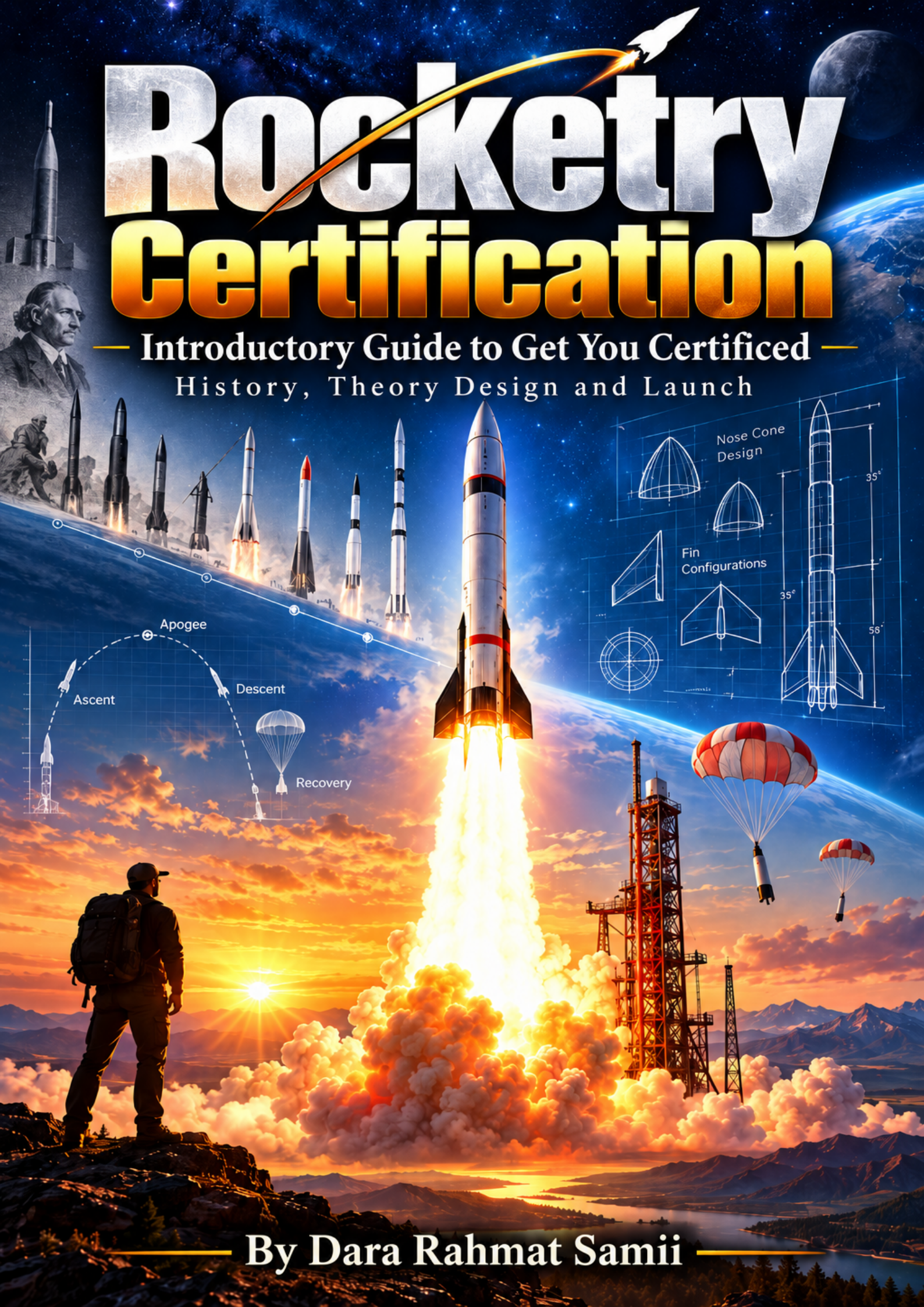
Rocketry Certification

Introductory Guide to Get You Certificed

History, Theory Design and Launch



By Dara Rahmat Samii

Abstract

About this book

This book is a study companion for high-power rocketry (HPR) certification in Canada, written around the Canadian Association of Rocketry / Association canadienne de fuséonautique (CAR/ACF) program with references to the Tripoli Rocketry Association. It covers the whole path to a certification flight: who the certifying organizations are and how the Level 1 to Level 4 and Electronics Endorsement tracks work; the Transport Canada rules that govern every high-power launch, reproduced together with the official Transport Canada practice exam and answer key; the flight theory behind stability, nose cone shapes, fin design, the Barrowman method, parachutes and terminal velocity, with worked problems and the full CAR/ACF practice exam and answer guide; flight performance, from the rail exit speed to apogee, derived step by step; the construction details that decide whether a certification rocket survives its flight; an illustrated, step-by-step parachute packing procedure; and a practical guide to the day itself, from the flight card and the Rocket Inspector's checklist to the oral questions a flier should expect at the pad. A final chapter on dynamic stability and roll lock-in serves readers heading towards Level 2 and Level 3, and a nomenclature and list of acronyms closes the book.

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CHAPTER 1

Introduction, Organizations, and Classification

High-power rocketry sits between the hobby shop and the professional range. The rockets are large enough, fast enough and energetic enough that Canada regulates every launch through the *Aeronautics Act* [1], yet the people who fly them are private citizens, students and clubs. The bridge between the two worlds is *certification*: a recognized association tests your knowledge, watches you build and fly a rocket, and then vouches to Transport Canada that you can be trusted with a given class of motor [2]. This chapter tells how that system came to be, introduces the organizations that certify fliers, walks up the certification ladder one step at a time, and teaches you to read a motor designation and a thrust curve. It ends with practice problems on motor naming and total impulse.

1.1 A short history

1.1.1 From model rockets to high power

Modern amateur rocketry starts with a safety idea. In 1954 Orville Carlisle, a licensed pyrotechnician, and his brother Robert designed the first modern model rocket and its commercially made, single-use motor [3]. The point was to replace home-made propellants, which regularly maimed young experimenters, with factory motors that nobody had to mix or pack. In 1957 G. Harry Stine, then a range safety officer at White Sands Missile Range, flew the Carlisle design, wrote a safety handbook from his range experience, and with Carlisle founded the National Association of Rocketry (NAR) [3, 4]. Model Missiles Inc. and then Estes Industries (1958) turned the hobby into a mass market [3].

Canada followed quickly, with its own professional and amateur threads. In September 1959 the first Black Brant sounding rocket, built by Bristol Aerospace of Winnipeg, flew from the Churchill Rocket Research Range in Manitoba [5]; the Black Brant family is still flying today. On the amateur side, Larry Brown, an American living in Québec, launched more than 200 rockets between 1959 and 1969, some of them supersonic [6]. The law had not caught up: under the *Explosives Act* private individuals could not make or experiment with rocket propellants. In October 1965, after the federal government asked aerospace organizations to propose an oversight body, the **Canadian Association of Rocketry** was formed, and in April 1966 model rocketry became legal in Canada [6, 7]. The first national competition, CARNAT-1, was held in Edmonton in 1973 [6].



Black Brant

a Black Brant IX on its launcher



Larry Brown

amateur rocketry in Québec, 1959–69

Figure 1.1. Two Canadian threads. Left: the Black Brant family, first flown from Churchill, Manitoba in 1959 and still in service [5]. Right: Larry Brown, who launched more than 200 amateur rockets in Québec before model rocketry was legal in Canada [6].

Membership then went through hard years: strict rules shrank the association from roughly 2 500 members to about 200 within a few years, and to around 50 by 1990 [6]. What revived it was *high power*. In the United States, the Tripoli club, formed by junior high school students in Rillton, Pennsylvania in December 1964, reorganized in 1985 and 1986 into a national, incorporated association dedicated to advanced rocketry, adopted its safety code on 1 January 1987 and took over the LDRS launch series [8]. In Canada, the first CAR-approved high-power launch took place in September 1993 [6].



Orville Carlisle

first modern model rocket (1954), NAR co-founder



G. Harry Stine

NAR co-founder (1957), first safety handbook



Francis G. Graham

founder of the Tripoli club (1964)

Figure 1.2. The founders behind the two US associations whose ideas shaped Canadian rocketry [3, 4, 8, 9].

1.1.2 The regulatory era

The modern Canadian framework was written between 1998 and 2000. A Transport Canada exemption letter of 28 September 1998 defined the *model rocket* (at most 160 N s and 1 500 g) and exempted it from section 602.43 of the Canadian Aviation Regulations [10, 11]. On 21 June 1999 the Canadian Launch Safety Office wrote to all high-power enthusiasts to explain its role, and named CAR and NAPAS (the Canadian group following Tripoli's process) as the two associations

whose certification it accepted [2]. On 4 January 2000 it issued the *Requirements for Launching High Power Rockets in Canada*, the document at the heart of Chapter 2 [10]. CAR's own High Power Rocketry Safety Code followed in 2005 and has been revised ever since, most recently to version 3.6 in February 2026 [12, 13]. The association was incorporated in its present form, CAR/ACF, in 2009 [14]. Student rocketry grew alongside: the first Launch Canada Challenge, a national student competition near Timmins, Ontario, was held in 2022 [15].

The 1999 letter is short and worth reading in full: it explains why the Transport Canada requirements bind everyone while an association's code binds only its members, how certification is obtained, and which federal agency is responsible for what. Figure 1.3 reproduces it; Chapter 2 walks through its content.

Key Point: why the history matters for the exam

- The **Transport Canada requirements date from 2000** and are still the legal baseline; the CAR/ACF code has been revised many times since (2011, 2016, 2025, 2026).
- Several Transport Canada exam questions quote the **1999 letter** directly (who does what between NRCan and the CLSO, and how certification is obtained).
- The practice exams in this book come from the 2018 Study Guide; where the code has changed since, this book says so (Section 2.14).

1.2 NAR, Tripoli and CAR/ACF: how the three fit together

Three associations appear again and again in this book. Two are American, one is Canadian, and a Canadian flier will usually meet all three: NAR through its safety codes and kits, Tripoli through its prefectures and certification process, and CAR/ACF as the association Transport Canada relies on at home.



NAR
National Association of Rocketry
USA, 1957



TRA
Tripoli Rocketry Association
USA, 1964 (national 1986)

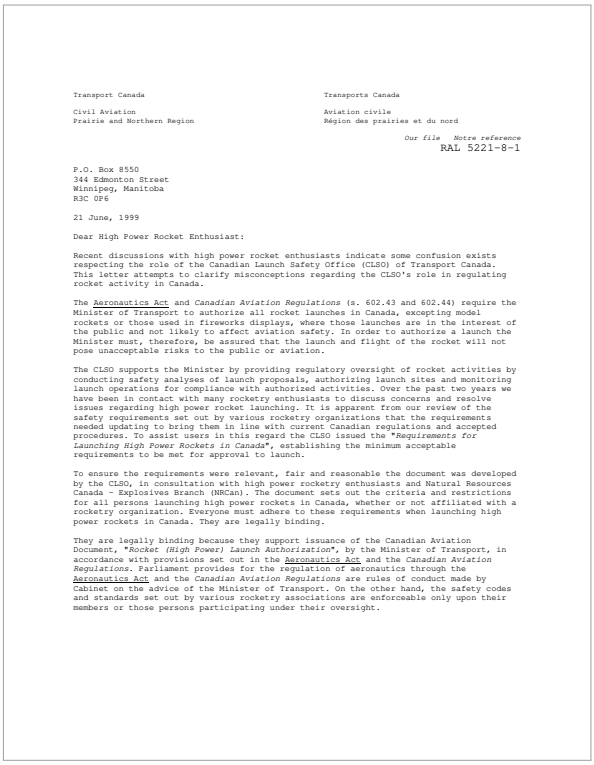


CAR/ACF
Canadian Association of Rocketry
Canada, 1965

Figure 1.6. The three associations a Canadian high-power flier meets.

Who they are

NAR (National Association of Rocketry)
The oldest of the three, founded in 1957 by G. Harry Stine and Orville Carlisle [4]. Its roots are in *model* rocketry: safety codes, competition and education, with a high-power certification program (Levels 1 to 3) added later. NAR launches fly only commercially made, certified motors.



Transport Canada

Civil Aviation
Prairie and Northern Region

Transports Canada

Aviation civile
Région des prairies et du nord

Our file *Notre reference*
RAL 5221-8-1

P.O. Box 8550
344 Edmonton Street
Winnipeg, Manitoba
R3C 0P6

21 June, 1999

Dear High Power Rocket Enthusiast:

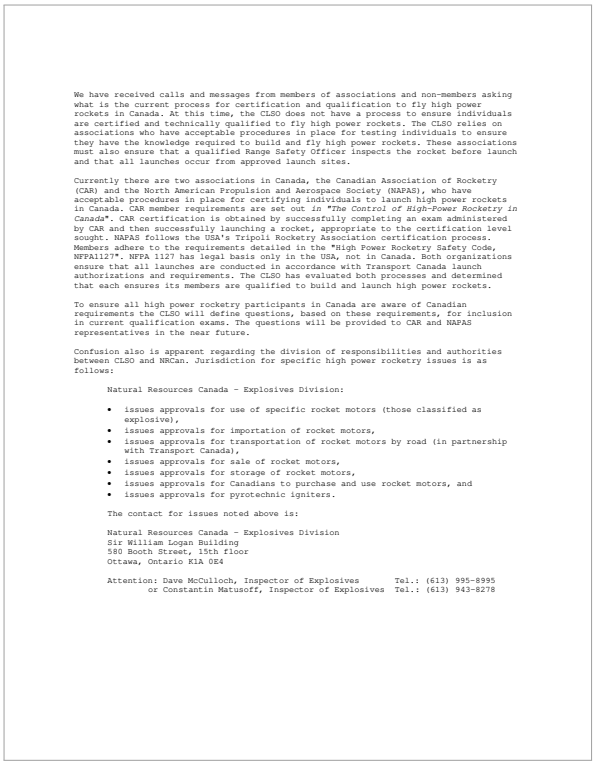
Recent discussions with high power rocket enthusiasts indicate some confusion exists respecting the role of the Canadian Launch Safety Office (CLSO) of Transport Canada. This letter attempts to clarify misconceptions regarding the CLSO's role in regulating rocket activity in Canada.

The Aeronautics Act and *Canadian Aviation Regulations* (s. 602.43 and 602.44) require the Minister of Transport to authorize all rocket launches in Canada, excepting model rockets or those used in fireworks displays, where those launches are in the interest of the public and not likely to affect aviation safety. In order to authorize a launch the Minister must, therefore, be assured that the launch and flight of the rocket will not pose unacceptable risks to the public or aviation.

The CLSO supports the Minister by providing regulatory oversight of rocket activities by conducting safety analyses of launch proposals, authorizing launch sites and monitoring launch operations for compliance with authorized activities. Over the past two years we have been in contact with many rocketry enthusiasts to discuss concerns and resolve issues regarding high power rocket launching. It is apparent from our review of the safety requirements set out by various rocketry organizations that the requirements needed updating to bring them in line with current Canadian regulations and accepted procedures. To assist users in this regard the CLSO issued the "*Requirements for Launching High Power Rockets in Canada*", establishing the minimum acceptable requirements to be met for approval to launch.

To ensure the requirements were relevant, fair and reasonable the document was developed by the CLSO, in consultation with high power rocketry enthusiasts and Natural Resources Canada – Explosives Branch (NRCan). The document sets out the criteria and restrictions for all persons launching high power rockets in Canada, whether or not affiliated with a rocketry organization. Everyone must adhere to these requirements when launching high power rockets in Canada. They are legally binding.

They are legally binding because they support issuance of the Canadian Aviation Document, "*Rocket (High Power) Launch Authorization*", by the Minister of Transport, in accordance with provisions set out in the Aeronautics Act and the *Canadian Aviation Regulations*. Parliament provides for the regulation of aeronautics through the Aeronautics Act and the *Canadian Aviation Regulations* are rules of conduct made by Cabinet on the advice of the Minister of Transport. On the other hand, the safety codes and standards set out by various rocketry associations are enforceable only upon their members or those persons participating under their oversight.



We have received calls and messages from members of associations and non-members asking what is the current process for certification and qualification to fly high power rockets in Canada. At this time, the CLSO does not have a process to ensure individuals are certified and technically qualified to fly high power rockets. The CLSO relies on associations who have acceptable procedures in place for testing individuals to ensure they have the knowledge required to build and fly high power rockets. These associations must also ensure that a qualified Range Safety Officer inspects the rocket before launch and that all launches occur from approved launch sites.

Currently there are two associations in Canada, the Canadian Association of Rocketry (CAR) and the North American Propulsion and Aerospace Society (NAPAS), who have acceptable procedures in place for certifying individuals to launch high power rockets in Canada. CAR member requirements are set out *in "The Control of High-Power Rocketry in Canada"*. CAR certification is obtained by successfully completing an exam administered by CAR and then successfully launching a rocket, appropriate to the certification level sought. NAPAS follows the USA's Tripoli Rocketry Association certification process. Members adhere to the requirements detailed in the "High Power Rocketry Safety Code, NFPA1127". NFPA 1127 has legal basis only in the USA, not in Canada. Both organizations ensure that all launches are conducted in accordance with Transport Canada launch authorizations and requirements. The CLSO has evaluated both processes and determined that each ensures its members are qualified to build and launch high power rockets.

To ensure all high power rocketry participants in Canada are aware of Canadian requirements the CLSO will define questions, based on these requirements, for inclusion in current qualification exams. The questions will be provided to CAR and NAPAS representatives in the near future.

Confusion also is apparent regarding the division of responsibilities and authorities between CLSO and NRCan. Jurisdiction for specific high power rocketry issues is as follows:

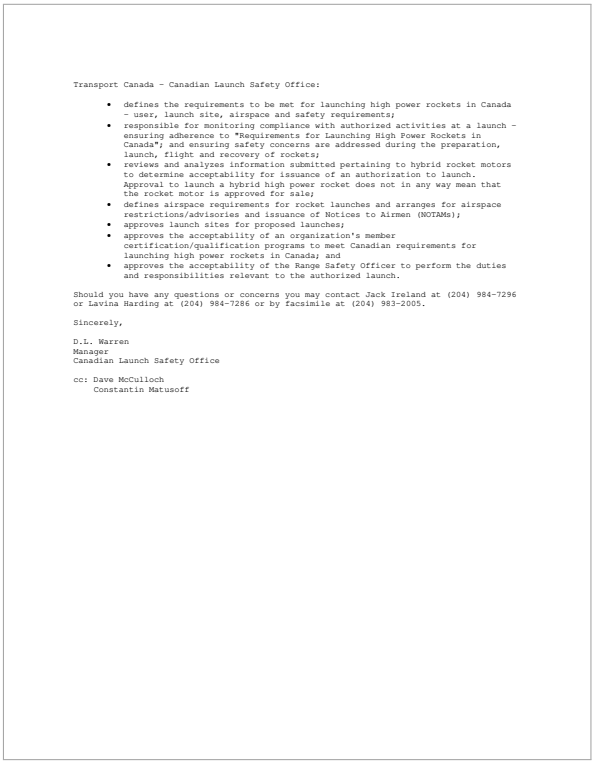
Natural Resources Canada – Explosives Division:

- issues approvals for use of specific rocket motors (those classified as explosive),
- issues approvals for importation of rocket motors,
- issues approvals for transportation of rocket motors by road (in partnership with Transport Canada),
- issues approvals for sale of rocket motors,
- issues approvals for storage of rocket motors,
- issues approvals for Canadians to purchase and use rocket motors, and
- issues approvals for pyrotechnic igniters.

The contact for issues noted above is:

Natural Resources Canada – Explosives Division
Sir William Logan Building
580 Booth Street, 15th floor
Ottawa, Ontario K1A 0E4

Attention: Dave McCulloch, Inspector of Explosives Tel.: (613) 995-8995
or Constantin Matusoff, Inspector of Explosives Tel.: (613) 943-8278



Transport Canada – Canadian Launch Safety Office:

- defines the requirements to be met for launching high power rockets in Canada – user, launch site, airspace and safety requirements;
- responsible for monitoring compliance with authorized activities at a launch – ensuring adherence to "Requirements for Launching High Power Rockets in Canada"; and ensuring safety concerns are addressed during the preparation, launch, flight and recovery of rockets;
- reviews and analyzes information submitted pertaining to hybrid rocket motors to determine acceptability for issuance of an authorization to launch. Approval to launch a hybrid high power rocket does not in any way mean that the rocket motor is approved for sale;
- defines airspace requirements for rocket launches and arranges for airspace restrictions/advisories and issuance of Notices to Airmen (NOTAMs);
- approves launch sites for proposed launches;
- approves the acceptability of an organization's member certification/qualification programs to meet Canadian requirements for launching high power rockets in Canada; and
- approves the acceptability of the Range Safety Officer to perform the duties and responsibilities relevant to the authorized launch.

Should you have any questions or concerns you may contact Jack Ireland at (204) 984-7296 or Lavina Harding at (204) 984-7286 or by facsimile at (204) 983-2005.

Sincerely,

D.L. Warren
Manager
Canadian Launch Safety Office

cc: Dave McCulloch
Constantin Matusoff

What the letter says, in five lines

1. The Minister of Transport must authorize every rocket launch except model rockets and fireworks.
2. The *Requirements for Launching High Power Rockets in Canada* are legally binding on everyone; association codes bind only members.
3. The CLSO does not test individuals: it relies on associations (then CAR and NAPAS).
4. CAR certification: pass an exam, then fly a rocket suited to the level.
5. NRCan looks after the motor; the CLSO looks after the launch.

Figure 1.3. The Transport Canada letter of clarification of 21 June 1999 to all high-power rocket enthusiasts (three pages) [2].

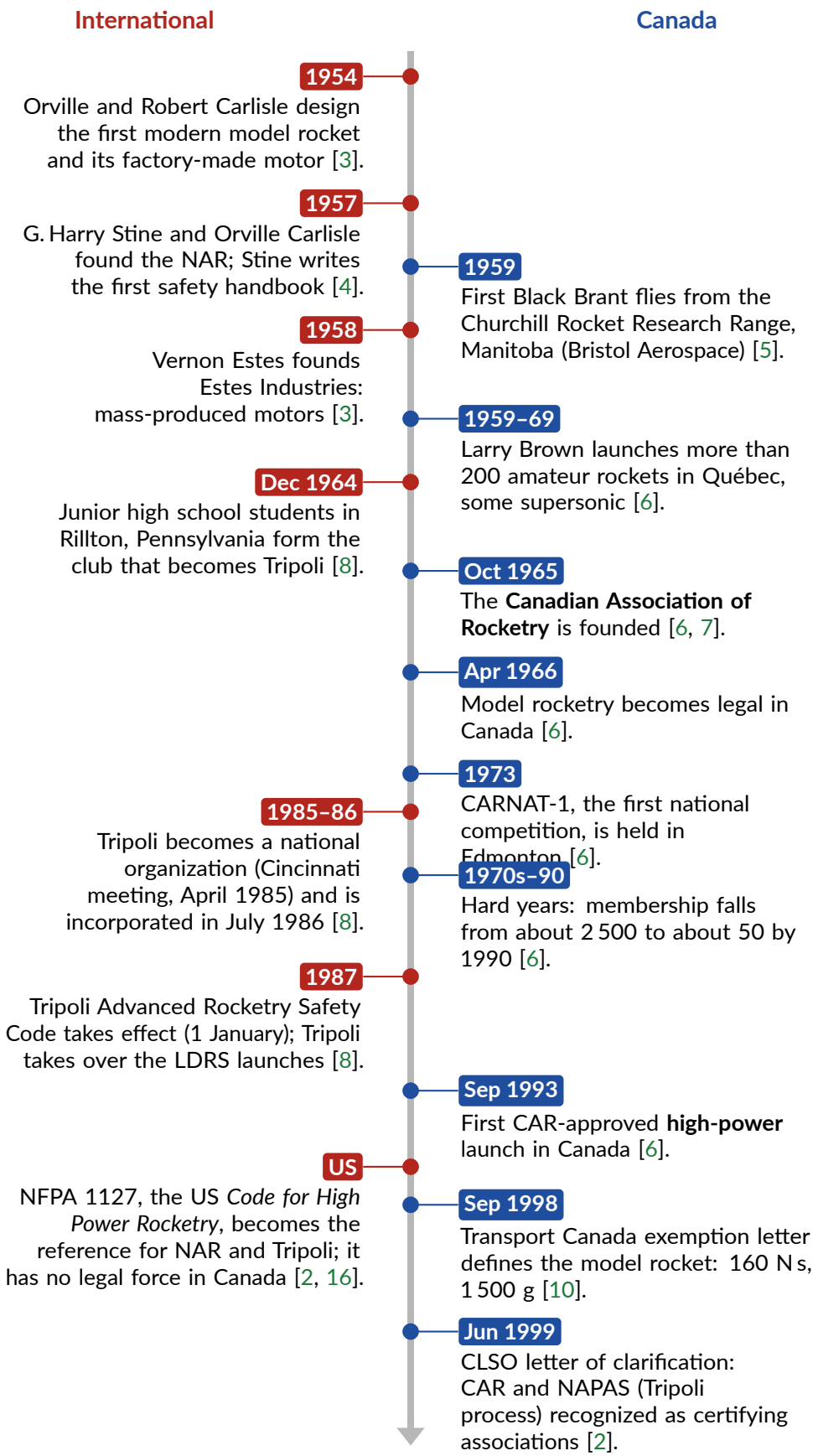


Figure 1.4. History timeline, part 1 (1954 to 1999). International milestones on the left, Canadian on the right. Spacing is by order of events, not to scale.

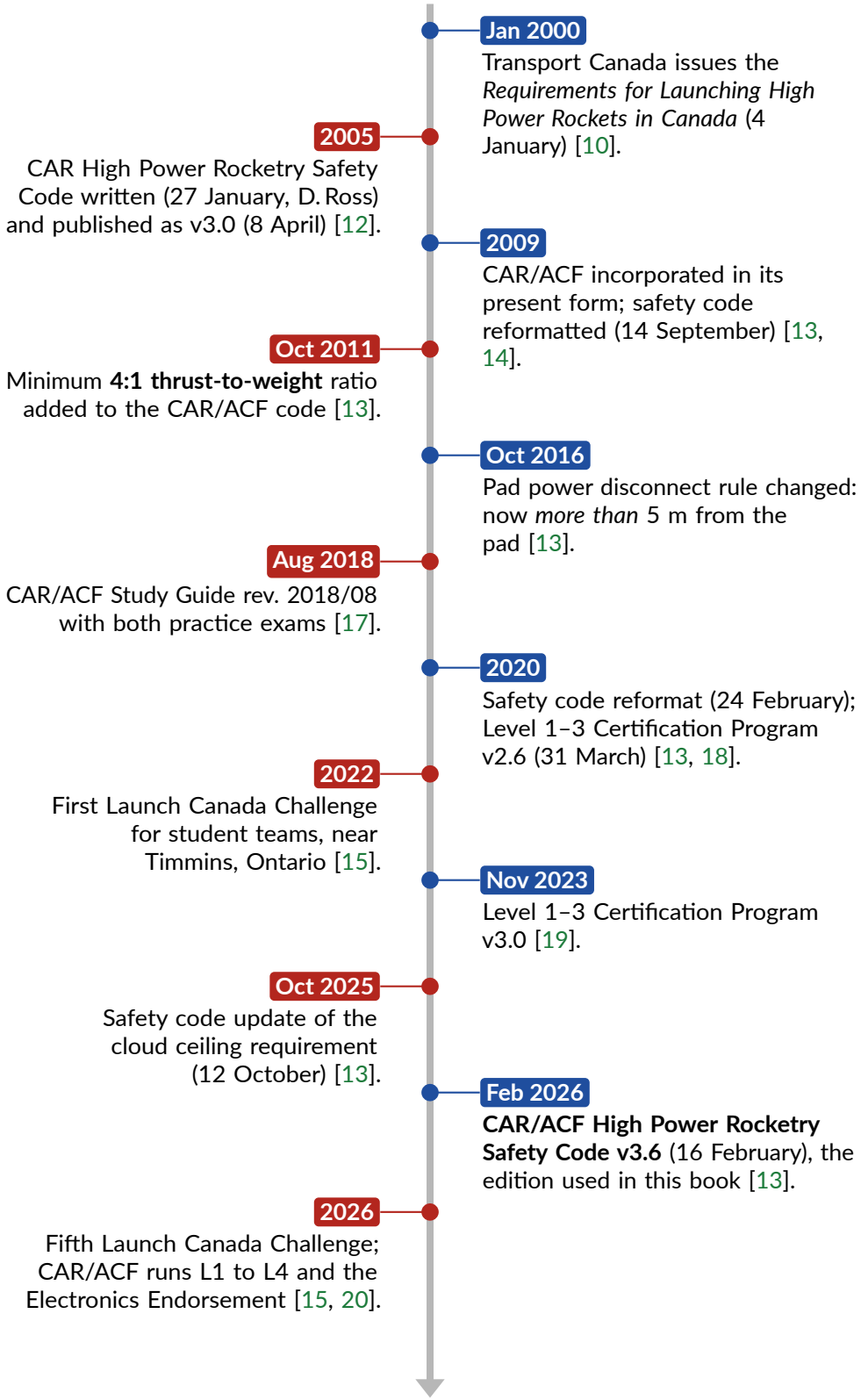


Figure 1.5. History timeline, part 2 (2000 to today): the rules you are tested on and how they changed.

TRA (Tripoli Rocketry Association)
Founded in 1964 as a school club, national since 1986, and built around *high-power* rocketry from the start [8]. It also runs a *research* program in which experienced members may fly motors they make themselves, something NAR does not allow. Its local clubs are called prefectures, and some are outside the United States, in Canada among others [9].

CAR/ACF (Canadian Association of Rocketry)
The Canadian national association, founded in 1965 to make model rocketry legal in Canada [6]. It writes a safety code consistent with the Transport Canada requirements, certifies fliers from Level 1 to Level 4 plus the Electronics Endorsement, and supplies RSOs and Rocket Inspectors at its launches [13, 20].

How they relate

- **NAR and Tripoli recognize each other.** Their certification levels line up (Level 1: H and I, Level 2: J to L, Level 3: M to O), so a flier certified by one may fly at the other's launches at the same level. Both base their high-power codes on the US standard NFPA 1127, which has no legal force in Canada [2, 16].
- **In Canada the law comes from Transport Canada, not from any association.** The CLSO relies on associations to test fliers. Its 1999 letter named CAR and NAPAS, a Canadian society that followed the Tripoli process [2]. NAR is not named.
- **CAR/ACF honours NAR and Tripoli certifications** at its launches and offers a transfer to the equivalent CAR/ACF level: join, show proof of the level, and pass the Transport Canada part of the exam once [18, 21].
- **The level letters do not line up exactly.** CAR/ACF uses four levels where NAR and Tripoli use three, so the same motor may need a different level in each program (Figure 1.10).
- **Whatever the association, the Transport Canada requirements apply** to every high-power launch in Canada: the site, the airspace, the RSO and the safe distances do not change with the badge on your membership card.

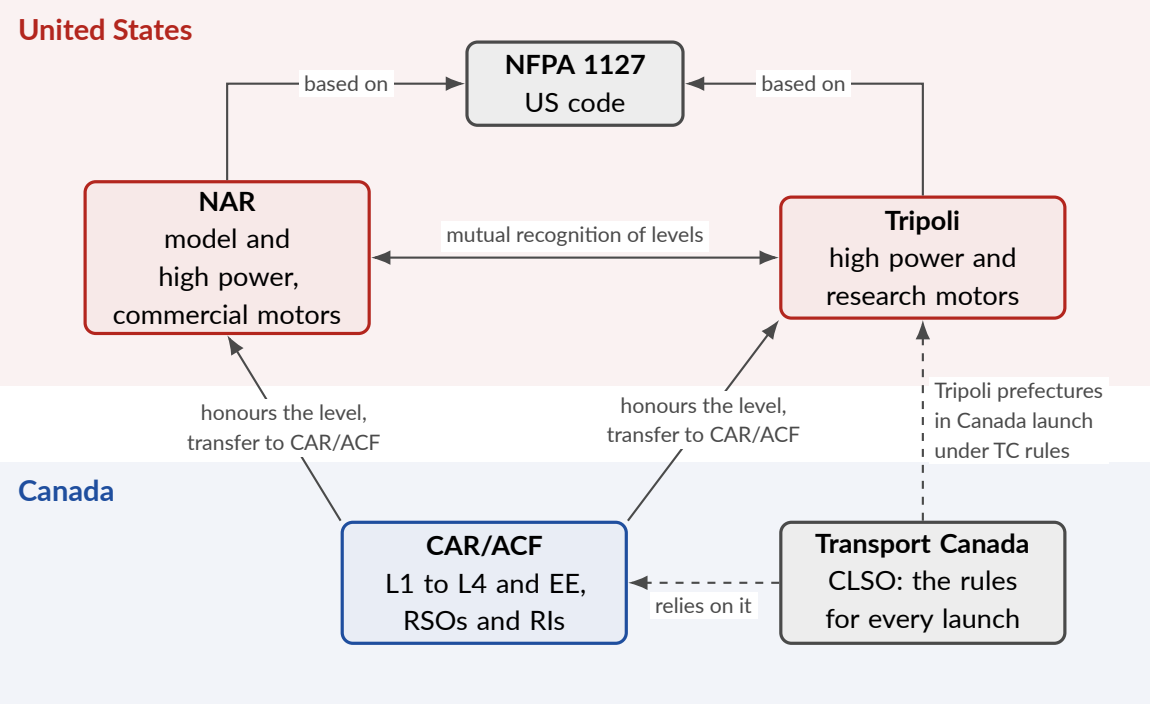


Figure 1.7. How the three associations relate. Solid arrows: recognition and shared standards; dashed arrows: the Canadian legal framework, which applies to everyone who launches in Canada [2, 16, 21].

Key Point: which association for me?

In Canada, CAR/ACF is the association built around the Canadian rules and the one this book follows. If you already hold a NAR or Tripoli level, you do not start again: CAR/ACF honours it and lets you transfer it. Whatever your membership, you fly under the Transport Canada requirements and the safety code of the association running the launch.

1.3 Tripoli Rocketry Association

The Tripoli Rocketry Association (TRA) began in December 1964 as a science club of junior high school students in Rillton, Pennsylvania, near Pittsburgh; Francis G. Graham is credited as its founder [8, 9]. It took the name “Tripoli” (roughly “three cities”) in 1967, because its members came from three towns [8]. After a 1985 meeting in Cincinnati it became a national organization, was incorporated on 18 July 1986, and put its Advanced Rocketry Safety Code into force on 1 January 1987 [8]. Today it is the largest high-power organization in the world, with local clubs called *prefectures* in the United States and in a number of other countries, Canada included [9].

Tripoli in one box

- **What it is:** a US-based association that certifies fliers for high-power motors and sanctions launches through its prefectures [9].
- **Certification ladder:** Level 1 (H and I motors), Level 2 (J, K and L motors, with a written exam), Level 3 (M, N and O motors, with a project overseen by a member of the Tripoli Technical Advisory Panel, TAP).

- **In Canada:** the 1999 Transport Canada letter recognized the North American Propulsion and Aerospace Society (NAPAS), which followed the Tripoli process [2]. CAR/ACF honours Tripoli (and NAR) certifications at CAR/ACF launches and offers a transfer path to the equivalent CAR/ACF level [18, 21].

Note that the Tripoli letter-to-level mapping is *not* the same as the CAR/ACF mapping. Figure 1.10 shows the two side by side: a Tripoli Level 1 flier may fly an I motor; a CAR/ACF Level 1 flier may not. Always check which program's privileges apply at the launch you are attending.

1.4 The Canadian Association of Rocketry (CAR/ACF)

1.4.1 Mandate

CAR/ACF is a federally registered not-for-profit organization headquartered in Edmonton, Alberta. Its stated purpose is to "promote development of Amateur Aerospace as a recognized sport and worthwhile amateur activity", through promotion, education and a dedication to safety and responsibility [7]. It is the nationally recognized body for amateur aerospace in Canada, represents non-military, non-commercial aerospace on Transport Canada's Canadian Aviation Regulatory Advisory Council (CARAC), and keeps working liaisons with Transport Canada and with Natural Resources Canada's Explosives Regulatory Division (NRCan) [7].

CAR/ACF in one box

- Founded **1965**; incorporated as CAR/ACF in 2009; headquarters in Edmonton [6, 7, 14].
- Publishes the **CAR/ACF High Power Rocketry Safety Code** (current edition v3.6, 16 February 2026), written to be consistent with Transport Canada's requirements [13, 22].
- Runs the **Level 1 to Level 4** HPR certification program and the **Electronics Endorsement** [20, 23].
- Insures sanctioned launches: every participant launching at a CAR/ACF-insured event must be a current member in good standing [21].

1.4.2 How CAR/ACF relates to Transport Canada

Transport Canada, through its Canadian Launch Safety Office (CLSO), must authorize every rocket launch in Canada except model rockets and fireworks [10]. The CLSO sets the *minimum* requirements for users, sites, airspace and safety, but it does not test individual fliers itself. In its letter of 21 June 1999 the CLSO wrote that it "relies on associations who have acceptable procedures in place for testing individuals" and named CAR and NAPAS [2]. Figure 1.8 shows the resulting chain of responsibility.

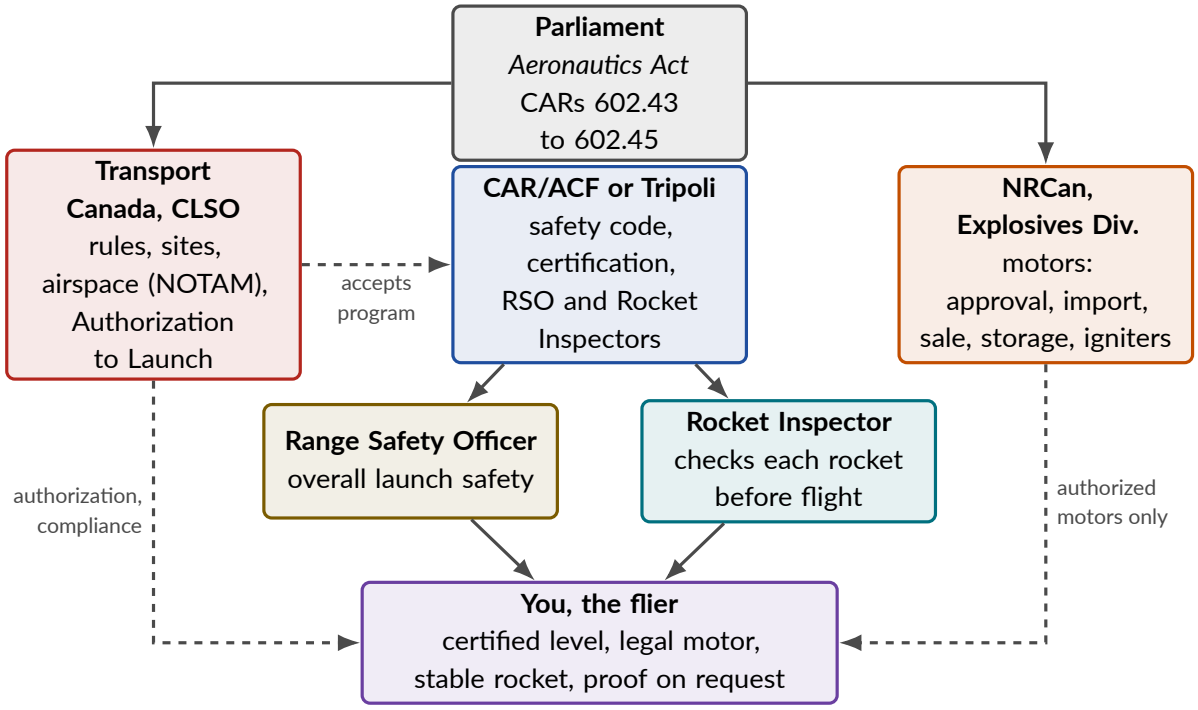


Figure 1.8. Who does what. Solid arrows: authority or delegation; dashed arrows: approvals and checks. Based on the 1999 letter of clarification and the Transport Canada requirements [2, 10].

