Space Operations: Inspiring Humankind's Future

SpaceOps Conference Book 2018 Review

This conference book collects the 33 best papers from the 15th SpaceOps Conference held in May 2018 in Marseille, France.

The titles of 33 best papers (including 2 from students) listed below were selected by the individual topic chairs and their associated review teams from over 338 technical papers according to peer review rules and criteria established by the international SpaceOps Organization:

Relevance: This topic is exclusively about space operations and many aspects of it. It is of broad interest to everyone at the conference.
Innovation: This topic is totally innovative, changes the whole game of space operations.
Substance: This topic is very important to all programs and projects in most agencies. It is very substantial.
Future: The topic is totally focused on enabling new space operations approaches for future programs and projects for most of all agencies.

For this Conference book by Springer International Publishing the papers have been enhanced by the authors.

The following expanded table of the best topic papers contains a brief description of each paper and the reviewer's evaluation comments, identified as J.K, Joachim J. Kehr, Editor SpaceOpsNews, Journal of Space Operations & Communicator (https://opsjournal.org).
The numbering order has no significance – it reflects the session order the papers were presented.
The final arrangement in the Conference book has been done according to other criteria, explained in the book by the Editors.

As can be seen from the following table, the selected best papers cover the whole field of space operations, including ground- and space segment operations, data systems well as launch vehicles, ranging from human spaceflight and robotic missions, covering scientific-, commercial- and small satellites (Cubesats) missions and all associated fields like tool and processes development, simulations, training, interfaces and standards, procedures etc., prepared and reviewed by experts in the field of space operations.

The 2018 Conference Book brings the operations community up to the latest developments and experiences in the never ending effort to make operations more secure and efficient, reduce cost, standardize and harmonize interfaces on an international level, introduce automation and knowledge

based operations and to come up with valid assessments and prognoses about future operational demands with respect to existing and planned infrastructure, respecting and accepting new "players" be it governmental or industrial.

One of my favorite papers is "Concept of Operations for the Gateway" (#25) because it presents the planned (international) next step for lunar exploration, summarizing the over twenty years of experience of International Space Station (ISS) operations and proposes to capitalizes on the international cooperation to smoothly and efficiently move into the future.

The Conference Book 2018 should be kept available to be consulted to gain an up-to-date overview of the current "school of thoughts" before making decisions others may have thought about – and probably came to grips already.

June 2019, Joachim J. Kehr, Editor SpaceOps News, Journal of SpaceOperations & Communicator
https://opsjournal.org

All 33 papers are assembled in the book (hardcover, e-book), but according to the publisher can be purchased as individual chapters/papers as well. If you are not interested in buying the whole book, the following table gives a more abbreviated description of the contents and its appreciation by the reviewer to help to pinpoint your individual interests.

	SpaceOps2018 Conference Titles of the 33 Technical Best Papers and contents
1	**The Cassini/Huygens Navigation** Ground **Data System: Design, Implementation, and Operations.** *Paper AIAA-2018-2434 describes the design, implementation, re-implementation and operations of the Cassini Huygens navigation system. The efforts to support and maintain the computer systems used by the Cassini Navigation team are described as well as the approach taken as to the design, their approach to implementation, and the very successful impact it had on the operations of the mission. While the implementations described in this paper have changed over the course of the mission and will change in the future, the principles and process shown may provide long lasting guidance. Although becoming much more significant, we have not examined closely a number of trends that have emerged in the last few years, such as the rise of cloud computing and virtual systems. Such systems do have the potential to lower costs – if they can meet the reliability and availability needs of their users.* *J.K: The paper is a very good example for solving the dilemma each operations unit has, the tradeoff between heritage, upgrading and upward compatible new implementations.*
2	**Ground Enterprise Evolution at NESDIS** *Paper AIAA 2018-2403 presents the transfer, integration and expansion of existing NOAA-NESDIS ground facilities (stovepiped designed) into a more efficient and modern multi-service oriented architecture. The plans address the migration of a set of algorithms based on common physics implementations, a modernized data archive potentially leveraging the cloud, shared product generation and distribution services for more efficient operations.* *J.K: The approach is of general interest for all multi-mission operations facilities*
3	**CNES Mission Operations Systems roadmap : towards rationalization and efficiency with ISIS** *Paper AIAA 2018-2628 aims at showing how CNES – operating more than 15 missions - has chosen to continue to improve its global efficiency for mission operations systems development and for spacecraft operations. In order to find a better development and operations cost optimization, as well as an optimization of the organization of its space operations. The ISIS (Initiative for Space Innovative Standard) project description gives the rationale for optimizing the space systems development and unifying the operations concept at CNES. The paper shows the major role given to various CCSDS and ECSS standards in this process.* *J.K: The standardization activities described in this paper will have an important and far-reaching effect on the European Ground System Common Care (EGS-CC) initiative.*

