DOI: 10.13009/EUCASS2022-6156
9TH EUROPEAN CONFERENCE FOR AERONAUTICS AND SPACE SCIENCES (EUCASS)

Standard Reuse System for Small Launch Vehicles

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Abstract
Since 2020, Sirius Space Services has been developing a range of sustainable launchers, reusable in the long term, dedicated to the launch of small satellites. The operators of small satellites will benefit the same launch services as those offered to operators of heavy satellites. Sirius Space Services reuse projects have resulted in the creation of its spin-off Orion Space System to develop a recovery system. Orion Space System wants to democratize the principle of the reusable launcher by developing a standardized solution for all small launchers launched from French Guiana. In a first approach, Orion Space System focused on the development of a parachute reuse kit to recover first stages of micro-launchers.

1. Introduction

NewSpace is turning to be a new era for the Space Market as actors are initiating new projects and innovations to democratize access to space and make it more sustainable. NewSpace is driving for more responsible and ecological approach for developing space systems. Solutions must be found to lower space pollution, while fostering the growth of NewSpace's activities. It is crucial to drive the small launchers market to a completely new approach: reusable small launchers for sustainable access to space.

Most of the operational launchers have been designed to be used only once. It is endangering the NewSpace's activities as many debris are remaining in low orbits. It is also increasing the pollution on Earth and on the maritime environment as some of them are crashing back in the sea. However, SpaceX has been changing this policy by introducing the first reusable stage on the launcher Falcon 9. Since the first successful launch of the American launcher, the SpaceMarket has been evolving fast and the projects of small reusable launchers have been spreading. With the democratization of the small launcher's development, the commercialisation of a standard reuse system should be considered to address small launchers the possibility to be sustainable and reusable.

Two types of recovery system are considered: one by parachutes, one by an autonomous drone ship equipped with a smart catcher. The development of a parachute reuse system is significantly more affordable. It is easier to design by using COTS and non-space systems with high maturity products. For heavier launchers, parachute might not be suitable, and a reverse thrust combined with a versatile drone ship will be developed. The standard reuse system will also provide logistic services for recovery, draining and transportation to address various small launchers.

The France 2030 program aims to invest 1.5 billion euros in space to help start-ups in the development of reusable mini and micro launchers by 2025. Sirius Space Services and Orion Space System programs should make it possible to bring Europe up to the level of other players in the reuse market by 2030. Orion Space System aims to face the challenge of small launchers' reusability by providing standardized recovery and reuse solutions to NewSpace actors, and especially to the ones operated from the Guiana Space Centre.

To come quickly with a solution adapted to the needs of micro launchers, Orion Space System has chosen to develop a recovery solution relying on parachutes followed by a mid-air recovery and maritime operations. This solution allows a slight decrease in the performance of the launch vehicle and is adapted to all the small launchers until a 2 000 kilograms dry mass.

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2. Recovery system

2.1. General description

To make the launcher sustainable and reusable, Orion Space System is developing a parachute recovery kit. With a crash back in the sea, it is endangering the launcher because seawater has a harmful impact on engines due to corrosion. It is also endangering all the electronics of the launcher. The logic of Sirius Space Services is to use COTS and non-space systems with high maturity products, so it would be difficult to make the launcher waterproof. For these reasons, an in-flight recovery is being developed.

Following the atmospheric re-entry of the launcher and the deployment of the parachutes, a helicopter will catch the suspension line between the two parachutes to recover the launcher. After the mid-air recovery operations, the launcher will be put and secured on a boat to go back to the Guiana Space Centre facilities for being requalified for the next mission. To have a successful recovery, several technical points are studied and developed in Orion Space System. Re-entry trajectory study allow to estimate the loads acting on the launcher so it’s possible to optimize the trajectory for a safe re-entry. It is also essential to know the fall-out area for the recovery operations. Regarding the deployment system and the parachutes, they must be designed and adapted to the launcher and its environment. Then, the recovery operations must be well defined for a controlled and safe recovery, whether for the launcher or the operators.

2.2 Trajectory

The study of the trajectory is fundamental in the parachutes recovery of a launcher first stage. Due to the lack of commercial software developed for re-entry trajectory simulation, there is the need to develop a dedicated software. Most of the existing software optimize the trajectory only considering the ascent phase and the uncontrolled splash down area of the stages. Before developing such a simulation tool, Orion Space System has defined the concept of operations of the trajectory presented in Figure 1. The recovery mission starts from the stage separation.