Key Point: who does what

- **Transport Canada (CLSO)** defines the rules for launching, approves launch sites, arranges airspace (NOTAMs), approves an association's certification program and the Range Safety Officer, and issues the Authorization to Launch [2].
- **NRCan Explosives Division** approves specific rocket motors, their import, road transport (with Transport Canada), sale, storage, purchase and use, and pyrotechnic igniters [2].
- **CAR/ACF (or a Tripoli-process association)** certifies the individual flier, supplies the Rocket Inspector and Range Safety Officer, and makes sure launches follow the Transport Canada authorization [2, 13].
- An association's safety code binds only its members; the Transport Canada requirements bind **everyone** launching a high-power rocket in Canada [2].

1.5 Certification levels: L1, L2, L3 and L4

CAR/ACF certification is earned one level at a time, and each level must be flown before the next one can be attempted. Figure 1.9 is the whole path on one page.

Exam rules

The written exam is taken before the Level 1 flight and has two parts: 25 Transport Canada questions that must **all** be answered correctly, and CAR/ACF technical questions drawn from a 48-question pool. The 2020 program document sets the technical pass mark at **75%** [18]; some clubs brief candidates to aim for 80% or better to be safe, so check the current program document [19] with your examiner. The exam can be taken only once in 30 days [18]. Chapter 2

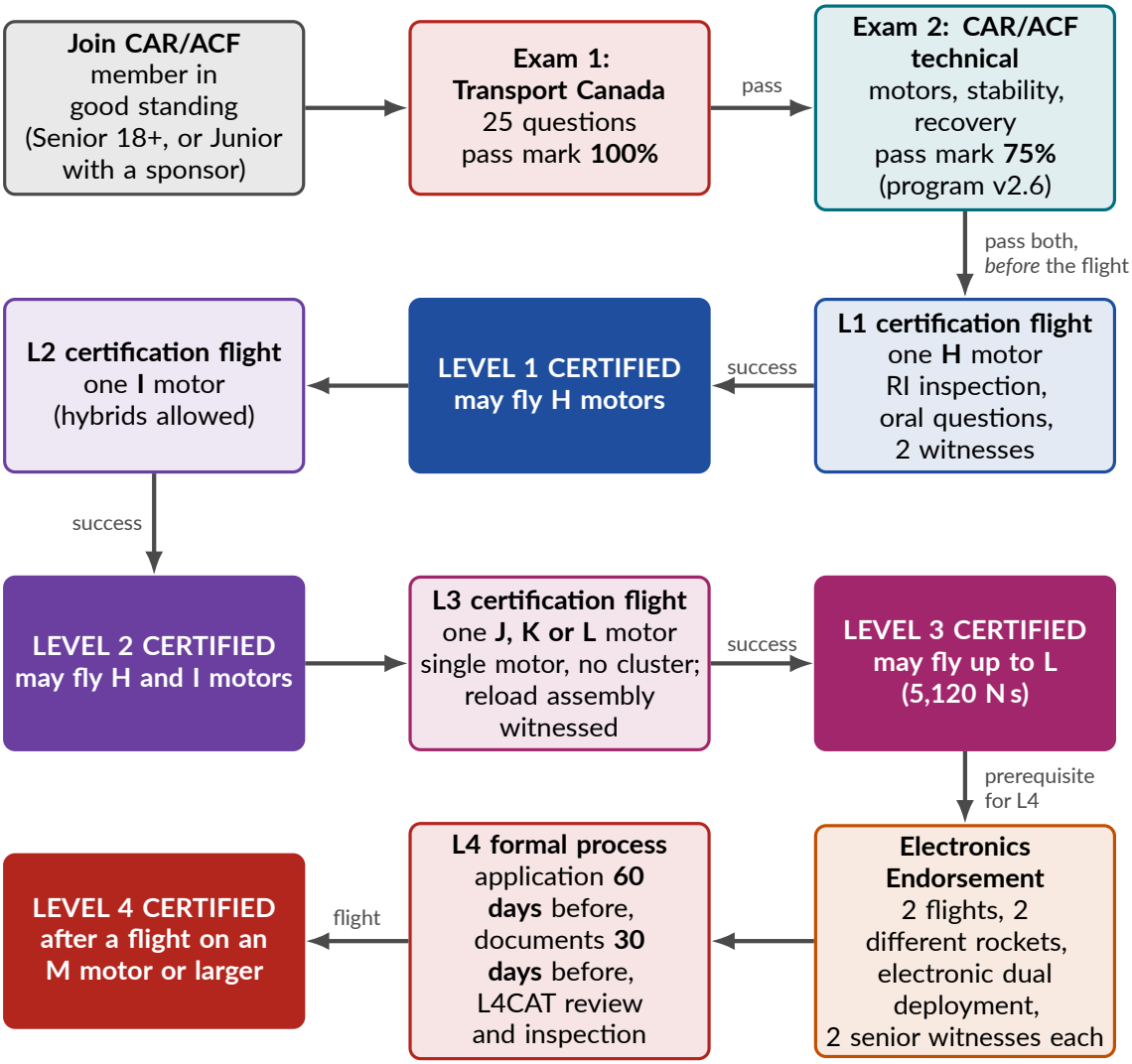


Figure 1.9. The CAR/ACF certification path. Coloured boxes are certification flights or programs; filled boxes are the levels you hold afterwards. A failed certification flight is simply re-flown after the problem is fixed. The exam may be taken only once in a 30-day period [18, 20, 23].

and Chapter 3 reproduce both practice exams with full solutions.

Each certification flight is witnessed by a certification team of two CAR/ACF members in good standing who are not related to the candidate, at least one of whom holds the same or a higher level. A Rocket Inspector performs the pre-flight inspection and asks oral questions (typically about the centre of gravity, the centre of pressure and the motor designation). The flight must show stability, deployment of the recovery system and a safe recovery; a catastrophic failure of the airframe, motor or recovery system disqualifies the attempt, and the rocket is inspected after landing for motor retention and flight damage [18].

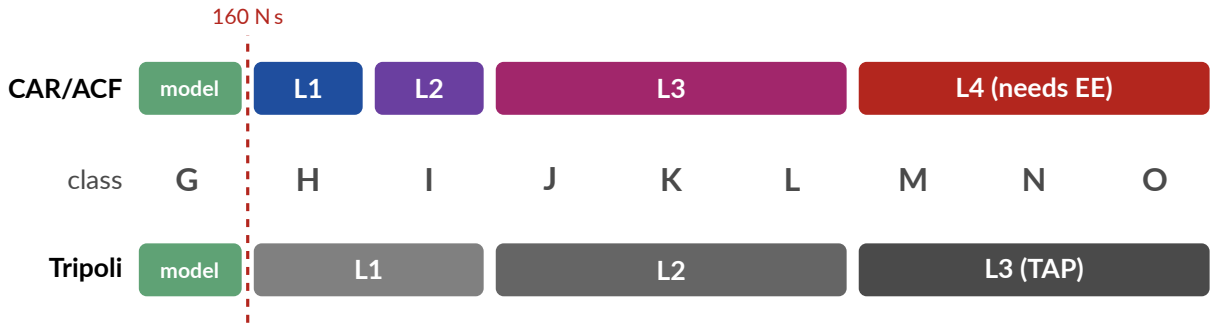


Figure 1.10. Which motor classes each level unlocks, CAR/ACF (top) versus Tripoli (bottom). The dashed line is the model/high-power boundary [9, 20].

CAR/ACF certification ladder

Level	Motors unlocked	Main requirements
L1	H (160.01 to 320 N s)	Written exam (TC part 100%, CAR part 75%); one successful certification flight on an H motor.
L2	I (320.01 to 640 N s) solids, and hybrids	Level 1; certification flight on an I motor.
L3	J, K, L (640.01 to 5,120 N s)	Level 2; certification flight on a single motor (no clusters or staging for the attempt); reload assembly witnessed.
L4	M and above (at least 5,120.01 N s, no clustering to reach it)	Level 3 and the **Electronics Endorsement**; formal design review (Section 1.5.1).

A certified member may fly motors up to the current certification level, never beyond it [18, 20].

Age rules

Standard candidates must be at least 18 years old. Junior HPR candidates may certify from age 14 for L1 and L2 and from age 16 for L3, with a senior sponsor certified to at least the same level who takes full responsibility, prepares and installs the motor. The junior builds the airframe. On turning 18, a junior must re-fly one rocket at the highest level achieved [18, 20].

1.5.1 The Level 4 process: an extra step above L3

Level 4 is not simply "the next letter". It is a design-review program run by an L4 certification committee (the L4CAT) and described in its own CAR/ACF L4 process document [20].

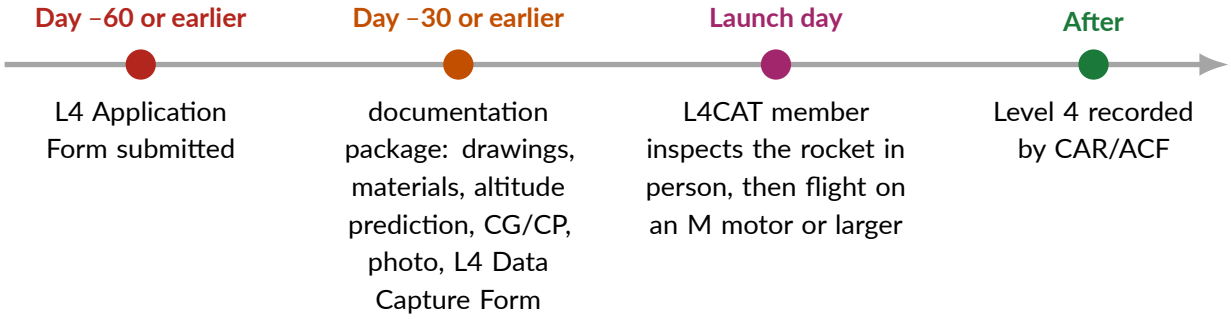


Figure 1.11. Level 4 timeline [20].

Level 4 requirements (CAR/ACF)

- Hold Level 3 **and** the Electronics Endorsement (a required prerequisite).
- Fly a motor of at least 5,120.01 N s (M class or larger); clustering to reach that total is not allowed.
- Submit the L4 Application Form at least **60 days** before the flight, and the documentation package at least **30 days** before.
- At least one L4CAT member must physically inspect the project before flight sign-off [20].

1.6 Electronics and the Electronics Endorsement

A motor's built-in ejection charge fires a fixed delay after burnout. That is simple and reliable, but it cannot know where apogee actually is, and it offers no backup. Onboard electronics solve both problems.

- A **barometric altimeter** senses the pressure drop during climb and the pressure rise after apogee; it fires an electric match (e-match) that ignites a small black-powder charge at the right moment.
- An **accelerometer-based** unit integrates acceleration and is useful where barometric data are unreliable (for example near Mach 1).
- **Dual deployment** uses two events: a small drogue at apogee so the rocket falls quickly and does not drift, then the main parachute at a low altitude for a gentle landing close to the pad (Figure 1.12).
- **Redundancy**: a second, independent altimeter (with its own battery, switch and charges) backs up the first; or electronics back up the motor ejection.

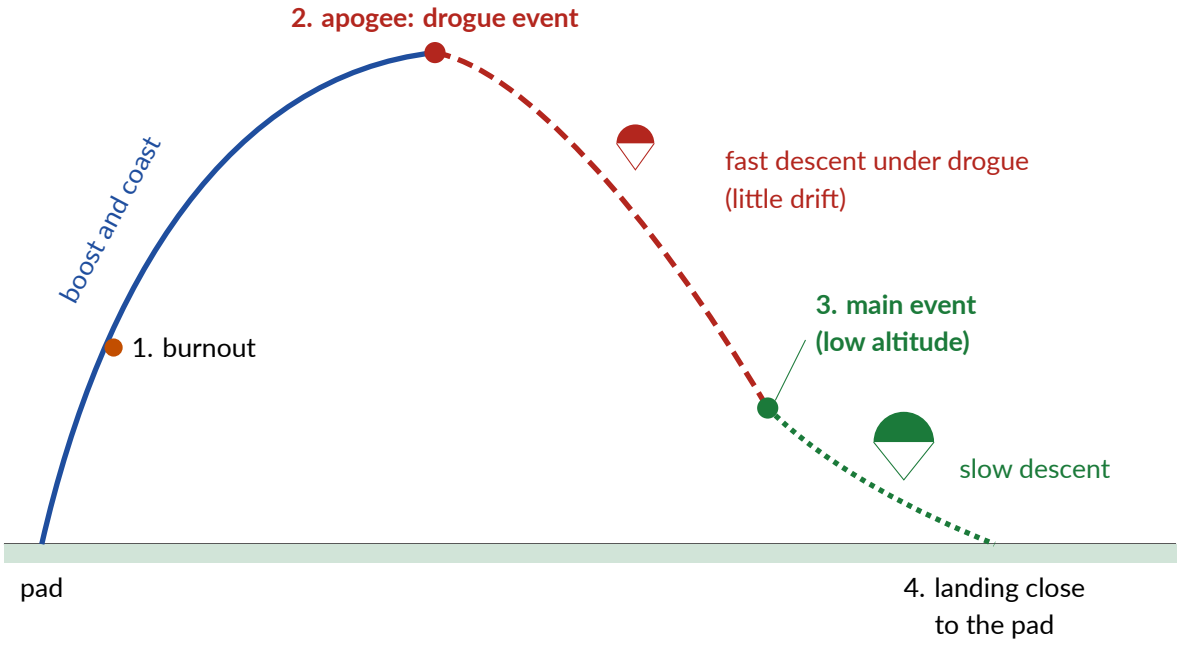


Figure 1.12. Dual-deployment flight profile, the configuration required for both Electronics Endorsement flights [23].

Rule: redundant deployment above 5 kg

All vehicles over **5 kg loaded mass** shall have a redundant deployment system, activated independently of and in addition to the motor ejection charge(s), that provides safe recovery if the primary deployment system fails [13].

The CAR/ACF Electronics Endorsement

- A certification track of its own that recognizes competence with flight electronics. It is not required for ordinary flights, but it **is the prerequisite for starting Level 4** and for serving on the L4 certification committee.
- No age restriction: senior and junior members may earn it.
- Two flights, each on a **different** rocket, both in a **dual-deployment** configuration with the deployment events controlled by the electronics.
- Both flights must reach an apogee where the apogee deployment can be seen from the ground; the recovery must work as designed with minimal damage.
- Two senior CAR/ACF members in good standing witness each flight; the signed form is sent to CAR/ACF headquarters with a small fee [23].

1.7 Membership and the student on-ramp

Joining CAR/ACF is done online through the association's website. Membership runs for one year and covers both model and high-power rocketry [24].

Membership essentials (CAR/ACF website, 2026)

- Individual Senior (18 and over): $65; Individual Junior (under 18): $15; Family bundle (up to 7 members): $80. Affiliate club memberships are also offered [24].
- You must be a member in good standing at the time of certification and to launch at any CAR/ACF-insured event [18, 21].
- Transferring a Tripoli or NAR level: join CAR/ACF, show proof of the existing level, and write the Transport Canada part of the exam the first time you transfer [21].
- A CAR/ACF certification flight does not have to be at a CAR/ACF launch: a launch sanctioned and insured by NAR, Tripoli or Launch Canada is accepted, and witnesses from those organizations may sign with an image of their membership card [25].

Many fliers start through a university or college team. Canadian student teams (for example the rocketry teams at McGill and SpaceConcordia in Montreal) design, build and fly high-power rockets and compete at events such as the Launch Canada Challenge [15]. Teams give students hands-on design reviews, access to certified mentors and a route to personal certification. A team's launches happen under a CAR/ACF (or Tripoli) sanctioned range with its RSO and Rocket Inspectors; team members who want to be the flier of record join the association and certify individually; and certified members of the team act as mentors and sponsors.

Key Point: teams and clubs

A student team is not a certifying body. Motors above the flier's level still require a certified flier of record, and every launch still runs under a Transport Canada authorization, an association's safety code and an RSO.

1.8 How the organizations are structured

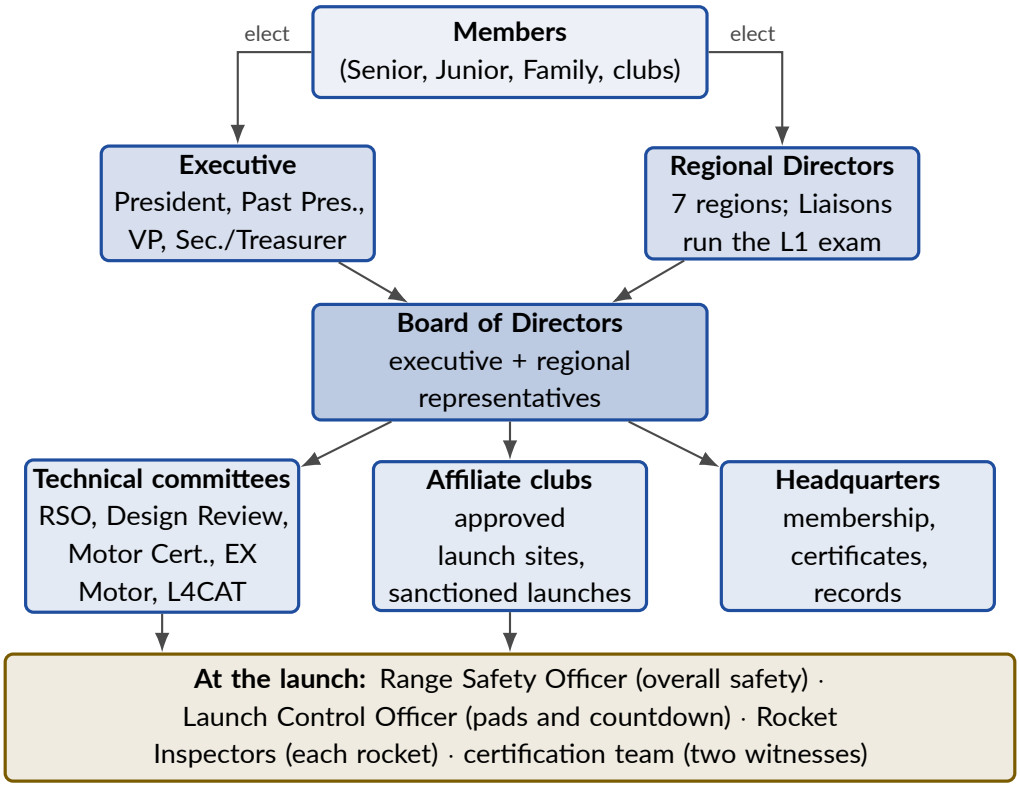


Figure 1.13. CAR/ACF organization, from members to the launch field [7, 13, 18].

CAR/ACF structure

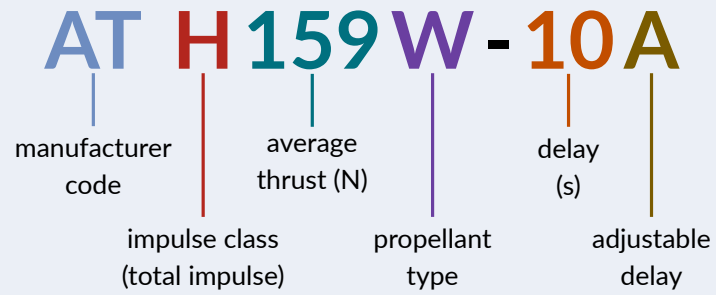
- **Executive:** President, Past President, Vice President, Secretary/Treasurer, elected by the members for two-year terms [7].
- **Board of Directors:** the executive plus representatives from seven regions. The Liaison or Regional Director administers the Level 1 exam [18].
- **Technical committees:** Range Safety Officer, Design Review (DRC), Motor Certification (MCC) and EX Motor committees; the L4CAT runs Level 4 reviews [7, 20].
- **Affiliate clubs:** local clubs that hold launches on CAR/ACF-approved sites [21].
- **At the field:** the **RSO** is responsible for the overall safety of the launch; the **Rocket Inspector** inspects every high-power rocket for stability and operation immediately before flight [13].

Tripoli is organized the same way at a larger scale: a national board, prefectures led by a Prefect, RSOs at each launch, and the Technical Advisory Panel for Level 3 projects.

1.9 Reading a motor designation

Every commercial motor carries a designation that encodes its performance. The full data (total impulse, burn time, thrust curve, propellant mass, maximum liftoff weight) is printed on the motor label, package or data sheet [26], and is also published on ThrustCurve.org for simulation [27].

Motor designation, field by field



- **Manufacturer code** (or product line), e.g. AT for AeroTech, CTI for Cesaroni. Some manufacturers also prefix the designation with the exact total impulse in N s.
- **Letter**: the total impulse class. Each letter doubles the upper limit of the one before it (Table 1.1).
- **Number**: the *average* thrust in newtons.
- **Suffix letters** after the thrust usually identify the propellant formulation.
- **Number after the dash**: the delay, in seconds, from burnout to the ejection charge. A trailing letter or "P" identifies adjustable or plugged (no ejection) versions, depending on the manufacturer. AeroTech's plugged H45W and I65W, for example, have no ejection charge at all [26].

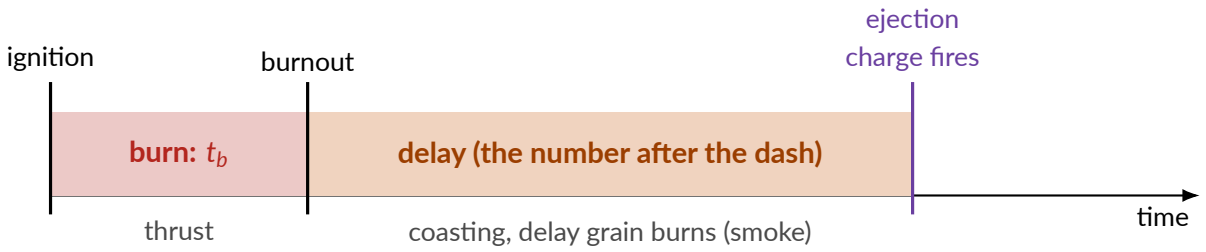


Figure 1.14. What the delay number measures: time from *burnout*, not from ignition, to the ejection charge.

Worked example: decoding "H159W-10A" (illustrative, not a catalogue motor)

1. **H**: total impulse between 160.01 and 320 N s. A CAR/ACF Level 1 motor.
2. **159**: average thrust $\bar{F} = 159$ N.
3. The data sheet lists a total impulse of $I_t = 273$ N s (the curve of Figure 1.15). The burn time follows directly:
$$t_b = \frac{I_t}{\bar{F}} = \frac{273\ \text{N s}}{159\ \text{N}} \longrightarrow t_b \approx 1.72\ \text{s}$$
4. **W**: the propellant formulation code used by that manufacturer.
5. **-10A**: ejection 10 s after burnout, adjustable downward by the flier with the manufacturer's tool (Chapter 6).

The same logic compares motors of one class: two full K motors of 2,560 N s, one a K1100 and one a K550, burn for $2560/1100 = 2.33$ s and $2560/550 = 4.65$ s. The higher the number,

the shorter and harder the push.

1.10 The thrust curve

A thrust curve is the measured thrust $F(t)$ of a motor, plotted against time from ignition to burnout. It is the motor's fingerprint: it tells you how hard the motor kicks off the rail, how long it pushes, and how much total "push" it delivers.

Total impulse is the area under the curve

$$I_t = \int_0^{t_b} F(t)\,\mathrm{d}t, \qquad \bar{F} = \frac{I_t}{t_b}.$$

Total impulse I_t (N s) decides the letter class. Average thrust $\bar{F}$ (N) is the number in the designation. For a quick check, $I_t \approx \bar{F}\, t_b$.

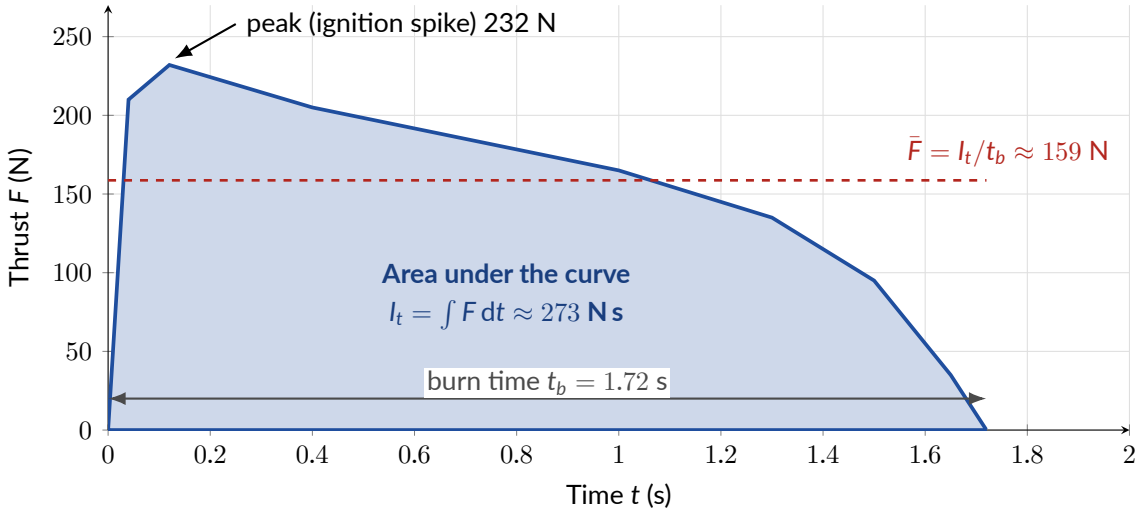


Figure 1.15. Representative H-class thrust curve (regressive profile). The shaded area is the total impulse; the dashed line is the average thrust that appears in the designation.

1.10.1 Regressive, neutral and progressive burns

The shape of the curve comes from how the burning surface of the propellant grain changes with time. Figure 1.16 compares the three families.

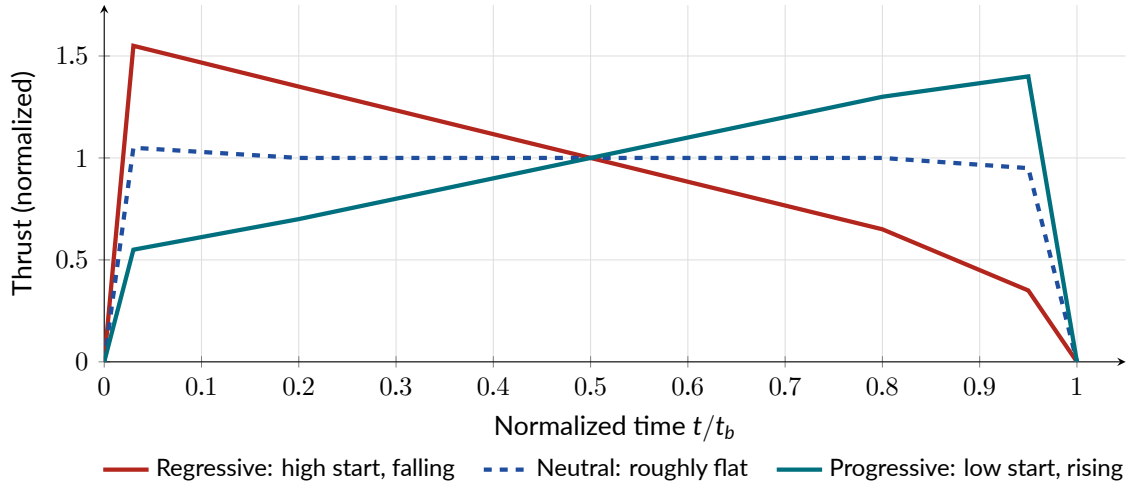


Figure 1.16. Three burn profiles with the same total impulse (equal areas).

Burn profiles

- **Regressive**: high initial thrust relative to the ending thrust.
- **Progressive**: low initial thrust relative to the ending thrust.
- For a heavy rocket with a marginal thrust-to-weight ratio, the safest choice is a **regressive** motor: the high initial thrust gets it off the rail quickly and fast enough to be aerodynamically stable [17].

1.11 Motor and rocket classification

Transport Canada classifies high-power motors by total impulse (Table 1 of the Transport Canada requirements [10]). Each class spans a factor of two, so on a logarithmic scale the classes are evenly spaced (Figure 1.17). Below H (160 N s and less) are the model rocket classes A to G.

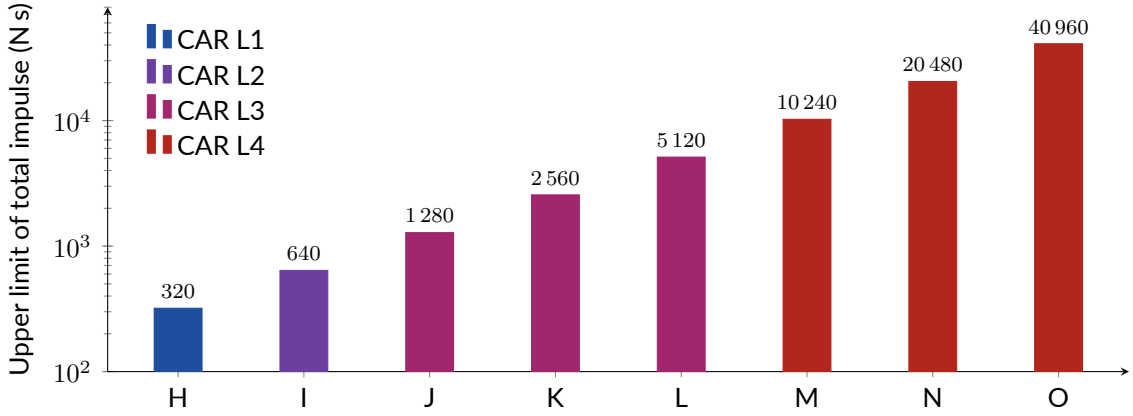


Figure 1.17. Each letter doubles the impulse. Bars coloured by the CAR/ACF level required [10, 20].

High-power motor classes (Transport Canada Table 1, CAR/ACF code)

Table 1.1. Motor impulse classes, CAR/ACF levels and minimum safe distances [10, 13].

Class	Total impulse (N s)	CAR/ACF level	Safe distance, single / complex (m)
H	> 160 to 320	L1	30 / 60
I	> 320 to 640	L2	60 / 100
J	> 640 to 1 280	L3	60 / 100
K	> 1 280 to 2 560	L3	60 / 100
L	> 2 560 to 5 120	L3	100 / 150
M	> 5 120 to 10 240	L4	200 / 300
N	> 10 240 to 20 480	L4	300 / 500
O	> 20 480 to 40 960	L4	300 / 500

The ceiling for a (non-advanced) high-power rocket is an installed total impulse of **40,960 N s**; above that is Advanced HPR, which needs a separate technical review [22].

What makes a rocket “high power” (Transport Canada)

A rocket is high power if it has motors contributing an installed total impulse greater than **160 N s** (up to 40,960 N s), *or* weighs more than **1.5 kg (3.3 lb)**. It must carry a parachute or other device to retard its descent, and be built of lightweight materials able to withstand the stresses of ignition and flight. A model rocket stays at or below 160 N s *and* at or below 1 500 g gross weight [10].

1.11.1 What the class means for altitude and weight

The letter sets the energy budget. Two consequences follow directly:

Weight: the 4:1 thrust-to-weight rule

CAR/ACF Safety Code v3.6: “I will not launch my rocket if the minimum thrust ratio is under 4:1 without explicit permission from the RSO” [13]. The largest liftoff mass a motor can safely lift is

$$m_{\max} = \frac{\bar{F}}{4\,g}.$$

Examples: H65 lifts at most $65/(4 \times 9.8) = 1.66$ kg; I211 lifts 5.38 kg; L1000 lifts 25.5 kg; M1439 lifts 36.7 kg [17]. The manufacturer’s maximum liftoff weight must also never be exceeded [10].

Altitude and site size

Doubling the impulse class roughly doubles the energy available, so each step up the alphabet pushes the expected apogee, and therefore the required launch site size (Table 3 of the Transport Canada requirements, Chapter 2) and the minimum safe distance, sharply upward. For example, the H-class rocket worked out in **??** reaches about 700 m (about 2 300 ft), which needs a site at least 500 m across; a rocket expected above 12,001 ft is assessed case by case [10].

1.12 Practice: motor names and total impulse

Try all five problems first. The solutions start on a new page.

Practice problems N1 to N5

Problem N1: decode a designation

A motor is labelled **J350W-M**. (a) What range of total impulse can it have? (b) What is its average thrust? (c) Which CAR/ACF level do you need to fly it, and which Tripoli level? (d) If the data sheet gives $I_t = 697$ N s, what is the burn time?

Problem N2: check a label

A motor is sold as **K550-14**, with a burn time of 3.8 s. Estimate its total impulse. Is the letter consistent? When does the ejection charge fire, measured from ignition?

Problem N3: which level?

For each motor, give the class and the CAR/ACF and Tripoli levels needed: G80, H128, I284, J350, K1100, L1000, M1315.

Problem N4: how heavy can the rocket be?

Using the 4:1 rule, what is the largest liftoff mass an I284 can fly? And an H128?

Problem N5: installed total impulse of a cluster

A rocket carries one central motor of 900 N s and two outboard motors of 250 N s each, all ignited at liftoff. (a) What is its installed total impulse and class? (b) What is the minimum safe distance? (c) Could this rocket be your Level 3 certification flight?

Solutions to the practice problems

✓ Solutions N1 to N5

Solution N1

J350W-M: impulse range, average thrust, levels, burn time for 697 N s.

(a) The letter J means more than 640 and up to 1,280 N s. (b) The number is the average thrust: $\bar{F} = 350$ N. (c) J is a CAR/ACF Level 3 motor (J, K, L) and a Tripoli Level 2 motor (J, K, L). (d) The burn time is the total impulse shared out at the average thrust:

$$t_b = \frac{I_t}{\bar{F}} = \frac{697\ \text{N s}}{350\ \text{N}} \longrightarrow \boxed{t_b = 1.99\ \text{s}}$$

The trailing "M" is a manufacturer suffix (for AeroTech, a medium-length delay range); check the data sheet for the actual delay.

Solution N2

K550-14 with a 3.8 s burn: total impulse, consistency, ejection time.

The total impulse is the average thrust multiplied by the burn time:

$$I_t \approx \bar{F}\, t_b = 550\ \text{N} \times 3.8\ \text{s} \longrightarrow \boxed{I_t \approx 2\,090\ \text{N s}}$$

K covers 1,280 to 2,560 N s, so the letter is consistent. The delay counts from burnout, so the ejection charge fires after the burn *plus* the delay:

$$t_{ej} = t_b + t_d = 3.8\ \text{s} + 14\ \text{s} \longrightarrow \boxed{t_{ej} = 17.8\ \text{s after ignition}}$$

Solution N3

Class and level for G80, H128, I284, J350, K1100, L1000, M1315.

Motor	Class	CAR/ACF	Tripoli
G80	G	model rocket, no HPR level	model
H128	H	L1	L1
I284	I	L2	L1
J350	J	L3	L2
K1100	K	L3	L2
L1000	L	L3	L2
M1315	M	L4	L3

Solution N4

Largest liftoff mass with the 4:1 rule for I284 and H128.

The 4:1 rule says the average thrust must be at least four times the weight, so the heaviest

rocket is the one whose weight is exactly a quarter of the thrust. For the I284:

$$m_{\max} = \frac{\bar{F}}{4g} = \frac{284\ \text{N}}{4 \times 9.81\ \text{m/s}^2} = \frac{284}{39.24} \longrightarrow \boxed{m_{\max} = 7.24\ \text{kg}}$$

and for the H128:

$$m_{\max} = \frac{128\ \text{N}}{4 \times 9.81\ \text{m/s}^2} = \frac{128}{39.24} \longrightarrow \boxed{m_{\max} = 3.26\ \text{kg}}$$

The manufacturer's maximum liftoff weight may be lower; the smaller limit wins.

Solution N5

Cluster: 900 + 2 × 250 N s.

(a) The installed total impulse is the *sum* over all motors ignited in flight (TC definition [10]):

$$I_{t,\text{installed}} = 900 + 2 \times 250\ \text{N s} \longrightarrow \boxed{I_{t,\text{installed}} = 1\,400\ \text{N s},\ \text{K class}}$$

(b) A cluster is a *complex* rocket, so use the complex column of Table 4: **100 m** for K. (c) No: the CAR/ACF Level 3 attempt must be flown on a single motor, without clusters or staging [18].

CHAPTER 2

Regulations

Every high-power launch in Canada happens under federal aviation law. The document that turns that law into practical rules is Transport Canada's *Requirements for Launching High Power Rockets in Canada*, issued by the Canadian Launch Safety Office on 4 January 2000. Every flier needs to know it well, together with the June 1999 letter of clarification and the Application for Authorization to Launch: these are the rules that keep people, property and aircraft safe at every launch you attend. This chapter walks through all three in the order of the Transport Canada document (sections 1 to 12), explaining what each rule means and why it exists, then compares them with the current CAR/ACF Safety Code. The chapter closes with the Transport Canada practice questions and a worked answer key, so you can check your understanding once you have learned the material. Section numbers in square brackets, such as [9.8], point to paragraphs of the Transport Canada document.

2.1 Legal basis [1]

The *Aeronautics Act* gives the Minister of Transport regulatory oversight of rocket launches in Canada. Three sections of the Canadian Aviation Regulations (CARs) apply:

Canadian Aviation Regulations 602.43 to 602.45

602.43 Rockets
No person shall launch a rocket, other than a model rocket or a rocket of a type used in a fireworks display, except in accordance with an authorization issued by the Minister pursuant to Section 602.44.

602.44 Authorization by the Minister
The Minister may issue an authorization where the launch of the rocket is in the public interest and is not likely to affect aviation safety.

602.45 Model aircraft, kites and model rockets
No person shall fly a model aircraft or a kite or launch a model rocket or a rocket of a type used in a fireworks display into cloud or in a manner that is or is likely to be hazardous to aviation safety.

§ Who authorizes what

- The Minister of Transport must authorize **all** rocket launches in Canada, **except** model rockets and rockets used in fireworks displays.
- The **Canadian Launch Safety Office (CLSO)** is the Transport Canada office that fulfils this obligation: safety analyses of launch proposals, authorizing launch sites, and monitoring launch operations for compliance.
- The Transport Canada requirements are **legally binding** on everyone, member of a rocketry

association or not, because they support the Canadian Aviation Document "Rocket (High Power) Launch Authorization". An association's safety code is enforceable only on its members and on people flying under its oversight.

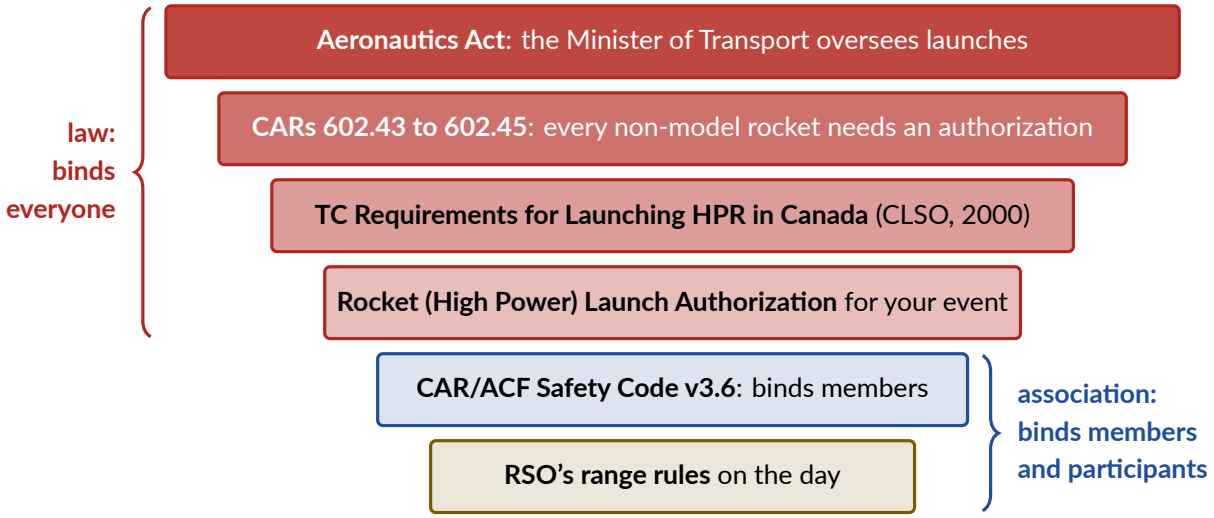


Figure 2.1. From the most general rule to the most specific. Everything above the blue box is federal law and binds anyone who launches; the association code and the RSO's rules add to it, never subtract from it [1, 2, 10, 11, 13].

