SECURE WORLD FOUNDATION

Broomfield, CO
525 Zang Street, Suite D
Broomfield, CO 80021 USA
+1 303 554 1560

Washington, DC
1779 Massachusetts Ave., NW
Washington, DC 20036 USA
+1 202 568 6212

Regulator to Regulator Dialogue on Approaches to Licensing of Large Constellations

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Suggested References on Orbital Carrying Capacity

The following is a sample list of current published research and analysis related to the topic of orbital carrying capacity and space environmental thresholds. We offer these as a starting point for finding more information and discussion of the topic covered in today's Dialogue.

European Space Policy Institute. (2022). "ESPI Report 82 - Space Environment Capacity - Full Report." https://espi.or.at/publications/espi-public-reports/send/2-public-espi-reports/608-space-environment-capacity

Partial Abstract: "Taking stock of the ESA-developed Space Environment Capacity Concept, ESPI's latest report explores policy, regulatory and diplomatic perspectives on threshold-based models for space safety & sustainability, discusses how metric-based approaches to the orbital environment can foster the development of fact-based discussions on sustainability and safety of operations."

Letizia, F., Lemmens, S., and Krag, H. (2020). "Environment capacity as an early mission design driver," *Acta Astronautica*, Vol. 173, 2020, pp. 320–332. https://doi.org/https://doi.org/10.1016/j.actaastro.2020.04.041

Partial Abstract: "In recent years, several metrics have been proposed to quantify the impact of a mission on the space debris environment. In our previous work, we introduced the environmental capacity as the number and typology of missions that are compatible with the stable evolution of the debris environment. This concept enables the evaluation of the effectiveness of mitigation guidelines by looking at the use of environmental capacity due to existing missions. The current work will investigate how the same concept can also be applied as a tool during the design of a mission, facilitating the comparison of different mission architectures depending on their overall contribution to the debris environment."

Lifson, Miles & Arnas, David & Avendaño, Martin & Linares, Richard. (2022*).* "Low Earth Orbit Slotting: Implications for Orbit Design and Policy." *IAA-STM-22-02-06.* 8th annual Space Traffic Management conference – STM 2022 02-03 March, 2022, Austin, TX, USA

Abstract: "As more and more operators propose and begin to deploy large constellations, finite orbital volume in Low Earth Orbit (LEO) is becoming increasingly congested. Over the last several years, we have been developing a proposal for LEO orbital slotting that uses carefully designed slots in nested concentric shells to avoid the potential for hazardous close approaches between participating on-station spacecraft. Slotting provides several benefits including a reduction in orbital risk, clear analytic tools to understand the opportunity costs associated with a particular shell and slot design, and methods to assess and improve the efficiency with which operators make use of LEO. This paper offers a high-level description of key findings from our previous work on shell design under orbital perturbations and slot reconfiguration; and provides related recommendations to the community for suggested best practices for orbit design. Future directions for slotting research are described."

Rao, A. and Rondina, G., (2022). “Open access to orbit and runaway space debris growth.” arXiv preprint: arXiv:2202.07442

Abstract: “As Earth's orbits fill with satellites and debris, debris-producing collisions between orbiting bodies become more likely. Runaway space debris growth, known as Kessler Syndrome, may render Earth's orbits unusable for centuries. We present a dynamic physico-economic model of Earth orbit use under rational expectations with endogenous collision risk and Kessler Syndrome. When satellites can be destroyed in collisions with debris and other satellites, the open-access equilibrium manifold allows for multiple steady states. When debris can collide to produce more debris, at least one steady state may be a tipping point and Kessler Syndrome can occur along equilibrium paths. We show open access is increasingly and inefficiently likely to cause Kessler Syndrome as satellites become more profitable. Calibrated simulations reveal Kessler Syndrome is expected to occur in low-Earth orbit around 2048 under recent historical sectoral growth trends, and may occur as early as 2035 if the space economy grows consistent with projections by major investment banks. These results highlight the urgent need for modeling and policy approaches which incorporate open access and positive feedbacks in debris growth.”

Trozzi, Valeria, Colombo, Camilla, and Trisolini, Mirko. (2021). “Analysis of possible definitions of the space environment capacity to pursue long-term sustainability of space activities.” *IAC-21,A6,IP,22,x66198.* 72nd International Astronautical Congress (IAC), 5-29 October 2021, Dubai, United Arab Emirates.

Partial Abstract: “The topic of sustainability is not a new one, and many studies have been conducted on the Earth’s resources over the years. From what has been done and is being done for this problem on Earth, we take the cue to analyse and address a possible application in the space field as well. Particularly, the concept of capacity of an ecosystem is investigated and related to the space debris environment. In this work a debris evolution model, based on MISSD (Model for Investigating control Strategies for Space Debris) developed by in Somma et al. (2017), is built. The model is a source-sink debris evolutionary model based on a set of first order differential equations, which describe the injection and removal rates of objects in several altitude bands. Explosions and collisions generate fragments via the standard NASA breakup model, while drag, the only natural sink mechanism, is computed through a piecewise exponential model of the atmospheric density. The post mission disposal is the other significant removing mechanism considered in the model. The evolutionary model is used to study the future trends of the space environment and different definitions of capacity are investigated to find a sustainable future scenario. Various possible thresholds were assumed and checked; values derived from studies of the limits of space environment as well as techniques used on earth regarding limitations of CO2 and other harmful agents in different domains.”