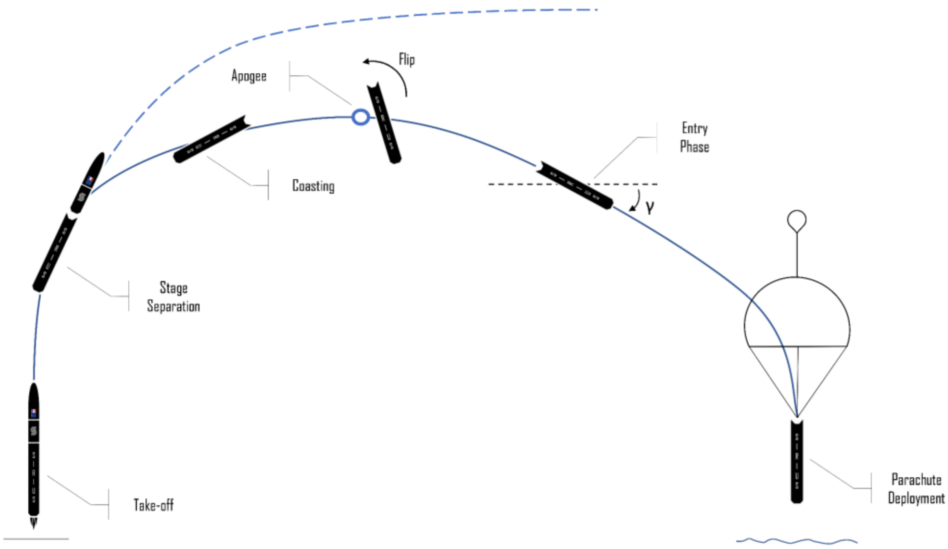

Figure 1: Re-entry trajectory of a first stage recovered with parachutes

Orion Space System team is developing a Python tool adapted to different launchers to study all the aspects of the trajectory. The choice of Python, which is an open-source language, reduces the cost of the development and provides a strong base with existing and powerful modules developed by the community.

The first impact of the trajectory on the recovery kit is the choice of altitude and velocity for the opening of the first parachute. The choice of the right point it is matter of analyse the ballistic trajectory and choose the best combination of speed and altitude to respect the requirements in terms of loads and time needed for the recovery operations. Higher the main parachute is opened, greater is the time for the helicopter to approach the launcher and attempt the catch. But higher the main parachute is opened, greater is the complexity of the environment. One of the biggest limitations on the parachute is to avoid the opening at supersonic speed and avoid any instability phenomena [1].

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The second important useful information recovered from the re-entry trajectory analysis is the evaluation of the splash-down area. This parameter is important to estimate and plan the recovery operations. The evaluation is done by means of a Monte Carlo analysis by selecting some inputs like the physical parameters of the stage and the atmospheric parameters. Ranges of uncertainties that depends on the actual design are considering and a lot of iterations on the model are done to obtain the mean and standard deviation of interesting input data of the trajectory.

Many technical challenges are taken to overcome a safe re-entry trajectory. Orion Space System also takes into consideration that recover a first stage is not sufficient to reuse it. The condition of the stage after the re-entry must be perfect and ready for the next mission after inspection and refurbishment. To achieve this, it is important to start directly from the design phase to handle the environmental aspects and allow a quick and profitable reuse. The aspects to consider with care are the aerothermal heating on the stage body, the high pressure acting on the structure due to high dynamic pressure at high speed, the high decelerations, and the need of a robust control logic to perfectly orientate the stage and handle the big aerodynamic loads.

It is important to underline the centrality of the ballistic coefficient (B) in the analysis of re-entry launchers stages, which is a parameter of merit for re-entry vehicles [2]. It depends on the weight (mg) of the stage, the average drag coefficient (C_d) and the surface (S) of the base. It can be used to easily compare different launchers body and have an estimation of the loads they experience during the re-entry trajectory. The impact of the loads also depends on the module of re-entry velocities in the atmosphere, so the velocities must be comparable to do a valid comparison.

$$B = \frac{mg}{C_d S} \tag{1}$$

To perform a ballistic re-entry, the ballistic coefficient of the first stage must be enough low to survive in the atmosphere. In the Table 1, a comparison is done between small launchers parameters and the ones of Falcon 9 which has already been recovered.

Table 1: Launcher trajectory input parameters comparison

Launcher First Stage	**Height (m)**	**Mass (kg)**	**Surface (m²)**	**Drag coefficient**	**Ballistic Coefficient (kPa)**
Falcon 9 (Space X)	47.7	25 600	10.75	1.5	15.5
Electron (Rocket Lab)	12.1	950	1.13	1.5	5.49
Sirius 1 (Sirius Space Services)	14	1 600	2.27	1.5	5.38

It can be noticed that the ballistic coefficient of Falcon 9 is three times the one of Electron. That is the reason why Falcon performs a re-entry burns to slow down and detach the high temperature shock layer from the launcher body. Instead, Electron has proven that stages with similar mass and shape can survive to a ballistic re-entry without major modifications.

The most critical loads to estimate during the re-entry is the aerothermal heating, which is useful for the sizing of the Thermal Protection System. The easiest way to evaluate the incoming heat flux with a good precision is by means of Computation Fluid Dynamics simulations. These numerical simulations can be avoided in a preliminary study considering the huge time-consuming task. An estimation can be done using the heat flux in the worst-case condition point. A lot of correlations have been developed the last years to evaluate the heat flux stagnation point of blunt nosecone. These formulas give comparable results and in accordance with the experiment [3]. The formula considered for this analysis is the one from Tauber, that evaluates the heat flux ($\dot{q}$), function of atmosphere density (ρ), velocity (V) and effective radius (R_{eff}).

$$\dot{q} = 1.83 \cdot 10^{-4} \left(\frac{\rho}{R_{eff}}\right)^{\frac{1}{2}} V^3 \tag{2}$$

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The radius in the original formula is associated to the one of a rounded nose associated of a truncated sphere. But using the velocity gradient parameter (β) [4], it is possible to estimate the effective radius of a blunt body, that is equivalent to the one of a sphere. The effective radius is $R_{eff} = R_{cyl} / \beta$, considering the stage body as a flat-end cylinder of radius R_{cyl}. For a blunt cylinder it has also being consider that the stagnation point doesn't correspond to the highest peak flux [5] as showed in Figure 3. So, the heat flux evaluated with Tauber is increased by a factor of 1.4. This evaluation can be used for a preliminary estimation only because it does not consider the possible hot spot that the cluster engine configuration can create.