The 1999 letter of clarification also split the work between the two federal agencies. Knowing which agency looks after what tells you whom to ask about a motor, a site or a launch.

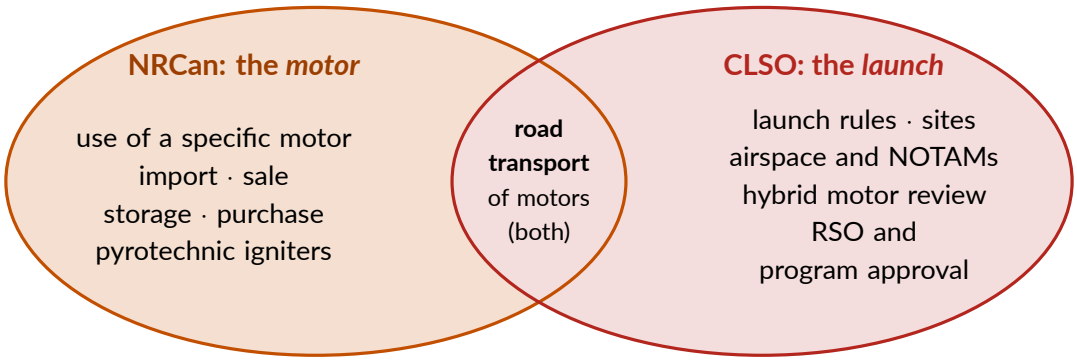


Figure 2.2. A memory aid: NRCan looks after the *thing* (the motor as an explosive), the CLSO after the *act* (the launch) [2].

Division of responsibilities (1999 letter)

Natural Resources Canada, Explosives Division

- approves use of specific rocket motors (those classified as explosive)
- approves importation of rocket motors
- approves transportation of rocket motors by road (with Transport Canada)
- approves sale of rocket motors
- approves storage of rocket motors
- approves Canadians to purchase and use rocket motors
- approves pyrotechnic igniters

Transport Canada, Canadian Launch Safety Office

- defines the requirements for launching: user, launch site, airspace and safety
- monitors compliance at launches
- reviews and analyzes information on **hybrid** motors to decide on an authorization to launch (this is not approval for sale)
- defines airspace requirements and arranges airspace restrictions, advisories and **NOTAMs**
- approves launch sites
- approves the acceptability of an association's certification programs
- approves the acceptability of the Range Safety Officer

§ How an individual becomes certified (1999 letter)

The CLSO does not test individuals itself; it relies on associations with acceptable procedures. CAR certification is obtained by **successfully completing an exam administered by CAR and then successfully launching a rocket appropriate to the level sought**. The associations must also make sure a qualified Range Safety Officer inspects the rocket before launch and that all launches occur from approved sites.

2.2 Scope [2]

The requirements apply to all launch operations of high-power rocket vehicles in Canada [2.1]. They are a guideline to launch proponents for safe operations that protect aviation and the public [2.2], based on Canadian aviation and explosives regulations, industry standards such as **NFPA 1127**, and the safety requirements of rocketry associations such as CAR, the Tripoli Rocketry Association (US) and the National Association of Rocketry (US) [2.3]. NFPA 1127 has legal force only in the United States, not in Canada.

2.3 Key terms in plain language [3]

The Transport Canada document opens with a long list of definitions. The ones below are the ones you must be able to use; the wording is simplified but faithful.

Definitions: people, paperwork and permission

Authorization to Launch
An approval issued by the CLSO, on behalf of the Minister of Transport, for the launch of a rocket or a series of rockets of similar type.

Certified User
A person who has met the requirements of NRCan's Explosives Division and is capable of all the requirements in the Transport Canada document.

Range Safety Officer (RSO)
A certified user of high-power motors whose duty during launch activities is to ensure safe operations, oversee public and participant safety, and confirm compliance with the requirements and the Authorization to Launch.

Deviation
A known hardware or procedural non-compliance where the intended requirement is still met by another means **with no increase in risk**. The RSO can approve it, but it must be justified, documented, signed and available to the CLSO on request.

Waiver
A non-compliance **discovered after** operations or the authorization process have begun. It needs a justification and an analysis of any added risk, must be approved by the RSO **and** the Manager, CLSO, and applies to a single instance only.

Shall / Should
"Shall" is a mandatory requirement. "Should" is a recommendation.

Third Party
Anyone not involved with the authorized launch, including on-site government employees and contractors and people from other launch firms not involved.

Liability
A legal obligation to pay claims for bodily injury, death or property damage resulting from authorized launch activities.

Casualty
A person suffering death or serious injury from an accident associated with the launch; for third-party liability purposes its cost is estimated at $1 million.

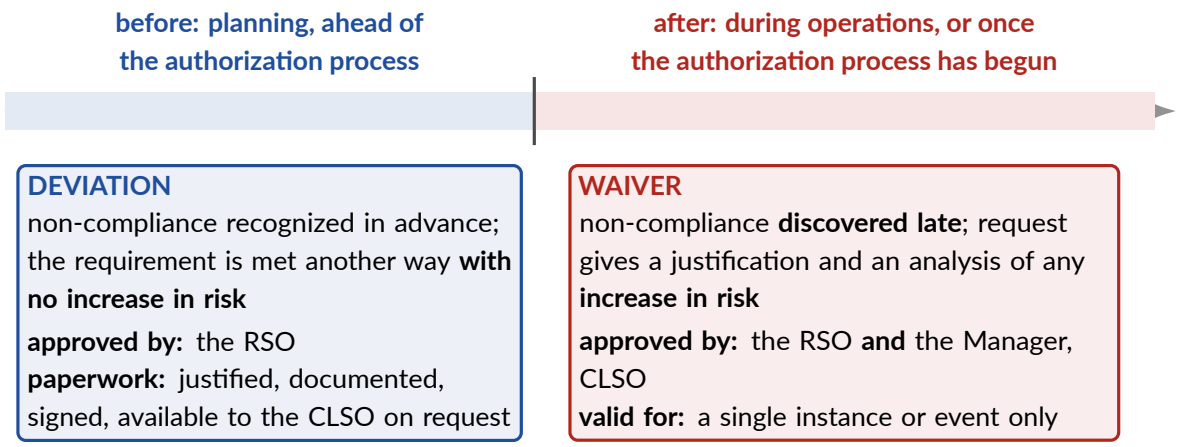


Figure 2.3. Deviation versus waiver: when the problem is found decides which one you need [10].

Definitions: rockets, motors and impulse

Installed Total Impulse
The **sum of the total impulses of all motors** installed in a rocket and intended to be ignited during launch and flight.

Complex Rocket
A multi-staged vehicle or one propelled by a cluster of motors (Table 4 footnote). The CAR/ACF code adds: or any rocket the RSO considers complex.

Hybrid Rocket Motor
A motor in which the fuel is in a different physical state from the oxidizer (for example a solid plastic fuel grain with liquid nitrous oxide).

Reloadable Rocket Motor
A motor whose casing the user loads, reloads and reuses with a manufacturer's **motor reloading kit** (propellant, nozzle, insulation, delay and ejection charge, igniter and seals).

Rocket Motor / Rocket Engine
"Motor" is customary for solid propellant (the case is both propellant tank and combustion chamber); "engine" for liquid propellant.

Structural Parts
The load-bearing parts: nose cone, body tube and fins.

Thrust
Force from a propulsion system: mass of gas ejected per unit time times exhaust velocity.

Production Lot
Motors, reload kits or hybrid grains made in one work shift, on the same equipment, from the same propellant batch.

Definitions: places and envelopes

Launch Site
The whole authorized area: preparation, launch, recovery, public viewing and parking.

Launch Area
The area designated by the RSO in which rockets are launched.

Defined Safety Envelope
A three-dimensional space from the ground up to above the vehicle's maximum altitude, including space for re-entry and recovery, sized so that no part of the vehicle can leave it whether the flight is nominal, off-nominal or terminated.

Predicted Flight Safety Envelope
A pre-determined three-dimensional area providing for the safe launch and flight of a high-power rocket.

Defined Cleared Area
An area cleared of all persons and third-party property that could be damaged by parts of the vehicle impacting there.

Prevailing Visibility
The greatest distance that can be seen throughout at least half of the horizon circle (not necessarily continuous).

Launch Activities
Everything from the arrival of the vehicle, payload or personnel on site until the vehicle is recovered and the personnel have left, whichever is later.

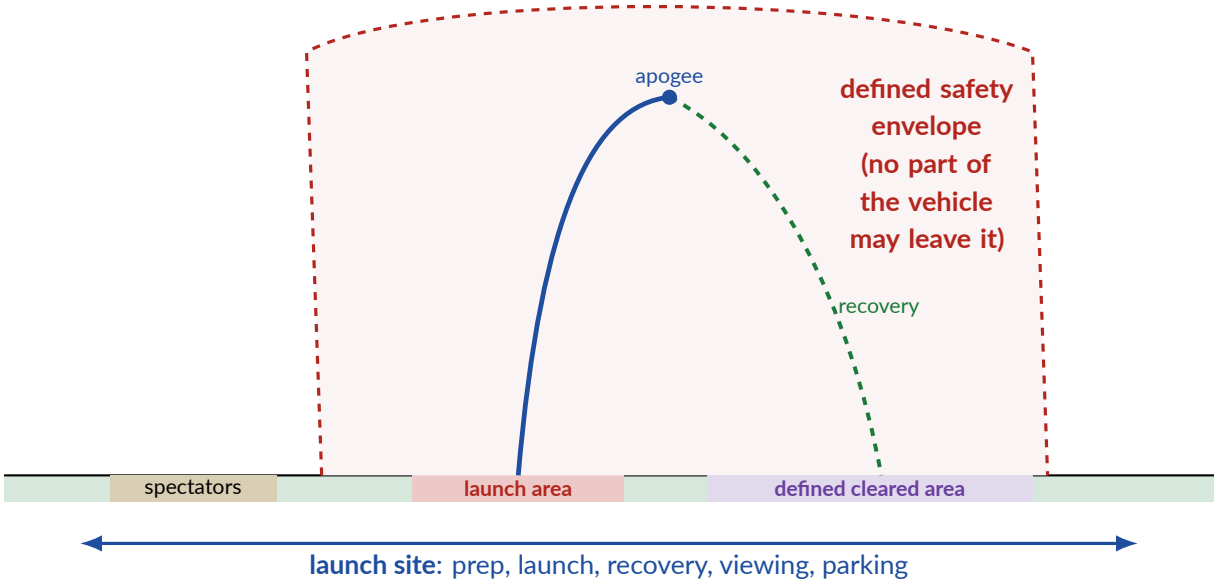


Figure 2.4. The places defined in section 3 of the Transport Canada requirements, seen from the side [10].

2.4 High-power rockets and motors [4]

§ High-Power Rocket versus Model Rocket

	Model Rocket	High-Power Rocket
Total impulse	$\leq$ **160 N s**	> **160 N s and** $\leq$ **40,960 N s** (installed total)
Weight	gross weight incl. motors $\leq$ **1 500 g (3.3 lb)**	> **1.5 kg (3.3 lb)**
Recovery	parachute or other device to retard descent	parachute or other device so it does not create a hazard to persons or property
Structure		lightweight materials able to withstand ignition and flight stresses
Primary use		education and/or recreation
Authorization	exempt from 602.43 (1998 exemption letter)	Authorization to Launch required

A rocket is high power if it exceeds **either** threshold [4.1.1]. A motor above 40,960 N s, or an installed total above it, is outside the high-power requirements altogether.

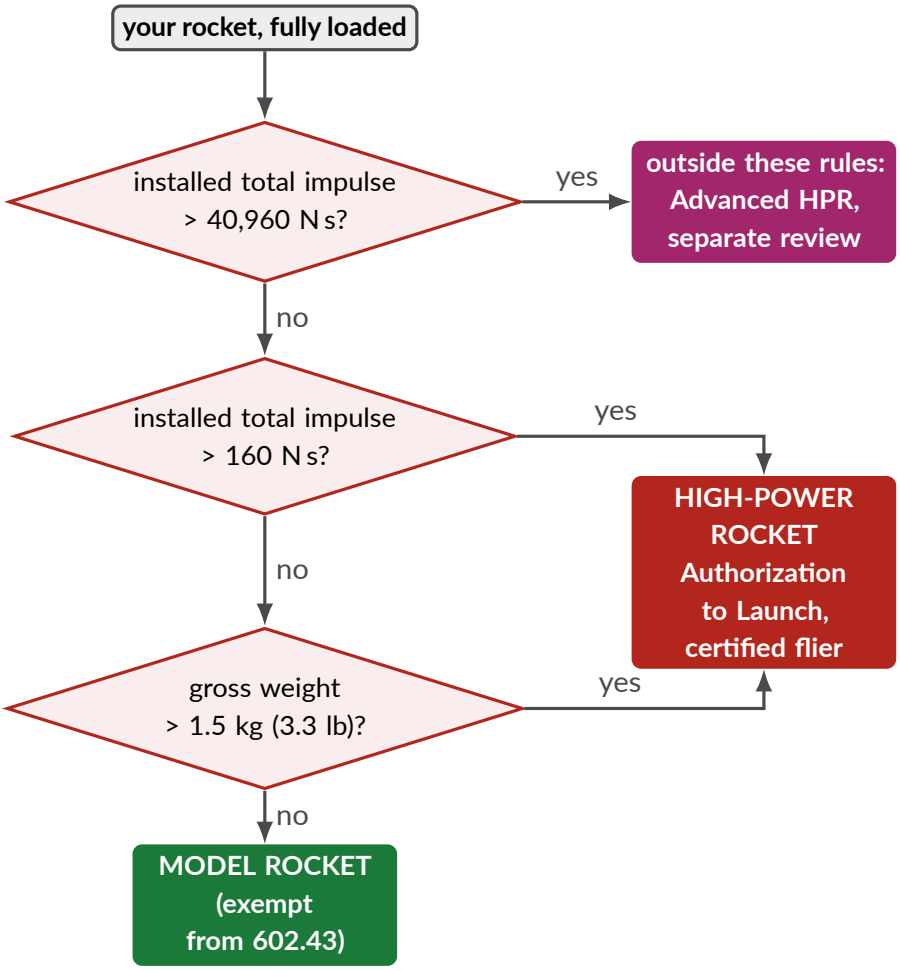


Figure 2.5. Is it a model rocket or a high-power rocket? Either threshold is enough [10, 22].

Motor classification by total impulse (Table 1)

Motor type	Total impulse (N s)
H	>160 to 320
I	>320 to 640
J	>640 to 1,280
K	>1,280 to 2,560
L	>2,560 to 5,120
M	>5,120 to 10,240
N	>10,240 to 20,480
O	>20,480 to 40,960

Motor authorization [4.3], [9.1]

- All **solid-propellant** motors and all pyrotechnic substances used in high-power rockets must be authorized by **NRCan** or covered by an NRCan General Import Permit. All other motors (for example hybrids) must be authorized by **Transport Canada**.

- Fliers shall use only **commercially manufactured** motors, reload kits or components authorized by NRCan and/or the CLSO, except by deviation approval.

Minimum motor qualification tests [4.4]

- Solid motor case temperature during firing shall not exceed **200 °C**.
- A case overpressure failure must not throw fragments beyond **one half of the minimum safe distance** for that motor.
- Solid motors must fail primarily along the **longitudinal axis** (nozzle or bulkhead expelled), and must not ignite spontaneously from air, water or shock.
- Casings must not rupture, bulge or burn through; propellant must keep adhesion and stay free of cracks and voids from **−30 °C to +30 °C**.
- Motors must perform within design burn time and impulse and reliably eject and deploy the recovery system.
- Only proven or approved igniters, which reliably ignite the motor when the firing circuit is actuated [4.5].

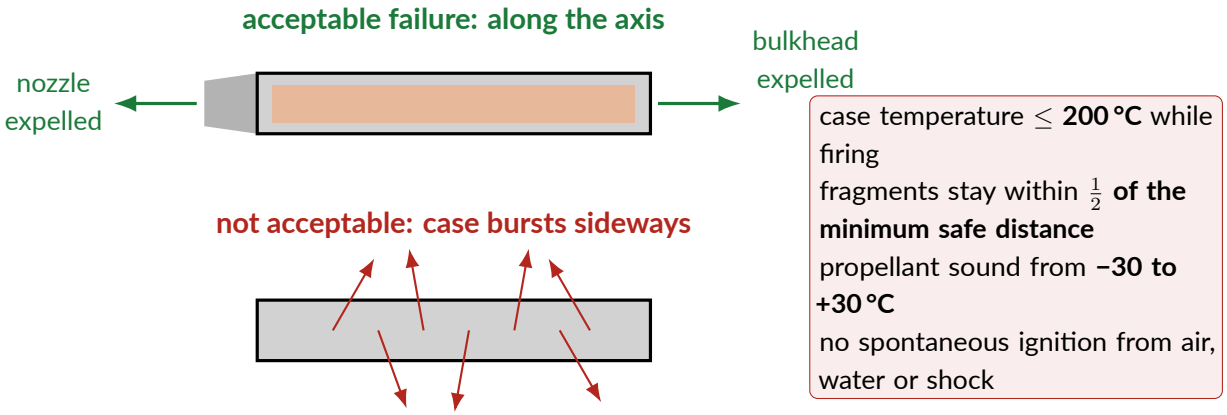


Figure 2.6. What motor qualification testing guarantees (Transport Canada [4.4]): if a motor does fail, it fails end-on, which is why you never stand in line with a rocket's nozzle or nose on the pad [10].

2.5 Requirements for individuals [5]

§ Every person launching a high-power rocket shall

[5.1] comply with all federal, provincial, municipal and local laws, rules, regulations, statutes and ordinances (the responsibility rests with **the individual launching**);

[5.2] launch only in accordance with the certification and/or qualification requirements for the rockets being launched;

[5.3] make proof of qualification and/or certification available to **Transport Canada representatives** on request;

[5.4] launch only under the terms of an **Authorization to Launch** issued by the CLSO;

[5.5] obtain **CLSO approval** for any change made after the Launch Authorization is issued.

2.6 Launch site requirements [6]

The site must be an open outdoor area where overhead hazards such as trees, power lines and buildings will not affect safety [6.1], where launches will not create hazards to people, property, or land, water or air traffic [6.2], and where the **owner or lessee has given permission** for launch and recovery [6.3]. It must be large enough for launch *and recovery* of every rocket flown [6.4].

§ Launch site dimensions (Table 3)

Expected altitude (ft)	Minimum site dimension
0 to 3,000	500 m
3,001 to 6,000	1 km
6,001 to 10,000	2 km
10,001 to 12,000	3 km
12,001 and over	to be determined, case by case

- For a circular site the dimension is the **diameter**; for a rectangle it is the **shortest side** [6.5].
- The minimum dimension is set by the **expected altitude**, not by the motor's impulse or the safe-distance table.
- The minimum dimension may never be less than **one half of the estimated maximum altitude** [6.6], and never less than **500 m** [6.7].

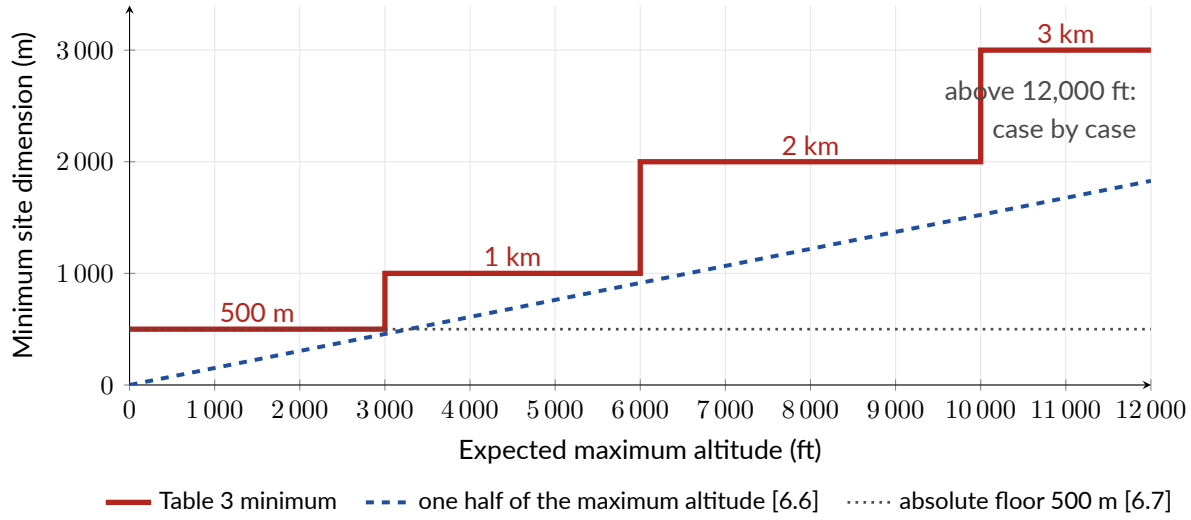


Figure 2.7. Launch site size against expected altitude. The site must satisfy all three lines: use the *largest* [10].

2.7 Launcher requirements [7]

The launcher shall

- be positioned so that recovery stays within the authorized site [7.1];

- be more than **500 m** from any **occupied building** or any **public road with more than 10 vehicles per hour** [7.2];
- sit in a cleared area of at least **5 m radius**, free of loose objects and flammable material such as dead grass [7.3];
- give **rigid guidance** so the rocket flies within its predicted flight safety envelope [7.4];
- include a **blast deflector** or other means to keep exhaust off the ground and flammable material [7.5];
- restrict the launch angle to within **20° of vertical** [7.6].

The rod or rail *should* be raised above eye level or capped with a shield between launches [7.7].

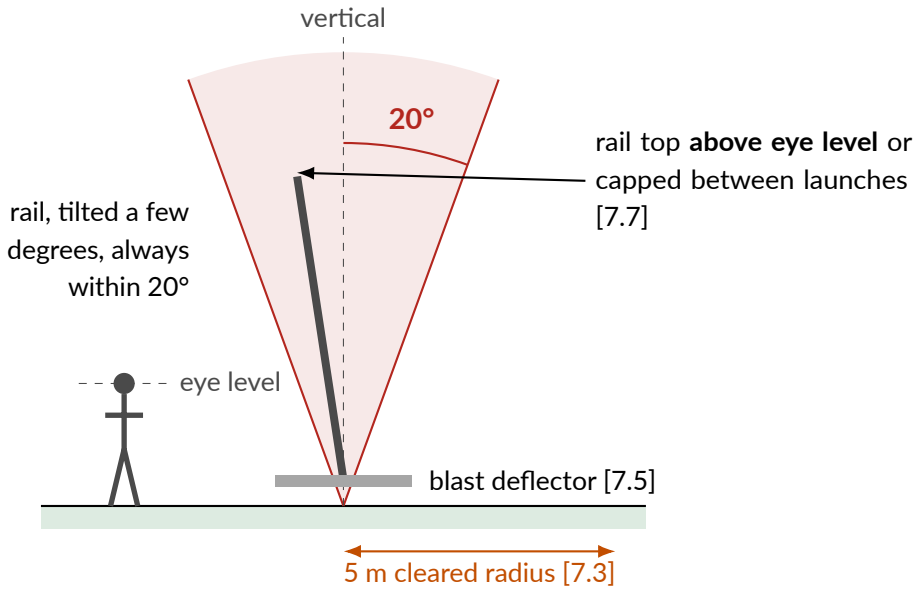


Figure 2.8. Launcher requirements at a glance [10].

2.8 Launch site safety requirements [8]

Who may stand where [8.1] to [8.3]

- Nobody may be closer to a launch than the person launching the rocket, unless authorized by the RSO.
- Nobody may be closer than the minimum safe distance of Table 4 (below).
- Spectators stay in the area the RSO designates as safe for public viewing.

§ Minimum safe distances (Table 4)

Motor type	Total impulse (N s)	Minimum distance (m)	Complex rocket (m)
H	>160 to 320	30	60
I	>320 to 640	60	100
J	>640 to 1,280	60	100
K	>1,280 to 2,560	60	100
L	>2,560 to 5,120	100	150
M	>5,120 to 10,240	200	300
N	>10,240 to 20,480	300	500
O	>20,480 to 40,960	300	500

A **complex** rocket is multi-staged or clustered. The firing system itself must be at least this far from the pad [9.19].

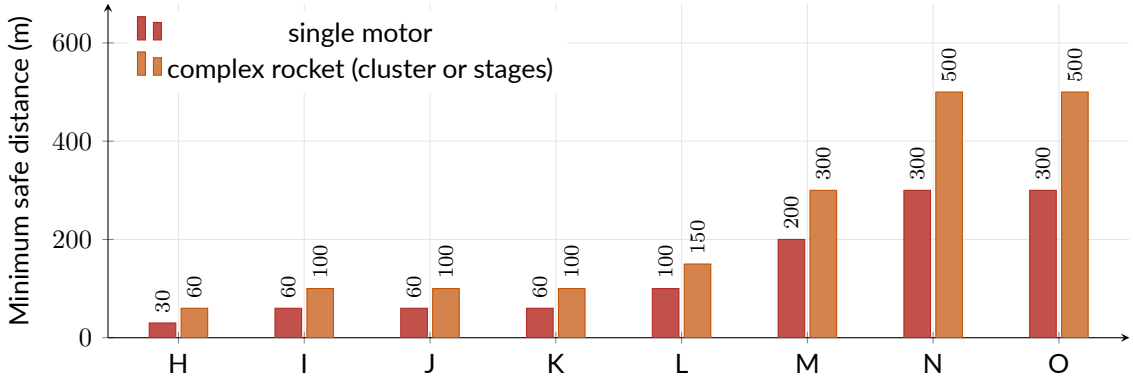


Figure 2.9. Table 4 as a chart: distance steps up at L, M and N [10].

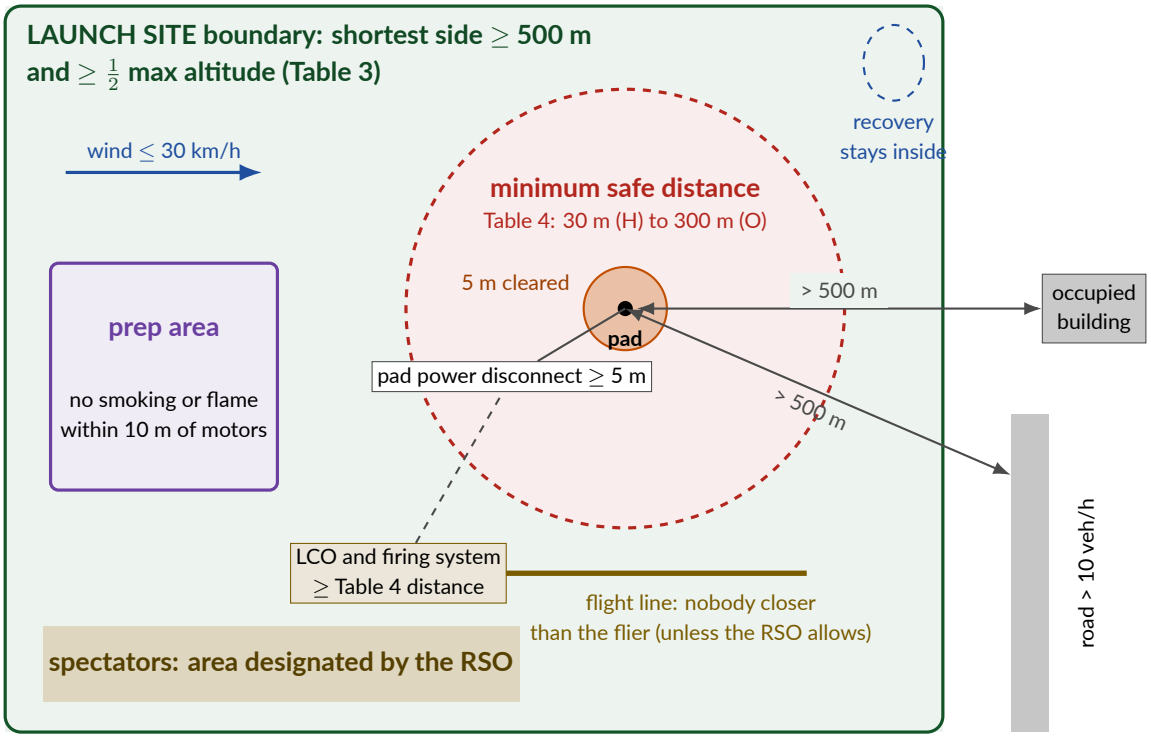


Figure 2.10. A high-power launch site from above (schematic, not to scale). Every number on it comes from sections 6 to 9 of the Transport Canada requirements [10].

2.9 Launch requirements and restrictions [9]

Section 9 is the heart of the Transport Canada document: it is what you actually do at the range. The 25 rules are grouped here by theme.

2.9.1 The rocket and its motor

§ Before the rocket may fly

- It has been **inspected and approved immediately before flight** by an authorized RSO [9.2] (at CAR/ACF launches this job is done by a Rocket Inspector).
- Its **stability** has been determined; CP and CG documentation is available to the RSO or Transport Canada on request [9.3].
- Its gross liftoff weight does not exceed the motor manufacturer's **maximum liftoff weight**, with documentation available on request [9.4].
- Its installed total impulse is **not more than 40,960 N s** [9.5].
- It carries a system that **effectively retards its descent** [9.6].
- It carries **no explosive, incendiary or live vertebrate animal** payload [9.15].

2.9.2 Weather and airspace

§ Weather and airspace minimums

- **Never into cloud** [9.8]. No exception, not even with an RSO watching for aircraft.
- **Prevailing visibility at least 5 km**; below 5 km, no launch [9.9].
- **Surface wind not greater than 30 km/h**; above 30 km/h, no launch [9.10].
- Never create a **hazard to aircraft** [9.13].
- The RSO cancels the launch when the wind exceeds 30 km/h or visibility drops below 5 km.

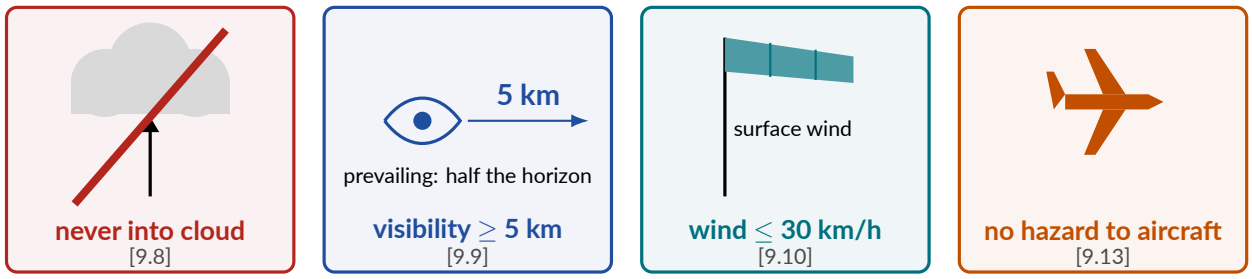


Figure 2.11. The four weather and airspace limits. If any one is not met, nobody launches, and the RSO cancels the launch [10, 13].

2.9.3 Direction and flight operations

Flight operations

- Only one high-power rocket in flight at a time, unless the one in flight has safely deployed its recovery system and the RSO judges the rest of its flight harmless [9.7].
- Never launch horizontally, or at an angle that would carry a **ballistic** (failed recovery) rocket beyond the site boundary [9.11].
- Never launch as a weapon at a surface or air target [9.12].
- Launch only under the oversight and approval of the RSO or as specified in the Rocket (High Power) Launch Authorization [9.14].
- No smoking or open flame in the launch or prep areas or within **10 m** of any motor, reload kit or pyrotechnic module [9.16].
- A countdown of at least **5 seconds**, audible in the launch, spectator and parking areas [9.17].

2.9.4 Firing systems and igniters

Ignition rules

- Ignition only by a **remote-controlled electrical firing system** with a firing switch that **returns to OFF when released** and a **safety interlock** [9.18].
- The firing system is no closer to the pad than the Table 4 distance [9.19].

- A way to **disconnect all power to the pad**, located a **minimum of 5 m** from the pad [9.20].
- Igniters are installed **only at the pad** (or where the RSO designates), as close to launch time as practical, with the rocket pointed in a safe direction; the same applies to removing them after an abort [9.21].

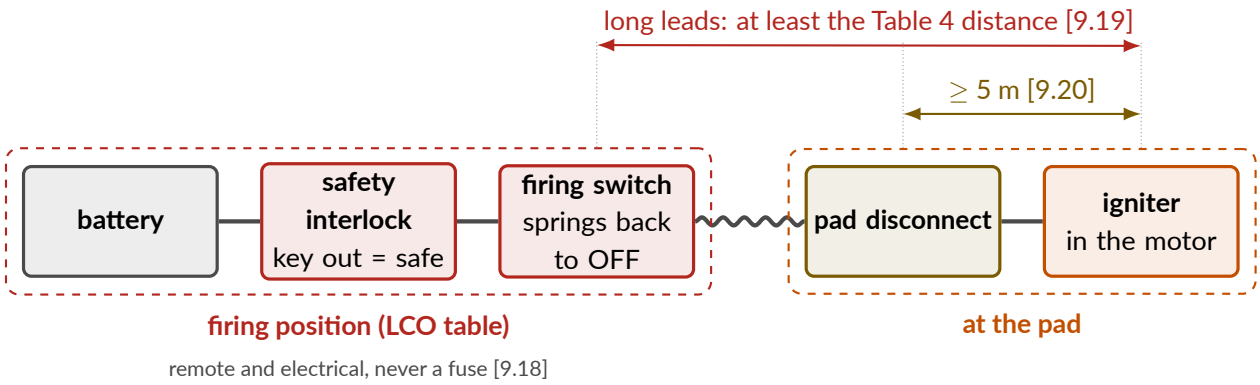


Figure 2.12. A compliant electrical firing system, from the LCO table to the motor [10, 13].

§ Misfire procedure [9.22], [9.23]

1. Remove the safety interlock **or** disconnect the battery from the ignition system.
2. Wait **5 minutes**.
3. The RSO authorizes **a single person** to approach and inspect.
4. After inspection, either fit a new igniter for another attempt, or remove the igniter and take the rocket away. Only the minimum number of people approach.

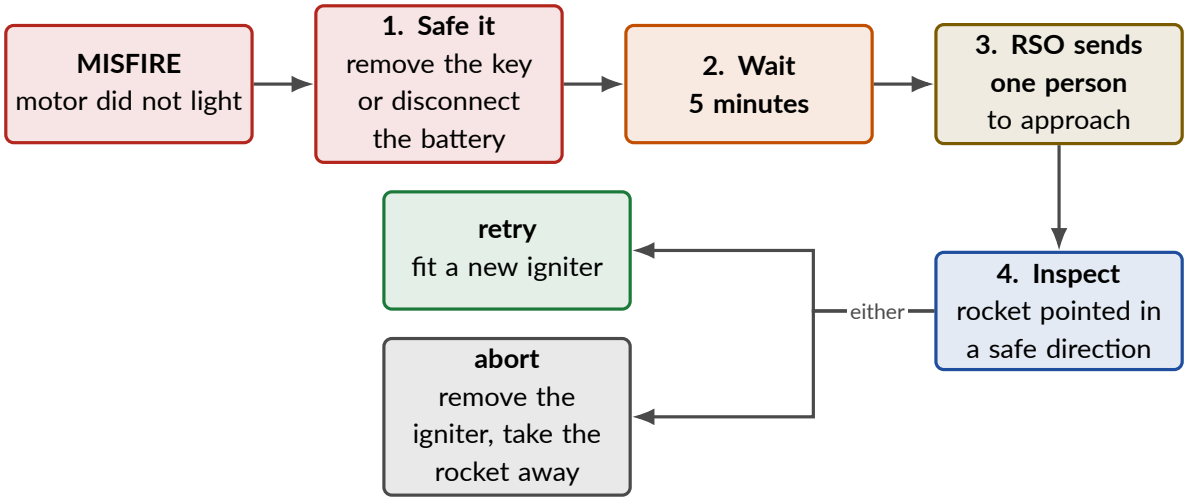


Figure 2.13. Misfire procedure. Only the minimum number of people approach the rocket [10, 13].

2.9.5 Recovery

After the flight

- Never try to **catch** a high-power rocket as it comes down [9.24].

- Never retrieve a rocket from a hazardous location such as a **power line** without approval of the appropriate authority [9.25].

2.10 Range Safety Officer requirements [10]

Anyone acting as RSO must meet qualification and certification requirements acceptable to the CLSO [10.1].

RSO responsibilities [10.2]

10.2.1 protect people, property and the environment from risks during pre-launch, launch, flight and recovery;

10.2.2 develop and implement ground and flight safety rules consistent with the law and accepted safe practice;

10.2.3 review and approve the schedule of launch operations;

10.2.4 ensure people launching are appropriately qualified and/or authorized;

10.2.5 review and approve launch operations and procedures;

10.2.6 monitor operations and control surveillance areas to minimize risk;

10.2.7 monitor countdowns and procedures for holds and misfires;

10.2.8 supervise and allocate safety roles to other safety monitors;

10.2.9 develop, approve and/or verify accident contingency plans;

10.2.10 after a mishap, secure the site and impound all relevant data and materials for investigation.

Monitoring vehicle traffic is *not* one of the RSO's listed duties.

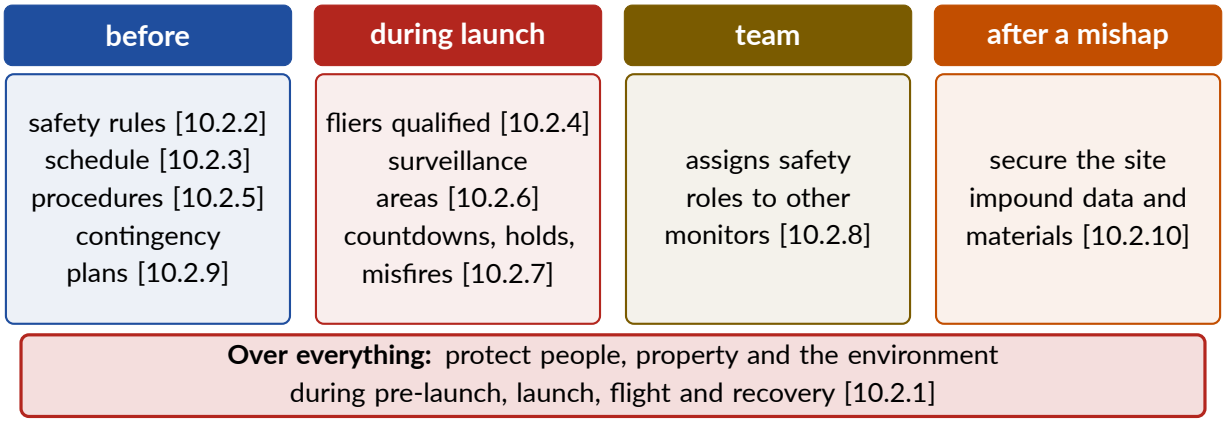


Figure 2.14. The ten RSO responsibilities grouped by when they happen [10].

2.11 Public safety and liability [11]

§ Liability

- Launches shall not create a hazard to persons or property [11.1].
- After an accident or incident, anyone launching or charged with safety oversight **could be held responsible and liable** [11.2].
- It is **recommended** ("should", not "shall") that everyone launching or overseeing safety carry **third-party liability insurance of $1,000,000 or more** [11.3].

2.12 Contact information [12]

The 2000 document lists the CLSO in Winnipeg (344 Edmonton Street) and NRCan's Explosives Division in Ottawa (580 Booth Street) as contacts. These addresses and telephone numbers date from 2000; use current Transport Canada and NRCan websites, or your CAR/ACF regional director, for present-day contacts.

2.13 The Application for Authorization to Launch

Launch organizers apply to Transport Canada with form 26-0659, "Application for Authorization to Launch High Power and Advanced High Power Rocket(s)". Even as a flier it is worth knowing what it contains, because it explains what the organizer promises on your behalf: the organizer or RSO must make sure the landowner has given permission, that every flier is a member in good standing of CAR/ACF or another recognized association, and that the launch complies with the Transport Canada requirements.

