POLITECNICO DI MILANO

PhD in INGEGNERIA AEROSPAZIALE / AEROSPACE ENGINEERING - 39th cycle

PARTENARIATO PNRR Research Field: SHORT AND LONG-TERM ANALYSIS AND RECONSTRUCTION OF IN ON-ORBIT BREAKUP EVENTS

Monthly net income of PhDscholarship (max 36 months)
€ 1400.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	The population of space debris has increased over the past decades including inactive satellites, rocket bodies and fragments generated from breakups in space due to collision events and explosions. Collisions with debris fragments objects can lead to the failure of operational missions and increase the operational cost for more often collision avoidance manoeuvres. Breaks up can occur also due to failure of subsystem of inactive spacecraft such as batteries and propulsion systems and more and more such events are identified. When a break-up event takes place and are communicated on-ground telescopes of the Space Surveillance Tracking networks are tasked to identify new fragments so that unrelated fragments appear in the in available debris catalogues. The aim of this PhD is to analyse and reconstruct on-orbit fragmentation from Two-Line Elements (TLEs) of observed fragments: a reverse engineering approach will be developed based on previous work at Politecnico di Milano. The operational goal is to set up a fragmentation alert and early impact risk service, which will make possible to identify the approaching of the analysed fragments to a subset of the examined objects present in the catalogue. A TLE catalogue is processed to identifies the objects connected to a common fragmentation event by identifying all the fragments in the catalogue generated from that fragmentation (with a given level of confidence), identifying the parents objects (with a given level of confidence). The analysis also characterises the

	fragmentation in terms of energy involved and relative velocity reconstructed from a given model of breakup. The reconstruction is done through backward propagation of the fragments from the presumed events backward in time up to the identification of the time window for the event. Different criterions are developed to associate fragments to a common parent object through evaluation of orbital distances, spherical orbit geometry, study of the evolution of the mean and proper elements. Moreover. once the fragmentation is reconstructed the risk of collision for neighbourhood spacecraft is also assessed to identify possible cascade effects. The developed tools and techniques will be applied to real fragmentation events thanks to the collaboration with the Italian Space Agency, the European Space Agency and the EU SST initiative. Borsa coperta da fondi ASI-IHS - Telespazio-ASI (CUP F83C22002460005)
Methods and techniques that will be developed and used to carry out the research	The dynamical study of an evolving cloud will be first tackled. The NASA break-up model and the new ESA model will be written directly in terms of distribution of orbital elements and area-to-mass ratio of the generated fragments. Long-term orbit evolution with semi-analytical techniques and perturbation theory will be used for the long- and medium-term analysis of the cloud, whereas for the short-term analysis the osculating variation of the elements will be considered through SGP4. Depending on the orbital region of the fragmentation the relevant orbit perturbation will be considered and the proper set of elements will be chosen for a smart representation of the cloud evolution in the phase space. From the TLE of a set of unknown fragments and from orbit observations, the B-star coefficient will have to be estimated and the uncertainty associated to a given orbit determination. Then backward propagation will be performed in the relevel elements for example analysing the long-term evolution of the orbit geometry and orientation. Different pruning criteria and filters will be developed such as the apogee-perigee filter, a minimum orbit intersection filter and the time window analysis. Uncertainties will be included in the process of reverse engineering of the

	fragmentation. Both short and long-term fragmentation will be characterised and depending on the time window, the proper set of elements, dynamical model and approached will be chosen. One of the challenges will be the definition of the switching time among the different models. The aim is to extend the analysis not only to Low Earth orbits but also Geostationary and medium Earth orbits. Finally, the process will be automatised to allow daily analyses on the whole catalogue. To this aim, the research will make use of advanced mathematical models of the dynamics but will also take advantage of high-performance computing techniques and GPUs. Selected references 1. M. Romano, 'PUZZLE software for the characterisation of in-orbit fragmentations', 8th European Conference on Space Debris, ESA/ESOC, Darmstadt, Apr. 2021. 2. S. Frey et al., 'Density based modeling and indication of break-up location and epoch from fragments using backwards propagation', 5th European Workshop on Space Debris Modelling and Remediation, Paris, June 2018. 3. A. Muciaccia et al., 'In-orbit fragmentations localisation: study and characterisation of the events', 16th International Conference on Space on Space Operations, 2021
Educational objectives	The objective of this PhD is to develop skills in the dynamical system theory and long-term orbit evolution, modelling of space debris and optimisation and reverse engineering of in-orbit fragmentations. Through this PhD project the candidate will develop skills in mathematical development, simulations, programming (Matlab, Phyton), high performance computing through CPU and GPUs. Being this PhD funded through a research and industrial contract, soft skills in presenting the research, writing reports, developing operational code, outreach, dissemination, and preparing industrial progress meetings will be also achieved through the PhD work. The PhD candidate will be also involved in the research, industrial projects, organisational and outreach activities of the group. For further information on the project visit: www.compass.polimi.it
Job opportunities	Job opportunities after a PhD on this topic can be in any of the space agencies, in particular the European Space

	Agency, the Italian Space Agency and the several European companies and research institutions involved in space debris mitigation, space traffic management, space situational awareness, space policies and mission design.
Composition of the research group	0 Full Professors 1 Associated Professors 2 Assistant Professors 6 PhD Students
Name of the research directors	Prof. Camilla Colombo

Contacts
Dipartimento di Scienze e Tecnologie Aerospaziali - Politecnico di Milano - via La Masa 34, 20156 Milano - Italy - tel. +390223998323 - fax +390223998334 - email: camilla.colombo@polimi.it - web site: www.compass.polimi.it; www.aero.polimi.it

Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

Scholarship Increase for a period abroad	
Amount monthly	700.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
The PhD candidate will receive a desk, possibly through a hot-desking procedure, and a personal computer, if needed. Apart from the compulsory ones, the PhD candidate will have the opportunity to follow additional courses and receive economic support to attend summer schools and participate in conferences. There will be the possibility of paid teaching assistantship.