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Conceptual Design of the Descent Subsystem for the Safe Atmospheric Re-Entry Flight of Space Rider

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Abstract

In the frame of the development of ESA's Space Rider, the new European space transportation system, the conceptual design of the Descent Subsystem has been performed, laying the basis for the following development work of next design phases.
The Descent System will be triggered at subsonic speed: a first phase of deceleration guaranteed by drogue parachute(s), a gliding parachute will be deployed and the controlled descent phase will begin. This solution will allow for a safe landing, reducing operating costs as well as recovery and refurbishment time of the vehicle. It is the first time that this kind of architecture for a descent subsystem is being developed in a major European space program and it is the most important space project with a gliding parachute since NASA's X-38, which was developed until 2001.
The design of the Descent Subsystem poses a number of challenges, given the demanding requirements defined for this project: pinpoint landing, featured by low peak g-forces and thus low vertical landing speed. Additionally, strict requirements in terms of available space and power, maximum attainable weight and maximization of reliability and reusability complete the framework.
In the phase A of the project a trade-off between different technical solutions has been carried-out by taking in account parameters such as development and recurring costs, readiness level of already available technologies, lead-time and heritage: two main possible architectures for the Descent Subsystem have been identified. The main difference between the two main solutions is the presence of a single reefed drogue parachute or the presence of two different drogues.
In this study all the main equipment have been defined, and advantages and shortcomings coming from each solution critically analyzed. Critical areas to be further investigated have been identified to focus on in the next phases of design.

1. Space Rider Program

The Space Rider overall objective is to develop an affordable reusable European space transportation system to be launched by VEGA-C and to perform experimentation and demonstration of multiple space application missions in low Earth orbit.
The program hints are: to perform application-driven missions with a payload mass capability up to 800 kg for a multitude of orbits altitudes and inclinations; benefit at the maximum extent possible from existing launchers technologies; and, address relevant progressive technological challenges with limited risks and minimal financial efforts for Europe.
Therefore, in line with the above, the Space Rider shall provide routine access to and return from orbit, with the purpose to perform in-orbit operation, experimentation and demonstration for the following applications: Free-Flyer applications, In-Orbit Demonstrations and Validation for the following technologies, and In-Orbit applications.

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The Program has successfully passed the Phase A critical milestone (Preliminary Requirements Review) and is currently in the Phase B1 targeting the final review of this stage, the System Requirements Review.

1.1 Space Rider Mission

The Space Rider system has to be able to operate in-orbit, de- orbit, re-enter, land on ground and allow fast recovery of payloads.
The baseline system architecture is a stack combination of a modified version of the AVUM as disposable deorbit module and an IXV derived lifting-body as re-entry reusable module.
The re-entry module hosts hosted payloads in the Multi-purpose Cargo Bay , hence it has to be reusable after landing and re-launched after limited refurbishment.

The re-entry module is a lifting body based on the IXV 1:1 scale vehicle, which had already demonstrated space entry and hypersonic/supersonic flight capabilities.
With respect to the IXV mission, the added value of the Space Rider is the capability of landing on ground and reusability, then an appropriate recovery approach has been defined based on adoption of a Descent and Landing system, the former exploiting parachutes, the latter Landing Gears.
As far as the descent phase is concerned, because the stability of a lifting body vehicle decays at high angles of attack and low airspeeds, piloted landings require high approach speeds and exacting control. As such, lifting body vehicles combine well with a parachute landing system. A combination of parachutes and parafoil has been investigated to perform the descent, where the parachutes allow early deceleration and the parafoil perform the controlled gliding up to soft landing to provide the lowest possible vertical velocity at landing and a reduced landing accuracy.
The parafoil system is capable of flared landings thus producing low vertical velocity component. Further, the parafoil system can be maneuvered with some degree of wind penetration, so that the SR landing dispersion and time for payload recovery is reduced as well.

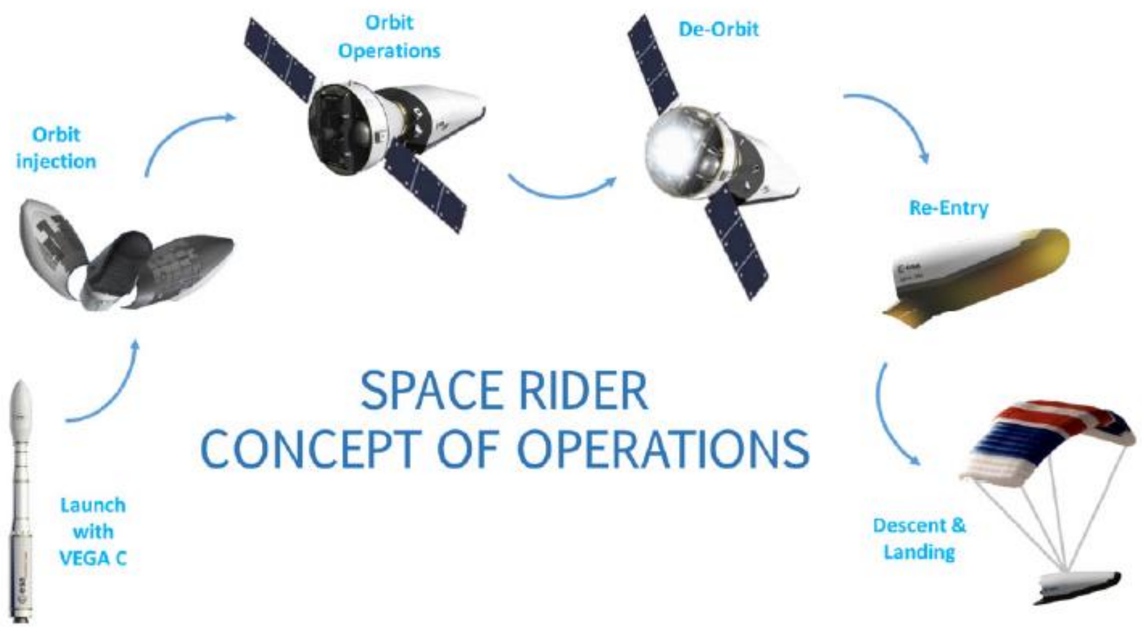

Figure 1 Space Rider Concept of operations

1.2 Descent System high-level needs

At the very early stage of the Phase A, in order to feed investigation of the Descent and Landing phase and allow the very preliminary analysis of the parachute/parafoil solutions, a set of high-level requirements has been identified from system/mission level.
In that perspective the following key-drivers were applied along with some peculiar figures to take into account for the analysis:

