

Pull-plugs at ground level are recommended for ease of accessibility, similarly to the safety pull-plugs or key switches required for disabling/arming on-board pyro-charges. From a checklist point of view, arming propellant valves should take place just before the engine igniter(s) are connected to the firing box.

4.2.4. 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.

These pressure vessels are subject to mandatory burst discs (see Section 4.2.1), regardless of nominal design pressure.

4.2.5. 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.

These pressure vessels are subject to mandatory burst discs, (see Section 4.2.1), except when the nominal design/operating pressure is 300 bar/4500 psi, or above, with a design safety factor of 3, or above.

4.2.6. 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.

4.2.6.1. 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 (which for example could be hours for self-pressurized nitrous oxide propellant systems).

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 may, 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.

4.2.6.2. 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. CONTROL FUNCTIONALITY

Launch vehicle active flight control systems may be implemented for pitch and/or roll stability augmentation, for aerodynamic "braking", guided recovery systems, precision landing or guided deployable loads.

Any active flight control system implemented in any part of the vehicle, must be clearly described in the Technical Report, as well as under any concept/design report/reviews. The organisers may make additional requests for information and draft unique requirements depending on the team's specific design implementation.

As for designated landing zones/coordinates, travel corridors, loitering zones, etc., these are until further notice decided on a case-by-case between the Range Safety Officer, Mission Control Officer and team’s recovery specialists.

5.2. UNNECESSARY FOR STABLE FLIGHT

Flight 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 should be designed to Fail Safe in any abnormal condition or during an active flight abort (if such functionality is implemented). This means disabling cold-gas thrusters, returning control surface deflections to neutral position, disabling thrust vectoring, or seeking to disable any control feature which will apply any kind of moment to the flight vehicle.

As for any actuators acting in a uniform, interlocked or mirrored fashion, which increases air drag without applying any moment to the flight vehicle (such as airbrakes) these should be attempted fully extended in a fault or abort scenario, to slow down the flight vehicle as quickly as possible. If within the capability of the Control Actuator System, pilot chutes and even main parachutes can be ejected, as soon as the vehicle forward velocity is low enough not to snap the parachute lines.

5.4. BOOST PHASE DORMANCY

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

For any CAS without demonstrated flight history, without a documented SW configuration control, the Boost Phase Dormancy ends at an altitude of no less than 1500 m AGL. The EuRoC officials can set the boost phase dormancy expiration criteria higher as seen fit and this parameter must be field-programmable.

For any CAS with a (limited) demonstrated flight history, the default Boost Phase Dormancy expiration criteria is an altitude of 500 m AGL, again subject to EuRoC officials' assessment.

For any CAS with adequate demonstrated flight history, ample simulation models, SW configuration control, single-fault tolerant design/FMECA analysis, and a hardware implementation considered by EuRoC officials as of superior quality of engineering and implementation, the Boost Phase Dormancy expiration altitude may on a case-by-case basis be set as low as the end of the launch rail.

A special case exists for CAS capable of exerting only lengthwise roll-control of the flight vehicle:

- If the CAS is inducing “spin stabilization” of the flight vehicle (a constant angular velocity), the roll control system can be enabled at the end of the launch rail.

- If the CAS is used to cancel spin or bring the flight vehicle to a particular angular position, the control system must remain inactive until an altitude of 1500 m or any altitude decided by the EuRoC officials.

Note: The above two can be combined, with the same system inducing spin stabilization from the end of the launch rail until an altitude of 1500 m is reached, whereafter the control system can be used to de-spin the flight vehicle.

5.5. RECOMMENDED FLIGHT TRAJECTORY FOR ACTIVE CONTROL SYSTEMS

The EuRoC nominal flight vehicle target trajectory is to maintain a compass direction of 133° from the launch rail (straight down the centreline of the ballistic corridor), maintaining an azimuth angle identical to the launch rail (nominally 84°±1°) until apogee.

It must be noted that there is no requirement for active control systems to be disabled at apogee. In the event of a complete failure to deploy recovery systems and deliberately breaking up the flight vehicle, the “controlled disposal point” is a point twice the downrange distance from the launch rail to apogee, still at a compass direction of 133° from the launch rail (still down the centreline of the ballistic corridor).

It is noted that the nominal flight trajectory is ground-fixed, allowing teams to implement high-altitude crosswind compensation, etc., to maintain the nominal trajectory over ground.

This target flight trajectory will mimic the intended nominal ballistic trajectory of a passively stable flight vehicle until apogee. It furthermore increases ground safety by ensuring a predictable flight path away from the spectator area, providing a predictable downrange apogee and increasing the chances of the flight vehicle staying within both the ballistic corridor and the safety zone, even in the event of a complete recovery failure.

5.6. 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 3.6, 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.

5.7. 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. 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).