What the application asks for

A. Event information
proposed dates and times, number of launches, maximum altitude requested (above sea level), sponsoring association.

B. Applicant or sponsor
name, address, contacts, membership number, certifications.

C. Range Safety Officer
name, club, certifications, description of experience.

D. Safety information
launch and recovery area dimensions; distances from the launcher to the public viewing area, the nearest building and the nearest road; association sanction and insurance; liability coverage; emergency plan and telephone numbers (police, hospital, fire department); fire extinguisher.

E. Site information
location, latitude and longitude, and a site layout drawing showing boundaries, buildings, transportation routes, residential areas, airports or aerodromes and navigational aids.

F. Declaration
signed commitment to follow the association's standards and codes, CAR 602.43 and all other laws; attached approvals from the property owner, the airport/aerodrome operator and neighbouring owners where applicable.

2.14 The CAR/ACF Safety Code: 2005 edition versus v3.6 (2026)

The study guide annex reproduces the 2005 edition of the CAR/ACF High Power Rocketry Safety Code. The current edition is v3.6 of 16 February 2026. Most text is unchanged; the differences below matter.

§ What changed in the CAR/ACF Safety Code

Topic	2005 edition (study guide annex)	v3.6, 16 Feb 2026 (current)
Thrust-to-weight	not stated	"I will not launch my rocket if the minimum thrust ratio is under **4:1** without explicit permission from the RSO" (added 2011).
Pad power disconnect	located "*within* 5 meters" of the pad	located "**greater than 5 meters**" from the pad (changed 2016); now matches TC [9.20].
Cloud, visibility, wind	no cloud, 5 km, 30 km/h	same limits, "unless specified otherwise in the Rocket (High Power) Launch Authorization" (updated October 2025).
Aircraft nearby	hazard to aircraft only	adds: no launch "when an aircraft is flying nearby, or when flight is unduly hazardous to persons or property".
Pyrotechnic protection	pyro systems mechanically protected against EMI and heat	line no longer present (still good practice, Chapter 4).
Motor authority	NRCan and/or Transport Canada	NRCan Explosives Regulatory Division (NRC/ERD) and/or TC.

§ CAR/ACF-specific rules not in the Transport Canada document

- Inspection before flight by an authorized **Rocket Inspector (RI)**.
- Reloadable motors used only as the manufacturer directs; **no modification** of cases, closures, grains, delays, nozzles, liners or seals, and no reuse of parts not meant to be reused. (Single-use motors may *not* be reloaded.)
- Wadding, if needed, must be **flame resistant and biodegradable** (no fibreglass).
- **Redundant deployment** for vehicles over **5 kg** loaded mass.
- Only manufacturer-recommended electric igniters that ignite the motor within **3 seconds** of pressing the launch switch.

- Fire control on hand: a **class A extinguisher and/or at least 20 L of water**.

2.15 Quick reference: every number on one page

§ The numbers to know by heart

Model rocket upper limit (impulse / gross weight)	160 N s / 1 500 g
High-power range of installed total impulse	>160 to 40,960 N s
Motor case temperature limit (solid)	200 °C
Propellant qualification temperature range	−30 to +30 °C
Minimum launch site dimension	500 m, and $\geq \frac{1}{2}$ max altitude
Launcher distance from occupied building / busy road (>10 veh/h)	>500 m
Cleared radius around the launcher	5 m
Maximum launch angle from vertical	20°
Minimum visibility	5 km
Maximum surface wind	30 km/h
No smoking / open flame near motors	10 m
Minimum countdown	5 s
Pad power disconnect from the pad	at least 5 m
Misfire wait before approaching	5 min, one person
Redundant deployment required above (CAR/ACF)	5 kg loaded mass
Minimum thrust-to-weight ratio (CAR/ACF)	4:1
Igniter must light the motor within (CAR/ACF)	3 s
Fire control (CAR/ACF)	class A extinguisher and/or 20 L water
Recommended third-party liability insurance	$1,000,000

2.16 Transport Canada High Power Rocket Exam: Practice Exam

Reproduced from the CAR/ACF Study Guide (rev. 2018/08). The real exam requires **100%** on these questions. Try all 25 before looking at the key in Section 2.17.

Transport Canada - High Power Rocket Exam Questions Practice Exam

Question 1

The Aeronautics Act and the Canadian Aviation Regulations provide regulatory authority to the Minister of Transport for authorization of all rocket launches in Canada excepting model rockets or those used in fireworks.

a) True
b) False

Question 2

Transport Canada's Requirements for Launching High Power Rockets in Canada require a launch proponent to:

a) obtain an Authorization to Launch from the Minister of Transport
b) obtain approval of the Range Safety Officer prior to launch
c) ensure the rocket has an appropriate device for retarding its descent
d) all of the above

Question 3

The total impulse of a rocket is:

a) the thrust generated by the largest motor used on the rocket
b) the analysis of thrust as determined by the Range Safety Officer
c) the sum of the total impulses of all the rocket motors used on the rocket
d) a & c only

Question 4

A high power rocket

a) must not be launched into cloud
b) must not create a hazard to aviation
c) must not be launched without an altimeter to determine the altitude it reaches
d) a & b only

Question 5

A High Power Rocket is considered to be any rocket:

a) weighing more than 1500 grams (3.3 lbs)
b) having a total impulse greater than 160 Newton-seconds
c) requiring a means of retarding its rate of descent to earth
d) all of the above

Question 6

The Authorization to Launch High Power Rockets document must be made available upon request to a federal or provincial police officer and:

a) a designated Transport Canada inspector
b) a CAR/ACF Headquarter personnel
c) a designated representative of the Land owner
d) all of the above

Question 7

All High Power Rocket motors used in rockets proposed for launch in Canada shall be approved or authorized by:

a) Natural Resources Canada - Explosives Division and/or Transport Canada
b) Canadian Association of Rocketry/Association canadienne de fuséonautique
c) Tripoli Rocketry Association
d) All of the above

Question 8

The responsibility for ensuring compliance with all federal, provincial, municipal and local laws, rules, regulations and ordinances rests with:

a) the Range Safety Officer in charge of a launch meet
b) Transport Canada's Canadian Launch Safety Office
c) the organizer of the launch meet
d) the individual launching a rocket

Question 9

An individual launching a rocket shall:

a) make available to Transport Canada representatives, upon request, proof of qualifications and/or certification
b) do so only in accordance with a Transport Canada authorization to launch
c) do so only in accordance with the certification and qualification requirements for the rocket(s) to be launched
d) all of the above

Question 10

A site to be used for launching high power rockets shall:

a) be approved by the local zoning authority
b) be sized to include the launch, flight, recovery and public viewing areas
c) be located at least 16 kilometers (10 miles) from any airport
d) all the above

Question 11

A launch site shall:

a) have a dimension of not less than 500 m.
b) be cleared of all trees
c) be accessible to the public
d) have the launch pads situated adjacent to a windsock or anemometer

Question 12

A launcher shall:

a) ensure the rocket launches vertically in winds over 10 km/h
b) be located more than 500 m from any occupied building
c) deflect rocket exhaust away from public areas
d) be located adjacent to the site boundary to maximize the recovery area

Question 13

A launch proponent may launch a rocket into a cloud if the Range Safety Officer verifies there are no aircraft approaching the launch site.

a) True
b) False

Question 14

Launchers shall be restricted to within _____ degrees of vertical.

a) 5
b) 10
c) 15
d) 20

Question 15

A complex high power rocket is:

a) very difficult to manufacture
b) restricted to "J" class and above
c) multi-staged or propelled by more than one motor
d) all of the above

Question 16

Under what atmospheric conditions will a rocket launch be cancelled?

a) surface winds are greater than 30 km/h
b) prevailing visibility is 5 km
c) temperature is above 30 °C
d) during rain showers

Question 17

A Range Safety Officer is responsible for performing the following duties:

a) protecting people, property and environment from safety risks that may arise during pre-launch, launch, and flight recovery of high power rockets
b) monitoring vehicle traffic at the rocket launch
c) ensuring persons launching high power rockets are appropriately qualified and/or certified
d) a & c

Question 18

Natural Resources Canada is the regulatory government agency responsible for:

a) approvals for use of rocket launch sites for proposed rocket launches
b) approvals for use of rocket motors
c) approvals for storage of rocket motors
d) b & c

Question 19

Canadian Launch Safety Office is the regulatory government agency responsible for:

a) issuing approvals for pyrotechnic igniters
b) issuing approvals for importation of rocket motors
c) defining airspace requirements for rocket launches and arrange for airspace restricting/advisories and issuance of a Notice To Airmen (NOTAM)
d) all of the above

Question 20

The minimum dimensions of the launch site are established in accordance with the minimum safe distances specified for each rocket motor type's total impulse.

a) True
b) False

Question 21

The government agency responsible for reviewing and analyzing information submitted pertaining to hybrid rocket motors to determine acceptability for issuance of an authorization to launch is:

a) Natural Resources Canada - Explosives Branch
b) Transport Canada
c) Natural Resources Canada
d) a and b

Question 22

Certification for individuals requesting approval to launch high power rockets in Canada is obtained by:

a) successful completion of a written exam and the building and flying of a rocket containing a high power motor
b) no requirements are necessary to launch high power rockets
c) approval received once written exam is completed and a pass mark obtained
d) the ability to successfully build and fly a rocket containing a high power rocket motor

Question 23

The launch organizer or the Range Safety Officer of the rocket launch must:

a) ensure the landowner has given permission for use of the land
b) ensure all individuals launching from the site are members in good standing of the CAR/ACF or other recognized association/club
c) ensure the launch is in compliance with Transport Canada's guidelines "Requirements for Launching High Power Rockets in Canada"

d) all of the above

Question 24

When is the Range Safety Officer responsible for taking action to cancel the rocket launch:

a) when there is no Transport Canada inspector at the launch
b) when the surface winds are greater than 30km/h
c) when prevailing visibility is less than 5km
d) b & c

Question 25

All participants must be located in safe area, away from rocket launches according to the minimum safety distances for each rocket motor type.

a) True
b) False

2.17 Transport Canada High Power Rocket Exam: Solutions

Each question is repeated with the correct choice highlighted in green, followed by an explanation and the source. The "Source" line is the citation given in the official answer key of the CAR/ACF Study Guide [17]; paragraph numbers in square brackets refer to the Transport Canada requirements [10].

✓ Transport Canada exam: questions, answers and explanations

Question 1 **Answer: a) True**

The Aeronautics Act and the Canadian Aviation Regulations provide regulatory authority to the Minister of Transport for authorization of all rocket launches in Canada excepting model rockets or those used in fireworks.

a) **True ✓**
b) False

Explanation. The *Aeronautics Act* gives the Minister of Transport oversight of rocket launches, and CARs 602.43 and 602.44 require the Minister to authorize every launch except model rockets and fireworks. The CLSO does this work for the Minister.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 1, General. [10]

Question 2 **Answer: d) all of the above**

Transport Canada's Requirements for Launching High Power Rockets in Canada require a launch proponent to:

a) obtain an Authorization to Launch from the Minister of Transport
b) obtain approval of the Range Safety Officer prior to launch
c) ensure the rocket has an appropriate device for retarding its descent
d) **all of the above ✓**

Explanation. All three are requirements: launch only under an Authorization to Launch from the CLSO, acting for the Minister [5.4]; have the rocket inspected and approved immediately before flight [9.2]; and carry a parachute or other device that retards descent [4.1.2].

Source: "Requirements for Launching High Power Rockets in Canada" document Section 5, Requirements for Individuals Launching High Power Rockets, para. 5.4; Section 9, Launch Requirements and Restrictions, para. 9.2; Section 4, High Power Rockets, para. 4.1.2. [10]

Question 3 **Answer: c)**

The total impulse of a rocket is:

a) the thrust generated by the largest motor used on the rocket
b) the analysis of thrust as determined by the Range Safety Officer
c) **the sum of the total impulses of all the rocket motors used on the rocket ✓**
d) a & c only

Explanation. This is the definition of *installed total impulse*: add the total impulses of every motor installed and intended to be ignited. Thrust (a) is a force, not an impulse, and the RSO does not determine it (b).

Source: "Requirements for Launching High Power Rockets in Canada" document Section 3, Acronyms and Definitions, see Installed Total Impulse. [10]

Question 4 **Answer: d) a & b only**

A high power rocket

a) must not be launched into cloud
b) must not create a hazard to aviation
c) must not be launched without an altimeter to determine the altitude it reaches
d) **a & b only ✓**

Explanation. Launching into cloud is forbidden [9.8] and so is creating a hazard to aircraft [9.13]. Nothing in the Transport Canada document requires an altimeter, so (c) is wrong and "a & b only" is right.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 9, Launch Requirements and restrictions, paras. 9.8 & 9.13. [10]

Question 5 **Answer: d) all of the above**

A High Power Rocket is considered to be any rocket:

a) weighing more than 1500 grams (3.3 lbs)
b) having a total impulse greater than 160 Newton-seconds
c) requiring a means of retarding its rate of descent to earth
d) **all of the above ✓**

Explanation. The definition of a high-power rocket covers all three: more than 1.5 kg, more than 160 N s installed, and a parachute or other device to retard descent. Either threshold alone makes a rocket high power; the recovery device is a required feature of every high-power rocket.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 3, Acronyms and Definitions, see High Power Rocket and para. 4.1.1 and 4.1.2. [10]

Question 6 **Answer: a)**

The Authorization to Launch High Power Rockets document must be made available upon request to a federal or provincial police officer and:

a) **a designated Transport Canada inspector ✓**
b) a CAR/ACF Headquarter personnel
c) a designated representative of the Land owner
d) all of the above

Explanation. Proof of qualification or certification must be shown to Transport Canada representatives on request [5.3]. The landowner and CAR/ACF headquarters staff are not named in the rule.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 5, Requirements for Individuals Launching High Power Rockets, para. 5.3. [10]

Question 7 **Answer: a)**

All High Power Rocket motors used in rockets proposed for launch in Canada shall be approved or authorized by:

a) **Natural Resources Canada - Explosives Division and/or Transport Canada ✓**
b) Canadian Association of Rocketry/Association canadienne de fuséonautique
c) Tripoli Rocketry Association
d) All of the above

Explanation. Motors must be authorized by NRCan (all solid motors and pyrotechnics) or by Transport Canada (other motors such as hybrids) [4.1.1, 4.3]. CAR/ACF and Tripoli certify *people* and test motors for their members, but legal authorization comes from the federal agencies.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 4, High Power Rockets, para. 4.1.1. [10]

Question 8 **Answer: d)**

The responsibility for ensuring compliance with all federal, provincial, municipal and local laws, rules, regulations and ordinances rests with:

a) the Range Safety Officer in charge of a launch meet
b) Transport Canada's Canadian Launch Safety Office
c) the organizer of the launch meet
d) **the individual launching a rocket ✓**

Explanation. Paragraph 5.1 puts compliance with all laws on "all persons launching high power rockets", that is, on you. The RSO, the organizer and the CLSO have duties of their own, but they do not carry yours.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 5, Requirements for Individuals Launching High Power Rockets, para. 5.1. [10]

Question 9 **Answer: d) all of the above**

An individual launching a rocket shall:

a) make available to Transport Canada representatives, upon request, proof of qualifications and/or certification
b) do so only in accordance with a Transport Canada authorization to launch
c) do so only in accordance with the certification and qualification requirements for the rocket(s) to be launched
d) **all of the above ✓**

Explanation. Each option is one paragraph of section 5: proof on request [5.3], only under an Authorization to Launch [5.4], only within your certification [5.2]. So all of the above.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 5. Requirements for Individuals Launching High Power Rockets, paras. 5.1, 5.2, 5.3 & 5.4. [10]

Question 10 **Answer: b)**

A site to be used for launching high power rockets shall:

a) be approved by the local zoning authority
b) **be sized to include the launch, flight, recovery and public viewing areas ✓**
c) be located at least 16 kilometers (10 miles) from any airport
d) all the above

Explanation. The site must include enough area for launch and recovery of every rocket [6.4], and by definition a launch site includes the viewing and parking areas. Zoning approval and a 16 km airport distance are not in the document; landowner permission is [6.3].

Source: "Requirements for Launching High Power Rockets in Canada" document Section 6, Launch Site Requirements: para. 6.4. [10]

Question 11 **Answer: a)**

A launch site shall:

a) **have a dimension of not less than 500 m. ✓**
b) be cleared of all trees
c) be accessible to the public
d) have the launch pads situated adjacent to a windsock or anemometer

Explanation. "In no case shall the launch site have a dimension less than 500 m" [6.7]. Trees need not all be cleared (only overhead hazards that affect safety matter), the public is kept in a designated area, and no windsock location rule exists.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 6, Launch Site Requirements, para. 6.7. [10]

Question 12 **Answer: b)**

A launcher shall:

a) ensure the rocket launches vertically in winds over 10 km/h
b) **be located more than 500 m from any occupied building ✓**
c) deflect rocket exhaust away from public areas
d) be located adjacent to the site boundary to maximize the recovery area

Explanation. The launcher must be more than 500 m from any occupied building or busy public road [7.2]. The blast deflector keeps exhaust off the ground (not "away from public areas"), launches may be up to 20° from vertical, and the launcher must be placed so recovery stays inside the site.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 7, Launcher Requirements, para. 7.2. [10]

Question 13 **Answer: b) False**

A launch proponent may launch a rocket into a cloud if the Range Safety Officer verifies there are no aircraft approaching the launch site.

a) True

b) **False ✓**

Explanation. Paragraph 9.8 is absolute: no launch into cloud, whatever the RSO sees. Rockets can be lost from view in cloud and aircraft can be hidden there.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 9 Launch Requirements and Restrictions, para. 9.8. [10]

Question 14 **Answer: d) 20**

Launchers shall be restricted to within _____ degrees of vertical.

a) 5
b) 10
c) 15
d) **20 ✓**

Explanation. The launcher shall restrict the launch angle to within 20 degrees of vertical [7.6].

Source: "Requirements for Launching High Power Rockets in Canada" document Section 7, Launcher Requirements, para. 7.6. [10]

Question 15 **Answer: c)**

A complex high power rocket is:

a) very difficult to manufacture
b) restricted to "J" class and above
c) **multi-staged or propelled by more than one motor ✓**
d) all of the above

Explanation. A complex rocket is multi-staged or propelled by a cluster of motors (footnote to Table 4). It needs larger minimum safe distances. Difficulty of construction and motor class have nothing to do with it.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 8, Launch Site Safety Requirements, para. 8.2. [10]

Question 16 **Answer: a)**

Under what atmospheric conditions will a rocket launch be cancelled?

a) **surface winds are greater than 30 km/h ✓**
b) prevailing visibility is 5 km
c) temperature is above 30 °C
d) during rain showers

Explanation. The launch is cancelled when surface wind exceeds 30 km/h [9.10]. Visibility must not be *less* than 5 km [9.9], so exactly 5 km is acceptable. Temperature and rain are not listed limits.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 9, Launch Requirements and Restrictions, para. 9.9 and 9.10. [10]

Question 17 **Answer: d) a & c**

A Range Safety Officer is responsible for performing the following duties:

a) protecting people, property and environment from safety risks that may arise during pre-launch, launch, and flight recovery of high power rockets
b) monitoring vehicle traffic at the rocket launch
c) ensuring persons launching high power rockets are appropriately qualified and/or certified
d) **a & c ✓**

Explanation. Protecting people, property and the environment [10.2.1] and making sure fliers are qualified [10.2.4] are RSO duties. Monitoring vehicle traffic is not on the list.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 10, Range Safety Officer Requirements, paras. 10.2.1, 10.2.2 & 10.2.4. [10]

Question 18 **Answer: d) b & c**

Natural Resources Canada is the regulatory government agency responsible for:

a) approvals for use of rocket launch sites for proposed rocket launches
b) approvals for use of rocket motors
c) approvals for storage of rocket motors
d) **b & c ✓**

Explanation. The 1999 letter gives NRCan the approvals for the use of specific motors and for their storage (also import, sale, road transport and igniters). Approving launch sites is the CLSO's job.

Source: Letter dated June 21, 1999 to all High Power Rocket Enthusiasts, page 2; "Requirements for Launching High Power Rockets in Canada" document Section 4, para. 4.3. [2, 10]

Question 19 **Answer: c)**

Canadian Launch Safety Office is the regulatory government agency responsible for:

a) issuing approvals for pyrotechnic igniters
b) issuing approvals for importation of rocket motors
c) **defining airspace requirements for rocket launches and arrange for airspace restricting/advisories and issuance of a Notice To Airmen (NOTAM) ✓**
d) all of the above

Explanation. The CLSO defines airspace requirements and arranges airspace restrictions, advisories and NOTAMs. Igniter and import approvals belong to NRCan, so (a), (b) and (d) are wrong.

Source: Letter dated June 21, 1999 to all High Power Rocket Enthusiasts, page 3. [2]

Question 20 **Answer: b) False**

The minimum dimensions of the launch site are established in accordance with the minimum safe distances specified for each rocket motor type's total impulse.

a) True
b) **False ✓**

Explanation. False. Site size comes from the *expected altitude* (Table 3) [6.5], not from the

safe distances of Table 4, which only set how far people stand from the pad.

Source: "Requirements for Launching High Power Rockets in Canada" document Section 6, Launch Site Requirements, para. 6.5. [10]

Question 21 **Answer: b) Transport Canada**

The government agency responsible for reviewing and analyzing information submitted pertaining to hybrid rocket motors to determine acceptability for issuance of an authorization to launch is:

a) Natural Resources Canada - Explosives Branch
b) **Transport Canada ✓**
c) Natural Resources Canada
d) a and b

Explanation. The 1999 letter lists hybrid motor review under the Transport Canada CLSO, adding that approval to launch a hybrid does not mean the motor is approved for sale.

Source: Letter dated June 21, 1999 to all High Power Rocket Enthusiasts, page 3, Transport Canada, Canadian Launch Safety Office. [2]

Question 22 **Answer: a)**

Certification for individuals requesting approval to launch high power rockets in Canada is obtained by:

a) **successful completion of a written exam and the building and flying of a rocket containing a high power motor ✓**
b) no requirements are necessary to launch high power rockets
c) approval received once written exam is completed and a pass mark obtained
d) the ability to successfully build and fly a rocket containing a high power rocket motor

Explanation. The 1999 letter: CAR certification is obtained by passing an exam administered by CAR *and then* successfully launching a rocket appropriate to the level sought. Exam alone (c) or flight alone (d) is not enough.

Source: Letter dated June 21, 1999 to all High Power Rocket Enthusiasts, page 2, second paragraph. [2]

Question 23 **Answer: d) all of the above**

The launch organizer or the Range Safety Officer of the rocket launch must:

a) ensure the landowner has given permission for use of the land
b) ensure all individuals launching from the site are members in good standing of the CAR/ACF or other recognized association/club
c) ensure the launch is in compliance with Transport Canada's guidelines "Requirements for Launching High Power Rockets in Canada"
d) **all of the above ✓**

Explanation. The Launch Authorization (Appendix A) makes the organizer or RSO responsible for all three: landowner permission, fliers who are members in good standing of a recognized association, and compliance with the Transport Canada requirements.

Source: Rocket (High Power) Launch Authorization, Appendix A. [28]

Question 24 **Answer: d) b & c**

When is the Range Safety Officer responsible for taking action to cancel the rocket launch:

a) when there is no Transport Canada inspector at the launch
b) when the surface winds are greater than 30km/h
c) when prevailing visibility is less than 5km
d) **b & c ✓**

Explanation. Wind above 30 km/h [9.10] or visibility below 5 km [9.9] cancels the launch. There is no rule requiring a Transport Canada inspector to be present.

Source: Rocket (High Power) Launch Authorization, Appendix A. "Requirements for Launching High Power Rockets in Canada" document Section 9, Launch Requirements and Restrictions, paras. 9.9 & 9.10. [10, 28]

Question 25 **Answer: a) True**

All participants must be located in safe area, away from rocket launches according to the minimum safety distances for each rocket motor type.

a) **True ✓**
b) False

Explanation. True: nobody may be closer to a launch than the minimum safe distances of Table 4 [8.2].

Source: "Requirements for Launching High Power Rockets in Canada" document Section 8, Launch Site Safety Requirements, para. 8.2. [10]

CHAPTER 3

Flight Theory

The Rocket Inspector will ask you where your centre of gravity and centre of pressure are, and why that matters. The written exam asks you how to move them, how a thrust curve relates to a motor's designation, and how fast a rocket comes down under its parachute. This chapter builds those ideas from first principles, with worked examples you can reproduce on a calculator, and ends with the complete CAR/ACF practice exam and its answer guide.

3.1 Stability: centre of gravity and centre of pressure

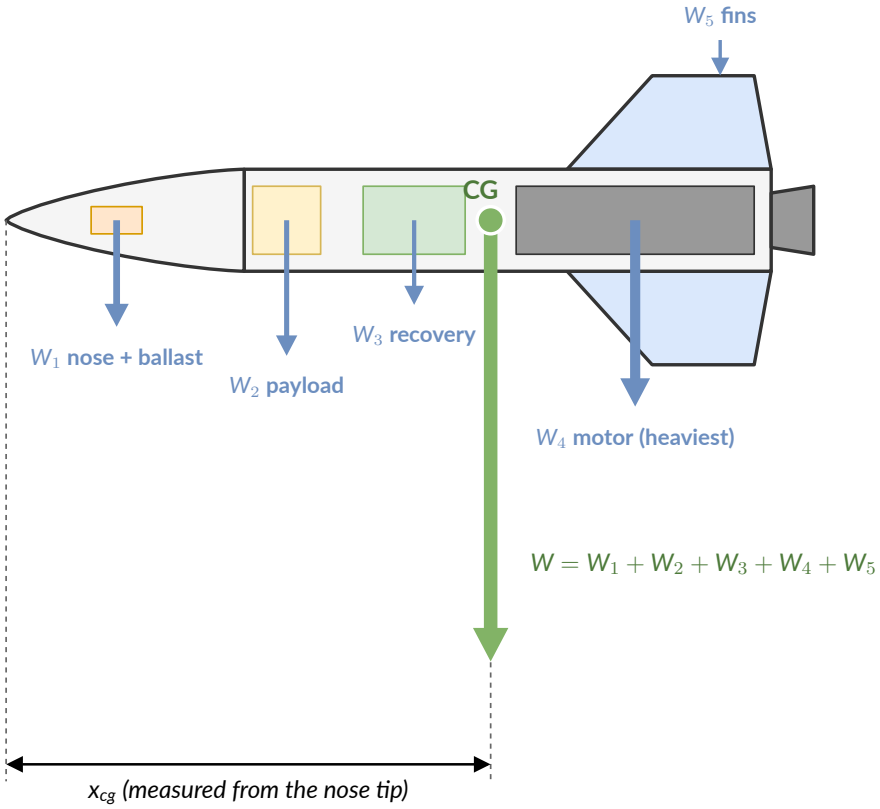
3.1.1 Centre of gravity (CG)

Every part of the rocket has weight: nose cone and ballast, payload, recovery gear, motor and fins. All those weights act together exactly as if one single weight W acted at one point, the *centre of gravity*. Its position, measured from the nose tip, is the weighted average of the part positions (Figure 3.1).

Centre of gravity

$$x_{cg} = \frac{\sum_i W_i x_i}{\sum_i W_i}$$

The CG is the balance point of the *complete*, *flight-ready* rocket: motor installed, recovery system packed, electronics fitted. Find it in practice by balancing the rocket on a finger, an edge or a loop of string.



$$x_{cg} = \frac{W_1 x_1 + W_2 x_2 + W_3 x_3 + W_4 x_4 + W_5 x_5}{W_1 + W_2 + W_3 + W_4 + W_5}$$

Figure 3.1. Many part weights (blue; longer and thicker arrow means heavier part) are equivalent to one weight W at the CG (green).

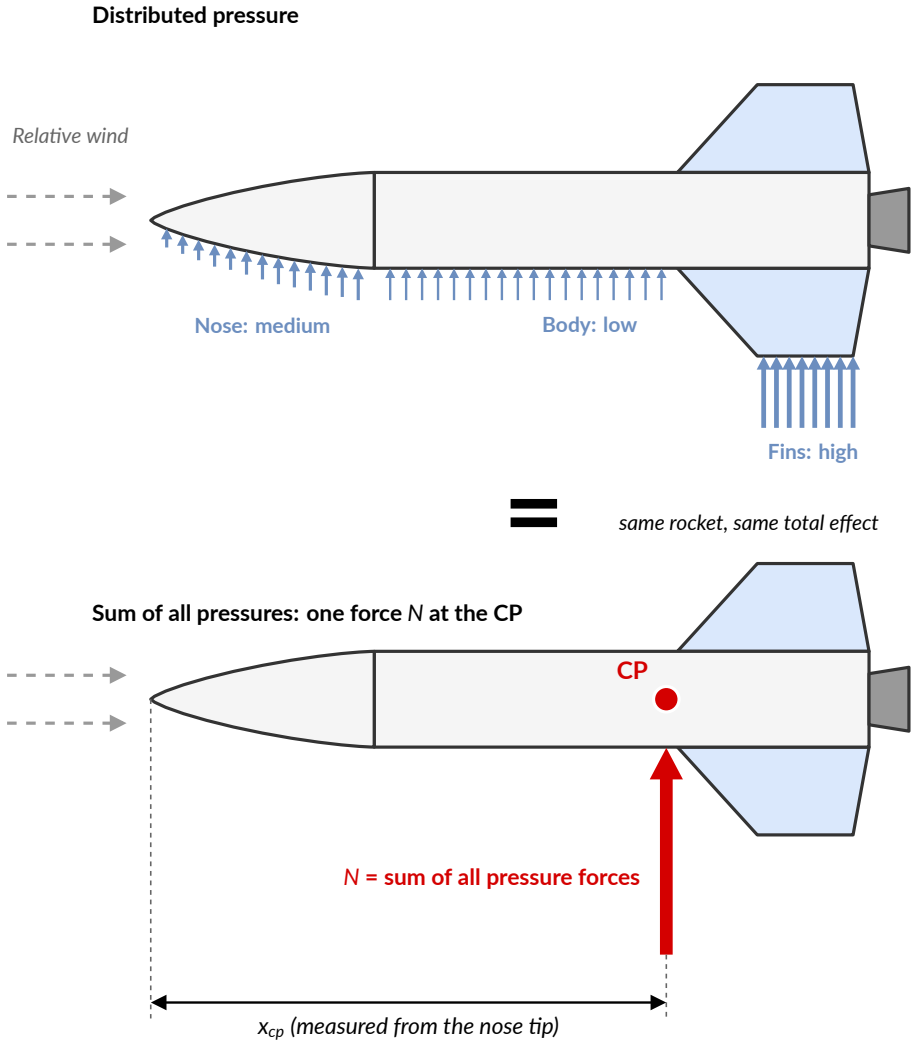
3.1.2 Centre of pressure (CP)

When the rocket flies at an angle of attack, air pressure pushes on the side facing the relative wind. The fins, far aft and flat, take the largest share, the nose a medium share and the body tube the least. All those pressure forces are equivalent to one normal force N acting at one point, the *centre of pressure* (Figure 3.2). The Barrowman equations are the standard hand method for locating the CP (they do *not* give the drag coefficient); simulation programs such as OpenRocket and RockSim apply them for you, and **??** works through them by hand.

Centre of pressure

$$x_{cp} = \frac{\sum_i N_i x_i}{\sum_i N_i}$$

The CP is the point where the total aerodynamic side force acts. It depends only on the rocket's external shape: larger fins, more fins, or a shorter body move it aft.



$$x_{cp} = \frac{N_1 x_1 + N_2 x_2 + \cdots + N_n x_n}{N_1 + N_2 + \cdots + N_n}$$

Figure 3.2. Distributed pressure forces (top) are equivalent to one force N at the CP (bottom).

3.1.3 Why the CP must sit behind the CG

Picture a gust that tilts the rocket by an angle θ. The side force N acts at the CP, a distance R from the CG. It creates a torque $T = NR$ about the CG. If the CP is *behind* the CG, that torque turns the nose back into the wind, just like the feathers on an arrow: the rocket is **statically stable**. If the CP were ahead of the CG, the same torque would push the nose further away and the rocket would tumble (Figure 3.3).

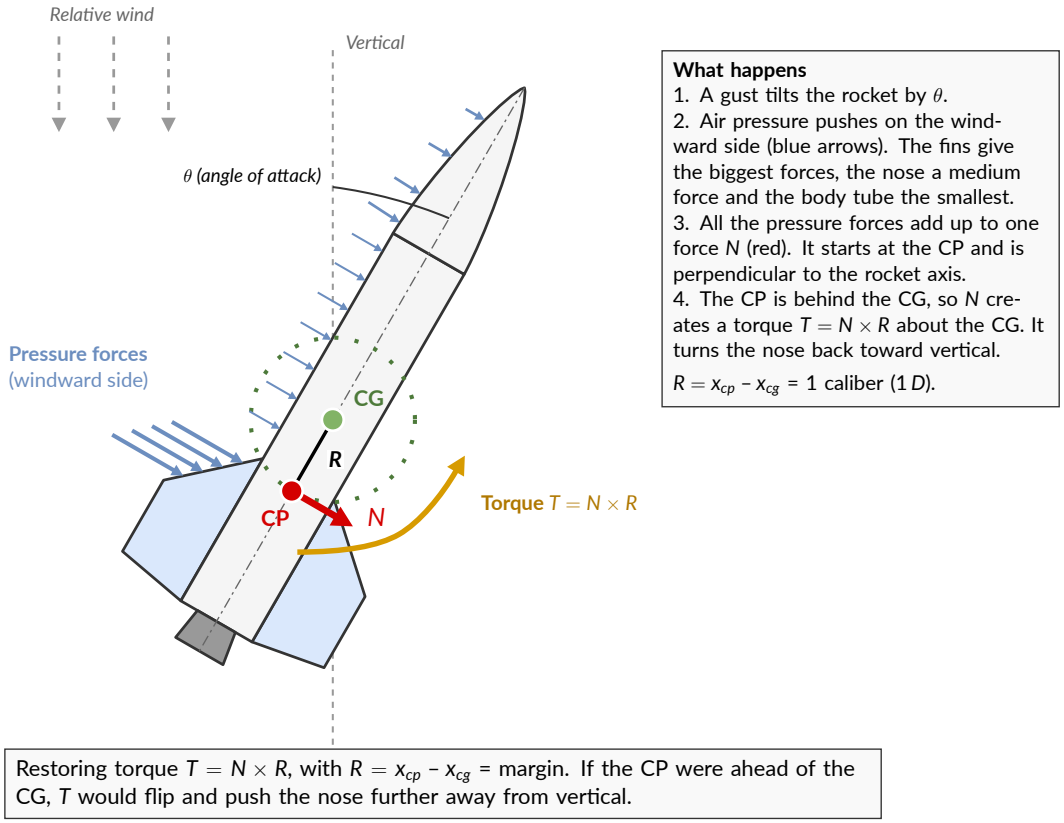


Figure 3.3. The restoring torque.

3.1.4 Static margin and the one-caliber rule

The distance between CP and CG only means something relative to the size of the rocket, so it is measured in *calibers*, where one caliber is one body diameter D.

Static margin

$$\text{SM} = \frac{x_{cp} - x_{cg}}{D} \quad \text{(calibers)}$$

- **Stable** when the CG is *ahead of* the CP ($x_{cp} > x_{cg}$).
- Rule of thumb: **at least 1 caliber**, typically 1 to 2. A 4-inch rocket should have its CG at least 4 inches ahead of its CP.
- Much more than about 2 calibers makes a rocket “overstable”: it weathercocks strongly into the wind.
- The margin changes in flight: burning propellant moves the CG, and the CP moves with Mach number and angle of attack. Check it with the motor installed.

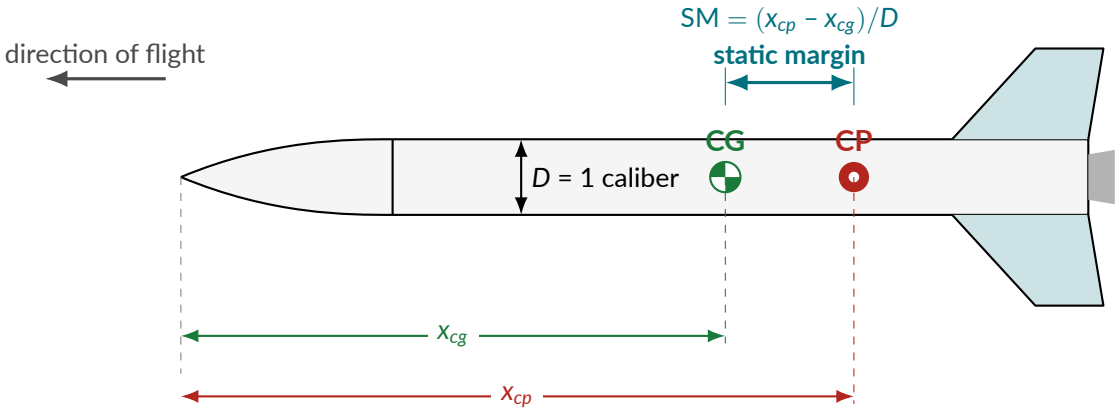


Figure 3.4. Rocket silhouette with the CG (green, checkered symbol) ahead of the CP (red). The distance between them, divided by the body diameter, is the static margin; here about 1.7 calibers.

Moving the CG and the CP

Move the CG forward	Move the CP aft
add weight to the nose	make the rocket shorter
lengthen the rocket	use larger fins
use a smaller (lighter) motor	increase the number of fins

Fins placed *ahead* of the CG move the CP forward and **reduce** stability.

Weathercocking

A stable rocket turns into the relative wind. In a crosswind, the relative wind at liftoff comes partly from the side, so the rocket tilts upwind. The effect grows with fin area and wind speed, and it lowers the apogee and shortens the flight. On windy days choose a **shorter delay** than on a calm day.

3.2 Nose cone shapes

The nose cone opens the path through the air. At the subsonic speeds of most certification flights the differences in drag between reasonable shapes are small compared with surface finish, fin shape and base drag, but the shape still affects weight, CP position and how easy the part is to make. Every nose cone formula describes the same thing: how the radius of the cone grows from the tip to the shoulder. Figure 3.5 names the quantities, using a tangent ogive as the example.

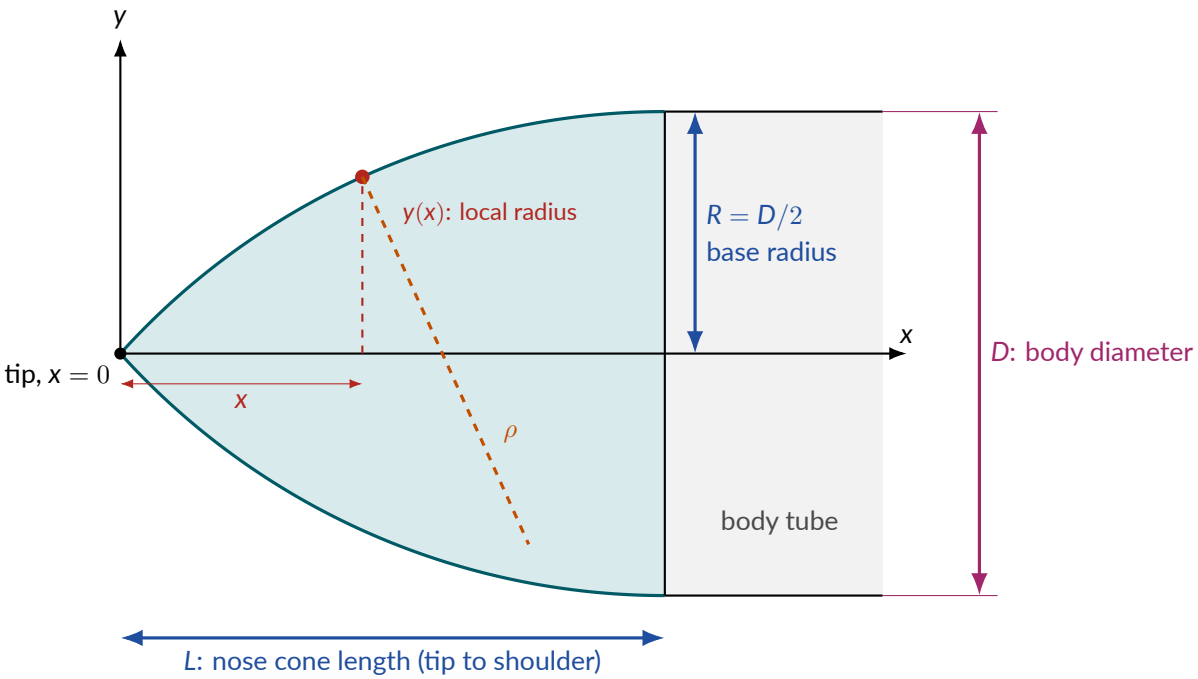


Figure 3.5. The quantities used in nose cone formulas, shown on a tangent ogive. The dashed orange line is part of the radius ρ of the circle whose arc forms the ogive; the centre of that circle lies far below, on the shoulder line.