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- reusability: 6 flights
- landing accuracy on open-field: 150m
- vehicle max weight: 2550kg
- limit landing speeds: horizontal 35m/s; vertical 3m/s
- maximum deployment shock requirement: 4g's
- minimize parachuted phase in order to reduce dispersion and to ease fulfillment of precision landing: triggering of the parachuted phase below Mach 0.8 / altitude 15000m
- parachutes triggering conditions shall comply with reference performance envelope of state-of-art solutions.

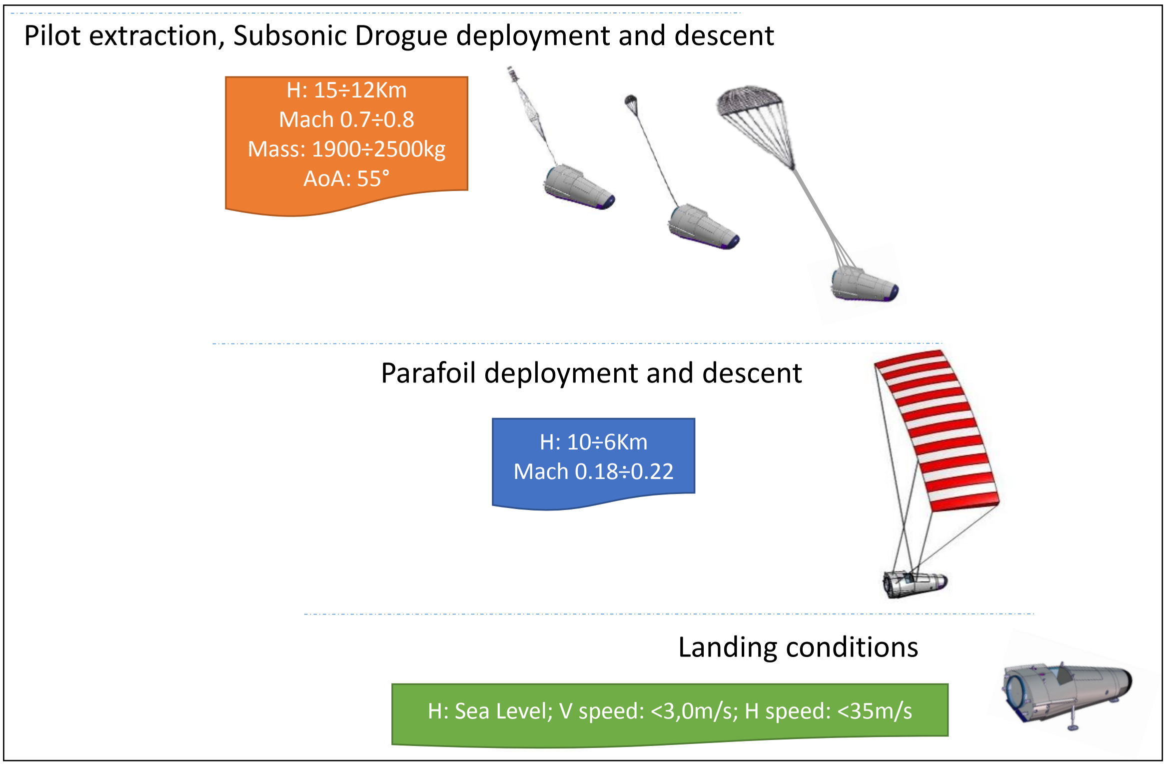

Figure 2: Space Rider descent phase strategy

2. Descent System architecture selection

Given the requirements and the identified descent phase strategy, the descent subsystem has been defined with the following structure:

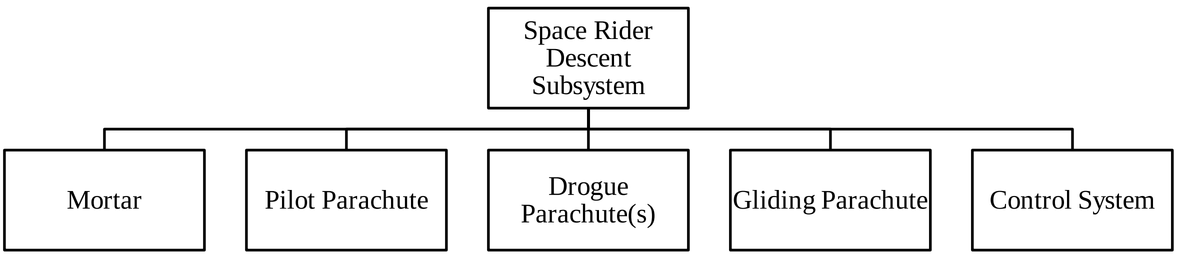

Figure 3 Conceptual product tree of the Descent System

This conceptual product tree is based on the architecture of vehicles/system that used a controlled descent with a parafoil such as the X-38, the GPADS, the PAS and divides the descent in two different phases: a passive one that aims to slow down the vehicle after a re-entry or an airdrop and then a controlled one that makes the system land near a defined point.

