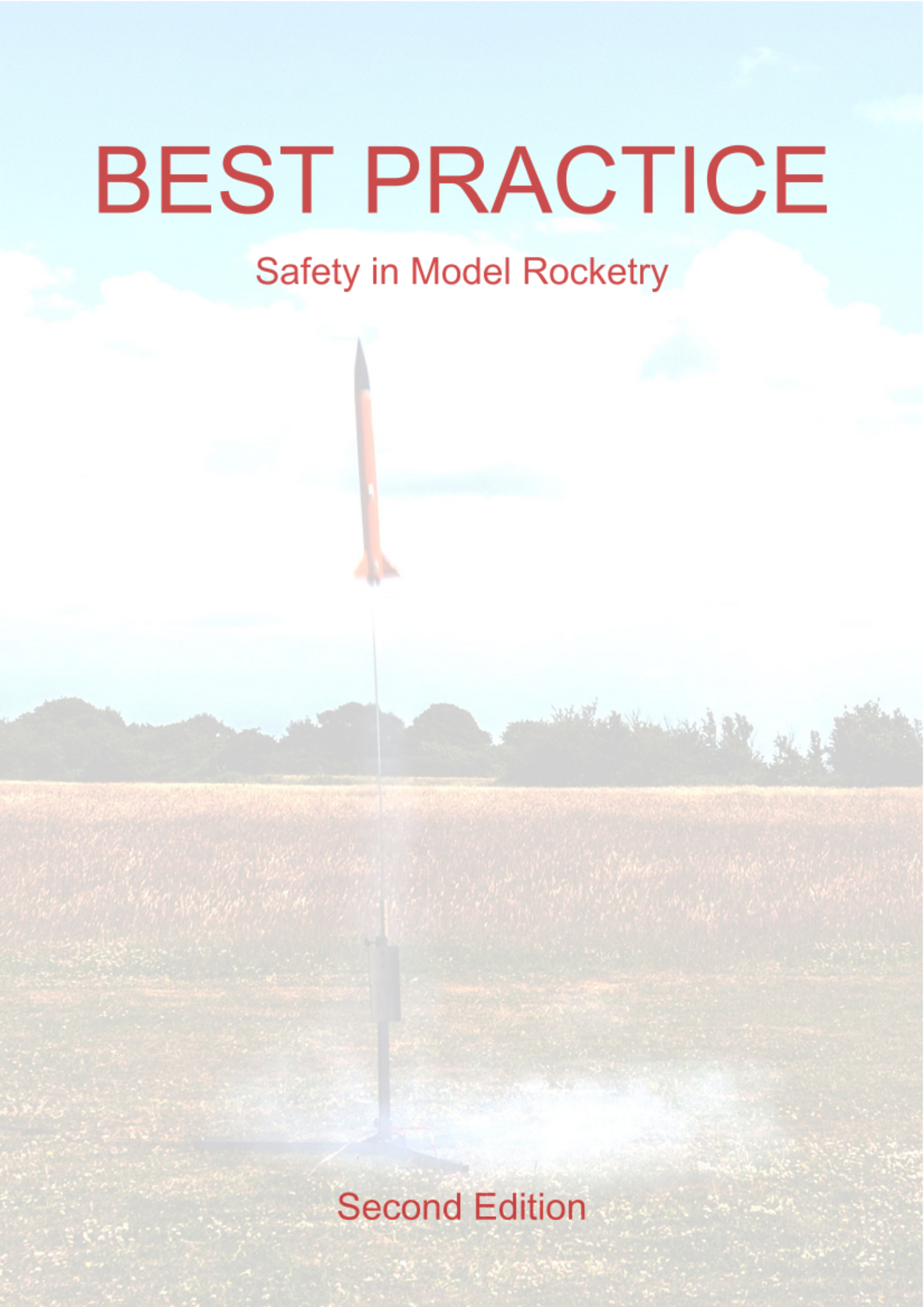
BEST PRACTICE

Safety in Model Rocketry



Second Edition

Second Edition

I shot ~~an arrow~~ a rocket into the air
It fell to earth, I know not where
For, so swiftly it flew, the sight
Could not follow it in its flight.
Longfellow

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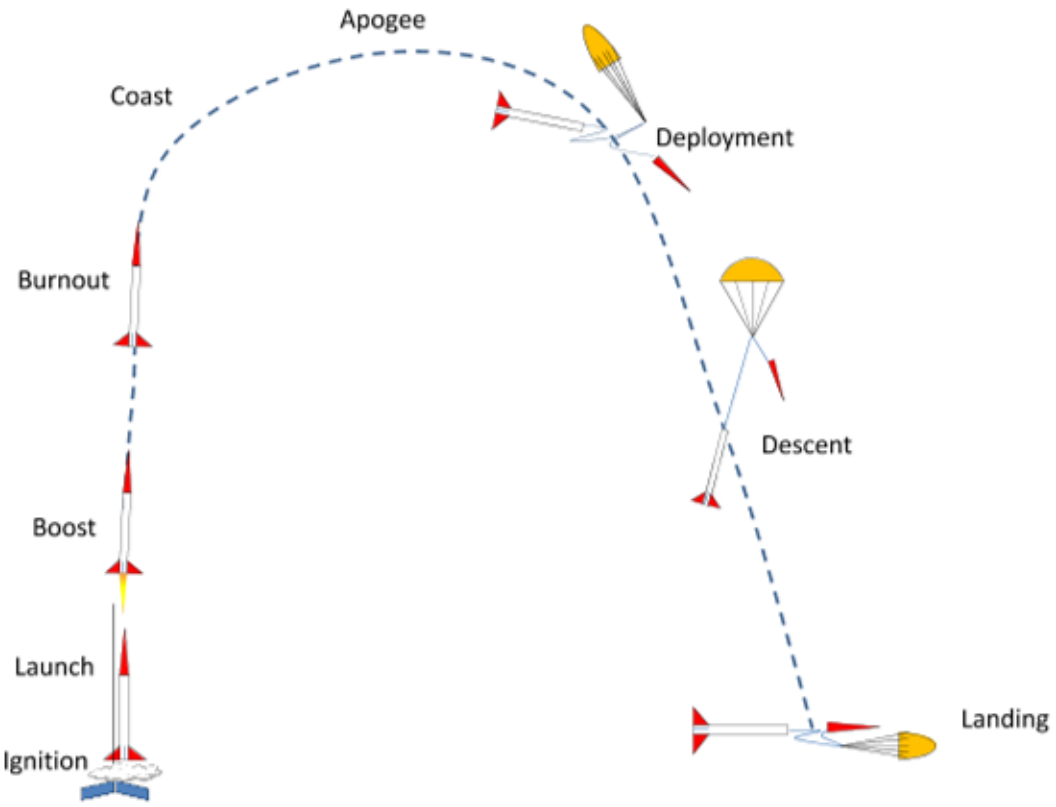
1. Introduction

