Autonomous Mission for On-Orbit Servicing (AMOOS): A Call for Action

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Fig.1 – A new image by the NASA/ESA Hubble Space Telescope of dwarf galaxy ESO 540-31 set against a background of distant galaxies. ESO 540-31 lies just over 11 million light-years from Earth, in the constellation of Cetus (The Whale). Source [Img1].

Throughout the ages, the humankind is fascinated by the outer space (Fig.1). Nowadays, thanks to sciences, technologies and great ingenuity, dreams have become a reality. We now have the capacity to travel and live in space, we can reach other planets and, most useful for
our daily lives, we are able to successfully launch satellites and keep them in orbit. Satellites and space assets have rapidly become essential to establish a world of communication. They ease our lives in numerous areas [1] such as telecommunications, navigation, safety-of-life, astronomy, weather forecasts, surveillance, defence, etc. In summary, satellites are essential to get a perceptive view of our observations, to understand the universe, and to study the Earth. But today, space is crowded, congested, contested. This article describes an Autonomous Mission for On-Orbit Servicing (AMOOS) project that could help to solve today’s and tomorrow’s space problems.

**Problematic of satellite lifetime**

*Fig.2 – In one final act that signaled the dawn of the space age, a pushrod connected to a bulkhead of the Russian R-7 intercontinental ballistic missile was activated the 4th of October 1957, shoving a 183-pound beach ball-sized aluminum sphere into the cold, harsh blackness of space. Sputnik had arrived. Source [Img2].*

Since **Sputnik-1** opened the space race in 1957 (Fig.2), thousands of satellites and space assets have been sent in outer space. According to the United States Space Surveillance Network (Fig.3) (part of the United States Strategic Command, **USSTRATCOM**) and **Union of Concerned Scientists** records, there are more than 1,071 active satellites in-orbits (through June 2013).
Today, satellite technology is more advanced, more accurate, and more robust. However, satellites pose a real problem due to their limited end-of-life [2-3]. Random and unpredictable events or malfunctions can shorten the mission and the life of a satellite.

The biggest challenge is to keep a satellite functioning during its mission. Usually, the loss of energy source represents nearly 50% of satellites abandons (Fig.4). Alongside this potential threat, there are also failures of communications modules, antenna malfunctions due to transmitter failures and sensor anomalies that may represent severe challenge to satellite operability.

These potential failures and bad events strongly contribute to shorten the duration of a satellite in-orbit. For these reasons, satellites have an estimated average useful lifespan of 1 to 10 years.

**Problematic of space debris**

Since the beginnings of space endeavors in 1957, mankind has been leaving behind a trail of debris orbiting Earth. Risks to satellites and other space exploration equipment are
continuously increasing due to the large amount of artificial space debris that has accumulated in more than 56 years of human space activity.

The generation of space debris has progressively continued throughout the space age. Some estimates suggest that there are approximately 14,000 objects larger than a diameter of 10 cm, 300,000 objects between a 1 and 10 cm diameter, and millions of smaller objects in orbit (Fig. 5).

If remediation strategies are not developed sooner, space debris problems will remain an unsolvable case, accentuated by Kessler Syndrome and the natural continuation of future satellites launches. Each one of these objects poses a serious hazard to current and future operations in space such as:

- Penetration of debris through protection hulls of satellites structures (avg. 10km/sec) (Fig. 6);
- In-orbit collisions with spacecraft or satellites leading to severe damages to structures (Fig. 7);
- High kinetic energy releases from hypervelocity collisions that may lead to in-orbit explosions (Fig. 8);
- Scattering radioactive fallouts can contaminate the ground;

Congestion of useful orbits.
**Space debris activities**

In recent years, awareness of space debris problem has grown considerably. There is now a growing consensus that the reduction of space debris population is a necessity if we want to maintain outer space as a sustainable environment. This is an international problem and it requires an international effort.

In 1989, space-faring created an international program, the Inter-Agency space Debris Coordination Committee (IADC), to study the issues of human-made and natural orbital debris [4] towards space debris mitigation.