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The system conceptual design has been performed with a bottom up approach: given the requirements of the landing phase, it has been analysed the gliding chute and the active descent phase. Once this analysis has been performed, the elements of the passive descent (the drogue parachutes) have been studied in order to match both the triggering conditions given by the requirements and the boundaries defined for the parafoil (*i.e.* the gliding parachute).

To maximise the heritage from other European space programs, the analysis on the drogue parachute has been based on the Conical Ribbon drogue used in the frame of ARD and on the Disk Gap Band parachutes from the Exomars and Huygens missions, while the gliding chute is based on the ram-air parachute developed in the frame of the programme PAS – Precision Airdrop System, a research project funded by the Italian DoD and developed by Aero Sekur (now Arescosmo) which had similar requirements for the descent phase.

In the study it has been assumed that the main features of the conical ribbon drogue remain unchanged, while the Disk Gap Band and the gliding chute are resized to meet the mission requirements.

The choice of the possible architecture has been made between 5 possible combinations of drogue parachutes and parafoil.

Table 1 Features of the analysed DS

ID	Drogue	Parafoil
DS-1	Conical Ribbon	Reefing
DS-2	Disk Gap Band with reefing	No reefing
DS-3	Conical Ribbon	No reefing
DS-4	Disk Gap Band	No reefing
DS-5	Conical Ribbon+ Disk Gap Band	No reefing

Definition of the main elements of the DS

Gliding parachute

The parafoil is the gliding parachute that is used in controlled descent phase. For the first iteration, it has been assumed that a ram-air parachute is used and for all the main parameter it has been used as reference the parachute developed. The parachute had a glide ratio of around 3.
The size of the parachute for Space Rider has been obtained by keeping constant the wingload at around 10 kg/m^2: given the mass of 2250 kg, the resulting size is 250 m^2. With these parameters the expected CD and CL of the parachute, it is expected to have a trim speed at sea level equal to 14.43 m/s, with a vertical speed of 4.56 m/s.
The vertical landing speed will be reduced in the last phases of the flight with the “flare” manoeuvre in order to fulfil the requirement of vertical landing speed by performing a flare before landing.

To assess the dynamic behaviour of the parachute it shall be computed the mass ratio, which is defined as:

$$\mathbf{M_r} = \frac{\mathbf{m}}{\boldsymbol{\rho} * \mathbf{S}^{1.5}} \qquad (1)$$

Where m is the mass, ρ is the air density and S is the surface of the parachute

According to Lingard [2], parachutes do not show adverse dynamics when the ratio > 0.4: with the current parameters the mass ratio of the parafoil is equal to 0.54, therefore with the current sizing it is expected to have a good dynamic behaviour. Parachutes with good dynamics show vertical speed reduction of the magnitude of 50-60% after a successful flare manoeuvre, so the final vertical speed will be lower than 2,5 m/s.

Once the first iteration of the sizing of the parachute has been done, it has been evaluated the deployment conditions in order not to exceed the maximum load defined in the requirements. In order to have a reasonable nominal downrange, it has been assumed a deployment altitude of the parafoil equal to 6 km, so that the nominal downrange is equal to 18 km.

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After the first iteration for the sizing and triggering conditions for the gliding parachute, it has been performed an analysis of the inflation forces, so that the drogues can be sized. The inflation force study has been carried by analogy with the inflation force model which is used for circular parachutes with the model described by Lingard [2]. The first step is the definition of the dimensionless inflation time as:

$$\boldsymbol{\tau_0 = \frac{V_s t_i}{D_0}} \tag{2}$$

Where V_s is the initial snatch velocity [m/s], t_i is the inflation time [s] and D_0 is the equivalent diameter of a circular parachute with the same area of the parafoil

τ_0 is approximately 2 – 5 for non-reefed systems, while it is about 10 for circular parachutes. In order to increase this value (and to decrease the relevant inflation loads) modern canopies usually adopt the slider reefing technique obtaining a 12-18 range depending on the slider design. For this preliminary analysis the value 14 has been assumed.

Fixing $\tau_0 = 14$ the inflation time, t_i, depends only on the initial snatch velocity (mission environment) and D_0 (sail sizing); the inflation force coefficient, C_F, is independent on the mass ratio and it can be well approximated as a function of time by:

$$\boldsymbol{\begin{cases} t \le t_i \;\rightarrow C_F = 1.5 * \left(\frac{t}{t_i}\right)^3 \\ t > t_i \;\rightarrow C_F = 1.0 \end{cases}} \tag{3}$$

The equation of motion can be written as:

$$\boldsymbol{\begin{cases} m\,\frac{dV}{dt} = mg\cos(\theta) - \frac{1}{2}\rho V^2 C_F(t) S_0 \\ \frac{d\theta}{dt} = -g\,\frac{\sin(\theta)}{V} \end{cases}} \tag{4}$$

Solving the equations for V (θ does not change in the initial phase and it is equal to FPA+90° because the vertical attitude is guaranteed by the stabilizing effect of the drogue parachute(s)) one can calculate the inflation force considering the additional deceleration contribution of the vehicle as $\frac{1}{2}\rho V^2 CDS0\ /m$.
Given the uncertainty which is present in the inflation phases of the gliding parachute, a 20% margin on the peak force has been defined, in order to mitigate the risk of exceeding the 4g acceleration requirement.

The preliminary sizing and the features of the parafoil are the same for all the studied architectures, the only difference being the presence of a reefing system in DS-1.

Control System

The control system will work during the active descent phase (i.e. when the gliding chute is deployed) and it will steer the parachute by pulling the lines connected to the “brakes” of the parafoil with the winches installed on the vehicle.

