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DAVID The First 6U Cubesat Mission of the Italian Space Agency Programme Iperdrone as Demonstration of New On Orbit Services Performed by Space Drones.

Raffaele Votta, Roberto Gardi, Emanuele Zaccagnino
Italian Aerospace Research Center (CIRA), Via Maiorise snc 81043 - Capua (CE) Italy; +390823623202
r.votta@cira.it

Margherita Cardi, Alessia Basler, Filippo Corradino, Giorgio Taiano
Tyvak International Via Orvieto 19 10149 Torino, Italy
+39 011 1911 6070
margherita@tyvak.eu

Fabrizio Carrai, Fabrizio Carubia
Kayser Italia S.r.l. Via di Popogna, 501 - 57128 Livorno, Italy +39 0586 5621
f.carrai@kayser.it

Marco Di Clemente, Marta Albano and Alberto Fedele
Italian Space Agency (ASI), Via del Politecnico snc 00133 - Roma (RM) Italy, +39 06 85671
marco.diclemente@asi.it

ABSTRACT

The Italian Space Agency is promoting a roadmap for the design, manufacturing and operation of a new space re-entry drone. The Iperdrone program will qualify a new type of operative mission, through an incremental phased approach. The program includes, as first step, the demonstration of inspection services for the International Space Station, optimizing the EVA activities and increasing the in space experimentation opportunities. The paper will present the status of development of the first mission, which will demonstrate the system's capabilities such as proximity operations, inspection and interaction with a target, including a close rendez-vous demonstration. The first mission, DAVID to be launched within 2023, is based on a 6U cubesat architecture.

INTRODUCTION

Since the late 1950's, when the first artificial satellite was launched into space there has been an interest to inspect spacecrafts in orbit. From simple inspection of non-cooperative vehicles to debris damage repair, commercial spacecraft life extension, space tug service of cooperative vehicles, the studies performed so far are many but for a variety of reasons, these systems have failed so far to come to fruition. One of the greatest challenges was the level of maturity of the technologies required, casting doubt on the economic viability and clear industrial need.

In the past decade, there has been a tendency to design and fabricate drones, which can perform autonomous missions in orbit. Generally, telescopes, satellites, robots and rovers are used in space. However, due to the advantages of drones compared to other approaches, a wider and wider research has been carried out by different space agencies in the world, including NASA to apply drones in space missions. Recently also the European Space Agency is promoting a program named Space Drone in order to provide a wide set of in orbit services such as debris removal, post mission disposal, transfer orbit etc.[1,2]

In this context, the Italian Space Agency is promoting a roadmap for the design, manufacturing and operation of a new space re-entry drone. The Iperdrone program will consist of a series of missions characterized by incremental objectives, aiming at qualifying new type of missions and related technologies. The program includes, as first steps, the demonstration of inspection services for spacecrafts and manned vehicles to optimize the EVA missions of astronauts and the retrieval of payloads and their re-entry on ground.

The design of the vehicle takes into account the safety requirements of the International Space Station and although constrained by a mass requirement of 20kg, is flexible to enable a wide variety of operational scenarios.

The paper will present the scenarios of application of this small satellite and the status of development of the first mission, which will demonstrate the system's capabilities such as proximity operations, inspection and interaction with a target, including a close rendez-vous demonstration.

ITALY AND THE RE-ENTRY SYSTEMS

Italian interest in re-entry systems dates back to 1987-1988 and it has evolved from small space systems to very complex ones. Technical efforts by Italian industries, mainly supported by the Italian Space Agency (ASI), enabled Italy to develop technology for re-entry systems.

ASI support for re-entry system technologies has resulted in a series of successes from national to international level.

First studies, funded by ASI, saw an extensive definition and preliminary design study of the Carina capsule, this capsule was a system able to perform microgravity experiments and return to Earth[3].

In the frame of technologies, ASI funded many projects for the development of the re-entry technologies such as for example the Advanced Space Assembly project that developed four different thermal protection systems and related materials[5,6,7].