4	**Return Link Service Provider (RLSP) Acknowledgement Service to confirm the detection and localization of the SAR Galileo alerts**
	Paper AIAA 2018-2514 describes how the CNES concepts of operations, with the Return Link Service Provider (RLSP), will address the European Commission's high level objectives which makes the RLSP state of the art in modern technology; in particular as the RLSP will be responsible for the establishment of the Return Link Messages and their coordination with the Galileo system, interfacing on one side with the COSPAS-SARSAT system and on the other side with the Galileo Ground Mission Segment (GMS). Finally, the paper concludes with some important lessons learned from the Accreditation, Integration and Qualification phases and the first months in operations of this system.
	J.K: Specialized paper with pertinent and relevant lessons learned information.
5	**Enhanced Awareness In Space Operations Using Multipurpose Dynamic Network Analysis**
	Paper 2018-2672 describes the approach of the Dynamic Network Analysis (DNA) interactive visualization tool and the importance of having a graph-based visualization capability in space operations to comprehend relationships at stake in different kind of problems with the help of a demonstrator.
	Network operators have to deal with in a world made of interconnected information. Yet no visualization tool clearly permitted to visualize the links, the relationships and their topology. DNA has proven that graph-based visualization is more efficient that an adjacency list based approach when it comes to verify and investigate issues. Thanks to this demonstrator, users could express additional needs, not foreseen in the beginning, which open to brand new development ideas.
	J.K: Demonstrator for a new, interesting tool to improve network operations.
6	**Analysis of automated techniques for routine monitoring and contingency detection of in-flight LEO operations at EUMETSAT**
	Paper AIAA 2018-2532 focuses on the experiences of the Copernicus Sentinel-3 and EPS MetOp flight control teams in using the EUMETSAT CHART framework, which allows engineers to define automated reports and perform ad-hoc analysis on large datasets with multiple input sources. Arguments are also presented regarding whether or not it may be appropriate for future missions to consider applying some of these techniques directly onboard as an extension of the currently in-place FDIR mechanisms.
	J.K: This is a mission specialized paper, relaying some general interesting aspects applicable for other and future missions.
7	**The Added Value Of Advanced Feature Engineering And Selection For Machine Learning Models In Spacecraft Behavior Prediction**
	Paper AIAA 2018-2561 presents an iterative and interactive pipeline framework which uses machine learning to predict, with more accuracy, the thermal power consumption. The prediction model, along with the estimation of the thermal power consumption, also provides insight on the effect of the context which could help operators to exploit spacecraft resources, thereby prolonged mission life.
	J.K: As power prediction and management will be one of the more critical and complex tasks during long duration spaceflights to Mars and other destinations, an accurate as possible power prediction might be mission decisive. This paper presents a promising improvement.
8	**Sentinels Optical Communications Payload (OCP) Operations: From Test to In-Flight Experience**
	Paper 2018-2654 describes the impact of the routine OCP (Optical Communications Payload) operations on important operational areas and will also summarize the benefits to each mission of optical communications, showing how the use of optical communications, together with X-band ground station downlinks, has been used to maximize the data output of the missions. Finally, the paper will describe how the OCPs will be used in the future on both Sentinel-1 and Sentinel-2.
	J.K: Valuable first-hand experience with applied optical communications which will play a

