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On the Cover
A view from the Cupola, a 360-degree observation area and remote control location on the International Space Station (Image Credit: NASA)
A tremendous “Thank You” to the planning committee for the Goddard Symposium. It is always a challenge put together a fresh and interesting program every year, but the planning committee did it again! By all accounts this year’s Goddard Symposium was one of the best, and live streaming the entire event proved very popular. The number of students and young professionals attending increased significantly compared to past years, and a tour of Goddard Space Flight Center was offered to them, as well as a private meeting with the NASA Acting Administrator. The panels and spotlights allowed ample time for discussion and questions, and Matt Mountain’s opening remarks were both thoughtful and moving. If you didn’t attend, I hope you will check out the video accessible from the AAS website.

The AAS Board of Directors held their spring meeting on March 7th, and I did want to highlight one specific area. Last year, AAS received a very generous donation from a private trust asking us to support activities that promote space travel. This year the Board has approved spending some of the grant money on three areas that have become signature activities for AAS. The following activities will be funded in 2017:

- $10,000 for the AAS contribution for hosting and managing the popular Google Hangouts
- $5,000 for the Student CanSat Competition
- $7,500 for complimentary student registrations for the Goddard Symposium (20), ISS Symposium (16) and Von Braun Symposium (20)

We have a diverse set of articles this month with highlights from the AAS/AIAA Space Flight Mechanics Meeting, including the first ever presentation from a high school student!

Look for our upcoming activities: the CanSat Competition in June in Texas and the ISS Research & Development Conference in July in Washington, D.C.

As many of you know, I have most recently been involved in the advanced nuclear energy world – think next generation non-light water reactors. There are a lot of interesting things happening on the technical, business, and political aspects to develop safe and more cost-effective nuclear energy. What struck me when I first started working in this arena was how similar it was, in many facets, to the beginning days of space commercialization – new entrepreneurs, the role of public/private partnerships, bi-partisan support from the Congress, and the combination of unbridled enthusiasm mixed with strong skepticism. Last week, I had the opportunity to participate in a meeting on Capitol Hill in which the Breakthrough Institute released a report that discussed, in part, how NASA and the emergence of a commercial space industry could be a model for a path forward for advanced nuclear energy. It was fascinating to hear an outsider’s perspective of the space community and its application to other sectors. I do think being on the leading edge – of exploration, science, engineering, and even business constructs – is the driver of what makes the space community so vibrant and captivating for many of us!

AAS – Advancing All Space

Carol S. Lane
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GALILEO Constellation Operations, Training and Simulations

by Michelangelo Ambrosini

The article describes the Constellation Operations, Training and Simulations activities carried out by DLR GfR at the GALILEO Control Centre in Oberpfaffenhofen, how these activities have evolved from the first GALILEO launch, and what is foreseen to happen in the future during the constellation development phase until full deployment, when the GALILEO system full operational capability will permit the provision of the GALILEO Navigation Services to the world users community. The article focuses on the high level of expertise and competence of DLR GfR personnel gained within the In Orbit Validation phase of the GALILEO program and on the challenges DLR GfR will face with the GALILEO Constellation Operations, Training and Simulations in the future.

Introduction

GALILEO is Europe’s program for a Global Navigation Satellite System (GNSS), providing a highly accurate, guaranteed global positioning and timing service. The complete GALILEO constellation will consist of 30 satellites in three orbital planes at an angle of 56 degrees to the equator. With the satellites taking about 14 hours to orbit Earth at altitudes of 23 222 km, there will always be at least four satellites visible anywhere in the world.

The IOV phase is the first of three incremental implementation steps or mission phases to develop the GALILEO System and to validate its in-orbit performance. The Full Operational Capability (FOC) phase will deploy in full the ground and space infrastructure as required to achieve full operational capability. The purpose of the final Exploitation phase is to operate the FOC infrastructure and to provide navigation services over the entire system lifetime. The Galileo core system components are the Space Segment (SSEG) includ-
ing launch services, the GALILEO Control Segment (GCS) and the GALILEO Mission Segment (GMS). The GCS is operated by the DLR Gesellschaft für Raumfahrtanwendungen (GfR) mbH as a company of the German Aerospace Center DLR, having its seat at the Galileo Control Center (GCC-D) in Oberpfaffenhofen. The GMS is operated by Telespazio SpA as a company of Leonardo-Finmeccanica and Thales at the Galileo Control Center (GCC-I) in Fucino.

In addition to the ground segments, support facilities have to be available as they are fundamental for the deployment, validation and maintenance of the GALILEO system. Launch and Early Operations Phase (LEOP) Control Centers (LOCCs) at CNES in Toulouse and ESOC in Darmstadt are required for providing LEOP services for all satellites of the GALILEO constellation. An In-Orbit Test (IOT) Station in Redu (B) is setup for providing a means to test the satellite functions and performance after launch and separation. The IOV constellation consists of 4 satellites and provides the capability of broadcasting globally a set of navigation signals and other navigation data supporting a number of services. The IOV constellation depicted in Figure 1 is thus the first step towards the final FOC constellation of 30 satellites. On October 21, 2011 the successful launch of the first two GALILEO satellites IOV L1 PFM and IOV L1 FM2 took place initiating the IOV phase followed by successful IOV L1 IOT campaign. On October 12, 2012 the successful launch of the second two GALILEO satellites IOV L2 FM3 and IOV L2 FM4 took place followed by successful IOV L2 IOT campaign.

The training of personnel for the first (IOV L1) and second (IOV L2) launches was based on a Training Need Analysis (TNA) provided by the customer. The main objectives of the IOV L1 and L2 simulations campaigns were to train and validate personnel for all operational phases as well as to validate systems and interfaces. After the IOV L1 IOT campaign, the training plan had to be revised according to changing training needs and requirements imposing a more certification-based training approach. The following section describes the GCC training and certification process applied to the GALILEO satellites of the FOC phase starting with the launch of the GALILEO satellites FOC L3 FM1 and FM2.

The described activities have been carried out under a contract via Spaceopal GmbH within a program of and funded by the European Union. The views expressed in this paper can in no way be construed as reflecting the official opinion of the European Union and/or of the European Space Agency.

The GCC Training and Certification

![Figure 2: The GCC multi-level training and certification process with its three different training process entry categories accounting for different training needs, system knowledge, and operational experience of trainees. The process is planned to be re-started ~7 months prior to each launch assuming a training period ~6 months.](image)
To develop and propose an appropriate GCC training and certification process several post-launch (IOV L1 and L2) requirements have been taken into account from which the most important ones are: (i) changing task-, team- and role-based training needs; (ii) refresher or recurrent training for experienced and qualified engineers to maintain qualification/certification; (iii) possibility of cross- and re-certification; (iv) flexibility regarding training methods and time slots to account for changing resource constraints, trainee and trainer availability; (v) assessment of trainees to measure their system knowledge and qualification progress by means of written or verbal tests and assessment reports; (vi) simulation campaign as the last training method to validate, qualify or certify personnel for real operations; and finally (vii) trainers are assumed to have appropriate training skills and expertise in their training subjects.

