# Level 1 certification parachute design guide

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This document has been written in support of young engineers and enthusiasts who want to design and develop their own parachute recovery system. It should contain a complete overview of what the system should do, and how well it should do this. Give an overview of possible design choices and some guidance on how to make the right discission.

## 1 Introduction

Building your own sounding rocket is one of the coolest and best things for young engineers to do. Not only does it help you to build up practical experience, but it also shows you the other aspects of engineering projects. Many websites and readers have written on the propulsion and structure of these sounding rockets. We from Chutes.nl want to share our knowledge when it comes to bringing your rocket and payload safely back to the ground. This reader is an addition to the design guide and EDL technology overview found on our website.

The reader starts with a quick overview of systems engineering and requirements setting. It follows a pragmatic approach where the focus is on results and “useful” systems engineering. It then continues with the typical flight paths of these types of rockets and why that is important to know. When it comes to the actual parachutes an overview is given on the types of parachutes that are relevant for this type of mission and several deployment methods that can be used to safely deploy the parachute.

## 2 Terminology

There are some terms used in this document that might be new or unclear. For the parachute hardware, we will use the same nomenclature used in Knacke.

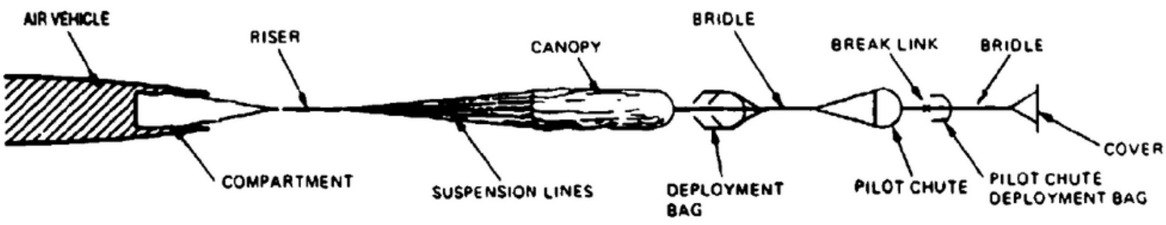

*Figure 1 Parachute system nomenclature from Knacke.*

Furthermore, we will use terms as:

- Deployment – The moment the parachute is ejected from the air vehicle.
- Inflation – The canopy going from folded state to a fully deployed state.

## 3 System engineering overview

Whenever you start to design anything, you need to be clear on what you need, this is written down in the need statement. So, you have to ask yourself the question, why do I want to recover my rocket? This can be for several reasons:

- The payload or mission requires a soft landing
- The launch site requires a soft landing
- You want to reuse the rocket

These needs then define your requirements. If you have a mission that requires you to launch and retrieve an egg, your landing velocity might be lower than when you need to have a parachute because the launch site requires it. This requirement can for instance come from the launch site wanting to limit the drift of the rocket under the parachute to ensure the rocket lands within the safe range. It can be hard to set these requirements exactly if you do not have a lot of experience, a good way is to set requirements into should and shall, in other words, a soft and a hard requirement. “Should” can be used to describe an ideal case whereas “shall” is used to indicate a hard limit. But how do you find these limits? One method is thinking in extremes. In the case of the egg, we know that a landing velocity of 50 m/s is definitely too fast, so there is an upper limit. What you can do is perform drop and landing tests that allow you to fine-tune and tweak this number.

As you can see there are a lot of places of which requirements originate from. It is therefore good to think about and determine who the stakeholders are and who is impacted by the parachute system. Some considerations for requirements can be:

- Minimum descent velocity
- Maximum descent velocity
- Maximum inflation load
- Findability/detectability of the rocket after landing

The entry descent and landing system consists of several subsystems. These often include:

- ~~Thermal protection~~
- Deceleration system
- Landing system
- Retrieval and localisation system

It is important to split the functions of these different systems and make them work independently and then continue to make them into a single system which cooperates with each other. The same goes for the entire system. A simplified N2 chart can be seen below. An N2 chart shows the interaction different systems have with each other and should be read clockwise. Here you can see that the structure limits the volume and force that the recovery system can use or generate. Additionally, it shows that the recovery system governs the design of the electronics when it comes to the registration of flight conditions for deployment.