Model rocketry is exciting. There are very few activities is which its possible for a hobbyist, on a small budget, to build a very fast and high performance flying object.
Rocketry is not without its risks. Fast moving objects with sharp points can cause serious injury. Parachutes, intended to slow a rockets descent, might fail to deploy with the consequence of a rocket descending uncontrolled at several hundred miles per hour. There are many ways in which launches might go wrong.
This booklet has been produced to offer safety guidance to people starting out in this fascinating activity. It is not intended to replace experience, but aims to introduce new rocketeers to good practice. Follow this and your early experiences of rocketry will be much safer.
Chapter 2 is a brief introduction to how model rockets work, introducing some basic terminology and concepts. Chapter 3 introduces the ground equipment that is required for launching. Chapter 4 explains how weather can affect the flight of rockets, while chapter 5 builds on this to explain how to lay out a rocket range. Chapter 6 explains how to run a safe rocket range. Chapter 7 covers some basic aspects of motor safety and describes how to launch rockets that use clusters of two or more motors.
Chapter 8 is a reprint of the Rocketry Safety Code by the British Model Flying Association (BMFA). This safety code, and the author's 16 years experience running rocket ranges, underpins the advice in this booklet.

2. Model Rocket Basics

How Model Rockets Work

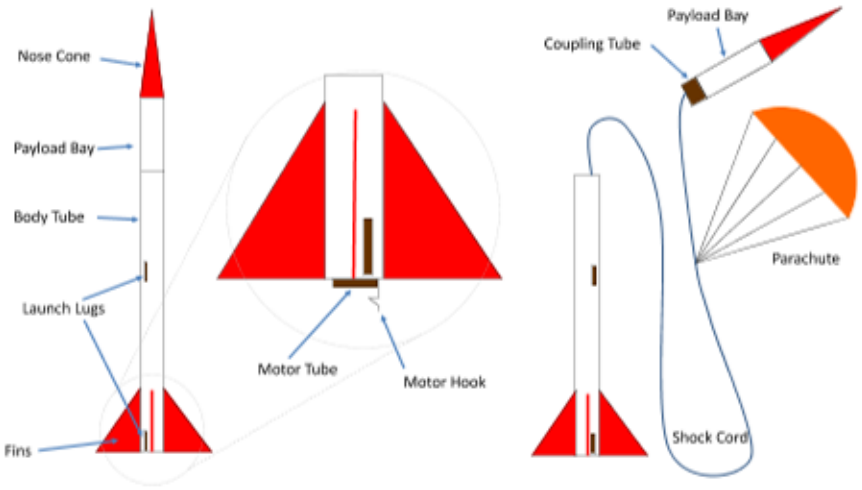


Flight Profile

The picture above explains some common rocketry terms for the phases of an ideal flight.
At the start of a flight the rocket is mounted on a launch pad. The flight starts with IGNITION, in which the motor is electrically ignited. The rocket accelerates up the

launch rod, gaining speed until it leaves the end of the rod. The motor continues to burn throughout the BOOST phase until all the propellant has been consumed (BURNOUT). The rocket then COASTS until wind resistance and gravity slow it to a halt at the highest point of its flight (APOGEE).
At apogee a small charge inside the motor deploys a parachute (DEPLOYMENT). All the parts of the rocket are held together by a shock cord so the parachute can slow the DESCENT of the whole rocket. The rocket will drift to earth attached to the parachute until LANDING.
After landing, the rocket can be prepared again for another flight.

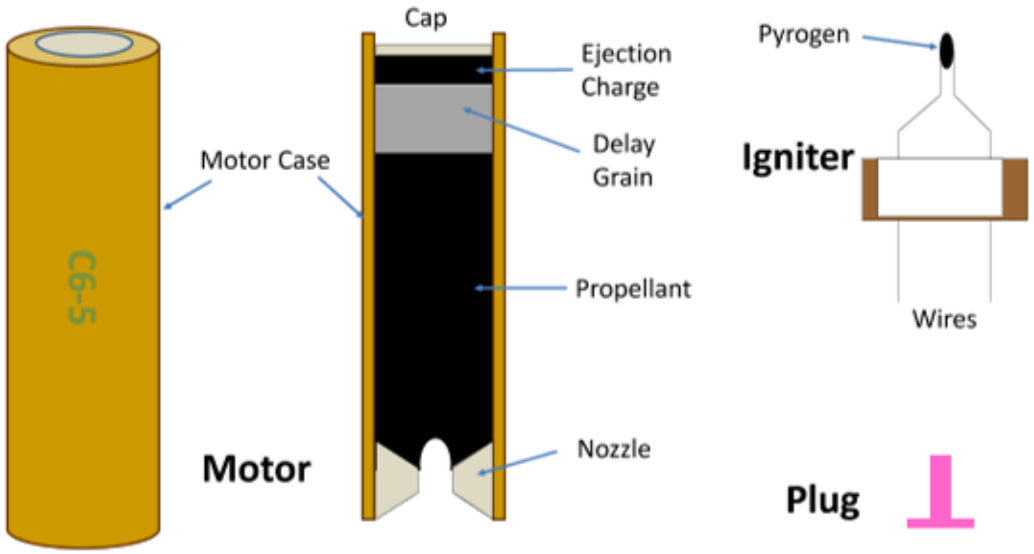
Parts of a Rocket



Parts of a Model Rocket

The main parts of a rocket are shown above.
The nosecone is aerodynamically shaped to minimise drag. It is fitted to the body tube and attached to the rocket body by the shock cord. Sometimes the nosecone and shock cord are attached to a short section of body tube that is designed to carry a payload.
The main section of the rocket is the body tube. The fins and launch lugs are attached to the body tube. Fins ensure that the rocket's flight is stable. The launch lug attaches the rocket to the launch rod while it accelerates to aerodynamic flight.
Inside the body tube is an assembly for mounting the motor. This comprises one of more tubes to hold the motors aligned. The motor is inserted into the motor tube where it is held in place by the motor hook.
A parachute is also attached to the shock cord. This allows all the parts of the rocket to descend slowly and safely together.