Based upon these requirements, a multi-level training approach with three different training process entry levels has been developed.

The process is depicted in Figure 2. The core process starts with the Cat 3 trainee – new employee – who has to go through the whole training curriculum from Level I to IV to achieve the required level of skills and knowledge for certification. So-called training and simulation participation matrices assign roles and trainees to Level I – III courses so that every candidate knows which course she or he has to take. Waivers may be requested for certain training courses if the Cat 3 trainee can prove knowledge and/or former operations experience. Recurrent and delta training as well as training for supporting teams like IT and network operations support is captured by training side processes. If cross-certification is desired the Cat 1 trainee has to step in again on Level II of the process. In case of cross-certification within the Flight Operations team the Cat 1 trainee can directly start with Level III training. The process has to be re-started ~ 7 months prior to each launch assuming a training period of ~ 6 months. In the following, scope and purpose of the training levels are described in more detail.

-  Level I is the GALILEO system overview training with GCS and GMS introductory courses.
-  Level II is meant to be the operations specialist training consisting of task- and role-specific training courses for GCS and GMS teams like the Flight, Ground and Mission operations teams.
-  Level III is an intermediate training level mainly devoted to the Flight Ops team. This level covers satellite subsystem training and is supposed to be done by self-learning.
-  Level IV is the simulations campaign training for final qualification and certification.

A simulations campaign can also be seen as a main validation step of a mission operational validation approach. The satellite and ground simulator is the prime data source for ground segment validation testing, for staff training and for exercising the complete ground system in a predefined series of simulations prior to launch2. The system simulator is also required as a means of validating operational procedures. As already mentioned in the introduction, this approach has been mainly applied to the IOV L1 and L2 training and simulations campaigns. However, FOC simulation campaigns will have to focus on training and certification of personnel. Additional system and operational product validation needs will be covered by delta training, i.e., delta systems and Flight Operations Procedure (FOP) validations performed by qualified operations experts (see Figure 2). For systems and FOP validation purposes, the simulations officer normally setup dedicated validation simulations. For the IOV L2 simulations campaign, training-relevant and validation-relevant simulations have been combined to keep up with the pace of the project. Training and validation simulations can be further used to create training relevant S/C configurations for breakpoints generation. That reduces the time effort to prepare simulations.

Figure 3: The GALILEO operational phases with single, dual- and multi-centers Operations
Simulations Planning and Execution

LOCC and GCC simulations campaigns validate, qualify or certify trainees and teams for the satellite operational phases shown in Figure 4. The simulations campaign plans provided by the simulations officers of each center prior to each simulations campaign defines the total number \( m \) of simulations, the scenarios and the schedule required to train and validate their personnel. In case of a new satellite system (e.g. the FOC SSEG w.r.t. the IOV SSEG) the entire Flight Operations team has to be certified for operating the new satellites, meaning that Flight Ops team members have to re-start the training process on Level III (see Figure 2). The LOCC flight operation team needs to be re-trained and re-validated for the critical LEOPs of the next launches as well, especially for FOC L3 although certification is not required.

The sequence for a simulation \( n \) within the simulations campaign is divided in three major phases: Phase I – simulation preparation; Phase II – simulation execution; and Phase III – simulation follow-up work. The flow or process is presented in Figure 4.

![Figure 4: The applied simulation planning and execution sequence for a stand-alone or multi-control-centers simulation \( n \) with its three distinct phases: I - preparation; II - execution; and III - follow-up work. The simulations campaign is accomplished when the total number of planned simulations \( m \) is reached.](image)

The Joint LOCC-GCC Control Handover Simulation

In order to handover the control of a spacecraft from LOCC to GCC in a controlled and well-structured way the handover phase has been split into the following sub-phases: (i) pre-handover; (ii) handover; and (iii) post-handover phase. The handover of a spacecraft from LOCC to GCC has always to take place in a joint pass that ensures that both control centers have adequate duration, visibility and access to the spacecraft to complete the handover activities. The pre-handover phase is devoted to joint FD activities like orbit determination whereas in the main handover phase the GCC-D flight ops team takes over responsibility by sending first test and up-linking time-tagged commands via the GCS ground stations. The handover phase is formally accomplished when the GCC-D operations director signs off a formal handover report sent by the LOCC operations director. The purpose of the post-handover phase is to archive the entire LEOP Telemetry (TM) and Tele-command (TC) history provided by LOCC.

The main objectives of the command and control handover simulation were to exercise the interfaces between the different teams, especially between the flight operations and the Flight Dynamics (FD) team and to validate operational interfaces and handover operations. Interfaces are required for (a) real-time TM and TC data transfer between LOCC and GCC, (b) near real-time TM flow from GCC to LOCC realized by rapid file transfer, (c) FD data transfer from LOCC to GCC, and (d) voice communication links. For verbal communication between both centers dedicated loops of the voice communication system are used. To train and validate all these interfaces as well as the handover operations in a joint LOCC/GCC inter-control-center simulation the following constraints had to be taken into account: Starting with identical initial S/C and thus breakpoint conditions, choosing a site in which GCS and LEOP ground stations are very close to each other, and finally having an uninterrupted simulation run.

Satellite Simulator

The satellite simulator provides a simulation of the GALILEO constellation of satellites, as well as the ground control network of TT&C stations. For each satellite, the simulator provides a behavioral model which responds to TC and provides down-linked TM information.
The simulator is capable of defining, storing and running a range of constellation satellites and ground station scenarios. These scenarios are to reflect the evolving configuration of the constellation and ground segment as well as failure conditions in various system elements. The simulator will be used by the Operations Team to assist with the validation of operational products as well as providing a training environment to exercise nominal and anomalous operational situations.

Simulation activities play a central role in GCS operations preparation, validation and training pertaining to routine, special and contingency operations. Specifically simulation activities are used in support of:

- development and validation of routine, special and contingency flight operating procedures
- validation of on-board software patches prior to upload to the spacecraft
- simulation of satellite and TT&C failure conditions
- satellite fault diagnosis through the simulation of candidate scenarios
- satellite TM/TC database validation
- new software implementation validation
- operations staff training
- operations rehearsals

Intensive simulation campaigns will be performed prior to the launch of the first IOV satellites and then again prior to the launch of subsequent satellites. In addition a certain amount of simulation activity is foreseen throughout the mission lifetime in support of:

- the training of new operations staff
- refresher training for existing operations staff
- procedure development and validation to enhance operations or accommodate changing circumstance e.g. a satellite failure

It is important that the simulation environment is as representative of the real operating environment as possible in order that simulations are performed with a high degree of fidelity. Individual satellites within the constellation are faithfully simulated using “real” on-board software, provided by the satellite manufacturer, running within an emulated execution environment.