*Table 1 Simplified N2 chart for a sounding rocket recovery system*

| | | |
|---|---|---|
| **Electronic** | Amount of actuation signals | |
| Information on deployment conditions | **Recovery** | |
| | Volume constraints<br>Force constraints | **Structure** |

# 4 Requirements

The requirements set on the parachute system should be things that are measurable and that can be checked. Earlier we mentioned a maximum landing velocity, this is something that can be validated by a drop test or by analysis. The maximum flight time cannot be validated as easily, therefore the input requirement for the EDL system is a minimum velocity. Of course, this flows down to the parachute as a performance requirement which in turn flows down as a drag area requirement. This example can be seen below.

| | |
|---|---|
| System/mission requirement | Be down in XX seconds |
| EDL (sub)system requirements | Have a landing velocity of at most XX m/s |
| Parachute requirement | Have a CdA of at most XX m2 |
| Landing subsystem requirement | The landing system shall be able to absorb a kinetic energy of at least XX J |

These requirements all say the same thing for different engineers. For these missions, you are often working in a small team so it would be advised to stay on the EDL subsystem requirements level.

Here you see that there are different types of requirements, ranging from what it should do to how well it should do this or how it should be designed. These are categorised into the following types.

- Functional requirements – What should it do?
- Performance requirements – How well should it do what it has to do?
- Design requirements – What should it look like?
- Operational requirements – How should it operate?
- Constraints – Requirements that cannot be broken no matter what.

To ensure your requirements are useful you can use the following criteria for requirements:

- **Necessary** – The requirement defines an essential capability, characteristic, constraint, and/or quality factor. If it is not included in the set of requirements, a deficiency in capability or characteristic will exist, which cannot be fulfilled by implementing other requirements.
- **Unambiguous** – The requirement is stated in such a way so that it can be interpreted in only one way.
- **Complete** – The requirement sufficiently describes the necessary capability, characteristic, constraint, or quality factor to meet the entity need without needing other information to understand the requirement
- **Singular** – The requirement should state a single capability, characteristic, constraint, or quality factor.
- **Feasible** – The requirement can be realised within entity constraints (e.g., cost, schedule, technical, legal, regulatory) with acceptable risk
- **Verifiable** – The requirement is structured and worded such that its realisation can be proven (verified) to the customer's or stakeholder's satisfaction at the level the requirements exist.
- **Correct** – The requirement must be an accurate representation of the entity need from which it was transformed.

More information on requirements can be found in our general design guide: https://chutes.nl/design-guide/requirements.html

# 5 Flight path

When determining the moment in flight to deploy the parachute it is important to understand the (predicted) flight path of the rocket. Say we have a rocket that flies to 100 km it might not make sense to deploy the parachute at apogee because there is no air to inflate the parachute. When the rocket flies to 1 km it might make sense to deploy at apogee.

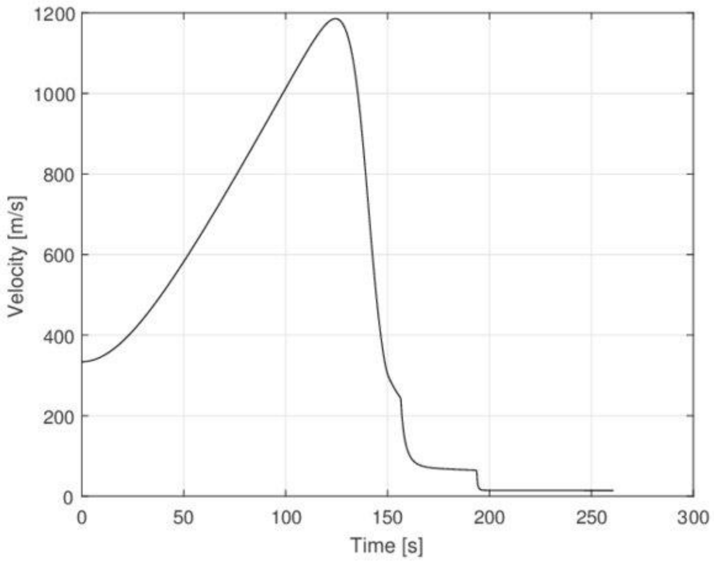

*Figure 2 Simulation result of the Stratos III sounding rocket starting from apogee. The velocity from apogee increases until the atmosphere becomes significant enough to decelerate the payload to velocities where parachute deployment becomes feasible.*

In general, it is recommended to find the point in the flight path where the dynamic pressure is the lowest, thus the loads of inflation on the rocket would be the smallest. For “low flights”, flights staying well within the atmosphere, it is most likely the apogee of the rocket. For “high flights”, going well outside of the atmosphere it most likely be some time after re-entering the atmosphere.