The IADC reports to United Nations Committee on the Peaceful Uses of Outer Space (UN-COPUOS) and produces the “IADC Space Debris Mitigation Guidelines” [5]. Space debris activities can be divided into two classes of action: mitigation and remediation:

*Mitigation activities refer to a class of actions designed to lessen the pain or reduce the severity induced by space debris. Mitigation measures are mostly preventive, and they are enacted to prevent the proliferation of space debris or to prevent orbital junk from getting worse. Mitigation activities will act on future space debris;*

Remediation activities refer to the act of applying a remedy in order to stop the generation and proliferation of space debris. Remediation activities target current and future space debris in order to address an undesirable event that has already occurred.

**Current space debris activities: Mitigation**

Space debris mitigation lies on preventive practices, international space laws & recommendations, and agencies operational experience. Commonly, there are 7 standards practices [5] recommended by for space debris guidelines:

- Limitation of collisions;
- Avoidance of destructive and harmful activities in space;
- Minimization of debris generation;
- Limitation of mission-related debris.

At this stage, several limitations are associated with prevention activities. Currently, debris mitigation efforts are limited to minimize the production of new debris and there are no measures to reduce existing debris objects. Space agencies and IADC organization have no
authority to bind space debris guidelines, especially against anti-satellites weapons practices (Fig.9). These guidelines are not universally respected and implemented and outer space laws are inadequate because of non-approved protocols, significant distrust between nations and military or commercial applicants.

**Futur space debris activities: Remediation**

The projections of space debris population in orbit have proved the necessity for remediation activities. Mostly, these are active debris removal techniques relying on technologies such as electromagnetic tethers, balloons, solar sails, propulsion engines, lasers beams capture nets, sweepers and robotic arms (proposed solution for AMOOS project).

These removal technologies have differences according to their operating principles: de-orbiting or capture. The capture principle is based on a safe and secure manner to remove debris without causing additional debris. Many solutions have been suggested, but few will prove viable and reliable in terms of technology limitations, technical efficiency, and costs issues [6].

**Unmanned space plane technologies**

The principal space-faring countries appear willing to continue their substantial support for unmanned space technology [7]. There are several advantages to use unmanned space plane for on-orbit servicing: they save lives, they save time, and they save money.

The XCOR Aerospace Lynx is the unmanned aerial vehicle [8] selected for AMOOS Project. Started in 2008, the first flight tests have been completed. It will transport at Single Stage to Orbit (SSTO) crew and payloads for autonomous on-orbit servicing. This horizontal takeoff and horizontal landing vehicle (HTOL) will use its own fully reusable rocket propulsion system to depart a runway and return safely. Its capabilities allow high tempo operations, rapid call-up, fast turnaround between flights, low cost operations and maintenance (O&M), and a focus on safety and reliability.
The following are other unmanned aerial vehicles projects [9] intended to orbital space travel:

- **Boeing X-37B**: this military orbital test vehicle is already in use as an advanced technology demonstrator.
- **Skylon**: still in research & development, this British/ESA project is projected at 2019 to serve for satellite servicing.
- **Space-X Dragon**: started in 2004, this unmanned vehicle serves already as cargo and crew transportation.
- **Virgin SpaceShipTwo**: unveiled in 2006, this vehicle is completing first flight tests. It will be intended for space tourism.

**The AMOOS Project**

The AMOOS project proposed as a team project for the next Space Studies Program (SSP2014) of the International Space University (ISU), organized by ÉTS and HEC Montréal that will be held in Montreal from June 9\textsuperscript{th} to August 8\textsuperscript{th} 2014 (Fig.10). The proposed project consists in the mission analysis, design, preparation, execution and post-mission analysis of an Autonomous Mission for On-Orbit Servicing (AMOOS) demonstrated for a Low Earth Orbit (LEO) Canadian satellite. The project is based on a virtual scenario in which a failure of a critical satellite subsystem has already been detected, on the need to repair this important Canadian LEO satellite directly on-orbit and on using autonomously a state-of-the-art Unmanned Aerial Vehicle (UAV).