The effects of any injected satellite failures are realistically modeled not just in the unit concerned but also to interfacing subsystems (for example unit failure may cause emergency reconfigurations, battery discharging, LOS at Ground Station, etc.). The orbital behavior of each satellite is simulated in order that the contacts with the simulated ground stations are realistically modeled. This orbit model can also take into satellite delta velocities (Vs) corresponding to maneuvers execution.

The spacecraft simulator generates all housekeeping telemetry that the real spacecraft generates including acceptance/execution of TCs. To respond correctly to TCs and a changing space environment, the spacecraft simulator also contains detailed models for: spacecraft attitude & orbit determination & control, data control & distribution, electrical power supply & distribution, thermal environment & control and additionally provides modeling of the space environment.

The ground simulator models multiple ground stations and simulates not only ground station equipment but also the S-Band space link to the satellites. The simulation of ground station equipment is limited only to those components required to contact the spacecraft (uplink of TC and downlink of TM) and is based on a generic ESA model rather than a faithful representation of the GALILEO TT&C stations.

**Training Management System**

A central Training Management System (TMS) has been introduced to support and manage all training related issues and to ease the steering of the training program. This tool shall be used by trainees, trainers and the training managers as well. Besides functional aspects, the TMS plays a vital role in providing courses, course material and interaction capabilities to all connected sites and trainees.

The TMS is the central interface and access point to all related training activities. The TMS has been installed at GCC-D site and is available to GCC-I (Fucino) site and remote sites via online access. The usage of the tool is restricted to authorized users. User privileges regulate the usage of the system. The TMS tool environment is shown in Figure 5.

**Lessons Learned and Advancements**

After the IOV L2 IOT campaign, the first joint simulations campaigns working group meeting took place at GCC-D to discuss lessons
learned together with the GCC-D training manager and LOCCs/GCCs simulations officers. This section summarizes lessons learned from IOV L1 and L2 real operations having an impact on the definition and configuration of future FOC simulations.

**Constellation flight operations concept**

Nearly all L2 simulations were run with only two S/Cs. Current IOV operations already require the execution of parallel activities for PFM, FM2, FM3 and FM4 satellites. E.g., after the control handover of the IOV L2 second satellite, reduced routine operations already had to start for the first IOV L2 satellite together with the parallel full routine operations execution for the two IOV L1 satellites, indicating that a full IOV and future FOC flight constellation will have overlapping operational phases and the requirement to execute many activities in parallel. Discussions of lessons learned gained from constellation operations of other missions state the training need for constellations flights with multiple S/Cs. To setup an advanced IOV + FOC constellation simulation the L3 simulation timelines will have to consider constellation flight scenarios with 4 or even 6 S/Cs. The distributed version of the simulator is available at GCC-D for the FOC L3 simulations campaign. This version is designed and configured to run in parallel the entire IOV + FOC satellites constellation in one single simulation scenario.

**Multi-control-center operations concepts**

The GALILEO mission operations concept requires single-, dual- and multi-control-centers operations to execute joint activities in the different operational phases.

Many of these activities and operational interfaces have been validated in the IOV L1 and L2 simulations campaigns in the framework of the operational validation concept as described in chapter II and are being proved in the on-going IOV mission phase. In a current human space flight mission personnel are trained and certified in various joint simulations showing that multi-control-centers training and operations is a state-of-the-art approach. However, a constellation flight simulation in an inter- or multi-control-centers environ-
Figure 6: Simplified example of Gantt chart visualizing a timeline of 4-spacecrafts constellation flight with contact operations in parallel

A high degree of automation and autonomy is achieved using a number of novel tools that are integrated into a coherent ground system to perform all required operations functions. In the area of routine task execution, a new multi-control-centers mission planning approach will be applied in the near future to make use of automation capabilities for command sequence generation and SoE execution. The GCC planning facility will create Short-Term-Plans (STP) based on a planning data base containing activity definitions and rules like ground station visibilities. The planning facility then sends the STP to the S/C monitoring and control system that automatically generates all required command sequences for all activities to be executed during the different contacts. To create the command sequences the S/C control system refers to an internal procedure file archive. This automated approach can be used to prepare and execute any future stand-alone or multi-control-centers simulation. The current approach is that a S/C controller, a S/C operations engineer or a trainee has to manually load the FOP command sequences at the S/C monitoring and control system based on the provided STP-based SoE.

Inter-control-centers constellation simulations

The IOV + FOC require more and more training, validation and certification simulations involving more control centers and sites like in real operations during which parallel special operations will be executed together with routine operations on different satellites of the constellation e.g. parallel routine contacts operations on IOV + FOC satellites (involving GCC-D and GCC-I) together with special operations on FOC satellites (involving LOCCs and GCCs). Next simulations campaigns will focus more and more on inter-control-centers constellation joint simulations involving GCCs and LOCCs in the same simulations scenarios.
Conclusions

The currently applied GCC training process accounts for the evolving training needs and resource constraints within the IOV mission + FOC preparation phases. Certification guidelines have been presented which are being successfully implemented in the FOC L3 training process on a very cost-effective basis. Training relies on highly skilled and experienced trainers and training mentors being involved in real operations.

Combining purely training- and certification-based with validation-based simulations as a merged simulation concept seems to be the preferred solution for the fast pace of the project. The merged concept expresses the IOV to FOC specific transition from a validation- to a certification-based simulation approach.

The timeline for the advanced inter-control-centers simulation includes overlapping operations phases and parallel activities for four satellites making IOV simulations much more realistic and advanced w.r.t. constellation flight and multi-control-centers operations. The configuration of the command and control handover simulation can be used as a valuable reference for the setup of any other multi-control-centers simulation.

Future contingency simulations will have to consider more inter-control-centers scenarios failures on constellations satellites and ground parallel operations to better prepare and qualify operations and hosting teams for real constellation contingency operations.

The automated command sequence generation approach will make the preparation of future stand-alone and multi-control-center simulations much more time- and cost-effective and will optimize inter-control-center joint simulations and operations.

Michelangelo Ambrosini is a senior space professional with strong work experience in national and international space industries, agencies, organizations, and associations. His background and expertise are Aerospace, Aeronautical, Astronautical and Space Engineering, Human Spaceflight, Space Exploration, Rocket Science, and Space Mission Operations. His is also an AAS senior member (michelangelo.ambrosini@gmail.com).

