Beyond current EDL Technologies on Mars: Evaluation of ARMADA Concepts

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ABSTRACT

The Entry, Descent and Landing System (EDLS) is one of the main system drivers for an interplanetary mission aiming at landing a payload on a planetary surface. It contains three main subsystems with distinct functions designed for the Entry, the Descent and the Landing phases. Each of these subsystems has specific constraints.
The first objective of the EDLS is to land safely a payload with a given mass and geometry onto the planetary's surface. Toward that end, the EDLS must decelerate the Descent Module from interplanetary velocities (about a few km/s) to typically less than a few tens of m/s and land the payload within close proximity of the pre-defined landing site (ideally a few hundreds of meters).
In the frame of an ESA's GSP study, GMV, in collaboration with the University of Bologna and EADS-Astrium, is carrying out a project whose main objective is to assess the feasibility of using an autorotation system, named ARMADA, as a component of the entry, descent and landing system. Even though Mars is assumed as the main planetary target, a preliminary assessment for landing on Venus or Titan is also made.
ARMADA replaces all deceleration systems for the DM (parachutes, airbags, and retrorockets) except for the heat shield. In consequence, the Entry, Descent and Landing scenarios used for past missions cannot be applied to ARMADA directly, but have to serve as a starting point for deriving a mission scenario suitable for an autorotation landing. For the scope of this project the ARMADA reference scenario is primarily based on an Exomars scenario.
Eventually, the study aims at assessing the performance of the ARMADA concept with respect to flight proven, traditional EDL systems. To that end, a set of criteria relevant to the EDLS performance has been derived.
A systematic survey/identification of potential ARMADA concepts has been carried out during the first phases of the project and this survey is presented here. This identification has been followed by an assessment of the suitability of each concept for the reference scenario and a trade-off analysis that concluded with a proposal on the best-estimated concept and a backup option.
This paper intends to offer an overview of the steps performed up to now and the obtained results.

INTRODUCTION

The main objective of the ARMADA study is to assess the feasibility of using an autorotation system as a component of the entry, descent and landing system of a spacecraft landing on Mars, while also making a preliminary assessment for landing on other planetary bodies with an atmosphere, such as Venus or Titan. The achievement of the main objectives depends on the fulfilment of the secondary objectives stated below:

1. Planetary EDL problem characterization and systems requirements definition
2. ARMADA system concepts trade-off and system modelling
3. Construction of an autorotation Performance Database (PD)
4. Construction of an Integrated Parametric Design Tool (IPDT) for autorotation landing systems
5. Comparison of the autorotation landing system with other types of EDL systems
6. Detailed investigation and proof-of-concept of the deployable rotor system

This paper is mainly focused on the first steps of the study, addressing the ARMADA system concepts based on qualitative high-level requirements. The concepts are generated based on functionalities to be covered by an autorotation based EDL system, and the selection of the concept elements is made by means of a trade-off where applicable. The results of this trade-off are then presented. The impact of different planetary atmospheres on the selection of suitable concepts is also addressed. Then, two concepts are synthesised from the most promising elements: one as reference for the rest of present study, and other will be kept as the backup option. These concepts are described in detail. A number of secondary back-up concepts are presented, without going into details. Finally, an outline of the present and future activities developed in the frame of the ARMADA study is presented.

Planetary EDL problem characterization

The fundamental need of a mission involving a landing on another planet is a significant deceleration. The lander needs to be slowed down from interplanetary cruise velocities (about several thousands m/s) to a few m/s over several tens km in altitude. Huge deceleration is thus needed to cancel out the original velocity while counteracting the acceleration induced by the gravitational field of the planet. All the while the spacecraft integrity must be insured. The lander must not be destroyed and be able to perform its mission during trajectory and after touchdown.
The total cost to develop a mission is extremely high. Therefore, all the systems must be tested and their correct functionality must be probed, so the potential risk of failure is minimized. In terms of production, this is achieved through the qualification, obtained through a large set of experimentations on the expected conditions at the arrival of the planet. The costs associated with those experimentations were afforded without limitations during the space race. They derived in the three main components of the Viking technology: the supersonic Disc-Gap Band (DGB) parachute, the 70 deg sphere-cone aeroshell with the SLA-561V ablative TPS, and the use of throttleable propulsive descent system (see **Error! Not a valid link.**). The rest of the past and some of the preview planetary mission to this planet, or others (Titan), have relied in those technologies with small or slight modifications.
Recently, interplanetary missions have become very demanding in landing specifications, with landed masses up to 1600 kg for Mars Science Laboratory. Such an increase in mass requires improvement of the EDL system in terms of braking and thermal protection (heat load and peak heat rate increase as mass does). Landing site locations are also chosen at higher altitude, which reduces the available path needed to slow down the spacecraft and diminish the drag effect. Finally, there is a strong need for hazard avoidance and pinpoint landing capability. It is clear, then, that substantial changes to current Mars EDL technologies must be studied, developed and tested in order to achieve a significant breakthrough in planetary exploration systems.