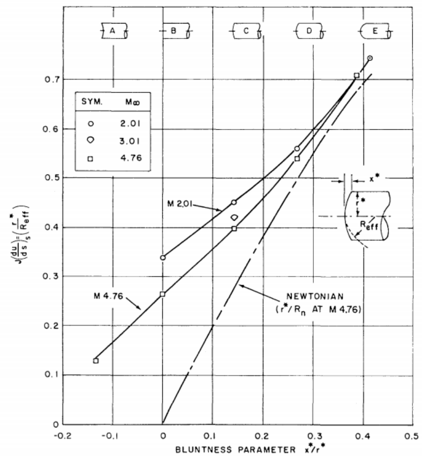

Figure 2: Stagnation point velocity gradient vs. body bluntness [4]

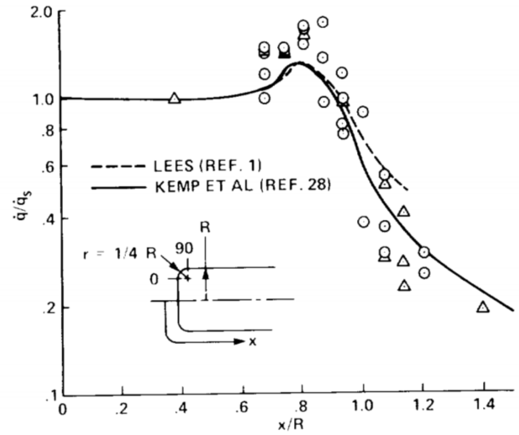

Figure 3: Heat transfer distribution on flat-nosed body [5]

All the above assumption is valid keeping the launcher stage oriented with the engine down facing the flow. The maximum allowable angle of attack with the flux depends on the limit in which the detached shocks created by the blunt bodies touch the body. This effect would engender a great increase in input thermal flux also on the side of the stage, requiring a more extended heat shield on the side. To avoid this effect, the development of a robust Guidance, Navigation and Control system will be done to keep the launcher stable. The algorithm must be quite robust due to the impossibility of testing before the actual launch. Also, every failed test means a complete loss of the vehicle. The solution will be to test the control logic with very high margin and perform extensive Monte Carlo analysis on that. The other important choice is the actuators selection for which the available possibilities are reported in Table 2.

Table 2: Advantages and disadvantages of three actuation system for the control of the first stage

Actuators	**Advantages**	**Disadvantages**
Cold gas thruster	Easy system with legacy, already existing for roll control on the stage, low electric power actuation, relative low weight, reliable.	Low thrust produced, on-off control.
Grid fins	Adapted for supersonic/transonic flight, high control authority, proportional control.	Complex system, high actuation torque/power, heavy system.
Canard fins	Common missile control surface, high control authorities, proportional control.	Not optimize for supersonic/transonic regime, high actuation torque/power, complex system.

In the end, the choice will depend on the wanted objectives. For a light and small launcher, the optimal choice is to sue the cold gas thruster. But in case of the need to control the trajectory a bit more of for heavier stages, an aerodynamic control surface gives more freedom in shaping of the re-entry path.

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2.3 Parachutes

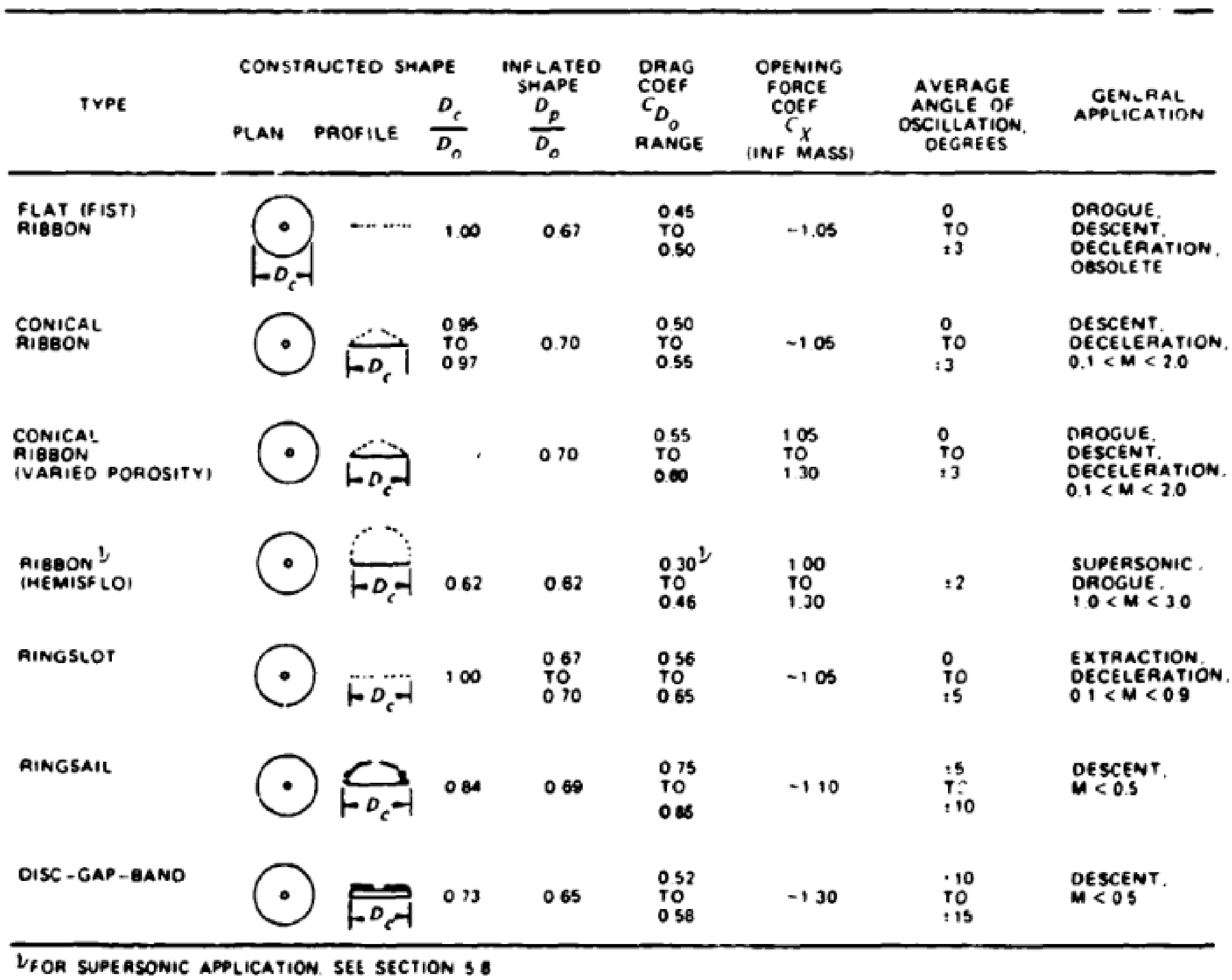
Parachutes are ideal to make recovery easy and accessible to small launchers. Several types of parachutes exist, and each parachute has its own role [6].