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Interdisciplinary Challenges in Space Domain Awareness

A Panel Session of the 2017 AAS/AIAA Space Flight Mechanics Meeting

by Cindy Schumacher

The AAS/AIAA Space Flight Mechanics Meeting held in San Antonio, Texas February 5-9, 2017, hosted a panel discussion on “Interdisciplinary Challenges in Space Domain Awareness.” The theme was addressed by panelists invited from a cross-section of expertise in this field, including established figures and new actors in government, industry, and academia. The panel discussion, organized and chaired by Dr. Marcus Holzinger, Assistant Professor at the Guggenheim School of Aerospace Engineering, Georgia Institute of Technology, was followed by questions from the audience. This special conference session attracted excellent participation, with all seating taken and many additional audience members standing during the nearly 2-hour discussion.

“The purpose of Space Domain Awareness (SDA) is to provide a quantifiable and timely body of evidence about space object behaviors attributable to specific scenarios, hazards or threats, to inform higher-level decision-making processes,” explained Dr. Holzinger. “The emerging field of SDA is by nature interdisciplinary. First, we must assemble evidence in the form of data from a variety of sensors, sensor networks and so-called ‘soft sources’. Second, we must apply rigorous analytical principles to interrogate this evidence in order to obtain a coherent, actionable picture of the overall situation. All investigators recognize that successfully achieving SDA objectives requires a fresh look at existing traditional tools, transfer of techniques from non-traditional fields, development of novel methodologies, and an improved understanding of how decision-makers ingest information and render decisions.”

Dr. Marcus Holzinger, Assistant Professor at the Guggenheim School of Aerospace Engineering, Georgia Institute of Technology, organized and chaired the panel session.

Dr. Paul Schumacher, Principal Investigator in Astrodynamics for SSA Air Force Research Laboratory, Directed Energy Directorate

Dr. K. Terry Alfriend, TEES Distinguished Research Chair Professor, Texas A&M University

Dr. Travis Blake, Senior Manager for SDA, Lockheed Martin Space Systems

Dr. Moriba Jah, Director, Space Object Behavioral Sciences, University of Alabama

Dr. Douglas Hendrix, Chief Executive Officer, ExoAnalytic Solutions

The five panel members are acknowledged experts in their individual disciplines:

DR. SCHUMACHER

Dr. Paul Schumacher has more than 29 years of experience in the military Space Control mission area. He has been with Air Force Research Laboratory (AFRL) since 2005 and is currently the Principal Investigator in Astrodynamics for Space Situational Awareness (SSA) in the Directed Energy Directorate’s Space Surveillance Systems Branch. Prior to 2005, Dr. Schumacher served as Technical Advisor for Operations at Naval Space Command in Dahlgren, Virginia. During his career, he has collaborated with every branch of service in the Department of Defense (DoD) and with many civilian Government agencies in solving Space Control problems. He is an
Associate Fellow of AIAA and has served on AIAA’s Astrodynamics Committee on Standards since 1995. He has served several terms with the AAS Space Flight Mechanics Committee, and is a charter member of the AAS Space Surveillance Technical Committee.

**DR. ALFRIEND**

Dr. K. Terry Alfriend is the TEES Distinguished Research Chair Professor of Aerospace Engineering at Texas A&M University. He is well known for his many years of diverse experience in the aerospace business, including research, development and management in the private sector, government, and academia. Dr. Alfriend is a member of the National Academy of Engineering, a Fellow of the AAS and AIAA, and a member of International Academy of Astronautics. He has served as Editor-in-Chief of both the AAS Journal of the Astronautical Sciences and the AIAA Journal of Guidance, Control, and Dynamics. He has received the AAS Dirk Brouwer Award and the AIAA Awards for Mechanics and Control of Flight as well as Guidance, Navigation and Control.

**DR. BLAKE**

Dr. Travis Blake is the Space Domain Awareness Senior Manager at the Advanced Technology Center (ATC) of Lockheed Martin Space Systems Company. He provides management and oversight for ATC’s internal research and development investments, as well as for contract R&D programs in all aspects of Space Battle Management/Command, Control, and Communications. Dr. Blake retired from the Air Force as a lieutenant colonel. Most recently in that service he served as a DARPA program manager in the Space Domain Awareness portfolio, before completing his military career at the Office of Science and Technology Policy within the Executive Office of the President.

**DR. JAH**

Dr. Moriba Jah is the Director of Space Object Behavioral Sciences at the University of Arizona. His research has applications to Space Domain Awareness, Space Protection, Space Traffic monitoring, and Space Debris risk assessment. Dr. Jah is a member of the U.S. delegation to the United Nations Committee on the Peaceful Uses of Outer Space and chairs the NATO SCI-279-TG activity on defining a Common NATO Space Domain Awareness Operating Picture. He serves on the Astrodynamics Technical Committee of the International Astronautical Federation and is a permanent member of the Space Debris Technical Committee of the International Academy of Astronautics. Dr. Jah has been elected a Fellow of the International Association for the Advancement of Space Safety, the AFRL, the AAS, and the Royal Astronomical Society, as well as an AIAA Associate Fellow and IEEE Senior Member.

**DR. HENDRIX**

Dr. Douglas Hendrix is Chief Executive Officer and co-founder of ExoAnalytic Solutions, Inc., the developer, owner, and operator of the ESpOC global telescope network. For 25 years, Dr. Hendrix has developed advanced software solutions to help the United States maintain its technological superiority in electro-optical visible-band and infrared sensing for missile defense and SDA. ExoAnalytic Solutions operates a global SDA telescope network producing, each month, more than two-million high-quality, real-time, observations of man-made space objects in GEO, HEO, MEO orbits. Using 50+ telescopes on 4 continents, ExoAnalytic collects astrometric and photometric measurements that are sold to U.S. Government and commercial customers.

The session began with short opening statements from each of the panelists:

**DR. SCHUMACHER**

Dr. Schumacher offered the opinion that achieving reliable and efficient Space Traffic Management (STM) in the future will require us to revisit a variety of fundamental technical questions, and may be the main driver for future SDA developments. He said that, to date, all our knowledge of the space object population and our operational requirements for space surveillance have been loosely quantified in terms of the three attributes of Accuracy and Timeliness of our orbit estimates and Completeness of our catalog of known objects. “These categories are insufficient for comprehensive STM, since the latter calls for real-time decisions having specified (or at least known) probabilities and confidence levels for the outcomes,” Dr. Schumacher explained. “In the current space cataloging system, probabilities and confidence levels cannot be calculated rigorously. Hence, in the future we must consider new attributes of our Space Domain Awareness related to Uncertainty Quantification and to more rigorous probabilistic analysis.” Dr. Schumacher posed the following questions to illustrate his point about fundamental issues related to STM:

What accuracy and precision do we need in our orbit estimates for every space object for STM?
What methods of orbit uncertainty quantification do we need for STM?
What statistical support (sampling) do we need in our orbit estimates for STM?
Should we use traditional least-squares batch estimation, Kalman-type sequential estimation or some other method entirely for STM?
What methods of sensor data uncertainty quantification do we need for STM?
What methods of tracking and data association should we adopt for STM?
What processing design and computing architecture do we need for STM?
Should we think in terms of maintaining a slowly changing catalog of space objects or continuously building a rapidly changing catalog? Dr. Schumacher also pointed out that the U.S. military is in much the same position now with STM as it was with air traffic management in the early 20th century before commercial aviation grew to be a significant part of the nation’s economy. “We can expect STM to follow a development over time similar to that of air traffic management,” he said. “We will see the establishment of some type of comprehensive civil authority for traffic management, which must be coordinated in increasingly complex ways with the on-going military traffic management. At the same time, we can also expect a large growth in the military mission of protecting the nation’s growing economic investment in space systems, just as in the air domain.”

