Title: ADR Mission with small Satellite
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Need

Space debris are an increasing problem in space environment for both operative satellites and human activity in space. Most recent international papers show that there is an already unstable situation in LEO that could lead to a degenerative event known as ”Kessler Syndrome”. In order to avoid this situation research groups are developing technologies able to move space junk in a safety orbit. Unfortunately at the moment a feasible system has not yet been found. Finding a system to remove space debris and at the same time avoid their growth (deorbiting low cost system) will be the main research objects in next years, in order to avoid possible impact that can lead to dangerous situation for civil people on earth (not controlled debris fall, see UARS satellite 24/9/2011).

Mission Objectives

The main purpouse of the mission is to reduce the presence of space debris in LEO orbit.
At the same time new solutions for all the different aspects linked to nanosatellite mission will be tested and qualified. Here are listed the 3 most important mission objectives in order of priority:

1) **Active debris removal (ADR):**
This is the main payload that consists in a small system able to catch little debris in LEO orbit. After a rendezvous manoeuvre a polyurethane foam is shot to create a rigid link in order to proceed with removal manoeuvre.
2) **Qualification of a Deorbiting System for nanosatellites:**
This system is based on a polymeric extractable sail to increase aspect mass ratio. Testing this system consists in offering a low cost solution for deorbiting of nanosatellites in future missions.
3) **Qualification of a new concept for cubesat / satellite structure:**
The structure is realized using ABS material. This solution can guarantee necessary mechanical features in a lighter structure. This can reduce costs for launch and for structure customization.

Concept of Operations

The principal objective of the mission is the tracking of the debris orbit and its catching and removal using a polyurethane foam as shown in Fig.1.

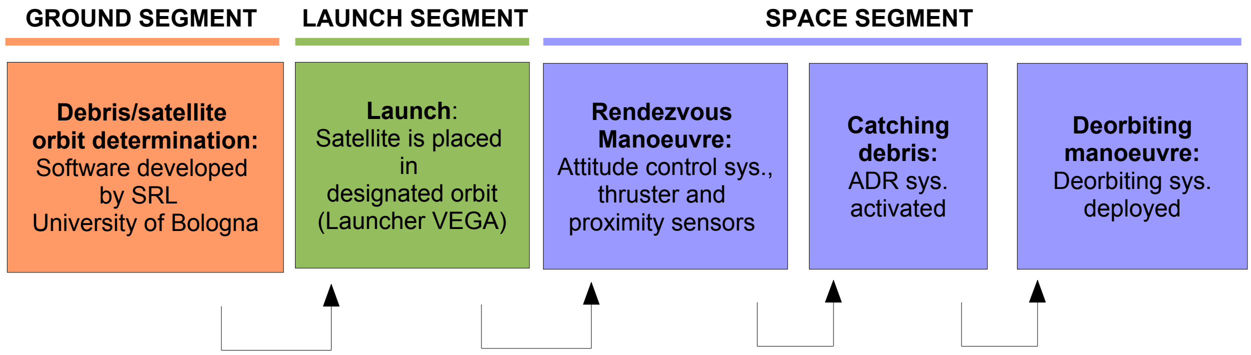

Fig.1 Mission Operation sequence (SRL= Space Robotic Lab)

Key Performance Parameters

Functional Parameters Table	
F1	The Satellite should be in the same orbit of the debris
F2	The ADR System should to be in condition to catch the debris
F3	The foam has to catch the debris
F4	The deorbiting system has to increase exposed surface
Performance Parameters Table	
P11	Satellite has to be injected by the launcher in the same orbit of the debris
P12	Accuracy tracking of the debris and its orbit
P21	The distance between satellite and debris has to be <20 cm
P22	The attitude of the satellite has to be corrected in order to hit the debris with the foam.
P31	Temperatures of the reagents shall be adequate (40 – 60°C as a range, 50°C the optimal T), in order to make the reaction occuring properly.
P32	The system has to eject the fluids
P41	The drag sail has to be deployed

Tab.1 Parameters function and performance table

Space Segment Description

The satellite is designed as a 3U cubesat. The very first part of the triple cubesat is dedicated to the deorbiting system, while the remaining volume of the upper part is occupied by the on-board electronic, the attitude control system, and the power system. The middle part contains the active debris removal system (ADR) while in the last segment of the satellite there is the propulsion system constituted by a plasma thruster. See Tab.2.
The structure is in ABS, realized through a rapid prototyping technique that allows optimal utilization of the useful volume. In Fig.2 it's shown the CAD model of the 3U cubesat configuration.