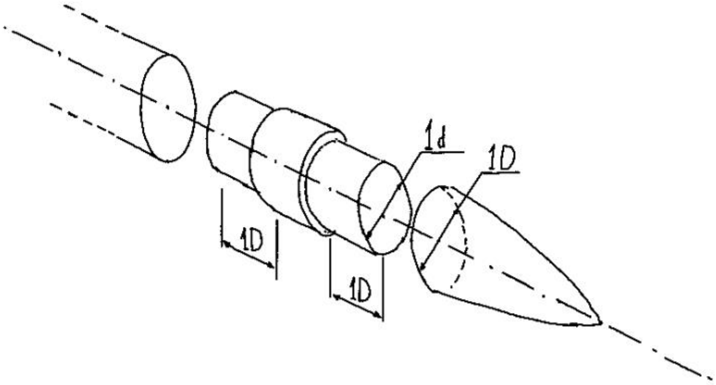


Figure 3: Examples for coupling tubes.

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. 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 organisers prior to EuRoC. Deployable payloads without two-stage recovery systems (drogue and main chute, like the rockets) will be subjected 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 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 3.6 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 Landing Site 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 landing site tracking system as all rockets and rocket stages as specified in Section 3.5 of this document.

The landing site tracking locator ID must differ from the ID of the launch vehicle. Teams shall assign to each transmitter a call-sign respecting the format described in Sections 3.5.3 and 3.5.4.

7.2. Payload Energetic Devices

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

8. LAUNCH AND ASCENT TRAJECTORY REQUIREMENTS

8.1. LAUNCH AZIMUTH AND ELEVATION

Launch vehicles shall nominally launch at an elevation angle of 84°±1° and a launch azimuth defined by competition officials at EuRoC. Competition officials reserve the right to require certain vehicles' launch elevation be as low as 70° if flight safety issues are identified during pre-launch activities.

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

8.2. LAUNCH STABILITY AND ADEQUATE RAIL TAKE-OFF VELOCITY

The vehicle shall be capable of achieving a rail departure speed higher than 30 m/s on the intended launch rail's length and shall be verified by analysis of the flight simulations, experimental thrust curves, and other vehicle data (i.e., by design, the vehicle in nominal conditions goes off the rail at more than 30 m/s).

Teams, particularly those with hybrid and liquid propulsion plants, should design their propulsion plants with ample (or even considerable) power margin. An over-powered propulsion system is preferable to an under-powered propulsion system.

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).

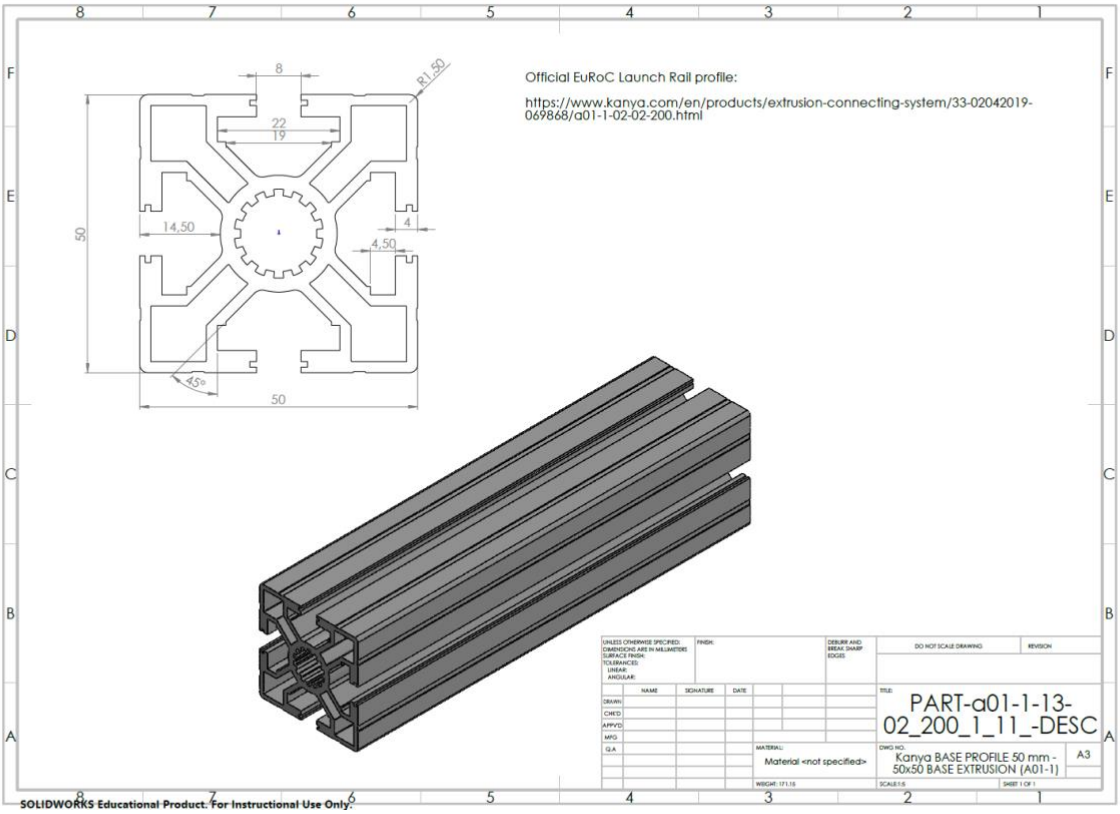
8.4. OVER-STABILITY

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. 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°±1° 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.