**DR. ALFRIEND**

Dr. Alfriend continued the conversation with some principal SSA challenges such as Uncertainty Realism, Sensor Characterization, Orbit Estimation, UCT Correlation, Nuisance Objects, and Non-SSN (Space Surveillance Network) Sensors. “An incorrect covariance can result in the wrong decision,” said Dr. Alfriend. “Doubling the size of the position, covariance can increase the probability of collision by 3 or 4 orders of magnitude. Hence, covariance realism is critical for conjunction assessment. Moreover, military’s SSN radar observations used to maintain the space catalog are not real observations. They are the output of a smoothing process at the sensor site, interpolated and reported at specific times. The result is a set of observations that are highly auto-correlated, having slowly varying biases and little noise, which are then modeled in the catalog orbit updates as uncorrelated, zero-mean Gaussian values. SSN sensor error statistics are obtained by tracking a few objects for which we have precise ephemerides a priori and obtaining residuals with the operational estimates. However, these calibration observations are processed and reported the same way as all the other observations. A major source of radar error is the ionosphere. These effects are a function of latitude, elevation and time of day, but the sensor calibration variances do not reflect these facts.”

“How can we improve this situation?” asked Dr. Alfriend. Mentioning that every object in the catalog starts as a UCT (Un-Correlated or unassociated Target), he noted that when the Space Fence and the Space Surveillance Telescope become operational, the number of UCTs will dramatically increase. Dr. Alfriend suggested that non-SSN sensors could probably enhance SDA, particularly for high-altitude space objects. “This needs to seriously be considered,” he said. “In proposing future algorithms and approaches, it is important to understand that the JSpOC (Joint Space Operations Center) astrodynamics algorithms will have to be used to maintain a catalog of 100,000 to 150,000 objects instead of the current 22,000.”

“What happens if orbit state covariances are incorrect?” Dr. Alfriend said. “We need a correct representation of the uncertainty. The primary problem in SDA is that there are a large number of targets, and a large number of sensor returns. It is not known with certainty which returns come from which object (the data association problem) and a particular object may not be in the field of view of a sensor for protracted periods of time, which further aggravates the data association problem. The number of objects being detected may not be known a priori and can vary over time.”

He explained further, “The SDA problem is an example of a multi-target multi-sensor (MTMS) tracking problem. However, the scale of the problem is enormous because of the large number of space objects, which tremendously complicates the data association problem. The MTMS-tracking problem can be framed by any of several advanced techniques as a recursive Bayesian filtering problem in which the size of the state (the number of objects) can vary in a random fashion.”

**DR. BLAKE**

Dr. Blake began with a history of SDA and how it evolved. He talked about Space Intelligence, Space Surveillance, Hyper-Spectral Image processing, Space Surveillance Telescope, DARPA’s Orbit Outlook program, STM, and Planetary Defense. “Space is now routine, including the warfighting” Dr. Blake said. “The effective understanding of the threats associated with the space domain which could impact the security, safety, or economy of the United States belongs to the whole of government, not just to the DoD. We need shared awareness with foreign partners and commercial entities as well.”

Based on his military experience, Dr. Blake identified common characteristics among Maritime Domain Awareness, Air Domain Awareness, and Space Surveillance. “We must have an understanding that requires close coordination across the United States Government to better integrate intelligence information and surveillance data,” Dr. Blake explained. “It is necessary to have analysis that is related to all domains in order to facilitate a shared situational awareness across federal, state, local and tribal governments plus private entities and foreign partners that have aviation security responsibilities.”

“The military SSA mission and SDA are connected,” Dr. Blake noted. “SSA defines situation awareness informally and intuitively as ‘knowing what’s going on’ and more formally as the perception of the elements of knowledge in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future. SDA is then integrated founda-
tional information that allows the necessary responses and actions. Understanding the natural connections among the Maritime, Air, and Space Domains makes SDA more routine.”

The principle challenges Dr. Blake described in SSA, SDA, and STM are making progress on the policy, authority, indemnity, resources and framework for the civil agency, and the technology of operator-centric, low-cost sensors, diverse sensors, and autonomous sensors, as well as Big Data analytics that engage the senses. “Big Data drives progress in the other domains for effective, efficient space management,” he said. “The United States requires space capabilities to project national power. National security is space security! One of the critical challenges moving forward is to prove the value of our technology to increase space security. This necessitates the need for a quantitative framework with value-driven metrics.”

DR. JAH

Continuing the discussion of issues in SSA, SDA, and STM, Dr. Jah considered the implications of good stewardship of the space environment. “We should have unhindered, low-cost, easy, and long-term access and use of the space environment,” said Dr. Jah. “Warning, protection, attribution of loss, degradation, interruption of space services, capabilities, or the ability to predict, quantify, and assess the behavior of objects in space is foundational.”

Dr. Jah likened the Space Frontier to the old Wild West. “There are little-to-no-rules and no real-estate deeds,” he exclaimed. “What should be the regulated geographical and social factors, values and attitudes? The potential to make lots of money is like the Gold Rush. Lack of easier and cheaper access to space is seen as a barrier; yet, what if New Space is not following the paradigm of traditional space actors? The result is that the risk of operating in space is rising!”

Current barriers in the SDA community, according to Dr. Jah, could include the well-known ‘tragedy of the commons’. In space, we have a shared-resource system where individual users acting independently according to their own self-interest behave contrary to the common good of all users by depleting resources through their collective action. “Investors believe it is somebody else’s problem,” he said. “Funding is greatly uncoordinated and there is uneven technical competence to assess proposed solutions. Moreover, academia is absent from the conversation! Current efforts focus on putting out daily fires, not the problem we will have in 5-10 years from now.”

Discussing today’s SDA problems, Dr. Jah suggested better space guidelines, policies and regulations. “There is a great need for openness, transparency, diversity, and sharing,” he said. “STM needs a thriving commerce in infrastructure and safety as well as some sort of taxonomy that enables meaningful space object classification. Examples include Track Custody requirements, Orbital Safety and Long-Term Sustainability of Space Activities as well as Space Laws, Policies, and Rules of the Road.” Dr. Jah proposed bringing scientific inquiry, rigor, and resources to the pressing questions at hand; developing new solutions from state-of-the-possible to a refreshed state-of-practice; providing so-called ‘Track II Diplomacy’; and delivering a modern, resilient workforce.