Another extensive program was the Unmanned Space Vehicle (USV) funded in the frame of the PRORA program and managed by CIRA under the supervision of ASI. This program started in 1999 and developed dedicated technologies and test beds for re-entry systems[5,6,0,]

The years spent in this research field brought Italy to promote as major contributor a European project named Intermediate eXperimental Vehicle. This was the most complex project in the frame of re-entry vehicles managed by the European Space Agency (ESA) with the support of the national space agencies such as ASI.

I-XV was launched with VEGA VV04 from the Guiana Space Center on 11 February 2015. Reaching 413 km of altitude and a maximum in orbit velocity of seven, 5 km/s it splashed down in the Pacific Ocean and it was successfully recovered. The program allowed demonstrating the European capacity to design, manufacture and perform a re-entry mission. Italian industries, research centers and universities participated to the program developing and consolidating national competences of system engineering and design authority, avionics, mission control, communication network, ground stations, antennas and telemetry, recovery operations, mission analysis and in the scientific field of aerothermodynamics, fluid dynamics, propulsion, verification. It allowed also the improvement of national manufacturing capacities of subsystems such as power distribution unit, thermal protections, recovery subsystem and composites.

The success of the IXV project led to the next step of the European re-entry program: the Space Rider vehicle.

The objective of this project is to define and develop a reusable orbital laboratory for multiple space applications able to perform in-orbit payloads operations, de-orbit, re-enter, land on ground, be re-launched after limited refurbishment, enabling European routine access to and return from space.

The target missions are micro-gravity experimentation, ISS cargo/experiments return, in space technologies verification. Italy, which has been the major funder of this project, sees the participation of Italian industries as prime and system architecture of this complex system and as supplier of part of the subsystems.

IPERDRONE PROGRAM STRUCTURE AND OBJECTIVES

The Iperdrone programme aims at Developing a Low cost reusable re-entry system able to interoperate with space infrastructures and to integrate space to ground.

The Iperdrone programme capitalizes the competencies gained by Italy in development and exploitation of satellites and re-entry systems.

The programme will foster the national competences in re-entry field at system level, improving the enabling technologies portfolio to pull Italy players closer to the technology frontier.

The Iperdrone has the overall objective to develop a small autonomous re-entry system able to perform in orbit operations, interoperate with space infrastructures, deliver experiments to users in a short time, re-enter and perform a precision landing.

The Iperdrone program is based on an incremental phased approach, implemented through a series of subsequent projects.

The first project consists in two missions aiming at qualifying the vehicle and its technologies. The first, named Iperdrone.0 DAVID (Autonomous Drone ISS Verification and Deorbit) is 6U Cubesat Mission and will validate the system performance, GNC algorithms, together with Optical Payload for inspection purposes and cold gas propulsion technology system for proximity operations. The second, named Iperdrone.1, will target the system re-entry, focusing on innovative propulsion systems for attitude control and De-orbiting manoeuvres and materials and structures for TPS (Thermal Protection System).

Iperdrone.0 DAVID objectives

The main objectives of Iperdrone.0 are the following:

- Demonstrating the capability to acquire images demonstrating capability of external inspection and survey purposes of a reference target;
- Demonstrating the capability to perform rendez-vous in space with a non-cooperative target;
- Demonstrating the capability to perform a manoeuvre to achieve precisely targeted re-entry.

IPERDRONE.0 STATUS AND DEVELOPMENT

Iperdrone.0 is currently in the AI&T Phase and target a launch in 2023"The first mission should take place in 2023 to demonstrate the capabilities of the space vehicle.

The design has been carried out according to a preliminary tailoring of the ISS safety requirements.

