PORTUGUESE SPACE AGENCY

European Rocketry Challenge

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1. INTRODUCTION

1.1. Background

The Portuguese Space Agency organizes EuRoC, the 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 the Portuguese Space Strategy, 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 within Portugal, with an increasing number of interested teams applying to the competition. 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.

1.2. Purpose

The System Requirements Document (SRD) defines the minimum mandatory design and testing requirements that teams must meet before launching at the competition. The organisers use these requirements to promote flight safety. Failure to satisfy a mandatory requirement will affect the flight status negatively and the project's score.

The content of this System Requirements Document is based on the previously designated EuRoC Design, Test and Evaluation Guide, so teams should consider this document as a revision/update of that document. The main purpose of this revision is to simplify the visualization and facilitate the reading, understanding and applicability of the requirements for launch vehicles competing at EuRoC.

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 or lack of compliance with the mandatory requirements.

Additional non-mandatory design and testing guidelines are contained in the appendices of this document, with the goal of sharing best practices with teams.

1.3. System Identification

The requirements contained in this document are applicable and mandatory to all the launch vehicles (LV), and respective systems, accepted and intended to launch at EuRoC.

Exceptionally, Section 11 is dedicated and applicable to the launch support equipment (SE) and not to the launch vehicle itself.

For the rules and requirements of the competition itself (e.g., eligibility, mandatory deliverables, flight status, etc.) teams should refer to the EuRoC Competition Rules document [RD01].

1.4. Document Overview

This System Requirements Document is organised as follows:

- Section 1 contains the scope.
- Section 2 contains the reference documents.
- Section 3 contains the acronyms and abbreviations list.
- Section 4 contains the propulsion systems requirements.
- Section 5 contains the recovery systems and avionics requirements.
- Section 0 contains the stored-energy devices requirements.
- Section 7 contains the active flight control systems requirements.
- Section 0 contains the airframe structures requirements.
- Section 9 contains the payloads requirements.
- Section 10 contains the trajectory and stability requirements.
- Section 11 contains the launch support equipment requirements.
- Appendix A contains the clustered propulsion guidelines.
- Appendix B contains the recovery systems redundant electronics and testing guidelines.
- Appendix C contains the onboard power systems guidelines.
- Appendix D contains the CATS system guidelines.
- Appendix E contains the SRAD pressure vessels guidelines.
- Appendix F contains the active flight control systems guidelines.
- Appendix G contains the payloads guidelines.
- Appendix H contains the fire control system design guidelines.
- Appendix I contains the EuRoC launch rails guidelines.

The requirements are defined according to the following template:

EuRoC-LV-RQT-XXXX	Requirement Title
Text of the requirement	
Rationale	(when applicable)
Note	(when applicable)
Applicability	Verification Method

Where the following definitions apply:

- XXXX: 4-digits field corresponding to the requirement number;
- Requirement title: title of the requirement;
- Text of the requirement: field for the full text of the requirement;
- Rationale: field for the rationale of the requirement, when applicable;
- Note: field providing complementary information, when applicable;
- Applicability: level of applicability of the requirement;
- Verification method: method of verification to be implemented by the EuRoC staff to each requirement. It will be verified during the different stages of the competition, for example through the delivery of the technical questionnaire or during the concept and design reviews, with the ultimate verification being performed at the FRR. The following verification methods and the respective degrees of depth are applicable:

Table 1: Verification methods.

Verification Method \ Degree of Depth	Basic	Thorough
Review of Design	**S**: Simple Confirmation	**A**: Reasoned Argumentation
Inspection	**SC**: Simple Check	**I**: Inspection
Analysis	**C**: Calculation	**IDT**: In-depth proofing (theoretical)

Test	**T**: Previous Testing	**IDE**: In-depth proofing (experimental)

1.5. Change Authority/Responsibility

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 issue number.

The authority to approve and issue revised versions of this document rests with the Portuguese Space Agency. The Portuguese Space Agency reserves the right to change any EuRoC criteria, procedures and requirements at its discretion and at any time, including during the event.

2. DOCUMENTS

2.1. Reference Documents

The documents listed in this section contain reference information useful in the application of this document.

No.	Reference	Title	File Location
[RD01]	PTS_EDU_EuRoC_ST_001905	EuRoC Competition Rules	http://www.euroc.pt
[RD02]	PTS_EDU_EuRoC_RC_000570	EuRoC Motors List	http://www.euroc.pt (Teams' Reserved Area)
[RD03]	PTS_EDU_EuRoC_PD_000599	EuRoC COTS Motors Acquisition	http://www.euroc.pt (Teams' Reserved Area)
[RD04]	N/A	EuRoC Technical Questionnaire	http://www.euroc.pt (Teams' Reserved Area)
[RD05]	PTS_EDU_EuRoC_ST_001932	EuRoC Logistics & Launch Operations Guide	http://www.euroc.pt (Teams' Reserved Area)

3. ACRONYMS AND ABBREVIATIONS

A	Reasoned Argumentation
ACS	Attitude Control Systems
AGL	Above Ground Level
APCP	Ammonium Perchlorate Composite Propellant
BS	British Standard
C	Calculation
CAS	Control Actuator System
CG	Centre of Gravity
COPV	Composite Overwrapped Pressure Vessels
COTS	Commercial of-the-shelf
CP	Centre of Pressure
DIN	Deutsches Institut für Normung (German Institute for Standardization)
ECHA	European Chemicals Agency
e-match	Electric match
EMI	Electromagnetic Interference
EuRoC	European Rocketry Challenge
FMECA	Failure Modes, Effects, and Criticality Analysis
FRP	Fibre Reinforced Plastics
FRR	Flight Readiness Review
GPS	Global Positioning System
H	Hybrid
I	Inspection

IDE	In-depth Proofing (Experimental)
IDT	In-depth Proofing (Theoretical)
IS	Industrial Standard
ISM	Industrial, Scientific, and Medical
ISO	International Organization for Standardization
NiMH	Nickel-Metalhydride
L	Liquid
LiFePO4	Lithium Iron Phosphate
Li-Ion	Litihium-Ion
LiPo	Lithium-Polymer
LOX	Liquid Oxygen
LRR	Launch Readiness Review
LV	Launch Vehicle
PPE	Personal Protective Equipment
PRD	Pressure Relief Device
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
RADAX	Radial-Axial
RD	Reference Document
RF	Radio Frequency
RQT	Requirement
S	Solid
S	Simple Confirmation

SC	Simple Check
SE	Support Equipment
SRAD	Student Researched & Developed
SRD	System Requirements Document
SW	Software
T	Previous Testing
TEB	Technical Evaluation Board
U	Unit, as in Cube-Sat unit
UHF	Ultra-High Frequency
ZSF	Zero Separation Force

4. PROPULSION SYSTEMS REQUIREMENTS

4.1. General Requirements

EuRoC-LV-RQT-0010	Non-toxic propellants
Launch vehicles entering EuRoC shall use non-toxic propellants.	
Rationale	
Note	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.
Applicability Propulsion systems	Verification Method S

EuRoC-LV-RQT-0020	Air-start ignition circuit electronics
All upper stage and secondary ignition systems shall comply with the recovery systems redundant electronics and safety critical wiring requirements specified in Sections 5.1 (EuRoC-LV-RQT-0240 to EuRoC-LV-RQT-0280) and 5.4 respectively.	
Rationale	
Note	In this case “initiation” refers to upper stage ignition rather than a recovery event.
Applicability Upper stage and secondary propulsion systems	Verification Method S, I

4.1.1. 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.

The EuRoC launch control system implements 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.

EuRoC-LV-RQT-0030	Ground-start ignition circuit arming distance
All ground-started propulsion system ignition circuits/sequences shall be capable of being armed and disarmed with no personnel within 15 m of the launch vehicle.	
Rationale	
Note	
Applicability Ground-started ignition circuits	Verification Method SC

EuRoC-LV-RQT-0040	Clustered vehicle release system
All clustered vehicles shall have a launch release system ensuring lift-off only occurs if a minimum threshold force is met.	
Rationale	Partial ignition may occur in clustered propulsion systems, leading to an increased probability of incident occurrence.
Note	The release system can be implemented for example by a breakaway coupling, a structural fuse, a rope with defined breaking force, slightly tilting the motors outward or air starting. Other alternative examples can be found in Appendix A.

