

**Payload Operations Center – Lessons from Commercial Engagement****Bobby J. Watkins<sup>a\*</sup>, Rebecca J. Buckles<sup>b</sup>, Kevin C. Kasperitis<sup>c</sup>**<sup>a</sup>NASA Marshall Space Flight Center, Mail Code HP01, Huntsville, AL, 35812, United States, [bobby.j.watkins@nasa.gov](mailto:bobby.j.watkins@nasa.gov)<sup>b</sup>NASA Marshall Space Flight Center, Mail Code HP26 Huntsville, AL, 35812, United States, [rebecca.j.buckles@nasa.gov](mailto:rebecca.j.buckles@nasa.gov)<sup>c</sup>NASA Marshall Space Flight Center, Mail Code HP21 Huntsville, AL, 35812, United States, [kevin.kasperitis@nasa.gov](mailto:kevin.kasperitis@nasa.gov)**Abstract**

The International Space Station (ISS) Payload Operations and Integration Center (POIC) at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, United States, has gone through an evolution from supporting exclusively government ISS users to providing 50% (or more) of their support to commercial users. At the same time, they have expanded ground and facility operations to support a United States Orbital Segment crew expansion from three to four astronauts allowing an additional of 34 hours crew time per week. These additional hours are dedicated to utilization and have already surpassed the 100 hour peak weekly milestone in July 2018. This paper discusses the Center's changes in planning, staffing, coordination, and operations while addressing topics from the addition of secondary flight control positions to dynamic operations product reviews. MSFC's Human Exploration and Development Operations Office, which manages payload operations, seeks through this paper to highlight the higher priority commercial users now receive in replanning and in additional crew time.

**Acronyms/Abbreviations**

CASIS	Center for Advancement of Science in Space
Comm Dash	Communications Dashboard
DFP	Dataflow Planner
DESI	DLR Earth Sensing Imaging Spectrometer
DMC	Data Management Controller
EXPRESS	Expedite the Processing of Experiments to the Space Station
FCT	Flight Controller Team
HOSC	Huntsville Operations Support Center
IP	ISS International Partner
ISS	International Space Station
JSC	Johnson Space Center
LSG	Life Science Glovebox
MSFC	Marshall Space Flight Center
MSFC GC	MSFC Ground Control
MSG	Microgravity Science Glovebox
MPSR	Multi-Purpose Support Rooms
MUSES	Multi-User System for Earth Sensing
NRCSD	NanoRacks ISS CubeSat Deployment
OCRs	Operations Change Requests
OC	Operations Controller
Ops Lead	Operations Lead
PARC	Payload Activity Requirements Coordinator
PAYCOM	Payload Communications Manager
PD	Payload Developer
PIM	Payload Integration Manager

POD	Payload Operations Directors
POI	Payload Operations and Integration
POIC	Payload Operations and Integration Center
POIWG	Payload Operations and Integration Working Group
POM	Payload Operations Managers
PPM	Payload Planning Managers
PREP	Product Readiness and Enhancement for Payloads
PRO	Payload Rack Officer
RIM	Research Integration Manager
RISE	Revolutionize ISS for Science and Exploration
S/G	Space-to-Ground
SME	Subject Matter Expert
STP	Short Term Planning
SYSCON	System Configuration Controller
TBE	Teledyne Brown Engineering
TSC	Tele-science centers
TCO	Increment Lead Timeline Change Officer
TIPS	Timeline Integration Product Summary
VoIP	Voice over Internet Protocol

## 1. Introduction

For 58 years, MSFC's capability and expertise have been at the forefront of design and operations in human spaceflight. In 1961, MSFC's Mercury-Redstone vehicle boosted America's first astronaut, Alan B. Shepard, on a suborbital flight. MSFC's first major program was development of the Saturn rockets, the largest of which boosted humans to the Moon in 1969. In 1973, Saturn rockets lifted Skylab, the first US-crewed space station into orbit. MSFC was responsible for the scientific experiments and the development of the Skylab Orbital Workshop. In 1975, a Saturn rocket lifted the Apollo spacecraft into Earth orbit for the historic linkup with the Russian-Soyuz spacecraft. That mission also included experiments provided by MSFC scientists.<sup>i</sup>

