# United Kingdom Rocketry Association

## Team Project Support v3.2

## *Additional Technical Guidance*

Produced by UKRA Safety & Technical.

# Contents

# 1 Introduction

This document has been compiled to provide some guidance for all those participating in the UKRA Team Project Support scheme (hereafter TPS). TPS was conceived to enable team projects to fly, once scrutinized by UKRA, to ensure they were as safe as possible. Compliance with this guideline is the first step. Larger more complex projects will, by their very nature, require more scrutiny.

For the construction and launch of medium to high power sounding rocket vehicles, a very wide subject matter must be covered. This document contains technical guidance and suggestions recommended for a safe flight, together with concise explanations of the reasons behind them. To encourage innovation, it is our intention that this document serves as a guideline for safe design and flight rather than an exhaustive and ridged protocol to be followed to the letter. Where departure from this guideline is felt to be required, the TPS process may allow this, following a favourable review of the overall safety of the project.

The UKRA TPS launches must be held at a launch site approved by the United Kingdom Rocketry Association (UKRA). As a result, much of the guidance and suggestions in this document are based on the UKRA safety code, with a few additional requirements that will assist with the safe construction of a TPS rocket vehicle.

UKRA is an organization run by members of the British rocketry community. It is the recognized body for safe high-power rocket flying, and gives access to insurance, and safe codes of practice. Team members may wish to join UKRA and pursue the UKRA Certification scheme, so that they can take up high power rocketry as a hobby.

If a team requires further clarification and explanation of any of the information set out in this document, they should contact the UKRA Safety and Technical committee

# 2 Launcher issues

## 2.1 Fin alignment

It is recommended that rockets be built with fins fixed parallel to their longitudinal axis and typically mounted perpendicular to the surface of the fuselage, however other designs may be considered.

Canting of the fins by a few degrees to create spin-stabilization may be allowed.

## 2.2 Specification of Launch Angle

Teams must specify an optimal launch angle for their flight between 70° and 90° to the horizontal.

As this has a profound effect on the flight profile, the range safety officer (RSO) may alter this angle within these boundaries depending on the prevailing weather conditions.

Teams should ensure that their rocket can be fixed to a suitable launch structure, such as a rail. This means of securing the launch vehicle must be sufficient to hold the fully fuelled weight of the vehicle.

## 2.3 Vehicle Mass Limits

Rocket vehicles must have a minimum take-off thrust-to-weight ratio of greater than three. This is a minimum and a thrust to weigh ratio of five times would be better.

## 2.4 Detachment of Umbilicals

Any umbilical cord used to power and communicate with the rocket when it is on the launch rail must be capable of being detached mechanically during lift-off through the movement of the rocket vehicle along the launcher. This must be demonstrated for a range of angles from 5° to 45° to the rocket body (see figure 2.3)

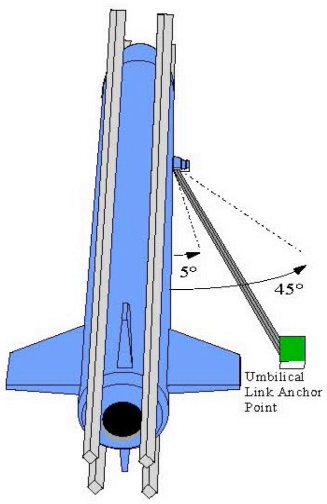


Figure 2.3

The force required to move the umbilical link must be significantly less than the net take-off thrust: (engine thrust minus rocket weight.) On launch it must cause no damage to the separating components.

# 3 Interface of the rocket engine

## 3.1 Rocket motor types and usage.

Please refer to the UKRA safety code section 2.2 Motors

## 3.2 Mounting of the engine in rocket

The teams must provide a means of securely mounting the engine with the rocket vehicle. This mount must transmit the thrust loads from the engine to the structure of the rocket vehicle, provide axial alignment of the engine within the rocket vehicle, and prevent it slipping out during handling and all flight phases.