A preliminary sizing of the winches that pull the control lines of the parafoil has been done, by analogy, using the experimental data coming from the wind tunnel data from the NASA’s ARS program which tested a ram air parachute with similar features to the one analysed for SR.
As part of ARS test campaign, it was studied the force necessary to pull the flaps under different dynamic pressure conditions (Figure 4)

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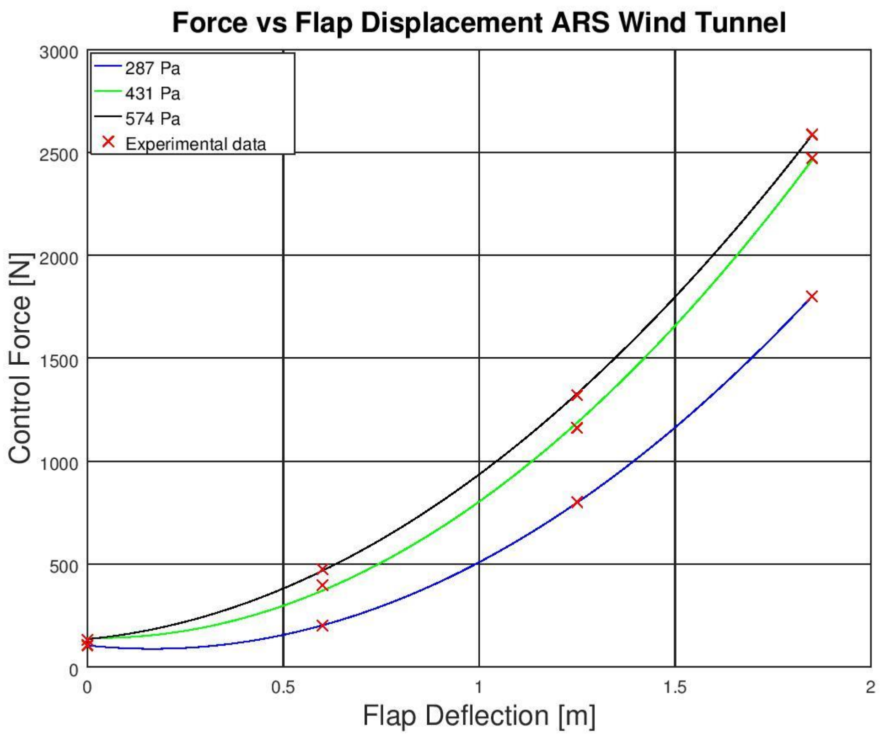

Figure 4 Experimental and interpolated data

The experimental data have been interpolated and the pulling force under different conditions has been estimated as:

$$\mathbf{F} = \mathbf{c_f}(\mathbf{q}) * \mathbf{q} * \mathbf{S} \tag{5}$$

Where c_f is a coefficient that depends on the dynamic pressure, q is the dynamic pressure and S is the surface of the flaps.

By estimating the force at 100% flap deflection with the dynamic pressure given by the trim speed at sea level, it has been assessed the maximum pulling force, which is the order of 2 kN. By scaling the dimensions of the sail of the PAS, it is obtained that the maximum length of the cord that can be pulled is 2,05 m. By using conservative assumptions it is estimated that energy necessary to completely pull one flap is 1600 J.

It has then been estimated the flare time by using a time constant coefficient:

$$\boldsymbol{\tau} = \frac{\mathbf{v} * \mathbf{t_{flare}}}{\sqrt{\mathbf{S}}} \tag{6}$$

where v is the velocity, t_{flare} is the flare time and S is the surface of the parafoil
In literature it has been found that a reasonable value for τ is 2.32, which leads to a flare time equal to 2,44 for a 250 m^2 parachute.

By diving the energy necessary to perform the flare manoeuvre by the time, it is possible to determine the necessary power of the winches: the total power is of the magnitude of 1.3 kW, which means that each winch shall deliver more than 650 W. To minimise the size of the motors, the flare manoeuvre will be performed at constant speed absorption: in the first phases, when the pulling force is lower the retraction speed of the lines is greater and as the necessary force increases the velocity decreases.

For the definition of the architectural scheme of the control system, it has been considered central the role of the Mission and Vehicle Manager (MVM), in order to leverage on the vehicle’s capabilities without introducing other elements.

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The triggering command of the mortar and of the parachute separation will be therefore made by the MVM and it will be set an altitude threshold to trigger the system. If a disreef command will be included in the system, it will be temporized after the deployment signal of the parachute, in order to have a system as simple as possible.
The descent under Drogue parachute is passive, i.e. it is not possible to perform any correction to the path of the vehicle, therefore no control system of the vehicle is implemented in the scheme for this phase.
To control the active descent phase under the parafoil the control of the movement of the vehicle has been divided in guidance, navigation and control to follow the common approach used in automated systems.
In the navigation block, two function have been identified: trajectory generation and trajectory tracking, also in this case to have a solid approach to this problem.
In the scheme has been included the possibility of a manual override of the control system in order to have a redundancy in case of failure of the automated descent system.