	prominent role in the future.
9	**Model Based approach for test and operations procedures** *Paper AIAA 2018-2521 proposes a Model Base System Engineering approach to streamline Validation & Verification processes. Traditional practices to specify test and procedures for satellites manufacturing activities rely on handwritten specification in Word or Pdf documents, provided as inputs for Validation & Verification activities (V&V)* *In complement to these activities, and based on a large background in Model Based System Engineering (MBSE), Thales Alenia Space has started to define a new approach to introduce more formalization in the test and procedure activities, especially using the open-source Capella modeling tool and its associated methodology, Arcadia.* *The innovative aspect of this work is to reconsider the process from a global point of view, with all the stakeholders, and to challenge today's practices. It is motivated by the feeling that global optimization will not always come from local optimizations. MBSE is considered as an opportunity, and its progressive adoption by engineers in Thales Alenia Space is making the "end to end MBSE approach for procedure and test definition" possible in short or medium term.* *J.K: Interesting approach to establish a more standardized V&V system with cost savings potential in the long run. General aspects can be applicable for other spacecraft companies as well.*
10	**The Evolution of Interface Specification for Spacecraft Command and Control** *Paper AIAA 2018-2446 describes an evolution from a traditional satellite commanding Interface Control Document (ICD) to a service suite which provides real-time propagation and validation of interface changes. TEL Handling, Elucidation, Modification, and Investigation Service (THEMIS) is the DigitalGlobe next generation software suite.* *Once generated, the ICDs are used in real-time operations. This approach has reduced interface interpretation errors by having a single service able to validate commanding generated by multiple sources against any interface baseline.* *J.K: The described interface approach must be thoroughly analyzed to insure to be able to benefit from the advantages vs. additional effort.*
11	**Flight Dynamics Operational Experience From Exomars TGO Aerobraking Campaign At Mars** *Paper 2018-2537 aims at giving a Flight Dynamics perspective on ExoMars Trace Gas Orbiter aero-braking operations, discussing the main challenges for both navigation and spacecraft commanding, describing the work-flow of activities within an operations cycle and presenting some results from the successful campaign, together with the most important lessons learnt.* *J.K: This paper discusses the latest experience with aerobraking techniques – an important talent to be mastered for re-entry and descent activites on Earth and all planetary and interplanetary explorations.*
12	**The Cassini Mission: Reconstructing Thirteen Years of the Most Complex Gravity-Assist Trajectory Flown to Date** *The paper 2018-2646 reports on the uniform reconstruction of the entire Cassini orbital mission, which uses one consistent Saturn system model and satellite ephemerides throughout. We discuss the challenges of undertaking this task, and comparison strategies.* *J.K: The use of Gravity assist techniques is another precondition for exploring interplanetary space and going to places which could not be reached using conventional propulsion techniques. The successful application for the Cassini mission demonstrates JPL's dominance in this field.*
13	**The EnMAP Mission Planning System** *Paper 2018-2525 presents novel Earth observation mission planning design technologies which include the Reactive Planning framework, which particularly stands out due to its high responsiveness to user input. Particular attention is furthermore paid to the inclusion of cloud coverage and sunglint information into the planning process—two challenges which are specific to EnMAP observing in the optical and near infrared part of the spectrum.*

