POLITECNICO DI MILANO

PhD in INGEGNERIA AEROSPAZIALE / AEROSPACE ENGINEERING - 39th cycle

THEMATIC Research Field: CISLUNAR ORBIT DYNAMICS AND APPLICATION TO CISLUNAR SPACE SITUATION AWARENESS

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 increasing interest in missions to the cislunar environment has been boosted in the last years by the launch of the Artemis programme, the recent Chandrayaan-3 mission and the development of the space Gateway that will offer a staging post for mission to the Moon. On the other side Libration Point Orbit mission are also planned for application to deep space astronomy, space weather and early warning. Even if the number of missions to the cislunar environment is increasing and will continue to do so due to the privatisation of the space sector, a debris mitigation approach is not in place yet for those regions. The aim of this PhD research is to study the dynamical environment of the cislunar space, from low lunar orbit to libration point orbits to study the long-term stability of such orbits and the transfer connecting them. Dynamical system theory will be used to identity the chaoticity of these regions and to characterise the phase space variables that allow a physical understanding of the dynamic evolution. The dynamical study will lay the basis for the design of several options of end of-life disposal option for those optional orbits including several disposal strategies such as: heliocentric disposal, moon disposal, Earth re-entry and so on. The study will synthetise a trade-off of different solutions for each family of operational orbit, highlighting their pros and cons not only in terms of mission analysis but also requirements in terms of operations. A second application will study the evolution of old space debris orbiting the cislunar

	environment and the spread of clouds of fragments that may generate due to failure of any of the future mission. Planetary protection tools will be used.
Methods and techniques that will be developed and used to carry out the research	The dynamical study of the cislunar environment will be firstly performed employing dynamical system theory and perturbation theory. The three and four body problem model will be firstly used, then the effect of solar radiation pressure will be also added. The gravity harmonics due to the Moon for lunar missions will be considered. Different reference frames and dynamics formulations will be employed, from the rotating frame to the orbital elements and Kustaanheimo-Stiefel variables. Different families of lunar orbits and libration point orbits will be first classified to the study their stability properties through finite-time Lyapunov exponents and numerical methods. Uncertainty propagation for a large set of initial condition will be applied using the continuity equation for the propagation of the phase space density and an index to assess the stretching of a given orbital region will be defined. Then disposal manoeuvres will be designed using local and global optimisation techniques or directly design them in the phase space. Robust disposals will be preferred and designed by including uncertainty in the optimisation phase. Robust control techniques will be devised to account for model uncertainties and mission failures. The PhD will be also devoted to identifying a preferred disposal for each family of orbit and trade-off the pros and cons of each solution. Current and planned missions to the cislunar space will be used as real test cases thanks to the collaboration with the European Space Agency and the Italian Space Agency. Moreover, some fragmentation scenarios will be simulated to study the fragment distribution in the cislunar environment and the consequent collision risk. The research will use advanced mathematical models of the dynamics but will also take advantage of high-performance computing techniques and GPUs. References Colombo C. et al., 'End-of-life disposal concepts for Libration Point Orbit and Highly Elliptical Orbit missions', Acta Astronautica, Vol. 110, 2015, Pages 298-312. Guardabasso P. et al., 'Lunar orbital debris mitigation: Characterisation of the

	environment and identification of disposal strategies', 8th European Conference on Space Debris. Colombo C., 'Long-Term Evolution of Highly-Elliptical Orbits: Luni-Solar Perturbation Effects for Stability and re-entry', Frontiers in Astronomy and Space Science, 02 July 2019, Vol. 6, 2019. Guardabasso P. et al., 'Massive GPU Parallelisation for Cislunar Debris Mitigation Analyses'
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 control of cislunar trajectories. Through this PhD project the candidate will develop skills in mathematical development, simulations, programming (Matlab, Phyton), high performance computing through CPU and GPUs. Soft skills in presenting the research, writing reports, outreach, dissemination, and preparing industrial progress meetings will be also achieved through the PhD project. 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 cislunar missions, 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.