DR. HENDRIX

“In order to achieve SDA and be able to exploit it as a community for, among other things, STM, we must think about timely, high-quality, Big Data availability; human-in-the-loop versus automated data processing; legal policy enforcement; and collaboration, coordination, and communication,” said Dr. Hendrix. “SDA is not a sparse-data problem. Big Data equals volume, velocity, veracity and complexity and requires new tools to be developed. It’s not enough to just brand this a Big Data problem. You need to be an expert in the domain details such as real-time collection processing and dissemination. Knowing that a maneuver was required yesterday, is useless.”

Dr. Hendrix discussed the human-in-the-loop versus automated data processing. He said that the level of automation is increasing in land, sea air and space. “Self-driving cars are a reality today, as are self-flying airplanes,” he noted. “Telemetry, Spacecraft Navigation, STM, Autonomous Spacecraft Navigation and customers with different needs interact at different levels of this layered data model. When processing supports decision-making, it must not lag the decision timeline. It needs to move to real-time automated processing. When processing supports decision making, it must be correct. Therefore, we need to have humans in the loop.”

Regarding legal policy enforcement, Dr. Hendrix told the audience, “If you are in this room right now, it is up to you to educate policy makers, otherwise policies will be made by an uninformed few. Data collection, analysis, and reporting merely provide the evidence. The legal, economic, and policy infrastructure is lagging technology. Policy guidelines should be developed based on well informed models of space traffic backed by a sufficient quantity and quality of evidence.”

The importance of SDA and STM collaboration, coordination and communication was emphasized by Dr. Hendrix as being a collaborative process from launch through disposal. “Coordination enables proactive versus reactive SDA,” he said. “For example, reacting to maneuvers versus sharing flight plans. Real-time dissemination of space monitoring information enables efficient awareness to inform
future decisions.”

FINAL QUESTION
Dr. Holzinger presented the final question of the session: “What non-traditional fields, methods, or techniques should our emerging researchers and graduate students look to for inspiration in addressing complex and wide-ranging problems in SDA?” Each of the panelists responded with insights. Mentioned repeatedly were Machine Learning, Artificial Intelligence methods, approaches used in Cyber-Defense, Cyber-Physical Systems, and the general fields of Psychology and Cognitive Engineering.

“Quality data is very important,” said Dr. Blake. “The psychology and science of human decision-making is of great importance to the field.” Dr. Jah added, “Statistical consistency is important. Plus, we need to talk to the United Nations.” Dr. Alfriend said, “We need really good physics in space!” Dr. Schumacher noted, “This San Antonio conference itself has offered valuable interdisciplinary information. For example, the physics of the sensors is a topic which is very important to astrodynamics as an engineering discipline and is a bridge to the more purely scientific problems in this field.”

Reflecting back on the panel discussion afterward, Dr. Holzinger concluded, “I believe the key to the success of the panel was the collegial participation of panelists representing new and established players in the SDA world, from government, industry, and academic perspectives.”

First High School Student Presentation, Ever!

At the 2017 AAS/AIAA San Antonio Space Flight Mechanics Meeting

by Cindy Schumacher

Chloe Baker, the first high school student to present a paper in this AAS/AIAA conference series, is a senior at La Cueva High School in Albuquerque, New Mexico. This past summer, Baker was an intern for Dr. Alan Lovell at the Air Force Research Laboratory (AFRL) in Albuquerque, New Mexico. At the end of the internship Dr. Lovell offered her the opportunity to present her work at the AAS/AIAA Winter Conference in San Antonio this past February. This was a completely new experience for Baker, and, though it was nerve-wracking, she is thankful for the insight and knowledge that she gained.

“Everyone at the conference was very professional and supportive, not to mention incredibly intelligent,” Baker said. “My project at AFRL was Solving Systems of Polynomials for Aerospace Applications. The purpose is to demonstrate the possibility of utilizing non-linear least squares (NLLS) techniques to solve over-determined systems of high-order equations. The work done on this project included the application of NLLS to initial relative orbit determination (IROD) and radio-frequency time-difference-of-arrival (TDOA) estimation. Our efforts produced solutions of systems of polynomials of degree three in as many as six variables. In order to test the precision of the method, we generated cases using user-defined initial conditions. These ‘true solutions’ were propagated forward to derive the several equations to be solved by our method. NLLS was preformed, the final equations were solved using advanced software, and the resulting solutions were compared to the original cases that generated the problem. Elimination of spurious solutions followed, by comparing various cases run on the same objects. The results were mixed. For the three-variable cases, including more observations in IROD reduced the effect of error. For the six-variable cases, this trend was not as obvious and further testing is necessary. However, the NLLS is a promising method to allow unbiased, batch processing of the maximum number of observations for accurate aerospace estimations.”

The two main achievements of this work are the batch inclusion of additional observations and the incorporation of nonlinear models. Though least squares approximation is not a new concept in orbit determination, existing methods work with linearized models because solving high-degree, multivariable systems can be inexact and tedious, and may result in many spurious solutions.

“Therefore, one must either use fewer observations with more exact equations (second degree), or use inaccurate linear equations,” Baker noted. “The latter option results in higher process error while the former is more susceptible to measurement errors. Fortunately, with the advent of more effective software, solving high-degree equations has become much more feasible and therefore, researching
nonlinear adaptations of least squares approximation is a worthwhile pursuit.”

Once they are able to solve complex systems resulting from NLLS operations, Baker and Lovell needed to find the true solution among the many solutions produced. Though in simulations they can simply compare the true conditions used to generate the problem to the solutions produced, in actual scenarios there must be a way to deduce the true solution. Baker explained, “Iteratively this can be done by considering only real, finite, and feasible solutions or by propagating each one forward. However, it is far more efficient and reliable to mathematically determine directly which solution is true.”

This work is of utmost importance considering the increasing number of space objects and the existing need to perform precise complex space-based missions. It is necessary to employ the most accurate methods of orbit determination and geolocation. To continue the efforts of Baker’s proposed method, her future work will include:

• Testing the six-variable code further to determine the usefulness of this application of NLLS;
• Programming a logical, non-iterative disambiguation script for eliminating spurious solutions;
• Modularizing the system of scripts for a user friendly interface;
• Developing a method to assign larger weighting factors to more accurate or higher quality observations.

Baker and her team are continuing to investigate the efficiency and accuracy of their work, including solidifying their disambiguation methods, and comparing their techniques to state-of-the-art standards. Her paper was supported by Dr. Alan Lovell, Dr. Kenneth Horne-man, Andrew Harris, Alex Sizemore, and Caroline Young.