The main chute is the most important parachute intended to greatly slow down the fall of a body. Depending on the object/vehicle to be slowed down, the dimensions and the mass of this parachute can be very high.

The pilot chute is a small auxiliary parachute used to deploy the main parachute or other auxiliary parachute. The pilot chute is the first deployed and is connected by a flange to the deployment bag containing the main chute.

The drogue chute, also called the stabilizer parachute or extractor, is an aerodynamic brake designed to be deployed from a fast-moving object to slow it down. It can also be used to improve the stability or deploy a larger parachute. The same parachute can be at the same time a pilot parachute and a drogue parachute.

The shape and the manufacturing methods of these parachutes can vary. Some types of parachutes are adapted to de deployed at high speeds to sufficiently reduce the fall rate and to allow the deployment of other parachutes. Other types can be used to drastically reduce the speed due to a huge drag surface but must be deployed at low speed. For example, Ringsail parachutes are usually used as the main parachute at the end of the descent, while Hemisflo Ribbon parachutes are usually used as a supersonic stabilizer at the beginning of the descent.



TYPE	CONSTRUCTED SHAPE PLAN	PROFILE	D_c/D_o	INFLATED SHAPE D_p/D_o	DRAG COEF C_{D_o} RANGE	OPENING FORCE COEF C_X (INF MASS)	AVERAGE ANGLE OF OSCILLATION, DEGREES	GENERAL APPLICATION
FLAT (FIST) RIBBON			1.00	0.67	0.45 TO 0.50	~1.05	0 TO ±3	DROGUE, DESCENT, DECELERATION, OBSOLETE
CONICAL RIBBON			0.95 TO 0.97	0.70	0.50 TO 0.55	~1.05	0 TO ±3	DESCENT, DECELERATION, 0.1 < M < 2.0
CONICAL RIBBON (VARIED POROSITY)			'	0.70	0.55 TO 0.60	1.05 TO 1.30	0 TO ±3	DROGUE, DESCENT, DECELERATION, 0.1 < M < 2.0
RIBBON [1] (HEMISFLO)			0.62	0.62	0.30 [1] TO 0.46	1.00 TO 1.30	±2	SUPERSONIC, DROGUE, 1.0 < M < 3.0
RINGSLOT			1.00	0.67 TO 0.70	0.56 TO 0.65	~1.05	0 TO ±5	EXTRACTION, DECELERATION, 0.1 < M < 0.9
RINGSAIL			0.84	0.69	0.75 TO 0.86	~1.10	±5 TO ±10	DESCENT, M < 0.5
DISC-GAP-BAND			0.73	0.65	0.52 TO 0.58	~1.30	±10 TO ±15	DESCENT, M < 0.5

[1] FOR SUPERSONIC APPLICATION, SEE SECTION 5.8

Figure 4: Example of parachutes types [6]

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To make the parachutes sizing easy, a tool has been internally developed to automatically adapt the dimensions of the parachutes according to the launcher stage parameters. The input data are the launcher mass, the launcher speed during the falling phase, the mechanical and thermal loads accepted on the launcher and the final speed that must be reached for the mid-air recovery operations. With all these data, it can be possible to choose the deployment altitude of each parachute and calculate the resulted equilibrium altitudes and velocities. Then, the tool gives the surface of each parachute and the available recovery operations time.

The calculation of the opening force of the parachute is done by calculate and using the opening time of the parachute, the ballistic coefficient, and the opening force reduction factor.