The objectives of the AMOOS Project are to perform satellite on-orbit servicing and space debris reduction/removal operations, while addressing recommendations on outer space laws and regulations, new satellite architectures to enhance on-orbit servicing, technical analysis of potential threats, etc.
Mission of AMOOS Project

The proposed virtual scenario focuses on repairing a Canadian satellite, but the developed infrastructure is analysed to be used in a commercial offer for several other situations. Given this type of project, goals and mission, there are significant risks of complications, potential accidents and other emergency situations that threaten human life (in space and on earth). The following stages will need to be addressed to realize this project:

- Stage 1 – Analysis of the mission features;
- Stage 2 – Design of robotic subsystems;
- Stage 3 – Preparation and planning of the mission;
- Stage 4 – Execution of the mission (Fig.11);
Stage 5 – Post-analysis mission.

The mission execution (stage 3) will consist of the use of a modified UAV for an autonomous orbit servicing as follow:

- Phase 1 – Horizontal takeoff from runway;
- Phase 2 – Autonomous navigation to orbital destination;
- Phase 3 – Orbital rendezvous with the faulty satellite;
- Phase 4 – Docking / berthing of the vessel;
- Phase 5 – On-board robotics for satellite defect repairs;
- Phase 6 – Return navigation mission;
- Phase 7 – Safe horizontal flight landing.

Such a project will require the use of key technologies in the domains of suborbital unmanned aerial vehicle (Fig.12 and Fig.13), advanced Canadian robotic arms (Fig.14), guidance, navigation and control equipment, flight research simulators, Satellite Communications facilities and ground control operation centers.

Fig.11 – example of the UAV’s mission
Sources [Img11].
Benefits of the AMOOS Project

Several studies have proven that recycling in space, such as in the form of on-orbit servicing to extend the life of satellites is notably beneficial. The AMOOS project will therefore provide several advantages for satellites performances and lifetime including the upgrade satellite technology, increase maintenance capabilities, extend mission duration, recycle and re-use of components and reduction of on-orbit servicing costs.

Additionally major benefits will occur on space debris reduction by participating in international efforts to reduce space debris proliferation and orbital junk, minimizing damages caused by space debris on space vehicles and reducing risks or threats caused on astronauts during orbital missions.

Interdisciplinary scope of the AMOOS Project

The AMOOS project proposed for the next SSP2014 is expected to have considerable international, intercultural and politically harmonizing significance. Numerous satellite projects are evolving every year all over the world to replace old satellites and/or to introduce new features. Limited international policies exist in satellite design and manufacturing process in order to favor on-orbit servicing. This project can be viewed as a strategic study and fundamental ambassador for such ambitious goals to improve and to upgrade existing on-orbit satellites. The proposed technology resulting from the team project could be applied to any satellite technology of any country, for important social, economic and environmental benefits.
Discover the ISU project's presentation (PDF) of Professor Landry

To inquire on future projects of the Lassena team, please consult the following link.

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Do Alexis Sanou is a master degree student doing a research at ÉTS on GNSS receivers interference and multipath reduction.

REFERENCES


[Img1] Picture from ESA: http://spaceinimages.esa.int/Images/2013/09/ESO_540-31


[Img8] Rocket body explosions. Released: 18/04/2013 8:59 pm. Copyright: European Space Agency (ESA). Source:

http://spaceinimages.esa.int/Images/2013/04/Rocket_body_explosions


[Img10] Picture took on the ISU website. http://www.isunet.edu/


[Img12] Lynx with people for scale. Picture took on the XCOR Aerospace website: http://xcor.com/press/2008/images/08-03-20_lynx_ground_v02.jpg

OTHER INTERESTS LINKS

- European Space Agency: [http://www.esa.int/Our_Activities/Operations/Space_Debris](http://www.esa.int/Our_Activities/Operations/Space_Debris)
- Space security: annual series about space security. [http://www.spacesecurity.org/publications.htm](http://www.spacesecurity.org/publications.htm)