Applicability	Verification Method
Clustered vehicles	I, IDT

EuRoC-LV-RQT-0050	Clustered vehicle stability proof
All clustered vehicles shall be capable of performing a stable flight for any lift-off force above the minimum threshold value.	
Rationale	
Note	This requirement is applicable in any situation in which the threshold force is met, even if the propulsion system fires asymmetrically.
Applicability Clustered vehicles	**Verification Method** C

EuRoC-LV-RQT-0060	Clustered vehicle arming
For vehicles with a “main” and several “secondary” propulsion systems, the arming function of the secondary propulsion systems shall only be armed by launch detection (i.e., air-start).	
Rationale	Prevention of ground arming of the clustered propulsion in the event of misfire.
Note	More information on the air-start circuit arming requirement in EuRoC-LV-RQT-0070.
Applicability Clustered vehicles	**Verification Method** I, A

EuRoC-LV-RQT-0070	Air-start ignition circuit arming
All upper stage and “secondary” (i.e., air-start) propulsion systems shall only be armed by launch detection.	

Rationale	This arming function will prevent the upper stage from arming in the event of a misfire.
Note	Possible implementations include accelerometers, zero separation force (ZSF) electrical shunt connections, break-wires, or other similar methods.
Applicability Upper stage and secondary propulsion systems	**Verification Method** I, A

4.2. Solid Motors

EuRoC-LV-RQT-0080	**COTS solid motors**
Error! Reference source not found.All COTS solid motors shall be selected from the official EuRoC Motors List [RD02].	
Rationale	
Note	More information on the motor acquisition process can be found in the EuRoC COTS Motors Acquisition [RD03], which will be made available before the event, in due time.
Applicability COTS Solid Motors	**Verification Method** S

EuRoC-LV-RQT-0090	**Ignition systems for solid motors**
All solid motors shall use the electronic ignition system provided by EuRoC.	
Rationale	
Note	
Applicability COTS and SRAD Solid Motors	**Verification Method** S

4.3. SRAD Propulsion Systems

4.3.1. Hybrid and Liquid Propulsion Systems

EuRoC-LV-RQT-0100	Active pressurization
All gaseous and liquid propellant system shall be able to be externally pressurized with inert gas.	
Rationale	The use of "passive" or "self-pressurization" of propellants have high safety risks and operational issues associated.
Note	This requirement removes the significant propellant density uncertainties of two-phase flows (a volatile and somewhat arbitrary mixture of gas bubbles and liquid) in injectors, reduces the need for thermal conditioning of propellants prior to loading, and creates conditions for the flight vehicle to be able to be pressurized in typically less than 15 seconds, at any point in time after having been loaded on the launch rail. Additionally, and specifically for nitrous oxide, the pressurization by inert gas dilutes the gaseous nitrous oxide in the ullage of the tank, raising its activation energy and lowering the probability of runaway decomposition.
Applicability Hybrid and liquid propulsion systems	Verification Method S, I

EuRoC-LV-RQT-0110	Loading lines disconnection
Systems employing any gaseous or liquid propellants shall perform propellant tank pressurization after all propellant and pressurant loading lines are disconnected.	
Rationale	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 launch vehicle.
Note	
Applicability Hybrid and liquid propulsion systems	Verification Method S, I

EuRoC-LV-RQT-0120	Dissimilar connections
All loading lines, used for pressurization gases or propellants, shall feature dissimilar connectors.	
Rationale	The safety hazards of such propellant and/or pressurant mix-ups are extreme and must be prevented at any level of design, manufacturing, integration, and test.
Note	The dissimilar connections shall be made in such a way that it is impossible to form a leak-tight connection with the wrong connector.
Applicability Hybrid and liquid propulsion systems	Verification Method S, I

EuRoC-LV-RQT-0130	Remote-controlled loading mechanism and respective emergency release mechanism
Any remote-controlled loading mechanism for gases or liquid propellants shall feature a clearly marked and labelled, single action, hand actuated, “Emergency Release Mechanism”.	
Rationale	In case a remote-controlled release mechanism jams and requires manual Launch Control Officer’s assistance.
Note	
Applicability Remote-controlled loading mechanisms	Verification Method SC

EuRoC-LV-RQT-0140	Filling/loading/unloading connections
Any filling/loading/unloading connections for fluid propellants shall be readily accessible from the ground, when the rocket is in vertical launch position.	
Rationale	
Note	All fluid connections shall be accessible without the need for stools, ladders, or other climbing devices.

Applicability	Verification Method
Hybrid and liquid propulsion systems	SC

EuRoC-LV-RQT-0150	Filling/loading/unloading timing
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).	
Rationale	
Note	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.
Applicability Hybrid and liquid propulsion systems	Verification Method A, T

EuRoC-LV-RQT-0160	Venting
For hybrid and liquid motors, teams shall facilitate oxidizer tank venting to prevent over-pressure situations.	
Rationale	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.
Note	
Applicability Hybrid and liquid propulsion systems	Verification Method S, I

EuRoC-LV-RQT-0170	Passive PRD in isolated sections of pressurized lines
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 that line section.	
Rationale	At no time must oxidizer tanks become safety liabilities.
Note	
Applicability Hybrid and liquid propulsion systems	Verification Method I, C

EuRoC-LV-RQT-0180	PRD discharge coefficient
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.	
Rationale	At no time must oxidizer tanks become safety liabilities.
Note	
Applicability Hybrid and liquid propulsion systems	Verification Method A, C

EuRoC-LV-RQT-0190	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.	
Rationale	
Note	
Applicability Hybrid and liquid propulsion systems	Verification Method A

4.3.2. SRAD Propulsion Systems Testing

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

EuRoC-LV-RQT-0200	Combustion chamber pressure test
SRAD and modified COTS propulsion system combustion chambers shall be designed and tested according to the SRAD pressure vessel requirements defined in Sections 0 and 6.3, respectively.	
Rationale	
Note	Combustion chambers are exempted from the requirement for a relief device.
Applicability SRAD and modified COTS combustion chambers	Verification Method T

EuRoC-LV-RQT-0210	Combustion chamber leak proof
Combustion chambers 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.	
Rationale	
Note	
Applicability SRAD and modified COTS combustion chambers	Verification Method A, T

EuRoC-LV-RQT-0220	Hybrid and liquid tanking test
SRAD and modified COTS propulsion systems using liquid propellant(s) shall successfully (without significant anomalies) have completed a propellant loading and offloading test in "launch-configuration", prior to the competition.	
Rationale	Loading and unloading of liquid propellants must be a well-drilled, safe and efficient operation during the competition launch operations.

Note	The 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 offloading checklist, complete with dates, signatures (at least three) and a statement of a successful test. Failure to deliver this annex will automatically result in a "denied" flight status. It is highly recommended to perform this test multiple times as part of the "all-up static engine test" configuration (please refer to EuRoC-LV-RQT-0230).
Applicability Hybrid and liquid propulsion systems	**Verification Method** T

EuRoC-LV-RQT-0230	Static hot-fire test
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.	
Rationale	"Test as you fly – Fly as you test". This test-mentality significantly increases the chances of a lift-off and a nominal flight.
Note	The test shall, to the extent possible, be conducted as an "all-up static engine test", which means that the complete 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. In the case of solid rocket motors, this test does not need to be performed with the same motor casing and/or nozzle components intended for use at EuRoC (i.e., teams must verify their casing design but are not forced to design reloadable/reusable motor cases). The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and an annex to the Technical Report. Failure to deliver this annex will automatically result in a "denied" flight status.
Applicability SRAD propulsion systems (S/H/L)	**Verification Method** T

5. RECOVERY SYSTEMS AND AVIONICS

5.1. General Requirements

EuRoC-LV-RQT-0240	Redundant recovery system electronics
Launch vehicles shall implement fully redundant recovery system electronics, including sensors/flight computers and "electric initiators", with a separate power supply (i.e., battery).	
Rationale	Assure initiation by a backup system if the primary system fails.
Note	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.).
Applicability Recovery system	**Verification Method** S

EuRoC-LV-RQT-0250	Redundant COTS recovery electronics
At least one redundant recovery system electronics subsystem shall implement a COTS flight computer.	
Rationale	
Note	Examples of COTS flight computers are: StratoLogger, G-Wiz, Raven, Parrot, Eggtimer, AIM, EasyMini, TeleMetrum, RRC3, CATS, etc. More information on the permitted systems and implementation of the redundant recovery electronics can be found in **Error! Reference source not found.**.
Applicability Recovery system	**Verification Method** S

EuRoC-LV-RQT-0260	Recovery electronics access panel
All electronics switches or connectors that need to be manually operated shall be accessible from outside the vehicle via either access panels or direct mounting on the outer skin.	
Rationale	Improve launch operations efficiency by a quick and easy access to the electronics while the vehicle is vertical on the launch rail.
Note	Access panels shall be secured for flight.
Applicability All electronics	Verification Method SC

EuRoC-LV-RQT-0270	Recovery electronics location
All electronics switches or connectors that need to be manually operated shall be readily accessible from the ground, when the rocket is in vertical launch position.	
Rationale	Improve launch operations efficiency by a quick and easy access to the electronics while the vehicle is vertical on the launch rail.
Note	All electronics shall be accessible without the need for stools, ladders or other climbing devices.
Applicability All electronics	Verification Method SC