Official EuRoC Launch Rail profile:

https://www.kanya.com/en/products/extrusion-connecting-system/33-02042019-069868/a01-1-02-02-200.html

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: PART-a01-1-13-02_200_1_11_-DESC

MATERIAL: Material <not specified>

DWG NO. Kanya BASE PROFILE 50 mm - 50x50 BASE EXTRUSION (A01-1)

A3

WEIGHT: 171.15

SCALE:1:5

SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

Figure 4: EuRoC launch rail profile.

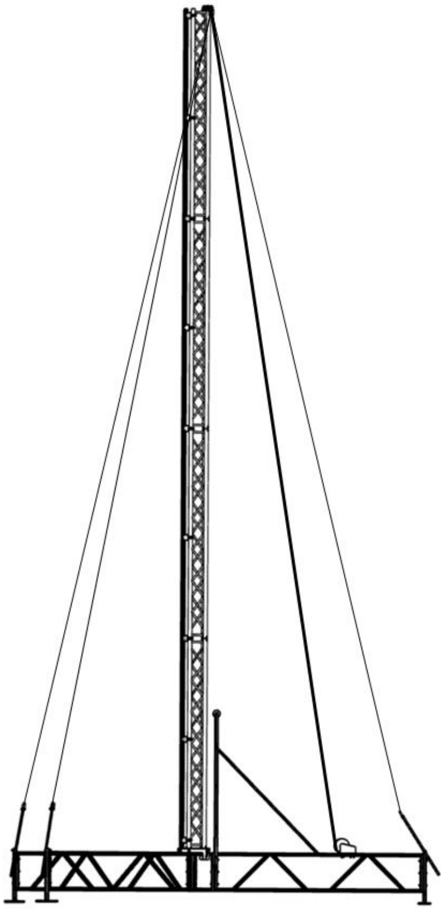


Figure 5: EuRoC launch rail fully assembled.

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 EuRoC officials. 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 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
ACS	Attitude Control Systems
AGL	Above Ground Level
AIT	Assembly, Integration and Test
APCP	Ammonium Perchlorate Composite Propellant
CAS	Control Actuator System
CATS	Control and Telemetry Systems
CG	Centre of Gravity
COPV	Composite Overwrapped Pressure Vessels
COTS	Commercial of-the-shelf
CP	Centre of Pressure
DTEG	Design, Test and Evaluation Guide
EuRoC	European Rocketry Challenge
FRP	Fibre Reinforced Plastics
FRR	Flight Readiness Review
GPS	Global Positioning System
H	Hybrid
NiMH	Nickel-Metalhydride
L	Liquid
LCO	Launch Control Officer
$LiFePO_4$	Lithium Iron Phosphate
Li-Ion	Litihium-Ion
LiPo	Lithium-Polymer
LOX	Liquid Oxygen
LRR	Launch Readiness Review
P	Points
PPE	Personal Protective Equipment
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
RADAX	Radial-Axial
RF	Radio Frequency

S	Solid
SRAD	Student Researched & Developed
TA	Target Apogee
TEB	Technical Evaluation Board
ZSF	Zero Separation Force

APPENDIX B. FIRE CONTROL SYSTEM DESIGN GUIDELINES

B1. INTRODUCTION

The following section illustrates safe fire control system design best practices and philosophy to student teams participating in rocketry events. 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.

B2. 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 6). 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.

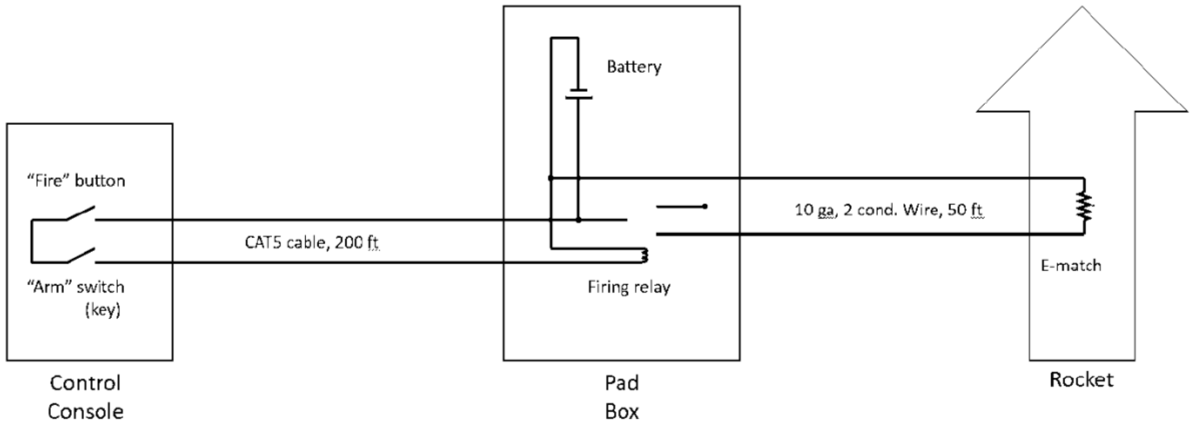


Figure 6: A simple high current fire control system.