Currently in her senior year of high school, Baker competes with the Speech and Debate team in Duo Interpretation, Public Forum Debate, and Lincoln-Douglas Debate. She is also president of Key Club, a community service organization, and the National English Honor Society. She has competed in Science Olympiad and is a member of Math Honor Society (Mu Alpha Theta). Her passion for learning has led her to take advantage of the rigorous classes available at La Cueva High School, and she is an AP Scholar and a National Merit Semi-Finalist. Her physics and calculus teachers have inspired her daily to explore the many applications in the STEM field.

Moving forward, Baker just finished applying to study engineering at several colleges and is anxiously awaiting decisions.

Chloe Baker, the first high school student to present a paper in this AAS/AIAA meeting series, is a senior at La Cueva High School in Albuquerque, New Mexico.

Cindy Schumacher is a journalist from Maui, Hawaii. She currently writes for the Lahaina News and Maui Economic Development Board. She has written numerous articles on topics related to space science, and has covered national and international conferences including the annual AMOS (Advanced Maui Optical and Space Surveillance Technologies) Conference.
2017 Goddard Symposium - “Future Space: Trends, Technologies and Missions”

by Mike Calabrese

The 55th Robert H. Goddard Memorial Symposium was held March 7-9, 2017, at the Greenbelt Marriott in Greenbelt, Maryland. This annual event is sponsored by AAS and supported by the NASA Goddard Space Flight Center (GSFC) in honor of Robert H. Goddard, the father of modern rocket propulsion.

On March 8 participants were welcomed by Alan DeLuna, AAS Executive Vice President, who introduced opening speaker Matt Mountain, President, Association of Universities for Research in Astronomy (AURA). Mountain compared images from Hubble to those from Ansel Adams with both having “emotional connections.” He referred to Hubble as the “most productive science machine in human history” and indicated that the public has a “tremendous interest in what NASA does” and that NASA needs to continue to inspire. He posed the question, “are we alone” in a universe with “$2 \times 10^{23}$ stars,” and indicated that our “search for life is enabled by exploration,” although a “telescope 2-3 times bigger” than Hubble is needed.

Chris Scolese, NASA GSFC Director, recognized the recent passing of Phil Sabelhaus, Marty Davis, Neil Gehrels, and Piers Sellers with a video tribute highlighting their incredible accomplishments for NASA and the Nation.

NASA Administrator (Acting) Robert Lightfoot referred to the Symposium title as “right on target for where we are and what we are trying to do,” and then characterized NASA at the “intersection of commercial, government, and international partnerships.” He reviewed current and future human and science exploration missions, and referred to “Human Exploration and (not or) Science.” He reminded us that “everyone of us can share our story…and talk about what we can do.”

Douglas Terrier, Chief Technologist (Acting), NASA Headquarters moderated a panel on NASA Leadership in the Future of Science and Technology which included Steve Jurczyk, AA for the Space Technology Mission Directorate, Gale Allen, Chief Scientist (Acting), and Thomas Zurbuchen, AA for Science.

Luncheon speaker Senator Gary Peters (D-MI), Member, Space, Science, and Competitiveness Subcommittee cited the importance of our investment in science and technology and indicated that a “robust commitment to exploration and discovery is critical to our future as a nation.” He described recent legislation in support of this objective which included the American Innovation and Competitiveness Act, The NASA Transition Authorization Act, The Space Weather Research and Forecasting Act, and The Scientific Integrity Act.

Alan DeLuna presented eight AAS Awards for 2016 which included the Space Flight Award for Robert Meyerson, President of Blue Origin, and awards to the LRO Mission Team, Destin Sandlin, SERVIR, AURA “HST & Beyond” Committee, Kenneth Hodgkins, and Monique Laney. The Honorable Kathryn Sullivan received the JFK Astronautics Award, and Debra Facktor Lepore and Renato Zanetti were recognized as new AAS Fellows.

Bill Gerstenmaier, AA for Human Exploration and Operations moderated a panel on International Exploration and Private Sector Development of Space. The panel included Gilles Leclerc, Eric Stallmer, and Mary Lynne Dittmar. Gerstenmaier noted that “deep
space exploration requires the best from all of us.”

Marcia Smith, Founder and Editor, SpacePolicyOnline.com, chaired a panel on the Political Environment. Panelists included Frank Mooring, Chris Shank, Nick Cummings, and Tom Hammond. Mooring posed the question of “what is the business case for space?” Shank cited the importance of “public private partnerships” in the transition. Cummings described the details of the NASA Authorization Bill which speaks of going boldly in space. Hammond spoke of NASA and the Private/Commercial community, not either, and the need for sustainable steps, not a race.

The closing spotlight was delivered by Sophia Porter, JHU, 2015 National Space Club and Foundation Keynote Scholar, who spoke to Painting a New Picture: The Art of Science.

On March 9, Chris Scolese introduced Opening Speaker Karen St. Germain, Director, Office of Systems Architecture and Advanced Planning, NOAA/NESDIS, who described the combined capabilities of GOES-R and JPSS in providing foundation environmental data for NOAA and the Nation. St. Germain described NOAA efforts to “architect the future with flexibility, response to evolving technologies, and economical sustainability.”

Colleen Hartman, Director, Sciences and Exploration Directorate, NASA GSFC, moderated a panel on Upcoming Missions with Big Science Payoffs. The panel included David Spergel, Ken Farley, Jerry Werdell, and Elsayed Talaat who provided updates and status reports on the WFIRST mission, the Mars 2020 Rover, PACE, and the Solar Probe Plus mission.

Gregory Chirikjian, Professor, JHU moderated a panel on Exploration Telepresence – Almost Like Being There, which included Dan Lester, Mark Lupisella, and Kelsey Young. Chirikjian spoke of “Humans and Robots needing and helping each other.” Lester described a “low latency virtual reality” with human telepresence in orbit to direct robots on a planetary surface with communication times of one second or less versus five seconds from Earth. Lupisella spoke to the tradeoffs between robotic autonomy and human supervision. Young described geologic extra-terrestrial field science enhanced with telepresence enabling flexible and faster execution.

Luncheon Guest Speaker Roger Launius spoke to the value of Space Exploration in a Distracted Culture from a historical perspective. He referred to the question of why do we need human exploration of space? He proposed three reasons: to discover if we are alone in the universe; to develop our capability for human interplanetary travel; and to preserve this planet and this species by travelling off the planet with some subset of our population.

A Spotlight on Space-Based Environmental Intelligence was presented by Sandra Smalley, NASA GSFC, with a video conversation recorded in 2016 with Piers Sellers and Leonardo DiCaprio highlighting the value of environmental data in understanding Earth’s changing climate.

Brian Weeden, Technical Advisor, Secure World Foundation spoke to China’s plan for space and traced the development and plans of the Chinese Space Program and the parallels with the U.S. Space Program.

Harley Thronson, NASA GSFC, moderated a panel on Cislunar Space: The Next Frontier for Human Exploration which included Matt Duggan, Rob Chambers, Steve Overton, Michael Fuller, and Michael Johnson. The panelists discussed the cislunar orbit stepping stones as a gateway to deep space human exploration.