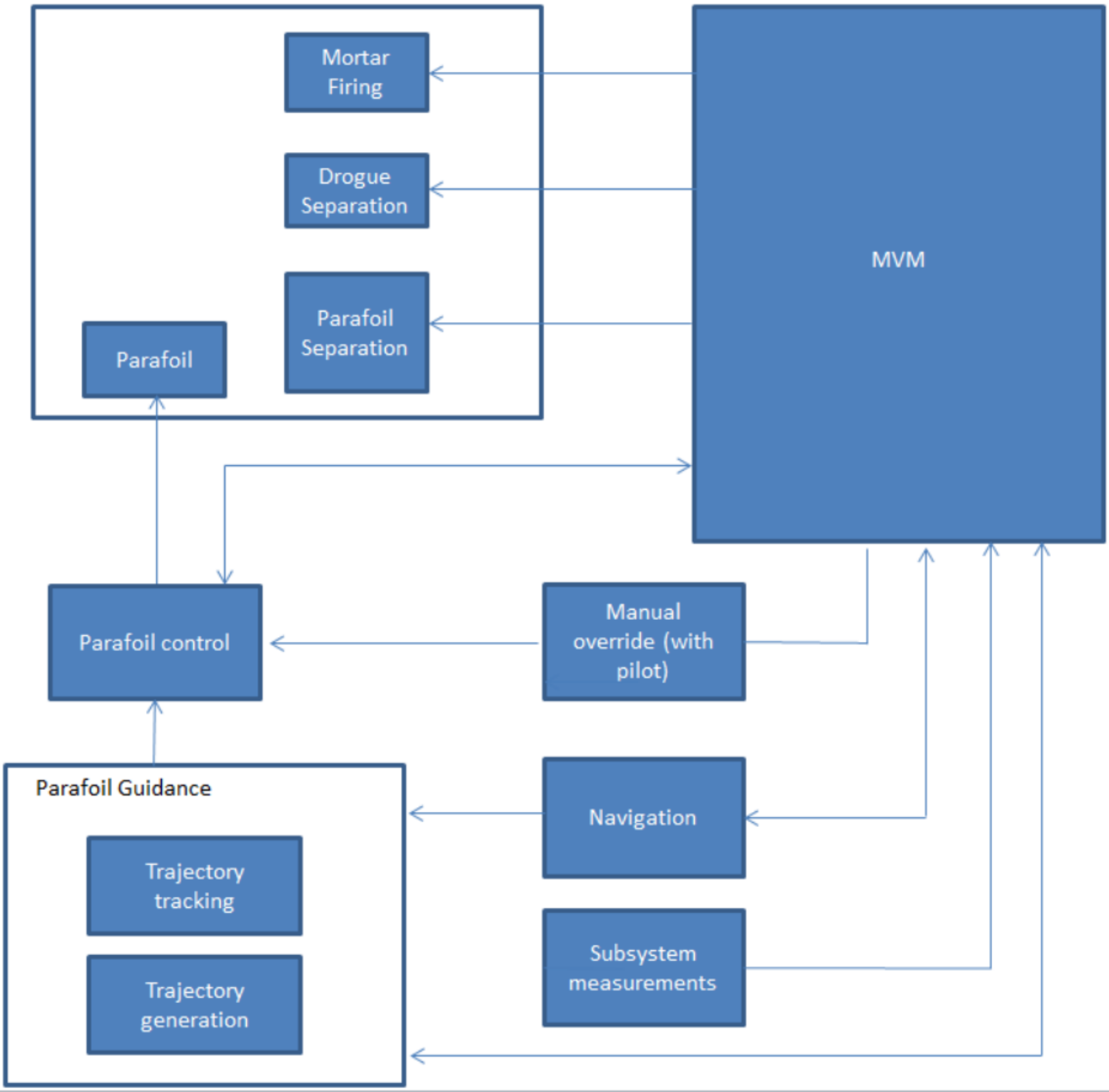

Figure 5 Architecture of the control System

The system will use the typical approach for automatic system that use gliding parachutes: in the first phase it will guide the system towards the landing target point ("homing phase"), then it will "loiter" near the target with the purpose of reducing the altitude before approaching the landing site, and once the vehicle is below a certain altitude threshold it will perform the necessary manoeuvres to land as close as possible to the target point ("approach phase" and "landing phase").

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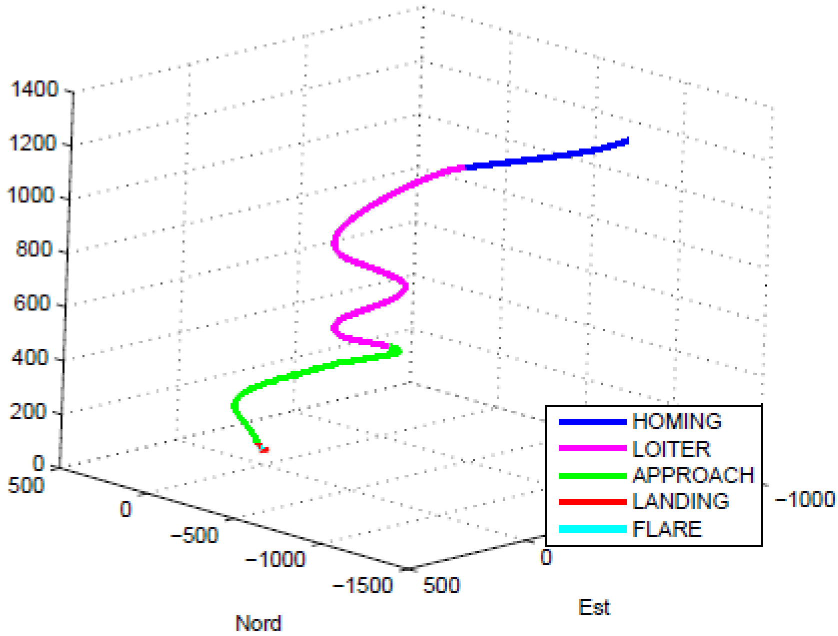

Figure 6 Simulated PAS mission

The control system is assumed to be the same for the architectures that are being analysed.

Drogue parachute(s)

To slow down the vehicle after the end of the entry phase to a conditions that allows the deployment of the parafoil, it shall be implemented a passive descent phase. All the parachute used in this phase shall be compatible with the opening window defined in the requirements and at the same time they shall not decelerate the vehicle over 4g during the inflation

To maximise the heritage, in the study of the drogue parachute it was assumed that the conical ribbon used in ARD remains unchanged (shape, dimensions and possibly materials), whereas the disk gap band is scaled to fit the needs of this mission. The Disk Gap Band would require in any case a significant delta design because of the different operative environment (Earth vs Mars and Titan), however during the scaling operations the main features of the canopy (shape, geometrical porosity, …) will not be changed in order to leverage on the tests and models devised in Europe for the previous missions.