The symbols

x **(m)**
axial position measured from the nose tip: $x = 0$ at the tip, $x = L$ at the shoulder where the cone meets the body tube.

y **(m)**
local radius of the nose cone at position *x*; $y(0) = 0$ and $y(L) = R$.

L **(m)**
length of the nose cone from tip to shoulder (not counting the shoulder that slides into the tube).

R **(m)**
base radius, equal to half the body tube diameter *D*.

ρ **(m)**
for the tangent ogive only: the radius of the circular arc that forms the profile. The arc is chosen so that it meets the body tube tangentially (no corner), which fixes $\rho = (R^2 + L^2)/(2R)$. It is much larger than *R*; for $L = 3R$, $\rho = 5R$.

n
for power-series shapes: the exponent in $y = R\,(x/L)^n$. $n = 1$ is a cone, $n = \frac{1}{2}$ a parabola lying on its side, and smaller *n* gives a blunter nose.

L/D
the fineness ratio. Typical HPR nose cones are between about 3 and 5 calibers long.

Figure 3.6 compares four classic profiles with the same length *L* and base radius *R* (fineness $L/2R = 1.5$ here, to exaggerate the differences).

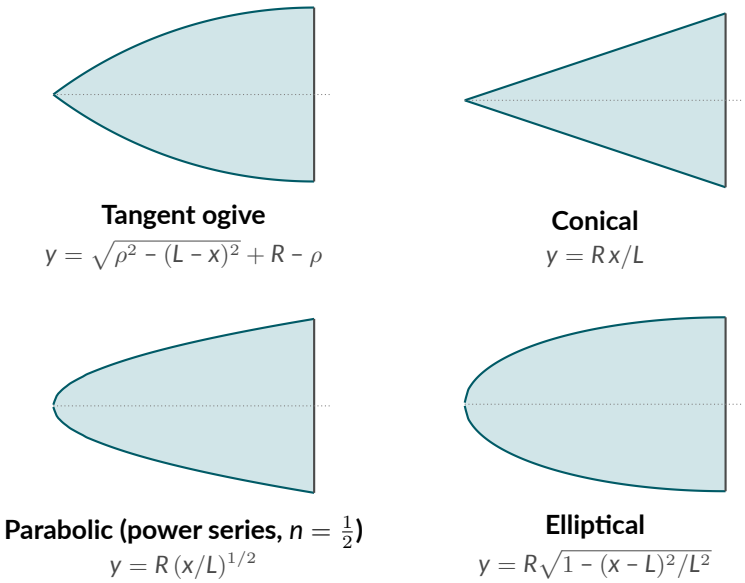


Figure 3.6. Nose cone profiles with the same length and base radius, tip on the left. For the tangent ogive, $\rho = (R^2 + L^2)/(2R)$ is the radius of the arc.

Which shape, when

Tangent ogive
The most common commercial HPR nose cone. Low drag at subsonic and transonic speeds, a smooth tangent joint with the body tube, easy to buy in plastic or fibreglass. A safe default for a certification rocket.

Conical
Simplest to make (a rolled cone or a turned part). The sharp tip suits supersonic flight; at subsonic speeds the corner at the shoulder costs a little drag.

Parabolic / power series
Blunter shapes that do well at transonic speeds and pack more internal volume near the tip (useful for payload or electronics).

Elliptical
Blunt and rounded; good at low subsonic speeds and very tolerant of angle of attack, but poor at high speed. Common on model rockets and low, slow flights.

3.3 Fin design

The fins do two jobs. They move the centre of pressure aft, which gives the rocket its static margin, and they damp the wobble that every rocket picks up at rail exit and in gusts (**??**). Their shape also decides whether they survive the landing. This section names the parts of a fin, compares the common shapes, and explains why the shape recommended here is a trapezoid whose tips stay ahead of the tail.

3.3.1 Fin geometry

Every trapezoidal fin is described by five numbers (Figure 3.7). The same symbols are used by the Barrowman equations in the next section and by OpenRocket.

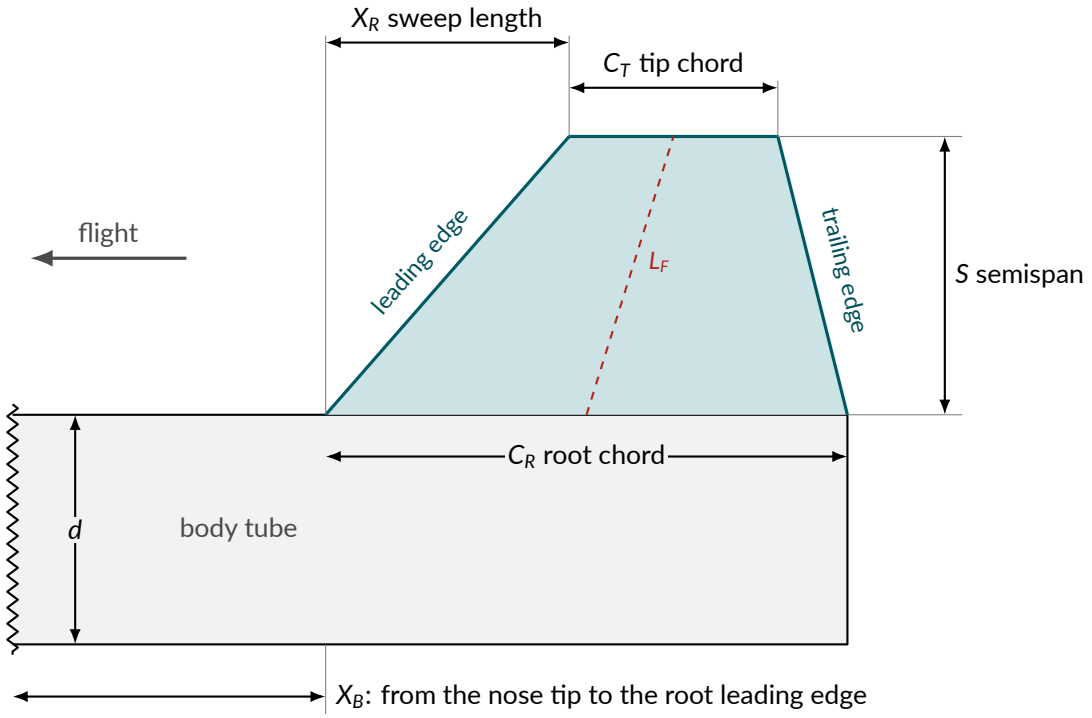


Figure 3.7. Fin geometry. C_R and C_T are the root and tip chords, S the semispan (height of the exposed fin), X_R the axial distance from the root leading edge to the tip leading edge, L_F the length of the mid-chord line, and X_B the distance from the nose tip to the root leading edge.

3.3.2 Fin shapes

Figure 3.8 compares five common planforms drawn with the same root chord and span. The aft end of the body tube is the vertical line on the right of each panel.

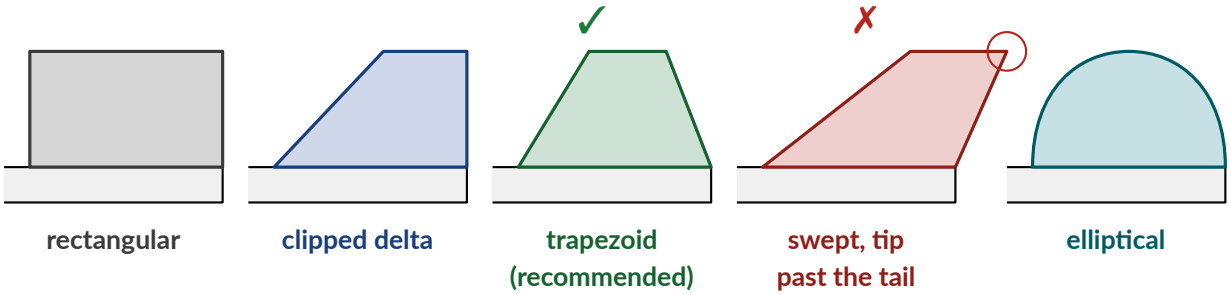


Figure 3.8. Common fin planforms, nose to the left. The trapezoid keeps its whole tip ahead of the aft end of the body; the swept fin's tip (circled) hangs behind it.

Rectangular

Easiest to cut and align, but the most drag for its area, and the square aft corner sits right at the tail, where it takes the first knock on landing.

Clipped delta

The classic kit fin: a swept leading edge and a trailing edge square to the body. Good compromise;

the aft tip corner is still flush with the tail.

Trapezoid (recommended)
Leading edge swept back, trailing edge swept *forward*, so the fin looks like /¯¯\ from the side. The whole tip chord is ahead of the aft end of the body tube, the tip corners are blunt, and there is no thin point to snap off.

Swept (tip past the tail)
Looks fast, and moves the CP furthest aft for its area, but the tip overhangs the tail. When the rocket lands tail first the fin tip touches the ground before anything else, and all the landing load goes into a thin corner and the fin root.

Elliptical
Aerodynamically efficient at subsonic speed, but hard to cut accurately and to repeat on three or four fins. Rarely worth it on a certification rocket.

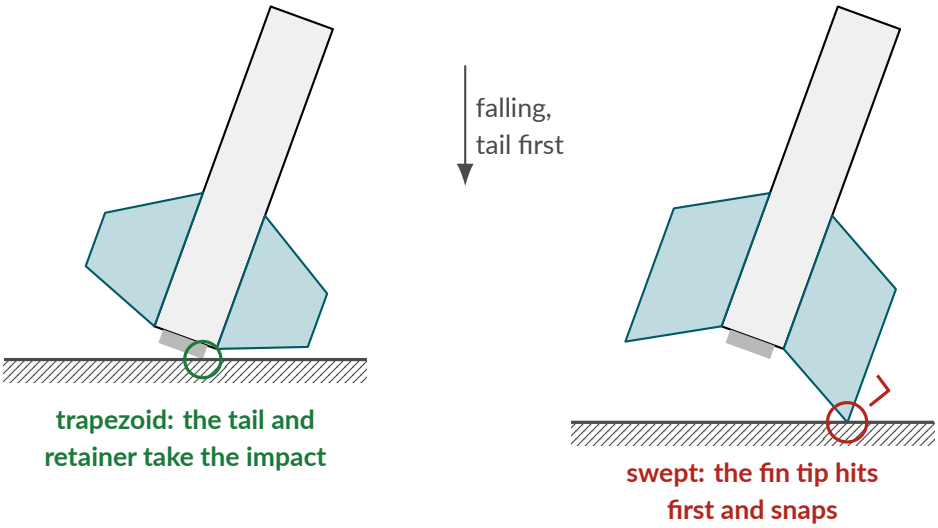


Figure 3.9. Why the fin shape matters at touchdown. A rocket usually lands tail first and slightly tilted. With the recommended trapezoid, the tail of the body tube and the motor retainer touch first; with fins swept past the tail, a thin fin tip carries the whole impact.

Recommended fin for a certification rocket

- A **trapezoid** with the leading edge swept back and the trailing edge swept slightly forward, like /¯¯\: the tip chord sits ahead of the aft end of the body tube. Fins that are pointed, or that hang behind the tail, are the ones that break on landing.
- **Blunt tips**: a tip chord of roughly one third to one half of the root chord. A sharp point chips, and a long thin tip flutters.
- **Size for the margin**: choose the semispan (typically 1 to 1.5 body diameters) so that the static margin is 1 to 2 calibers with the motor installed; check it with the Barrowman method (**??**).
- **Three or four fins**: both are fine for a certification rocket. Three is lighter; four is easier to align and to lay flat on the table. (More fins also help against a rare spin-related instability, **??**.)
- **Edges**: round the leading edge and the tip, taper or round the trailing edge; keep all fins

identical so none of them pushes the rocket into a roll.

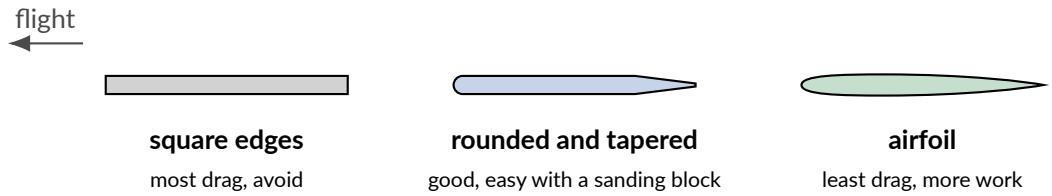


Figure 3.10. Fin cross-sections (cut along the chord, leading edge on the left).

Flutter and thickness

A thin fin at high speed can start to oscillate like a flag and tear itself off. Stiffness, not strength, is what prevents it: thicker fins, stiffer material (G10 fibreglass or aircraft plywood rather than balsa), a shorter span and a longer tip chord all raise the speed at which flutter starts. As a common starting point, 3 mm (1/8 in) aircraft plywood suits a Level 1 rocket on an H motor, and 4.5 to 5 mm (3/16 in) plywood or G10 suits Level 2; check the simulated maximum speed (**??**) and go thicker, or add tip-to-tip fibreglass (Section 4.3), for faster flights.

3.4 Parachutes and descent under canopy

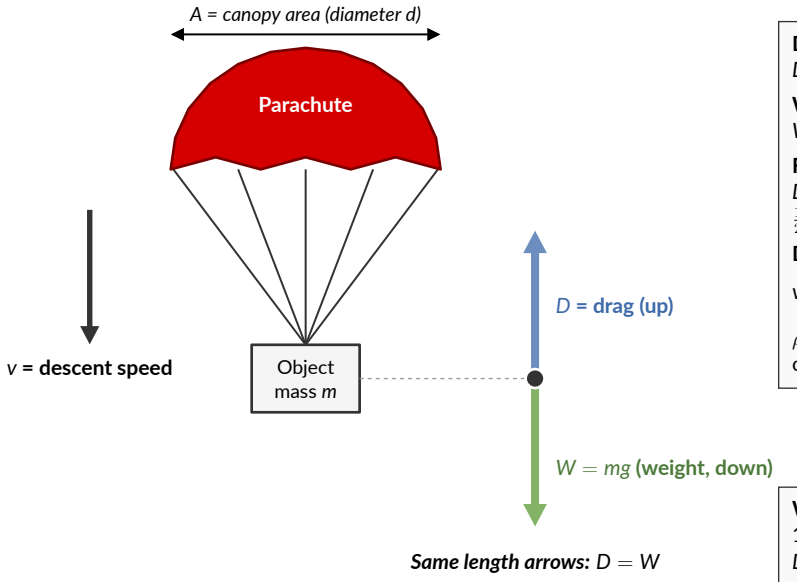
After apogee the rocket must come back without hurting anyone and without breaking. A parachute does this by creating drag that grows with the square of speed; within a few seconds of opening the drag equals the weight and the rocket descends at a steady *descent rate*.

Why the descent rate matters on certification day

- The certification flight must show **deployment of the recovery system and a safe recovery**; the rocket is inspected after landing for flight damage and motor retention, and a failure of the airframe or recovery system disqualifies the attempt.
- **Too fast**: kinetic energy grows with v^2; fins crack, tubes zipper, and the rocket is a hazard to people on the field.
- **Too slow**: the rocket drifts with the wind for a long time and may land outside the site or in trees or power lines (which you may not retrieve without approval).
- A common target for the main parachute is about **4.5 to 7 m/s** (15 to 23 ft/s) at touchdown; drogues in dual deployment typically bring the rocket down at a few tens of m/s until the main opens. These are community guidelines, not regulatory limits.

The drag of a parachute is written with a drag coefficient C_d referenced to the canopy area A. Flat circular and hexagonal canopies (like the one packed in Chapter 5) have C_d of roughly 0.75 to 0.8 on their flat area; domed and cruciform canopies differ. Use the manufacturer's value when you have one.

3.5 Terminal velocity



Drag force
$D = \frac{1}{2}\rho v^2 C_d A$

Weight
$W = mg$

Force balance (constant speed)
$D = W$
$\frac{1}{2}\rho v^2 C_d A = W$

Descent speed
$v = \sqrt{\frac{2W}{\rho C_d A}}$
ρ = air density, C_d = drag coefficient, A = canopy area, v = speed

What happens
1. At release the speed is small, so D is smaller than W and the object speeds up.
2. Drag grows with v^2, so it rises quickly as the speed rises.
3. When $D = W$ the forces cancel, there is no acceleration and the speed stays constant. This is the terminal (descent) speed.

Bigger canopy (A) = slower descent. Heavier object (W) = faster descent. Four times the weight doubles the speed, because v depends on the square root of W.

Figure 3.11. Descent speed: drag balances weight.

3.5.1 Derivation

Take downward as positive. Two forces act on the rocket under canopy: its weight $W = mg$ downward, and aerodynamic drag upward,

$$D = \tfrac{1}{2}\rho v^2 C_d A,$$

where ρ is air density, v the descent speed, C_d the drag coefficient and A the reference (canopy) area. Newton's second law gives

$$m\frac{dv}{dt} = mg - \tfrac{1}{2}\rho v^2 C_d A.$$

At first v is small, drag is small and the rocket accelerates. Drag grows with v^2 until it equals the weight; the acceleration is then zero and the speed stops changing. That constant speed is the terminal velocity v_t:

$$0 = mg - \tfrac{1}{2}\rho v_t^2 C_d A \quad \Longrightarrow \quad \tfrac{1}{2}\rho v_t^2 C_d A = mg.$$

Terminal (descent) velocity

$$\boxed{v_t = \sqrt{\frac{2mg}{\rho C_d A}}}$$ and, solved for the canopy, $$A = \frac{2mg}{\rho C_d v_t^2}, \quad d = \sqrt{\frac{4A}{\pi}}.$$

- Bigger canopy, slower descent: $v_t \propto 1/\sqrt{A} \propto 1/d$.

- Heavier rocket, faster descent: $v_t \propto \sqrt{m}$. Four times the mass doubles the speed.
- Thinner air (higher altitude, hotter day) means faster descent: $v_t \propto 1/\sqrt{\rho}$.
- Use the *burnout* (empty motor) mass for descent, not the liftoff mass.
- Sea-level standard air: $\rho = 1.225$ kg/m^3, $g = 9.81$ m/s^2.

Worked example: descent rate of a Level 1 rocket

The H-class rocket of **??** has a burnout mass of $m = 1.67$ kg. It lands under a 36-inch ($d = 0.914$ m) hexagonal parachute with $C_d = 0.8$ in sea-level air. Find the descent rate and the kinetic energy at touchdown. Is it acceptable?

✓ Worked solution, step by step

Step 1: canopy area

The canopy is treated as a circle of diameter $d = 0.914$ m:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.914\ \text{m})^2}{4} = \frac{\pi \times 0.835}{4} \longrightarrow A = 0.656\ \text{m}^2$$

Step 2: weight

The rocket descends empty, so we use the burnout mass:

$$W = mg = 1.67\ \text{kg} \times 9.81\ \text{m/s}^2 \longrightarrow W = 16.38\ \text{N}$$

Step 3: terminal velocity

At the steady descent rate the drag equals the weight. Put every known value into the terminal-velocity formula:

$$v_t = \sqrt{\frac{2mg}{\rho C_d A}} = \sqrt{\frac{2 \times 1.67 \times 9.81}{1.225 \times 0.8 \times 0.656}} = \sqrt{\frac{32.77}{0.643}} = \sqrt{50.96} \longrightarrow \boxed{v_t = 7.14\ \text{m/s}}$$

That is about 23 ft/s.

Step 4: energy at touchdown

The landing energy tells you how hard the fins and tube are hit:

$$E_k = \tfrac{1}{2} m v_t^2 = \tfrac{1}{2} \times 1.67 \times (7.14)^2 = 0.835 \times 50.96 \longrightarrow \boxed{E_k = 42.6\ \text{J}}$$

What it means

The rocket lands at the fast end of the usual 4.5 to 7 m/s window. Because $v_t \propto 1/d$, a 48-inch ($d = 1.2$ m) canopy would bring it down at

$$v_t' = v_t \frac{d}{d'} = 7.14 \times \frac{0.914}{1.2} \longrightarrow v_t' = 5.44\ \text{m/s},$$

and cut the landing energy to about 25 J, which is kinder to the fins on a hard field.

3.6 Practice exercises

Try all the exercises first. Use $g = 9.81$ m/s^2 and $\rho = 1.225$ kg/m^3 unless stated. Worked solutions start on a new page.

Exercises 1 to 7

Exercise 1: sizing a main parachute

A rocket has a burnout mass of 2.4 kg. You want it to land at 5.0 m/s under a flat canopy with $C_d = 0.8$. What canopy diameter do you need?

Exercise 2: drogue descent rate

A dual-deployment rocket of 4.5 kg burnout mass deploys an 18-inch ($d = 0.45$ m) drogue with $C_d = 0.8$ at apogee. How fast does it fall until the main opens?

Exercise 3: forces at liftoff

The H-class rocket of **??** leaves the pad at $m = 1.80$ kg with an average thrust of 159 N. What is the net upward force, the initial acceleration, and the thrust-to-weight ratio? Does it meet the CAR/ACF rule?

Exercise 4: static margin check

A 66 mm diameter rocket has its CG 72.0 cm and its CP 81.0 cm from the nose tip (motor installed). What is its static margin? A modification moves the CP to 76.0 cm; what now?

Exercise 5: balancing forces during canopy opening

Just after the 36-inch parachute of the worked example opens, the 1.67 kg rocket is still falling at 10 m/s. What are the drag and the net force, and is the rocket speeding up or slowing down?

Exercise 6: finding C_d from flight data

You watch the recovered altimeter's log from the Level 1 rocket of the worked example: burnout mass 1.67 kg, 36-inch (0.914 m, $A = 0.656$ m^2) canopy, but the logged descent speed is **8.0 m/s**, not the 7.14 m/s predicted with $C_d = 0.8$. Rearrange the terminal-velocity formula to find the canopy's actual drag coefficient. Why might the real C_d come out lower than assumed?

Exercise 7: drogue and main open together

Many dual-deployment fliers leave the drogue attached when the main opens, rather than cutting it away, so for the rest of the descent *both* canopies pull at once and their drags add: $D_1 + D_2 = W$. The 4.5 kg dual-deployment rocket of Exercise 2 (18-inch drogue, $C_d = 0.8$) also carries a 60-inch ($d = 1.524$ m) main with $C_d = 0.75$. If the drogue stays attached, how fast does the rocket land? Compare it with landing on the main alone.

Try these on your own (answers only, on the solutions page)

P1. A 3.0 kg (burnout) rocket descends under a 1.5 m diameter canopy with $C_d = 0.75$ in sea-level air. Find the descent rate.

P2. What canopy diameter gives a 1.2 kg rocket a descent rate of 6.0 m/s with $C_d = 0.8$?

P3. The worked-example rocket (1.67 kg, 0.914 m canopy, $C_d = 0.8$) flies from a field where the air

density is 1.058 kg/m^3 (about 1 500 m elevation). Find its descent rate.

Solutions to the exercises

✓ Solutions to Exercises 1 to 5

Exercise 1

2.4 kg rocket, target 5.0 m/s, $C_d = 0.8$: canopy diameter?

Solve the force balance for the area instead of the speed, and put in the values:

$$A = \frac{2mg}{\rho C_d v_t^2} = \frac{2 \times 2.4 \times 9.81}{1.225 \times 0.8 \times (5.0)^2} = \frac{47.09}{24.5} \longrightarrow A = 1.922 \text{ m}^2$$

Then turn the area into a diameter:

$$d = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 1.922}{\pi}} = \sqrt{2.447} \longrightarrow \boxed{d = 1.56 \text{ m } (\approx 62 \text{ in})}$$

Pick the next size up that you can buy, for example a 64-inch canopy.

Exercise 2

4.5 kg rocket on an 18-inch drogue, $C_d = 0.8$: descent rate?

First the drogue area and the weight:

$$A = \frac{\pi \times (0.45)^2}{4} \longrightarrow A = 0.159 \text{ m}^2, \qquad W = 4.5 \times 9.81 \longrightarrow W = 44.1 \text{ N}$$

Then the terminal velocity:

$$v_t = \sqrt{\frac{2W}{\rho C_d A}} = \sqrt{\frac{2 \times 44.1}{1.225 \times 0.8 \times 0.159}} = \sqrt{\frac{88.2}{0.1558}} = \sqrt{566.1} \longrightarrow \boxed{v_t = 23.8 \text{ m/s}}$$

Fast enough to limit wind drift, slow enough that the main can open without shredding. (At 4.5 kg this rocket is under the 5 kg threshold, but a redundant altimeter is still wise.)

Exercise 3

1.80 kg at liftoff, average thrust 159 N: net force, acceleration, thrust-to-weight?

The weight:

$$W = mg = 1.80 \times 9.81 \longrightarrow W = 17.66 \text{ N}$$

At liftoff the speed is zero, so there is no drag, and the net upward force is thrust minus weight:

$$F_{net} = \bar{F} - W = 159 - 17.66 \longrightarrow F_{net} = 141.3 \text{ N (up)}$$

Newton's second law gives the acceleration:

$$a = \frac{F_{net}}{m} = \frac{141.3 \text{ N}}{1.80 \text{ kg}} \longrightarrow \boxed{a = 78.5 \text{ m/s}^2 \approx 8.0\,g}$$

and the thrust-to-weight ratio:

$$\frac{T}{W} = \frac{159}{17.66} \longrightarrow \boxed{T/W = 9.0}$$

well above the **4:1** minimum of the CAR/ACF code [13].

Exercise 4

66 mm rocket, CG at 72.0 cm, CP at 81.0 cm (then 76.0 cm): static margin?

The static margin is the CG–CP distance divided by the diameter:

$$\text{SM} = \frac{x_{cp} - x_{cg}}{d} = \frac{81.0 - 72.0}{6.6} = \frac{9.0}{6.6} \longrightarrow \boxed{\text{SM} = 1.36 \text{ calibers}} \quad \text{(stable)}$$

After the change the CP is closer to the CG:

$$\text{SM} = \frac{76.0 - 72.0}{6.6} = \frac{4.0}{6.6} \longrightarrow \boxed{\text{SM} = 0.61 \text{ calibers}}$$

This is below the one-caliber rule. Add nose weight (moves the CG forward) or enlarge the fins (moves the CP aft) until the margin is back above 1.

Exercise 5

1.67 kg rocket falling at 10 m/s just after a 36-inch canopy opens: drag, net force?

The drag at 10 m/s, with the canopy area of the worked example:

$$D = \tfrac{1}{2}\rho v^2 C_d A = 0.5 \times 1.225 \times (10)^2 \times 0.8 \times 0.656 \longrightarrow D = 32.1 \text{ N (up)}$$

The weight is $W = 16.4$ N (down), so the net force is

$$F_{net} = D - W = 32.1 - 16.4 \longrightarrow \boxed{F_{net} = 15.8 \text{ N upward}}$$

which decelerates the rocket at

$$a = \frac{F_{net}}{m} = \frac{15.8}{1.67} \longrightarrow a = 9.4 \text{ m/s}^2.$$

The rocket slows down until $D = W$, at the terminal velocity of 7.14 m/s found above.

Exercise 6

1.67 kg rocket, 0.656 m^2 canopy, logged descent speed 8.0 m/s: actual C_d?

Start from the force balance at terminal velocity, $\tfrac{1}{2}\rho v_t^2 C_d A = mg$, and solve it for C_d instead of v_t:

$$C_d = \frac{2mg}{\rho v_t^2 A} = \frac{2 \times 1.67 \times 9.81}{1.225 \times (8.0)^2 \times 0.656} = \frac{32.76}{51.43} \longrightarrow \boxed{C_d = 0.64}$$

Lower than the assumed 0.8: the canopy fell faster than predicted, so it was producing less drag than a textbook flat hexagonal chute. In the field this usually means a smaller effective opening: a partial line tangle, a canopy that did not fully inflate, a small tear or burn hole, or shroud lines cinched a little short. It is exactly this kind of check, comparing a predicted C_d with one measured from real descent data, that lets you correct next flight's simulation instead of guessing.

Exercise 7

4.5 kg rocket, 18-inch drogue ($C_d = 0.8$) left attached under a 60-inch main ($C_d = 0.75$): landing speed?

With both canopies open, their drags add, so the force balance is $D_1 + D_2 = W$, i.e. $\frac{1}{2}\rho v^2(C_{d1}A_1 + C_{d2}A_2) = mg$. First the two areas:

$$A_1 = \frac{\pi \times (0.45)^2}{4} \longrightarrow A_1 = 0.159 \text{ m}^2, \qquad A_2 = \frac{\pi \times (1.524)^2}{4} \longrightarrow A_2 = 1.824 \text{ m}^2$$

Then each canopy's share of C_dA, and their sum:

$$C_{d1}A_1 = 0.8 \times 0.159 \longrightarrow 0.127 \text{ m}^2, \qquad C_{d2}A_2 = 0.75 \times 1.824 \longrightarrow 1.368 \text{ m}^2$$

$$C_{d1}A_1 + C_{d2}A_2 = 0.127 + 1.368 \longrightarrow 1.495 \text{ m}^2$$

Solving $D_1 + D_2 = W$ for v is the same rearrangement as for one canopy, with the combined C_dA in place of a single canopy's:

$$v = \sqrt{\frac{2mg}{\rho\,(C_{d1}A_1 + C_{d2}A_2)}} = \sqrt{\frac{2 \times 4.5 \times 9.81}{1.225 \times 1.495}} = \sqrt{\frac{88.29}{1.830}} \longrightarrow \boxed{v = 6.94 \text{ m/s}}$$

On the main alone ($C_{d1}A_1$ dropped from the sum), the same formula gives

$$v_{\text{main only}} = \sqrt{\frac{2 \times 4.5 \times 9.81}{1.225 \times 1.368}} = \sqrt{\frac{88.29}{1.676}} \longrightarrow \boxed{v_{\text{main only}} = 7.26 \text{ m/s}}$$

Leaving the drogue attached only trims the landing speed from 7.26 to 6.94 m/s: the main's C_dA is more than ten times the drogue's, so it does almost all the work. The drogue is worth keeping (it costs nothing and helps a little), but do not expect it to substitute for sizing the main correctly.

Answers to P1 to P3

P1: 6.0 m/s. P2: 0.92 m (about 36 in). P3: 7.7 m/s.

3.7 CAR/ACF High Power Certification Practice Exam

Reproduced from the CAR/ACF Study Guide (rev. 2018/08): 48 questions on construction, motors, propellants, igniters, stability and hybrids. The real exam needs **75%** on this part. The answer guide follows in Section 3.8.

CAR / ACF High Power Certification Practice Exam

Question 1

High power rocket airframes may be constructed from lightweight materials including wood, phenolic, fiberglass, plastics and metals.

a) True
b) False

Question 2

Single use high power rocket motors may be reloaded.

a) True
b) False

Question 3

It is unlawful to alter commercially manufactured high power motors.

a) True
b) False

Question 4

What types of payloads are prohibited for on board flight in high power rockets?

a) Incendiary devices
b) Explosive devices
c) Live vertebrate animals
d) All of the above

Question 5

What are 3 methods, which can be used to shift the center of gravity of a rocket forward?

a) Add weight to the nose, lengthen the rocket and move the fins back.
b) Add weight to the nose, lengthen the rocket and use a smaller (lighter) motor.
c) Add weight to the nose, shorten the rocket and use a smaller motor.

Question 6

Which motor has a higher total impulse?

a) J135
b) J415
c) K185

Question 7

Assuming a full 2560 Ns K motor, a K1100 will burn out twice as fast as a K550.

a) True

b) False

Question 8

Assume a rocket 200 cm tall with a body diameter of 7.5 cm. The Center of Gravity is 7.5 cm behind the Center of Pressure. This is a stable design for a high power rocket.

a) True
b) False

Question 9

What is the purpose of drilling a vent hole in the body tube above the upper bulkhead and below the nose cone?

a) To prevent premature ejection of the nose cone.
b) To prevent a vacuum from forming in the body tube preventing the nose cone from being able to eject.
c) To prevent a vacuum from forming in the body tube resulting in the body tube shredding upon ejection.

Question 10

Electronic or remote firing circuits may be armed in the prep area prior to installation of the high power rocket on the launch stand.

a) True
b) False

Question 11

Redundant or back up recovery systems are required for vehicles when they exceed:

a) 1 kg mass
b) 5 kg mass
c) 10 kg mass
d) 15 kg mass
e) Never

Question 12

Fiberglass recovery wadding is allowed by the CAR/ACF safety code.

a) True
b) False

Question 13

Electrical igniters may be safely installed in High Power Rocket motors prior to transport to the launch stand.

a) True
b) False

Question 14

Rocket motors in excess of a total impulse of 40,960 Ns fall within the Requirements for Launching High Power Rockets in Canada.

a) True
b) False

Question 15

What are three methods, which can be used to shift the Center of Pressure of a rocket aft?

a) Make the rocket shorter, use larger fins and increase the number of fins.
b) Make the rocket longer, use larger fins and increase the number of fins.
c) Make the rocket shorter, add weight to the nose and use larger fins.

Question 16

An igniter installed in a motor should be continuity checked before the rocket is taken to the launch pad.

a) True
b) False

Question 17

When flying a single stage or multi-stage vehicle, what is the safest, most reliable number of motors to use in each stage?

a) One
b) Two
c) Three
d) It makes no difference

Question 18

Igniters for rockets powered by a cluster of motors must be wired in:

a) Parallel
b) Series
c) Either a or b

Question 19

Which type of propellant ignites the quickest?

a) Composite
b) Black Powder
c) Both a and b

Question 20

The Barrowman equation may be used to calculate the drag coefficient?

a) True
b) False

Question 21

For a rocket to achieve stable flight the center of gravity (CG) must be located in front of the center of pressure (CP).

a) True
b) False

Question 22

The static stability of a rocket is often measured by the distance between the CG and the CP divided by the body diameter. For a rocket to be stable the CP should be how many body diameters behind the CG?

a) 0.25 caliber
b) 0.50 caliber
c) 1.00 caliber
d) 1.50 caliber

Question 23

In comparison to a calm day, on windy days a shorter than usual delay should be selected for any given rocket.

a) True
b) False

Question 24

Fins placed forward of the center of gravity will tend to stabilize an unguided rocket in flight.

a) True
b) False

Question 25

Ammonium nitrate is the most common oxidizer used in solid reloadable rocket motors.

a) True
b) False

Question 26

The tendency for unguided rockets to “weather cock” increases with the area of the fin.

a) True
b) False

Question 27

Electric match igniters are not susceptible to discharge by static electricity.

a) True
b) False

Question 28

Calculate the average thrust for a rocket motor with a total impulse of 1280 Ns and a burn time of 10.0 seconds.

a) 28.76 N
b) 128.0 N
c) 67.0 N
d) None of the above

Question 29

Calculate the average thrust for a rocket motor with a total impulse of 2560 Ns and a burn time of 5 seconds.

a) 512.0 N
b) 51.20 N
c) 128.0 N
d) None of the above

Question 30

Which of the following igniters requires the greatest current to initiate?

a) Solar igniters
b) Wire wrap thermalite
c) Squibs or electric matches
d) Copperhead igniters
e) Flashbulb igniters

Question 31

The total impulse for a given weight of composite fuel is more than twice that of black powder. That is why solid high power rocket motors use composite rather than black powder.

a) True
b) False

Question 32

All high power rockets must be inspected by CAR/ACF qualified rocket inspector prior to flight.

a) True
b) False

Question 33

The coefficient of drag increases with the length of the rocket airframe.

a) True
b) False

Question 34

Where should an igniter be placed in a composite motor?

a) At the top of the core
b) In the middle of the core
c) At the bottom of the core
d) Position makes no difference

Question 35

If the general rule of thumb for the minimum average thrust to weight ratio is 4:1, what is the maximum mass of a rocket that the following motors will safely lift? (2 Marks)

a) H65 _____ kg
b) L1000 _____ kg

Question 36

If the general rule of thumb for the minimum average thrust to weight ratio is 4:1, what is the maximum mass of a rocket that the following motors will safely lift? (2 Marks)

a) I211 _____ kg

b) M1439 _____ kg

Question 37

A rocket has been equipped with a cluster of 3 motors, a central J415 and 2 outboard G-80's. Electric matches are used to ignite the motors. Assuming all 3 electric matches ignite at the same time:

a) The J415 will ignite first.

b) The 2 G-80's will ignite first.

c) All three motors will ignite at the same time.

Question 38

Which answer best describes the typical operation of a nitrous oxide hybrid rocket motor?

a) The nitrous is ignited and then released, blowing a hot flame onto the fuel in the combustion chamber.

b) The fuel is ignited and the nitrous is then released onto the burning fuel in the combustion chamber.

c) The nitrous is combined with the fuel in the combustion chamber, becoming highly flammable and is then ignited.

Question 39

What happens when changing to smaller or fewer injector orifices in an ideal hybrid rocket motor (assume the oxidizer weight stays the same)?

a) The total impulse decreases and the average thrust increases.

b) The total impulse stays the same and the average thrust increases.

c) The total impulse stays the same and the average thrust decreases.

Question 40

What is the oxidizer most commonly used in a commercial hybrid rocket motor?

a) N_2O

b) N_2O_4

c) NO_2

Question 41

What is the nominal tank pressure of a nitrous oxide hybrid motor at 24 °C (75 °F)?

a) 689 kPa (100 psi)

b) 4971 kPa (721 psi)

c) 10342 kPa (1500 psi)

Question 42

Above what temperature does pressurized nitrous oxide change to a gas?

a) 36 °C (97 °F)
b) 24 °C (75 °F)
c) 3 °C (37 °F)

Question 43

The boiling point of nitrous oxide at atmospheric pressure is:

a) −55.7 °C (−68.3 °F)
b) −73.3 °C (−99.9 °F)
c) −88.5 °C (−127.3 °F)

Question 44

Nitrous Oxide is:

a) A hydrocarbon fuel
b) An oxidizer
c) An acid

Question 45

Nitrous Oxide is:

a) Highly regulated and available only with proper permits and authorization.
b) A controlled substance available only through the medical community.
c) Available at most high performance automobile shops.

Question 46

The thrust curve of a regressive burn motor has a high initial thrust relative to the ending thrust of the motor.

a) True
b) False

Question 47

The thrust curve of a progressive burn motor has a low initial thrust relative to the ending thrust of the motor.

a) True
b) False

Question 48

The safest burn rate for a rocket whose thrust to weight ratio is marginal is:

a) Regressive burn
b) Progressive burn
c) Makes no difference

3.8 CAR/ACF High Power Practice Exam: Solutions

Each question is repeated with the correct choice highlighted in green. The explanation starts with the official *Answer Guide to CAR High Power Practice Exam* [17], word for word, and adds a short note where it helps; the source line gives the document to look up.

✓ CAR/ACF exam: questions, answers and explanations

Question 1 **Answer: a) True**

High power rocket airframes may be constructed from lightweight materials including wood, phenolic, fiberglass, plastics and metals.

a) **True ✓**
b) False

Explanation. *Answer guide:* a) True. See section 4.1.3 of Transport Canada's "Requirement for Launching High Power Rockets in Canada" document

Any lightweight material able to withstand the stresses of ignition and flight is allowed.

Source: Answer guide; TC [4.1.3] [10, 17]

Question 2 **Answer: b) False**

Single use high power rocket motors may be reloaded.

a) True
b) **False ✓**

Explanation. *Answer guide:* b) False. See section "Launch Requirements and Restrictions" of the CAR High Power Rocket Safety Code.