Autorotation

Autorotation is a condition of descending flight where the rotors blades are driven by the aerodynamic forces of the airflow through the rotor. It is a normal safety procedure after a partial or total engine failure, especially for single engine helicopter. In autorotation regime, the rotor acts as a windmill and the lift generated is used for slowing down the descent to a safe rate, compatible with the helicopter structures resistance and on board personnel safety. Moreover, it also generates forces necessary to control the landing position so to avoid possible obstacles. Examples of autorotation can be found in nature, with anemochory or biological dispersal of seeds and spores or with toys for children like the “Chinese top”. Autorotation is also used in high-drag bombs as an air brake. This last example is quite similar to the ARMADA concept, because folded blades are deployed to form a rotor for slowing down the bomb rate of descent.

Autorotation EDL State-of-Art

Most significant past, current, and future projects for planetary EDL using the autorotation concept or other advanced landing technologies are **Error! Not a valid link.**, **Error! Not a valid link.** and **Error! Not a valid link.**. In addition to the cited efforts in the field of parafoil technology, as a potential land-landing system for reusable space vehicles, within the AURORA program ESA has undertaken an alternative descent/landing technologies (ADTL) activity **Error! Not a valid link.** aimed at modelling the entire descent and landing phase of a planetary probe. NASA has been studying the possibility of an EDL system based on the autorotation concept since the sixties and seventies. A theoretical investigation **Error! Not a valid link.** was followed by comprehensive experimental tests in subsonic **Error! Not a valid link.**, transonic **Error! Not a valid link.** and supersonic **Error! Not a valid link.** regime. Other studies **Error! Not a valid link.** investigate the possibility to perform an autorotation descent on Venus, due to the thick atmosphere, which seems to guarantee an effective deceleration of an entry capsule. One of the main advantages of rotary wing atmospheric decelerators seems to be their ability to control their descent rate. If three or more rotors are present, the capability to control the descent angle can also be achieved. For a soft landing on the planetary surface, the decelerators must incorporate rotor collective pitch-angle control to perform the flare manoeuvre (decelerating to almost zero vertical velocity). More recently, an Earth crew entry vehicle was studied in detail during an informal study undertaken on personal initiative by **Error! Not a valid link.**. Most of the rotor blade deployment mechanisms developed in the course of this study seems to be perfectly applicable to the ARMADA concept.

REFERENCE SCENARIO AND PERFORMANCE CRITERIA

Reference Scenario Definition

ARMADA being designed primarily to land on Mars, the following analysis is done with respect to typical Martian scenario such as Exomars **Error! Not a valid link.**, MSR **Error! Not a valid link.** or those from US missions **Error! Not a valid link.**. It will then be modified to cope with the characteristics of Titan and Venus. Provided that Mars has the smallest density **Error! Not a valid link.**, it is considered as the critical case. Indeed, small density implies weak aerodynamic effects on blades and thus small lift force for potential deceleration. Therefore, the approach consists in defining the reference scenario for a Martian landing. The ARMADA reference scenario is primarily based on an Exomars scenario as investigated in **Error! Not a valid link.**. This choice has been motivated by several reasons:

- Similarly to ARMADA requirements by ESA, the scenario was indeed developed to land the payload at an altitude up to 2km MOLA with a vertical velocity between 10 and 20 m/s for a payload between 20-200kg.
- The aeroshell investigated was a 70° Viking-shaped aeroshell, the shape in which ARMADA is also based.
- Retro-rockets are used during landing to perform manoeuvres. Similarly, the autorotation system of ARMADA will provide lift and lateral manoeuvring capability.

The main difference lies in the descent and landing phase where the rotor is actually used in lieu of parachutes, rockets and airbags. Provided the rotor capabilities are not as well known, as these of parachutes, airbags or retrorockets, iterations on the reference scenario will be necessary throughout the study.