All the inflation analyses of drogue parachutes have been performed with the model provided by Knake [1] where the parachute force F, as function of time is:

$$\mathbf{F} = \mathbf{C_D S_0 q} + (\mathbf{m_a} + \mathbf{m_v} + \mathbf{m_p})\frac{\mathbf{dv}}{\mathbf{dt}} + \mathbf{v}\frac{\mathbf{dm_a}}{\mathbf{dt}} + \mathbf{W_v} * \mathbf{sin}(\boldsymbol{\theta}) \qquad \textbf{(7)}$$

Where:

F	parachute force, acting parallel to the flight trajectory
Dv	drag of the vehicle
Wv	weight of the vehicle
Θ	trajectory angle against the horizontal
g	gravity acceleration
$C_D S_0$	drag area of the parachute
q	dynamic pressure
v	velocity
m_a	apparent mass (added mass)
m_p	mass of the parachute
m_v	mass of the vehicle

To define the dynamics of the parachute during the inflation phases it is defined the canopy filling time as:

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$$\mathbf{t_f} = \frac{\mathbf{n\,D_0}}{\mathbf{v}} \tag{8}$$

Where n is a constant, D_0 is the nominal diameter and v is the velocity at line snatch. The constant n depends on the type of parachute and for the disk gap band it has been assumed as equal to 7,while for the conical ribbon it has been assumed 14.

Pilot chute and mortar

The triggering of the DS will be given by the activation of the mortar, that will deploy the pilot parachute. The pilot will then extract the drogue parachute. The current baseline is to use a flat ribbon parachute that allows the deployment at high dynamic pressures and that provides sufficient pull to extract the first drogue parachute, if possible it will be used the same pilot used in the frame of ARD.

Architectures analysis

DS-1 Conical Ribbon Drogue and Reefed Parafoil

The ARD-like Conical Ribbon drogue parachute allows a wide operative range, since it has a high max dynamic pressure which is around 5.3 kPa. However given its relatively small dimension, it wouldn't slow down the vehicle to speed that allows an uncontrolled deployment of the parafoil. Given the speed in steady state conditions at 6000 m, it has been evaluated that it is necessary a reefing ratio equal to at least 0.25 in order not to exceed the 4g (minus margin) requirement. The reefing technique foreseen for the parafoil is the mid-span reefing: with this technique the first part that is opened is the central section of the parafoil and then are opened the lateral spans. This technique has been used in the frame of the X-38 development and in other research project, however the European heritage is limited and the development effort is expected to be significant.

DS-2 Disk Gap Band with reefing, Parafoil without reefing

The first step to study the system is the definition of a scaled DGB that slows down the vehicle enough to allow a non-reefed deployment of the parafoil: according to the model devised for the inflation of the parafoil, the maximum allowable speed at 6000 m is 42 m/s.
Given the mass of the vehicle and the deployment of the parafoil at 6 km, this corresponds to a drag area of 39.8 m^2: if in this phase is neglected the drag area of the vehicle to keep a conservative approach, this corresponds to a nominal diameter of the parachute of 9.6 m.

In order to comply with the triggering window, it shall be implemented a high reefing ratio which in the first iteration has been assumed equal to 0.3. To take in account the uncertainty in the dynamics of the deployment of the reefed parafoil, a 20% margin has been defined: with these assumptions the maximum dynamic pressure at deployment is 4200 Pa. A preliminary analysis, based on the membrane theory, has shown that if the canopy is manufactured with strong fabrics and webbings it will be able to withstand the load, however more complex simulations and tests shall be carried to confirm this result.

DS-3 Conical Ribbon, Parafoil without reefing

The minimum speed to allow a non-reefed deployment of the parafoil is 42 m/s, however with the ARD conical ribbon drogue, this speed is not reached even at sea level: for this reason there is no possible operative envelope for this system.

DS-4 Disk Gap Band without reefing, Parafoil Without reefing

This solution guarantees a simple Descent System, which is composed only by two parachutes, however given the dimension of the drogue parachute and the absence of any reefing system it shall be limited the dynamic pressure at the moment of the deployment. The maximum dynamic pressure at deployment that allows not to exceed the 4g requirement has been estimated around 2000 Pa, which is far below the values needed to match the requirements, therefore this solution cannot be implemented in the mission.

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DS-5 Conical Ribbon, Disk Gap band without reefing, Parafoil without reefing

With the two drogues, the drogue that is extracted at high speed is the Conical Ribbon, and after it is deployed a disk gap band with the same dimensions computed for the DS-2, so that it is possible to have an unreefed deployment of the gliding parachute.
The inflation force analysis has shown that it is possible to implement this parachute deployment sequence without exceeding the inflation load. This system has the advantage of having a large triggering operative envelope, which is possible by leveraging on the features of the conical ribbon drogue and a simple deployment sequence, because no inflation control system is implemented on any parachute. The drawback is the presence of two drogue parachutes, with the consequent impacts in terms of mass and volume of the DS.

Architecture comparison and selection

The preliminary selection of the descent system has been based on high level criteria such as the minimization of the development cost and time, the minimization of the risk of failures, the minimization of mass and volume for the subsystem.