When a rocket flies to a point where the dynamic pressure is too low, there will be not enough air to inflate the parachute, so there is a minimum dynamic pressure limit. When a body falls through the atmosphere, it will slow down on its own, this is referred to as a peak of maximum deceleration or drag peak. Beyond this peak the body is at its terminal velocity and will not slow down significantly anymore and thus the parachute can be deployed. It should be noted that the deployment altitude should be high enough to allow the parachute to decelerate the body to landing velocities.

There is an alternative option where the parachute is force-inflated in a very low dynamic pressure. But this is not needed for these types of missions. Interested readers are referred to the LDSD, Super Loki Starute, and M-100 missions.

# 6 Parachutes

Once you have determined your payload mass and terminal velocity, you can start sizing your parachute. Parachutes are manufactured using gores. A gore is one of the panels of fabric that make up the canopy of any parachute design. The edges of these gores are sewn together to form the desired shape of the parachute. The number, size, and shape of the gores determine the parachute's overall size, shape, and performance characteristics.

## 6.1 Parachute types and selection criteria

There are a few different types of parachutes you can choose from.

1) **Solid Textile Parachutes**
    a) Use: Main Parachutes.
    b) Pros: High drag coefficient, easier to manufacture.
    c) Cons: Limited manoeuvrability, lower stability.
    d) Examples: Cross, Round, Annular, Conical
2) **Slotted Parachutes**
    a) Use: Drogue and Main Parachutes
    b) Pros: High stability, large operating envelope.
    c) Cons: Low-Medium Drag Coefficient, Labor-intensive manufacturing.
    d) Examples: Conical Ribbon, Ringslot, Disc- Gap Band
3) **Rotating Parachutes**
    a) Use: Main Parachutes for small payload mass
    b) Pros: Very high drag coefficient.
    c) Cons: Complex Manufacturing, lack of scalability.
    d) Examples: Rotafoil, Vortex Ring
4) **Gliding Parachutes**
    a) Use: Main Parachutes.
    b) Pros: Manoeuvrable, High Drag Coefficient.
    c) Cons: Requires an active control mechanism to use effectively.
    d) Examples: Parafoil, Parawing, Sailwing

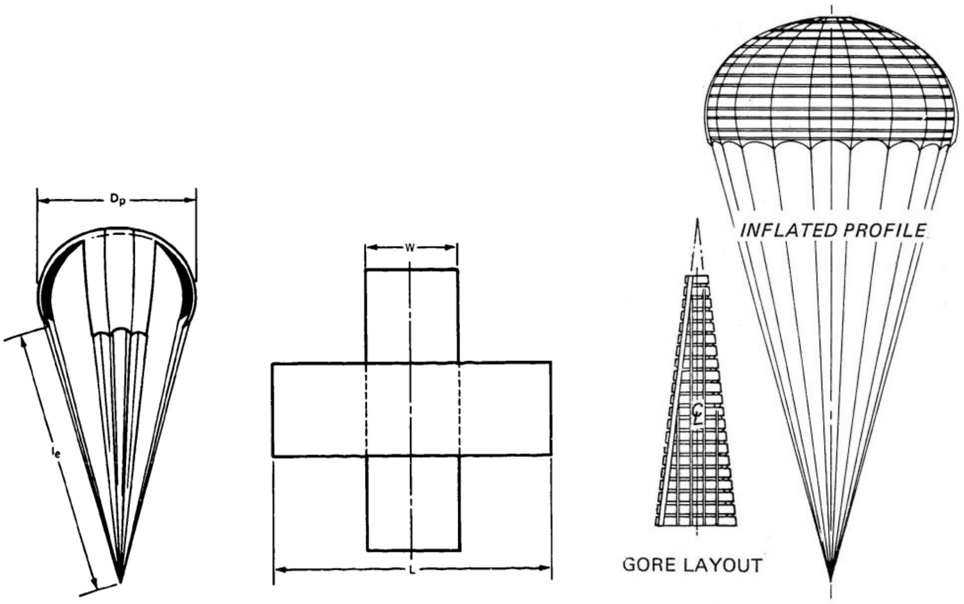

*Figure 3: Gore comparison of a solid canopy cross parachute and a Ribbon Parachute*