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 7). 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).

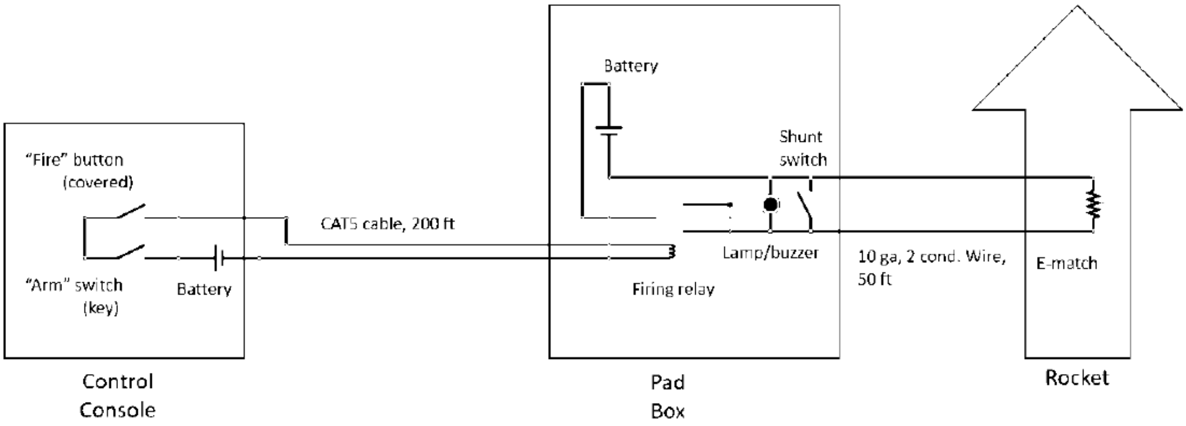


Figure 7: An improved high current fire control system.

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. SRAD BURST DISC DESIGN, MANUFACTURING AND TESTING.

The following sections detail one successful approach to designing, manufacturing, and testing SRAD burst discs, which can be meticulously tailored to any desired burst pressure.

Recognizing the fact that the COTS market for burst discs offer a limited range and selection of options, this section provides guidelines for manufacturing and test of SRAD burst discs, which can be tailored to the specific burst pressure, demonstrating a high degree of reliability and repeatability.

While the following illustrated examples are based on ISO 1127 ferrules with a flange diameter of 50,5 mm, the general design principles are expected to apply to smaller/lighter ferrule diameters (although not tested). ISO 1127 ferrules with a flange diameter of 50,5 mm was primarily selected due to wide availability/low cost, the availability of (hard) Teflon gaskets and was initially a proof-of-concept, which proved so successful that the extra mass was deemed acceptable for flight vehicles in the 100 kg class and above.

C1. DESIGN, MATERIALS AND MANUFACTURING

General considerations of design and choice of materials allows for a significant solution space.

Clamp ferrule standards of interest for mass/volume considerations could be:

- ISO 1127 (the smaller 25 mm flange diameter)
- DIN 32676 series 1/2/3 (34 mm flange diameter)
- BS 4825-3 (25 mm flange diameter)

The main clamp ferrule components required for SRAD burst discs are illustrated in Figure 8.

Figure 8: General clamp ferrule, blank, gasket and clamp examples. (Source: Copenhagen Suborbitals)

The two core elements of the burst disc design and the tailoring options is the selection of burst disc material and the modifications of the blanks. The burst disc material selected in the example is a large sheet of annealed aluminium. This material was coincidentally obtained in large quantities from a closed typesetting facility, in which large sheets of annealed aluminium of a very thin (0,5 mm) and well-defined thickness tolerance was used for offset printing after etching. The exact nature of the material becomes less relevant since the burst pressure and repeatability are documented through testing. Thin, annealed aluminium sheets should be generally available.

While initial burst discs were cut in hand, a simple punching tool significantly increased output and uniformity, as illustrated in Figure 9 (the annealed aluminium material was coincidentally anodized blue on one side).

Figure 9: Initial burst discs cut by hand. Simple punching tool allowing "mass production" of discs. (Source: Copenhagen Suborbitals)

A convenient feature of selecting hard Teflon gaskets over softer elastomer gaskets, besides the fact that Teflon is one of the most oxidizer compatible materials available, is that they are hard enough to form a retaining grove in the thin, flat, circular annealed aluminium discs. No pre-forming has proved necessary, and the retaining grove prevents the burst disc sliding under the deformation process, as illustrated in Figure 10.

As a suggested guideline for the desired burst disc rupturing pressure is 120% ±3% of the pressure vessel operating pressure. It is sufficient margin to avoid accidental rupturing of the burst discs during normal operation, while ensuring a healthy margin up to the 150% test pressure required in Section 4.2.6.1. With proper attention to manufacturing quality of the orifice blank, a reproduceable ±3% burst pressure tolerance should be easily obtainable.