The following table summarizes the main features of the analyzed architectures:

Table 2 Descent Systems Summary

DS	Drogue Parachutes	Parafoil – 250 m^2	Pro	Cons
1	Conical Ribbon	Mid-span reefing	Large operative envelope. Two stages	It must be developed the reefing of the parafoil
2	Disk Gap Band D=9,6 m (0,3 reefing ratio)	No reefing	Relatively large triggering envelope. Two stages	Drogue reefing development, Smaller operative envelope than DS-1
3	Conical Ribbon	No reefing		No possible operative envelope
4	Disk Gap Band D=9,6 m	No reefing	No reefing on the system, single drogue chute	Very low allowable dynamic pressure at deployment
5	2 Drogues : Conical Ribbon and 9,6 m Disk Gap Band	No reefing	No reefing -> robust solution Large operative envelope	Mass and volume higher than the other solutions (three stages)

The analysis has shown that the solutions number 2 and 3 are not viable either because there is not any operative envelope (DS-3) or because the triggering conditions are very far from the ones required at mission level (DS-4) therefore they are excluded from the candidates for the implementation in the mission.

The solution number one requires the development and qualification of the mid-span reefing. Given the complexity of the system, the effects of a failure and the goal of the minimization of costs and development time, this solution has been discarded.

The DS-2 requires the development of the reefing system of the disk gap band and the verification of the behaviour of the reefed parachute both with proper mathematical models and with tests, however it has the advantage of minimising the number of drogue parachutes with the consequent advantages in terms of mass and volume of the subsystem.

DS-5 has the minimum development effort because all the deployment are non-reefed and the maturity level of all the elements that compose this system is high. This DS has a maximum allowable deployment dynamic pressure higher than the one computed for DS-2 (Figure 7).

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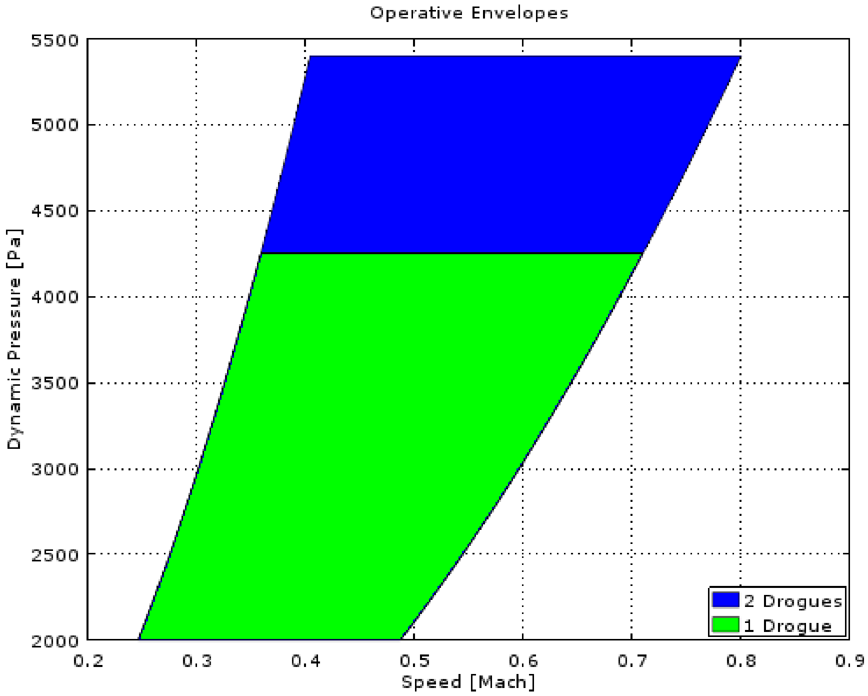

Figure 7 Operative envelope of the DS-2 and DS-5

If at system level it is assessed that the delta mass is acceptable, the most promising architecture is the DS-5, while DS-2 is the second best candidate.

3. Descent System development and verification logic

In order to meet the Program objectives and cost goals, the Space Rider Descent system acquisition process builds on minimization of effort to reach the required applicability for the Space Rider mission. Hence, design relies to adopting solutions from already flown missions as much as possible and limit new development to most critical and peculiar components as the parafoil, including related avionics and GN&C aspects.

3.1 Mortar

As far as the mortar is concerned, the proposed solution is the Exomars component, then in favor of European technology.
The Exomars mortar “as is” is most likely suitable to be exploited, nevertheless if necessary minor delta-design and qualification activity might be performed in order to get fully suitability to the Space rider needs.
One of the objective during the design phase will be to minimize the differences with reference to the EXM Piston Deployment Device in order to require little delta development and qualification at equipment level only.

3.1 Pilot

As far as the pilot itself is concerned, none test are foreseen at equipment level. However some effort is planned at component level as the deployment bag, the canopy, and the set of risers/bridles.
The baseline deployment bag is inherited from ARD vehicle, but given the adoption of a new mortar some development tests will be performed as static extraction test (SET) and dynamic extraction test (DET) are foreseen.
The static test will be performed in quasi-static conditions i.e. the chute will be extracted at very low speed and it will be measured the extraction force and the displacement. The dynamic test will verify the parachute deployment by means of a pressurized gas mortar. In this way it is possible to verify the sequence of the extraction process without using gas generators or the actual mortar. This test is used also to qualify the Piston Capture Element.
The flat ribbon parachutes have been qualified up to Mach 0.8, therefore no delta qualification for the inflation and deployment process of the pilot canopy is foreseen. The parachute has a high margin of safety with reference to the operative conditions; therefore the strength of the parachute will be verified by mean of material tests and analysis.
Riser and Bridles will be sized with conservative safety factor, so that no dedicated strength test is foreseen.

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3.1 Drogues

As far as the drogues are concerned, two different approaches are identified for the Ribbon drogue and the DGB drogue.

Conical ribbon drogue

The ribbon drogue derives from the one used in ARD, which was deployed in subsonic conditions at Mach 0.8. It is planned to make minor or no modifications on the canopy and on the lines, whereas it will be necessary to adapt the riser and the bridles for this mission.

