THE EARS PROJECT: A NEW CONCEPT FOR A EUROPEAN REUSABLE SMALLSAT PLATFORM

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ABSTRACT

Space exploitation can be made more affordable - and sustainable - by the development of reusable, low-cost spacecraft. In the EARS project, we aim at the development of an affordable and flexible platform that can be re-used and easily produced in large numbers, targeting the low-cost SmallSat market. The EARS spacecraft is conceived to be launched in Low Earth Orbit to support microgravity manufacturing and a variety of small experiments. The spacecraft is planned to de-orbit after several months in orbit, to perform a controlled re-entry and finally to be recovered in order to deliver its products and results back to the Earth. The spacecraft will be also conceived to be re-used with minimal refurbishment for several times, thus minimizing pollution and cost of access to space. In the EARS project, besides identifying the spacecraft overall architecture and concept of operation, we have focussed on the development of the key technologies needed for its implementation, such as: efficient propulsion system, reliable Guidance, Navigation and Control (GNC) for the re-entry phase and heat shield to prevent major damage to the spacecraft during the re-entry phase. The study has been complemented by an analysis to identify the most promising application fields.

1 INTRODUCTION

New Space Economy and its swift growth is posing new challenges in space exploitation: the space sector is quickly changing and this has led to an increasing need for flight opportunities to be exploited both not only for scientific but also for commercial applications. On one hand, this implies a wider choice of opportunities to both the public and private sectors as well as benefits to the society at large; on the other, this is raising several concerns about resource exploitation and the need to move forwards a more sustainable and greener exploitation of the outer space. In this context, the development of reusable, low-cost spacecraft can provide an interesting means of promoting a more affordable - and sustainable – exploitation.

In the EARS project, we want to introduce the disruptive concept of ‘re-usability’ in the small satellite segment for a greener and sustainable Europe. The project’s main objective, actually, is the development of an affordable, flexible spacecraft that can be re-used and easily produced in large numbers, targeting the low-cost segment of the SmallSat market in order to match the increasing need for affordable flight opportunities. Main target applications can range from in-space manufacturing to In-Orbit Demonstration and Validation (IOD/IOV) activities, small scientific experiments and educational programmes.

The EARS spacecraft is conceived to be launched in Low Earth Orbit. The spacecraft is planned to de-orbit after several months in orbit, to perform a controlled re-entry and finally to be recovered in order to deliver the payload with its products and results back to the Earth. The spacecraft has also been conceived to be re-used with minimal refurbishment for several times, thus minimizing pollution and cost of access to space. The main goal of the EARS project is thus the preliminary design of a small reusable spacecraft and the development of the relevant key technologies, specifically: a green and efficient propulsion system, a heat-shield able to withstand the atmosphere re-entry and a reliable and precise Guidance, Navigation and Control (GNC) solutions for the control of the de-orbit, re-entry, descent and recovery phase of the spacecraft.

In this paper, we present the preliminary overall architecture of the EARS spacecraft, the main technical solutions identified for the key technologies enabling its implementation and the devised concept of operation. Finally, we introduce the main application fields that could benefit from the availability of the EARS spacecraft.

2 EARS SPACECRAFT: OVERALL ARCHITECTURE

The EARS spacecraft concept has been based on an incremental approach, which promoted the selection of a commercial SmallSat platform with flight heritage as a starting baseline, avoiding full capsule or spaceplane configurations. Thus, the approach relied on the selection of a commercial SmallSat platform to be optimised and integrated with an inflatable heat-shield, an efficient propulsion system and a recovery procedure based on a parafoil-catcher solution.

Two different commercial satellite platforms - M16P and MP42, both manufactured by Kongsberg NanoAvionics (KNA) that is also partner of the project - were initially considered as a baseline for this study. Due to a greater degree of flexibility, a better shape and an easier housing of the heat shield protrusion, in the initial phase of the study we identified the MP42 platform as the most suitable baseline for the EARS concept development. In addition, a scale effect is expected by choosing a slightly larger platform, leading to a better performance in terms of payload fraction and relevant costs: while the MP42 platform can accommodate payloads with a maximum mass of 60 kg and a total footprint of 572 mm x 460 mm x 370 mm, the MP16P CubeSat allows for a maximum mass of 10 kg and an available payload volume of 10 U. On the other hand, this has implied to give up the advantages offered by a platform based on the CubeSat standard like the MP16P one.