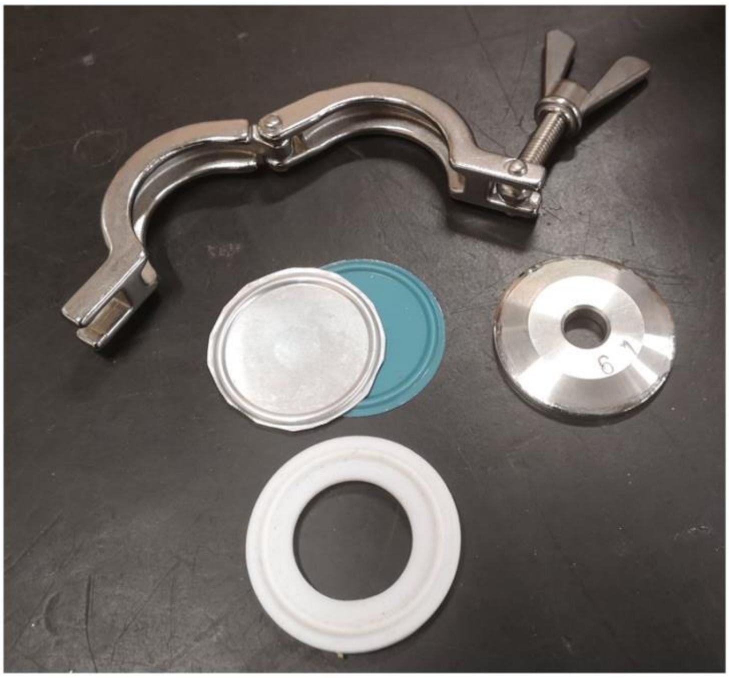


Figure 10: An early SRAD burst disc "set" based on COTS clamp ferrule parts. (Source: Copenhagen Suborbitals)

C2. MACHINING OF THE BLANK

Experience has shown that particular attention needs to be paid to the quality of machining of the blank, resulting in the burst disc orifice. Failure to do so has demonstrated fluctuating and non-uniform burst pressures and poor repeatability.

Since the order of components (from pressure vessel to ambient) are:

Tank ferrule →Teflon gasket →Orifice blank

The burst disc will lie flat against the rear face of the orifice blank, hence the hole quality of the orifice blank is important:

- Machine the blank in a lathe. Pre-drilling is acceptable, but the final diameter is obtained from inside machining in a lathe.
- While chamfering the ambient side of the orifice blank is non-critical, it is imperative to maintain a sharp edge on the burst disc mating side. Machining introduces burrs and/or deformation which must be removed. A sheet of fine grain wet sanding paper on a plane surface results in a clean and sharp orifice edge, without protruding burrs.
- Calibration of the exact burst pressure shall be governed by the machined diameter of the cylindrical orifice, even if being a more time-consuming process. While chamfering the burst disc mating side of the orifice blank is tempting, experience indicates that it has a severe negative impact on the spread of the resulting burst pressure repeatability and must be refrained from.

C3. SRAD BURST DISC TESTING, CHARACTERIZATION AND DOCUMENTATION

Burst disc testing, characterization and documentation is paramount. This process is however fairly quick and simple, requiring few tools for most rocket-relevant burst disc pressures. Machined orifice blanks are to be treated as separate components with unique characteristics, which the test campaign and documentation must reflect. This means a permanently and un-erasable marking with rupture pressure as well as a unique identifier (serial number).

For burst pressures up to 60 bar (and with some abuse of the test equipment, up to 100 bar), a simple manual hydraulic (water) tester and some basic pipework will suffice, as illustrated in Figure 11 and Figure 12. Hydraulic testers can be found easily and affordably if teams wish to acquire a dedicated unit. Pump replacement o-rings are standard sizes and are also easily found and affordable.

Figure 11: A simple burst disc test rig and an example of a ruptured burst disc. (Source: Copenhagen Suborbitals)

Figure 12: Manual hydraulic tester for water. (Source: ahlsell)

While the test setup utilized during proof-of-concept validation illustrated in Figure 11 relied on a simple mechanical pressure meter, proper accuracy and quality of burst pressure documentation should rely on an added pressure transducer and a data logger. A logging frequency of 100 Hz should suffice.

Clean water testing, having removed pockets of trapped air, is quite low-key. A minor splash of water is generated as the burst disc ruptures, as illustrated the frame grabs in Figure 13. No observation of burst disc fragment generation has been made during testing and the ruptured section of the burst disc remains attached to the disc, as illustrated in Figure 11.

It must however be stressed that gas testing of burst discs (contrary to using incompressible water as a test fluid) is to be considered dangerous and should be discouraged. This is irrespectively if the burst disc is tested with or without the pressure vessel it is intended to secure.