**Selection Criteria**

- **Drag Coefficient**: For a desired landing velocity, the drag Coefficient is inversely proportional to the required size of the parachute canopy. Therefore, a higher drag coefficient is desirable.
- **Shock Load Coefficient**: The shock coefficient is a critical factor when sizing the structural elements of the parachute system (ropes, links, canopy strength). It's influenced by the

parachute's inflation rate and the mass of the payload it carries. Parachutes with higher porosity inflate more slowly, resulting in a lower shock load coefficient. This is beneficial because it reduces the initial force impact on both the payload and the parachute system.
- **Supporting System Elements**: Components like swivels, links, and active controls are crucial in the overall design and function of the parachute system, especially for smaller rockets. These elements contribute significantly to the final mass and complexity of the parachute system. Therefore, parachutes with a higher drag coefficient which require additional swivels/ control systems may end up being heavier.
- **Stability:** Stability of parachute controls both the drift (air travel) of the parachute and the oscillation during descent. Controlling the drift is essential for range safety and retrieval. Controlling oscillation is critical for minimizing the impact location and impact velocity of the rocket.
- **Manufacturability**: The complexity of manufacturing parachutes varies with their design. A Cross Parachute, made from solid textile, is the simplest type to produce, requiring the fewest parts. Curved parachute designs demand a greater number of parts and precise shaping of each segment. Ribbon Parachutes are even more complex, as they consist of multiple ribbons per segment, significantly increasing manufacturing time.

## 6.2 Parachute Packing

While the mass of a parachute is crucial, the volume of the packed parachute also plays a key role. Efficient packing can reduce the final volume, which is important for storage and deployment. Proper packing methods are essential to prevent parachute entanglement and ensure reliable inflation. One could say that the packing might be one of the most difficult parts of the operations as it requires much more than engineering and manufacturing. It requires skills. To train this one should pack the parachute as many times as possible and perform tabletop testing. This type of testing is simply put, the engineer unpacks the parachute and see how it unfurls.

## 6.3 Clusters

Using multiple parachutes in a cluster instead of a single large one can offer advantages such as redundancy and load distribution. However, this approach increases the risk of entanglement and complicates the design.

## 6.4 Safety Factors

Safety factors are carefully chosen based on the predictability and reliability of the parachute system. For example, assuming all suspension lines share the load equally is a good starting point. However, in cases of uneven inflation, some lines may bear more load. Increasing the number of thinner lines can mitigate the risk. Similarly, when using parachute clusters, the varying shock loads due to different inflation timings must be considered in the design.

# 7 Deployment system

Once you have determined what your flight will look like and how many parachutes you want to use to recover your rocket, then comes the tricky part of deploying your parachute. The critical requirement here that you need to know is what the ejection velocity needs to be. Many factors can determine this, but it is mainly driven by the time the parachute riser might need to entangle itself around the rocket. This can be different for every shape and size of your rocket. What can be said is that the faster the deployment, the better, but this has to be weighed against the reaction force and the mass of the deployment system.

Many parachute deployment options exist. However, not all are practical on smaller rockets.

- Aerodynamic
- Spring
- Mortar
- Slug Gun
- ~~Tractor Rocket~~

The deployment system also depends on whether a single or two-stage parachute system is used. As with a two-stage system, the first parachute is deployed at higher velocities and might need a more heavy-duty deployment system. Consequently, once the first parachute is deployed, it can be used to deploy the second parachute.

At a minimum, the three previously mentioned criteria must be balanced when considering a deployment system: mass, ejection velocity and reaction load. The first speaks for itself; the other two are a balancing act and need input from the expected flight path and basic rocket concept.

| Deployment System | Ejection Velocity | Reaction Load | System weight |
|---|---|---|---|
| Aerodynamic | Low | Low | Low |
| Spring | Low | Low | Medium |
| Mortar | High | High | High |
| Slug Gun | High | Medium | High |
| ~~Tractor Rocket~~ | ~~High~~ | ~~Low~~ | ~~Medium~~ |

## 7.1 Aerodynamic

The simplest concept, in theory, is to use the airflow around the rocket to deploy your parachute. In practice, it depends on the situation how simple it is. If a parachute is deployed, it is simple: hook the second parachute up to the first with a quick release in between. The first parachute then functions as a pilot chute for the second, pulling it out. Various release mechanisms exist, such as pyrotechnic bolts, wire cutters, bolt cutters, and pulling pins. However, using aerodynamics to deploy the first parachute is more difficult due to the wake behind the rocket, which could prevent the parachute from deploying.