	J.K: Pioneering mission planning techniques for many manned and unmanned missions the TerraSARanDEM-X based DLR system was improved again with the introduction of hard to predict variables. The paper definitely will inspire further improvements for further missions.
14	**Ant-based Mission Planning: Two Examples** *Paper 2018-2498 proposes an automated Mission Planning System based on the ants' foraging mechanism and apply it to two different mission planning problems (Earth Imaging and a Data Relay mission), investigates the system's ability to be generalized. The planning process for the two problems is compared and generalized on the type of planning problems the system can address.* *J.K: interesting approach since nature is always a good teacher – it remains to be traded off whether the introduction of a new strategy justifies the effort for a specific mission.*
15	**InSight Cruise and Surface Operations: Integrated Planning, Sequencing and Modeling using APGen** *Paper 2018-2552 presents an integrated planning, sequencing and modeling tool developed for the InSight mission. The project has been able to do this by investing in multi-mission software tools and sharing code with other missions, such as the Europa Clipper project. Building off of the lessons learned from the Phoenix lander, Mars Science Laboratory (MSL) and Mars Exploration Rover (MER) missions, InSight developed a multi-mission system design, from which both small and large projects can learn.* *J.K: The combination of inherited software systems into a single multi mission tool is a powerful effort to reduce cost, however side effects like project duration(s), maintenance, compatibility and interface control have to be taken into account.*
16	**New Ways to Fly an Old Spacecraft: Enabling Further Discoveries with Kepler's K2 Mission** *Paper 2018-2697 reviews several examples of the challenges introduced by the failure of a second reaction wheel, aging hardware, the increasing distance from the Earth and the desire to make the mission last as long as possible, and presents the solutions that were devised and their outcomes with regard to improving performance, extending the mission lifetime and demonstrating the cost-effectiveness of a small mission operations team.* *J.K: As demonstrated in previous missions the maximum use of a long lasting mission with aging hardware (and software) problems the effectiveness of an mission extension and its justification basically depends on the skills of the mission operations team. Although the experience discussed in this paper is very mission specific it might inspire other mission operations teams around the world.*
17	**In-orbit experience of the Gaia and LISA Pathfinder cold gas micro-propulsion systems** *Paper AIAA 2018-2716 presents in-flight experience of the cold gas micro-propulsion systems (MPS) used on-board the Gaia and LISA Pathfinder spacecraft. The aim is to present the in-flight results that have been derived from post-processing of the Gaia and LPF housekeeping telemetry archives in terms of micro-thruster performances. MPS off-nominal events that have been encountered in-flight on individual or both spacecraft will be presented as well as mitigation actions that have been put in place to restore nominal conditions.* *J.K: Specialized paper on micro-propulsion systems (MPS). It is concluded that although the MPS is a new propulsion technology with highly challenged performances, its in-orbit behaviour is excellent in meeting Gaia's and LPF's unparalleled requirements in terms of attitude and rate stability.*
18	***NEOSSat Recovery Following Magnetometer and Torque Rod Failure*** *Paper AIAA 2018-2664 provides a description of NEOSSat, its hardware failures, and discusses the development and implementation of the innovative flight software upgrades that facilitated its recovery: After suffering the failure of its magnetometer and all torque rods, the NEOSSat microsatellite has recovered operations through the use of novel attitude determination and control algorithms that utilize a minimal sensor and actuator suite.* *J.K: Specialized mission operations paper on ingenious recovery methods for a failed attitude control system*

19	**Formation Flying of a Two-CubeSat Virtual Telescope in a Highly Elliptical Orbit**
	In paper AIAA 2018-2633 a novel approach is investigated for attitude control of 2 satellites acting as a virtual telescope. The Virtual Telescope for X-ray Observations (VTXO) is a mission exploiting 2 6U-CubeSats operating in precision formation.
	J.K: VTXO demonstrates the key technologies that should be developed to keep spacecraft in formation. The high accuracy involved in this mission requires more challenging technologies to be developed further such as more advanced controlling algorithms, more accurate filters, and better sensors. The technology that was developed here provides high accuracy with the involved noises influencing the attitude and so the attitude accuracy. A novel approach to expand the use of cubesats for very ambitious applications with significant relevance for the future.
20	***Ariane 6 Launch System Operational Concept - Main Drivers***
	Paper AIAA 2018-2489 presents the drivers established to build the Ariane 6 operational concept, the related trade-offs performed and the rational for the selected choices. Finally, some aspects of the preliminary operations plan resulting from the CONOPS exercise are compared with former Ariane operations plans to show differences and highlight improvements with respect to user's expectations.
	J.K: A "must-read" paper for all potential users of the Ariane-6 launch system
21	**Next Generation Relay Services at Mars via an International Relay Network operations**
	Paper AIAA 2018-2429 discusses the existing architecture and considers how several technologies might be applied to the next generation of relay services at Mars. Ultimately these are expected to lead to the implementation of a delay and disruption tolerant network at Mars a precursor to becoming a major element in an emerging solar system internet
	J.K: A paper pointing far into the future – a necessary planning effort which can't be finished soon enough.
22	**Space Mobile Network Concepts for Missions Beyond Low Earth Orbit**
	Paper AIAA 2018-2423: The Space Mobile Network (SMN) is an architectural framework that will allow for quicker more efficient and more easily available space communications services, providing user spacecraft with an experience similar to that of terrestrial mobile network users. This paper details how SMN concepts such as user initiated services which will enable users to request access to high-performance link resources in response to real-time science or operational events, would be applied in and beyond the near-Earth regimes. Specifically the paper explores the application of user initiated services to direct to earth DTE relay and DTE / relay hybrid scenarios in near-Earth-lunar, martian and other space regimes.
	J.K: Excellent approach by JPL for implementing flexible data service on user demand.
23	**Toward a NASA Deep Space Optical Communications System**
	Paper AIAA 2018-2554: The next two orders of magnitude are predicted to come from the introduction of Deep Space optical communications. Studies indicate that optical receive apertures of between 8 and 12 cm are desired. The large cost of dedicated receive telescopes makes is method unrealistic. We propose a novel hybrid design in which existing DSN 34m beam waveguide (BWG) radio antennas can be modified to include an 8m equivalent optical primary. By utilizing a low-cost segmented spherical mirror optical design, pioneered by the optical astronomical community, and by exploiting the already existing extremely stable large radio aperture structures in the DSN we can minimize both of these cost drivers for implementing large optical communications ground terminals.
	J.K: Promising low cost optical communications introduction for the DSN
24	**Recommendations Emerging from an Analysis of NASA's Deep Space Communications Capacity**
	Paper AIAA 2018-2528: For the vast majority of the postulated future deep space mission set scenarios, analysis of trends in spacecraft numbers, downlink numbers, antenna-hour requirements, and loading simulations suggest a steep increase in demand for antenna network capacity over the next 10 years. Careful assessment of this demand relative to planned