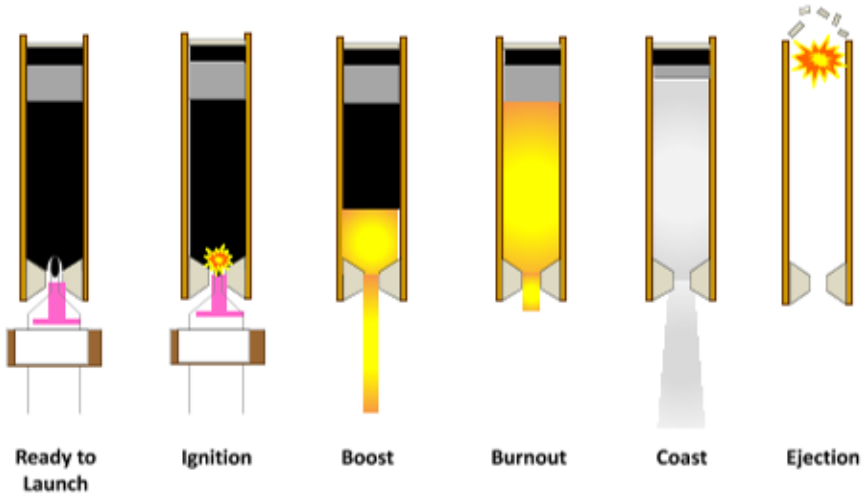
Rocket Motors



Rocket Motors

There are many types of model rocket motor. Understanding how motors work, and how to select the right motor, is very important. Using the right motor will reduce the number of crashes you have, and the number of rockets you lose.
The picture shows a section through a typical motor. The motor case is made of a thick and dense cardboard as it has to contain the pressure of combustion. The ceramic nozzle is moulded into the motor.
The propellant is black powder, sometimes called BP. The hot gas from the burning propellant is accelerated through the nozzle producing the motor's thrust. When the propellant is all consumed it ignites the delay grain. This is a sulphur rich powder which burns slowly, releasing smoke so that the rocket can be tracked while it coasts. When all the delay grain has been consumed it ignites the ejection charge. This small charge shatters the ceramic cap and pressurises the rocket, forcing off the nosecone and deploying the parachute.

Phases of Flight

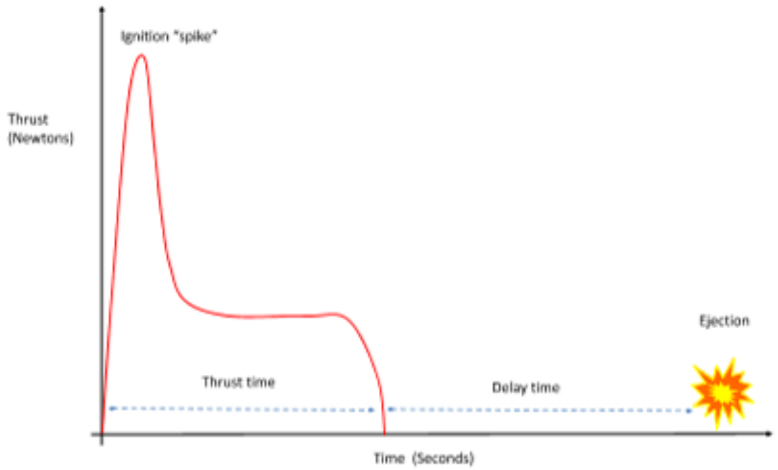


Motor Profile

The motor burns in four stages:

1. Ignition a current through the igniter sets off the pyrogen and ignites the propellant.
2. Thrust phase the propellant burns, accelerating the rocket to its maximum velocity.
3. Coasting phase the motor burns a smoke-emitting delay charge as it coasts to apogee.
4. Ejection phase a small charge blows the nose cone off the rocket and deploys the parachute.

Thrust Curve



Thrust Curve for a Model Rocket Motor

The thrust time curve shows the amount of thrust a motor gives as the propellant burns.
When the motor ignites it gives a short spike of thrust. This helps to get the rocket started up the launch rod. The motor then burns its propellant until all the propellant is consumed. The rocket then coasts while the delay grain burns and emits tracking smoke. The ejection charge is fired when all the delay grain has been consumed.

Rocket Motors

There are many different motors available for model rockets with codes like A8-3, C6-7 and A-3T. Choosing a motor with the right code will make the difference between a good flight, a crash, or a lost rocket. This section explains motor codes so you know which motor to select.
Using all this information, we can now start to understand the motor code. The first letter (A, B, C etc) tells us the impulse of the motor, the first number tells us the average thrust, and the second number tells us the delay before the ejection charge is fired.
Motors are specified by three factors:

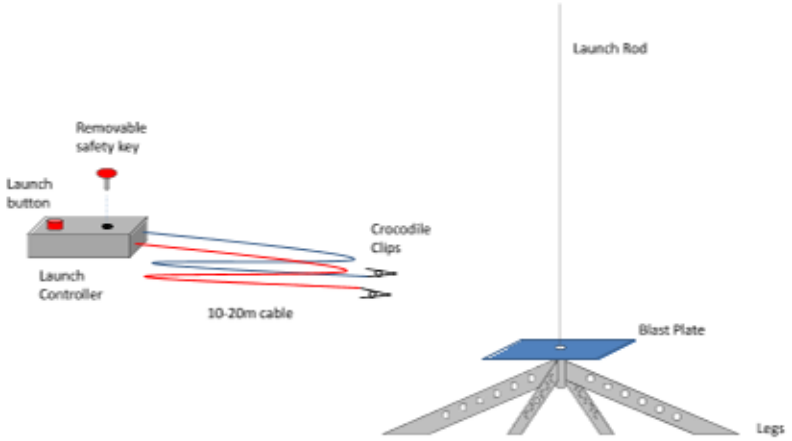
1. the average thrust which they produce
2. the time for which they produce that thrust
3. the delay before the ejection charge is fired.

Clearly 1 and 2 are related. The same amount of propellant can be burned quickly to produce high thrust for a short time, or slowly to produce a small amount of thrust for a long time. The combination of thrust and time is called the IMPULSE of the motor. More scientifically:

$$impulse = average\ thrust\ x\ burn\ duration$$

Thrust is measured in Newtons, and time is measured in seconds. Impulse is measured in Newton-seconds. The impulse is thus directly related to the amount of propellant. The more propellant, the greater the impulse of the motor.