In the early 1980s, the Huntsville Operations Support Center (HOSC) began its vital role in supporting Shuttle launches. In 1983, the first Spacelab (a reusable laboratory managed by MSFC personnel), launched in the payload bay of the Space Shuttle. One of the beneficial components that came out of Spacelab includes a multiple-user rack system created by MSFC. Today's ISS racks, called Expedite the Processing of Experiments to the Space Station (ExPRESS) racks, provide structural interfaces, power, data, cooling, water and other items needed to operate science experiments.<sup>ii</sup>

*"Spacelab served as a precursor to the space station because it taught scientists how to design, integrate and operate experiments in an orbiting laboratory."*

*- Rick Rodriguez, retired ISS Payload Operations Manager*

Another facility developed from successes on Spacelab, the Microgravity Science Glovebox (MSG), was installed on the ISS in 2002. The Life Science Glovebox (LSG), discussed in more detail later in this paper, will be installed in October 2018.

From 2001 to present day, the Payload Operations Integration Center (POIC), located within the HOSC at MSFC, has been the primary NASA ground facility responsible for integrated payload planning for the ISS, operations product development, and payload flight control and ground operations.

The ISS Expeditions have achieved some impressive utilization statistics since December 1998:

- More than 100 countries/areas have participated in ISS Research projects - demonstrated in Figure 1 ISS Research Participation

- More than 2,441 total investigations have been initiated
- More than 1,829 investigations have been completed<sup>iii</sup>

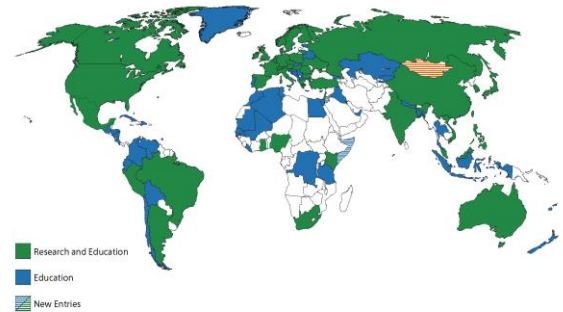


Fig.1 – ISS Research Participation.

The ISS has contributed to the international understanding of the capabilities needed to live and work in space and spurred the development of commercial space transportation with more than half of the ISS's cargo capabilities provided by commercial providers as of June 2018. Major commercial developments aboard the ISS, beyond the visiting vehicles, include commercial external payload platforms and small satellite deployers to life sciences gloveboxes, 3D printing, and commercial pharmaceutical experiments. Brief discussions of just a few of the more than 330 current investigations, conducted by over 660 scientists, payload developers (PDs), and commercial programs, are presented throughout the paper. The examples highlight successes and lessons learned in comparison to operations sponsored solely by government and academic institutions before initiatives to change the customer focus began in 2014.

In May 2013, the ISS Program received a challenge to shorten the payload integration template. The general mandate to the team was to completely transition ISS culture and processes from "assembly" mode to "science discovery/commercialization" mode. The challenge was called RISE (Revolutionize ISS for Science and Exploration). Although progress was slow to adjust while sustaining payload operations, commercial use of the ISS increased and science achievements multiplied along with MSFC's POIC improvements in preparation, staffing and execution.

*In August 2014, the ISS Program manager chartered a dedicated team to reengineer core ISS Processes, including tools and activities, to align with the ISS mission and vision.*