EuRoC-LV-RQT-0280	Recovery electronics access
All electronics switches or connectors that need to be manually operated shall be mounted on the vehicle side opposite to the launch rail.	
Rationale	Improve launch operations efficiency by a quick and easy access to the electronics while the vehicle is vertical on the launch rail.
Note	

Applicability Recovery system	**Verification Method** SC

EuRoC-LV-RQT-0290	**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 6.1 of this document.	
Rationale	
Note	
Applicability Recovery system energetic devices	**Verification Method** S

EuRoC-LV-RQT-0300	**Onboard power systems**
All onboard systems shall be free of batteries with either lithium-polymer or lithium (non-rechargeable) chemistry.	
Rationale	LiPo cells have negligible mechanical resilience, low ignition temperature and an exothermic decomposition nature. Lithium chemistry (non-rechargeable) cells have high probability of metallic lithium, REACH concerns or toxicity/environmental impact.
Note	This requirement applies regardless of the battery encapsulation form factor and only applies to the onboard systems, off-board systems are exempt of such requirement. Teams can find the battery general prioritisation, and allowed characteristics, according to toxicity, flammability, environmental hazards, etc. in Appendix C.
Applicability Onboard power systems	**Verification Method** S, I

EuRoC-LV-RQT-0310	Onboard power systems access
Onboard batteries shall be readily accessible from the ground, when the rocket is in vertical launch position.	
Rationale	Improve launch operations efficiency by a quick and easy access to the onboard power systems while the vehicle is vertical on the launch rail.
Note	Teams can find implementation strategies and examples for improved onboard power systems design on Appendix C.
Applicability Onboard power systems	Verification Method SC

EuRoC-LV-RQT-0320	Launch rail standby time
Onboard power systems shall have at least six hours of battery lifetime on the launch rail.	
Rationale	
Note	Teams can find implementation strategies and examples for improved onboard power systems design on Appendix C.
Applicability Onboard power systems	Verification Method S

EuRoC-LV-RQT-0330	Non-parachute/parafoil recovery systems
Teams exploring other recovery methods (i.e., non-parachute or parafoil based) shall mention it in the dedicated field of the Technical Questionnaire [RD04].	
Rationale	
Note	EuRoC organisation may make additional requests for information and draft unique requirements depending on the team's specific design implementation.

Applicability	Verification Method
Non-typical recovery methods	S, I, A, IDT

5.2. Dual Deployment Parachute and Parafoil Recovery

EuRoC-LV-RQT-0340	Dual deployment recovery
Each independently recovered launch vehicle body, anticipated to reach an apogee above 450 m above ground level (AGL), shall follow a dual deployment recovery operations concept.	
Rationale	
Note	A dual-deployment recovery operations concept features 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.
Applicability	Verification Method A, C

EuRoC-LV-RQT-0350	Initial deployment event altitude
The initial deployment event shall occur at or near apogee.	
Rationale	To stabilize the vehicle's attitude (i.e., prevent or eliminate tumbling).
Note	
Applicability Any part, assembly or device, featuring an initial deployment event	Verification Method A, C

EuRoC-LV-RQT-0360	Initial deployment event descent velocity
The initial deployment event shall result in a descent velocity between 23 and 46 m/s.	
Rationale	Reduce the vehicle descent rate sufficiently to permit the main deployment event, yet not so much as to exacerbate wind drift.
Note	
Applicability Any part, assembly or device, featuring an initial deployment event	Verification Method A, C

EuRoC-LV-RQT-0370	Main deployment event altitude
The main deployment event shall occur at an altitude no higher than 450 m AGL.	
Rationale	
Note	
Applicability Any part, assembly or device, featuring a main deployment event	Verification Method A, C

EuRoC-LV-RQT-0380	Main deployment event descent velocity
The main deployment event shall result in a descent velocity of less than 9 m/s.	
Rationale	Reduce the vehicle's descent rate sufficiently to prevent excessive damage upon impact with ground.
Note	
Applicability Any part, assembly or device, featuring a main deployment event	Verification Method A, C

EuRoC-LV-RQT-0390	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.	
Rationale	
Note	
Applicability Recovery systems using hot ejection gases	Verification Method S, I

EuRoC-LV-RQT-0400	Parachute swivel links
The recovery system rigging (e.g., parachute lines, risers, shock chords, etc.) shall implement swivel links at any connections including single-threaded anchors.	
Rationale	Mitigate the risk of torque loads unthreading bolted connections during recovery as well as parachute lines twisting up.
Note	The use of swivel links is intended to relieve torsion in the rigging, which can unscrew eyebolts and similar components. Mechanical connections that use multiple threads in parallel and thus cannot be untwisted by line torsion are exempt from this requirement.
Applicability Recovery systems rigging	Verification Method S, I

EuRoC-LV-RQT-0410	Dual deployment parachute coloration
Dual deployment parachutes shall be visually highly dissimilar from one another.	
Rationale	This will enable ground-based observers to characterize deployment events more easily.
Note	This is typically achieved by using parachutes whose primary colours contrast those of the other chute.

Applicability	Verification Method
Dual deployment parachutes	S

EuRoC-LV-RQT-0420	Parachute coloration
Utilised parachutes shall use colours providing a clear contrast to a blue sky, a grey/white cloud cover and ground vegetation (i.e. avoiding certain shades of green and brown, as well as black).	
Rationale	To ease the location of the vehicle during descent and recovery operations.
Note	Colours such as orange and red are favourable.
Applicability All parachutes	Verification Method S

5.3. Official Altitude Logging and Tracking System

EuRoC-LV-RQT-0430	Mandatory system
Launch vehicle stages and deployable payloads shall feature a mandatory operational CATS Vega Flight Computer for official altitude logging and landing site tracking purposes.	
Rationale	Provide the EuRoC team with the means to easily determine and record the apogee altitude in a fast, efficient, consistent and equally fair (hence identical) way for all teams. Provide the student/recovery teams an efficient means of quickly tracking down the location of all launch flight vehicles (and any other tracked payload/components), to quickly clear the launch range.
Note	Modifications/adaptations to the mandatory CATS system are not allowed. More information, guidelines and examples applicable to the CATS system can be found in Appendix D. Technical details on the CATS Vega Flight Computer along with recommendations can be found in the CATS User Manual, available on the EuRoC website. For more general information on the CATS systems refer to https://catsystems.io.

Applicability	Verification Method
Stages of launch vehicles and deployable payloads	S

EuRoC-LV-RQT-0440	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 a specific string format to be found in Appendix D.	
Rationale	
Note	Teams should expect to be required to functionally demonstrate all CATS flight computer to CATS ground station telemetry links of their flight vehicle during the Flight Readiness Review.
Applicability CATS systems	**Verification Method** S

EuRoC-LV-RQT-0450	CATS Vega firmware update
Teams will be required to fly a specific firmware version in each mandatory CATS flight computer, mandated by the EuRoC organization.	
Rationale	
Note	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. Information on the CATS Vega firmware update procedure can be found in the CATS User Manual, available on the EuRoC website.
Applicability CATS systems	**Verification Method** S

EuRoC-LV-RQT-0460	CATS receiver
The CATS Ground Station shall be used for telemetry and tracking in conjunction with the mandatory system.	
Rationale	
Note	Information on the CATS Ground Station can be found in the CATS User Manual, available on the EuRoC website.
Applicability CATS systems	**Verification Method** S

EuRoC-LV-RQT-0470	CATS electronics
CATS devices shall comply with the electronics general electronics requirements EuRoC-LV-RQT-0260, EuRoC-LV-RQT-0270 and EuRoC-LV-RQT-0280.	
Rationale	Improve launch operations efficiency by a quick and easy access to the electronics while the vehicle is vertical on the launch rail.
Note	
Applicability CATS systems	**Verification Method** S

5.4. Safety Critical Wiring

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

EuRoC-LV-RQT-0480	Cable management
All safety critical wiring shall implement a cable management solution (e.g., wire ties, wiring, harnesses, cable raceways).	
Rationale	Prevent tangling and excessive free movement of significant wiring/cable lengths due to expected launch loads.

Note	A slack is necessary at all connections/terminals to prevent unintentional de-mating due to expected launch loads transferred into wiring/cables at physical interfaces.
Applicability Safety critical wiring	Verification Method S, I

EuRoC-LV-RQT-0490	Secure connections
All safety critical wiring/cable connections shall be sufficiently secure as to prevent de-mating due to expected launch loads.	
Rationale	
Note	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.
Applicability Safety critical wiring	Verification Method I

EuRoC-LV-RQT-0500	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.).	
Rationale	
Note	
Applicability Safety critical wiring for cryogenic conditions	Verification Method I

5.5. Electronics and Recovery System Testing

EuRoC-LV-RQT-0510	Electronics thermal testing
Teams shall thermally test the 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.	
Rationale	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.
Note	The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and annex to the Technical Report. Failure to deliver this annex will automatically result in a "denied" flight status. Teams must take 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. Black coloration results in maximum thermal absorption. Teams shall also treat the electronics and systems considering 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.
Applicability Electronics	Verification Method T

EuRoC-LV-RQT-0520	Recovery system 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.	
Rationale	Correct, reliable and repeatable recovery system performance is absolute top priority from a safety point of view.
Note	In the case of ground tests, sensor electronics shall be functionally included in the demonstration by simulating the environmental conditions under which the deployment function is triggered.