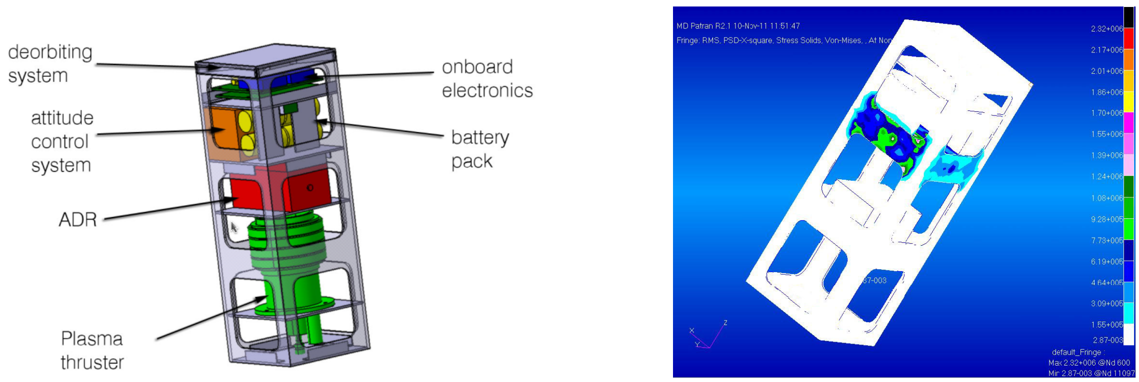

Fig.2 On the left: cubesat configuration. On the right: PSD stress analysis.

A preliminary FEM analysis has demonstrated the capability of the ABS structure to resist to static and dynamic loads. In Fig.2 is presented the result of the PSD simulation analysis: stresses experimented by the structure are compatible with ABS tensile strength. The analysis were performed using the qualification specifics provided by VEGA launcher user's guide.
ADR system (Fig.3) consists in a mechanical device that shoot a polymeric rigid foam: two liquid components are mixed trigging an expansion reaction and creating a rigid and strong structure that links the cubesat with the debris. Optimal mechanical behaviour ensures the stability of the link. The system is designed as two separated tank to store liquid components with two flexible thermal heaters to warm up these before the usage. The components are forced in a static mixer through two plungers moved by a spring: two electro-valves guarantee tank's closure and the lock of the spring.

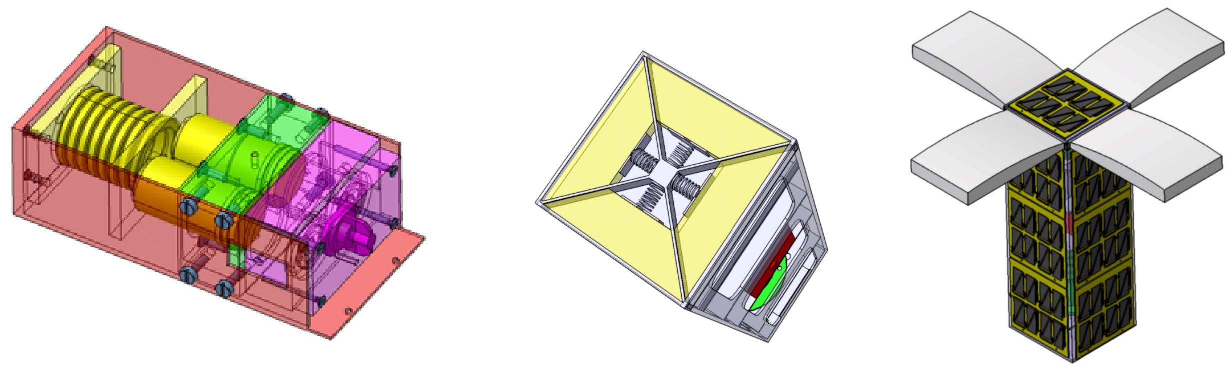

Fig.3 In order from the left: ADR system; Stored deorbiting system; Deployed deorbiting system