## 2. Planning

Historically, NASA's ISS processes focused on space station assembly, but since 2014, the ISS culture has been evolving through the RISE initiative to better support customers in the Science, Technology, Exploration, and Commercial ventures. As part of this, the Payload Integration and Operations (POI) function at MSFC worked to understand the needs of our commercial customers in relation to the various planning stages. This section discusses improvements the POI made to enable all PDs earlier integration into operational processes. This led to more efficient research for all the current and future investigators. A few tools POI developed to advance real-time engagement are also demonstrated. The RISE initiative impacted the culture and integration from all groups involved in the ISS research program. The improvement in payload-centric roles and responsibilities for planning, design, development, manifesting and operations of ISS payload experiments and facilities is spread across many NASA Centers including NASA Headquarters, the Langley Research Center, Goddard Space Flight Center, Glenn Research Center, Ames Research Center, Kennedy Space Center, and the White Sands Test Facility. Integration from all the centers and numerous tele-science centers (TSC) is required for successful Payload Operations. In particular, the Johnson Space Center (JSC) is central to vehicle and systems integration and the POI at MSFC integrates the science and research efforts across the country and around the globe. The POI also includes the HOSC and all of its essential ground control functionality and data distribution services required by all payloads. Many of the unique software tools and operational processes discussed in this paper were created through the integrated efforts of flight and ground control personnel.

Starting early in the planning processes, the Research Integration Manager (RIM) and the Payload Integration Manager (PIM) are positions that facilitate the connection between ISS program elements. The RIM, in particular, works with PDs, Mission Operations, and Payload Operations to enable the research integration goals of a payload once it is identified by the program. In many cases, the two positions play an integral role in the process of identifying and manifesting a PD's experiment during the concept, design, manufacturing, and development phases.

The PIM is the payload-specific integrator who ensures the successful integration of a PD's hardware from the design or the manufacturing phases to the myriad of systems – from safety to data distribution.

The PIM works with the MSFC operations positions to qualify the payload through safety gates and collect HOSC's blank book data to enable integration with ISS facilities. They manage the initial resource requests and coordinate the users with the providers.

The PIM and RIM commercial engagement connection is evident in many areas from fit testing, data compliance and integration, utilization testing to operations product development, and crew training products. Commercial payloads can be challenged with design and hardware development constraints early in the process. Oftentimes they are working on shorter development templates than their government and academic counterparts and must meet aggressive vehicle manifesting targets. They may also have unique requirements for data distribution because of proprietary or sensitive science technology transfer issues. The PIM, in conjunction with the ISS Research Integration Office, will work to ensure a commercial payload has the appropriate support from the operations community and the facility project offices while enabling PDs to comply with the rigor of utilization testing and documentation.

The operations community relies on the integration expertise of the RIM and PIM positions to proceed through expedited processes and provide consistency that is essential to efficient operations. The RISE initiative and lessons learned, both created insight leading to modified processes and stronger interfaces with the POI.

The Operations Lead (Ops Lead) is a harbinger for development of operational products for ISS science and research. This position works closely with commercial investigators at the initial stages of concept development and they eventually become the POI's Subject Matter Expert (SME) on their assigned payload complement. Every payload has an assigned Ops Lead who gains operational knowledge about the science objectives and its real-time activities on board the ISS. The Ops Lead's early involvement and insight qualifies them to complete the required tasks including procedure authoring, developing crew and Cadre training, conducting product reviews, and supporting payload integration into other ISS systems. The Ops Leads work to closely align the PDs and other stakeholders with executable operational products. This is one of the clear successes, demonstrated time after time, when accelerated commercial payload initiatives are presented to the POI.

The Ops Lead ensures robust planning requirements are documented and works closely with planning and operations positions to transfer universal and unique details of payload operations. Collaboration from the Ops Lead team to other POI disciplines from planning to training has enhanced

the flow of information required to experiments on ISS.

Another position central to the success of commercial payload integration is the Payload Activity Requirements Coordinator (PARC). The personnel in this position are the mission planning interface to the investigators. They coordinate with users to ensure feasibility and correctness of payload planning requirements and resolve problems associated with templates and user inputs. Because the PARC develops the planning inputs for all NASA payload racks and facilities regardless of the location on the ISS; they are critical to payload successes in all the ISS laboratories from the US Lab to the Columbus and JEM modules. The influx of commercial payloads with shorter planning and development templates led to process improvements initiated by the PARC team. The team accommodated accelerated templates and unique development and operational needs with integrated communications. They worked independently, and together with PDs and teammates, to create new product standards and processes. In particular, the PARC team revised their product review system in the POI configuration management system. The review system for delivery of baselined planning products used by the PARC team created a new level of process-oriented dexterity for the reviewer. While their efforts are generally pre-flight in the payload development process, the successes they earned were the precursor to the real-time process improvements and lessons learned.