The opening time of the parachute (t_f) depends on the nominal parachute diameter (D_0), the velocity at line stretch (v) and the typical constant parachute type (n).

$$t_f = \frac{n \, . D_0}{v} \tag{3}$$

The ballistic coefficient (A) depends on the weight (W), the drag area (C_dS), the gravity acceleration gravity (g), the air density at the inflation altitude inflation (ρ), the velocity (v) and the canopy inflation time (t_f).

$$A = \frac{2W}{(C_D S) \, . \rho \, . g \, . v \, . t_f} \tag{4}$$

The following graph is used to determine the value of the opening force-reduction factor (X_1) as a function of the ballistic coefficient.

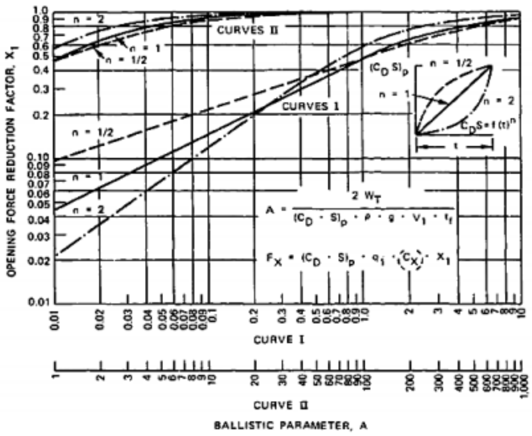

Figure 5: Opening-force-reduction factor versus ballistic parameter [6]

Finally, the opening force (F_x) depends on the drag area, the dynamic pressure (q), the opening force coefficient which is different for each parachute (C_X) and the opening force reduction factor.

$$F_X = F_C \, . C_X \, . X_1 = (C_D S) \, . q \, . C_X \, . X_1 \tag{5}$$

To calculate the dynamic phase after the opening of a parachute, the tool applies the Newton's second law and the Euler's method for differential equation solving. In the preliminary phase, only the weight of the launcher and the weight of the kit (m_{l+k}) and the drag of the parachute (T) are considered. A preliminary study demonstrated that the drag of the first stage is negligible compared to the ones of the parachutes, so it is useless to consider them.

$$\sum \vec{F} = \vec{W} + \vec{T} = m_{l+k} \, . \vec{a} \tag{6}$$

$$m_{l+k} \, . g + \frac{1}{2} \, . \rho \, . \, v^2 . (C_D S) = \, m_{l+k} \, . a \tag{7}$$

$$\dot{v} - \left[\frac{\rho\ .\ (C_D S)}{2m_{l+k}}\right] v^2 = g \tag{8}$$

The calculation of the static phase of the parachute uses the same method with the Newton's first law.

$$m_{l+k}\ .\ g + \frac{1}{2}\ .\ \rho\ .\ v^2 . (C_D S) = 0 \tag{9}$$

$$v = \sqrt{\frac{2m_{l+k}\ .\ g}{\rho\ .\ (C_D S)}} \tag{10}$$

After sizing the parachutes, research on parachutes fabrics and analysis of the materials datasheet are done. Different fabrics were selected by mixing the performances ranges and the finish to have an estimation of the weight and the cost of each parachute. The choice of the material will be done after some tests.

Regarding suspension lines, longer suspension lines allow the canopy to inflate fully and thus create more drag, slower descent rates, and more stability. They also add more weight. Shorter suspension lines create less drag, faster descent rates, and less stability. However, suspension lines that are too long may become tangled, while suspension lines that are too short may prevent the parachute canopy from fully inflating [6].

For large parachutes with long suspension lines, it has been proven practical to gather several lines in a single riser. This arrangement prevents length differences in the suspension lines that can be caused by differences in the elongation of adjacent lines. The effective suspension line length is always the distance from the skirt of the canopy to the real or hypothetical confluence point of the suspension lines. The suspension line length on the extended-skirt parachutes is usually equivalent to 0.95 to 1.0 inflated diameter of the parachute.

The suspension line length will, in fact, be determined by several parameters. This length is usually equal to the inflated diameter of the parachute but, to allow a fully inflation of the parachutes, the parachutes must be at a minimum distance of six times the diameter of the falling body. But, at the same time, the suspension lines can't exceed a certain distance to ensure a control and safe recovery by the helicopter. A compromise will be done to optimize the solution and respect all the requirements. To control the position of the parachutes deployment, ejected system can be used.

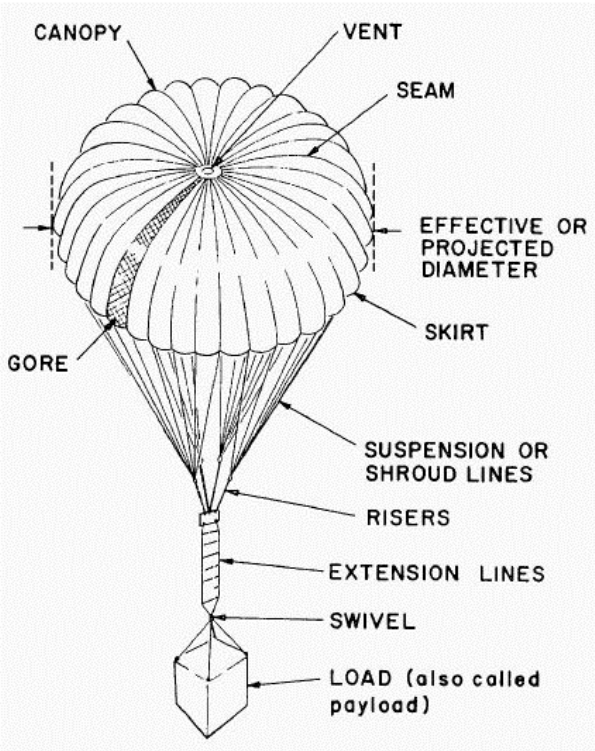

Figure 6: Parachute system configuration [7]