One noticeable exception from the above ban of gas testing, is a quite informative realistic use case test, utilizing mostly water and a comparably small volume of gas, as described in the next section.

Figure 13: Frame grabs from a rupturing burst disc. (Source: Copenhagen Suborbitals)

C4. ALL-UP STATIC BURST DISC TESTING FOR PROPELLANT TANKS

Provided that teams have access to a sufficiently secure/hardened test facility, it is advisable that they become familiar with the sound and experience of a rupturing burst disc. Such a test can be conducted under safe conditions, provided that proper attention to hazard control is observed.

General guidelines are as follows and can be conducted on pressure vessel sub-systems:

A test environment capable of sustaining a critical rupture of the intended pressure vessel or propellant tank is selected. Line-of-sight to the pressure vehicle is prohibited and test personnel must be protected from potential debris, even if severe/total sound muffling defeats part of the intent of the test.

The propellant tank securely mounted in a vertical position and typically filled to 90% capacity with water.

- The propellant tank and dedicated burst disc assembly is rigged up to a suitable source of pressurization gas. This can be a simple industrial pressure bottle and a connecting line, although a more useful solution is to use the intended rocket pressurization system.
- All personnel present is equipped with suitable personal protection equipment, in particular hearing protection.
- Video cameras and datalogging allows remote observation and documentation of the test.
- The tank is slowly pressurized to burst disc rupture, never exceeding 140% of the intended operating pressure of the pressure vessel (which has already been proof tested to 150% of operating pressure.

The described test will validate the intended burst disc solution's effectiveness in safeguarding pressure vessels from catastrophic over-pressure events.

C5. KNOWN FAILURE MODES OF THE DESCRIBED SRAD BURST DISC SOLUTION

Two characteristic failure modes of these clamp fitting based SRAD burst discs currently exist:

- Inadvertent mounting of two burst discs, instead of one.
- Rupture pressure drift due to low (cryogenic) temperatures affecting disc yield strength.

C5.1. INADVERTENT MOUNTING OF TWO BURST DISCS IN THE SAME CLAMP FITTING

This was a human error, which was helpfully highlighting a burst disc problem to the operator, due to the geometry of clamp fitting elements. Two burst disc blanks had stuck together and underwent compression to achieve proper seal and extruding the retaining collar. Obviously, a burst disc with twice the material would fully disable the proper safety functionality of the burst disc. Luckily, the clamp fitting system clearly highlights the problem, if the operator recognizes the symptoms.

It was only when the clamp fitting didn't seem to close properly, with the wing nut not fully engaging in the clamp threading, that the issue was detected and recognized. With a single burst disc clamp position is rather closed and visible thread where the wing nut is tightened, illustrated in Figure 14. Just one additional (unintended) burst disc with a thickness of 0,5 mm, prevented the clamp from closing properly and the wing nut from engaging the threading fully, as illustrated in Figure 15. Even with the wing nut vigorously tightened, the clamp did not seem to properly engage and would not appear properly closed.

On a different note, the heavy wing nuts can obviously be replaced for smaller conventional (imperial) nuts, saving weight.

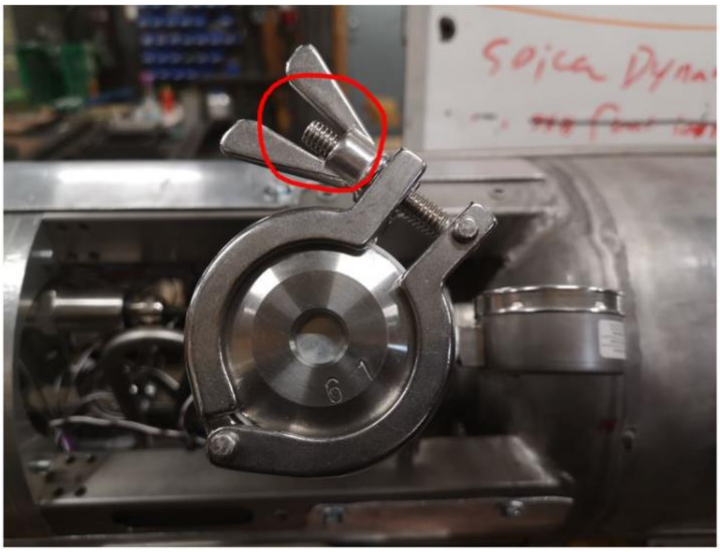


Figure 14: Nominal clamp position with one burst disc. (Source: Copenhagen Suborbitals)