Analyses and tensile tests will be performed and the qualification will take place at equipment level.

Dynamic extraction test will be carried out in order to verify the structural integrity of both parachute and deployment bag during drogue extraction in flight representative conditions. That can be carried out via a low altitude drop test with a light payload of about 500 kg (dart like shape) from an altitude of 1500 m.

Given the different volume, the deployment bag shall be re-designed. Prior to the qualification, it will be performed the static extraction test to assess the necessary force to extract the parachute.

Since the riser and bridles will have to be redesigned, they will be tested with the maximum load before the equipment test.

An OTS separation nut from Pyro Alliance (mod. ME027) for the drogue parachute release will be used therefore no delta qualification proposed at sub-assembly level.

Since the attachment points will be a new design, it shall be made a dedicated test campaign to verify that they withstand the whole inflation load.

Disk-gap-band drogue

The DGB parachute derives from the ones manufactured for the Exomars program, the main differences being the diameter, and the dynamic pressure at deployment. Similar canopies have been used in space mission both at subsonic and supersonic speed, but a delta qualification for this canopy is required.

The verification philosophy for the other aspects of the parachute is the same of the Conical Ribbon: it will be performed a dynamic Extraction Test by mean of a Low Altitude Drop Test, the static extraction test will verify the extraction forces and sequence in quasi static conditions, and tensile and material tests will be performed.

The riser and bridles will be tested with the maximum load, the separation nut will undergo no delta qualification, whereas the attachment points will be tested with a dedicated campaign.

If the reefing system is implemented, it will be necessary a proper qualification campaign in flight representative conditions.

3.1 Parafoil and related Avionics

As far as the parafoil is concerned, the candidate solution derives from the one developed in the frame of the Precision Air-delivery System project appointed by Aero Sekur in the frame of a program funded by the Italian Air Force. The PAS heritage will be widely exploited both for the parafoil sail and the relevant avionics (including GN&C).

The Parafoil sub-system being the most critical sub-assy of the Descent System then a significant effort will be put in place for its development both at design and experimental levels.

Appropriate design choices have been identified for the peculiar wing aspects as airfoil geometry, wing span and wing load. Structural design relies also to conservative safety factors.

Virtual simulation of the mission as well as of the parafoil sub-assy will be developed, based on an appropriate a mathematical model. The model will be fed along the process as long as tests will provide data.

An extensive yet incremental test logic is planned for the verification and qualification, ranging from static to dynamic tests, ground-level to flight-level tests, small-scale to full scale tests.

Among those tests there will be mechanical characterization of canopy and fixtures, tensile static and dynamic extraction tests, packing and deployment tests, drop tests with incremental payload mass from 500kg to a 2500kg at representative flight conditions in terms of dynamic pressure and g-loads.

Small scale sailing tests will mainly contribute to development of Parafoil GN&C design. Proper scaling factors will be applied to the sail and to the actuators. With this test it will be verified the mathematical model of the sail, the maneuvers and the strategy of the control system to achieve a precision landing.

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Medium Scale Sailing tests will be performed with a vehicle with the 30%-50% of the mass of Space Rider with the aim to validate and to refine the mathematical model used in the design phase.
These test will also validate sizing of the actuators (winches).

Full Size Sailing Tests will validate and qualify the whole Parafoil sub-system.

In terms of hardware, COTS devices will be identified in order to minimize the delta qualification required, especially for the winches and related power electronics. The assembly motor+gear+pulley will undergo all the necessary environment tests.

3.1 System-level Drop Test

For a challenging endeavor as the Space Rider mission, in order to mitigate the risk and to get a robust approach against uncertainties the Descent phase verification and validation passes through the execution of a System-level Drop Test.
With this respect, the Descent system will be an integral and crucial part of this approach and from the Descent system perspective the following objectives can be met by the drop test:

- Verify and demonstrate the integrated functioning of the Descent System with the vehicle and with other systems during the descent and landing (e.g.: Landing System, GN&C, and Mechanisms).
- Demonstrate ability of the Descent System to allow the vehicle to perform an autonomous flight from parachute triggering down to landing.
- Demonstrate an overall integrated Parafoil GN&C software and avionics system in representative flight conditions.
- Demonstrate and characterize the ability to achieve a precision landing (accuracy) by the PGNC

For the system-level drop test a full flight-model version of the Descent system will be most likely adopted.

4. Conclusions

In the frame of the development of ESA’s Space Rider, the new European space transportation system, the conceptual design of the Descent Subsystem has been performed, laying the basis for the following development work of next design phases.
The paper has illustrated the Phase A technical work carried out with respect to definition and design of the Descent Subsystem. In particular, the work performed in the phase A of the program has identified the most promising baselines for the descent system of Space Rider and it has highlighted the most critical areas of the project. In the phase B-1 of the project the phase concept will be consolidated and the choice of the baseline architecture (DS-2 vs DS-5) will be finally appointed by refining the analysis and by assessing the consequences of the choice of one system or the other at system level. More complex simulation will be carried and the elements that compose the system will be defined in order to reach a sufficient definition level for the System Requirement Review.

Acronyms

ARD	Atmospheric Re-entry Demonstrator
ARS	Advanced Recovery System for Advanced Launch Vehicles
AVUM	Attitude and Vernier Upper Module
CD	Drag Coefficient
CL	Lift Coefficient
DET	Dynamic Extraction Test
DGB	Disk Gap Band
DoD	Department of Defence
DS	Descent System
FPA	Flight Path Angle
GPADS	Guided Precision Aerial Delivery Systems
EXM	Exomars
GN&C	Guidance, Navigation & Control

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MVM	Mission and Vehicle Manager
OTS	Off the shelf
PAS	Precision Airdrop System
SET	Static Extraction Test
SR	Space Rider

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