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2.4 Deployment system

To slow the fall of a launcher stage, the parachutes must be deployed at a certain distance of the launcher body. Indeed, it is essential to position the parachutes outside the wake of the stage to allow a fully inflation and an efficient and stable deceleration. Behind a falling body, a parachute deployment is too complex because of the high turbulence and the general behaviour of the flow which is difficult to predict. Referring to tests carried out in the NASA and in the Wilbur Wright Field vertical wind tunnels [6] parachute must be ejected at a distance greater than six times the diameter of the body in free fall to ensure a complete canopy inflation. For micro-launchers recovery, the ejection distance is therefore about 12 m at least, for a two meters diameter launcher.

Systems used in space must be as light as possible, and the deployment system is not an exception to this rule. Thus, the most interesting way to deploy the main parachute with a nominal surface area of several hundred square meters and a mass of a few dozen kilograms, is aerodynamic deployment.

The aerodynamic deployment is possible thanks to the high density of our Earth's atmosphere and works with the help of a small auxiliary parachute. When the auxiliary parachute is deployed, the force generating during the inflation of its canopy allows the main parachute to be extracted from the body in free fall. This method can also be used to deploy another auxiliary parachute. For example, a pilot parachute can extract a drogue parachute which will extract the main parachute.

Apart from the aerodynamic deployment, many other methods exist to eject a parachute at the right distance from the launcher stage, like spring, pyrotechnic or pneumatic systems. The pneumatic system, also called the parachute mortar, have been used in several space mission such as the Apollo and Mars 2020. Referring to the Technology Readiness Levels scale, parachute mortars can be considered as TRL 9.

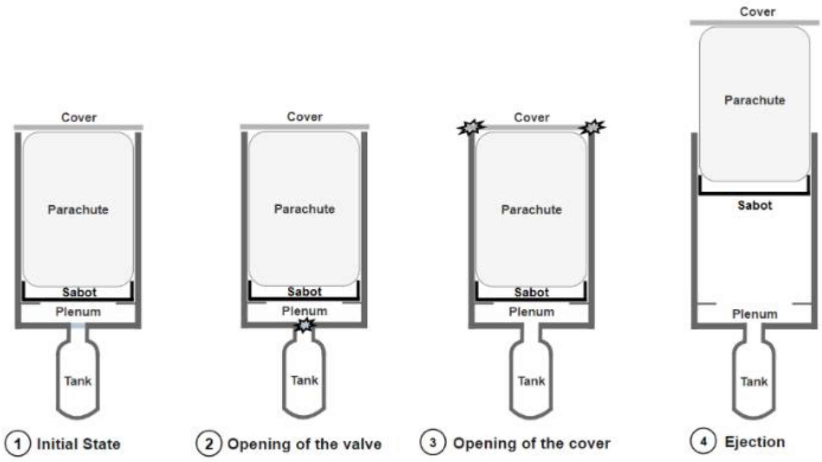

Figure 7: Illustration of a parachute mortar

The operation of a cold gas parachute mortar is as follows: a pressurized gas is stored in a tank (usually Carbon dioxide or Nitrogen), when the tank is opened, the gas flows into a plenum, which is a low-pressure area, and starts to exert a pressure under the sabot containing the parachute. Once a certain pressure has been reached, the cover holding the parachute breaks and releases the sabot. The sabot then provides the necessary momentum for the parachute to be ejected out of the launcher's wake.

The main part of the mortar is the cylinder acting as the container of the parachute and as a plenum. The container must accommodate the folded parachute and withstand the significant internal pressure. The dimensions are determined by the dimensions of the folded parachute. Concerning the plenum, it must accommodate the highly pressurized gas at the beginning of the ejection process and allow a precise pressure to be reached before the cover breaks.

The sabot acts like a piston by moving along the container. The purpose is to keep the gas at the back of the projectile by ensuring a seal and to keep the projectile aligned with the centre of the container during firing. This system helps for an optimizing deployment.

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The cover plays a key role in the deployment. It must maintain the parachute during the launcher trajectory but break at the deployment time.

The gas tank can be a refillable one or a disposable one, also called cartridge. Cartridges are already filled by the manufacturers whereas refillable tanks must be filled before each use, cartridges are more interesting in terms of mass. Usually, the gases used for this type of system are nitrogen or compressed air which are easy to obtain. The carbon dioxide can also be used, it has the advantage of being in liquid form at acceptable pressures and can therefore be stored in small volumes.

The valve system is the most complex part of the mortar. Depending on the type of tank used, the type of valve can vary. For example, there are solenoid valves for conventional tanks or mechanical and pyrotechnic systems for opening cartridge tanks.

To estimate the mass if the mortar system, data from existing systems can be used. The figures below shows the mass values of several systems used in space and the tendance curve.