*“Part of what we do is manage the resources on the space station for the investigations. We looked at the resources we have on the ground and ways we could be more efficient.”*

*~Katie Presson/Payload Operations*

The improvements, precipitated by the fast-paced needs of commercial PDs, to existing planning resources and tools, impacted multiple positions throughout the POI. With up to 200 investigations operating aboard the ISS at any time, and nearly half of them from the commercial sector, it was important to modernize the POI methods for planning and communication.

*“Improving the flow of information helps solve issues faster,” Presson said. “We created a timeline handover application and a communications dashboard where notes about investigations are integrated with the timeline of scheduled activities and everyone is literally on the same page.”*

The Payload Operations Managers and Directors (POM/POD) led the flight controller teams in an effort to analyze how the POIC functioned and specifically searched for potential improvements. The team decided to streamline communications to efficiently exchange important information between POIC’s planners, investigators, and the flight controllers who are on duty the day those experiments happen. Tools were developed with the payload customer’s participation and specific consideration toward the imminent increase in the Payload operations tempo. The team simultaneously developed the requirements and tested the functionality in simulations as new tools were deployed and eventually approved several new innovative and effective communications methods used in the POIC today.

A timeline handover application and a communication dashboard tool are discussed to provide insight into two of the most essential tools created to enhance information transfer in the control room environment.

POI developed the Timeline Integration Product Summary (TIPS) application, represented in Figure 2, to provide flight controllers and payload investigators with a method to communicate and to view specific details for each scheduled payload activity. The tool provides a consolidated resource for users to enter information that is useful for the real-time execution team. It is used to prepare for activity support, provide handover information between shifts, and document essential planning and operational reference material required during every execution shift. It is updated automatically by the planning software and manually, when required, by the users.



Fig. 2. TIPS Report Example

The POIC Communications Dashboard (Comm Dash) is a consolidated tool that combines a configurable view of all the communications tools onto one screen. The tool can be uniquely configured to the console position or flight controller

preferences. The individual tools can also be displayed separately when desired. *Figure 3 – Comm Dash Layout* shows a representation of three of the windows that can be used to consolidate information into one console display.

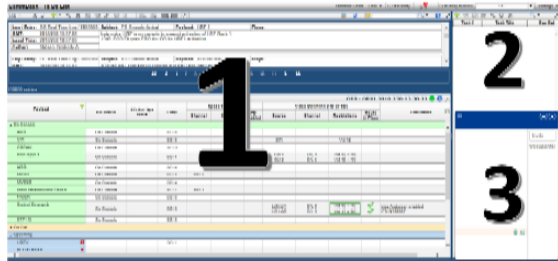


Fig. 2. Comm Dash Layout

One of the most frequently used tools available in the *Comm Dash* suite, and usually displayed on the POIC's video wall, is the *PD Status Display*. This display shows a summary of payload teams supporting active and upcoming mission operations on the current day. It allows users to quickly obtain information that was previously coordinated over voice loops. This visual communication tool frees the voice channels for other needed coordination. The display is populated through a combination of Flight Controller input and automated synchronization with planning software. The display is available to all Flight Controllers and designated payload investigators through a restricted web-based interface.

The PD Status Display is divided into the several sections as demonstrated in *Figure 4 – PD Status Display*:

- a. *Payload and PD Status*: This portion of the display provides insight into which payload investigators are in their work location (On Console) and ready to support operations. It also gives insight into which payload investigators are on-call, have upcoming operations, or have already completed their operations for the day.
- b. *Loop*: This field indicates the voice channel where the payload investigator may be contacted.
- c. *Space-to-Ground (S/G)*: If the investigator will be speaking directly with the ISS crew, the particular S/G voice channel will also be shown. There are four S/G channels available. Displaying the channel assignments in this tool ensures the ground teams know which channel to follow for each payload. Several methods exist to establish communication between the ISS crew and the payload investigators, for

example, a phone connection or Voice over Internet Protocol (VoIP). In addition, the channels may be privatized between only the ISS crew and the payload investigator. This information can be found in the "Config" column. The "PD enabled" column shows when the connection is made between the payload investigator and ISS crew.