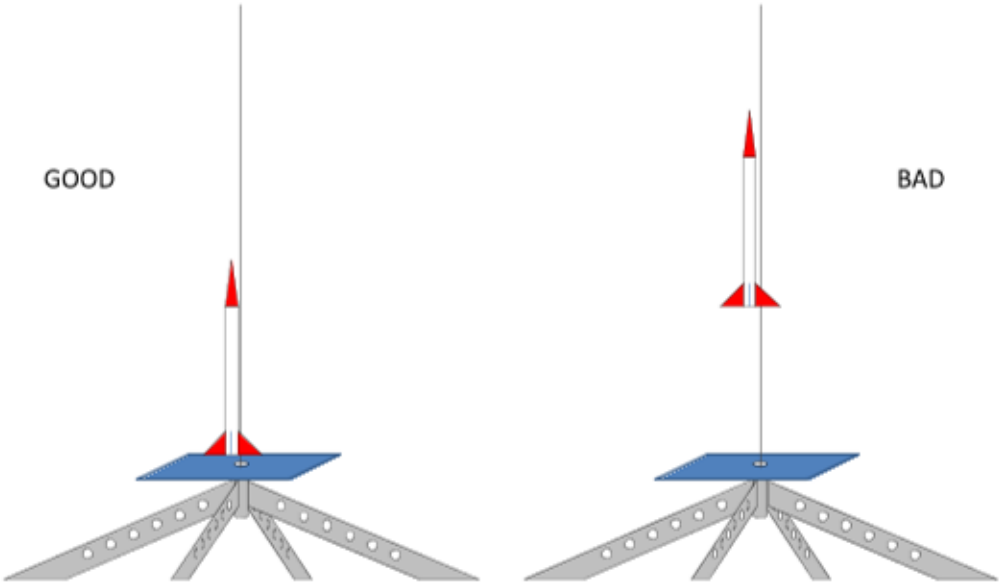
3. Launch Equipment



Ground Support Equipment

Launch equipment is often referred to as 'ground support equipment' or GSE. The two main items of GSE are the launch pad and the launch controller.

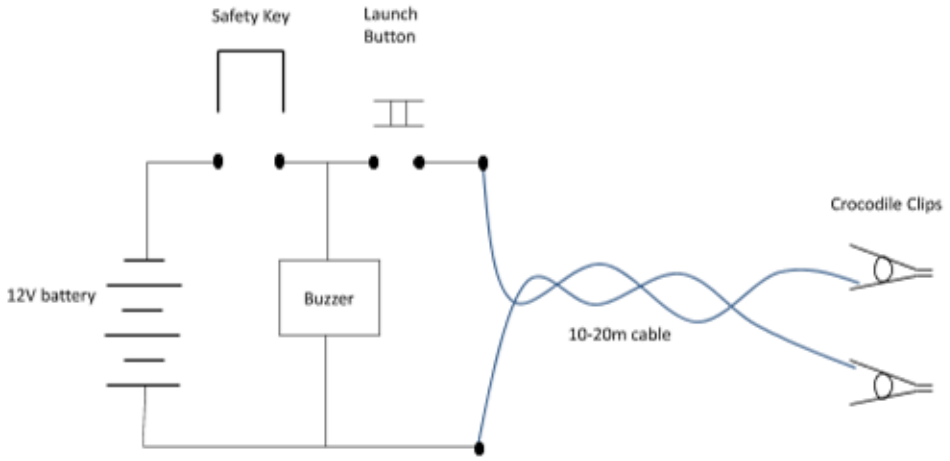
Launch Pads



Using a Launch Pad

The launch pad has two main functions. Firstly, it sets the direction of flight of the rocket while it accelerates to a speed where aerodynamic forces can steer the rocket. Secondly, it diverts the hot gases from the motor away from the ground to reduce the risk of igniting the grass.
A good launch pad will have a wide base and low centre of gravity to ensure that it is stable. This will prevent it from falling over during a launch.
Thin rods can "whip" when the rocket is moving, sometimes causing the launch lug to detach from the rocket. This can be overcome by having a launch rod that is metallic and at least 6mm thick.
The launch rod or rail needs to be long enough to ensure that the rocket leaves with a high velocity. A 1.5m to 2.0m long rod is generally sufficient. The rocket should be placed at the bottom end of the launch rod so that it uses the whole length of the rod; this maximises its takeoff speed.

Launch Controllers

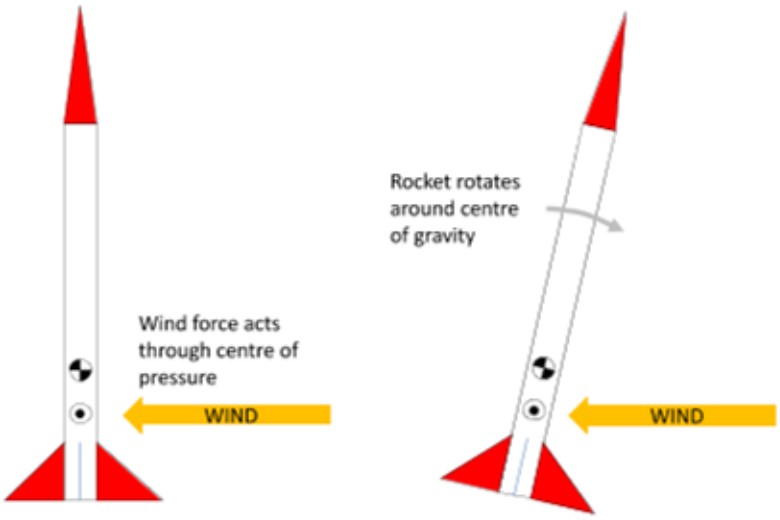


Launch Controller

The launch controller applies the electrical signal that ignites the motor. It is connected to the igniter by a long cable, terminated in two crocodile clips.
The launch controller has four main components. The first is a battery, typically a 12V lead acid gel type as the controller will have to deliver several Amps of current.
The battery is isolated from the other components by a safety key. The purpose of this is to ensure that the crocodile clips cannot be "live" when the rocket is being wired up, reinventing the rocket from going off in your face when you wire it up. KEY SWITCHES MUST NOT BE USED as it is possible to remove the key when the system is live. Good practice is to have a removable link on a lanyard. This allows one person to keep the key around their neck until everything is ready for a launch.
It is also good practice to have a buzzer in the box so that, when the key is inserted, the buzzer sounds. This will alert people that the safety key has been inserted.
When ready to launch the safety key can be inserted the buzzer will sound. After a countdown the launch button can be pressed, sending power through the cable to the igniter.