An example engine mount arrangement is shown in figure 3.2:

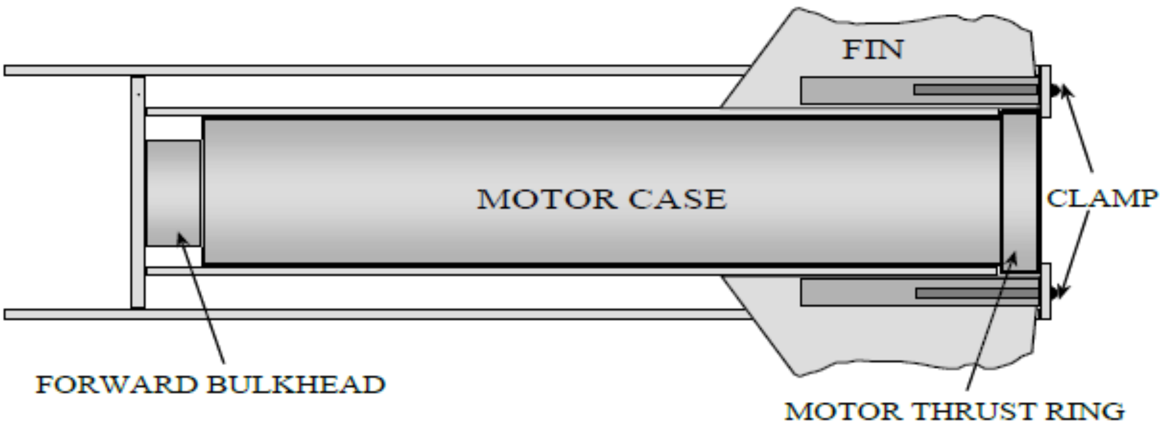


Figure 3.2

As suggested in the figure, the engine can be clamped at the engine thrust ring to the base of the rocket. Please remember this configuration is just an example and will not work for everyone's purposes.

## 3.3 Engine Mount Strength Requirements

The engine mount must be designed to take all the thrust loads, both axial and lateral via the engine thrust ring (referred to in figure 3.2). It must be designed to withstand and transmit into the body tube a force equivalent to twice the maximum engine thrust without permanent deformation of the tube.

The mount must also withstand a lateral force in any direction equal to a thrust misalignment of 5° at the maximum thrust value, cantilevered about the rocket vehicle's centre of gravity position upon ignition.

Documentation outlining these calculations and tests must be shown and included in the rocket vehicle report

# 4 Performance Margins

All rocket vehicles launched under UKRA must comply with certain stability criteria. These concern aerodynamic stability, and their verification will be performed using Barrowman's slender body theory. If these basic criteria cannot be met according to these rules, comprehensive documentation must be presented to the RSO to demonstrate that the rocket is both statically and dynamically stable.

For slender body theory to apply, the following three constraints are set on the vehicle:

1. Rockets must have a length to diameter ratio (L/D) which is greater than 5.0
2. The vehicle is flying at subsonic speeds. Although the theory strictly only applies at low subsonic speeds, a lightweight vehicle might exceed Mach 1. Stable flight at supersonic speeds can be achieved by increasing the stability margin required for low speed. (standard HPR practice)
3. The vehicle is axi-symmetrical about its long axis.
4. The fins are of thin cross-section.

## 4.1 Static Stability Margin

The static stability margin (distance between the centre of mass and the centre of pressure) must be between 1.0 and 2.0 calibres stable during all phases of flight before recovery (see figure 4.1). The vehicle's calibre is the diameter of the thickest part of the fuselage. (Aerospace students will know the 'centre of pressure' as the Neutral point: the combined centre of pressure of the nosecone, fins, and boat-tail if included.)

For lightweight vehicles that exceed 0.8 Mach during ascent, 0.5 calibers must be added to the lower limit, which then will equal 1.5 (this is to ensure stability in the transonic region).