	antenna capacity suggest that it should be manageable, so recurring periods of significant asset scheduling contention are likely to occur. This capacity study points out bottlenecks and proposes measures (downlink beam sharing, 8m RF-optical link hybrid antenna) to alleviate envisaged problems. *J.K: This is an important DSN specific in depth capacity study which definitely is of interest for external/cooperative DSN DSN users and their future plans.*
25	**Concept of Operations for the Gateway** *Paper AIAA 2018-2464: NASA has outlined a phased approach to expand human presence deeper into the Solar System starting with the moon. Phase 1 of this plan begins in the 2020s, with missions in cislunar space and assembly of the lunar orbital platform-gateway. The gateway is an evolvable, flexible, and modular space platform in lunar orbit. It can support crewed missions 30 to 60 days long, with increasing duration each mission. When the gateway is uncrewed, robotic science missions will be performed. The gateway allows astronauts to practice the skills and test technologies needed for months and years beyond low Earth orbit. A key to success for this Deep Space missions will be carefully coordinated operations by ground support, flight crew and autonomous spacecraft.* *J.K: One of my favorite papers, because it combines the presentation of the current Gateway concept and outlines an operational concept based on NASA's international-partner experience with the ISS by critically applying the gained operational experiences.*
26	**Educational Outreach and International Collaboration Through ARISS---Amateur Radio on the International Space Station** *Paper AIAA 2018-2437: Amateur radio on the International Space Station (ARISS) was first deployed and operated on the ISS about 2 weeks after the first ISS expedition crew arrived on the station. It has been continuously operational since that time. This makes ARISS the first operational payload and first educational outreach program on the ISS. This paper will provide some historical background on the ARISS programme, it will describe the international volunteer team that is responsible for making this low-cost, high payoff program such a huge success, and will provide an overview of the proposal submittal, selection and contact preparation process.* *J.K: A fine example of a highly successful, ongoing educational program.*
27	**Space Education and Awareness in South Africa- Programs, Initiatives, Achievements, Challenges & Issues** *Paper AIAA 2018-2312: South Africa's involvement in the space science started at the dawn of the "space age". Before this South Africa has been involved in astronomy since 1820, when the first permanent astronomical Observatory and scientific institution in the Southern Hemisphere was completed at the Cape of Good Hope. This paper discusses the various space-based STEM programs that have been put in place to promote space education awareness and the contribution made by various role players. Furthermore this paper will showcase a concept for a new approach to space awareness activities, and it's potential to drive STEM programs in the country. Lastly this paper aims to recognize the achievements of South Africa in promoting space education and awareness in the country and the related issues and impediments to pursue these programs.* *J.K: A paper emphasizing the enthusiasm for and importance of space based education with respect to STEM activities in South Africa.*
28	**Improving Spacecraft Design and Operability for Europa Clipper through High-Fidelity, Mission-Level Modeling and Simulation** *Paper AIAA 2018-2469: NASA's planned Europa Clipper mission seeks to assess the habitability of Jupiter's moon Europa, which exhibits strong evidence of an ocean of liquid water underneath it's icy crust. High fidelity mission level simulations that models the spacecraft, ground, and environment from launch to end-of-mission with a given trajectory and mission plan have been employed early in the project lifecycle to better understand the intentions between various components of the mission and how design changes impact the entire system.*