Figure 1 shows the overall architecture of the EARS spacecraft addressed by the system level studies conducted by the University of Padua. Besides the platform bus derived from the MP42 commercial platform, the main sub-systems consist of the heat shield accommodated at the top of the spacecraft, the payload housing, the deployable solar panels, the deceleration and recovery system (parafoil) and the propulsion system with four thrusters installed at the bottom four corners of the spacecraft.

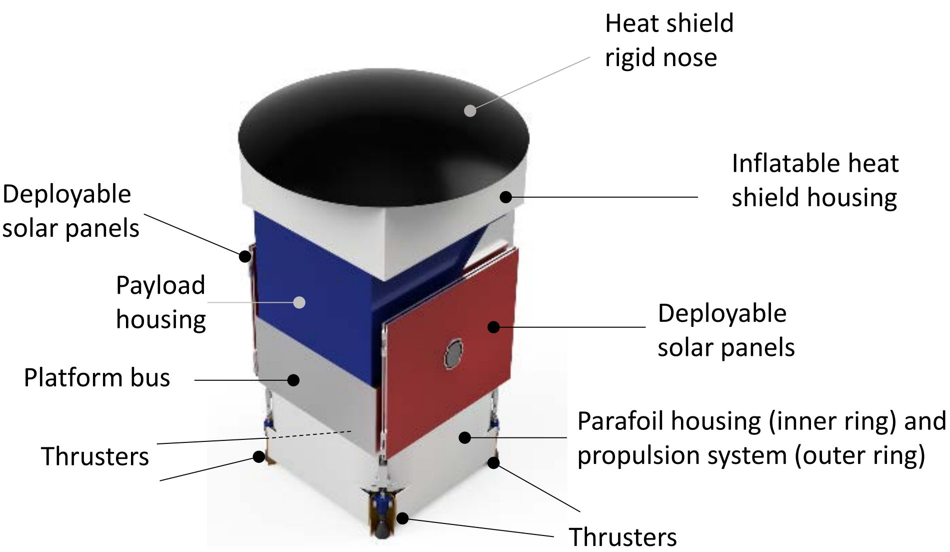

Figure 1. EARS spacecraft overall architecture with its sub-systems.

Based on the preliminary Mission Design performed by Deimos [1], the inflatable technology was chosen as the best solution for the heat shield in the present study. The heat shield is made of two main parts: the rigid nose at the top of the spacecraft and the inflatable thermal protection system accommodated in the relevant housing beneath the rigid nose. According to the literature [2,3], the inflatable thermal protection system can be implemented by means of a multilayer structure made by three different layers: outer layer, insulator layer and gas barrier. The inflatable heat-shield has been designed to support standard launch and in-orbit operation, but also to provide a ballistic re-entry with relatively moderate thermomechanical load. Innovative materials for its construction have already been selected and procured, and they are presently under test at the Von Karman Institute (VKI), who is the partner in charge of heat shield-related studies, relevant material characterisation and tests in a representative condition for Earth atmospheric re-entry by using the VKI Plasmatron [4,5].

As for the propulsion system, the studies conducted by T4i identified a liquid chemical propulsion system as the best option. Actually, it guarantees a higher specific impulse, being more efficient with respect to a cold gas that requires a higher quantity of propellant [6]. In addition, the choice of a liquid system rather than solid or hybrid ones, allows for a better thrust control and also to shut-off and re-start the engine and it is also preferable for safety reasons with respect to the solid one [6]. The liquid chemical system, however, poses additional challenges to meet the EARS requirements in terms of envelope and mass minimisation. In this respect, we opted for the design and construction of an innovative bipropellant thruster that allows for a dramatic reduction of the wet mass. The liquid propulsion system - presently under development and test at T4i laboratories - employs green, no-toxic and low-cost propellant and it is built by using additive manufacturing to reduce production costs. The EARS propulsion module will enjoy several capabilities, such as differential steering and multiple restarts, and will provide in orbit mobility and precise de-orbiting.