	The test results and a statement of a successful test, complete with dates and signatures (at least three) are considered a mandatory deliverable and annex to the Technical Report. Failure to deliver this annex will automatically result in a "denied" flight status. More information on optional and advisable tests are referred to in Appendix B3.

Applicability	Verification Method
Recovery systems	T

6. STORED-ENERGY DEVICES

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

6.1. General Requirements

EuRoC-LV-RQT-0530	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".	
Rationale	
Note	While EuRoC-LV-RQT-0030 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.
Applicability All energetics other than propulsion related	Verification Method SC

EuRoC-LV-RQT-0540	Arming device access
All energetic device arming features shall comply with the requirements EuRoC-LV-RQT-0260, EuRoC-LV-RQT-0270 and EuRoC-LV-RQT-0280.	
Rationale	Improve launch operations efficiency by a quick and easy access to the electronics while the vehicle is vertical on the launch rail.
Note	
Applicability All energetics	Verification Method SC

EuRoC-LV-RQT-0550	Arming device location
All energetic device arming features shall be located on the airframe.	
Rationale	Any inadvertent energy release by these devices will not impact personnel arming them.

Note	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.	
Applicability All energetics		Verification Method S

6.2. SRAD Pressure Vessels

The following requirements are applicable to 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) combustion chambers are included as well but are exempted from the relief device requirement.

EuRoC-LV-RQT-0560	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 millimetres. The burst (or rupture) disc solution can be either COTS or SRAD.		
Rationale		
Note	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 E2 practical examples of manufacturing, burst pressure tailoring and testing. 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.	
Applicability SRAD and modified COTS pressure vessels and tanks		Verification Method A, I

EuRoC-LV-RQT-0570	Burst disc pressure
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.	
Rationale	
Note	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. This leaves adequate margin up to the 1,50 times proof pressure (see requirement EuRoC-LV-RQT-0640 regarding proof pressure testing)
Applicability Burst discs	Verification Method A, I, C

EuRoC-LV-RQT-0580	Burst disc marking
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.	
Rationale	
Note	Punching, engraving, grinding, etching, etc. counts as permanent marking. Various permanent markers based on ink or paint do not. For COTS burst disks, an equivalent certificate shall be requested from the manufacturer. More information on the burst disc testing can be found in Appendix E2.
Applicability Burst discs	Verification Method I

EuRoC-LV-RQT-0590	Burst discs material
All SRAD burst discs shall come from the same stock material sheet, both for flight, testing and rupture pressure characterization.	
Rationale	Using the same sheet material everywhere eliminates risk incurred by accidentally mixing up burst discs of different material thickness.
Note	Teams are recommended to pick out a sheet of material sufficiently large to cover all burst disc needs.
Applicability SRAD burst discs	Verification Method S

EuRoC-LV-RQT-0600	Relief device
SRAD pressure vessels shall implement an additional relief device, set to open in the range of 1,10 to 1,20 times the nominal operating pressure.	
Rationale	
Note	For the applicable exception to this requirement please refer to the note on requirement EuRoC-LV-RQT-0200.
Applicability SRAD and modified COTS pressure vessels	Verification Method A, T

EuRoC-LV-RQT-0610	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.	
Rationale	
Note	The maximum operating pressure is the maximum pressure expected during pre-launch, flight, and recovery operations.

Applicability	Verification Method
Metallic SRAD and modified COTS pressure vessels	A, IDT

EuRoC-LV-RQT-0620	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.	
Rationale	
Note	The maximum operating pressure is the maximum pressure expected during pre-launch, flight, and recovery operations.
Applicability: Composite SRAD and modified COTS pressure vessels	Verification Method: A, IDT

6.3. SRAD Pressure Vessel Testing

The following requirements concern 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) combustion chambers are included as well.

EuRoC-LV-RQT-0630	Burst discs testing
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.	
Rationale	

Note	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 annex to the Technical Report. Failure to deliver this annex will automatically result in a "denied" flight status.
Applicability Burst discs	**Verification Method** T

EuRoC-LV-RQT-0640	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).	
Rationale	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.
Note	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 a mandatory deliverable and annex to the Technical Report. Failure to deliver this annex will automatically result in a "denied" flight status. 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.

Applicability	Verification Method
SRAD and modified COTS pressure vessels	T

7. ACTIVE FLIGHT CONTROL SYSTEMS

Designated landing zones/coordinates, travel corridors, loitering zones, etc., can be found on the EuRoC Logistics & Launch Operations Guide [RD05], which will be made available before the event, in due time.

EuRoC-LV-RQT-0650	Restricted control functionality
Launch vehicle active flight control systems, if implemented, can only be implemented for pitch and/or roll stability augmentation, for aerodynamic "braking", guided recovery systems, precision landing or guided deployable loads.	
Rationale	
Note	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/review. EuRoC staff may make additional requests for information and draft unique requirements depending on the team's specific design implementation. Guidelines and best practices on how to design control actuator systems and recommended flight trajectories can be found in Appendix F.
Applicability Active flight control systems	**Verification Method** S

EuRoC-LV-RQT-0660	Unnecessary for stable flight
Flight vehicles implementing active flight controls shall be naturally stable without these controls being implemented.	
Rationale	
Note	Attitude Control Systems (ACS) will serve only to mitigate the small perturbations which affect the trajectory of a stable rocket that implements only fixed aerodynamic surfaces for stability. The 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.

	The organisers may make additional requests for information and draft unique requirements depending on the team's specific design implementation.
Applicability Active flight control systems	**Verification Method** A, C

EuRoC-LV-RQT-0670	Designed to fail safe
Control Actuator Systems shall be designed to Fail Safe in any abnormal condition or during an active flight abort (if such functionality is implemented).	
Rationale	
Note	Designed to fail safe 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 shall 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.
Applicability Active flight control systems	**Verification Method** A, IDT

EuRoC-LV-RQT-0680	Boost phase dormancy
Control Actuator Systems shall be designed with a field adjustable boost dormancy capability, which will disable them in the initial period of the flight.	
Rationale	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.

Note	For any CAS without demonstrated flight history and a documented SW configuration control, the boost phase dormancy shall end at an altitude of no less than 1500 m AGL. For any CAS with a limited demonstrated flight history, the default boost phase dormancy expiration criteria is an altitude of 500 m AGL, 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, etc., the boost phase dormancy expiration altitude may on a case-by-case basis be set as low as the end of the launch rail. The EuRoC officials can set the boost dormancy phase expiration criteria higher as seen fit. In case the CAS is only capable of exerting longitudinal roll control please refer to Appendix F1 for more information.
Applicability Active flight control systems	**Verification Method** A, I

EuRoC-LV-RQT-0690	**Active flight control system electronics**
All electronics shall comply with the recovery systems redundant electronics and safety critical wiring specified in Sections 5.1 (EuRoC-LV-RQT-0240 and EuRoC-LV-RQT-0260 to EuRoC-LV-RQT-0280) and 5.4 respectively.	
Rationale	
Note	In this case "initiation" refers to CAS commanding rather than a recovery event.
Applicability Active flight control system	**Verification Method** SC

EuRoC-LV-RQT-0700	**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 6.1 of this document.	
Rationale	

Note	
Applicability Active flight control system energetics	**Verification Method** S

8. AIRFRAME STRUCTURES

8.1. General Requirements

EuRoC-LV-RQT-0710	Venting
All non-pressurized compartments of the airframe shall be vented in such a way that the pressures during flight are never above 1,05 times the atmospheric pressure at that point in the flight.	
Rationale	Prevent unintended internal pressures developed during flight from causing either damage to the airframe or any other unplanned configuration changes.
Note	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.
Applicability Airframe non-pressurized compartments	**Verification Method** S, SC, C