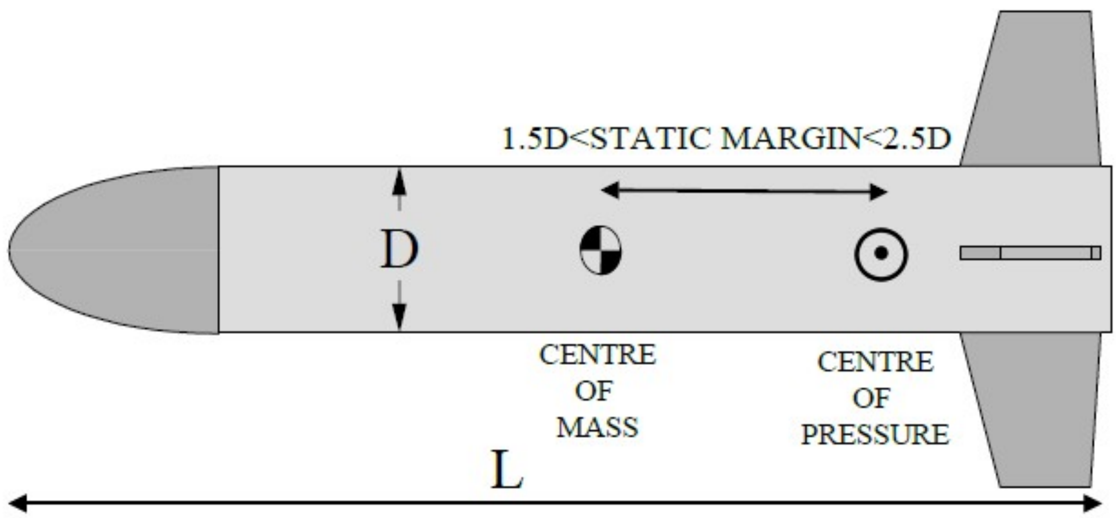


Figure 4.1

# 5 Structural Requirements

For a rocket to be deemed safe to fly and have the best chance of an optimal flight, there are several structural requirements we recommend your vehicle meets.

If a team's vehicle does not meet these requirements, a reasonable justification should be provided within the pre-flight documentation.

## 5.1 Fin Alignment

The alignment of the fins is critical for stable flight. The geometric alignment of each fin should be within 2° of the projected longitudinal axis of symmetry of the rocket. For spin-fins all fins must be within 2 degrees of each other.

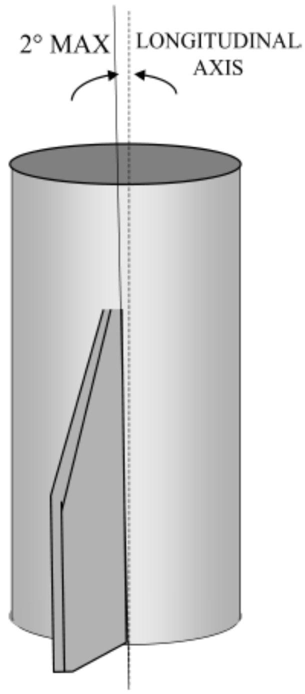


Figure 5.1

## 5.2 Fin Longitudinal Loading

Each fin must be able to support a suspended load from its tip equal to twice the fin mass times the rocket's maximum axial acceleration occurring during any flight phase (fig 5.2)

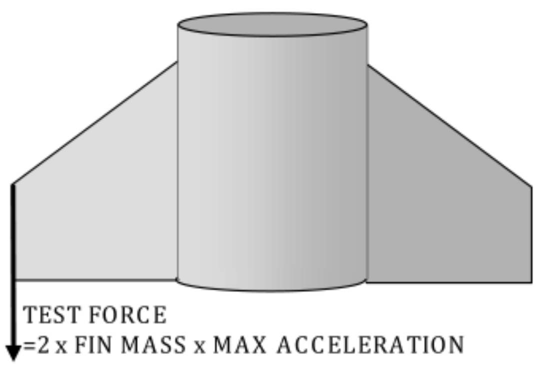


Figure 5.2

## 5.3 Fin Lateral Loading

Each fin must withstand a transverse load equal to the rocket vehicle's launch mass when suspended from the fin tip. When subjected to this load, the maximum lateral deflection measured at the tip should be less than 10° in either direction: an overly flexible fin is susceptible to flutter which can destroy the fin.