4. Weather and Rocketry

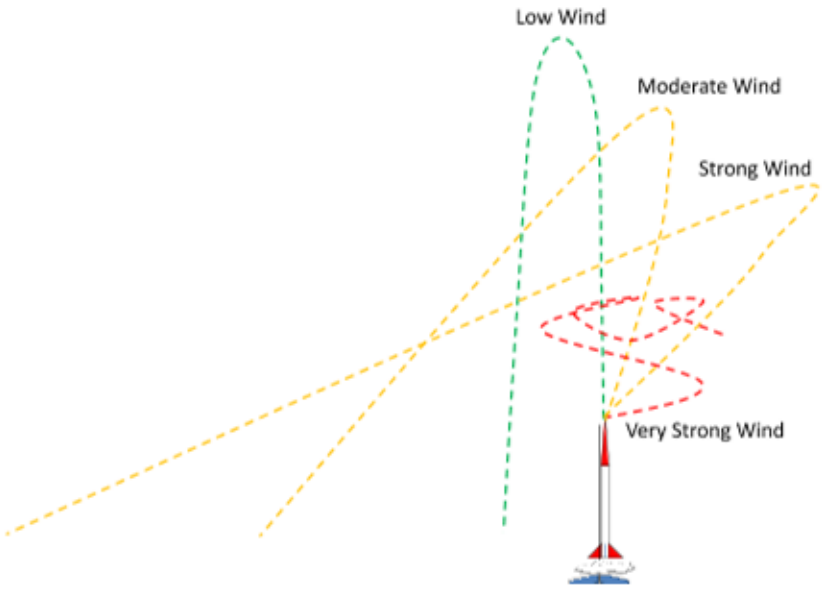
Wind and Rockets



Weathercocking

The wind has a significant effect on the trajectory of a rocket.
The launch rod keeps the rocket pointing skywards as it accelerates. When a rocket leaves the launch rod it is affected by the wind. Wind causes the rocket to rotate and turn into the wind. This is called "weathercocking".

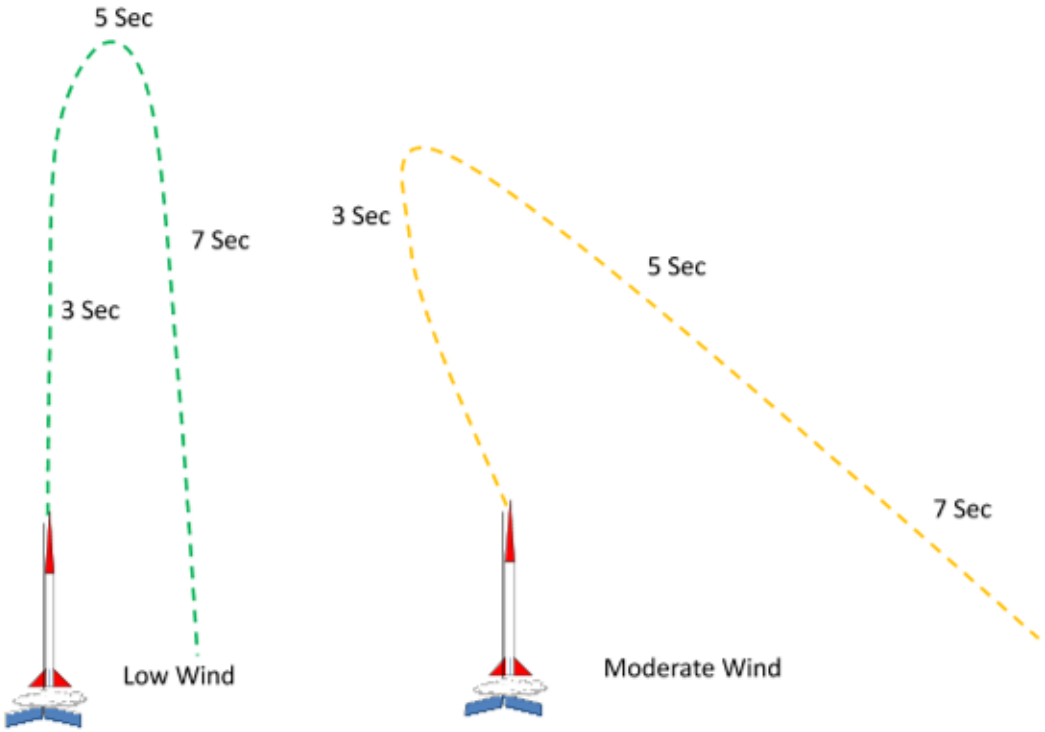
4.1 Weathercocking



Effects of Wind

In a low wind the rocket should leave the launch rod and fly vertically. When the patrachuts deploys it will drift downwind.
As the wind speed increases the rocket will become motor likely to weathercock. It will tend to fly into wind and will reach a lower altitude. When the parachute deploys it will drift further downwind.
In very strong winds the rocket might tip over completely and fly erratically. This is very dangerous.
The amount of weathercocking depends on the speed of the wind and the rocket. A slow moving rocket is very susceptible to weathercocking, whereas a fast moving rocket is less sensitive to wind speed. Heavy rockets with low thrust motors are the most susceptible, whereas light rockets with high thrust motors are relatively immune to weathercocking.
Also, using a longer launch rod can help to reduce susceptibility to weathercocking because the rocket accelerates for longer and has a higher velocity when it leaves the launch rod.

4.2 Choosing the Right Motor



Motor Delay and Wind

Rockets go higher and faster when they have a high take off speed. The thrust of the rocket should always be greater than five times its weight, ideally ten to twenty times its weight. Note that its weight (in Newtons) is about ten times is mass in kilogrammes.
As an example: A 100gm (0.1kg) rocket has a weight of $0.1 \times 10 = 1$ Newton. A motor with 6 Newtons of thrust will be acceptable.
Selecting a motor with the correct delay can make a big difference to the outcome of the flight. If a rocket is expected to coast for 5 seconds then a motor with a delay of 5 seconds must be used. If the delay is too short the ejection charge will deploy the parachute while the rocket is still coasting. Similarly too long a delay will deploy the parachute while the rocket is descending. Deploying parachutes while the rocket is travelling at speed is a good way of damaging or destroying it. When its a bit windy you should shorten the delay and use a high thrust motor.

Using clusters of two or more motors is more complex. With skill it is possible to ensure that all the motors light simultaneously. You should always consider what will happen if they don't all light.
For example, if you are launching a 3 motor cluster and only two motors light:

- The rocket will leave the launch rail at a lower velocity and be susceptible to weathercocking.
- The rocket will have a lower flight, thus the parachute will deploy late.