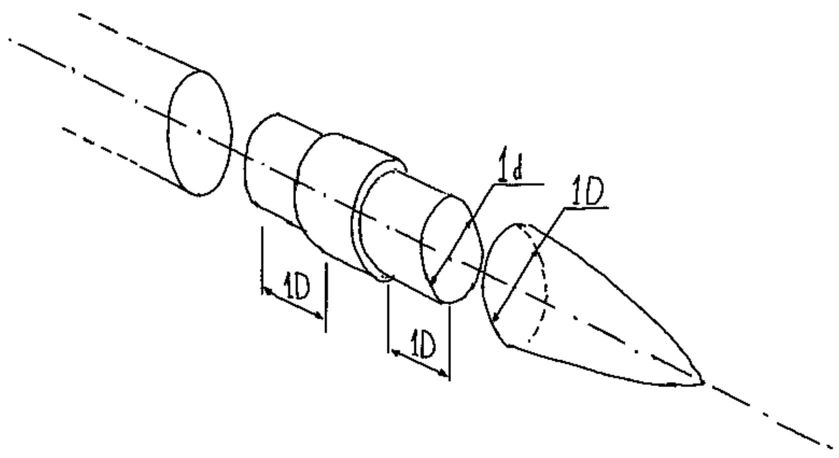
EuRoC-LV-RQT-0720	Material selection
PVC (and similar low-temperature polymers) Public Missiles Ltd. Quantum Tube components shall not be used in any structural (i.e., load bearing) capacity, most notably as load bearing eyebolts, launch vehicle airframes, or propulsion system combustion chambers.	
Rationale	
Note	
Applicability Load bearing structures	**Verification Method** S

EuRoC-LV-RQT-0730	Load bearing eyebolts type
All load bearing eyebolts shall be of the closed-eye, forged type.	
Rationale	

Note	This requirement extends to any bolt and eye-nut assembly used in place of an eyebolt.
Applicability Load bearing eyebolts	**Verification Method** SC

EuRoC-LV-RQT-0740	Load bearing eyebolts and U-bolts material
All load bearing eyebolts and U-Bolts shall be steel or stainless steel.	
Rationale	
Note	This requirement extends to any bolt and eye-nut assembly used in place of an eyebolt.
Applicability Load bearing eyebolts and U-bolts	**Verification Method** SC

EuRoC-LV-RQT-0750	Coupling tubes
Airframe joints which implement "coupling tubes" shall 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.	
Rationale	
Note	This requirement 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). Regardless of implementation (e.g., RADAX or other joint types) airframe joints need to be "stiff" (i.e., prevent bending).



Applicability	Verification Method
Coupling tubes	A, SC

EuRoC-LV-RQT-0760	Launch lugs mechanical attachment
Launch lugs (i.e., rail guides) shall implement "hard points" for mechanical attachment to the launch vehicle airframe.	
Rationale	Assist in mitigating lug "tear outs" during operations.
Note	Hardened/reinforced areas on the vehicle airframe, such as a block of wood installed on the airframe interior surface where each launch lug attaches.
Applicability Launch lugs	**Verification Method** SC

EuRoC-LV-RQT-0770	Aft launch lug support
The aft most launch lug shall support the launch vehicle's fully loaded launch weight while vertical.	
Rationale	

Note	EuRoC staff 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.
Applicability Aft launch lug	Verification Method I, T

EuRoC-LV-RQT-0780	RF transparency
Any internally mounted RF transmitter, receiver or transceiver, not having the applicable antenna(s) mounted externally on the airframe, shall employ "RF windows" in the airframe shell plating (typically glass fibre panels).	
Rationale	Enable devices with antennas mounted inside the airframe, to transmit the signal through the airframe shell.
Note	RF transmitters, receivers or transceivers are not allowed to be mounted externally.
Applicability Internally RF devices	Verification Method S

EuRoC-LV-RQT-0790	RF windows dimensioning
RF windows in the flight vehicle shell shall be a 360° circumference and be at least two body calibres in length.	
Rationale	
Note	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 not true when the rocket engine is active, since the ionized exhaust gas from the engine is highly disruptive to RF signals, so degradation or loss of link is to be expected.
Applicability RF windows	Verification Method S

EuRoC-LV-RQT-0800	RF windows material
RF windows shall be of a material other than carbon fibre.	
Rationale	Carbon fibre is conductive and will significantly shield and/or degrade RF signals.
Note	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.
Applicability RF windows	Verification Method S

EuRoC-LV-RQT-0810	RF antennas' location
RF antennas shall be kept as far away as possible from wiring and metallic structural elements.	
Rationale	Poor installation practice degrades telemetry and link performances.
Note	Teams are highly advised to follow best RF-practices.
Applicability RF antennas	Verification Method S

EuRoC-LV-RQT-0820	Internal RF antennas' location
The internally mounted RF antenna(s) shall be placed at the midpoint of the RF window section.	
Rationale	Facilitate maximizing the azimuth radiation pattern.
Note	
Applicability Internal RF antennas	Verification Method S

EuRoC-LV-RQT-0830	Identifying markings
The Team ID shall be clearly and prominently displayed on the launch vehicle airframe, visible on all four quadrants of the vehicle, as well as fore and aft, and on all components that separate from the vehicle such as deployable payloads.	
Rationale	Assist EuRoC officials to identify the project hardware with its respective team throughout EuRoC.
Note	As a recommendation for the airframe coloration, mostly white or lighter tinted (e.g., yellow, red, orange, etc.) airframes are especially favourable to mitigate the possible solar heating during 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.) allow ground-based observers to track and record the launch vehicle's trajectory more easily.
Applicability Airframe and components with separation from the vehicle	**Verification Method** S

9. PAYLOADS

EuRoC encourages teams to launch functional payloads in the form of creative scientific experiments and technology demonstrations. Nevertheless, non-functional "dummy mass" payloads are also permitted, if these compliant with the applicable requirements.

9.1. General Requirements

EuRoC-LV-RQT-0840	Payloads
Teams are required to carry payload(s) on the vehicle.	
Rationale	
Note	More information on payload definition and types can be found in Appendix G.
Applicability Aft launch lug	Verification Method S

EuRoC-LV-RQT-0850	Payload form factor
Payloads shall fulfil one of following basic form factors: • CanSat: cylindrical shape with 115 mm height and 66 mm diameter; • CubeSat: cubic shape with one CubeSat Unit (1U) being defined as a 100 mm x 100 mm x 100 mm cubic structure; • PocketSat: cubic shape with 50 mm x 50 mm x 50 mm.	
Rationale	
Note	The volume of the payload may be a multiple/stack of the basic payload form factors, e.g., 3 CanSats (345 mm height x 66 mm diameter), 2U (200 mm x 100 mm x 100 mm), 5 PocketSats (250 mm x 50 mm x 50 mm) or likewise. Teams intending on carrying payloads which do not fulfil the payload form factor, require prior case-by-case review and EuRoC approval. In case of approval there will be a negative impact on the scoring since the payload is still not compliant with the requirement.

Applicability	Verification Method
Payloads	S

EuRoC-LV-RQT-0860	Payload minimum mass
The launch vehicle shall carry no less than 1000 g of payload, with no requirement applicable to the upper limit.	
Rationale	
Note	A weigh-in will be conducted during Flight Readiness Review. Competition officials will accept payload weigh-ins as much as 5% (50 g) less than the specified minimum. If this requirement is not met, "nominal" flight status may be denied, resulting in an action item to increase payload mass. If a functional payload is chosen, with the functional part itself not providing enough mass to reach the minimum requirement, additional dummy-masses may be added to the functional payload until the requirement is reached. Examples of payloads fulfilling the minimum mass requirement can be found in Appendix G2.
Applicability Payloads	**Verification Method** I

EuRoC-LV-RQT-0870	Payload mass factor
Payloads shall fulfil one of the following basic mass increments: • A single CanSat-type payload has a mass between 300 g and 350 g; • A single CubeSat-type payload has a mass between 1000 g and 1330 g; • A single PocketSat-type payload has a mass between 200 g and 250 g.	
Rationale	
Note	

Applicability	Verification Method
Payloads	S

EuRoC-LV-RQT-0880	Independent payload functionality
The payload functionality must be completely independent of the launch vehicle and at the same time payloads cannot be a part of the launch vehicle functionality (e.g., a guidance and control system).	
Rationale	
Note	Launch vehicle recovery systems shall be able to bring the vehicle down in a safe and controlled manner, as per the recovery system requirements, independently of whether the payload is active, passive, deployable or fixed inside the launch vehicle.
Applicability: Payloads	Verification Method: S

EuRoC-LV-RQT-0890	Payload removal for weigh-in
Teams must ensure that the payloads shall not be inextricably connected to other launch vehicle associated components (e.g., recovery system, internal structure, or airframe) while being weighed.	
Rationale	
Note	If the payload cannot be removed for weigh-in, the team will not get points for an onboard payload. Neither the payload's location in the launch vehicle nor its method of integration and removal is specified.
Applicability:	Verification Method: I

EuRoC-LV-RQT-0900	Payload materials
Payloads shall not contain significant quantities of lead or any other hazardous materials, and in case of payloads with potential biohazards such as seeds or living beings, those must not contain invasive species. The use of radioactive materials is not permitted.	
Rationale	
Note	In case of doubts or concerns on hazardous materials, please consult the European Chemicals Agency (ECHA) database (https://echa.europa.eu/information-on-chemicals/cl-inventory-database). For more information on the invasive species both plantae and animalia in Portugal, please refer to the following: • Plants/seeds: https://invasoras.pt/en/invasive-species-in-portugal; • Global Register of Introduced and Invasive Species: https://griis.org/view-checklist?id=4f94d674-5a95-4c2c-9213-54881beed63a. • In the documentation submitted to EuRoC, teams shall specify the scientific name of the species and not only the generic name. The EuRoC organisation reserves the right to prohibit the deployment of payloads in case of safety concerns.
Applicability Payloads	Verification Method S

EuRoC-LV-RQT-0910	Payload energetic devices
All stored-energy devices (i.e., energetics) used in payload systems shall comply with the energetic device requirements defined in Section 6.1 of this document.	
Rationale	
Note	
Applicability Payloads energetics	Verification Method S

9.2. Deployable Payloads Recovery

Deployable payloads are characterized by the payload being ejected or separated from the main vehicle during flight.