- d. *Video Downlink*: The video capability and configurations are also displayed. This includes the video source (location on ISS), which downlink channel will be used (there are six available), and any needed restrictions (for proprietary or private medical experiments).

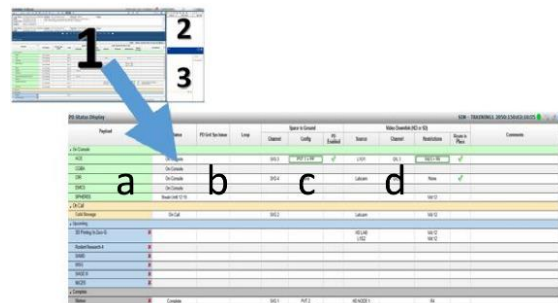


Fig. 3. PD Status Display

Using lessons learned from a previous application, the POI collaborated with the HOSC's software design team and developed new software to enhance, modernize, and streamline the processing of Operations Change Requests (OCRs) – the real-time POI Configuration management tool. OCRs, are generated for a variety of reasons to affect changes in the operational products and timelines and is regularly used to request scheduling changes for payload activities, update crew procedures, specify payload commanding, ground process documentation, and update training conducted on ISS.

Previously, OCRs were only available through specialized software that had to be individually loaded onto certain computers. Using lessons learned from legacy applications, the POI personnel developed requirements that would facilitate engagement with commercial investigators and other ground personnel. MSFC Contractors integrated these requirements in a web-based tool, which is accessed via SharePoint. This new capability was especially convenient for commercial users with dynamic teams and limited access to HOSC services.

Ultimately, the desired end-result was achieved and the team initiatives and tool improvements enabled flight controllers and payload teams to request, distribute, review, approve, or modify

operational changes requests from any PC that can access the POIC SharePoint. Real-time tools are essential for communication but the POI also coordinates change initiatives with the entire payload community through daily, weekly, and large semi-annual meetings.

The Payload Operations and Integration Working Group (POIWG) is one of the main forums for integrating commercial investigators, PDs, and POI personnel. This conference is hosted twice a year by MSFC's Payload Operations Integration team.

Dozens of scientists and engineers from around the world will join NASA team members at the next biannual POIWG meeting scheduled to occur October 23-25, 2018. This event gives PDs, investigators and project managers the opportunity to coordinate processes and schedules and to review the status of commercial/academic/institutional payloads currently operating on the ISS or on an upcoming manifest.

During this forum, investigators interact closely with the POI flight controllers, organization representatives, and other Payload and industry teams. The overall ISS program direction and upcoming capabilities are also discussed, along with PD feedback, lessons learned, and potential upcoming improvements. PD Teams, other NASA Control centers, and ISS International Partner (IP) representatives attend large forum and small group discussions to help inform the community about modified or new capabilities and processes. Many participants attend for information only or to conduct splinter meetings and work one-on-one with their POI colleagues. There are also opportunities to learn about other payloads and dedicated time is allocated for special topics like external payload statuses, new tools, innovative training sessions, and problem solving with key players like the HOSC Ground Systems and specialized subject matter expert teams.

### 3. Staffing

The origin of MSFC's mission control room personnel, now referred to as the Cadre, began long before ISS. Throughout the 1980s and 1990s, MSFC supported payload operations for the Space Shuttle's Human Space Flight Program. During designated missions, a Spacelab module was flown inside the Payload Bay. It served as an extended laboratory for astronauts to conduct multiple experiments over the length of a Space Shuttle mission. When MSFC was designated as the control center for ISS payload operations, the center used expertise gained with Spacelab to form a new ISS support center - the POIC. Since 2001, the POIC has supported the ISS operations 24 hours a day/365 days a year. The POIC interacts continuously with other NASA centers, TSC

in universities and commercial offices and control rooms throughout the United States and in mission control facilities for CSA, ESA, JAXA, and Roscosmos. Much like Houston's ISS Flight Controller Team (FCT), the team at MSFC expanded on legacy positions to designate the call-signs and responsibilities for ISS payload support, with minor modifications.