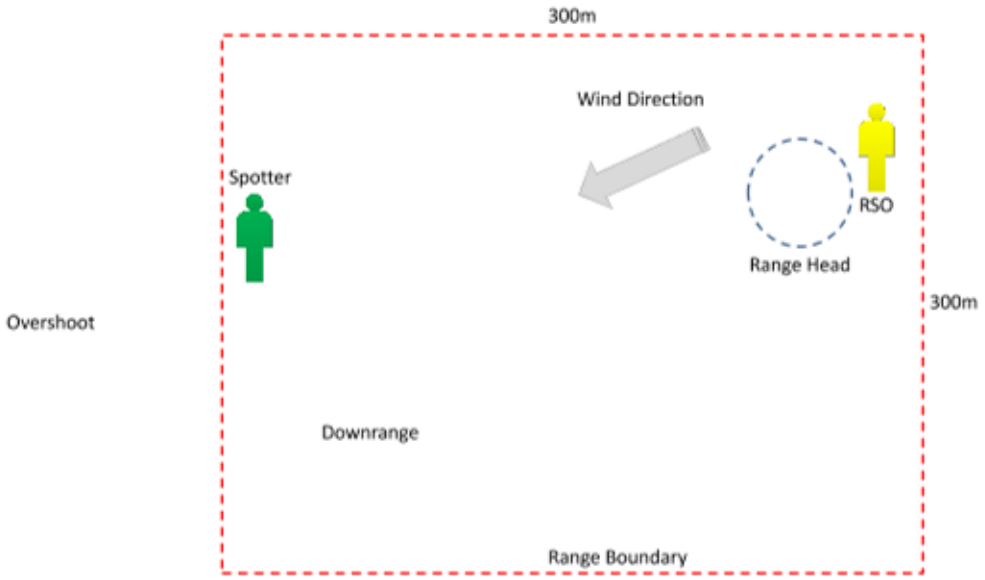
5. Setting Up a Rocket Range

Criteria for a Rocketry Range

Dimensions	A good launch site will measure at least 300m by 300m. This gives rockets plenty of space to drift on windy days.
Surroundings	It must not be within five miles of an airport as it is prohibited to launch near an airfield withour permission of Air Traffic Control.
Coasts & mountains	Rockets can be mistaken for flares. If the site is on the coast or in mountainous areas inform the coastguard or maountain rescue before you launch.
Roads	It must not alongside a busy road or motorway. A rocket landing on a road could cause an accident.
Buildings	The site should not be near any houses or public buildings.
Access	The land should only be accessible to people involved in the launch. Public parks and public land must not be used.
Visibility	It should be possible to see all entry points to the site so that unauthorised people can be quickly spotted.
Hazards	The land should be hazard free. Ideally there should be no trees or overhead cables that could snag a rocket.
Landowners permission	Landowners permission must be obtained.

The area in which rockets are launched and recovered is called the range. Picking a good location for a range is an important decision. You need to ensure that rockets do not injure other people or damage their property. Some key criteria for launch sites are listed above.

Range Layout



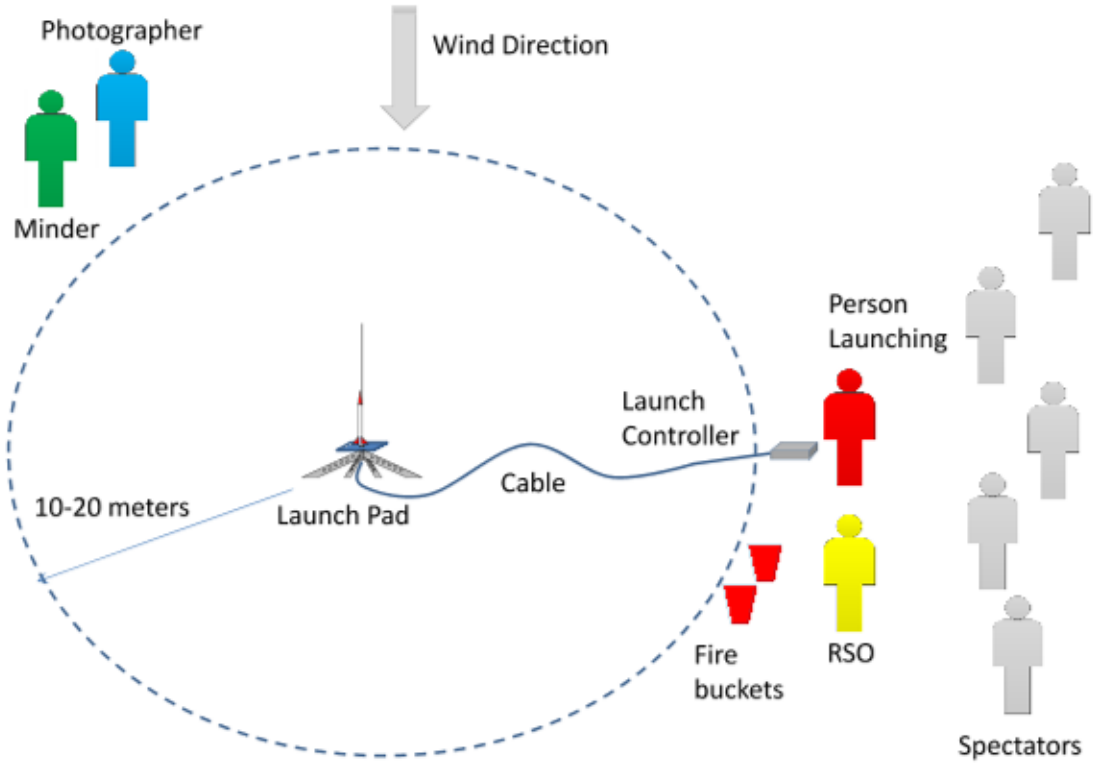
Range Layout

The layout of the range makes a significant contribution to safety. Assuming that the range is suitable, then you should consider the weather conditions when laying out the range.
The point from which rockets are launched is called the range head. The area downwind of the launch site is called the downrange. To maximise the area in which rockets can land it is good practice to have the range head at the upwind end of the range.
The RSO will be based at the range head so that he/she can supervise launches. There may be parts of the range that are not visible, for example depressions or areas behind hedges. It is a good idea to put a spotter in those areas. A spotter can:

- Look out for any unauthorised people entering the range.
- Monitor people who are recovering rockets.
- Note where rockets land, helping the recovery teams.

The spotter should have radio/phone communications with the RSO. This allows the spotter to warn the RSO of any issues downrange.

Range Head



The Range Head

Participants and spectators are closest to the rockets at the range head, and are therefore at greater risk. A good layout of the range head can make a significant contribution to safety.