Only a reloadable motor with a manufacturer's reload kit may be reloaded; a single-use motor case is discarded after firing, and parts not designed for reuse must not be reused.

Source: Answer guide; CAR/ACF Safety Code, Launch Requirements and Restrictions [13, 17]

Question 3 **Answer: a) True**

It is unlawful to alter commercially manufactured high power motors.

a) **True ✓**
b) False

Explanation. *Answer guide:* a) True

Motors must be used exactly as the manufacturer directs; modifying cases, closures, grains, delays, nozzles, liners or seals is forbidden.

Source: Answer guide; CAR/ACF Safety Code; TC [9.1] [10, 13, 17]

Question 4 **Answer: d) All of the above**

What types of payloads are prohibited for on board flight in high power rockets?

a) Incendiary devices
b) Explosive devices
c) Live vertebrate animals
d) **All of the above ✓**

Explanation. *Answer guide:* d) All of the above. See section "Launch Requirements and Restrictions" of the CAR High Power Rocket Safety Code.

Both the CAR/ACF code and TC paragraph 9.15 forbid explosive, incendiary and live vertebrate animal payloads.

Source: Answer guide; CAR/ACF Safety Code; TC [9.15] [10, 13, 17]

Question 5 **Answer: b)**

What are 3 methods, which can be used to shift the center of gravity of a rocket forward?

a) Add weight to the nose, lengthen the rocket and move the fins back.

b) **Add weight to the nose, lengthen the rocket and use a smaller (lighter) motor. ✓**

c) Add weight to the nose, shorten the rocket and use a smaller motor.

Explanation. *Answer guide:* b) Add weight to the nose, lengthen the rocket and use a smaller (lighter) motor.

Weight in the nose, a longer body (more length, and mass, ahead of the old CG) and a lighter motor all move the CG forward. Moving fins back moves the CP, not the CG.

Source: Answer guide; Chapter 3 [17]

Question 6 **Answer: c) K185**

Which motor has a higher total impulse?

a) J135

b) J415

c) **K185 ✓**

Explanation. *Answer guide:* c) K185. See Section 4.2 of Transport Canada's "Requirement for Launching High Power Rockets in Canada" document.

Compare letters, not numbers: K (>1,280 N s) beats any J (at most 1,280 N s). The number is the average thrust.

Source: Answer guide; TC [4.2], Table 1 [10, 17]

Question 7 **Answer: a) True**

Assuming a full 2560 Ns K motor, a K1100 will burn out twice as fast as a K550.

a) **True ✓**

b) False

Explanation. *Answer guide:* a) True. The numbers following the letter indicate the average thrust per second a motor will produce. The K1100 will produce 1100 N average thrust, thus a burn time of 2.33 seconds (2560 Ns / 1100 N = 2.33s). The K550 has a burn time of 4.65 seconds (2560 Ns / 550 N = 4.65s).

Burn time $= I_t/\bar{F}$. Same impulse, twice the thrust, half the time.

Source: Answer guide; Section 1.9 [17]

Question 8 **Answer: b) False**

Assume a rocket 200 cm tall with a body diameter of 7.5 cm. The Center of Gravity is 7.5 cm behind the Center of Pressure. This is a stable design for a high power rocket.

a) True
b) **False ✓**

Explanation. *Answer guide:* b) False. In order for a rocket to be stable, the CP must be behind (or aft) of the CG.

Here the CG is *behind* the CP, so the restoring torque points the wrong way and the rocket is unstable, whatever the distance.

Source: Answer guide; Section 3.1 [17]

Question 9 **Answer: a)**

What is the purpose of drilling a vent hole in the body tube above the upper bulkhead and below the nose cone?

a) **To prevent premature ejection of the nose cone. ✓**
b) To prevent a vacuum from forming in the body tube preventing the nose cone from being able to eject.
c) To prevent a vacuum from forming in the body tube resulting in the body tube shredding upon ejection.

Explanation. *Answer guide:* a) To prevent premature ejection of the nose cone. The differential in air pressure outside the rocket versus the air pressure inside an unvented body tube can result in the nose cone ejecting prematurely.

As the rocket climbs, outside pressure falls while the sealed tube stays at ground pressure; the pressure difference can push the nose off. A small vent hole equalizes it.

Source: Answer guide [17]

Question 10 **Answer: b) False**

Electronic or remote firing circuits may be armed in the prep area prior to installation of the high power rocket on the launch stand.

a) True
b) **False ✓**

Explanation. *Answer guide:* b) False. See section “Launch Requirements and Restrictions” of the CAR High Power Rocket Safety Code.

Electronics and ignition circuits are armed only at the pad, with the rocket on the launcher and pointed in a safe direction.

Source: Answer guide; CAR/ACF Safety Code; TC [9.21] [10, 13, 17]

Question 11 **Answer: b) 5 kg mass**

Redundant or back up recovery systems are required for vehicles when they exceed:

a) 1 kg mass
b) **5 kg mass ✓**
c) 10 kg mass
d) 15 kg mass
e) Never

Explanation. *Answer guide:* b) 5 kg Mass. See section "Launch Requirements and Restrictions" of the CAR High Power Rocket Safety Code.

The rule applies to loaded (liftoff) mass: over 5 kg, a second, independent deployment system is required.

Source: Answer guide; CAR/ACF Safety Code [13, 17]

Question 12 **Answer: b) False**

Fiberglass recovery wadding is allowed by the CAR/ACF safety code.

a) True

b) **False ✓**

Explanation. *Answer guide:* b) False. See section "Launch Requirements and Restrictions" of the CAR High Power Rocket Safety Code specifies that where wadding is required by the design of the rocket, the wadding shall be biodegradable. Fiberglass is not biodegradable.

Wadding, if used, must be flame resistant *and* biodegradable.

Source: Answer guide; CAR/ACF Safety Code [13, 17]

Question 13 **Answer: b) False**

Electrical igniters may be safely installed in High Power Rocket motors prior to transport to the launch stand.

a) True

b) **False ✓**

Explanation. *Answer guide:* b) False. See section "Launch Requirements and Restrictions" of the CAR High Power Rocket Safety Code.

Igniters are installed only at the pad (or where the RSO designates), as close to launch as practical (TC 9.21).

Source: Answer guide; CAR/ACF Safety Code; TC [9.21] [10, 13, 17]

Question 14 **Answer: b) False**

Rocket motors in excess of a total impulse of 40,960 Ns fall within the Requirements for Launching High Power Rockets in Canada.

a) True

b) **False ✓**

Explanation. *Answer guide:* b) False. See definition Section "High Power Rocket" Sub-section (a) of Transport Canada's "Requirement for Launching High Power Rockets in Canada" document.

High power ends at 40,960 N s; anything above is outside these requirements and needs a separate review.

Source: Answer guide; TC Section 3, High Power Rocket (a), and [9.5] [10, 17]

Question 15 **Answer: a)**

What are three methods, which can be used to shift the Center of Pressure of a rocket aft?

a) **Make the rocket shorter, use larger fins and increase the number of fins. ✓**

b) Make the rocket longer, use larger fins and increase the number of fins.

c) Make the rocket shorter, add weight to the nose and use larger fins.

Explanation. *Answer guide:* a) Make the rocket shorter; make the fins larger and increase the number of fins. Adding weight to the nose shifts the CG forward. Making the rocket longer shifts the CG forward.

The CP depends only on the outside shape: more fin area aft and a shorter body move it aft.

Source: Answer guide; Section 3.1 [17]

Question 16 **Answer: b) False**

An igniter installed in a motor should be continuity checked before the rocket is taken to the launch pad.

a) True

b) **False ✓**

Explanation. *Answer guide:* b) False. Low current igniters require very little power to ignite, and even the minimal power of a continuity circuit may be sufficient to ignite the bulb.

Continuity is checked at the pad, with the pad's low-current tester, after the rocket is on the rail.

Source: Answer guide [17]

Question 17 **Answer: a) One**

When flying a single stage or multi-stage vehicle, what is the safest, most reliable number of motors to use in each stage?

a) **One ✓**

b) Two

c) Three

d) It makes no difference

Explanation. *Answer guide:* a) One. Clusters of more than one motor are always more difficult, as it is almost impossible to get all engines to light at exactly the same time.

Source: Answer guide [17]

Question 18 **Answer: a) Parallel**

Igniters for rockets powered by a cluster of motors must be wired in:

a) **Parallel ✓**

b) Series

c) Either a or b

Explanation. *Answer guide:* a) Parallel. If you wire igniters in series, then when the first igniter activates it will break the circuit to any subsequent igniters.

In parallel each igniter has its own path, so the first one to burn out does not cut power to the others. Clusters need a high-current firing system.

Source: Answer guide [17]

Question 19 **Answer: b) Black Powder**

Which type of propellant ignites the quickest?

a) Composite
b) **Black Powder ✓**
c) Both a and b

Explanation. *Answer guide:* b) Black Powder. Composite motors require a combination of heat and pressure in order to burn properly. It takes a measurable amount of time in order to build up sufficient pressure in a composite motor, where as black powder motors do not require a pressure build up.

Source: Answer guide [17]

Question 20 **Answer: b) False**

The Barrowman equation may be used to calculate the drag coefficient?

a) True
b) **False ✓**

Explanation. *Answer guide:* b) False. The Barrowman equation is used to calculate the Center of Pressure of a rocket.

Barrowman's method (1966) gives the CP from the rocket's shape [29].

Source: Answer guide [17, 29]

Question 21 **Answer: a) True**

For a rocket to achieve stable flight the center of gravity (CG) must be located in front of the center of pressure (CP).

a) **True ✓**
b) False

Explanation. *Answer guide:* a) True. The "Rule of thumb" used in rocketry is to have the Center of Gravity at least 1 body diameter ahead of the Center of Pressure. I.E. A 4-inch diameter rocket would have its CG at least 4 inches ahead of the CP.

Source: Answer guide [17]

Question 22 **Answer: c) 1.00 caliber**

The static stability of a rocket is often measured by the distance between the CG and the CP divided by the body diameter. For a rocket to be stable the CP should be how many body diameters behind the CG?

a) 0.25 caliber
b) 0.50 caliber
c) **1.00 caliber ✓**
d) 1.50 caliber

Explanation. *Answer guide:* c) 1.0 Caliber. The "Rule of thumb" used in rocketry is to have the Center of Gravity at least 1 body diameter ahead of the Center of Pressure. I.E. A 4-inch diameter rocket would have its CG at least 4 inches ahead of the CP.

Source: Answer guide [17]

Question 23 **Answer: a) True**

In comparison to a calm day, on windy days a shorter than usual delay should be selected for any given rocket.

a) **True ✓**

b) False

Explanation. *Answer guide:* a) True. On windy days a rocket tends to weather cock, or fly slightly into the wind, thus reducing both its overall altitude achieved as well as reducing its overall flight time.

Weathercocking tilts the flight into the wind, so apogee comes sooner.

Source: Answer guide [17]

Question 24 **Answer: b) False**

Fins placed forward of the center of gravity will tend to stabilize an unguided rocket in flight.

a) True

b) **False ✓**

Explanation. *Answer guide:* b) False. Fins placed forward of the CG will result in moving the overall CP of a rocket forward thus reducing its stability.

Source: Answer guide [17]

Question 25 **Answer: b) False**

Ammonium nitrate is the most common oxidizer used in solid reloadable rocket motors.

a) True

b) **False ✓**

Explanation. *Answer guide:* b) False. The most common oxidizer used in composite motors is Ammonium Perchlorate (AP).

Ammonium perchlorate composite propellant (APCP) is the standard HPR solid propellant.

Source: Answer guide [17]

Question 26 **Answer: a) True**

The tendency for unguided rockets to “weather cock” increases with the area of the fin.

a) **True ✓**

b) False

Explanation. *Answer guide:* a) True. As the largest percentage of the fin area is below the CG, an increase in the fin area will result in there being a larger surface area for the wind to push the bottom half of the rocket resulting in an increased tendency to fly into the wind (weather cock).

Source: Answer guide [17]

Question 27 **Answer: b) False**

Electric match igniters are not susceptible to discharge by static electricity.

a) True
b) **False ✓**

Explanation. *Answer guide:* b) False. Electric matches require a small amount of current to fire, and a static discharge can be more than sufficient to ignite the match. ALL igniters should be shorted out until ready for use.

Keep the igniter leads twisted together (shunted) until you connect them at the pad.

Source: Answer guide [17]

Question 28 **Answer: b) 128.0 N**

Calculate the average thrust for a rocket motor with a total impulse of 1280 Ns and a burn time of 10.0 seconds.

a) 28.76 N
b) **128.0 N ✓**
c) 67.0 N
d) None of the above

Explanation. *Answer guide:* b) 128.0 N. 1280 Ns Total impulse divided by 10 seconds = 128 N. $\bar{F} = I_t / t_b$.

Source: Answer guide [17]

Question 29 **Answer: a) 512.0 N**

Calculate the average thrust for a rocket motor with a total impulse of 2560 Ns and a burn time of 5 seconds.

a) **512.0 N ✓**
b) 51.20 N
c) 128.0 N
d) None of the above

Explanation. *Answer guide:* a) 512.0 N. 2560 Ns Total impulse divided by 5 seconds = 512 N. $\bar{F} = I_t / t_b$.

Source: Answer guide [17]

Question 30 **Answer: d) Copperhead igniters**

Which of the following igniters requires the greatest current to initiate?

a) Solar igniters
b) Wire wrap thermalite
c) Squibs or electric matches
d) **Copperhead igniters ✓**
e) Flashbulb igniters

Explanation. *Answer guide:* d) Copperhead igniters.

Source: Answer guide [17]

Question 31 **Answer: a) True**

The total impulse for a given weight of composite fuel is more than twice that of black powder. That is why solid high power rocket motors use composite rather than black powder.

a) **True ✓**
b) False

Explanation. *Answer guide:* a) True. One pound of Black Powder contains approximately 1/2 the total power of a pound of composite fuel. This is why an AeroTech (composite) E engine is the same size as an Estes (black powder) D engine.

Source: Answer guide [17]

Question 32 **Answer: a) True**

All high power rockets must be inspected by CAR/ACF qualified rocket inspector prior to flight.

a) **True ✓**
b) False

Explanation. *Answer guide:* a) True. The RSO (Range Safety Officer) is charged with the overall safety of the launch (see the "Requirements for Launching High Power Rockets in Canada" document). This includes ensuring that every high power rocket be inspected for safety prior to launch; the CAR/ACF create a specific role, the Rocket Inspector.

TC 9.2 requires inspection immediately before flight; at CAR/ACF launches the Rocket Inspector does it.

Source: Answer guide; TC [9.2]; CAR/ACF Safety Code [10, 13, 17]

Question 33 **Answer: a) True**

The coefficient of drag increases with the length of the rocket airframe.

a) **True ✓**
b) False

Explanation. *Answer guide:* a) True. The CD of a rocket is determined by any inconsistencies on the finish, launch lugs, base drag, fin drag and overall length.

Source: Answer guide [17]

Question 34 **Answer: a) At the top of the core**

Where should an igniter be placed in a composite motor?

a) **At the top of the core ✓**
b) In the middle of the core
c) At the bottom of the core
d) Position makes no difference

Explanation. *Answer guide:* a) At the top of the core. In this way you can ignite the entire motor. Placing the igniter in the middle or bottom of the core will result in a "chuff", as only the lower half of the propellant is burning and thus the motor is not producing its full thrust capability.

The igniter must reach the top (forward end) of the core so the whole grain lights at once.

Source: Answer guide; AeroTech DMS instructions, step 3.3 [17, 26]

Question 35 **Answer: 1.66 kg / 25.51 kg**

If the general rule of thumb for the minimum average thrust to weight ratio is 4:1, what is the maximum mass of a rocket that the following motors will safely lift? (2 Marks)

a) H65 **1.66 kg ✓**

b) L1000 **25.51 kg ✓**

Explanation. *Answer guide:* a) 1.66 kg. 65 Ns / 4 = 16.25 N / 9.8 m/s^2 = 1.66 kg.
b) 25.51 kg. 1000 Ns / 4 = 250 N / 9.8 m/s^2 = 25.51 kg.

$m_{\max} = \bar{F}/(4g)$.

Source: Answer guide; CAR/ACF Safety Code (4:1) [13, 17]

Question 36 **Answer: 5.38 kg / 36.71 kg**

If the general rule of thumb for the minimum average thrust to weight ratio is 4:1, what is the maximum mass of a rocket that the following motors will safely lift? (2 Marks)

a) I211 **5.38 kg ✓**

b) M1439 **36.71 kg ✓**

Explanation. *Answer guide:* a) 5.38 kg. 211 Ns / 4 = 52.75 N / 9.8 m/s^2 = 5.38 kg.
b) 36.71 kg. 1439 Ns / 4 = 359.8 N / 9.8 m/s^2 = 36.71 kg

$m_{\max} = \bar{F}/(4g)$.

Source: Answer guide; CAR/ACF Safety Code (4:1) [13, 17]

Question 37 **Answer: b)**

A rocket has been equipped with a cluster of 3 motors, a central J415 and 2 outboard G-80's. Electric matches are used to ignite the motors. Assuming all 3 electric matches ignite at the same time:

a) The J415 will ignite first.

b) **The 2 G-80's will ignite first. ✓**

c) All three motors will ignite at the same time.

Explanation. *Answer guide:* b) The 2 G-80's will light first. The core in the J415 is much larger, therefore requiring a much longer period of time to build up sufficient pressure to fully ignite. It is for this reason that clustered projects should be either:
1- Able to lift off safely under the power of the smallest motor in the cluster.
2- The smaller motors should be set on a time delay, where they do not light until after the largest motor in the cluster has come up to full pressure. This is often accomplished by using a G-switch timer, which is set to ignite the smaller motors at a specific time after lift-off is detected.

Source: Answer guide [17]

Question 38 **Answer: b)**

Which answer best describes the typical operation of a nitrous oxide hybrid rocket motor?

a) The nitrous is ignited and then released, blowing a hot flame onto the fuel in the combustion chamber.
b) **The fuel is ignited and the nitrous is then released onto the burning fuel in the combustion chamber. ✓**
c) The nitrous is combined with the fuel in the combustion chamber, becoming highly flammable and is then ignited.

Explanation. *Answer guide:* b) Answer a) is impossible because N_2O is nonflammable. Answer c) is impossible because a liquid N_2O and a solid plastic will not mix.

In a hybrid the solid fuel grain is lit first, then the liquid N_2O oxidizer is released onto it.

Source: Answer guide [17]

Question 39 **Answer: c)**

What happens when changing to smaller or fewer injector orifices in an ideal hybrid rocket motor (assume the oxidizer weight stays the same)?

a) The total impulse decreases and the average thrust increases.
b) The total impulse stays the same and the average thrust increases.
c) **The total impulse stays the same and the average thrust decreases. ✓**

Explanation. *Answer guide:* c) The total thrust is mostly dependent on the total volume of N_2O delivered. The average thrust depends on the rate of delivery, which is a function of orifice size. In this example the total volume of Nitrous remains the same but is delivered into the combustion chamber more slowly, lowering the average thrust and increasing the burn time.

Same oxidizer mass, so roughly the same total impulse; slower flow, so lower thrust and a longer burn.

Source: Answer guide [17]

Question 40 **Answer: a) N_2O**

What is the oxidizer most commonly used in a commercial hybrid rocket motor?

a) **N_2O ✓**
b) N_2O_4
c) NO_2

Explanation. *Answer guide:* a) N_2O is Nitrous Oxide

Source: Answer guide [17]

Question 41 **Answer: b) 4971 kPa (721 psi)**

What is the nominal tank pressure of a nitrous oxide hybrid motor at 24 °C (75 °F)?

a) 689 kPa (100 psi)
b) **4971 kPa (721 psi) ✓**
c) 10342 kPa (1500 psi)

Explanation. *Answer guide:* b) 4971 kPa (721 psi). This is an important number because it is the minimum pressure that all hybrid components must be able to withstand.

Source: Answer guide [17]

Question 42 **Answer: a)**

Above what temperature does pressurized nitrous oxide change to a gas?

a) **36 °C (97 °F) ✓**
b) 24 °C (75 °F)
c) 3 °C (37 °F)

Explanation. *Answer guide:* a) 36 °C (97 °F)

36 °C is the critical temperature of N_2O: above it the liquid cannot exist.

Source: Answer guide [17]

Question 43 **Answer: c)**

The boiling point of nitrous oxide at atmospheric pressure is:

a) −55.7 °C (−68.3 °F)
b) −73.3 °C (−99.9 °F)
c) **−88.5 °C (−127.3 °F) ✓**

Explanation. *Answer guide:* c) −88.5 °C (−127.24 °F)

Source: Answer guide [17]

Question 44 **Answer: b) An oxidizer**

Nitrous Oxide is:

a) A hydrocarbon fuel
b) **An oxidizer ✓**
c) An acid

Explanation. *Answer guide:* b) An oxidizer is any substance that gives up a significant amount of Oxygen to support the combustion in the motor.

Source: Answer guide [17]

Question 45 **Answer: c)**

Nitrous Oxide is:

a) Highly regulated and available only with proper permits and authorization.
b) A controlled substance available only through the medical community.
c) **Available at most high performance automobile shops. ✓**

Explanation. *Answer guide:* c) Nitrous Oxide (N_2O) is readily available to the general public, most often in high performance auto shops.

Source: Answer guide [17]

Question 46 **Answer: a) True**

The thrust curve of a regressive burn motor has a high initial thrust relative to the ending thrust of the motor.

a) **True ✓**
b) False

Explanation. *Answer guide:* a) True.

Source: Answer guide [17]

Question 47 **Answer: a) True**

The thrust curve of a progressive burn motor has a low initial thrust relative to the ending thrust of the motor.

a) **True ✓**
b) False

Explanation. *Answer guide:* a) True.

Source: Answer guide [17]

Question 48 **Answer: a) Regressive burn**

The safest burn rate for a rocket whose thrust to weight ratio is marginal is:

a) **Regressive burn ✓**
b) Progressive burn
c) Makes no difference

Explanation. *Answer guide:* a) Regressive Burn. Heavy rockets benefit from the higher initial thrust offered by a regressive burn motor.

Source: Answer guide [17]

Note on Q35 and Q36

The study guide writes the motors' average thrust with the unit "Ns"; the quantity divided by 4 is the *average thrust in newtons* (the number in the designation), and dividing that force by g gives the maximum liftoff mass. The arithmetic and the answers are correct.

CHAPTER 4

Manufacturing

A certification flight is judged on the whole flight: a clean boost, a stable climb, deployment, and a landing that leaves the rocket ready to fly again. Most failed attempts are not failures of theory but of construction: a fin that lets go, a motor that leaves the rocket at ejection, a shock cord that burns through. This chapter covers what to build, what to build it from, and where rockets usually break. Anything in an orange box is safety-critical.

4.1 Anatomy of a certification rocket

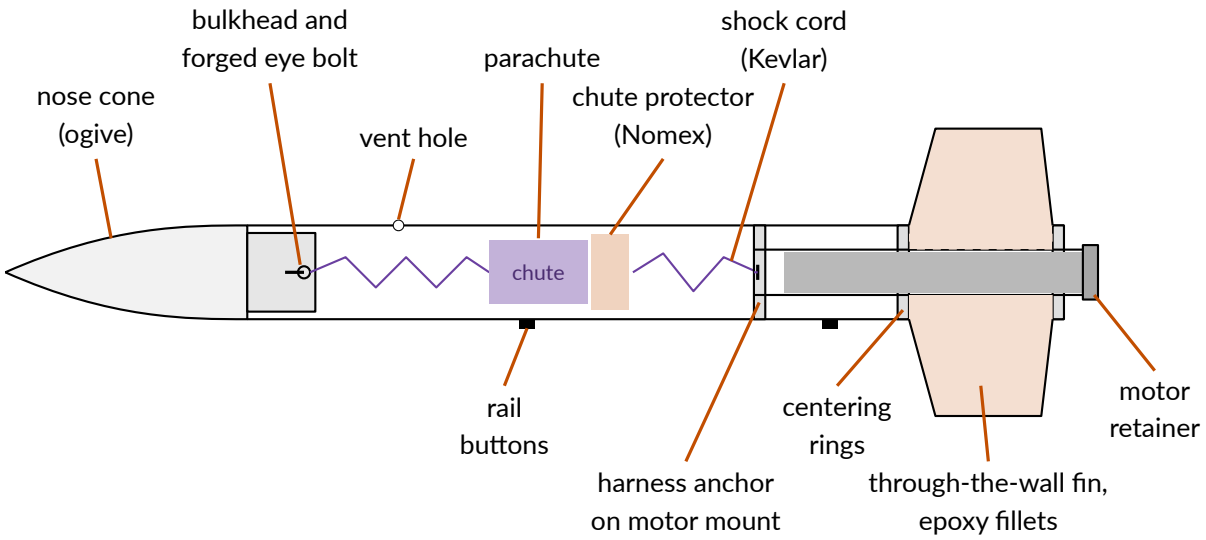


Figure 4.1. Cutaway of a typical single-deployment Level 1 rocket. The shock cord is anchored to the motor mount, runs past the parachute and protector, and ends on the nose cone eye bolt.

4.2 Material choices

Transport Canada [4.1.3] and the CAR/ACF code require a high-power rocket to be made of *lightweight materials capable of withstanding the stresses anticipated during ignition and flight*. Wood, phenolic, fibreglass, plastics and metals are all acceptable. What matters is that each part is strong enough for its load.

Part	Common choices	Notes for a certification build
Body tube	Heavy-wall kraft paper, phenolic, fibreglass, carbon fibre	Paper and phenolic are light and cheap but dislike moisture and hard landings; a layer of fibreglass over paper is a common upgrade. Fibreglass is the most forgiving.
Fins	Aircraft plywood (birch), G10 fibreglass, carbon laminate	Avoid balsa or thin basswood at HPR speeds. Grain of plywood face plies should run toward the tip for flutter stiffness.
Nose cone	Plastic (polystyrene, polypropylene), fibreglass	Plastic is fine for L1 and L2. Fibreglass for higher speed and energy.
Centering rings, bulkheads	Aircraft plywood, fibreglass	Fibreglass or thick plywood for the aft ring that carries thrust.
Motor tube	Kraft or phenolic tube sized to the motor case	The motor case slides in with a snug but not forced fit.
Adhesives	Slow-cure structural epoxy (15 to 30 minute or laminating)	Wood glue and CA are for model rockets; use epoxy for every structural joint.
Recovery harness	Tubular Kevlar, nylon	Kevlar near the motor (heat), nylon elsewhere is acceptable.

Table 4.1. Typical materials for a Level 1 to Level 3 airframe.

⚠ Materials: rules and limits

- Build only from lightweight materials able to withstand ignition and flight stresses (TC [4.1.3]). No metal nose cones or fin cans unless the design and the RSO justify them.
- The loaded rocket must not exceed the motor manufacturer's **maximum liftoff weight** (TC [9.4]), and the thrust-to-weight ratio must be at least **4:1** (CAR/ACF code v3.6), unless the RSO explicitly permits otherwise.
- Recovery wadding, if used, must be **flame resistant and biodegradable**. Fibreglass insulation is not allowed.

4.3 Fin attachment

Fins carry large aerodynamic loads at high speed and take the impact at landing. The strongest common method is **through-the-wall (TTW)** construction: slots are cut in the body tube, each fin root tab passes through the slot and is glued to the motor tube between two centering rings.

1. Cut accurate slots with a fin-slotting guide; mark fin lines at equal angles (120° for three fins, 90° for four).
2. Dry-fit the fins; use a fin alignment jig so each fin is straight and perpendicular to the tube. A crooked fin makes the rocket roll or arc.
3. Epoxy the root tab to the motor tube (*internal fillets*, injected through the aft end before the

aft ring goes on, or through small holes).

4. Add smooth *external fillets* of epoxy (thickened with a filler such as microballoons or milled glass) along each fin-body joint.
5. Optionally lay fibreglass from fin tip to fin tip over the body ("tip-to-tip") for rockets that will fly fast or land hard.

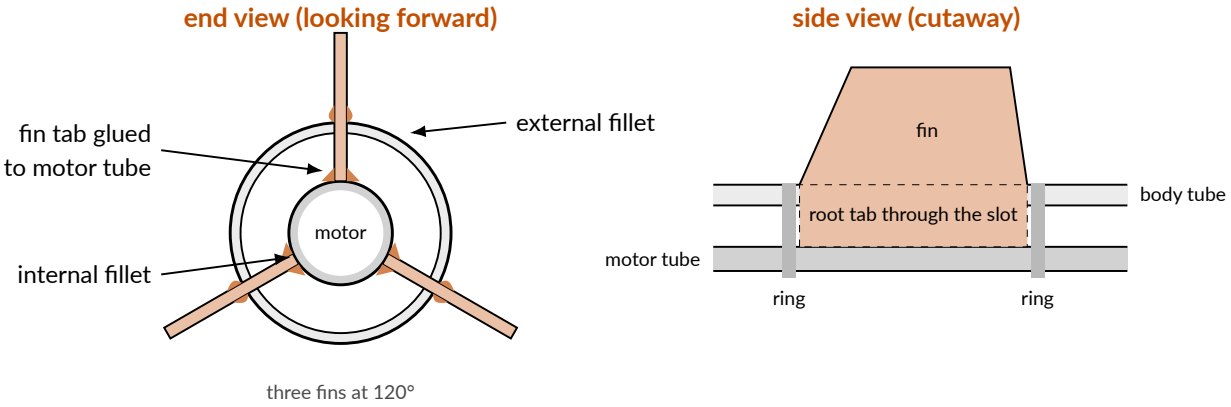


Figure 4.2. Through-the-wall fins: the root tab passes through a slot in the body tube and is glued to the motor tube between two centering rings, with fillets inside and outside.

Fin failure modes

- **Surface-mounted fins** (glued only to the outside of the tube) peel the tube skin and shed in flight. Use TTW construction for any HPR rocket.
- **Flutter**: thin or flexible fins at high speed oscillate and break. Use stiff material and thickness appropriate to the expected velocity.
- **Fins forward of the CG** reduce stability.
- Sand fin edges round (leading) and taper or round (trailing); sharp flat plates add drag but, more importantly, uneven edges add asymmetric forces.

4.4 Motor mount construction

The motor mount transmits the full thrust of the motor into the airframe and must keep the motor in the rocket at ejection.

1. Use at least two centering rings, epoxied with fillets on both faces. The forward ring usually carries the recovery harness anchor.
2. The motor's thrust must bear on something solid: the motor case's aft flange or a thrust ring bearing on the aft end of the motor tube and aft centering ring.
3. Install a positive **motor retainer**: a screw-on retainer cap, or clips or hooks. Friction fit and masking tape are not retention for HPR.
4. Leave the motor tube extending slightly aft of the body tube if the retainer needs it, and keep the retainer away from fin roots so heat does not soften the fillets.

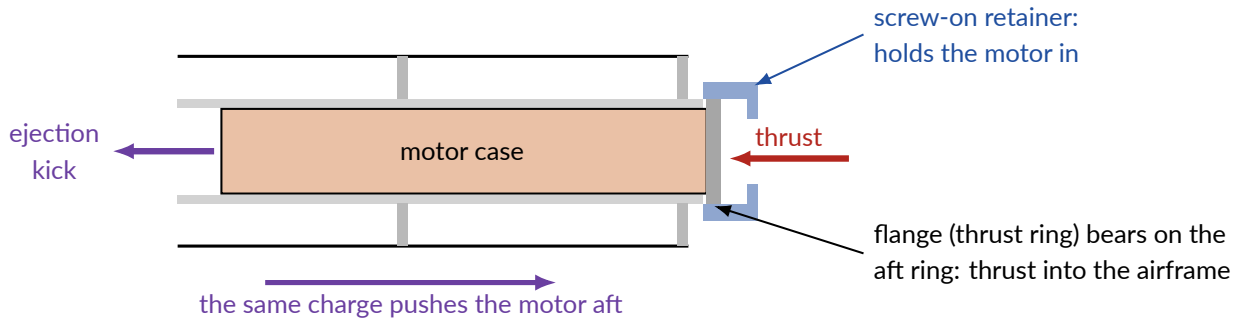


Figure 4.3. Motor mount load paths. Thrust goes forward through the flange into the aft centering ring; at ejection the charge pushes the nose forward and the motor aft, which only a positive retainer resists.

⚠ Motor retention is inspected

The certification rules call for the rocket to be returned and inspected after landing specifically **to verify motor retention**. A motor that is ejected by the ejection charge (it pushes backwards as hard as it pushes the nose cone forwards) falls ballistically and can disqualify the flight. Positive retention is mandatory in practice.

⚠ Reload assembly

Assemble reloadable motors **only as the manufacturer's instructions direct**. Do not modify the case, closures, grains, delay element, nozzle, liner or O-rings, and do not reuse any single use part (CAR/ACF code; TC [9.1]). Single-use motors may not be reloaded, and it is unlawful to alter commercial motors. Delay adjustment is done only with the manufacturer's tool and method. At Level 3 the reload assembly is witnessed.

4.5 Recovery harness and attachment points

The ejection event is violent: the charge pressurizes the tube, the nose cone leaves at speed, and the harness snaps taut. Everything in that load path must be stronger than the shock.

- **Anchor** the harness to the motor mount (a U-bolt or forged eye bolt through the forward centering ring, or a Kevlar strap epoxied along the motor tube), never to the thin body tube wall with a paper mount.
- Use **forged** eye bolts (not bent-wire ones) and **rated quick links** to connect harness, parachute and nose cone.
- Harness length: a common rule of thumb is about **three times the rocket's length**, so the nose cone and body cannot hit each other on deployment.
- Put the parachute on the harness a short distance from the nose cone, and use a **swivel** so the canopy does not wind up its shroud lines (Chapter 5).
- Protect the parachute from the ejection gas with a **Nomex** chute protector or deployment bag, or with flame-resistant biodegradable wadding.

⚠ Recovery hardware: the non-negotiables

- A **vent hole** in the body tube between the upper bulkhead and the nose cone prevents premature ejection of the nose cone during climb (Section 4.6).
- The nose cone must separate cleanly: snug enough not to fall out, loose enough to pop with the charge. Test by hand. Heavier or high-drag nose cones may need shear pins.
- Loaded mass above **5 kg**: a redundant, independent deployment system is required (CAR/ACF code).
- Protect every pyrotechnic system mechanically against premature ignition from EMI or heat (2005 code; still good practice): shunted e-matches, covered terminals, switches that keep electronics off until the rocket is vertical on the pad.

4.6 Vent holes

The parachute compartment is closed at the bottom by the motor mount and at the top by the nose cone shoulder. At the pad it is full of air at ground pressure. As the rocket climbs, the outside pressure falls, but the air inside can only escape through gaps. Without a way out, the trapped air pushes on the nose cone from inside like a piston, and a friction-fitted nose cone can pop off during the climb or at high speed near burnout. The parachute then opens at high speed, which is the classic recipe for a zipper or a shredded canopy (Section 4.8). A small **vent hole** drilled through the body tube into the compartment lets the inside pressure follow the outside pressure, so the nose cone only leaves when the ejection charge fires. The Rocket Inspector checks for it [30].

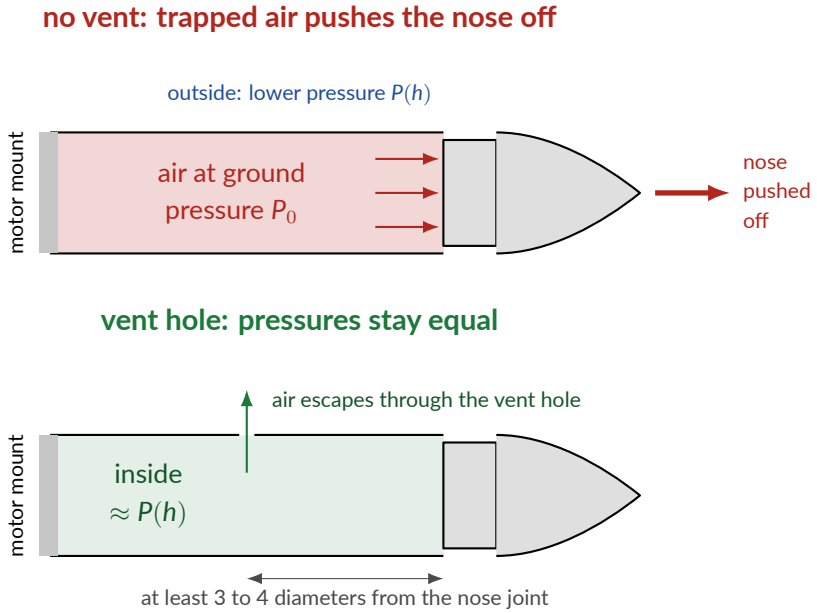


Figure 4.4. Why a vent hole is needed. Top: the air sealed in at ground pressure pushes the nose cone out as the outside pressure falls. Bottom: a small hole lets the inside pressure follow the outside one; the nose cone leaves only when the ejection charge fires.

4.6.1 How big a push, and how big a hole?

⚠ Worked example: vent hole for the Level 1 rocket

The 66 mm rocket of **??** has a parachute compartment about 50 cm long (inside diameter about 64 mm) and climbs to 720 m, at up to 134 m/s near the ground.

Step 1: pressure difference at apogee without a vent

The standard atmosphere gives the pressure at height h:

$$P(h) = P_0\,(1 - 2.256 \times 10^{-5}\,h)^{5.256} = 101\,325 \times (1 - 2.256 \times 10^{-5} \times 720)^{5.256}$$

$$P(720) = 101\,325 \times (0.98376)^{5.256} = 101\,325 \times 0.9175 \;\longrightarrow\; P(720) = 92\,970 \text{ Pa}$$

$$\Delta P = P_0 - P(720) = 101\,325 - 92\,970 \;\longrightarrow\; \Delta P = 8\,360 \text{ Pa}$$

Step 2: the force on the nose cone

The pressure difference acts on the full cross-section of the tube:

$$F = \Delta P \times \frac{\pi d^2}{4} = 8\,360 \times 3.42 \times 10^{-3} \;\longrightarrow\; \boxed{F \approx 29 \text{ N}}$$

About the weight of 3 kg: far more than a friction fit is meant to hold.

Step 3: how fast the air must leave

Climbing at speed v, the outside pressure falls at $\rho g v$ pascals per second. To keep up, the compartment (volume V) must lose the same fraction of its air each second:

$$\frac{dP}{dt} = \rho\, g\, v = 1.225 \times 9.81 \times 133.7 \;\longrightarrow\; 1\,607 \text{ Pa/s}$$

$$V = \frac{\pi \times (0.064)^2}{4} \times 0.50 \;\longrightarrow\; V = 1.61 \times 10^{-3} \text{ m}^3$$

$$Q = V\,\frac{1}{P_0}\,\frac{dP}{dt} = 1.61 \times 10^{-3} \times \frac{1\,607}{101\,325} \;\longrightarrow\; Q = 2.55 \times 10^{-5} \text{ m}^3/\text{s}\ (25 \text{ cm}^3/\text{s})$$

Step 4: the hole size

Air through a small hole flows at $\sqrt{2\,\Delta P_{hole}/\rho}$ with a discharge coefficient of about 0.61. Allowing only $\Delta P_{hole} = 100$ Pa (a force of 0.3 N on the nose cone):

$$A_{hole} = \frac{Q}{0.61\sqrt{2\,\Delta P_{hole}/\rho}} = \frac{2.55 \times 10^{-5}}{0.61 \times \sqrt{2 \times 100/1.225}} = \frac{2.55 \times 10^{-5}}{0.61 \times 12.8} \;\longrightarrow\; A_{hole} = 3.27 \times 10^{-6} \text{ m}^2$$

$$d_{hole} = \sqrt{\frac{4A_{hole}}{\pi}} = \sqrt{\frac{4 \times 3.27 \times 10^{-6}}{\pi}} \;\longrightarrow\; \boxed{d_{hole} \approx 2 \text{ mm}}$$

A common 3 mm (1/8 in) hole leaves only about 20 Pa of difference, a push of less than 0.1 N.