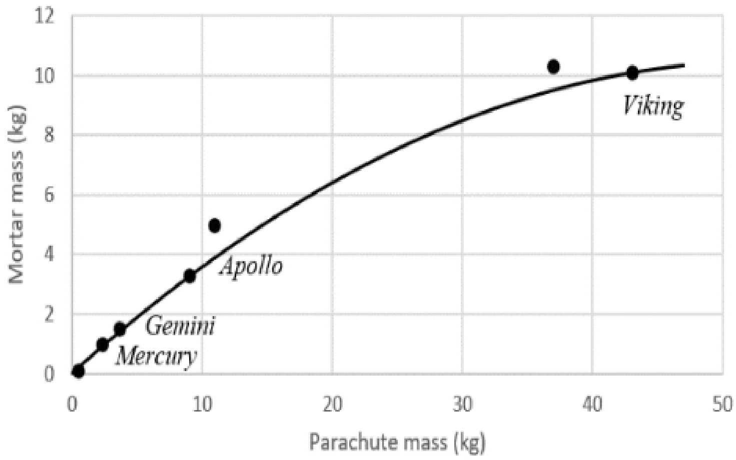

Figure 8: Example of mortar mass in function of parachute mass

To model the behaviour of the mortar in a simple way, several assumptions can be made. A tool has been developed internally to size the mortar following the parachute sizing. This tool allows us to determine the flow regime, the mass flow rate, the pressures in the mortar at each time in the mortar…

By performing a force balance with the ejection force and the weight of the cover, plenum and parachute assembly, the ejection velocity can be deduced.

To get an idea of the magnitude order of the ejection velocity of a mortar, the following table can be used.

Table 3: Mortar data from the Planetary Entry Parachute Program [9]

Parachute mass (kg)	**Ejection velocity (m/s)**	**Mortar mass (kg)**
18	38	8
29.5	34	11
34	40	10.5

These values were obtained during the Planetary Entry Parachute Program. During this program the parachutes to be deployed were of large mass and the ejection distance required to exit the wake was high due to the large diameter of the atmospheric re-entry vehicles. In the case of mortars used on micro-launchers, the mass of the pilot parachute to be ejected will be less than 10 kg and the necessary ejection speed will be rather between 20 and 30 m/s. This implies having light mortars compared to those used until now in the space domain.

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2.5 Recovery operations

To recover a first stage of a two tons maximum mass of the first stage, Orion Space System chose to use a mid-air recovery with a helicopter.

The recovery mission will be carried out by two experienced pilots who will be assisted by four technicians during the placement of the launcher in the net. Before giving the permission of the recovery, the following checks will be done to ensure the safety of the operators: launchers parameters (purge of tanks, position, velocity), recovery kit parameters (parachutes deployed) and visual inspection.

For the boat, the choice was done considering the mass and the dimensions of the launcher and of the helicopter, but also the number of people to accommodate to handle the mission. As the swell is important in the recovery area, the pilots will not be able to put the launcher on a specific position on the boat. A net will be used, then, the launcher will be secured in a cradle with on-boat operations. To secure the helicopter on the boat, a helipad will be built on the deck.

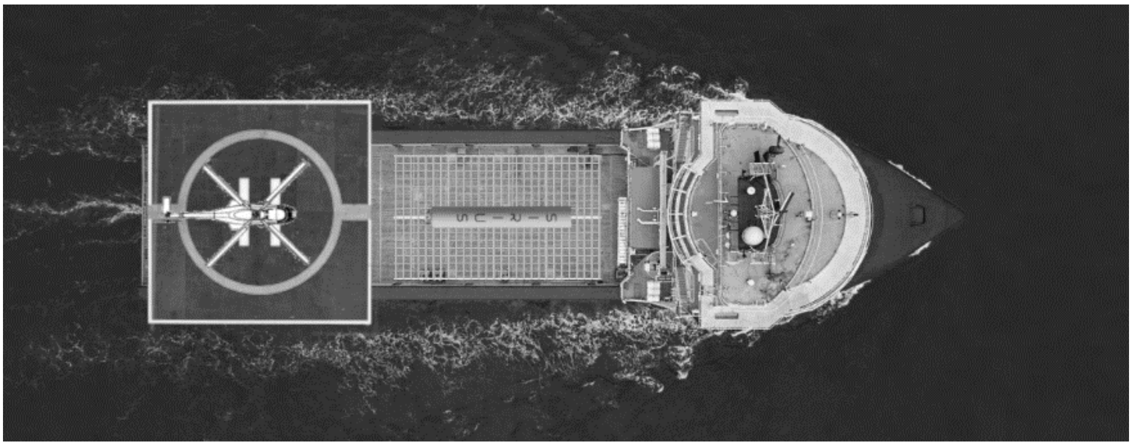

Figure 9: Artist's view of the boat with the helicopter and the launcher in the net

The recovery system is standardized to allow the catching of any launcher with a mass of less than two tons.

Figure 10: Artistic image of the recovery system and operations

To allow the recovery of the first stage, it is essential to design parts that allow the launcher to be hung and secured. The system designed by Orion Space System is composed of two parts. The first is a hook that will be on the helicopter sling and the second one is a mechanical stop that allows to block the hook along the line.

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2.6 Operational concept

The operational concept of the recovery mission has been done to give an overall picture of the operations. The quantitative and qualitative system characteristics have been defined to achieve the desired objective of the launcher recovery and reusability.

The operational concept of the Orion Space System's recovery kit is separated into several parts, which correspond to the different phase of the recovery mission. The first one is the launcher operations with the lift-off, the trajectory, the separation, the atmospheric re-entry, and the stabilization with the parachutes deployment. During the launcher operations, the helicopter and the boat will prepare for the recovery mission. Then, the recovery operations can take place with the mid-air recovery and the maritime operations. Once the launcher is secured on the boat, the mission can be ended with the return to the Space Guiana Centre facilities.