	These simulations have already resulted in tangible benefits to the project by providing vital input to key spacecraft trades, assessing impact to operability, and quantifying how well the scientific objectives of the mission can be achieved. *J.K: This JPL paper describes the benefits of the early introduction of high fidelity simulations into the mission lifecycle in order to reduce cost and risk of an exploratory mission to an unknown environment.*
29	LUMIO: achieving autonomous operations for Lunar exploration with a CubeSat *Paper AIAA 2018-2599: The Lunar Meteorite Impact Observer (LUMIO) is one of the four projects selected within a ESA's SysNova competition to develop a small satellite for scientific and technology demonstration purposes to be deployed by mother ship around the moon. In this paper we will describe the mission concept and focus on the performance of a novel navigation concept using moon images taken as byproduct of the LUMIO camera operations - aming at autonomous orbit-attitude navigation and control.* *J.K: This is a very promising low-operations cost, small satellite program which might have bearings on future Cubesat operations as well.*
30	Terrain-based Analysis as a Design and Planning Tool for Operations of a Lunar Exploration Rover for the TeamIndus Lunar Mission *Paper AIAA 2018-2494: The starting point for planning planetary surface exploration missions begins with deciding upon a landing site. TeamIndus, who participated in the Google lunar x prize competition to soft-land a Lander on the Moon had to perform detailed studies on the terrain at the chosen landing area to ensure that the missions objectives were achievable. The main objectives of the mission where (1) to achieve a stable and soft landing on the lunar lander for touchdown speeds less than 0.5 m/s per second and (2) to operate the surface exploration Rover over a distance of at least 500 metres with the Lander serving as a communication relay between Earth and the Rover. The results of the studies brought out the recommendation to increase the antenna height on both lander and the rover and thereby extend the range of the Rover communication and to employ a lunar surface global path planning methodology allowing the landing point localisation to within 20m of known landmarks.* *J.K: Results of the Lunar X-Prize participating team "TeamIndus" are presented, again aiming for efficient and low-cost operations.*
31	Ethological Approach of the Human Factors from Space Missions to Space Operations *Paper AIAA 2018-2450: The benefits of using the ethological approach in space field was first demonstrated on short duration human missions at the Toulouse Space Center then developed in the perspective of long-term missions for manned Mars exploration and moon Village. As transfer of knowledge, new goals of application are to propose complementary tools and an efficient methods that assesses positive actions of operators in interactive space operation in to coping with routine works and unexpected events while minimising human factors (HF) risks in interactive space operations. In this prospective study we applied the ethological method for HF assessment within the operations system interactions during satellites control command operations. The preliminary results support the relevance and constraints of such an approach for upcoming space operations. We emphasize the relationships between human behaviour and human factor.* *J.K: This is an interesting approach to make operations more efficient. More data is needed to see whether the effort is justified by the benefits.*
==32==	Statistical Methods for Outlier Detection in Space Telemetries ==Nr.32== = Student paper *Paper AIAA 2018-25334: Satellites monitoring is an important task to prevent the failure of satellites. For this purpose, a large number of time series are analyzed in order to detect anomalies. In this paper we provide a review of such analysis focusing on methods that rely on features extraction. In particular we setup features based on fixed functional basis like Fourier, wavelets, kernel basis etc. The outlier detection methods we apply on those features can be distance or density-based. Those algorithms will be tested on real telemetry data.*

	J.K: A clever proposal towards more reliable automation in operations.
<mark>33</mark>	Operational Benefit and Applicability of a 3D Printer in Future Human Mars Missions - Results from Analog Testing <mark>Nr. 33</mark> = Student paper
	Paper AIAA 2018-2410: The remote nature of human missions to Mars requires a different paradigm for how operations should be performed. In particular there is a need for greater independence from Earth, and the ability to adapt to evolving scenarios. A series of experiments were carried out under AMADEE-18 Mars analogue simulation to investigate the potential benefit of integrating a 3D printer into operations. Crew- and earth-controlled printing as well as a hybrid combination of printed plastic with high quality metal printed on "Earth" was exercised and shown to be successful, it definitely presents an avenue for future research.
	J.K: This excellent student paper adds a new facet to the intensively researched application of 3D-printing to space operations presenting as realistic as possible "hands-on" results.

End of Table