## 7.2 Spring

The first active deployment system which is discussed is a spring system. This is stored in a compressed state during the entire flight and, when needed, releases its stored energy, deploying the parachute. The ejection velocity is, in this case, only dependent on the spring constant and the friction of the mechanism. The friction of the parachute pack with the side wall of the parachute storage container should not be underestimated, as your parachute is not a rigid system, it will try to move out of the way of the spring before moving with it. Therefore, it is advised to use springs that are approximately the entire length of your parachute storage container to prevent the friction of stopping the parachute halfway through. The ejection force can then be tuned by adjusting the spring constant.

Be aware that spring-based deployment systems increase significantly in mass when the ejection force increases. Finally, it should be said that a spring system also has a limited safety risk during operations as the spring needs to be “armed” while still handling the rocket, however, this can be easily worked around.

## 7.3 Parachute Mortar

Parachute mortar deploys the parachute by directly ejecting the parachute with a certain velocity into the airflow. There are two main types of parachute mortars: cold gas and hot gas. The first uses stored compressed gas released by a valve to eject the parachute. The latter, hot-gas system, uses pyrotechnics and combustibles to create the gas to eject the parachute.

The cold-gas system can be used with standard tubing and valves, which are readily available, and the gas canisters can also be easily purchased. An additional benefit is that it does not require any pyrotechnics. The drawback of this system is the mass of the plumbing and the valves that are needed. Additionally, it can also take up a lot of volume to be able to mount everything securely.

Usually, the gasses that can be used for such a system are CO2 and N2O, which can be bought in various-size canisters to control the burst's time and the parachute's initial acceleration. However, keep in mind that the plumbing also needs to be adapted with a higher initial pressure in the canister.

The hot-gas system still relies on the same concept of using gas to eject the parachute. However, where it differs from the cold-gas system is that it creates that gas from a chemical reaction instead of having it stored during the entire flight. This has the benefit that you can do away with the plumbing system and the valves of the cold-gas system, which makes this a lighter option and also more volume-efficient.

However, the drawbacks are that you need to be allowed to handle the combustibles required to create a large volume of gas in a short amount of time. Additionally, a reliable ignition system is required to function in any orientation and free-fall conditions. The difficulty of a hot-gas system is that the pressure given by the system is preferably constant over time. This is achievable but would require something resembling a miniature solid rocket motor to be used. Alternatively, it is possible to have a high initial pressure peak, which is easier to do with an uncontrolled reaction. However, this increases the reaction force of the system.

Although for both the cold and hot gas systems, the gas needs to be trapped until the parachute is ejected to be as efficient as possible, it is slightly more important with the hot gas system as the gasses produced by the reaction have a higher temperature than the melting point of the standard parachute materials.

Both parachute mortars can deploy the parachutes with a significant ejection velocity and can be tailored to the most extreme deployment conditions. However, they also have a significant reaction force that needs to be absorbed by the rocket. Both employ a sabot system to minimise the pressure losses and have an easy platform to eject the parachute. Therefore, the friction between the sabot and the mortar wall must also be controlled so as not to dissipate too much energy during the ejection.

## 7.4 Slug Gun

The slug gun and a mortar system have a lot in common. The key difference is that instead of deploying the parachute directly, it ejects a mass with a high momentum to pull out the parachute. Because of this, it can be lighter in mass than a hot-gas parachute mortar for smaller parachutes. For larger parachutes, due to the larger momentum needed, a slug gun can become less efficient than a parachute mortar system. The most significant drawback is the safety aspect, as a system that ejects a mass at a high momentum can be dangerous without an adequate safety system.

# 8 Conclusion

The design of a parachute system is in the conceptual phase quite straightforward. One needs one or two parachute stages with parachute deployment systems. During later stages parachute systems are much more difficult as, generally, they are a single-attempt system. One cannot stop the EDL flight and reset. Therefore, quality insurance, verification and validation are of the utmost importance.