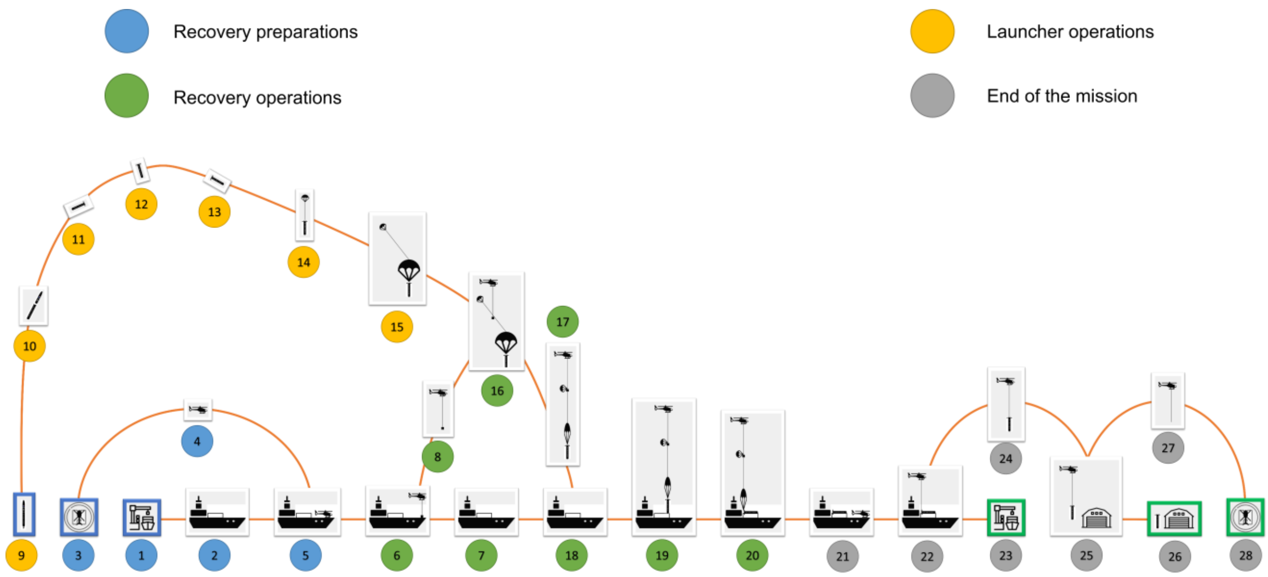

Figure 11: Operational concept

The interest of this operational concept is also to determine the mission time with the duration of each operation. Given the dimensions of the launcher fallout zone and the speed of the boat, the mission could last between three and four days. A margin at the level of the journey was obviously considered to compensate for all eventualities.

The Orion Space System mission is therefore completed after the first stage is back at the Guiana Space Centre. It is commonly accepted that a few launchers part will need to be changed before it can fly again. Nevertheless, the goal is to recover and reuse between ten and twenty times the first stage, and to decrease over the time the number of parts that need to be changed. Launcher recovery limits the impact of manufacturing and launch operation on the planet and its environment.

3. Conclusion

As space actors in Europe are developing reusable launchers, Orion Space System has started to develop standardized solutions for all categories of launchers to answer to the challenges of recovering and re-using stages.

The development of a first solution adapted to micro launchers relying on parachutes, mid-air recovery and maritime operations is underway with an entry service planned for 2025. With the Orion Space System's first solution, the reuse of the stage is profitable after only two missions, considering also all the expenses for the recovery operations. The more times the stage will reuse instead will impact on the number of mission necessary to recover the initial investment to make reusable the first stage.

The development of an autonomous drone ship with a smart catcher, adapted to the heavier launchers, will be done in a second phase. A smart catcher is a mechatronic system to recover and secure the launcher automatically. Several sensors will detect the presence and the position of the launcher. Then, platforms with wires will be activated to move

DOI: 10.13009/EUCASS2022-6156

and received the launcher. This system will be able to recover all types of launchers launched from the Guiana Space Centre.

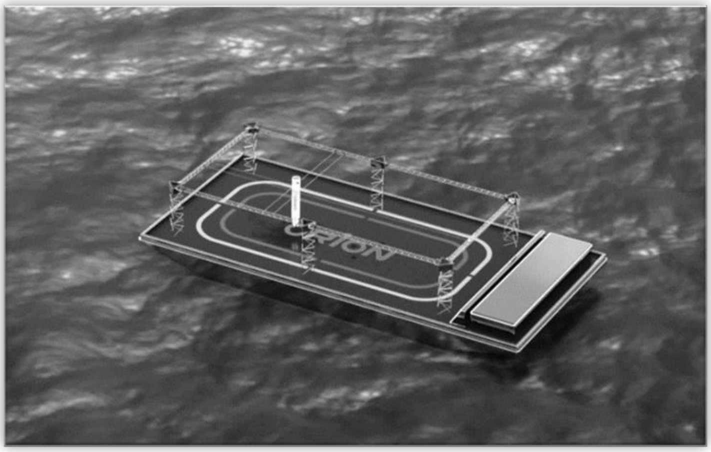

Figure 12: Artistic image of the drone ship with the smart catcher recovering the launcher

The European space actor would strongly benefit from the standardization of the recovery systems and from a communalization of the ground means to minimize the cost of making European launchers reusable.

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