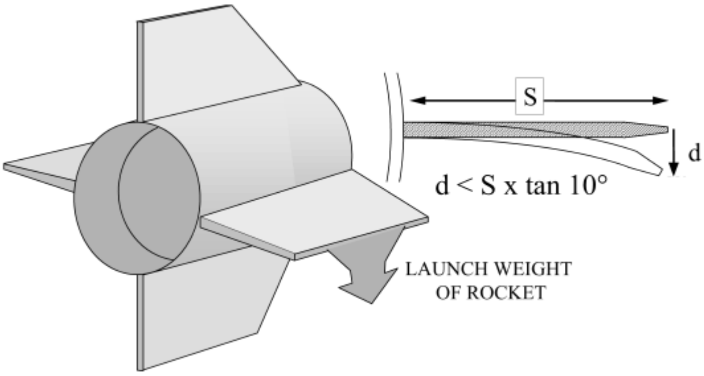


Figure 5.3

## 5.4 Fuselage Stiffness

When a fully assembled and loaded rocket vehicle is suspended from its centre of mass it must produce a lateral deflection in any direction of less than 0.01 radian = 10 millimetres deflection per metre length.

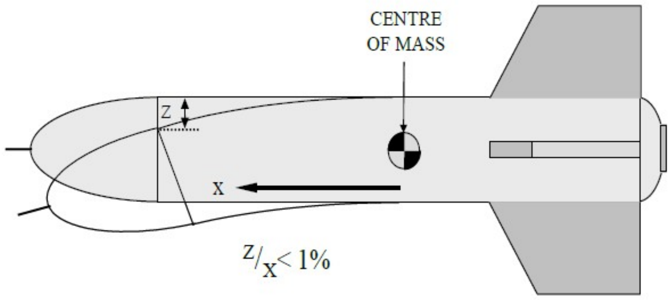


Figure 5.4

Fuselage stiffness is a basic guide to fuselage strength. Fuselage stiffness also ensures that the nosecone and fins fly at the same angle of attack when hit by a side gust of wind, which reduces fuselage loadings.

When a rocket is coupled together from several tubes, the method of joining the tubes is left to the application and discretion of the designer.

However, it is recommended that the mating length between the coupler and each tube should be a minimum of 1 diameter when using plastics or composites and a minimum of 1/2 a diameter when using metals (see figure 5.5). This is advised to maintain satisfactory levels of stiffness along the length of the rocket.

For sliding connections, the minimum mating length between coupler and tube should always be 1 diameter. Additionally, the fit between parts must prevent any noticeable lateral rotation at the joint