*"We wanted to allow flight controllers to take more ownership of the work we do ... These are professionals who train and practice for months. They have the knowledge, and now the responsibility, for executing routine operations without taking up valuable time to track down and get approval from the shift leader. The whole point is to become a more efficient group."*

*~ Tim Horvath, Payload Operations Manager*

The Ames Research Center for instance, has seen a rise in investigation collaboration. The center provides a research platform, the Wetlab RNA SmartCycler, for conducting real-time quantitative gene expression analysis aboard the ISS and attracts a dynamic list of interested scientists and investigators.<sup>iv</sup> As investigations increase, and changes in personnel are noticed, the POI planners, trainers, and operators react deftly and adjust to meet the needs of the customers.

In fact, collaboration between NASA centers and IP agencies have benefited through cooperative research between commercial users, scientists, and POI personnel. Since 1998, IP partner collaboration has continued to steadily increase.

Since the POIC support infrastructure was first conceived, there has been a steady increase in the number of international and commercial payloads operating on the ISS. The ISS crew expansion from three USOS crew members to four crew members also increased the number of commercial opportunities for research. More than 232 people from 18 countries have visited the ISS that has hosted more than 2,400 research investigations from researchers in more than 103 countries since June 2018. In anticipation of this higher demand for customer payload support, the POIC Cadre formed a leadership team to evaluate the existing functions, roles, and responsibilities. The efforts of the team resulted in completely new positions, SME positions based on Cadre heritage and experience, and requisite duplications in staff support for the existing Cadre. The evolution of the Cadre from the original grouping in 2000 to the current configuration is demonstrated in Figure 5. The changes ensured the

Cadre's enhanced roles and responsibilities would meet the growing complement of commercial, international, and NASA payload investigators.

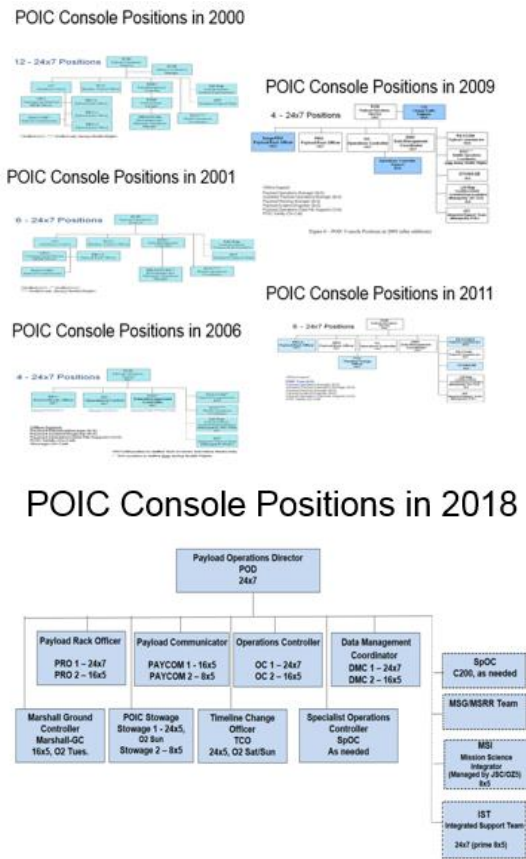


Fig. 5. Current Cadre Org Chart

Accelerated templates for commercial payloads preparing for ISS operations, from manifest, to science collection, to sample return, was a clear driver that led POI to an effective process improvement. Specialist OCs were organized to combine some functions of the Operations Controller (OC) and Ops Lead positions to provide a vital integration and leadership role for the ISS Program, POIC, PDs and commercial customers. The experience requirements for SME roles are unique and upheld through the hiring and training phases for new or existing employees. The candidates hired demonstrate expert knowledge to efficiently facilitate safe execution of payload operations, have the ability to apply advanced team communication skills, and prove an inherent capacity to analyze complex payload integration scenarios and lead anomaly resolution. All SMEs are selectively assigned to specific payloads or groups and the inherited responsibilities often include both the traditional real-

time OC role and the pre-increment tasking done by an Ops Lead.