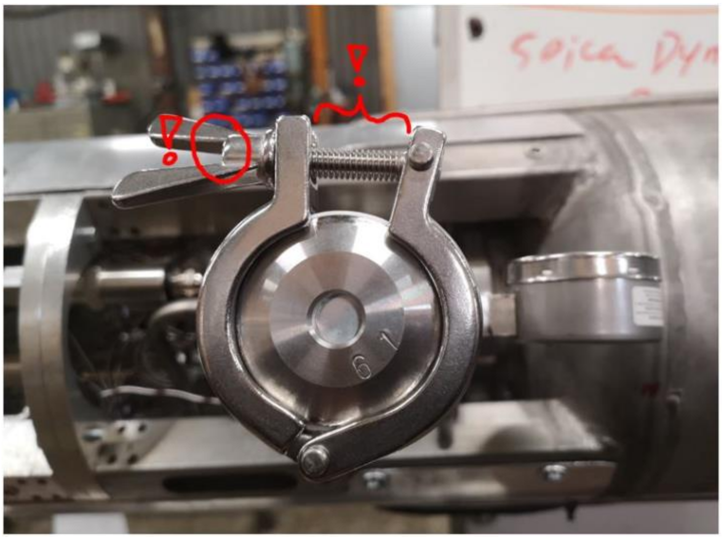


Figure 15: Fault indications facilitated by one additional 0,5 mm burst disc. (Source: Copenhagen Suborbitals)

C5.2. RUPTURE PRESSURE DRIFT DUE TO BURST DISC TEMPERATURE

The rupture pressure both burst discs and pressure vessels increase in inverse proportion to the material temperature. This is a positive trait, particularly with liquid oxygen tanks, but highly undesirable with burst discs. Efforts must thus be made, to keep the burst disc material within reasonable range of ambient temperature.

Such measures include:

- Always mount burst discs and burst disc lines at the top of propellant tanks, well free of the fluid phase. Never at the bottom or in a position where the burst disc can be filled with liquid (cryogenic or otherwise).

- Isolate the burst disc from the tank with a length of stainless-steel tube of perhaps 200 mm. This tube may be bent into a U-shape or a circle to fit inside the fuselage. This prevents conductive cooling.
- Add thermal isolation between the burst disc and the propellant tank/lines, but not between the burst disc and the outer casing or shell plates. This lowers convection cooling and increases convection heating of the burst disc.
- Put the burst disc line in either a separate tank entry point or at a “dead end”, to make sure that pressurization gasses are not passing the burst disc, causing unintended cooling. Pressure fluctuations and adiabatically expanded gas on a busy line, with a burst disc connected on a side branch, may enact severe cooling on the burst disc.

C6. ADDITIONAL INTEGRATION AND TESTING TIPS

A simple and practical AIT (Assembly, Integration and Test) burst disc “extender” is illustrated in Figure 16. An easily observable manual pressure gauge is quite useful for AIT purposes, especially when the confidence in electrical pressure measurements is still low. The burst disc is mounted in the right-side clamp fitting for AIT purposes and mounted in the left clamp (under a missing shell plate) in the flight configuration.

Figure 16: A handy burst disc "extender" for AIT purposes. (Source: Copenhagen Suborbitals)

Another practical device is a pneumatically hydraulic pressure amplifier. This device becomes relevant when the standard lever-operated hydraulic tester output pressure becomes insufficient. Checking a high-pressure external nitrogen pressurization system for leaks requires test pressures on a different magnitude.

This hydraulic amplifier is commonly referred to as a “Maximator”, which is probably related to the Maximator GmbH brand name, allows hydraulic testing of pressurization systems, with water pressure up to 1000 bar or higher. The “power source” to this hydraulic pressure amplifier consists of nothing more than regular 10 bar compressed shop air, making it a rather elegant solution.

Make sure that proper safety precautions are observed:

- Make sure that the tested system is filled with water and devoid of trapped air pockets, as far as feasible.
- Conduct the pressure test in a suitable test facility, that can contain any unintended rupture. A standard or reinforced shipping container will do.
- Keep any and all personnel outside the test facility and avoid line of sight to the test setup. Control the compressed air flow from the outside too.
- Make sure to connect a high-pressure bleed valve on the test setup, mounting it on the far end of a long line extending outside the test enclosure. The below picture was only captured due to the test crew underestimating how a pressurization system can have no leaks on the first try and forgetting/neglecting adding a “remote” bleed valve option. The pressure gauge was initially monitored using a webcam on a tripod inside the test container, but without leaks or means of bleeding the pressurized system, it was needed to go inside with two wrenches and provoke a leak. This experience was not harmful with a fully water filled system and a test pressure of less than half the burst pressure of the COPV.

Figure 17: “Maximator” testing a Dynamic Pressure Regulation system for a bi-liquid, checking for leaks. (Source: Copenhagen Suborbitals)

APPENDIX D. CHECKLISTS REQUIREMENTS AND EXAMPLES

Teams shall present their checklists during the Flight Readiness Review (FRR) for verification. After the verification and approval by the TEB, it is mandatory for teams to present their checklists on the launch day to EuRoC officials (on the Launch Readiness Review). Several formats and variations from the checklists below examples, can be accepted, nonetheless checklists shall contain the following items:

- Team identification;
- Account for all vehicle modules and all stages from assembly to recovery after launch;
- Personnel responsible for each task/vehicle system or subsystem and the responsible for certification/approval;
- Description of each task;
- Tools and equipment necessary, including personal protective equipment;
- Small description of each step;
- Total time required for completeness of the task;
- Time required to complete each step based on previous wet-rehearsals;
- Clear space/square for a check mark on each step, for the personnel performing the task and the responsible for certification/approval;
- Detailed page numbering (e.g. motor assembly – Page 3 of 5);
- Signature from all the involved personnel in last the page of each checklist;
- Any additional comments;
- **Clear the pad instructions shall be included.**

Checklists shall be presented in printed format on the FRR. In case of questions or doubts, checklists can be shown in digital format, before being printed. Teams without printed checklists on the Launch Readiness Review (LRR) will be held until the checklists are presented to EuRoC officials.