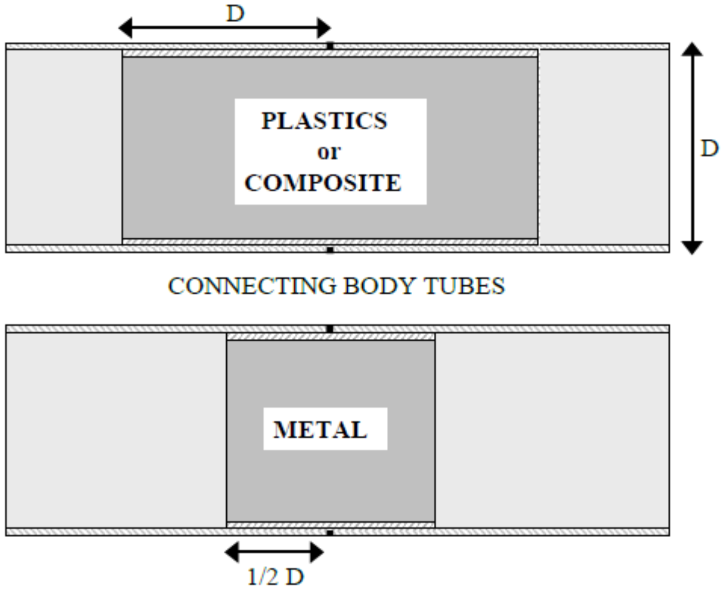


Figure 5.5

## 5.5 Static Strength Requirements

All structural calculations in the project report should show that all structural parts can withstand twice the inertial and aerodynamic loads on them during all phases of flight without failure.

Teams wanting to perform a detailed fuselage structural analysis are free to contact UKRA S&T for advice.

All rocket vehicle design and produced, should be capable of being launched more than once. With this re-use of vehicles in mind, all parts must withstand 1.5 times applied loads without permanent deformation (yield).

# 6 Electrical System Layout

There are likely to be several electrical subsystems onboard a rocket vehicle, such as payloads, a telemetry system, and a flight sequencer to control the recovery system.

## 6.1 Earthing Practices

All interconnected electrical sub-systems must share a common ground or earthing point to prevent stray potentials.

Multiple earth points should be hardwired together - it is inadvisable to rely on the conduction between metallic parts of the rocket vehicle to provide an earth path.

## 6.2 Internal Power Supply

The rocket vehicle must be capable of being switched on and left to run autonomously using its internal power source for up to 15 minutes at the launchpad for the usual launchpad and range safety preparations. This time should be budgeted for in addition to the energy used during the predicted total flight time.

## 6.3 Electrical design considerations

It is strongly recommended that single strand wire not be used as electrical cable for primary systems since it is considered too fragile. Multi-strand wire is considered tougher and more reliable under handling and flight conditions.

During assembly, testing and flight, electronic circuits and wiring are subjected to a high level of abuse. This requires that construction should be rugged, tidy, and of as high a standard of workmanship as possible.

Care should be taken when using electromechanical components (such as relays, switches and connectors) to ensure that they are capable of withstanding high acceleration and vibration loads, whilst maintaining continuity.

# 7 Telemetry

Competitors may wish to transmit their experimental data to ground during flight

## 7.1 Electromagnetic Compatibility (EMC)

The team should ensure that the RF output from the transmitter does not adversely affect any other systems in the rocket vehicle.

## 7.2 Licensing of Telemetry System

Teams are required by law to obtain a licence from the Radio Communications Agency for their telemetry system. Transmission licenses must be arranged by the team for use at the launch event. UKRA will not allow any system to be used unless the correct documentation is presented to the RSO to confirm the legality of the system.

# 8 Recovery Requirements

## 8.1 Use of Recovery System

All rocket vehicles must have a system to recover them in a safe and controlled manner. This can be single or dual stage depending on predicted altitude and launch site dimensions.

One method of recovery is to deploy a small (drogue) parachute which is activated when the rocket vehicle reaches apogee, and a second landing ‘chute which opens later at a lower altitude. However, this is only one example and there are many other recovery techniques.

It is advisable to make the recovery device highly visible to assist visual tracking and post-landing recovery.

## 8.2 Landing Speeds

The recovery system must reduce the rocket's vertical landing speed to between 5 and 8 metres per second. A higher descent speed is unsafe for persons/property on the ground whereas a lower descent speed could cause the rocket vehicle/parachute system to drift too far downrange on the wind.

## 8.3 Transmission of Recovery Shock Loads

The main recovery shock loads must not be transmitted in shear through screw threads into the rocket vehicle body as this would be an inherent weakness.

It is recommended that these loads be transmitted though links, carabiners and hook-eye anchor points. The load is then typically distributed into the vehicle fuselage via a substantial bulkhead bonded/fixed to the fuselage.

## 8.4 Engine Ejection Charge

Certain engines have an adjustable ejection charge which can be used to trigger the recovery system. This is a relatively passive approach, as the recovery system will deploy at a fixed time after burnout no matter what stage of flight the rocket is in.