Spacecraft configuration

The main components on the external surfaces of the spacecraft are:

- The propulsion system;
- The optical payloads (accommodation was defined to minimize the risk of plume impingement and contamination)
- Platform avionics, including main subsystems and solar arrays

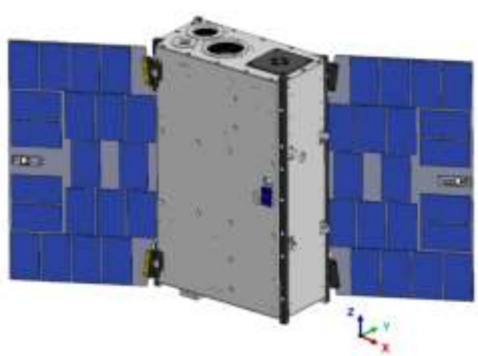

Figure 1: External configuration

The internal configuration was studied to properly accommodate the propulsion system, optical payloads, battery packs, Attitude and Orbital Control System (AOCS) the Command and Data Handling (CDH).

It is worth to underline that a proper Propulsion System, based on the green propellant R-134a called PERSEUS has been developed in the framework of Iperdrone Project.

The Iperdrone Ground Segment will be a network composed by the Kayser Italia Operation Control Center (OCC) located in Livorno, Italy and by the Vehicle Control Center (IPE-CC) managed by Tyvak International (TO, Italy)

Figure 2: Operation control center

The Iperdrone Control Center (IPE-CC) will interface with Tyvak ground stations and with the geographically distributed stations for mission data downlink.

Operation control center

The Iperdrone Operations Control Center (OCC) will manage the Iperdrone images from the IPE-CC and will manage the distribution to ASI and to qualified partners. It will guarantee a reliable transfer of the Iperdrone data and support the mission operations. Kayser Italia will manage the OCC. The OCC is already interfaced with the NASA ground and space networks and can support future ISS communication protocols for next Iperdrone missions.

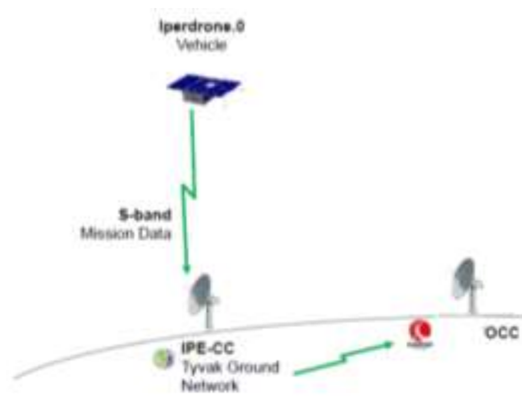

Figure 3 Iperdrone.0 ground segment high level architecture

During Iperdrone.0 mission, the satellite will have to perform in orbit operations with the involvement of a virtual Target simulating the International Space Station, performing operations that are functional to the ISS and a virtual crew on board. In order to meet this requirement, and considering the constraints of the project such as development times, available technologies and costs, a trade-off was executed aiming at choosing a reference scenario.

In this context, an inspection mission has been identified as a possible reference activity for the Iperdrone.0 mission, for the provision of the following capabilities for the inspection and surveillance of specific areas of the ISS:

IPERDRONE.0 MISSION

1. Release and commissioning. In this phase, there will be the deployment of the CubeSat and the commissioning of the platform. This phase could last a couple of weeks on average, depending on the amount of tests and verifications intended to be performed.

2. Non-collaborating target inspection. In this phase Iperdrone will approach the target and perform the manoeuvres in order to carry out the inspection.

3. Rendezvous demonstration with a virtual orbiting target.

4. De-orbiting, in this phase there will be the de-orbiting manoeuvre demonstration and passivation of the CubeSat, which will lower its orbit into a pre-defined re-entry corridor.

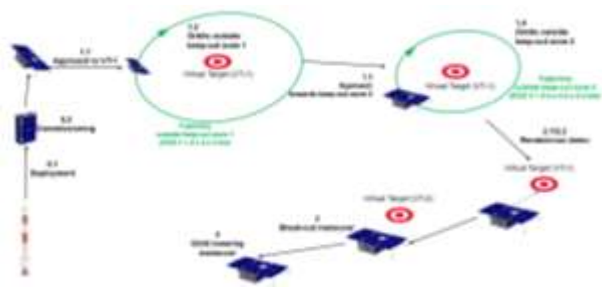

Figure 4 Iperdrone.0 Mission Phases

DE-ORBITING STRATEGY

Upon inspection completion, the vehicle will move away from the operation area to perform last phases of the mission, demonstrating a rendez-vous manoeuvre with a virtual target and de-orbiting capability.