For teams who have specific names, vehicle sections or parts, in case of the non-regular or standard names, the parts shall be identified with pictures, drawings or schemes.

Table 3: Checklist example.

<table>
<tr><td>Team Name:</td><td colspan="9">TEAM ONE</td></tr>
<tr><td>Team ID:</td><td>01</td><td colspan="2">Time to Launch:</td><td colspan="2">3 hours</td><td>Location:</td><td colspan="3">Tent/preparation area</td></tr>
<tr><td colspan="10">Combustion Chamber Integration</td></tr>
<tr><td colspan="2">Responsible(s):</td><td colspan="2">Member 1</td><td colspan="3">Member 2</td><td colspan="3">Member 3</td></tr>
<tr><td colspan="2">Approved by:</td><td colspan="2">Member 4</td><td colspan="3">Member 5</td><td colspan="3">Member 6</td></tr>
<tr><td colspan="3">Required time for completeness:</td><td colspan="7">15 min</td></tr>
<tr><td>Summary description:</td><td colspan="9">In this task we will procced with the integration of the Combustion Chamber in the following order…</td></tr>
<tr><td rowspan="3">Tools:</td><td>Torque wrench</td><td></td><td rowspan="3">Protective equipment:</td><td>Gloves</td><td></td><td rowspan="3">Vehicle parts:</td><td>Combustion chamber</td><td></td><td></td></tr>
<tr><td>Lube XYZ</td><td></td><td>Goggles</td><td></td><td>(…)</td><td></td><td></td></tr>
<tr><td>(….)</td><td></td><td>(…)</td><td></td><td>(…)</td><td></td><td></td></tr>
<tr><td>Step #</td><td colspan="2">Task description</td><td colspan="2">Additional comment</td><td>Status:</td><td colspan="2">Approved:</td><td colspan="2">Time required:</td></tr>
<tr><td>1</td><td colspan="2">Check assembly for completeness</td><td colspan="2">Check previous signed checklists;
Check all wires and connectors, for possible damage</td><td></td><td colspan="2"></td><td colspan="2">2 min</td></tr>
<tr><td>2</td><td colspan="2">Lube the O-rings</td><td colspan="2">Use lube XYZ on the O-rings, apply a thin layer</td><td></td><td colspan="2"></td><td colspan="2">6 min</td></tr>
<tr><td>3</td><td colspan="2">(…)</td><td colspan="2">(…)</td><td></td><td colspan="2"></td><td colspan="2">10 min</td></tr>
<tr><td>4</td><td colspan="2">(…)</td><td colspan="2">(…)</td><td></td><td colspan="2"></td><td colspan="2">2 min</td></tr>
</table>

We hereby confirm that all tasks of this checklist were completed:

____

Signature of member 1

____

Signature of member 2

____

Signature of member 3

____

Signature of responsible

Integration of Combustion Chamber Checklist – Page 1 of 1

Table 4: Second checklist example.

Team Name:	TEAM ONE				
Team ID:	01	**Time to Launch:**	50 min	**Location:**	Launch pad
Filling Station Setup					
Responsible(s):	Member 6	Member 7	Member 8		
Approved by:	Member 9	Member 10	Member 11		
Required time for completeness:	25 min				
Summary Description:	In this task we will procced to place the filling station in position and procced to the filling of the vehicle (…)				

Tools:	6 mm Allen Wrench		**Protective equipment:**	Gloves		**Vehicle parts:**	Filling Station	
	Hammer			Goggles			Power cord	
	(….)			(…)			Yagi-Antenna	
							(…)	

Step #	**Task description**	**Additional Comment**	**Status:**	**Approved:**	**Time required:**
1	Place in the filling station in the designated position	Check for the turned-off status of all lights and buttons.			1 min
(…)	(…)	(…)			X min
6	Connect Filling Station Antennas cabling	Connect the 3 m cable to 2,4 GHz antenna; Connect one side of a longer ethernet cable to dish; and other side to injector PoE Port; Secure cables to tripod and extend tripod to max height.			2 min
4	(…)	(…)			X min

12	CLEAR THE PAD and inform mission control	Check for clear pad and clear pad before filling starts. After pad clear, member 8 uses intercoms: “Mission Control – do you copy?” **Only in case of “Yes” or “Copy” reply** “Pad is clear. Start filling”			5 min

We hereby confirm that all tasks of this checklist were completed:

____

Signature of member 6

____

Signature of member 7

____

Signature of member 8

____

Signature of responsible

Filling station Setup – Page 5 of 5