Performance criteria

The ARMADA EDLS performances need be assessed in light of competitive technologies, namely EDL systems made up of stabilizing drogues and chutes (such as DGB), airbags or retrorockets. A large amount of data is provided by studies of future ESA missions (Exomars, MSR) and previous US missions (Viking, MPF, MERs, future Phoenix). This data come either from high-fidelity simulations or post flight data. Therefore, these data will be less affected by model inaccuracies when compared to data resulting from the ARMADA systems models (PD, IPDT). The comparison of performance will therefore be on an order of magnitude basis.
These criteria of performances parameters are common to any EDL systems:

- Altitude at landing: The ideal altitude is 2 km MOLA whereas US missions have landed to altitude be-tween -4 km and -1.9 km. Exomars and MSR will also not reach the 2 km altitude. Varying conditions at entry may prevent the ARMADA DM to reach the 2 km altitude as well.
- Payload fraction: This is probably the main criterion of performance for any EDL system. The landed/entry mass ratio is between 54 and 66% as far as past US missions are concerned, **Error! Not a valid link.**.
- Retargeting capacity: It is an important parameter to consider and is usually given in terms of lateral range capacity for a given altitude.
- Landing accuracy: With the payload mass, this is the primary performance of any EDL system. Future missions will be more and more demanding in terms of landing accuracy (precision landing). Landed ellipses of US missions (3s) are well known, ranging from 280×100 km to 80×12 km, **Error! Not a valid link.**.

AUTOROTATION SYSTEMS CONCEPTS ASSESMENT

The autorotation system needs to be stowable, and the stowed configuration needs to fit within a typical EDL package with an aeroshell and heatshield, without intruding into a representative payload envelope. The autorotation system concept assessment is done based on functional breakdown of the ARMADA system: layout, deployment mechanism and control landing.
For each of those components, several alternatives are presented and evaluated. The system components are first presented individually, and a concept synthesis is presented later on.

Layout concepts trade-off

This classification attends mainly to the number of rotors of the concept selected. Here a distinction is made between the single, dual and multiple rotors possible configurations together with their main characteristics (see Fig. 1).

- For the single rotor configuration there are only two options The one with the rotor at the top: this configuration is the design concept used in most studies, most notably the studies conducted during the Apollo program **Error! Not a valid link.**, **Error! Not a valid link.**, **Error! Not a valid link.**, **Error! Not a valid link.**, and the study performed by Jeff Hagen **Error! Not a valid link.**. And another one with the rotor at the bottom: this is comparable to the rotornet hypersonic decelerator **Error! Not a valid link.**. The rotornet is implemented as a flexible, filamentous net that is wound around the rotor hub. The single bottom rotor features a rotating ring and a support ring mounted at the broadest part of the lander body, approximately at the interface plane between the back shell and the heat shield.
- The next concept involves two rotors. The strategy to mount both rotors leads to different possible configurations. In the side-by-side configuration, the rotors are mounted over auxiliary elongated structures that avoid the contact between the rotors. The number of rotors can be also extended to three, increasing the controllability, but also the complexity and the mass. Studies for powered, extra-terrestrial vertical lift vehicles often use this layout **Error! Not a valid link.**, **Error! Not a valid link.**, **Error! Not a valid link.**. The counter-rotation coaxial rotors offer the advantage that the torque generated by the powered rotors ideally cancels each other out. The coaxial counter-rotating dual rotor is a design used as an alternative to a tail rotor for torque balancing. Finally, the third dual rotor configuration, the synchropter, is a rotor system where the circles traced by the rotor blades intersect, hence they mesh like the gears in a transmission system.
- Finally the multiple rotors configurations are ideally similar to dual rotors, extending its advantages and disadvantages. The top view in the schematic to the right shows four rotors. This configuration uses small rotors with single-piece blades. This concept has been explored in the study of an autorotation system for descending into the atmosphere of Venus **Error! Not a valid link.**.

The most important criteria for the layout trade-off are considered to be the mechanical complexity and reliability, and the stability. Next in importance are mass, stowage space and controllability. Finally the rotor area is considered least important in this trade-off, since it will be addressed more by the deployment system.