Deployable payloads implementing a parachute or parafoil based recovery system are not required to comply with the dual deployment requirements described in Section 5.2 of this document, being allowed to utilize a single deployment recovery system with 8-9m/s descent rate from apogee, subject to case-by-case EuRoC approval. Deployable payloads without dual deployment recovery systems (drogue and main chute) will be subjected to considerable drift during descent.

EuRoC-LV-RQT-0920	Recovery system
Deployable payloads shall have its own independent recovery system.	
Rationale	
Note	
Applicability Deployable payloads	**Verification Method** S

EuRoC-LV-RQT-0930	Unique recovery system
If teams plan to develop a deployable payload that requires a specific unique recovery system, they shall contact the EuRoC organization well in advance of the event to clarify if the payload satisfies all requirements.	
Rationale	
Note	
Applicability Deployable payloads	**Verification Method** A, IDT

EuRoC-LV-RQT-0940	Descent velocity
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.	
Rationale	
Note	
Applicability Deployable payloads	Verification Method A, C

EuRoC-LV-RQT-0950	Recovery system electronics
Payloads implementing independent recovery systems shall comply with the launch vehicle redundant electronics requirements defined in Section 5.1 (EuRoC-LV-RQT-0240 to EuRoC-LV-RQT-0280).	
Rationale	
Note	
Applicability Deployable payloads	Verification Method I

EuRoC-LV-RQT-0960	Payload safety critical wiring
Payloads implementing independent recovery systems shall comply with the launch vehicle safety critical wiring requirements defined in Section 5.4.	
Rationale	
Note	
Applicability Deployable payloads	Verification Method I

EuRoC-LV-RQT-0970	Recovery system testing
Payloads implementing independent recovery systems shall comply with the launch vehicle recovery system testing requirements defined in Section 0.	
Rationale	
Note	
Applicability Deployable payloads	Verification Method T

EuRoC-LV-RQT-0980	Payload tracking
All deployable payloads shall feature the mandatory altitude logging and tracking system (see Section 5.3).	
Rationale	Deployable payloads are equivalent to flight vehicle bodies and sections and can be difficult to locate after landing.
Note	
Applicability Deployable payloads	Verification Method S

EuRoC-LV-RQT-0990	Payload tracking call-sign
Teams shall assign to each transmitter a call-sign respecting the format described in Appendix D.	
Rationale	
Note	The landing site tracking locator ID must differ from the ID of the launch vehicle.
Applicability Deployable payloads	Verification Method S

10. TRAJECTORY AND STABILITY

EuRoC-LV-RQT-1000	Launch azimuth and elevation
Launch vehicles shall nominally launch at an elevation angle of 84°±1° and a launch azimuth defined by the organisation at EuRoC.	
Rationale	
Note	Competition officials reserve the right to require certain vehicles' launch elevation to be as low as 70° if flight safety issues are identified during pre-launch activities. The tolerance expressed within the nominal launch azimuth is an expression of acceptable human error by the operator setting the launch rail elevation prior to launch.
Applicability All launch vehicles	Verification Method S

EuRoC-LV-RQT-1100	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.	
Rationale	
Note	This requirement 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. 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.
Applicability All launch vehicles	Verification Method C

EuRoC-LV-RQT-1020	Hold-down system
All vehicles using at least one liquid propellant shall employ a hold-down system that will release the rocket only after sufficient thrust for stable flight is achieved.	
Rationale	
Note	The hold-down mechanism may be actively or passively release. The holding force should be distributed symmetrically on the airframe. For use with the EuRoC rail, additional accessories may need to be fitted.
Applicability Hybrid and Liquid launch vehicles	Verification Method I, C, T

EuRoC-LV-RQT-1030	Stability margin
Launch vehicles shall maintain 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 CP location due to wave drag effects (which may become significant as low as 0,5 Mach).	
Rationale	
Note	All launch vehicles should avoid becoming over-stable during ascent, meaning with a static margin significantly greater than 2 body calibres (e.g., greater than 6 body calibres). Sloshing effects of fluids on payloads, should also be taken into consideration during calculations.
Applicability All launch vehicles	Verification Method C

11. LAUNCH SUPPORT EQUIPMENT

EuRoC will provide standardised launch rails for the teams that do not intend to bring their own launch rail, as well as a launch control system. The following requirements are applicable to the teams' launch support equipment to be used at EuRoC.

11.1. General Requirements

Teams should make their launch support equipment man-portable over a short distance. Environmental and safety considerations at the launch site permit only limited vehicle use beyond designated roadways, campgrounds, and basecamp areas.

EuRoC-SE-RQT-0010	Operational range
All team provided launch control systems shall be electronically operated and have a maximum operational range of no less than 750 metres from the launch rail.	
Rationale	
Note	The maximum operational range is defined as the range at which launch may be commanded reliably.
Applicability Teams launch control systems	Verification Method S

EuRoC-SE-RQT-0020	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.	
Rationale	
Note	Appendix H of this document provides general guidance on assuring fault tolerance in amateur high-power rocketry launch control systems.

Applicability	Verification Method
Teams launch control systems	S

EuRoC-SE-RQT-0030	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.	
Rationale	
Note	Mercury or "pressure roller" switches are not permitted anywhere in team provided launch control systems.
Applicability Teams launch control systems	**Verification Method** S

11.2. Launch Rails

For more information on the EuRoC launch rails please refer to Appendix I.

EuRoC-SE-RQT-0040	Launch rail fit check
Teams using EuRoC launch rails shall perform a launch rail fit check as part of the Flight Readiness Review, before going to the launch range.	
Rationale	The launch rail fit check will ensure that surprises are not encountered on the launch rails, causing delays and loss of launch opportunities. Arriving at the launch rails and only then discovering that a team's launch lugs do not fit the launch rail, will be considered gross negligence by EuRoC officials.
Note	This requirement is particularly important if a team is not bringing their own launch rail but instead relying on EuRoC launch rails.
Applicability Launch vehicles to be launched by EuRoC launch rails.	**Verification Method** I

EuRoC-SE-RQT-0050	Launch rail bottom spacer
Teams shall provide their own bottom spacer to define their vehicles' vertical position on the rail.	
Rationale	
Note	
Applicability EuRoC launch rails	Verification Method S

EuRoC-SE-RQT-0060	Launch rail nominal elevation
Team provided launch rails shall be able to implement a nominal launch elevation of 84°±1°.	
Rationale	
Note	
Applicability Teams launch rail	Verification Method S

EuRoC-SE-RQT-0070	Launch rail elevation range
Team provided launch rails with adjustable elevation shall only allow inclinations between 70° and 85°.	
Rationale	
Note	
Applicability Teams launch rail	Verification Method S

APPENDIX A. 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 will be 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.

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.

APPENDIX B. RECOVERY SYSTEM REDUNDANT ELECTRONICS AND TESTING

B1. Redundant COTS Recovery Electronics

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., 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, nichrome 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 **Error! Reference source not found.**.

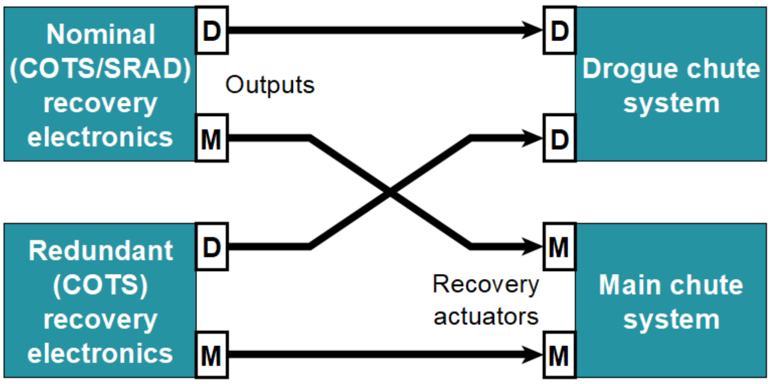


Figure 2: Interconnection redundancy implementation. (Source: Jacob Larsen)

B2. 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.