Having decided on the location of the range head, mark out an are of 10-20m radius around the launch pads. Only people with a need to approach the launch pad are allowed in this area.

Lay out the launch cable so that the launch point is not upwind or downwind on the launch pad. This reduces the possibility of rockets weathercocking over the heads of people.

Position one or two fire buckets full of water, or water-gas extinguishers, at the launch point.

When launching, the RSO and person launching a rocket will stand together at the launch controller. Everyone not involved in the launch should be behind the RSO.

If this is the first time that a rocket has flown or the RSO decides that the weather

conditions are marginal, then spectators may be asked to stand up and move apart so that they can see the rocket if it misfires.
Photographers often want to get shots from different angles. Photographers can be distracted by the technical aspects of their art, so it is a good idea for them to be accompanied by a minder who can ensure their safety.

6. Running a Rocket Range

Range Safety Officer

A Range Safety Office (RSO) should be appointed at the start of every launch session. The RSO is responsible for the safe running of the range, including recovery of rockets.
The RSO provides an independent check on safety issues and must not be part of the launch team; An RSO who is concentrating on preparing the rocket for launch will not be sufficiently aware of other activities that might be happening on the range.
It is standard practice that the RSO wears a hi-viz yellow jacket with "RSO" or "Range Safety Officer" on the back. This ensures that the RSO can be readily identified.
Selection of an RSO is an important decision. The ideal RSO will:

- Be familiar with this document
- Have sufficient knowledge and experience of rocketry to be able to advise participants and spectators about specific hazards.
- Be a person who has the maturity and judgement to be able to refuse a flight that is deemed to be unsafe

Every rocket that is to be launched must checked by the person launching it. It must then be presented to the RSO for inspection. The RSO will make an independent decision whether the rocket is safe to be launched, taking cognisance of

- Its construction and state of repair.
- The intended motor, delay and prevailing conditions.
- Whether the rocket has flown before in similar conditions.
- Whether the range and downrange are clear of people.

If the RSO approves the launch then the rocket may be placed on the launch pad. The igniter will be inserted only when the rocket is on the launch rod and pointing vertically.
When ready, the RSO will:

- Check the sky for incoming aircraft.
- Check the range and downrange for people.
- Call "LAUNCHING" in a loud voice
- Ensure that everyone is watching the rocket
- Give the safety key to the person launching the rocket.

The person launching the rocket will:

- Insert the safety key
- Countdown from five to zero
- On reaching zero press the launch button.

After ignition than the person launching the rocket will return the safety key to the RSO. When the rocket lands the RSO will decide whether it is safe to go and retrieve the rocket. If, for example, there are several rockets to be launch the RSO might decide to keep everyone at the range head until all rockets have landed.
Several things can go wrong: during a launch:

Problem	Action
The rocket fails to ignite	Wait 60 seconds in case it is smouldering. After that ONLY the person launching the rocket and the RSO will approach the rocket to determine the problem.
The rocket flies erratically	Everyone watches the rocket and steps aside if it comes towards them. DO NOT run away - you wont outrun the rocket. DO NOT dive to the gropund as you have nowehere else to go if the rocket comes towards you.
During descent the rocket starts to drift towards someone	The RSO, and anyone who sees this problem, calls "HEADS UP". Everyone looks up to see if the rocket is coming towards them. If so, they step aside and let it land. No-one tries to catch the rocket as it it may still be hot.
The parachute fails to deploy.	The RSO, and anyone who sees this problem, calls "HEADS UP". Everyone looks up to see if the rocket is coming towards them. If so, they step aside and let it land.

Table 6.1: Problem launches

Checking Rockets

Before every flight the person launching the rocket, and the RSO will satisfy themselves that the rocket is in flightworthy condition.
This will comprise at least the following checks:

- Is the motor suitable for the conditions?
- Is the parachute large enough for the weight of the rocket?
- Is the nose cone or payload compartment sufficiently loose that it will allow the parachute to deploy?

- Is the rocket damaged in any way and, if so, has the damage been repaired to an acceptable standard?
- Are the fins all attached and soundly constructed?
- Are the launch lugs firmly attached and strong enough?
- Is the shock cord attached and undamaged (breaking shock cords are one of the most common failures)
- Its the motor retention strong enough to retain the motor?

7. Motor Safety

Model rocket motors are safe if used properly but can cause injury if abused. This chapter covers some essential safety information for model rocket motors.

Motor Storage

Model rocket motors are covered by the 2014 Explosives Regulations.
Under current UK regulations individuals do not need an explosives licence if they store of model rocket motors with a total propellant weight of under 5kg. In these circumstances there are no minimum separation distances between the store and other premises.
Storage should be away from any flammable liquids and potential sources of ignition, for example naked flames, sparks, lightning or excessive temperature. It is good practice to store motors in a wooden box rather than a metal box. In the event of a fire a metal box will conduct heat to the motors very quickly whereas a wooden box will ablate, slowing the rate of heat transfer. The wooden box should:

- Have wooden walls 20mm thick.
- Have no conduction paths between the outside and inside, for example screws or metal fittings.
- Be easily moved away from any heat source, if time permits.
- Have a seal around the lid using intumescent strip so that any gaps are sealed in the presence of heat.
- Have a suitable lock.
- Be located away from any means of escape.

It is good practice to only remove motors from the store when they are about to be used, and return any unused motors.

Instructions

Model rocket motors are provided with safety instructions. All personnel handling motors should read these instructions and comply with them.
Modifying motors or reload kits is illegal and can be very dangerous. Motors can overpressure and explode, set fire to the rocket, or fire the nozzle out when the ejection charge blows. NEVER modify motors.

Clustering

It is a common practice to power a rocket with two or more motors. This technique, known as clustering increases the thrust of the rocket and allows heavier rockets and payloads to be launched. There is a risk that one or more of the motors will fail to ignite, resulting in an underpowered and unstable flight.
The reliable ignition of clusters of multiple motors is a skill that can challenge experienced rocketeers. These guidance notes are intended to help teams to safely ignite all the motors.
This section addresses two methods for igniting clusters of Estes black powder (BP) motors.Ammonium perchlorate (AP) motors, or mixtures of BP and other propellants, should never be clustered as they rarely ignite simultaneously.
Some suppliers provide dedicated clustering kits for their motors. When these are available they should always be used.