In this sense, the top rotor concept ranks the best position, after detailed analyses, since it is mechanically the simplest solution, so this concept is least massive, while it is also closest to traditional helicopter designs, making it the most reliable concept. The top rotor is the layout type that has been studied most extensively. It is the most promising layout concept in terms of complexity, stability, rotor area and other criteria. The bottom rotor is retained as a basis for a secondary concept. It will be somewhat heavier, since the rotor is mounted on a ring structure instead of a central hub.

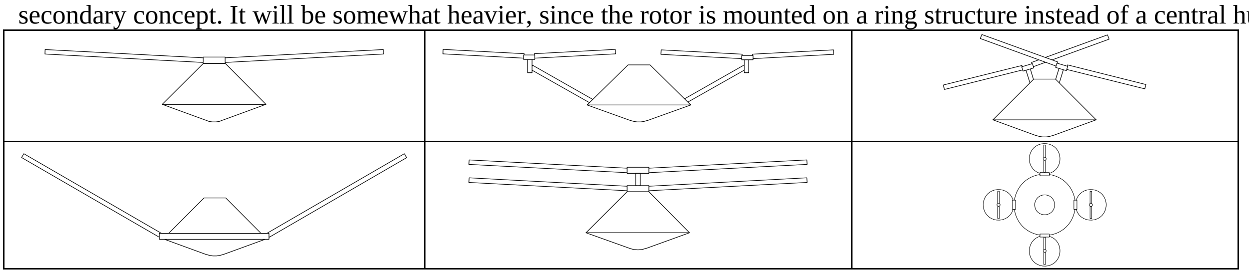

Fig. 1: Rotor configurations layout. Single rotor at the top (up-left), single rotor at the bottom (down-left), dual rotor side-by-side (up-centre), coaxial-counter-rotating rotors (down-centre), synchropter (up-right), and multiple rotor(down-right).

Rotor deployment trade-off

Deployment mechanisms are one of the most critical areas when there is the need to identify the system's overall reliability. As a matter of fact, for extremely simplified space systems (low-cost, low-weight) a high level of reliability is usually identified with the concept of "no moving parts". This is why, for critical deployment mechanisms associated, for example, to manned mission, the highest level of redundancy must be guaranteed.

Deployment concepts for aerodynamic decelerators are listed in **Error! Not a valid link.**, while **Error! Not a valid link.**, **Error! Not a valid link.** and **Error! Not a valid link.** discuss a number of these options in greater detail. Different types of rotor blades deployment systems can be envisaged in order to achieve blade deployment during a Martian atmosphere EDL. The basic types of blades rotor deployment systems are presented in Fig. 2 and listed below:

- Single-piece: Single piece blade rotors are by necessity relatively small. Designs to date of entry, descent and landing systems incorporating a rotor system (such as the ROTON **Error! Not a valid link.** and early Apollo studies **Error! Not a valid link.**, **Error! Not a valid link.**, **Error! Not a valid link.** and **Error! Not a valid link.**) all use single-piece blades.

- Telescopic: The telescoping blade rotor consists of multiple sections (up to 3-4), and each section is capable of sliding into the next section, like the antenna of a car. The telescopic blade rotor has been proposed in a study for the autorotation landing system of a crewed transportation vehicle **Error! Not a valid link.**.
- Inflatable: The rotor is composed of a gas-pressurized coated fabric, which can be rolled up for stowage. The deployment mechanisms consist mainly of a pressurized gas tank, piping and valves. Parafoil-type parachutes obtain and maintain their shape by means of ram-air compression.
- Foldable: A foldable blade rotor consists of one or more blade sections joined together by means of hinges. Most current studies of Martian aircraft envisage foldable wings in their design. The NASA AME deployment studies **Error! Not a valid link.** showed many minor failures that prevented full deployment of the wings. The ARES **Error! Not a valid link.** is a successful example of spring loaded deployable wings.
- Flexible: The rotor is made out of a flexible material that can be folded or rolled up. The structure is stabilised by means of reefing lines, extendable stiffeners, and / or centrifugal forces (by means of a mass placed at the tip) or dynamic pressure and strings in the deployed configuration. Flexible wings are used mostly for hang gliding and paragliding. Flexible rotating aerodynamic decelerators made out of fabric have been studied in the past, in the form of the Rotornet **Error! Not a valid link.**, **Error! Not a valid link.**, **Error! Not a valid link.** and the Rotochute (see **Error! Not a valid link.**)
- Scissor extension: A scissor extension consists of folding, linked bars arranged in a stacked 'X' pattern. The deployment can be controlled by means of the contracting segment closest to the body, or by means of a cable running the length of the scissor extension. This mechanism requires some form of flexible skin covering.
- Mixed systems: Combinations of the deployment mechanisms can be considered. Pairs of opposite blades can have a different deployment mechanism, or individual blades can be composed of sections that are deployed in a different way. Alternatively, a secondary deployment system can be used to modify the shape of the blade for the purpose of reefing.