Table 1 summarises the main technical specifications of the EARS platform and its main sub-systems.

Table 1. EARS spacecraft: main technical specifications.

EARS main technical specifications	
Baseline platform bus	MP42 platform
Orbit type	Low Earth Orbit, equatorial
Orbit altitude (nominal)	300 km
Mission duration	At least 6 month of payload operation
Communication with the ground station	1x S-band + 1x UHF
Propulsion system type	liquid chemical system
Propulsion system thrust (nominal)	4 thrusters, 10 N each
Heat shield type	Inflatable
Heat shield structure	Rigid nose + inflatable multilayer protection system
Recovery system	Deceleration parafoil + Mid-Air Recovery
Total spacecraft length	< 1.1 m
Average Orbital Power (AOP) generation	170 W
Payload mass	10-20 kg
Total (wet) mass	100-150 kg

The preliminary design of the EARS spacecraft sub-systems allowed to provide a preliminary estimate of the mass budget of each sub-system. Table 2 reports the preliminary mass budget range for the whole spacecraft and its sub-systems (data refers to wet mass).

Table 2. EARS spacecraft: preliminary mass budget.

Item #	**Mass (kg)**
Propulsion	15-20
Recovery	10-15
Heat Shield	15-20
Platform	50-75
Payload	10-20
Total	*100-150*

Presently, the study has achieved an overall (wet) mass budget - with 5% margins - of 142 kg, included a 12-kg payload. The EARS goal overall (wet) mass is 120 kg. Besides further reducing the impact of the mass of the additional sub-systems, the Consortium is presently working on optimisation strategies of the baseline platform bus in order to increase the payload fraction. In this respect, the KNA partner is investigating the feasibility of reducing the mass of the power generation system (solar panels) and of the power storage system (batteries) that seem to be overestimated with respect to the EARS requirements. An overall optimisation of the mechanical structure of the platform, also in synergy with the mechanical structures of the additional sub-systems, can yield a meaningful improvement of the final mass budget of the spacecraft.

3 EARS CONCEPT OF OPERATION

The concept of operation (CONOPS) of the EARS space craft is illustrated in Figure 2: (1) at the end of the orbital mission, just before de-orbiting, the spacecraft is pointed with the back, i.e. the thrusters, in the direction of flight in order to decrease its velocity; (2) once phase 1 is completed, the spacecraft has to be flipped by 180 degrees in order to have the heat shield pointing in the direction of the velocity; (3) the heat-shield is inflated and reaches the re-entry configuration; the heat-shield is dimensioned to protect the forward part of the spacecraft and to cover within its wake the satellite exposed parts; (4) the spacecraft passively re-enter the atmosphere in a ballistic trajectory; (5) the parafoil is released and the EARS spacecraft glides toward a predetermined position; (6) the rescue helicopter recovers the spacecraft by a Mid-air retrieval (MAR) manoeuvre and flies back to the post-flight support facility for payload recovery and subsequent refurbishment of the spacecraft. It is to be noted that MAR has been done successfully for decades, and the small size and mass of the EARS spacecraft make it compatible with the majority of utility helicopters.

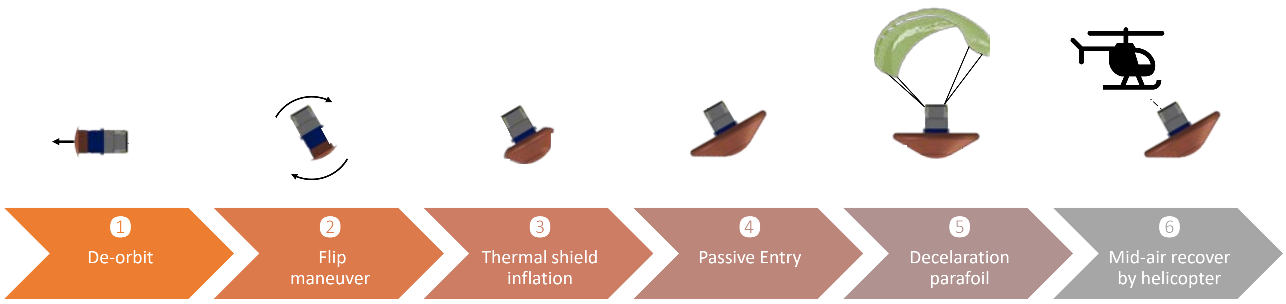

Figure 2. EARS spacecraft: concept of operation for the re-entry mission.