Some delays are only adjustable to certain time intervals from a maximum meaning you have a limited amount of options for delay times.

## 8.5 Flight Sequencer

The purpose of the flight sequencer is to activate the 1$^{st}$ stage of the recovery system when the rocket reaches apogee.

A simple way of achieving this is to use an electronic timer. This timer is activated on launch and is pre-programmed then to wait for a set time interval before firing the recovery system actuators. Many commercial rocketry flight computers are also available and are reliable. These use barometric and or accelerometer data to detect apogee.

## 8.6 Isolation of Recovery Circuit

All the recovery sequencing circuit must be electrically isolated (including battery) from any other electrical circuit used in the rocket vehicle.

The only exception allowed is if the sequencer is to signal the telemetry system its status and the firing of the recovery timer. In this case the sequencer signal lines must be opto-isolated from the telemetry circuits.

It is important that special attention is paid to the design of the recovery system sequencing circuit. This is one of the most safety critical components. Good design will produce a safe and reliable system.

The sequencing circuit consists of three main parts: the launch detector, the timer/apogee detection and the actuator. Whilst there are many commercially available flight timers / computers available, teams are also at liberty to develop their own systems.

The Launch Detector

Detection of the actual launch can be done in a variety of ways: pulling out of a connector fixed to the launchpad (recommended), use of an optical sensor, use of a threshold accelerometer to initiate the time, or any other system a team wishes to develop.

The Timer/Apogee Detection

The best point to open the recovery device is at the instant the rocket vehicle reaches apogee. This is when the airspeed of the rocket is at its lowest and the parachute opening shock loads on the rocket vehicle are the smallest. Normally, calculations are made using computer simulations to find the time from lift-off to apogee. This is set into a timer which activates the recovery system. Alternatively, accelerometer or barometric data can be used to detect apogee. In this case it is still useful to simulate the flight profile to predict the time to apogee and any period of transonic velocity. Special consideration needs to be given when using flight computers in transonic flights as pressure changes in this region of the flight can lead to premature detection of flight events.

However, if a team wants to employ other non-commercial techniques for directly sensing apogee, the use of a commercial system they are familiar with, as a back-up timer/flight computer is strongly recommended.

## 8.7 Detection of Apogee

Simple detectors relying on the physical orientation of the rocket relative to the gravity vector to detect apogee (e.g. tilt switches) are inaccurate and should not be used. Gyro-based systems are acceptable.

## 8.8 Flight Sequencer Disarming Mechanism

The flight sequencer must have a safe and secure disarming mechanism which prevents inadvertent activation of the recovery system during handling and loading (this is especially important where pyrotechnic actuators are used).

The safety disarm mechanism must disconnect the actuator/s from the flight sequencer and should be separate from the flight sequencer power switch.

The system must be kept in the disarmed (safe) condition until the rocket is safely loaded onto the launch rail. At the designated point during countdown the rocket can then be armed.

Some of the recommendations outlined above are illustrated in an example electrical diagram (see figure 8.1).