The deployment trade-off criteria considered to be most important are the stowage space required, the ability to store kinetic energy and the reefing capability inherent to the deployment mechanism. The mechanical complexity, technological maturity and stability during deployment have, in second place, all the same weight. The last criterion is the mass of the deployment system. According to this, the most promising concept is a telescopic blade rotor. Any deployment system that can modify the blade length in-flight is highly desirable, since this allows an easy method of reefing. In this sense, all deployment mechanisms, which can support this feature, have a distinct advantage over those systems that do not. The runner-up would be a combination of flexible and/or inflatable blades with a form of stiffening (functionally similar). Both technologies have been already the subject of earlier studies on autorotation EDL systems: **Error! Not a valid link.**, **Error! Not a valid link.** and **Error! Not a valid link.**.

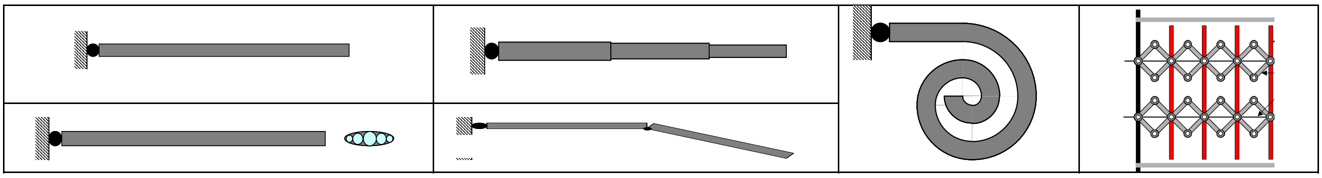

Fig. 2: Rotor deployment systems

Lander control concepts trade-off

The variables to be controlled, in order to achieve a successful and accurate landing, are the lander attitude, descent rate, horizontal velocity, rotor angular momentum & angular velocity.

The control concepts will be treated in a different way from the layout and deployment concepts. The control systems that will be required depend mainly on the dynamical behaviour of the autorotation lander, that is, on the eigenmodes and the eigenfrequencies. A number of concepts will be discarded based on the discussion of their practicality, but the ultimate decision needs to rely on a study of the characteristics of the dynamical system that to be controlled.

Below are listed the different lander control options that are available. The control concepts are divided in two groups according to the ARMADA system breakdown:

- Lander body control concepts: Centre-of-mass shifting, aerodynamic surfaces, vertical rotor or ducted fan, spinning body, reacting wheels, control jets.
- Rotor: Collective and cyclic pitch control, tip rockets, blade morphing, blade aerodynamic flaps, blade length reefing, blade coning angle reefing, rotor spin-up/down, differential braking of rotors.

A number of the control options mentioned in this section are either intrinsically linked or especially well-suited to specific deployment system or layout concepts. The control system should not incorporate additional high-mass control systems such as reaction wheels, if such systems are not already present in the design. This means that control options that use or modify the properties of the rotor or the mass distribution of the lander are preferable to other control options that rely on additional systems.

AUTOROTATION SYSTEM CONCEPT SYNTHESIS

The results of the layout trade-off suggest that the most promising concept is the top rotor, followed by the bottom rotor. The deployment system trade-off suggests that a deployment system that allows reefing of the blade length is highly preferred. In this sense, the telescopic blade solution seems most promising, while at the same time it can serve as a model for other deployment systems that feature an extending blade. An internal preliminary sizing of the ARMADA system reveals that relative high rotor to capsule ratios are required in order to accomplish the reference scenario constrains. From this point of view there are two options: either the problem is approached by means of currently feasible technology, or current trends in technology are extrapolated to a level applicable to the autorotation lander. The approach selected for this study is the first one. As a result, the rotor size will be limited to a maximum of 4 sections, and other additional systems (such as tip rockets or a flywheel) will be incorporated to ensure a safe landing. This approach is in line with the requirement to test the deployment and reefing mechanisms in a windtunnel.
From the results of the layout, deployment and control concepts, clearly two main concepts can be generated:

- Top rotor with telescopic blades and cyclic pitch for lateral and longitudinal control.
- Bottom rotor with telescopic blades and c.g. shifting for lateral and longitudinal control.