It is to be noted, in fact, that the EARS CONOPS requires a highly reliable and precise GNC system for the control of the de-orbit, re-entry, descent and recovery phase of the spacecraft. The study for the development of a dedicated GNC system has been performed by the Deimos partner. The study has included several activities for the definition of the whole mission profile, from the initial operational orbit to the final descent phase. The study started from a given set of initial conditions in order to perform the de-orbit analysis. The latter was followed by the Local Entry Corridor (LEC) analysis at the so-called Entry Interface Point (EIP), located 120 km above Earth's surface, and providing the feasible flight envelope, that is the region defined in terms of entry flight path angle and ballistic coefficient that can withstand the re-entry loads. Finally, the reference trajectory was identified by selecting the most promising values from the feasible region of the LEC.

The EARS GNC system devised by Deimos contains two GNC sub-systems integrated in two different On-Board Computers (OBC): one controls the attitude and orbital operations prior to the vehicle re-entry (Platform GNC) and the other is responsible of the re-entry (Re-entry GNC). The latter GNC subsystem for the re-entry is in charge of the activities that the vehicle must perform to complete the full re-entry mission (Figure 2). The main objective of the Re-entry GNC solution is to control the trajectory and the attitude of the satellite during the different re-entry phases to allow a safe recovery of the overall system. This includes the attitude manoeuvres and the guided trajectory that the vehicle shall follow to reach the Mid-Air Recovery (MAR) location. In addition, the GNC has to generate the commands for the propulsion system and the activation signals for the deployment of the heat-shield and the parafoil. Further details on the results of the preliminary study of the mission analysis and the dedicated GNS system can be found in [1].

4 FORESIGHT AND EXPLOITATION CHANNELS

The EARS project's activities have included a preliminary analysis of the main future exploitation channels of the EARS spacecraft, with the draft of a business case report and the identification of the most promising application sectors. The first step of the business case study has consisted in the identification of the EARS Unique Selling Points (USP), which can be summarised as follows:

- Recover of the payload for use/inspection/analysis;
- Flexible for use in different tasks, easily produced in large numbers, rapidly deployable;
- Re-use of the spacecraft for different missions, after quick refurbishment;
- Possibility to abort a mission without loss of the payload;
- Capability of precise manoeuvring and landing control;
- Debris mitigation and limited pollution, thus reducing the risk of space exploitation;
- Competitive cost.

It should be underlined again that the EARS spacecraft development will abide by an incremental approach, promoting the increase of the spacecraft capabilities step by step by means of the implementation of upgraded versions. The concept of re-usability itself will be implemented by means of subsequent steps, gaining valuable knowledge each time from past experience and lessons learnt.

Expected main applications of the novel platform include scientific research studies, in-orbit demonstration and validation (IOD/IOV) activities and innovative in-orbit manufacturing like high quality innovative material growth or microbiological studies. The latter can in fact pave the way to new exploitation paths for high value-added sectors, such as: biotech, pharmaceutics and advanced materials.

The main macro-sectors that we have identified as potentially interested in the use of the EARS spacecraft are summarised in Figure 3. Just to mention an example, semiconductors detain a major global market, with sales projected to reach $725 billion by 2025, and research spending expected to reach $90 billion by that time [7]. Space-based research and development (R&D) has the potential to reduce the number of gravity-induced effects on chips, such as contaminants landing on them, which can affect their quality and output. By manufacturing semiconductors in space that allows for a more controlled and precise manufacturing process, companies may be able to improve production and its quality.