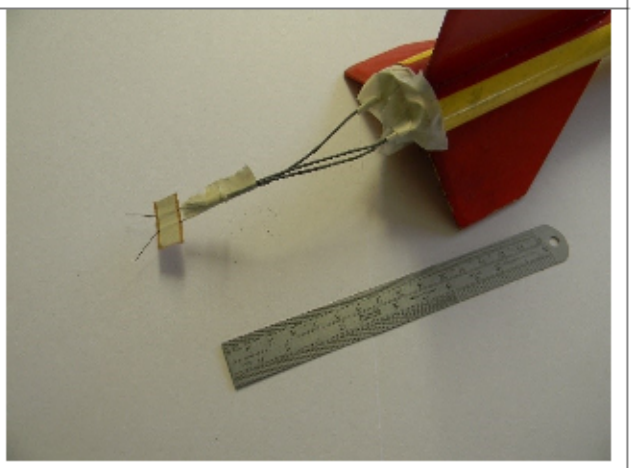
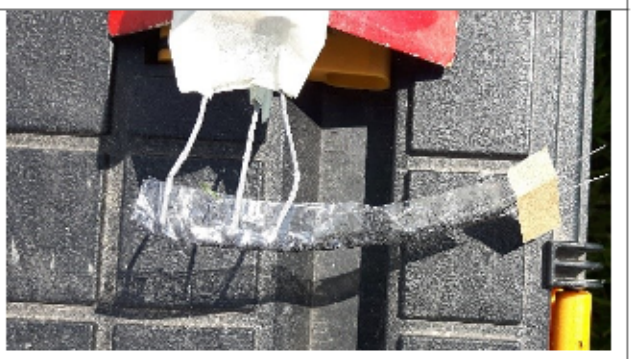
Method One

One method for igniting clusters is to insert an igniter into each motor. By wiring them in parallel the motors should all fire simultaneously. This method is generally not very reliable. If one or more igniters fail to fire then the rocket could have insufficient to launch safely. Common problems with this method are: Failure to put all the igniters in full contact with the propellant. Damage to igniters when inserting the plug. One igniter might fire slightly before the others. It lifts the rocket and the cable pulls the igniters out the other motors so they fail to ignite. This method is NOT recommended by UKRoC.

Method Two

A preferred method is to ignite all the motors from a single igniter. If this igniter fires then all the motors will ignite, if it fails to fire then none of the motors will ignite. This overcomes the problem of partial ignition of the cluster. The trick is to cut short fuses from quickmatch and insert these into each motor. The fuses

can them be lit simultaneously, wither by connecting them with tapematch or by bundling them together around a single igniter. When the igniter fires it simultaneously ignites all the fuses. These burn at the same rate, and simultaneously ignite all the motors. Examples of this method are shown below. Quickmatch and tapematch can be obtained from specialist rocketry or fireworks suppliers.

An e-match (the orange cable) fires the tape match. This burns very fast and simultaneously ignites all the quickmatches (green). These burn into the motors aand ignite them all at the same time.	
Three quickmatches are inserted into the motors and held in place using masking tape. The matches are brought together and taped to a single Estes igniter.	
As before, three quickmatches are inserted into the motors. This time the matches are connected to the igniter using tapematch.	

8. BMFA Model Rocketry Safety Code

Model rocketry is a sport with an exemplary safety record. One reason is that participants have followed an established Model Rocketry Safety Code, which originated in the United States of America. The introduction of novel rocketry products in the UK has made it necessary to update the basic safety code. The code below provides baseline standards for the launching of any model rocket - space model in the UK.

8.1 Construction

All model rockets shall be made from lightweight materials, such as paper, wood, plastic and rubber, with only minimal metal parts. The model shall be soundly and accurately constructed and the stability must be checked before it's first flight, unless of proven design.

8.2 Motors

Only propellants (motors) produced by a bonafide manufacturer shall be employed. These motors must be stored and used in accordance with the relevant manufacturer's instructions. No modification of the case, nozzle, or contents shall be carried out, nor any reloading of single use motors undertaken. The motor manufacturer's pertaining to Maximum Launch Weight for safe operation must be adhered to.

8.3 Preparation and Recovery

All model rockets must have provision for, and contain at launch, a recovery system - or have appropriate aerodynamic surfaces - so that the model may be returned to the ground and flown again. Great care in preparation must be employed to

ensure that the recovery system deploys correctly and that any insulating recovery wadding is flameproof. Multiple stage prototypes, or vehicles with discarding booster sections, shall have a form of recovery device in each portion, to ensure a safe return to the ground. No model shall carry an explosive, flammable, or live animal payload. No ballistic flights may be attempted, or any attempt to strike a target.

8.4 Launch Systems

Model rockets must be launched from a stable platform, with a device - such as a rigid launch rod, rail, tower or other system - to provide initial direction and stability. The angle of the launching device must not deviate from the vertical by more than 30 degrees. The exposed top of any such launch rod shall be capped except for the execution of a launch and where possible should be set to above eye level. The launch system must incorporate a blast deflector to prevent motor exhaust from sticking the ground.

8.5 Firing System

A model's rocket motor(s) must be ignited on the launch system using an electrical device (Igniter), According to the relevant manufacturer's instructions. The electrical system must allow the operator to place him / herself 5 meters - or any such greater distance recommended by the motor manufacturer from the rocket to be launched. The system must include a Safety Key to facilitate the disarming of the electrical circuitry when removed and shall possess switchgear the reverts to the 'off' position when released. The Safety Key shall be inserted for the moment of launch and removed immediately afterwards. A clearly audible countdown of at least 5 seconds shall be given before launching. In the event of an igniter misfire, no one shall approach the model until the safety key has been removed from the launching system and until it is certain that there is no likelihood of ignition.

8.6 Launch Site and Safety Conditions

Model rockets must be launched from open sites, away from buildings, railways and roads and in conditions of good visibility in clear air space. Launching should not be attempted in high wind conditions, where they could endanger full-size aircraft, flammable materials or in any situation that could cause a nuisance/danger to people or property. No attempt must be made to recover model rockets from

high-tension electricity cables or telephone lines. Great care must be exercised in the recovery of model rockets - space models from high trees, water or any other potentially dangerous situation. If there are any concerns whatsoever relating to personal safety in the recovery of a model, in any situation, appropriate specialist guidance should be sought. In group flying sessions, with members of the public / onlookers present, a Range Safety Officer (RSO) shall be appointed. The RSO is responsible for the safe conduct of the flying model rockets and keeping all personnel 5 meters, or and such greater distance defined by the motor manufacturer, from the point of any launch.

8.7 Controls

At all times, model rocket flying must comply with Civil Aviation Authority (CAA) Publication CAP658 Appendices A, F and I and Air Navigation Order (ANO), article 55, 56 and 76 ANO87A and Art129. High power rockets and large model rockets are subject to a separate safety code.