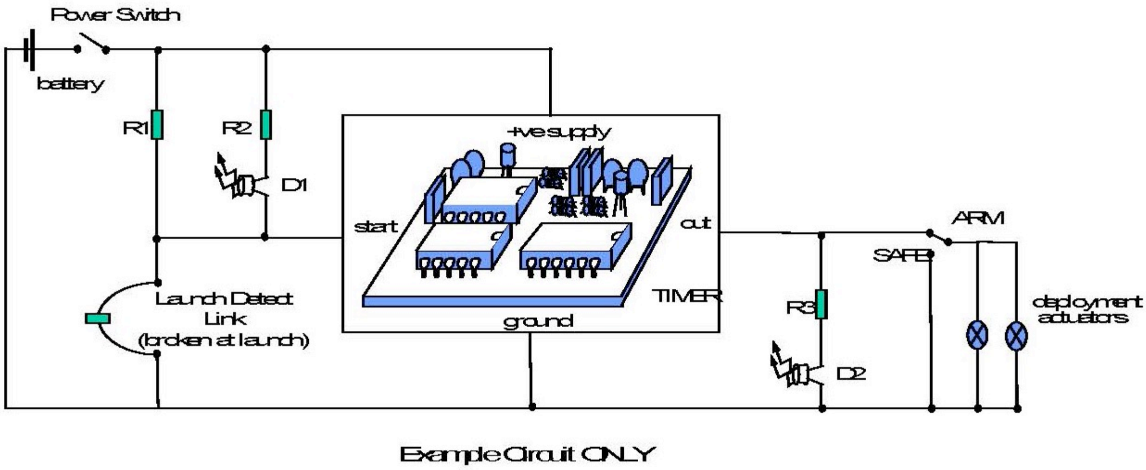


Figure 8.1

## 8.9 Use of Inert Compressed Gases

If teams use a pneumatic actuator, the compressed gas employed must not be flammable.

The pressure cylinders used must withstand twice the operating pressure without yielding. This must be supported by manufacturer's documentation and/or documented proof tests performed by the team.

## 8.10 Validation of Flight Sequencer

Teams must demonstrate the reliability and reproducibility of their flight sequencer and recovery system prior to launch. If the system contains any expendable components (such as pyrotechnics), a sufficient quantity must be bought to demonstrate the proper functioning of the system prior to launch. Any failure at this point will necessitate a considerably greater number of tests.

## 8.11 Integrity of Circuit under Force

The circuit must be structurally and electrically robust so that no parts of the circuit can change state or function due to any mechanical loads from transportation, manipulation on the launch rail, or in flight.

Recovery system deployment shock loads are a very important design case and can exceed the thrust loads. The recovery system design must be well researched and documented in the project report.

# 9 Safety Requirements when Arming the Rocket for Launch

## 9.1 Position of electrical components

For safety, when the ignitor is connected to the firing circuit during the final phases of the countdown there must be no electrical circuits or wires located near the nozzle end of the rocket engine.

## 9.2 Inclusion of Mechanical Safety Device

Any side-ejection pyrotechnic or spring system must have a mechanical safety device. This must prevent the ejection of any projectiles in the event of a misfire.

All recovery devices must be 'safed' to prevent potential injury to the launch crew due to a misfire during handling, transportation, or arming on the launchpad.

Pyrotechnics must be completely isolated from any power-source by arming switches, and mechanical systems must incorporate safety-devices such as locks.

The safety device will be removed once arming is complete and system stability is confirmed. The arming and activation switches should be positioned well away (preferably on opposite side) from the actuator door.

It is recommended that danger areas are clearly marked on the body, using either highly visible colours or appropriate labelling.

## 9.3 The Timer

The sequence circuit must be designed in such a way that its state of activity and arming can be determined at any time by mechanical (sound) or optical (lamps) or electronic (connected to a ground computer) indicators.

For example, a series of LED's can be included to indicate that (1) the power is on, (2) the system is armed, (3) the timer(s) is running, (4) the firing circuit has activated.

# 10 Safety Considerations

Teams will be expected to have read and understand all the safety aspects of rocket flying as described in the UKRA safety code.

Additionally, team will be expected to provide a risk assessment detailing all parts of their team's activities. Some extra points for consideration are included below.

## 10.1 - Rocket engine propellant safety

Rocket propellant - whatever its type - is a system comprising a large store of chemical energy, and needs handling with respect.

If you use commercial rocket engines, follow the manufacturer's safety documentation explicitly. Failure to do so not only places you and others at risk, but would cause the RSO to scrub your flight.

Solid propellant can crack under a shock loading, so take care not to drop the propellant. A cracked solid fuel grain will explode when launched.

If you use pressurised propellants, be sure that your pressure vessels can withstand at least twice worst-case expected pressure.