Further back-up concepts are flexible skin and telescopic spars, bottom rotor with single-piece blades and tip rocket and inflatable or flexible blades with tip rockets.

Top Rotor With Telescopic Blades

Fig. 3 shows the top-rotor concept in stowed configuration. Rotor blade pitch, rotor tilt control and flapping / lead-lag motion-damping systems are located at the top of the rotor, and the blades are stowed by folding them down. The blades themselves consist of three telescopic sections. The back shell of the lander forms an obstacle to the deployment of the rotor and the body flaps. Therefore, at least a second deployment mechanism is required to eject the protections that cover the blades and the flaps.
The attitude of the lander during deployment is controlled by means of the body flaps and by differential control of the individual blade deployment. In the supersonic regime, the lander could remain in a partially deployed configuration, where the rotor is still stationary, and the blades and body flaps function as supersonic air brakes.
In the following we show a possible deployment mechanism approach for the top rotor system concept

1. To safely keep the blades in the retracted position during the early entry phase, mechanical blocks can be used instead of magnetic or pyrotechnical devices. Blocks will be disengaged before the Mars entry phase starts. After blocks disengaging, the blades will be controlled by cables, which are needed to reduce tilt loads. Motors will be placed under the rotor plate, on top of the entry vehicle, and a pulley system will be used to reduce the motor load as well as overall dimensions and absorbed power. Before the blade deployment sequence is started, the cable must be preloaded to maintain the blades in a fully closed position.
2. To protect blades during the deployment phase, aerodynamic flaps shall be extended. Flaps will be also used them for the entry vehicle spin rate control during descent. Flaps will be retracted after complete deployment of rotor blades to reduce the aerodynamic interference. Mechanical rotor brake will be engaged to prevent the rotor from spinning.
3. After flaps deployment, the stepper motor will remove the cable preload. The deployment is either initiated by means of either centrifugal force (residual spin remaining from the initial spin-up for lander stabilisation), or by means of springs. Aerodynamic drag provides the force required to continue the deployment.
4. During release, the blades will be rotated in “feather position” in order to obtain minimum drag resistance. Once blades will be exposed to the aerodynamic field, cable load will in-crease proportionally to blade deployment angle and the stepper motors will be used to reduce tilt loads.
5. Cap ejection: The blade will be placed, by means of the control cables to a “ready to spin” position. Cables ejection by igniting pyrotechnical devices and rotor brake disengaging. A slow pitch-up command will be applied to the blades in order to start the supersonic autorotation.
6. After a spin-up transient phase, equilibrium will be reached between the aerodynamic and inertia forces and the vertical velocity will be rapidly decreased down to subsonic regime. Flaps will be closed to reduce aerodynamic perturbations.
7. When the aerodynamic field surrounding the main entry capsule will be completely subsonic, telescopic blades will be extended.

Bottom Rotor With Telescopic Blades

The bottom rotor concept is inspired by the study of the Rotornet described in **Error! Not a valid link.**. Fig. 3 (right) shows the stowed configuration of the bottom rotor layout concept. The functional elements are highly similar to the elements of the top rotor concept, but their arrangement is different. The rotor consists of the blades and a rotating ring, which is mounted onto a rotor support ring. The connection between the rotor and the rotor support ring features bearings and structural support. The rotor support ring is connected to the lander body by means of a Stewart platform that can be lowered during deployment, and actuated during the descent phase to control the flight. The deployment control mechanism is located on the rotor support ring. Contrary to the top rotor concept, the deployment control mechanism needs to actively deploy the blades, since aerodynamic forces will likely oppose the deployment. Body flaps are mounted to the lander body by means of struts; the flaps and the blades are staggered with respect to each other.

