Paper ID: 98262
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IAF SPACE EXPLORATION SYMPOSIUM (A3)
Interactive Presentations - IAF SPACE EXPLORATION SYMPOSIUM (IP)

Author: Mr. Qurban Haciyev
Azerbaijan State Oil and Industry University (ASOIU), Azerbaijan

Mr. Ayaz Damirov
Azerbaijan State Oil and Industry University (ASOIU), Azerbaijan

A HOLISTIC ROADMAP FOR SUSTAINABLE SPACE EXPLORATION: INTEGRATING NATIONAL STRATEGIES AND COMMERCIAL INNOVATION

Abstract

The global space community is embarking on a transformative new era: the period when established national programs will intermingle with innovative private ventures to change the exploration strategies and architectures. This paper addresses a very comprehensive and penetrating roadmap around which national policy frameworks, the most advanced technologies, and inventive business models might act together to shape and stimulate an efficient course toward sustainable space exploration.

From the recent trend, much public investment and private initiative has either been on track toward a model where singular missions were replaced by collaborative endeavors of several stakeholders. In our roadmap comes such a multitiered strategy which would revolve around flexible, modular spacecraft architectures; scalable infrastructures at low Earth orbit and beyond; and advanced systems-from autonomous robotics to AI-enhanced operations to digital twin simulations-optimizing mission planning and execution.

On the basis of international case studies and strategic assessments, we point out major obstacles to aligning different mission goals with complex inter-agency and cross-sector collaborations. It surveys the various projects and development levels in public-private partnerships that have spawned inclusive lunar bases and Mars surface operations to asteroid mining and deep space exploration. In addition, emerging regulatory frameworks and global alliances are appraised for their contributions toward ensuring safety, sustainability, and ethicality in space activities.

The focus of our proposals is therefore around the need for a flexible technology road that would keep pace with speedy changes in technology and market requirements. Interoperability, scalability, and resilience are intended for a speedily changing mission requirements, as well as possible future exploratory aspirations. The inclusion of commercial innovations into the national strategies will surely help in inducing technological development and lead to low-cost, low-risk exploration programs.

Our integrated approach is offering the overall prospect and vision into the future that connects national aspirations with commercial possibilities. Aligning strategic objectives, technological roadmaps, and international cooperation would surely enable this system to end in securing sustainable presence in space, catalyzing scientific discovery, and creating new economic opportunities at the new frontier for expanding space.