Do not insert/arm the engine ignition system until allowed to do so by the RSO.

## 10.2 - Expulsion charge powder safety

Take due care when handling expulsion charge powder.

The powder should be stored in a non-metallic container with a lid that will pop-off if the powder catches fire and pressure builds up.

Powder in tight containment can generate extreme pressures and can detonate. Keep the powder dry and uncontaminated.

# 11 Countdown Checklist and Procedure

A countdown checklist is a document written by the team describing all the procedures needed to prepare the rocket vehicle for launch, and their sequence. A checklist is strongly advised to save time/delays whilst the rocket vehicle is sitting on the launch rail. Other UKRA members/flyers may well want to use the rail.

Before arriving at the launch site, you must perform a mock countdown (sans engine) to ensure your rocket vehicle and its systems will perform when you arrive at the launch site.

## 11.1 Countdown Checklist

A countdown checklist should be designed so that the minimum number of people are required to complete the final actions once the engine has been armed (ignitor connected to the firing circuit). It must specify the exact procedural order for arming the rocket vehicle for launch.

The countdown checklist must also have a section to disarm the engine in the event of a scrubbed launch or misfire.

The following must be checked before arriving at the launchpad and initiating countdown.

1 Rocket vehicle is complete with the recovery system fully assembled and switched off.

2 The fully prepared rocket engine is loaded into the rocket vehicle.

3 Recovery system anti-deployment safeties are in position.

4 Weather margins and range conditions are considered acceptable by the RSO to begin countdown.

5 The RSO gives permission for launch.

An example of a typical countdown procedure is:

- Telemetry test with the rocket vehicle outside the launchpad.
- Arrival at the launchpad: mating of rocket vehicle to the launch rail.
- Elevation of the launch rail to the correct altitude and azimuth.
- Evacuation of non-essential personnel from the launch pad.
- Ignitor is inserted into engine and leads anchored to the launch pad.

Arming of the Rocket Systems:

a) Turn on system bus power.

b) Turn on Control Computer.

c) Turn on Payloads.

d) Turn on Telemetry (verify transmitted signal).

Arming of the Recovery Sequencer:

a) Confirm actuators disarmed.

b) Arm launch detector.

c) Turn on Sequencer power.

d) Activate Actuator Circuit.

- Evacuation of the team from the launchpad.
- Connect ignitor to firing circuit.
- Confirmation from RSO of a 'Go for launch'.
- Audible countdown of at least 5 seconds in 1 second intervals.

Ignition. Team members should note that the Arming portion of the Countdown Procedure will be specific to the requirements of each rocket vehicle. However, other parts of the list represent what is considered standard for launching vehicles of this type.

# 12 Research

A great deal of material on rocket vehicle design and construction can be found on the internet, and you are encouraged to read this.

A suggested reading list could begin with: -

- Stine G.H. 2004 (7th Ed). *Handbook of Model Rocketry.* Jossey Bass
- Canepa M. 2005. *Modern Hi-Power Rocketry 2.* Trafford Publishing
- Lodge S. 2004. *The Model Rocketry Handbook: 21st Century Edition*. Special Interest Model Books
- Newlands R. 2013 (2nd Ed). *Rocket Science and Spaceflight for young Rocketeers*. Lulu.com

Further general and topical background reading: -

- Sellars J.J. 2007 (3rd Ed). *Understanding Space: An Introduction to Astronautics*. McGraw-Hill
- Rogers L. 2008. *It's Only Rocket Science: An Introduction in Plain English*. Springer.
- Taylor T.S. 2009. *Introduction to Rocket Science and Engineering*. CRC Press
- Thompson W.T. *Introduction to Space Dynamics*. Dover Publications Inc.

This list is not exhaustive and there are many other good sources of information accessible. Teams are free to contact UKRA S&T to validate any source or uncertain origin.

It is in your team's interest to attend a UKRA rocket flying event prior to designing your rocket vehicle to learn about rocketry by example, and observe the UKRA launch procedures and etiquette.