The altimeter-port formula

Altimeter manufacturers size the *static ports* of an electronics bay with an empirical formula (all

dimensions in inches) [31, 32]:

$$d_{port} = 0.004396 \times D \times \sqrt{\frac{L}{n}}$$

where D is the bay diameter, L its length and n the number of holes. For our 2.6 in by 19.7 in compartment and one hole it gives $0.004396 \times 2.6 \times \sqrt{19.7} = 0.051$ in (1.3 mm); with three holes, 0.7 mm each. Those ports are kept small so that the altimeter reads a smooth, accurate pressure; a plain vent hole has no such constraint and is usually made a little larger.

⚠ Vent holes: practical rules

- Drill **one to three holes of 2 to 5 mm** (about 1/16 to 3/16 in) into **every sealed compartment**: the parachute bay, and each bay of a dual-deployment rocket. Holes much smaller than the tube wall is thick tend to clog.
- Place them in the body tube, clear of the nose cone shoulder and any coupler, and preferably **3 to 4 body diameters behind the nose-cone joint**, away from the disturbed pressure near the nose.
- An electronics bay needs **static ports** sized with the altimeter maker's formula above, several small holes spaced evenly around the tube, and no other leaks.
- Drill cleanly and deburr; seal paper tubes around the hole with thin CA so the edge does not fray.
- The Rocket Inspector will ask to see it: know where it is [30].

4.7 Launch guides: rail buttons

Launch lugs work for small rockets on rods; most HPR rockets use **rail buttons** on a 1010 (1 in) or 1515 (1.5 in) rail. Two buttons, correctly placed and solidly backed, guide the rocket straight until it is fast enough for the fins to take over (**??**).

Where to put them

- **Aft button as close to the tail as practical**, a few centimetres from the aft end. The rocket is guided until the *aft* button leaves the rail, so the distance it travels on the rail is the rail length minus the height of that button. On a 1.52 m rail, moving it 30 cm up the rocket shortens the guided length to 1.22 m and lowers the rail exit speed of the Level 1 example from 15.4 to about 13.8 m/s.
- **Forward button near the CG** (slightly ahead of it is common). The two buttons should be far apart: a long base keeps the rocket from rocking about one button and binding as it slides.
- **Both on one straight line** parallel to the rocket's axis, and **midway between two fins** (60° from a fin for three fins, 45° for four), so the rail never touches a fin.
- **Solid backing** for each screw: a centering ring, a wooden block glued inside the tube, a coupler or bulkhead, or a T-nut or well-nut. A button screwed only into the tube wall pulls out. Check that the screw does not reach into the motor tube.

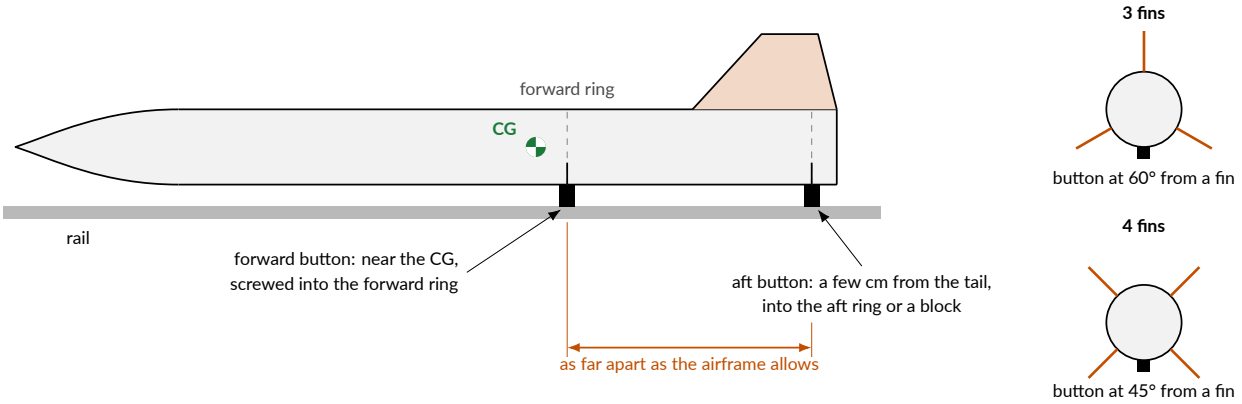


Figure 4.5. Rail button placement. Left: side view, nose on the left; each button sits over a centering ring (dashed) that gives its screw solid backing. Right: end views looking forward; the rail line runs midway between two fins.

Think about the build order

The best place for each button is over something solid, and that something is usually glued in early and closed off for good. The aft centering ring, the fin roots and the motor retainer together seal the fin can: once they are epoxied you can no longer reach inside to add a backing block, a T-nut or a blind nut, or to check where a screw goes. Figure 4.6 shows an order that keeps every option open.

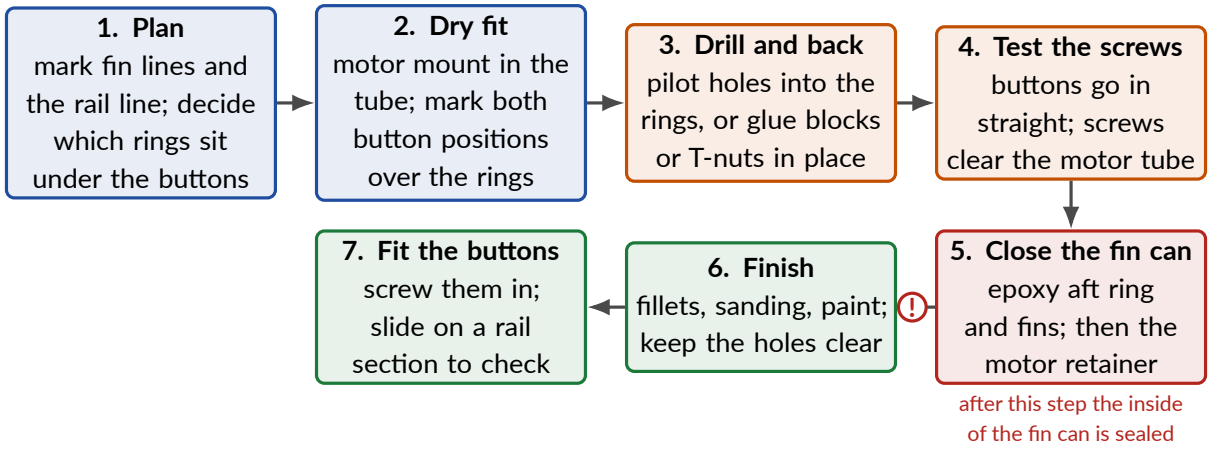


Figure 4.6. A build order for the motor mount and rail buttons: everything that needs access to the inside (steps 1 to 4) is done before the fin can is closed (step 5).

⚠ Rail buttons: plan them before the epoxy

- Decide the button positions **before** gluing the aft centering ring, the fins and the motor retainer. Drill the pilot holes, or glue in the backing blocks or T-nuts, while the inside is still open.
- Put the aft button over the aft centering ring (or a block glued just ahead of it), a few centimetres from the tail; put the forward button over the forward ring or a block near the CG.
- Make sure no screw can reach the motor tube, the fin tabs or the retainer thread.
- Before calling the rocket finished, slide it along a real rail: it must move freely over the

whole length without binding [30].

4.8 Common failure points to avoid

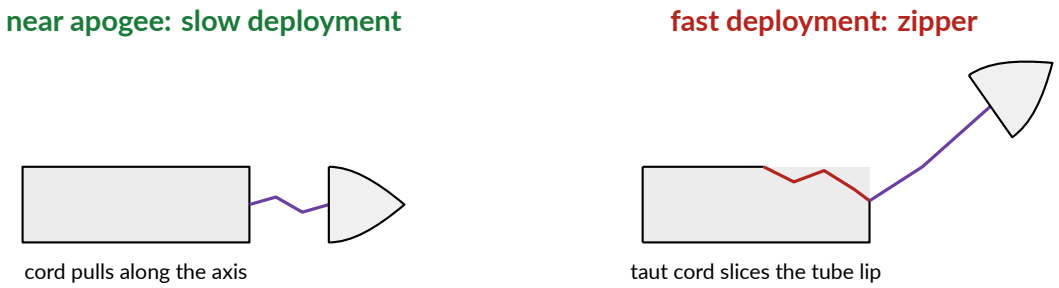


Figure 4.7. Zippering: when the nose separates at high speed the shock cord snaps sideways against the tube lip and cuts it. Correct delay, a longer harness and flat strap cords reduce it [33].

Top ten failure points

1. **Zippering**: the harness slices the body tube lengthwise when the nose separates at high speed. Cause: late or early deployment, short harness. Fix: correct delay, longer harness, reinforced tube lip.
2. **Motor ejection**: no positive retention.
3. **Shock cord burn-through**: elastic or nylon exposed to hot ejection gas. Use Kevlar near the motor and protect the chute.
4. **Fin loss**: surface-mounted or poorly filleted fins, flutter.
5. **Nose cone stuck**: too tight a fit, or a paper tube swollen by humidity. Test separation by hand before the flight.
6. **Premature separation**: nose cone too loose or no vent hole; drag separation at burnout.
7. **Harness anchor pull-out**: eye bolt in a thin bulkhead, or glued only to the tube.
8. **Parachute not deploying**: packed too tightly, or wrapped by its own shroud lines.
9. **Understable rocket**: CG moved aft by a heavier motor or tail paint; always check the CG with the flight motor installed.
10. **Binding rail buttons** or a bent rail: slow, wobbling rail exit.

⚠ Before you call it finished

- ☐ Mark the CG (with the flight motor installed) and the CP on the airframe.
- ☐ Weigh the loaded rocket; check it against the motor's maximum liftoff weight and the 4:1 thrust-to-weight ratio.
- ☐ Pull-test the harness anchor, eye bolt and quick links by hand, hard.
- ☐ Check the nose cone and any couplers slide apart with firm hand pressure.
- ☐ Confirm the motor retainer is installed and the motor cannot slide forward or aft.

- [ ] Check fin alignment by sighting down the tube; no loose fins or cracked fillets.

CHAPTER 5

Parachute Packing

A perfect boost means nothing if the parachute stays in the tube. Packing is the one recovery task you will do at the field, often in wind and in a hurry, so practise it at home until it is automatic. This chapter gives a complete fold for a flat hexagonal canopy (the most common certification parachute), one figure per step, followed by the steps that get the folded parachute into the rocket.

Before you start

- Work on a clean, dry surface out of the wind (a tarp or a table in the prep area).
- Check the canopy for burns, holes and torn seams, and every shroud line for fraying.
- Untangle all shroud lines *before* folding: hold the canopy apex and let the lines hang, or run your fingers from the canopy edge to the swivel along each line.
- Know the legend of the figures: **blue dashed lines** are fold lines, **yellow arrows** show the direction of the fold.

5.1 The fold, step by step

Steps 1 and 2: halve the canopy, then fold the gores in

Lay the canopy flat with the shroud lines outward. Fold the hexagon in half along a line through two opposite corners, so the lines from both halves come together on one side. Then fold the top and bottom panels inward along the diagonal fold lines so the canopy becomes a narrow wedge with all gores stacked.

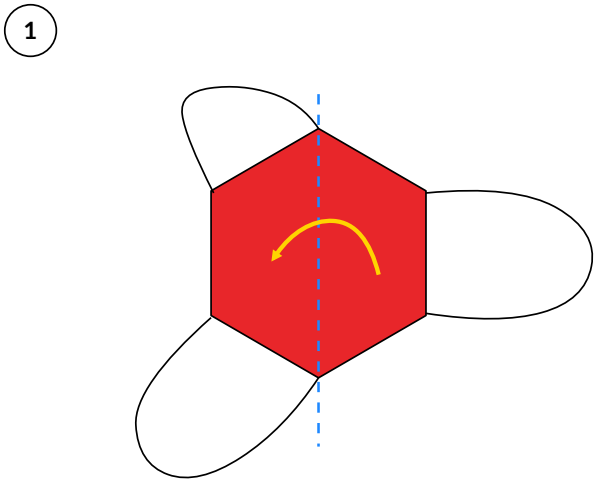


Figure 5.1. Step 1: Fold the hexagon in half.

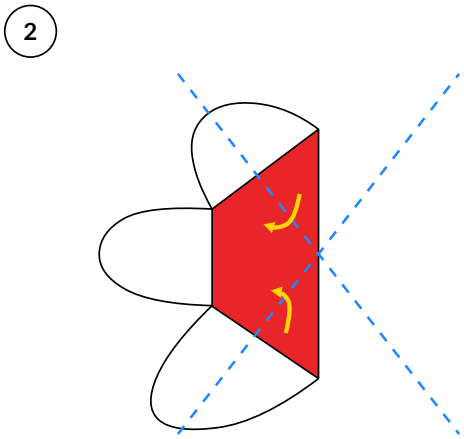


Figure 5.2. Step 2: Fold the top and bottom inward.

Steps 3 and 4: fold the wedge lengthwise into a strip

Fold the wedge in half lengthwise along its centre line. The result is a slim strip whose width should be a little less than the inside diameter of the body tube (or of the chute protector you will wrap it in). All shroud lines leave the strip at one end.

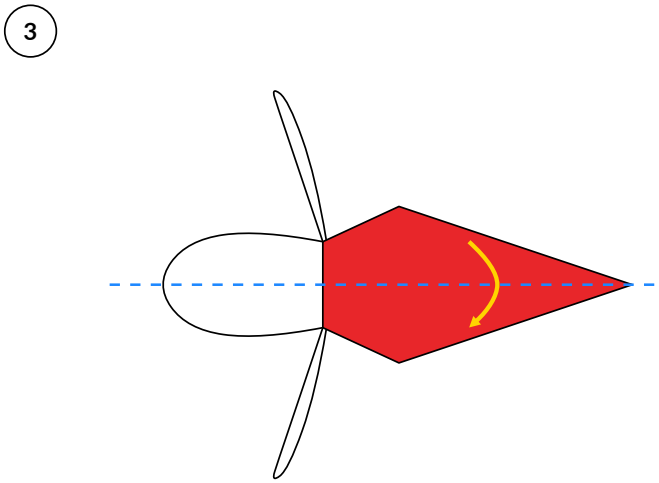


Figure 5.3. Step 3: Fold the wedge in half lengthwise.

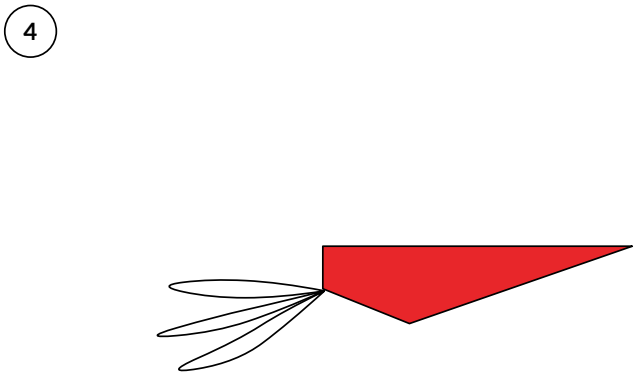


Figure 5.4. Step 4: Slim strip with shrouds fanned out.

☞ Getting the width right

The strip width sets the final bundle diameter. If the strip is wider than the tube, fold the wedge once more lengthwise rather than forcing it in later. A parachute jammed into the tube is the classic cause of a failed deployment.

Steps 5 and 6: gather the shroud lines and attach the swivel

Pull all the shroud lines straight and even, so that none is slack, then tie (or check) the ends together in a knot or on a single attachment ring. Attach the swivel to that point; the swivel connects to the quick link on the recovery harness.

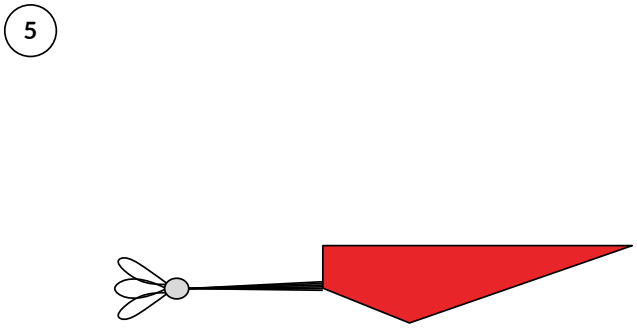


Figure 5.5. Step 5: Stretch the shrouds and tie the ends in a knot.

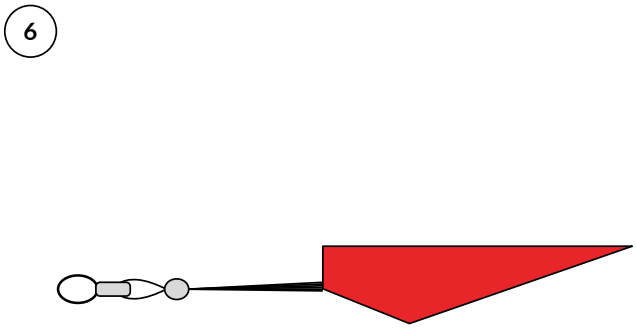


Figure 5.6. Step 6: Stretch the shrouds, tie the ends and attach the swivel.

☞ Avoiding line tangles

- Always fly a **swivel** between the shroud lines and the harness. A spinning rocket otherwise twists the lines together and the canopy cannot open.
- Keep the lines **parallel and equal in length** as you gather them; one long line forms a loop that can catch a fin or the nose cone.
- Never wrap the lines tightly around the folded canopy. Loose wraps can tie the canopy shut; lay the lines along it instead (steps 7 and 8).

Steps 7 and 8: lay the lines on the canopy and trap them

Lay the shroud lines along the top of the folded strip in neat, loose zig-zags, leaving the knot and swivel free at the base. Then fold the strip horizontally so the lines are trapped inside the canopy; they will pay out in order when the canopy is pulled from the tube.

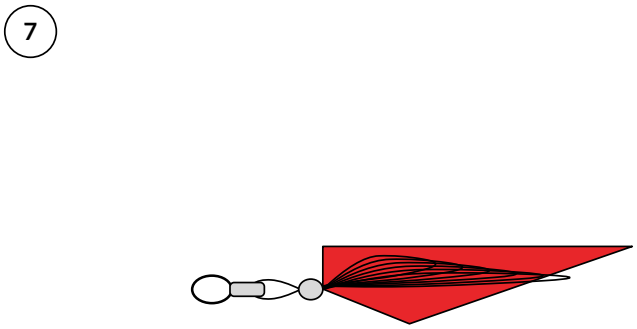


Figure 5.7. Step 7: Lay the shrouds on top of the canopy.

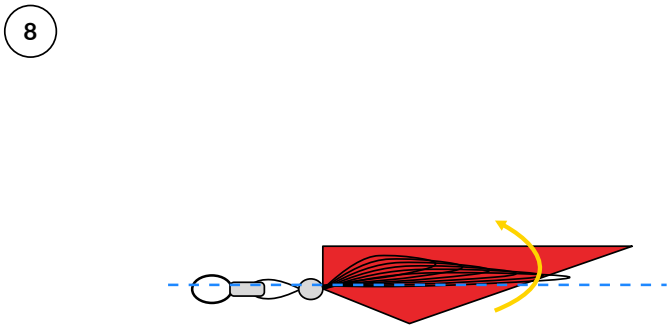


Figure 5.8. Step 8: Fold horizontally and trap the shrouds in the parachute.

Steps 9 to 11: fold the strip to length

Fold the right-hand end over to the left, twice, then fold once more, until the bundle is about as long as the space you have for it in the recovery bay. Do not roll it tightly: a firm but soft bundle comes out of the tube far more easily than a hard roll.

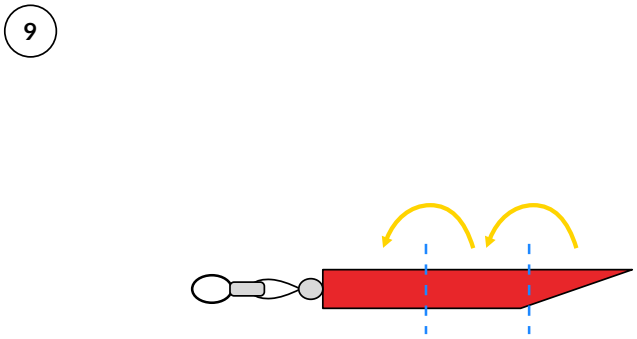


Figure 5.9. Step 9: Fold the right side over to the left, twice.

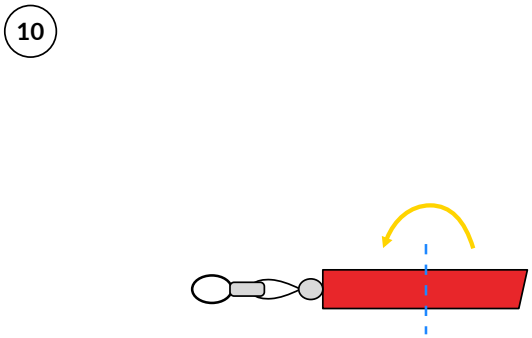


Figure 5.10. Step 10: Fold once more.

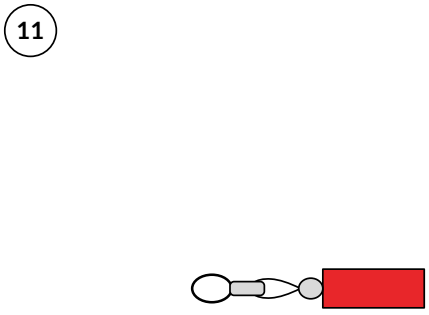


Figure 5.11. Step 11: Fold once more: the finished bundle, with the knot and swivel free.

5.2 Into the rocket

1. **Protect the canopy.** Wrap the bundle in a Nomex chute protector (the "burrito" wrap of Figure 5.12) or slide it into a deployment bag. A square cut from an old pair of **cotton denim jeans** works too: cotton chars instead of melting, so it shields a nylon canopy from ejection gas at almost no cost. Attach the protector to the harness (a small hole or a sewn loop over the shock cord) so that it comes out with the parachute.
2. **Harness first, then the parachute.** Push the motor-end part of the harness into the tube first, in loose zig-zags (a rubber band or a bit of masking tape to hold the bundle is fine, as long as it breaks easily). Then the protected parachute, then the rest of the harness up to the nose cone (Figure 5.13).
3. **Nothing tight.** The parachute bundle should slide into the tube under its own weight or with a light push, and slide out with a light pull.
4. **Close the rocket** and check that the nose cone fit is correct, not forced shut by an overstuffed

bay.

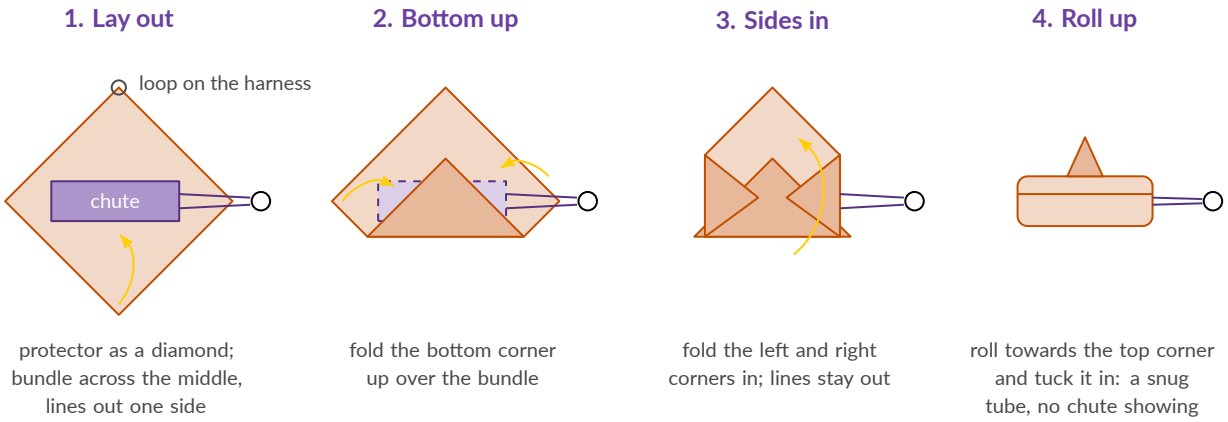


Figure 5.12. The burrito wrap with a Nomex (or cotton denim) protector. The canopy is fully enclosed; only the shroud lines and swivel come out of one end. Load it with the protector towards the motor end, so that the ejection gas meets the protector first.

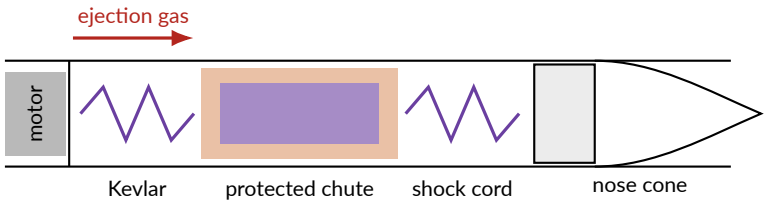


Figure 5.13. Loading order from the motor end: Kevlar harness first, protected parachute, remaining cord, nose cone. The protector always sits between the gas and the canopy.

☞ Protecting the canopy from ejection heat

- Ejection gas is hot and full of burning particles. Nylon canopies melt; a single burn hole or melted panel can stop the canopy from opening.
- Use a **Nomex** protector or deployment bag sized to the tube, or a square of heavy **cotton denim** cut from old jeans (never a synthetic fabric, which melts like the canopy), and position it between the canopy and the motor end of the bay.
- If you use wadding instead, it must be **flame resistant and biodegradable** (CAR/ACF code). Fibreglass insulation is prohibited.
- Keep the Kevlar section of the harness on the motor side, where the gas is hottest.

Packing tips from the field

- A light dusting of talc or baby powder on the canopy helps it slide and open, especially in humid or cold weather.
- Pack as late as practical. A parachute left folded for days or packed cold takes a set and opens more slowly.
- Do a **slide test** at home with the actual rocket: pack, then pull the nose cone by hand. Everything should come out in order with a firm tug.
- Take a spare quick link, spare rubber bands and a small roll of masking tape to the field.

CHAPTER 6

Day of Certification

Certification day compresses everything in this book into a few hours on an open field. You write the exam (it must be passed before the flight attempt), prepare the motor and the rocket, fill in the flight card, pass the Rocket Inspector, fly, recover, and get the paperwork signed. This chapter is a field guide in the order things happen. It follows the AeroTech single-use motor instructions [26], the CAR/ACF Flight Data Sheet and Rocket Inspector checklist [30, 34] and the CAR/ACF certification form [25]. Printable one-page versions of the checklists and forms are collected in Appendix A.

6.1 The weeks before: a preparation timeline

Good certification days are decided weeks earlier. Figure 6.1 is a timeline for one flier preparing a Level 1 or Level 2 attempt at a sanctioned launch.

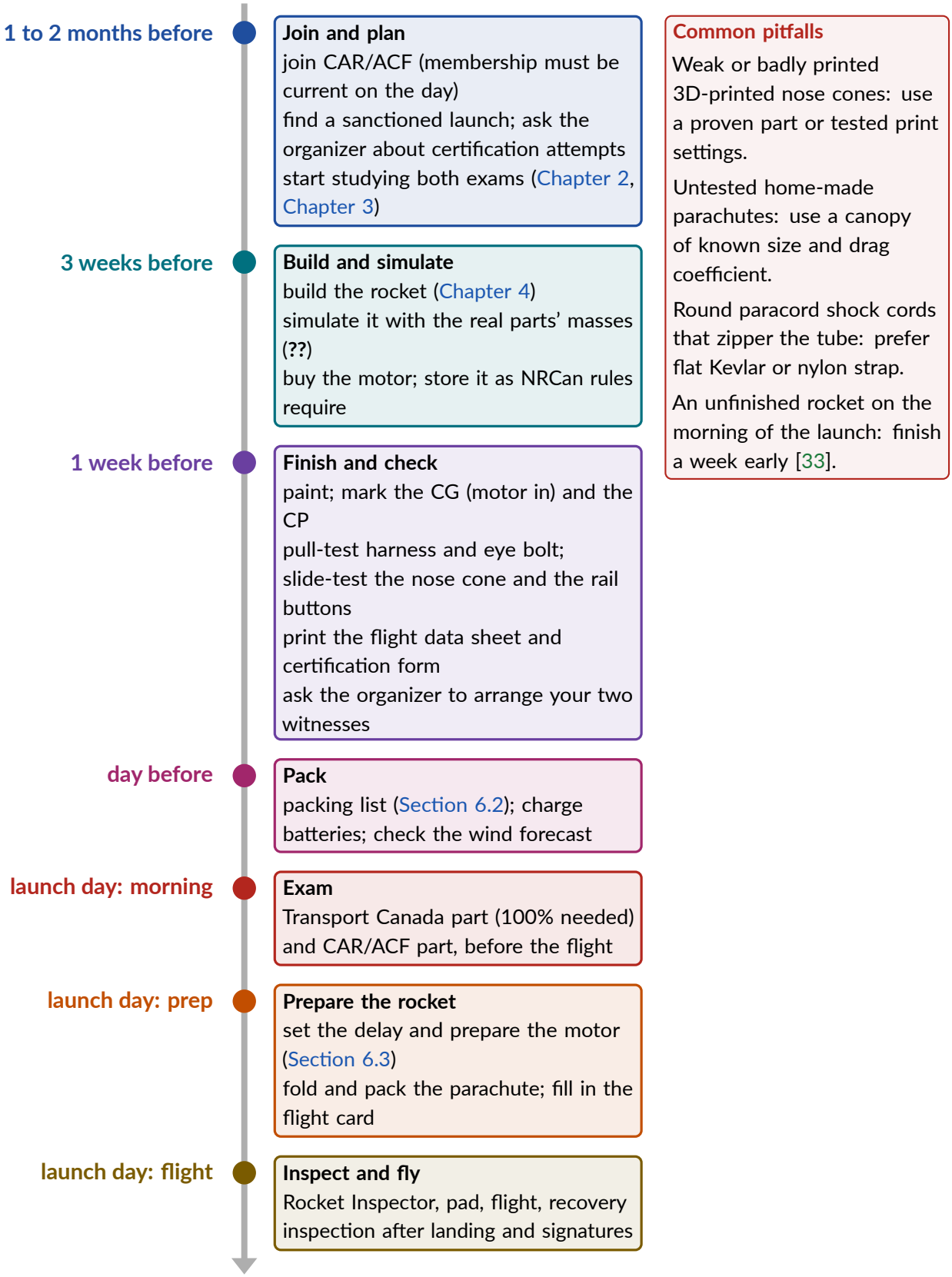


Figure 6.1. Preparation timeline for a certification attempt, with the pitfalls that most often spoil the day.

Paperwork and people, before you leave

- ☐ CAR/ACF membership current (card with you).
- ☐ Certification form printed (Figure 6.10), with your details filled in.
- ☐ Two witnesses: CAR/ACF members in good standing, not related to you, at least one certified at your target level or higher [18]. Members of NAR, Tripoli or Launch Canada may witness; they must provide an image of their membership card [25].
- ☐ Launch confirmed: sanctioned and insured (CAR/ACF, NAR, Tripoli or Launch Canada), with date, site and RSO [25].
- ☐ Motor bought and stored legally; its data sheet (thrust curve, delay, maximum liftoff weight) with you.
- ☐ Simulation printout or laptop: CG, CP, margin, apogee, delay (**??**).

6.2 Packing list

Tick it off the evening before.

Rocket, motor and papers	Tools and spares	Clothing and personal
☐ rocket: body, nose cone, parachute, harness	☐ screwdrivers, hobby knife, scissors	☐ warm coat, long pants
☐ motor and its igniter (in the original packaging)	☐ masking tape, rubber bands	☐ boots (fields are wet and muddy)
☐ motor retainer	☐ small scale, measuring tape	☐ toque and gloves
☐ Nomex protector or cotton denim square	☐ epoxy (5-minute) and mixing cups	☐ sun hat, sunglasses, sunscreen
☐ quick links, swivel	☐ sandpaper	☐ water and food
☐ CG and CP stickers	☐ spare quick link and shear pins (if used)	☐ binoculars, to watch the deployment
☐ flight data sheet and certification form	☐ nose weight (ballast)	
☐ membership card	☐ talc or baby powder for the canopy	
☐ simulation printout or laptop		
☐ calculator, pens, pencils		

Table 6.1. Packing list for certification day.

Motors, igniters and black powder are explosives in the eyes of the law: they are bought, stored and carried under NRCan rules [2], kept away from heat and flame, and handled only by the people allowed to. AeroTech asks that its motors be stored dry between about 7 °C and 38 °C (45 to 100 °F) and never used if damaged [26].

6.3 Preparing the motor

Most Level 1 and Level 2 flights use either a *single-use* motor (AeroTech calls theirs DMS, Disposable Motor System) or a *reloadable* motor (RMS) assembled from a reload kit. The steps below follow the AeroTech 29–54 mm DMS instructions [26]; reloadable motors add the assembly of the grains, liners and closures into the case, which must be done exactly as the manufacturer's sheet says (and is witnessed for a Level 3 attempt [18]).

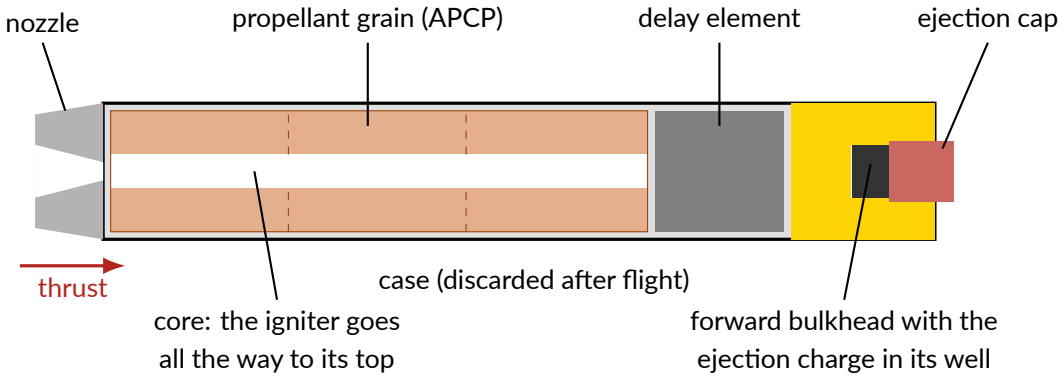


Figure 6.2. Inside a single-use (DMS) motor, nozzle on the left. The motor burns from the nozzle end forward: propellant, then the delay element (smoke, no thrust), then the ejection charge fires forward into the rocket [26].

6.3.1 Step 1: set the time delay

The delay printed on the motor is the longest one. If your simulation calls for a shorter delay (**??**), remove part of the delay element with the manufacturer's delay tool [26]:

1. No smoking, flames or heat sources nearby.
2. Assemble the Universal delay drilling tool with the side marked with the wanted reduction (−4 or −8 s) facing the drill bit. Add the washer under the knob to remove 2 s less (−2 or −6 s).
3. Put the open end of the tool over the motor bulkhead, hold tool and motor firmly together and turn the knob clockwise until it sits flush with the tool body.
4. Remove the tool, shake the shavings out of the tool and the bulkhead, and dispose of them by burning them safely.

If you want the full printed delay, skip the tool. Plugged motors (for example AeroTech's H45W and I65W) have no delay or ejection charge; they need electronic deployment [26].

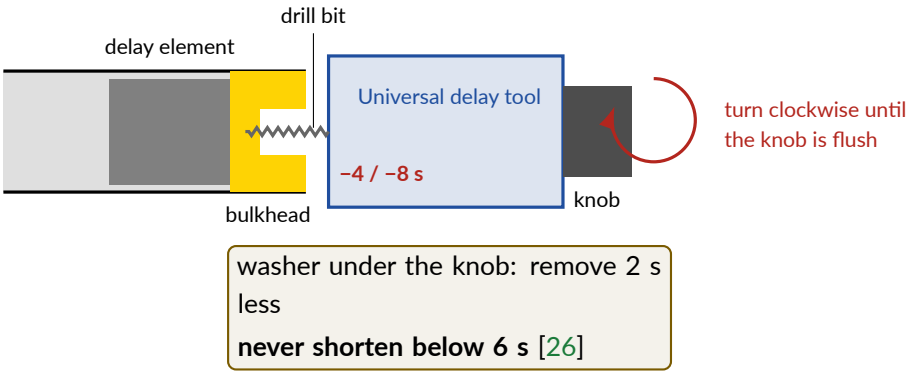


Figure 6.3. Shortening the delay with the delay tool: the side facing the bit sets how many seconds are drilled away.



Figure 6.4. The AeroTech Universal delay drilling tool, assembled for an 8-second reduction: the drill bit comes out of the end labelled “−8”. Photo from the AeroTech instructions [26].

Figure 6.5 breaks the operation into its four steps, and Table 6.2 shows which setting gives which delay. Work out the delay you need first: it is the coast time from your simulation (**??**); for the Level 1 example, $t_c = 10.2$ s, so a motor printed “14” is shortened by 4 s.

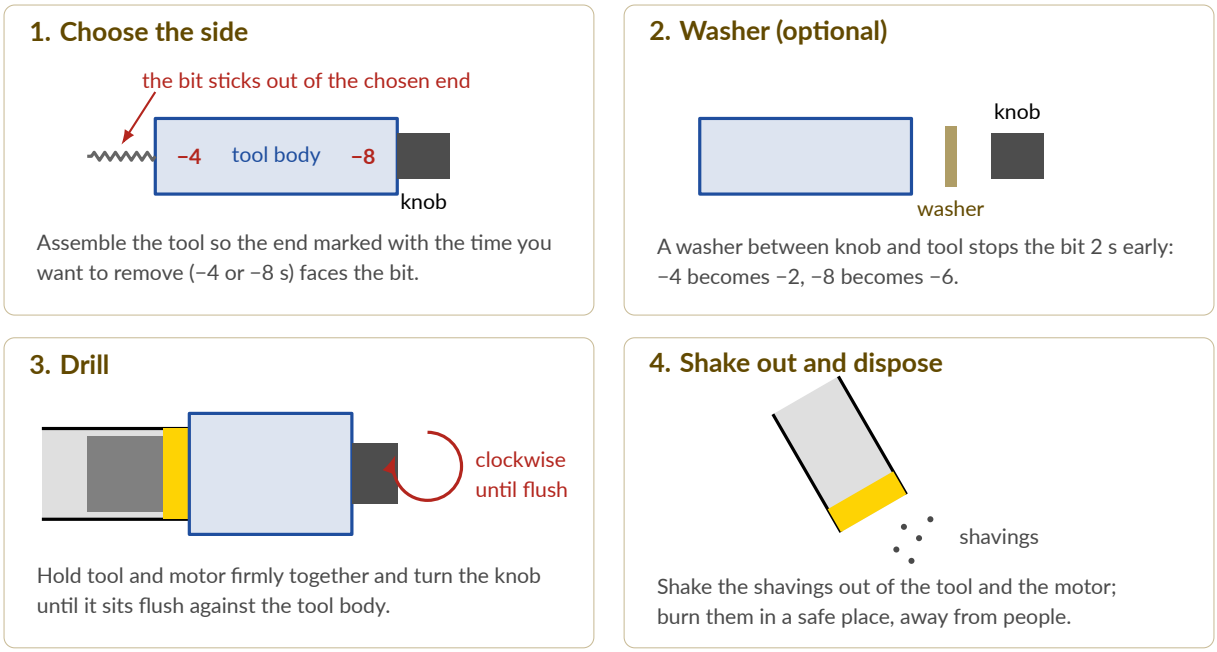


Figure 6.5. Setting the delay, step by step, with the AeroTech Universal delay drilling tool [26]. No smoking, flames or heat nearby at any step.

Tool setting	Removes	Motor printed “14”	Motor printed “10”
no tool (as supplied)	0 s	14 s	10 s
−4 side with washer	2 s	12 s	8 s
−4 side	4 s	10 s	6 s
−8 side with washer	6 s	8 s	4 s: not allowed
−8 side	8 s	6 s	2 s: not allowed

Table 6.2. Which setting gives which delay. Never shorten an AeroTech DMS delay below 6 s [26].

6.3.2 Step 2: ejection charge and cap

1. Open the igniter and ejection charge kit.
2. Place the ejection charge baffle washer into the ejection charge well of the bulkhead.
3. With no flame or heat nearby, pour the black powder into the well: about **half the vial** for rockets of 2.6 in (66 mm) diameter and smaller, the **whole vial** for 3 in (76 mm) and larger. Rockets above 4 in (102 mm) may need more [26].
4. Insert the **rounded end** of the ejection charge cap into the well and press it in **completely** with the end of the igniter tube or a similar object, so that the cap sits flush and the powder cannot spill [26].