The complexity and unique support requirements of specific PDs or Payload Investigators are used to determine the need to designate a payload SMEs and will be used to stand up additional teams in the future. The specialists from all discipline teams support pre-flight product development and real-time timeline execution for first time and complicated operations of their team's payload complement. While in the control room, they ensure ISS resources are configured and ready to support real-time payload operations. The induction of subject matter experts in the Cadre is an improvement to the POIC staffing concept.

*"Through proven expertise, the Cadre's specialist teams are able to efficiently develop and integrate operations products and bridge the gap between the science community and the flight control teams."*

*~ Damon Self, Team Lead*

Another improvement to the POIC control team was the relocation of an MSFC Ground Control (MSFC GC) representative from a back room location to the primary control room where the rest of the team supports real-time operations.

The MSFC GC is a new position in POIC intended to bring the HOSC ground systems expertise into the POIC control room. The position monitors real-time payload operations and leads ground system troubleshooting. The MSFC GC, previously known as System Configuration Controller (SYSCON), has always been key to providing commercial payload teams with expert support for all ground system related issues. Now, they have expanded roles and responsibilities including, but not limited to, monitoring real-time operations, leading ground system troubleshooting, and control of the enablement process allowing payload investigators to talk directly with the crew on the S/G loops.

*"The Marshall Ground Control expertise will be right there in the room and can address the problem immediately."*

*~ Tim Horvath, Payload Operations Manager*

In addition to the newly formed positions described above, existing positions in the POIC were augmented with extra team members. The OC, Payload Communications Manager (PAYCOM),

POIC Stowage, Data Management Coordinator (DMC), and the Payload Rack Officer (PRO) now staff two positions on most days with crew activities. A flexible division of payload responsibilities was created based on where the research is being conducted and to balance the activities at each console.

The transition from one to two people (and at times more) in certain positions and the overlapping support was a successful attempt to increase situational awareness. It was a logical growth from compounding lessons learned. As the crew complement grew and payload activities increased in numbers, often topping over 100 hours of crew time in a single week, the possibility of a loss in situational awareness also increased. The paradigm shift stemmed from the ever-growing need for “single-case based staff augmentation” to the norm of the high operations tempo. The new Cadre is now prepared for consistently robust timelines instead of making staffing decisions based on short-term activity predictions. The transition was seamless because several years of reacting to need for increased staff fleshed out the division of duties logic. During the decision making process the POIC leadership and Cadre designed and executed tailored simulations and tested all aspects of the Cadre interactions. The simulations and real-time testing of the changed processes provided opportunities for all flight controllers to evaluate and improve communications techniques and operations skills through carefully designed training exercises.

The POIC support positions, working in a non-real-time environment, were also impacted by the influx of new payloads and the need to accommodate more commercial users of the ISS. In 2011, a new team was formed to ensure all of the products were ready to support operations. The Product Readiness and Enhancement for Payloads (PREP) team consists of leadership positions from each discipline that corresponds to the equivalent control room position. The driving purpose of this team is to assume the timeline review responsibilities so the Cadre can focus on real-time execution of payload activities. Another focus of the team is to review and disposition OCRs to ensure all of the execution products are ready to support the crew and ground activities. The PREP Team is now responsible for the maintenance of crew procedures, integration of payload commanding, ground process documentation, and training product updates for all NASA research conducted on the ISS. The creation of the PREP team and the corresponding shift in responsibilities is one of the largest undertakings based on lessons learned the POIC has experienced since the ISS assembly phase was completed.