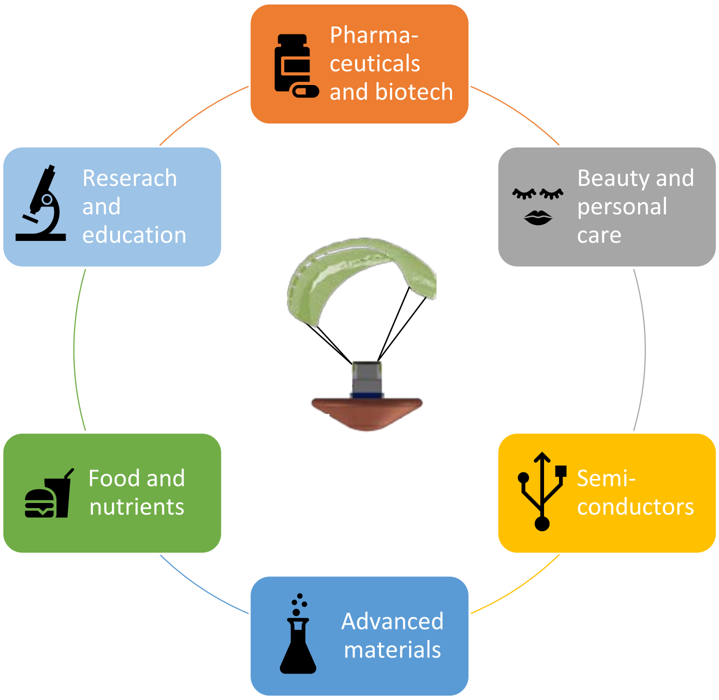

Figure 3. EARS spacecraft: main application sectors.

5 CONCLUSIONS

In this paper, we have presented the preliminary architecture and the concept of operation of a novel, reusable European spacecraft aimed to introduce the disruptive concept of 're-usability' in the small satellite segment for a greener and more sustainable exploitation of the outer space. The EARS spacecraft has been designed to belong to the SmallSat class with a total wet mass less than 150 kg. Its architecture – based on a commercial platform with flight heritage – has been conceived to enable affordable access to microgravity conditions for a wide choice of applications in different scientific and commercial sectors as well as high operational flexibility. The preliminary studies carried out on the mission engineering of the EARS spacecraft, the development of its chemical propulsion system and the studies performed on the heat-shield system design and relevant construction materials have provided very promising outcomes that will be further investigated and developed in the next steps of the project.

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7 REFERENCES

[1] Medici G., Marey Oton R., Gutierrez Briceño J., de Zaiacomo G., *European Advanced Reusable Satellite Mission Engineering*. Proceedings of ASCenSIon Conference, 12-14 September 2023, Dresden, 2023.

[2] Del Corso J., McNeil Cheatwood F., Bruce III W.E., Hughes S.J., and Calomino A.M.. *Advanced high-temperature flexible TPS for inflatable aerodynamic decelerators*, American Institute of Aeronautics and Astronautics, 2011.

[3] Governale G., et al., *Advanced European Re-entry System Based on Inflatable Heat Shields Technology Roadmap and Technical Challenges (EFESTO project)*, IAC Proceedings, 2020.

[4] https://www.vki.ac.be/index.php/research-consulting-mainmenu-107/facilities-other-menu-148/plasma-facilities/71-1200-kw-induction-plasmatron (accessed on 12/04/2024).

[5] A. Cipullo, B. Helber, F. Panerai, O. Chazot, *Investigation of Freestream Plasma Flow Produced by Inductively Coupled Plasma Wind Tunnel*, Journal of Thermophysics and Heat Transfer Vol. 28(3), 381-393, 2014.

[6] *Space Propulsion Analysis and Design*, edited by R. W. Humble, G. N. Henry, and W. J. Larson, Space Technology Series, McGraw-Hill, New York, 1995.

[7] Hirschberg C., Kulish I., Rozenkopf I., and Sodoge T., Mc Kinsey & Company: *The potential of microgravity: How companies across sectors can venture into space*, on line at: https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/the-potential-of-microgravity-how-companies-across-sectors-can-venture-into-space#/ (accessed on 30/04/2023).