Deorbiting system is based on a different form of the same polymeric foam: a polymeric sail is already stored in the cubesat (Fig. 3). For this device the foam is characterized by flexibility and high expansive ratio. In this way it is possible to allocate the deorbiting sail in a small compressed volume locked by a mechanical device. The great advantage of this solution is that the structure is able to absorb energy due to possible impact with other debris, without functional failure. Trough software DAS has been possible to obtain the orbit lifetime of a satellite in respect of the altitude and A/m ratio (Fig.4).The designed deorbiting system for the mission can increase the aspect mass ratio from 0.01 to 0.05, and satisfy in that way IADC disposition.

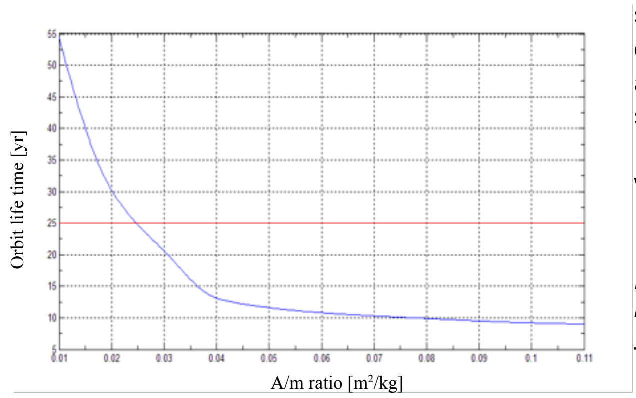

Fig. 4 On the left: orbit lifetime as function of aspect mass ratio (Orbit: 700kmx45°). Red line indicates the limit of 25 years (IADC disposition).

SPACE SEGMENT					
Component	**Description/Function**	**Mass [g]**	**Power [W]**	**Dimension [mm]**	**Cost**
Structure	ABS 3U cubesat	200	-	100x100x300	Developed by students with free spare parts
ADR system	Catcher device based on polymeric foam.	600	-	100x50x30	Developed by students with free spare parts supplied by interested enterprise
Deorbiting system	Polymeric foam sail	200	-	100x100x10	Developed by students with free spare parts
Power system	6 NiMh battery 12 triple junction solar panel	360 100	-	50x100x30 100x100x1	8000 €
Attitude control & determination	Magnetorquer and reaction wheels, solar sensor	250	0.5	45x45x10	10000 €
Propulsion system	Electric thruster	1000	0.6	70x70x140	provided by an experimental propulsion system supplied by a research centre
Proximity determination sys	Camera ad sensor	50	0.16	10x9x7.34	2000 €
PCB	SRL specific design	200	0.04	85x83x18	800 €
TX/RX	VHF downlink/UHF uplink/S-band	100	0.15	-	10000 €
Thermal system	Flexible thermal heater for foam components.	-	4.00	-	100 €
TOTAL		**3.060 Kg**	**-**	**-**	**30.900 € (without launch)**

POWER SYSTEM	
Average Power	1.45 W
Peak Power	4 W (During Thermal heater activation)
Battery Pack Power	3.30 A/h @ 7.2 V
Solar Panels	~0.50 A @ 5 V