A closing conversation was provided by Chris Scolese, John Grunsfeld, Sam Scimemi, and Jonathan Malay.

Complete video coverage of the Symposium and selected presentations may be viewed at www.astronautical.org.

**Mike Calabrese is retired from the NASA Goddard Space Flight Center and has been a member of the Robert H. Goddard Memorial Symposium Planning Team since 2000.**

**Photos courtesy of Bill Hrybyk, NASA Goddard Space Flight Center**
Snapshots of the 55th Goddard Symposium

All Goddard Symposium photos courtesy of Bill Hrybyk, NASA Goddard Space Flight Center

Matt Mountain
Harley Thronson, Planning Committee Chair
Sandra Smalley

Exploration Telepresence Panel
NASA Leadership Panel
Cislunar Space Panel

Karen St. Germain
Upcoming Missions Panel
Brian Weeden and Stephen Garber

Eric Stallmer
Sophia Porter

Closing Conversation with Jon Malay, Sam Scimemi, John Grunsfeld, and Chris Scolese
Honors and Awards Luncheon

Robert Meyerson (right) receiving Space Flight Award from Alan DeLuna

Dan Irwin for SERVIR, Earth Science and Applications Award

The Honorable Kathryn Sullivan, John F. Kennedy Astronautics Award

Kenneth Hodgkins, Advancement of International Cooperation Award

Monique Laney, Eugene M. Emme Astronautical Literature Award

Renato Zanetti receiving AAS Fellow Plaque from David B. Spencer at SFMC Meeting

Felix Hoots receiving Dirk Brouwer Award from Jeff McMahon at SFMC Meeting

John Keller for LRO Mission Team, Neil Armstrong Space Flight Achievement Award

Alan Dressler for HST & Beyond Team, Carl Sagan Memorial Award

Destin Sandler, Sally Ride Excellence in Education Award

Debra Facktor Lepore, AAS Fellow

Join us March 13-15, 2018, at the Greenbelt Marriott in Maryland for the 56th Annual Robert H. Goddard Memorial Symposium! We hope to see you there!
NOTES ON A NEW BOOK

William Leitch: Presbyterian Scientist and the Concept of Rocket Space Flight, 1854–1864

Reviewed by Michael Ciancone


The only machine, independent of the atmosphere, we can conceive of, would be one on the principle of the rocket. The rocket rises in the air, not from the resistance offered by the atmosphere to its fiery stream, but from internal reaction. The velocity would, indeed, be greater in a vacuum than in the atmosphere, and could we dispense with the comfort of breathing air, we might, with such a machine, transcend the boundaries of our globe, and visit other orbs.

Such were the words of the Reverend William Leitch in the last of a series of essays … written in 1861. Who would’ve thought that a science-minded Presbyterian minister in Scotland would raise the notion of rockets operating in a vacuum decades before others would seriously begin to explore the idea?

I was first approached by Robert Godwin about this obscure and unattributed quote in Space Travel by Kenneth Gatland and Anthony Kunesch (1953), which he had traced to the Reverend William Leitch, a Presbyterian minister in nineteenth-century Scotland. The quote (extracted above) proposes the use of rockets in space more than forty years before the first appearance in print of Konstantin Tsiolkovsky’s proposal for the exploration of space using reactive devices. Needless to say, I was a wee bit skeptical of the technical basis of this quote and suggested that Leitch might have been speaking allegorically and had perhaps engaged in a bit of poetic license. I was also curious about the educational background that might have prepared Leitch to credibly engage in scientific discussions of his era.

Godwin has tracked down details about the life, education, and avocation of Leitch, as well as providing historical context and an examination of his interaction with contemporaries, to produce an image of an educated and well-informed man with a keen interest in the sciences who was not shy about tackling a wide variety of issues. His sermons must have been fascinating! Godwin also provides ample footnotes and illustrations to guide the reader who wishes to explore further.

With this additional information, it is clear that Leitch’s rocket reference represented more than idle speculation, but rather was part of a well-developed view that played out in discussions on the plurality of worlds. Leitch organized his ideas in a series of essays that provided a virtual tour of the solar system. The “rocket” essay, “A Journey through Space,” was in fact the twelfth in the series. Although the rocket was a means of conveyance for the journey, not the focus of the discussion, Leitch seems to have understood the principles of a rocket operating in vacuum. This is significant because the idea of rocket propulsion in a vacuum was not widely accepted, even within scientifically literate audiences of that era (as Robert Goddard also discovered in editorials responding to his 1919 monograph). Other essays in the series addressed topics such as “The Moon—Is It Inhabited?” “Lunar Landscape,” and “Discovery of the New Planet Vulcan.” Godwin also provides a discussion of these essays and other lectures and presentations by Leitch, as well as a brief history of rocket development, to place the essays in historical context and allow him to assess influences.

While Leitch’s interests and activities in nineteenth-century Scotland are unlikely to draw comparisons with the adventures of Jamie Fraser in Outlander or Connor MacLeod in Highlander, this book offers substance to a claim of primacy in the evolution of ideas. Robert Godwin is to be commended for his inquisitiveness, diligence, and persistence in raising awareness of William Leitch within the spaceflight history community. I would recommend this book as an interesting read, especially for students of the history of rocket development for spaceflight.

Michael Ciancone is a space safety engineer in Houston, Texas. He also serves as chair of the AAS History Committee and a member of the IAA History Group.
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Thank you for your continued support!

2017-2018 AAS Schedule of Events

May 9-11, 2017
Humans to Mars Summit
George Washington University
Washington, D.C.
www.exploremars.org

May 29-June 1, 2017
IAA Conference on Dynamics and Control of Space Systems (DyCoSS)
RUDN-University
Moscow, Russia

June 9-11, 2017
Student CanSat Competition
Tarleton State University
Stephenville, TX
www.cansatcompetition.com

June 19-21, 2017
International Workshop on Satellite Constellations and Formation Flight (IWSCFF)
The University of Colorado
Boulder, Colorado
http://ccar.colorado.edu/iwscff2017

July 17-20, 2017
International Space Station Research and Development Conference
Omni Shoreham Hotel
Washington, D.C.
www.issconference.org

August 20-24, 2017
AAS/AIAA Astrodynamics Specialist Conference
Skamania Lodge
Stevenson, Washington
www.space-flight.org

September 25-29, 2017
International Astronautical Congress (IAC)
Adelaide Convention Centre
Adelaide, Australia
www.iac2017.org

October 24-26, 2017
Wernher von Braun Memorial Symposium
The University of Alabama in Huntsville
Huntsville, Alabama
www.astronautical.org

March 13-15, 2018
Robert H. Goddard Memorial Symposium
Greenbelt Marriott
Greenbelt, Maryland
www.astronautical.org
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