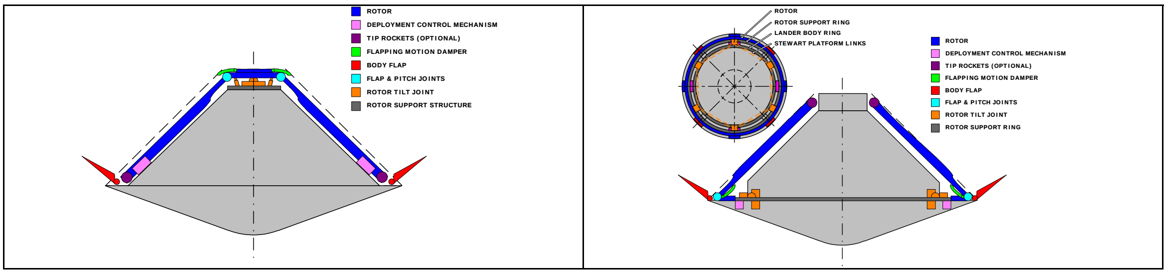

Fig. 3: Top (left) and bottom (right) rotor concepts layout

ASSESMENT OF CONCEPT FEASIBILITY

The concepts identified in the previous section are compared qualitatively and where possible quantitatively (using the performance requirements as a benchmark). From these high-level performance criteria, some system parameters for the autorotation system can be derived: rotor area (altitude at landing), low-mass autorotation system with a small-stowed volume (payload fraction), controllability and stability ('retargeting capacity' and 'landing accuracy'). The criteria place requirements on the control system. These criteria are added to the requirements of the previous trade-off. Technology maturity is the trade criteria with the highest confidence (i.e., the criteria which can be assessed more adequately at a high level). The technology maturity is intrinsically related with the system cost and reliability. This is followed by the mass and manoeuvrability & controllability criteria, which can reasonably be compared qualitatively, and which are important for the high-level parameters. The technologies required by both concepts fall within the B/C and D categories According to ECSS-E-10-03A **Error! Not a valid link.**. However the Top Rotor concept makes use of technologies much closer to traditional systems used in the field of aeronautics, from where it could benefit to lower the needs for technological innovation (developing, testing and qualifying) compared to the Bottom Rotor concept. Moreover, its reliability is also affected given the stronger dependence of the Bottom Rotor concept on power to operate correctly. Besides, the proximity of the pressure centre to the gravity centre is a source of instability in the system. The Stewart platform and additional deployment and stability-aids mechanisms, as well as the potential increase in overall lander size to accommodate the payload, make it in the end considerable heavier. Summarizing, the Bottom Rotor concept performs worse than the Top Rotor in terms of size, complexity and technological innovation. This makes the Top Rotor concept less costly and more reliable, and hence the one retained as basis concept for subsequent analyses.

ONGOING AND FUTURE ACTIVITIES

- Performance database – IPDT: The construction of a PD and an IPDT will aid in evaluating the performance of an autorotation system, and in establishing an envelope within which an autorotation system is expected to function. The PD will characterize the conditions under which autorotation occurs, and identify the required dimensions and operational characteristics of a rotor (such as the angular velocity) for sufficiently decelerating a lander of a given mass. Furthermore, the PD will assess the stability and controllability of autorotative flight during the descent and landing for the specific system configurations that are achievable within the most promising concept selected.
- CFD simulations are required to provide additional information about the aerodynamic properties of the autorotation system under Martian EDL conditions. Attention shall be devoted to the simulation of autorotation in supersonic regime, for which the level of confidence of standard rotor analytical tools is not well established.

- Comparison with competitive technologies: Even if the autorotation system is a viable concept, the competitiveness of such a system with other EDL systems needs to be established. It also needs to be practical and effective with respect to other EDL techniques if it is to be considered feasible in a practical sense. To establish the competitiveness of the autorotation system, a performance comparison with other EDL techniques needs to be performed. Since the results from high-fidelity simulations (for competitive EDL technologies) as well as post-processed results from actual missions are believed to be less affected by model inaccuracies than an IPDT-based ARMADA performance evaluation., the comparison shall be based preferably on order of magnitude considerations rather than exact values.
- Wind tunnel deployment systems demonstrator: As remarked, the deployment mechanism is a critical technical aspect of the autorotation system. The requirement that the rotor system be deployable sets a definite limit on the attainable rotor size, since any structure that incorporates (deployment) joints is inherently weaker structurally than a comparable structure without such joints. Additionally, the "moving parts" category of the deployment mechanisms has a direct impact on the system reliability level. Demonstrating the deployment of a rotor of sufficient size and strength to provide adequate deceleration during the descent and landing, as well as stability and controllability is a major step towards the validation of the autorotation landing system concept. These tests will be carried out at the Von Karman and UniBo premises in the supersonic and subsonic regime respectively.

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