LINK BUDGET		
	S-Band	**UHF**
T antenna [K]	25	250
GLna	26	0.1
FLna / TLna	2.69 / 490.1	1.65 / 188.5
Tlink / Frec / Trec	290 / 4 / 870	
Total Internal Noise (Lp=1)	**548.56154**	**9138.5**
Freq[Hz] /dmax [m]/ Length wave	$22x10^8$ / $7x10^5$ / 0.1363	$45x10^7$ / $7x10^5$ / 0.6666
Space Loss (Space Loss [dB])	$2.406x10^{-16}$ (-156.1878)	$5.7496x10^{-15}$ (-142.4036)
Powr trasm. (Powr trasm [dB])	4 (6.020599)	
Grx [dB] / Gtx [dB]x2	23.4 / 15.07	
Point Loss / Gpr / Gpt	-3 / 26.4 / 9.035	
Latm (Latm [dB])	1.8 (2.552725)	
rf losses sat ant-transmitter	-2	
P Total	**-111.144457**	**-97.36025**
Tcosmicbg [K]	2.7	0
Tsun [K]	10000	0
Tgaln [K]	5	3000
Tman-made	50	80
Tsky	50	0
Theavyrain	4	0
Total External Noise	**10113.86**	**3080**
TOTAL NOISE [K] ([dB])	**10662,4215 K (40.2785 dB)**	**12218.5 K (40.8701 dB)**
Bit rate (Bit rate dB)	$8x10^6$ / 69.03089	
B (B dB)	$16x10^6$ / 72.04119	
K	-228.6	
Implementation losses [dB]	-1	
filtering-timing-frequency fix	2	
P/N	4.13578	17.3283
(P/bit)/N	10.1460	23.3386
Margin	0.1460	13.3386

Tab.2 Space segment specifics(Component description – Power – Link budget)

Orbit/Constellation Description

Orbit parameters are fixed by the debris that needs to be recovered. In Fig.5 it's possible to notice that the major presence of debris is comprised in a range from 500 to 1100 km: a LEO orbit of 700 km and 45° is a plausible debris orbit. In this case, mask angle would be, considering a single ground station as the worst case, 20°. That means that there will be a time of 402 seconds to cross the clearance area to downlink the information or do an uplink for correction of attitude and orbit.

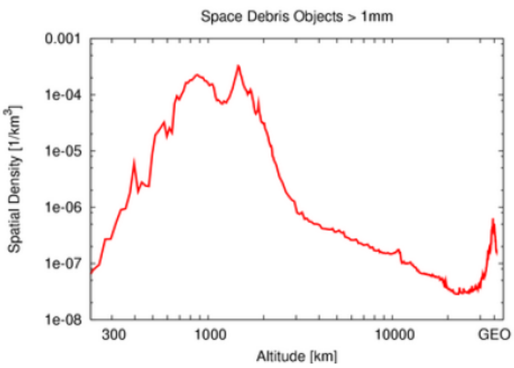

Fig.5 space debris object density at different altitude.

Implementation plan

Mechanical and Electronic Manufacturing are over planned to the design in order to start to develop first prototypes to test solutions before the definitive setup (Fig.6). Operational life time is scheduled for one month in order to reach the target and make the rendezvous with reserve time.

After the catching of the debris and the deploying of the deorbiting system, deorbiting time will be 15 years instead of 55 (Fig.4). The main 5 risk are listed in risk register table (Tab.4)