The deorbiting function is one of the most critical function of the space drone. The ability to perform a precise re-entry pass through the implementation of dedicate critical subsystems and manoeuvre strategies able to assure the insertion into the right re-entry corridor and a sufficient propulsion thrust.

Within the Iperdrone.0 mission the satellite would then afford a de-orbiting manoeuvre in order to achieve the nominal selected re-entry.

Telemetry from this phase would then be used to verify that Iperdrone.0 could stay within the re-entry corridor for the whole duration of the manoeuvre.

FUTURE IPERDRONE MISSIONS

The challenging re-entry capability required to the future Iperdrone missions imposes also the validation of key technologies able to assure a safe and controlled re-entry of the spacecraft. Some technical studies have been activated on two of the most enabling subsystems: the de-orbiting propulsion and Tethered System.

Potential De-orbiting Propulsion System

Main System Requirements for De-orbiting Propulsion System are:

• ΔV=100m/s

• Volume - 5 U up to 7 U

• Mass below 5 kg

• Controllability during first phase of re-entry

Starting from the design drivers and guidelines a preliminary trade-off analysis of the propulsion subsystem has been performed, considering different potential concepts:

• Solid Rocket Motor;

• Liquid Bipropellant Rocket Motor;

• Liquid Monopropellant Rocket Motor.

A model used for analysis has been developed to establish the best propulsion solution for Iperdrone.1 with four main stringent requirements on mass, volume, controllability and re-entry accuracy.

Liquid Bipropellant Rocket Motor is confirmed as the main baseline configuration not only in terms of mass and volume, but also in terms of controllability and performances

Tethered System

The use of a different de-orbiting strategy has also been evaluated in order to provide Iperdrone family with an alternative de-orbiting system better coping with the safety rules, for instance those one imposed by the interaction with the ISS.

The CONOPS of a tethered system comes from the safety issues concerning the propulsion system storage inside the ISS or in its proximity. The tethered system would allow to reduce the number of propulsion system burns and consequently to increase the safety of the spacecraft.

The technique for providing a ΔV able to decrease the altitude of the lowest mass (the drone) and raise, in inverse proportion to its mass the space station, is called swing and release[8] and consists in cutting the wire when the librating tethered system crosses the LV in the direction opposite to the orbital motion (i.e, a backward swing).

In this way, the ΔV needed for deorbiting could be distributed among the one provided at the beginning of the manoeuvre from the tether system and the remaining portion provided by the propulsion system.

In case the system is released from ISS, the first step to design a de-orbit system based on librating tether is to identify launch positions and directions such that the trajectories of deployment and the speed profiles meet the requirements of the corridors of approach and departure from the ISS.

A 9-km-long tethered system, considering different deployment speed has been analyzed and is able to produce a DeltaV of about 24 m/s of the overall 100 m/s needed for the entire deorbiting maneuver.

TECHNOLOGY TRANSFER AND INNOVATION IN THE IPERDRONE PROGRAM

Innovation is the key element of Iperdrone. New subsystems will be developed such as thermal protections systems, the propulsion system and alternative de-orbiting systems.

The technology transfer in this programme is complex and can offer a wide range of opportunities. The research and development activities are carried out by universities and industries in order to develop the aforementioned systems.

The development of the TPS starts from the use of materials normally used in high temperature applications on earth such as blast furnaces. Possible uses on the developed TPS could be for example an inflatable shield for firemen.

CONCLUSIONS

Iperdrone is a small satellite that can be employed in different missions. Some examples are its use as courier of small payloads, which can be transferred between two space vehicles, re-entry of payloads, inspections of launcher stages, in orbit inspections of space vehicles/assets. This innovative employment of such a space drone shows all its synergies with on-going space vehicles and programs such as ISS, Space Rider and Vega C.

The Italian Space Agency is fostering this incremental program in order to promote innovative space transportation systems and the Italian excellences in re-entry technologies.

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