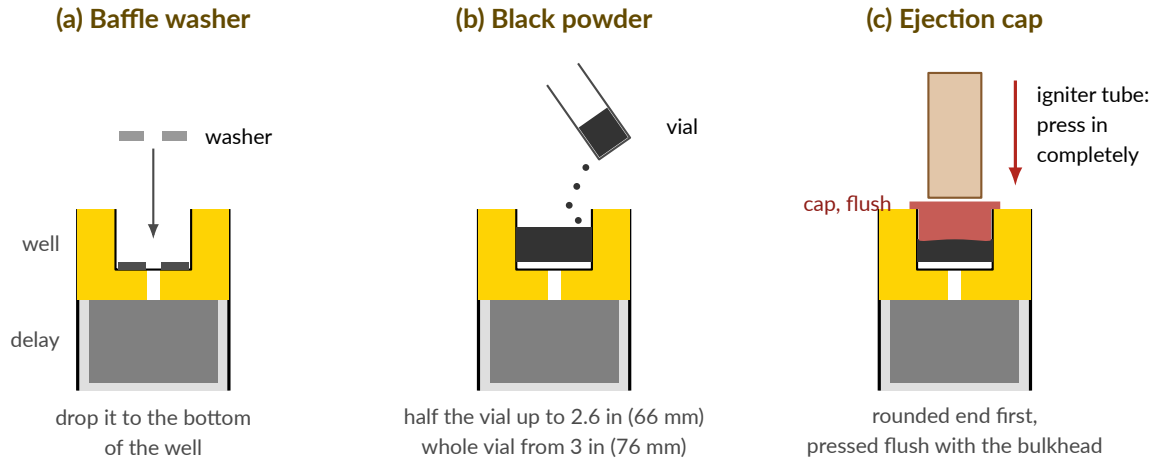


Figure 6.6. Installing the ejection charge in an AeroTech DMS motor (cut-away of the forward end, bulkhead in yellow): (a) baffle washer into the well, (b) black powder, (c) ejection cap, rounded end first, pressed fully home with the end of the igniter tube [26].



(b) pouring the black powder into the well (c) pressing the cap home with the igniter tube

Figure 6.7. The same steps on a real motor: the yellow part is the forward bulkhead with its ejection charge well; the red cap is pushed in flush with the end of the cardboard igniter tube. Photos from the AeroTech instructions [26].

6.3.3 Step 3: install the motor in the rocket

Slide the motor into the motor mount and secure it with **positive mechanical retention** (screw-on retainer, clip or hook) so the ejection charge cannot push it out of the rocket [26]. This is what the Rocket Inspector checks when asking whether all motors are firmly retained [30]. The igniter is *not* installed yet: it goes in at the pad.

Motor preparation: the rules

- Open the motor package only when ready to use it; never modify a motor beyond what the instructions describe [13, 26].
- Delay never shorter than 6 s on AeroTech DMS motors; choose it from your simulation.
- Correct black powder amount for your diameter; ejection cap fully seated.
- Positive motor retention; igniter only at the pad [10].

6.4 Installing the igniter without a short

The igniter is installed at the pad, with the rocket on the rail and pointed in a safe direction, as close to launch time as practical [10]. Two things can go wrong. The first is an *accidental ignition*: a static discharge or a stray current can fire an electric match, so the leads stay twisted together until the last moment. The second is a *short circuit*: if the two bare leads, or the two clips, touch each other or the same piece of metal, the current takes the short path and never reaches the igniter head. The motor does not light, the pad may even show continuity through the short, and the misfire procedure has to be followed.

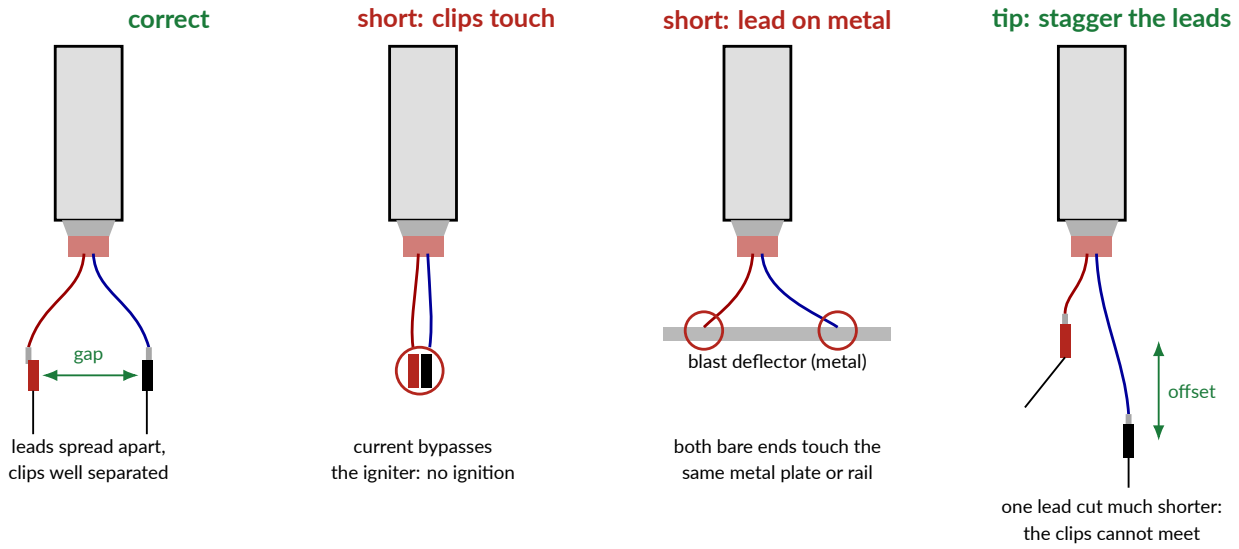


Figure 6.8. Clip connections at the pad. Keep the two bare leads, and the two clips, apart from each other and off the rail and blast deflector. A simple trick (right): cut one lead much shorter than the other, so that the two clips hang at different heights and cannot touch even if the leads swing together.

Igniter installation, step by step

1. Wait for the LCO to open the range; carry the rocket to your assigned pad. Make sure the pad is **not powered** (safety interlock out or pad disconnect open) before touching the clips [10].
2. Slide the rocket onto the rail, standing to the side, never over the nozzle or the nose.
3. Take the igniter out of its tube and straighten the leads. Keep the two lead ends **twisted together** (shunted) while you work.
4. If they are not already bare, strip **12 to 25 mm** (1/2 to 1 in) of insulation from the lead ends only [26].
5. Push the coated tip of the igniter through the nozzle and **all the way up the core** until it touches the delay element at the top. Motors with an off-centre (“moonburner”) core need the igniter pushed to one side and the motor rotated until the core is found [26].
6. Hold it there with the plastic nozzle cap, after cutting a small corner off the cap (a vent of about 1.5 to 3 mm), or with a piece of masking tape [26].
7. Untwist the lead ends, **spread them apart** and bend each into a small hook. Attach one clip to each lead; clips must be clean (sand off soot) and must not touch each other, the rail or the

blast deflector (Figure 6.8).

8. **Tip:** before you go to the pad, cut one igniter lead **much shorter** than the other (by 5 to 10 cm) and strip both ends. The two clips then sit at different heights and cannot touch each other, which removes the most common cause of a "misfire" at the pad.
9. Tape or loop the clip wires to the launch stand so their weight does not pull the igniter out of the core.
10. Check continuity with the pad box, arm any electronics now, and walk back to the flight line. The LCO gives the countdown.

6.5 Rocket prep: the condensed recap

Full details are in Chapter 4 (construction) and Chapter 5 (parachute). This is the order at the prep table, before you go to inspection.

1. **Inspect the airframe**: fins solid, fillets intact, rail buttons tight, vent hole clear (Section 4.8).
2. **Recovery**: harness anchor, eye bolt and quick links pull-tested; swivel fitted.
3. **Prepare the motor** (Section 6.3); *do not* install the igniter.
4. **Install the motor** and its retainer; confirm it cannot move.
5. **Size, fold and pack the parachute** (Section 5.1): lines untangled, strip width right, protector on the motor side, nothing tight (Section 5.2).
6. **Close the rocket**; test that the nose cone is snug but separable.
7. **Balance and mark the CG** with the motor installed; put the CG and CP stickers on; confirm the stability margin is at least 1 caliber.
8. **Weigh** the loaded rocket; check the maximum liftoff weight and the 4:1 thrust-to-weight ratio.
9. **Fill in the flight card** (next section).

6.6 The flight card: the CAR/ACF Flight Data Sheet

Every flight at a sanctioned launch starts with a flight card. At CAR/ACF launches it is the **Flight Data Sheet** of Figure 6.9, printed back to back with the Rocket Inspector's checklist [34]. The Rocket Inspector and the RSO use it to check that you, the rocket and the motor are a legal and safe combination, and the Launch Control Officer reads it before the countdown.

Canadian Association of Rocketry
Association canadienne de fuséonautique

Flight Data Sheet

Flyer's Name:		Pad #:
Rail Length:	Radio Frequency:	Expected Altitude:
Mass:	Total Impulse:	Thrust/Weight Ratio:
Rocket Name:		
Rocket Length:		Diameter:
Kit Manufacturer: Modified? Yes ☐ No ☐		Colour(s):
Motors (number, type & manufacturer in each stage):		
Purpose of Flight: Certification ☐ Competition ☐ Sport ☐		
Payload, Special Recovery/Ignition Systems, etc.:		
CAR/ACF #:	Launch:	Date:
LCO Post Flight Evaluation: Good Flight: Yes ☐ No ☐ Comments:		LCO Name:

February 6, 2022 version 3.2

Figure 6.9. The CAR/ACF Flight Data Sheet (version 3.2, 6 February 2022), redrawn [34]. A full-size copy to print is in Appendix A.

Table 6.3 goes through it box by box, filled in for the Level 1 rocket of **??**.

Fill the card in *after* the final CG and weight check, not from the design sheet, and write the motor exactly as printed on the motor or reload. Keep your CG, CP and stability margin at hand as well: the card has no box for them, but the Rocket Inspector will ask (Section 6.7).

6.7 The Rocket Inspection Checklist

At the inspection table the Rocket Inspector works through a standard checklist, grouped in five parts: propulsion, flight estimation, airframe, recovery system and electronics [30]. Expect every question below to be asked, or at least checked, for your rocket. The right-hand column says how to

Box	What it means and how to fill it	Example
Flyer's Name / Pad #	Your name; the pad is assigned by the LCO, leave it blank until then.	A. Flier / (LCO)
Rail Length	Length of the rail you will use; it sets the rail exit speed.	1.52 m (60 in), 1010
Radio Frequency	Frequency of any tracker or telemetry; otherwise "none".	none
Expected Altitude	From your simulation, in feet or metres (say which).	720 m (2 360 ft)
Mass	Liftoff mass, weighed with the motor in and recovery packed.	1.80 kg
Total Impulse	Installed total impulse of all motors, in N s.	273 N s
Thrust/Weight Ratio	Average thrust divided by liftoff weight; at least 4.	9.0
Rocket Name	Helps spotters and the recovery crew identify it.	"Aurora"
Rocket Length / Diameter	Overall length and body diameter.	116 cm / 66 mm
Kit Manufacturer, Modified?	Kit name, or "scratch built"; tick whether you changed the kit.	scratch built
Colour(s)	What the spotters will look for in the sky.	red and white
Motors	Number, full designation and manufacturer, for each stage.	1 × H159W-10A (illustrative), delay set to 10 s
Purpose of Flight	Tick **Certification**: the RI then knows to do the post-flight check.	Certification (L1)
Payload, Special Recovery / Ignition	Anything unusual: altimeters, dual deployment, trackers, a camera.	motor ejection; 36 in hex chute, Nomex protector
CAR/ACF #, Launch, Date	Your membership number, the event name and the date.	#..., event, date
LCO Post Flight Evaluation	Filled in by the LCO after the flight.	(LCO)

Table 6.3. The Flight Data Sheet, box by box.

be ready for each; the last column is for your own tick at home. The form itself, as the inspector fills it in, is reproduced full size in Appendix A (Section A.1).

Propulsion: the inspector asks	How to be ready	✓
Is the thrust to weight ratio high enough to assure safe flight?	Know your liftoff mass and $\bar{F}$; ratio at least 4:1 (Section 1.11).	☐
Is the thrust transfer ring or equivalent adequate to transfer motor thrust to airframe?	Show the thrust ring or motor flange bearing on the aft centering ring (Section 4.4).	☐
Are all motors firmly retained to the vehicle?	Screw-on retainer or clip installed; motor does not move.	☐
Is appropriate ignition source present for multi-stage or cluster? (i.e., low current, wired in parallel)	Single motor for certification; for clusters, parallel wiring.	☐
If used, is motor deployment appropriate?	Delay chosen from the simulated coast time; correct black powder amount.	☐
If multiple stage, is system fail-safe in event of catastrophic failure during boost?	Not applicable to a certification flight (single stage).	☐
If hybrid, is motor vent isolated from the deployment system, and visible from the LCO table?	Only for hybrids (Level 2 and up).	☐
If hybrid, is the LCO familiar with the required launch procedure?	Only for hybrids; brief the LCO.	☐

Flight Estimation: the inspector asks	How to be ready	✓
Has the maximum altitude been calculated using appropriate means?	OpenRocket or RockSim printout; hand check (**??**).	☐
Has the maximum acceleration and velocity been calculated using appropriate means?	Read them from the simulation summary; Mach number noted.	☐
Does the model have an adequate stability margin? (CG/CP relationship appropriate for the design)	CG and CP stickers on the rocket; margin at least 1 caliber with the motor in.	☐
If multiple stages present, was stability margin calculated and shown for all stage configurations?	Not applicable to a single-stage rocket.	☐
Was the CP calculated using an appropriate method? (e.g., RockSim)	Barrowman method in OpenRocket or RockSim [29].	☐

Airframe: the inspector asks	How to be ready	✓
Is the overall airframe structure adequate to withstand the anticipated flight forces?	Materials suited to the speed (Section 4.2); no soft or crushed tubes.	☐
Are the fins secured to the airframe with adequate reinforcement?	Through-the-wall fins with fillets; nothing moves when flexed (Section 4.3).	☐
Are adequate launch guides present? (i.e., rail buttons, or tower)	Two rail buttons, aligned, screwed into solid backing; the rocket slides freely (Section 4.7).	☐

Recovery System: the inspector asks	How to be ready	✓
Is the shock cord adequate to handle the forces of high speed deployment?	Kevlar or strong flat strap, about 3 times the rocket's length.	☐
Are the shock cord attachment points sufficient to handle the forces of high speed deployment?	Anchored to the motor mount; forged eye bolt; rated quick links (Section 4.5).	☐
Is the parachute or streamer structurally sound, and adequately sized for safe recovery?	Canopy checked; size gives about 4.5 to 7 m/s (Section 3.5).	☐
Is adequate protection present to protect parachutes or streamers from ejection charges?	Nomex or cotton denim protector, or flame-resistant biodegradable wadding.	☐
Are deployment charges adequately sized, installed, sealed, and ground tested when appropriate?	Motor charge per instructions; altimeter charges ground tested.	☐
Are nosecone and payload sections sufficiently snug to prevent drag separation?	Nose does not fall out held upside down, but separates by hand. (If shear pins are installed, a roaming RI signs this check.)	☐
Is a vent-hole present to prevent in-flight separation at altitude?	Point to it (Section 4.6).	☐
Is a redundant deployment system present if loaded vehicle mass is over 5 kg?	Loaded mass on the card; second system if over 5 kg [13].	☐

Electronics: the inspector asks	How to be ready	✓
Are all components adequately secured against acceleration forces? (i.e., batteries, connectors)	Batteries strapped or zip-tied; connectors locked; nothing rattles.	☐
Is the electronic circuit armed safely? (e.g., remote switches/indicators present to protect the user)	External switch; armed only on the pad.	☐
If RF active control is used, is the operating frequency in the 27, 50, 53, or 72 MHz bands?	Not used on certification flights; know the answer if asked.	☐
If RF active control is used, has the system been ground tested?	Not applicable without RF control.	☐
Does the flyer have a checklist or equivalent to arm the system prior to flight?	Written arming checklist in your pocket.	☐

6.8 The certification form

The certification form (Figure 6.10) is the record CAR/ACF uses to grant your new level [25]. Three groups of people fill it in:

- **You**: the attempt information at the top (name, CAR/ACF number and expiry, level attempted,

motor and manufacturer, launch authority, event and date), then you sign that you are the member named, in good standing and at least 18.

- **The Rocket Inspector**: the checklist in the middle (pre-flight, flight and post-flight items), whether the flight was successful and why not if it was not, and the RI's signature, organization and member number.
- **Two witnesses**: the affidavit at the bottom, stating the total installed impulse you are now qualified for. A witness who is a NAR, Tripoli or Launch Canada member (not CAR/ACF) must attach an image of their membership card showing name, expiry date and certification level.

Canadian Association of Rocketry
Association canadienne de fuséonautique

HPR Certification / Formulaire de certification haute-puissance

Certification Attempt Information / Informations sur la tentative de certification

Name / Nom	CAR/ACF #	Expiry / Expiration
Certification Level Attempted Essai niveau certification	Motor Used Moteur utilisé	Motor Manufacturer Fabricant du moteur
Launch Authority / Autorité de lancement: ☐ CAR/ACF ☐ NAR ☐ TRA ☐ Launch Canada	Launch Event Évènement (lancement)	Date of Flight Date du vol

I certify that I am the individual named above, that I am a member in good standing of the Canadian Association of Rocketry and that I am 18 years of age or older.

Je certifie que je suis la personne ci-haut mentionnée, que je suis un membre en règle de l'Association canadienne de fuséonautique et que j'ai 18 ans ou plus.

Signature : _____ Date: _____

Checklist (by Rocket Inspector) / Liste de contrôle (par l'inspecteur de fusée)

Pre-Flight / Pré-vol	**Flight / Vol**	**Post-Flight / Post-vol**
☐ Passed Certification Test / Test certification passé ☐ Safety Checklist Completed / Liste de contrôle complétée ☐ Motor is "approved" / Moteur « certifié »	☐ Model is stable / Fusée est stable ☐ Recovery system deployed / Système de récupération déployé ☐ Safe recovery / Récupération sécuritaire	☐ Verify that no major damage is present, minor impact damage is acceptable / Vérifier s'il y a des dommages majeurs, dommages mineurs acceptables ☐ Verify motor(s) are present / Vérifier si le ou les moteurs sont présents

Successful Flight? **Vol réussi?**	☐ **Yes / Oui** ☐ **No / Non**	RI Signature, Organization & Member Number: Signature du IF, organisation et numéro de membre:
Reasons / Raison?		

Certification Affidavit / Certification – Déclaration sous serment

We, the undersigned, have witnessed the successful certification flight by the applicant named above. We believe this member is qualified to build and operate high power rockets with a total installed impulse up to:

Nous, soussignés, avons été témoins du succès du vol de certification du demandeur nommé ci-dessus. Nous pensons que ce membre est qualifié pour construire et exploiter des fusées de grande puissance avec une impulsion totale installée allant jusqu'à :

Name / Nom	☐ CAR/ACF ☐ NAR* ☐ TRA* ☐ Launch Canada*	Member Number / Numéro de membre	Certification Level / Niveau de certification
Signature		Expiration Date / Date d'expiration	
Name / Nom	☐ CAR/ACF ☐ NAR* ☐ TRA* ☐ Launch Canada*	Member Number / Numéro de membre	Certification Level / Niveau de certification
Signature		Expiration Date / Date d'expiration	

* Image of membership card showing expiration date and certification level is required.
* Une image de la carte de membre indiquant la date d'expiration et le niveau de certification est requise.

CAR_HPR_Certification_Form_En-Fr_V3.0_20240102

Figure 6.10. The CAR/ACF HPR certification form (version 3.0, 2 January 2024), redrawn; page 1 of 2 [25]. A full-size copy to print is in Appendix A.

Submitting the form

- The form must be **complete**; incomplete applications are not processed.
- Send it to CAR/ACF at `Memberships@Canadianrocketry.org` (with the L4 data capture form, for a Level 4 attempt).
- The launch does not have to be a CAR/ACF event if it is sanctioned by a recognized organization (NAR, Tripoli, Launch Canada) **and** insured; confirm with the organizer.
- Keep the original documents yourself [25].

6.9 At the pad and after the flight

Pad sequence

1. Carry the rocket to the assigned pad only when the LCO opens the range.
2. Rail angle at most 20° from vertical, set as the RSO directs [10].
3. Install the igniter as in Section 6.4; check continuity; arm electronics.
4. Return to the flight line. The LCO gives a countdown of at least 5 seconds; the launch switch returns to off when released [10].
5. Misfire: interlock out or battery disconnected, wait **5 minutes**, then only **one person** approaches with the RSO's authorization (Figure 2.13).

After landing, watch where the rocket comes down and never try to catch it; never retrieve it from a power line without approval [10]. Bring it back **as found** to the Rocket Inspector and your certification team, who check motor retention and flight damage before signing [18]. Then send the signed certification form to CAR/ACF as it instructs (Section 6.8). A spent single-use motor case goes in the ordinary trash once cool [26].

6.10 Mock oral certification question

The Rocket Inspector's oral check is usually a conversation at the inspection table, not a quiz. The exchange below is a realistic example for a Level 1 attempt with the rocket of **??**. Read it aloud with a friend playing the RSO.

Mock exchange at the inspection table

RSO:
This is your Level 1 attempt? Walk me through the motor and tell me why this rocket is going to fly straight.

Flier:
Yes, Level 1. It's an H159 with a 10-second delay: H class, so between 160 and 320 newton-seconds, 273 on the data sheet, average thrust 159 newtons, burn about 1.7 seconds. The rocket weighs 1.80 kilograms loaded, so the thrust-to-weight ratio is about 9 to 1, more than the 4 to 1 minimum. For stability, the CG is marked here, 80 centimetres from the tip, measured

with the motor installed. The CP from OpenRocket is here, at 91 centimetres, which matches my Barrowman hand calculation. That puts the CG 11 centimetres ahead of the CP; the body is 6.6 centimetres across, so the margin is about 1.7 calibers.

RSO:
Good. Why does it matter that the CG is ahead of the CP?

Flier:
If a gust tips the rocket, the side force acts at the CP. With the CP behind the CG, that force twists the nose back into the relative wind, like feathers on an arrow. If the CP were ahead, it would push it further off and the rocket would tumble.

RSO:
It's gusting to about 20 today. Anything you'd change?

Flier:
It will weathercock a bit into the wind, so it will go lower and reach apogee sooner. My simulation gives a 10-second coast in calm air, so I'd keep the 10-second delay and not go longer. I'll angle the rail a few degrees away from the flight line, however you want it, still well inside 20 degrees from vertical.

RSO:
And how's it coming down?

Flier:
Motor ejection at about 700 metres, 36-inch hex chute with a Nomex protector, Kevlar harness anchored to the forward centering ring, swivel on the shroud lines. That gives about 7 metres per second at landing. The motor is held by a screw-on retainer. The igniter goes in at the pad.

RSO:
Fine. Pull test on the harness, then take it to pad 3.

What the RSO was really checking

- You can decode your own motor and know it matches your level.
- You know the CG and CP *of this rocket*, *with this motor*, and what stability means.
- You thought about the day's conditions and the delay.
- You understand your recovery system and the safety rules (retention, igniter at the pad).

APPENDIX A

Printable Field Sheets

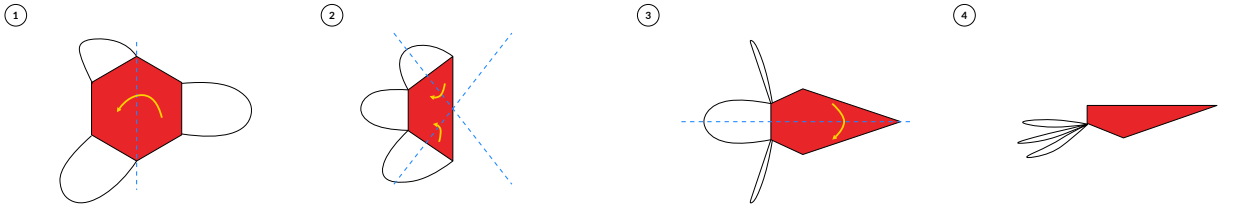
The pages of this appendix condense the procedures of Chapter 5 and Chapter 6 into sheets you can print and take to the field, most of them a single page. The last three are full-page, borderless redrawn copies of the CAR/ACF forms; use the current official forms when the organizer provides them.

What is in this appendix

A.1 Parachute packing, step by step
A.2 Motor and ejection charge preparation (AeroTech DMS)
A.3 Prep table and pad checklist
A.4 Flight Data Sheet
A.5 Rocket Inspector pre-flight inspection checklist
A.6 HPR certification form

A.1 Parachute packing

Clean, dry surface. Check the canopy for burns and holes and every line for fraying. Untangle the lines first. Blue dashed lines: fold lines; yellow arrows: fold direction.

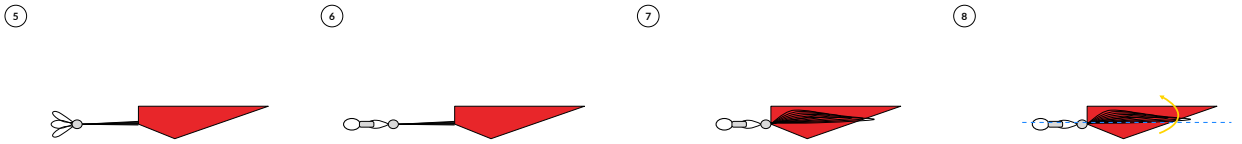


01. Fold the hexagon in half.

02. Fold top and bottom inward.

03. Fold the wedge in half lengthwise.

04. Slim strip, lines fanned out.

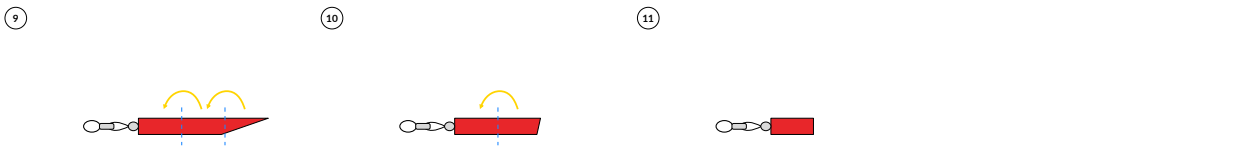


05. Stretch the lines, knot the ends.

06. Attach the swivel.

07. Lay the lines on the canopy.

08. Fold to trap the lines inside.



09. Fold the right side over, twice.

10. Fold once more.

11. Finished bundle, swivel free.

Width: strip a little narrower than the tube's inside diameter.

Length: about the length of the space in the bay. Firm, never rolled tight.

Into the rocket

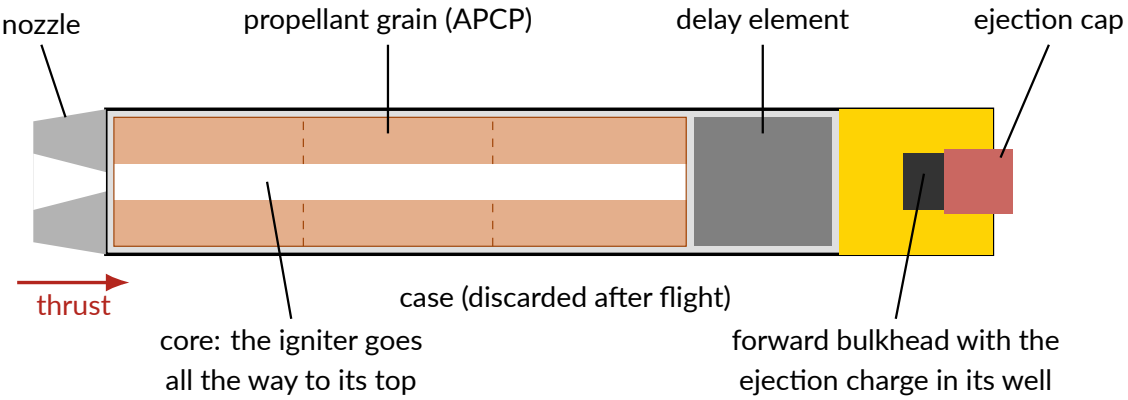
- ☐ Burrito-wrap the bundle in the Nomex or denim protector; only lines and swivel stick out.
- ☐ Protector attached to the harness; it faces the motor end.
- ☐ Load: Kevlar harness (loose zig-zags) → protected chute → rest of the cord → nose cone.
- ☐ Nothing tight: the bundle slides in and out with a light push or pull.
- ☐ Nose cone snug but separable by hand; not forced shut.

Avoid

- ☐ No swivel (a spinning rocket twists the lines shut).
- ☐ Lines wrapped around the canopy.
- ☐ A strip wider than the tube (fold once more lengthwise).
- ☐ Synthetic fabric as a protector (it melts); fibreglass wadding (prohibited).
- ☐ Packing hours or days ahead, or in the cold.

A.2 Motor and ejection charge preparation

AeroTech 29–54 mm DMS motors [26]. **No smoking, flames or heat sources nearby at any step.** Open the package only when ready.



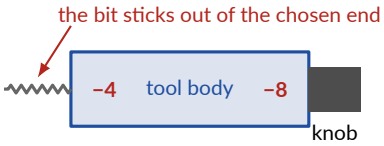
nozzle, propellant, delay element, ejection charge well, ejection cap: the motor burns nozzle to bulkhead, then fires forward into the rocket.

1. Delay (only if shorter than printed)

- ☐ Needed delay ≈ coast time from the simulation.
- ☐ Tool end facing the bit: −4 or −8 s; washer under the knob removes 2 s less (−2 or −6).
- ☐ Tool over the bulkhead, hold firmly, turn the knob clockwise until flush.
- ☐ Shake out the shavings; burn them safely.
- ☐ **Never below 6 s.**

Setting	printed 14	printed 10
no tool	14 s	10 s
−4 + washer	12 s	8 s
−4	10 s	6 s
−8 + washer	8 s	no
−8	6 s	no

1. Choose the side



Assemble the tool so the end marked with the time you want to remove (−4 or −8 s) faces the bit.

2. Washer (optional)



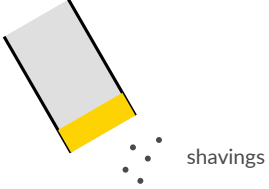
A washer between knob and tool stops the bit 2 s early: −4 becomes −2, −8 becomes −6.

3. Drill



Hold tool and motor firmly together and turn the knob until it sits flush against the tool body.

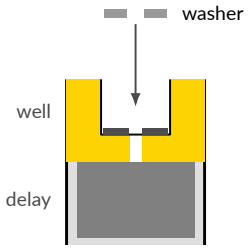
4. Shake out and dispose



Shake the shavings out of the tool and the motor; burn them in a safe place, away from people.

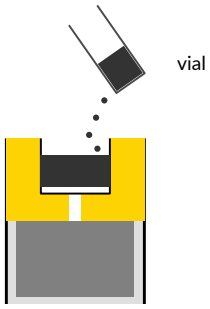
2. Ejection charge

(a) Baffle washer



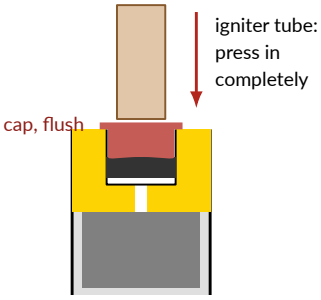
drop it to the bottom of the well

(b) Black powder



half the vial up to 2.6 in (66 mm)
whole vial from 3 in (76 mm)

(c) Ejection cap



rounded end first,
pressed flush with the bulkhead



delay tool



black powder into the well



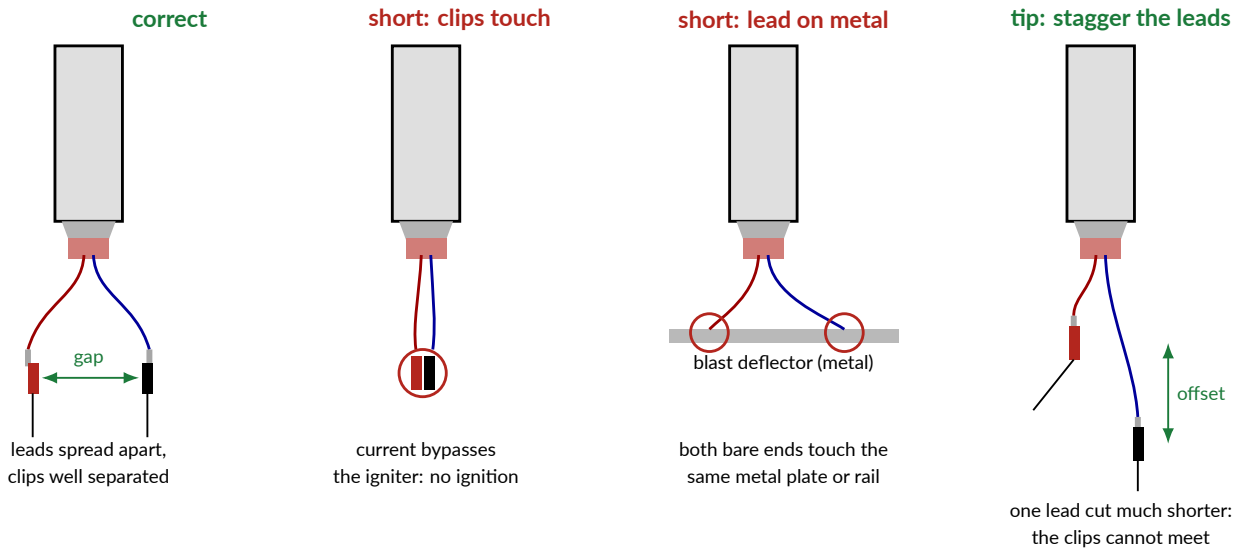
cap pressed in with the igniter tube

- ☐ Baffle washer to the bottom of the ejection charge well.
- ☐ Black powder: **half the vial** up to 2.6 in (66 mm) diameter; **whole vial** from 3 in (76 mm); more may be needed above 4 in (102 mm).
- ☐ Ejection cap, **rounded end first**, pressed in **completely** with the end of the igniter tube.

3. Into the rocket

- ☐ Motor into the mount; **positive retention** (screw-on retainer, clip or hook); it cannot move forward or aft.
- ☐ **Igniter stays out**: it is installed at the pad only.

4. Igniter, at the pad



- ☐ Pad not powered (interlock out). Rocket on the rail; stand to the side.
- ☐ **Cut one lead much shorter than the other** (5 to 10 cm), strip 12 to 25 mm of both.
- ☐ Leads twisted together until the last moment.
- ☐ Igniter **all the way up the core**, to the delay element; held by the vented nozzle cap or masking tape.
- ☐ Clips clean, apart from each other and off the rail and deflector; wires taped to the stand. Continuity check, arm electronics, walk back.

A.3 Prep table and pad checklist

Before leaving home

- ☐ Membership current; card with you.
- ☐ Flight data sheet and certification form printed.
- ☐ Two witnesses arranged through the organizer.
- ☐ Motor, igniter, retainer; data sheet.
- ☐ Simulation printout: CG, CP, margin, apogee, delay.
- ☐ Packing list done (Table 6.1).

At the prep table

- ☐ Exam written and passed.
- ☐ Airframe: fins solid, fillets intact, rail buttons tight, vent hole clear.
- ☐ Recovery: anchor, eye bolt, quick links pull-tested; swivel fitted.
- ☐ Motor: delay set, ejection charge and cap in, retained; no igniter.
- ☐ Parachute folded, protected, loaded; nothing tight.
- ☐ Nose cone snug but separable.
- ☐ CG marked with the motor in; CP marked; margin ≥ 1 caliber.
- ☐ Liftoff mass weighed: $\leq$ motor's maximum; $T/W \geq 4$.
- ☐ Flight data sheet filled in; "Certification" ticked.

Rocket Inspector: be ready to show

- ☐ Thrust ring or flange on the aft centering ring; retainer.
- ☐ Delay chosen from the coast time.
- ☐ Apogee, maximum velocity and acceleration (simulation).
- ☐ CG and CP stickers; margin in calibers; CP method (Barrowman).
- ☐ Fin attachment; rail buttons; airframe strength.
- ☐ Shock cord and anchor; parachute size; protector.
- ☐ Vent hole; redundant deployment if over 5 kg.
- ☐ Electronics secured and safely armed (if any).

At the pad

- ☐ Only when the LCO opens the range.
- ☐ Rail at most 20° from vertical, as the RSO directs.
- ☐ Igniter as in A.2; continuity; arm electronics.
- ☐ Back to the flight line; countdown of at least 5 s.
- ☐ **Misfire**: interlock out, wait **5 minutes**, then **one person** approaches when the RSO says so.

After landing

- ☐ Never catch it; never retrieve from a power line.
- ☐ Bring it back **as found** to the RI and witnesses.
- ☐ Motor still retained; no major damage.
- ☐ Certification form signed; send it to CAR/ACF.

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Flight Data Sheet

Flyer's Name:		Pad #:
Rail Length:	Radio Frequency:	Expected Altitude:
Mass:	Total Impulse:	Thrust/Weight Ratio:
Rocket Name:		
Rocket Length:		Diameter:
Kit Manufacturer: Modified? Yes ☐ No ☐		Colour(s):
Motors (number, type & manufacturer in each stage):		
Purpose of Flight: Certification ☐ Competition ☐ Sport ☐		
Payload, Special Recovery/Ignition Systems, etc.:		
CAR/ACF #:	Launch:	Date:
LCO Post Flight Evaluation: Good Flight: Yes ☐ No ☐ Comments:		LCO Name:

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Rocket Inspector Pre-Flight Inspection Checklist

Propulsion

- Is the thrust to weight ratio high enough to assure safe flight? ☐
- Is the thrust transfer ring or equivalent adequate to transfer motor thrust to airframe? ☐
- Are all motors firmly retained to the vehicle? ☐
- Is appropriate ignition source present for multi-stage or cluster? (i.e., low current, wired in parallel) ☐
- If used, is motor deployment appropriate? ☐
- If multiple stage, is system fail-safe in event of catastrophic failure during boost? ☐
- If hybrid, is motor vent isolated from the deployment system, and visible from the LCO table? ☐
- If hybrid, is the LCO familiar with the required launch procedure? ☐

Flight Estimation

- Has the maximum altitude been calculated using appropriate means? ☐
- Has the maximum acceleration and velocity been calculated using appropriate means? ☐
- Does the model have an adequate stability margin? (CG/CP relationship appropriate for the design) ☐
- If multiple stages present, was stability margin calculated and shown for all stage configurations? ☐
- Was the CP calculated using an appropriate method? (e.g., RockSim) ☐

Airframe

- Is the overall airframe structure adequate to withstand the anticipated flight forces? ☐
- Are the fins secured to the airframe with adequate reinforcement? ☐
- Are adequate launch guides present? (i.e., rail buttons, or tower) ☐

Recovery System

- Is the shock cord adequate to handle the forces of high speed deployment? ☐
- Are the shock cord attachment points sufficient to handle the forces of high speed deployment? ☐
- Is the parachute or streamer structurally sound, and adequately sized for safe recovery? ☐
- Is adequate protection present to protect parachutes or streamers from ejection charges? ☐
- Are deployment charges adequately sized, installed, sealed, and ground tested when appropriate? ☐
- Are nosecone and payload sections sufficiently snug to prevent drag separation? ☐

(If shear pins installed previously, obtain Roaming RI check of above. Signature: _____)

- Is a vent-hole present to prevent in-flight separation at altitude? ☐
- Is a redundant deployment system present if loaded vehicle mass is over 5 kg? ☐

Electronics

- Are all components adequately secured against acceleration forces? (i.e., batteries, connectors) ☐
- Is the electronic circuit armed safely? (e.g., remote switches/indicators present to protect the user) ☐
- If RF active control is used, is the operating frequency in the 27, 50, 53, or 72 MHz bands? ☐
- If RF active control is used, has the system been ground tested? ☐
- Does the flyer have a checklist or equivalent to arm the system prior to flight? ☐

RI Name (Print):	RI Signature:	Date:

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