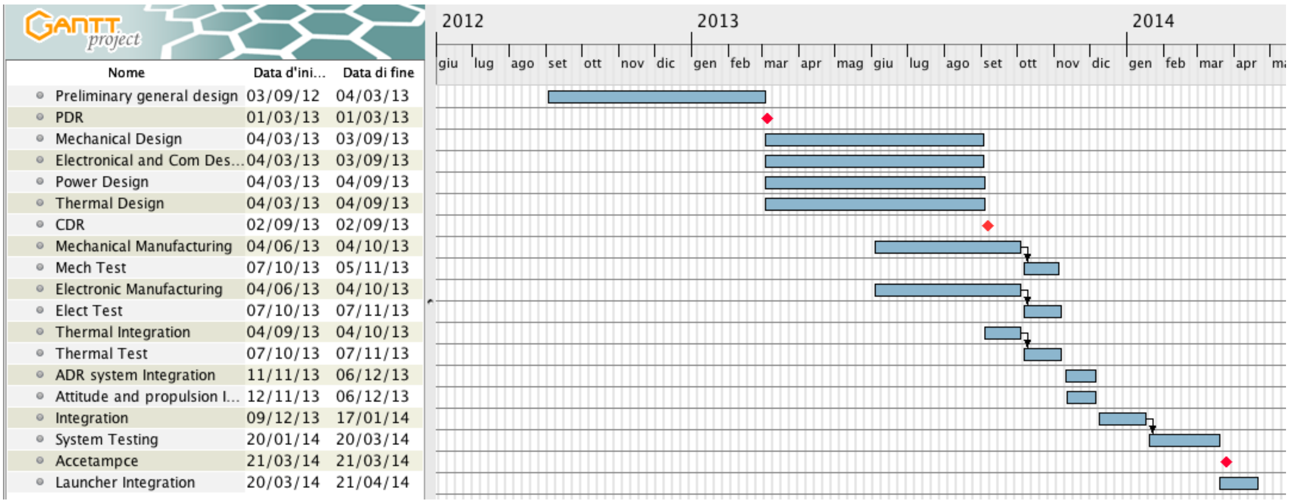

Fig.6 Gantt project of the mission

RISK	PROBABILITY	PREVENTION
Pyrocutter to open deorbiting system Failure	Very low	Double line for Power On signal and double number of Pyrocutters
Injector of ADR System failure	Very Low	Ground test in order to find the best configuration
Temperature of liquid of ADR system to low	Medium	Injection during light-day orbit period and pre heating system for fluids
ABS Structure Failure	Medium	During vibration test will be used a safety factor of 2 in addition to the value suggested by user manual of the launcher
Missing rendezvous	High	Using tested and affordable algorithm to design the system. Use of specific software for simulation

Tab.4 Risk register table

This will be a university project that will use students work: ABS structure, ADR system and deorbiting system are in state of development (Fig.7) by master students (Niccolò Bellini, Davide Rastelli, Marcello Valdatta) inside projects of the Space Robotic Lab (Prof. Fabrizio Piergentili). Partnership for payload segment are Duna-Corradini Group, Producer of the foam.

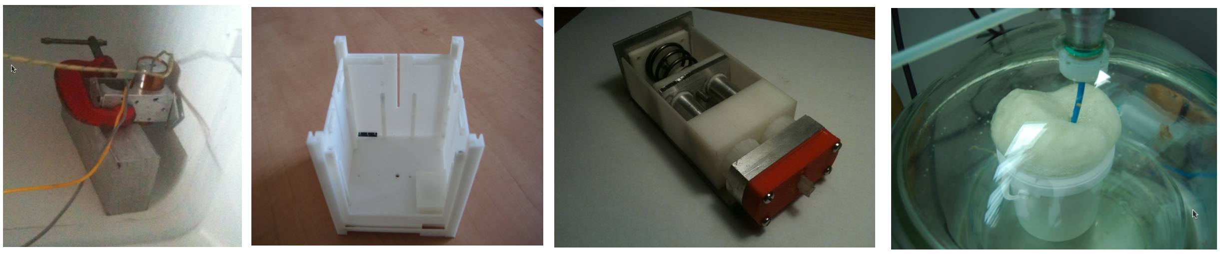

Fig.7 Photos of different prototypes and experimentation

Reference

- REDEMPTION SED (Student Experiment Document) F. Piergentili, M.L. Battagliere, G.P. Candini, J. Piattoni, F. Romei, A. Spadanuda, S. Toschi, M. Valdatta, F. Santoni, “REDEMPTION: a microgravity experiment to test foam for space debris removal” IAC-11-A6,5,7,x11777, 62nd International Astronautical Congress, 3 – 7 october 2011, Cape Town, SA.
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- “Confronto tra un cubesat in ABS e un cubesat in alluminio nell'ambito della campagna di qualifica al lancio” Final dissertation of Davide Rastelli, Bachelor degree 2011
- “Controlling the growth of future LEO debris populations with active debris removal” J-C. Liou, N.L.Johnson, N.M.Hill
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