B3. Optional 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 implement even during the most stressful launch days.

B3.1. 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 backup booster may be used).

B3.2. 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.

APPENDIX C. ONBOARD POWER SYSTEMS

Lithium-Polymer (LiPo) batteries are not allowed due to the increased flammability and thus an increased fire hazard. 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 the 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.

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 onboard 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 onboard 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 onboard charging bus to individual battery subsystems shall be reverse current flow protected by a suitably rated diode;
- All onboard 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 are always launched with 100% peak charged batteries.

APPENDIX D. CATS SYSTEM

D1. 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 EuRoC-LV-RQT-0250, 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.

D2. 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.

D3. 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.

D4. CATS Transmitter Call-signs 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 EuRoC-LV-RQT-0430 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.

APPENDIX E. SRAD PRESSURE VESSELS

E1. 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.

E2. Burst Discs

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.

E2.1. 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 3.

Figure 3: 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 4 (the annealed aluminium material was coincidentally anodized blue on one side).

Figure 4: 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 5.

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 EuRoC-LV-RQT-0640. With proper attention to manufacturing quality of the orifice blank, a reproduceable ±3% burst pressure tolerance should be easily obtainable.

Figure 5: An early SRAD burst disc "set" based on COTS clamp ferrule parts. (Source: Copenhagen Suborbitals)

E2.2. 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.

E2.3. 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 6 and Figure 7. 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 6: A simple burst disc test rig and an example of a ruptured burst disc. (Source: Copenhagen Suborbitals)

Figure 7: Manual hydraulic tester for water. (Source: ahlsell)

While the test setup utilized during proof-of-concept validation illustrated in Figure 6 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 8. 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 6.

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

E2.4. 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.

E2.5. 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.

E2.6. 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 did not 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 9. 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 10. 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.

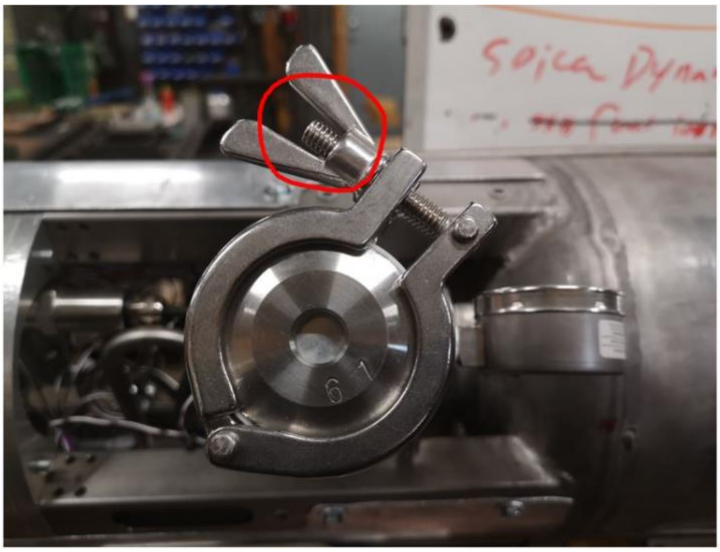


Figure 9: Nominal clamp position with one burst disc. (Source: Copenhagen Suborbitals)

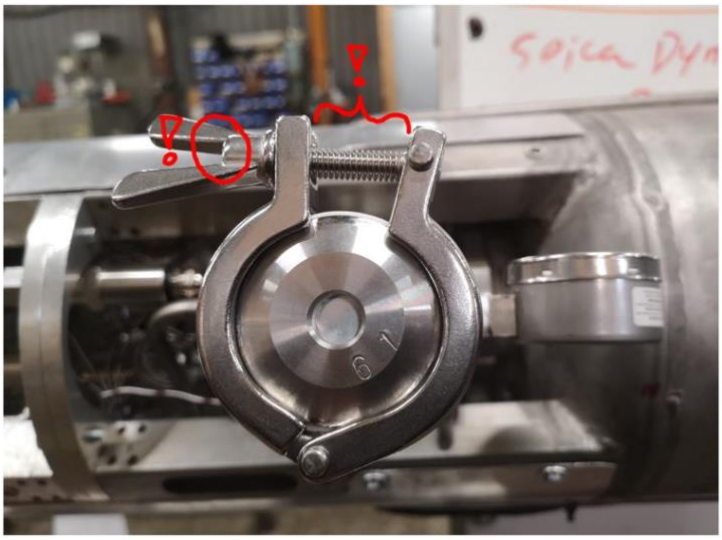


Figure 10: Fault indications facilitated by one additional 0,5 mm burst disc. (Source: Copenhagen Suborbitals)

E2.7. 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.

E2.8. Additional Integration and Testing Tips

A simple and practical AIT (Assembly, Integration and Test) burst disc "extender" is illustrated in Figure 11. 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 11: 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 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 12: "Maximator" testing a Dynamic Pressure Regulation system for a bi-liquid, checking for leaks. (Source: Copenhagen Suborbitals)

APPENDIX F. ACTIVE FLIGHT CONTROL SYSTEMS

F1. Boost Phase Dormancy for Longitudinal Roll Control

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. The boost phase dormancy altitude requirement is defined in EuRoC-LV-RQT-0680, nonetheless 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.

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.

F2. Recommended Flight Trajectory for Active Control Systems

The current 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.

APPENDIX G. PAYLOADS

G1. Payload Definition

A payload is defined as an independent component that is replaceable by a ballast of the same mass, with no change to the launch vehicle's functionality and trajectory in reaching the target apogee, or its' successful recovery.

Payloads can be of the following type:

- Non-functional (i.e., dummy mass) OR functional payload (i.e., a purposeful device, e.g., an experiment or technology demonstrator);
- Non-deployable OR deployable payload (e.g., deploying a CanSat to the ambient).

If a functional payload is chosen, it can either be:

- Passive (i.e., non-powered/non-energetic) OR active (i.e., powered/energetic).

This payload may be assumed present when calculating the launch vehicle's stability. As such, launch vehicles competing at EuRoC do not need to be stable without the required payload mass on board.

G2. Minimum Payload Examples

Some examples of payloads to fulfil the minimum mass requirements could be:

- A stack of three single CanSat-type payloads (115 mm height and 66 mm diameter each) with a mass between 300 g and 350 g each, amounting to a total mass of at least 1000 g;
- A 3-unit size CanSat-type payload (345 mm height x 66 mm diameter) with a mass of at least 1000 g;
- A CubeSat-type payload with a minimum form factor of 1U with a mass of at least 1000 g, but not exceeding 1330 g;
- A 4U CubeSat-type payload with a mass of 4000-5320 g;
- A 5-unit size PocketSat payload (250 mm x 50 mm x 50 mm) with a mass of at least 1000 g;
- A stack of five single PocketSat-type payloads (50 mm x 50 mm x 50 mm each) with a mass between 200 g and 250 g each, amounting to a total mass of at least 1000 g.

APPENDIX H. FIRE CONTROL SYSTEM DESIGN

H1. 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.

H2. 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 13). 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.

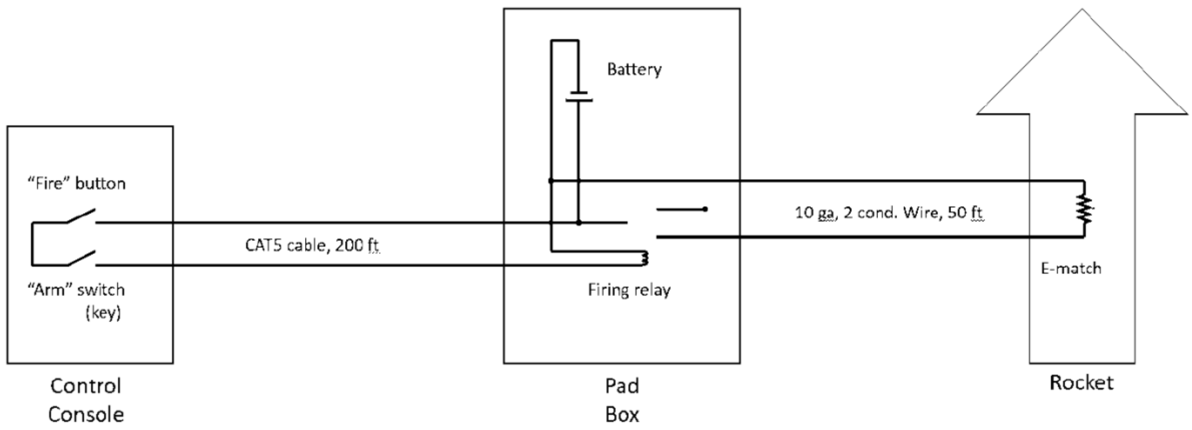


Figure 13: A simple high current fire control system.

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 14). 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).

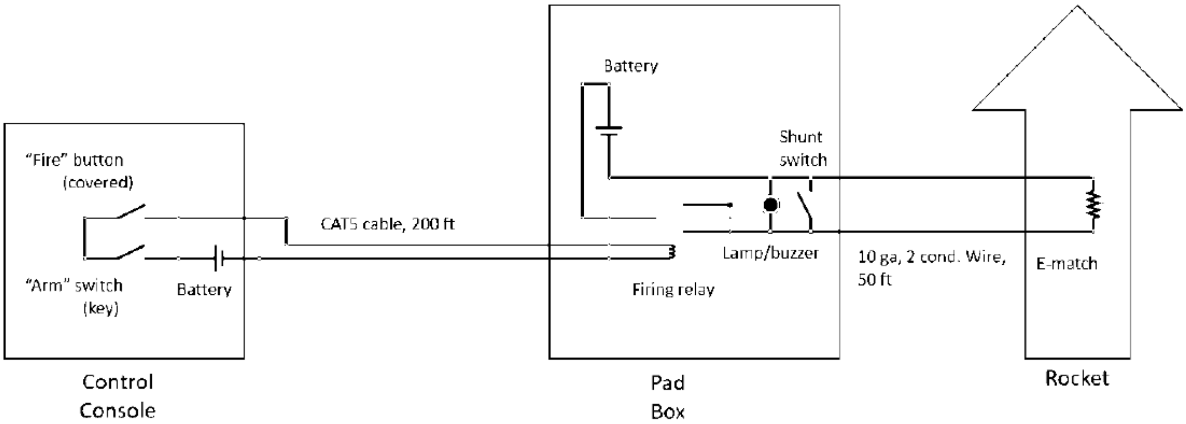


Figure 14: An improved high current fire control system.

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 I. EUROC LAUNCH RAILS

On the EuRoC launch rails the vehicle is guided by a 50 mm x 50 mm cross-section aluminium rail by Kanya (see Figure 15 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 EuRoC-LV-RQT-0760 and EuRoC-LV-RQT-0770.

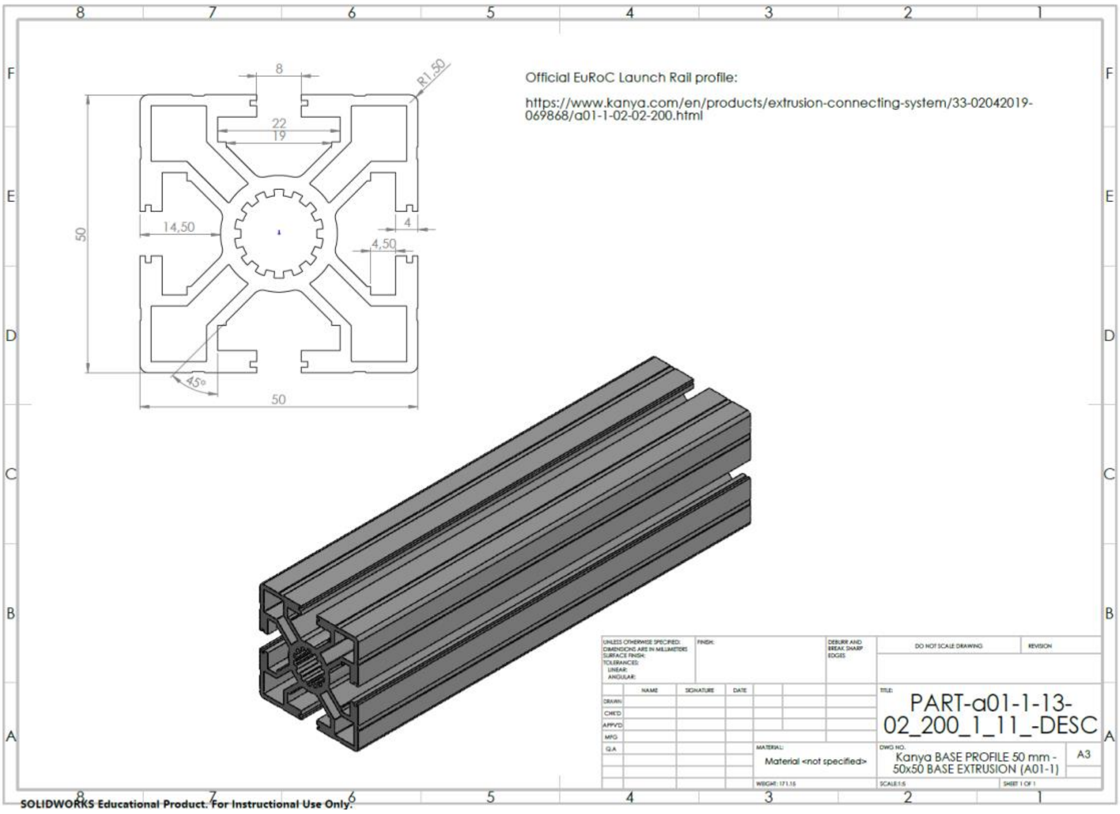


Figure 15: EuRoC launch rail profile.

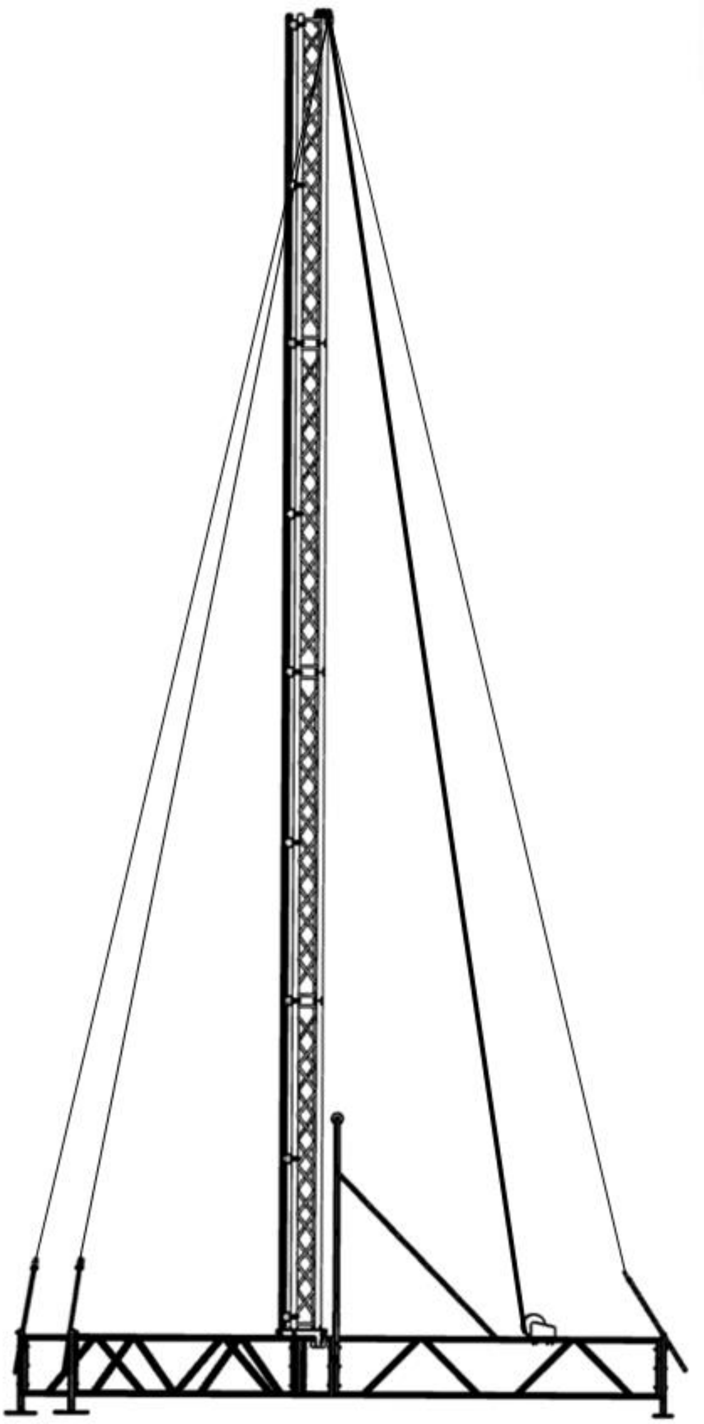


Figure 16: EuRoC launch rail fully assembled.

Please note that EuRoC launch rails might suffer small adjustments/modifications, as necessary.