In 2016, a Special Studies Team was formed to assess the tasking that could be offloaded from the real-time team to allow them to maintain acute situational awareness during current operations. The team’s analysis yielded the following changes that were implemented incrementally in 2017:

- The PREP team is responsible for timeline reviews up to the day before execution (E-1) instead of handing over technical review and change processes three days before execution (E-3)
- New PREP team support was added for the primary front room positions: PREP OC, PREP DMC, and Increment Lead Timeline Change Officer (TCO).
- New Multi-Purpose Support Rooms (MPSR) were added for the tactical Dataflow Planner (DFP) positions, the Stowage Support teams, POIC Safety, Visiting Vehicle Support and generic use space for additional flight controllers and product testing.

The Short Term Planning (STP) room was reconfigured to include additional Payload Planning Managers (PPM) who focus on weekly plans and alternate (slip) plan development. The lead positions for the OC and DMC teams also moved into the STP area and are providing enhanced subject matter expertise for timeline development. The additional Cadre support demonstrated an immediate and noticeable reduction in timeline fidelity and readiness for real-time execution.

Lastly, the Operations Support Manager (OSM) is a key, cross-cutting function in the ISS Payload Operation and Integration community. This senior systems engineering position provides key support to the Payload Operation Directors. The personnel selected for this role are leaders chosen from the POIC cadre and provide experience in all aspects of payload operations from planning and training to ISS systems knowledge. Their broad knowledge and delegated authority provided a new level of management to the dynamic processes required to prioritize and execute ISS utilization goals.

The OSM performs extensive operations integration management across the POI disciplines to bring a recommended solutions to the Operations Directors Office for final approval. The focus of their efforts involves developing, evaluating, and integrating operational procedures and constraints, and reviewing flight products, ISS Program Change Requests (CR).

The increase in flight control personnel has improved support for, and real-time access to, the commercial payload teams in all phases of

operations. It has also provided increased flexibility to support and maximize the science objectives. The decision to augment the Cadre was not only a reaction to the increase in ISS utilization; it was driven by the commercial payload development needs and unique interface requirements. Existing employees analyzed and tested and the functionality improvements while providing uninterrupted support of payload operations. The solutions started with a simple think tank and focused on streamlining processes, procedures, and the fundamental questions surrounding legacy processes: Is a labor-intensive process necessary? Are existing reports and deliverables providing information or value? Will new staffing allow teams to unite in solving problems or increase efficiency?



Fig. 6. POIC Control Room Images

The staffing improvements set the tone for realigning the existing work and the foreseeable growth in ISS Payload Operations. The changes, in the spirit of RISE, represent a revolution from the “way things were” and met the challenge presented to the POIC. Considerations for crew safety, vehicle safety, and experiment hardware safety as keys to mission success were always the priority when changes were conceived, tested, and ultimately implemented.



Fig. 6. POIC Control Room Images

#### 4. Payload Operations: NASA Partner Built Facilities, Consortium Management and Commercial Endeavors

MSFC has partnered with nearly every major aerospace company involved in U.S. space initiatives, beginning with early rocket programs and extending through the Space Shuttle, ISS, and other programs. MSFC has developed hardware and provided services in partnership with many NASA control centers in the US and worked with our international partners in the European Space Agency (ESA) and the Japanese (JAXA) space programs. The center is the primary integrator of NASA’s science operations and enables space research and the hardware and operations development efforts across multiple disciplines ranging from microgravity research to remote Earth sensing to human biology. Over many years of contracting with industry, academic institutions, and international space agencies, the POIC is expanding commercial engagements and making strides to enable more science from the aerospace industry leaders to the companies developing better, more efficient pharmaceuticals. In partnership with NASA, many more companies are now able to conceptualize, design, and build hardware for deployment to the ISS.

One commercial company, Teledyne Brown Engineering (TBE) in particular, shares the same city as MSFC and has recently partnered with NASA to enhance the operations side of their space business with the Multi-User System for Earth Sensing (MUSES.) TBE designed, built, owns, and operates, under a Cooperative Agreement with NASA, this Commercial Remote Sensing Platform on the ISS. It is a Facility Class Payload that hosts up to four attached instruments that can be installed and removed in-flight. The MUSES Mission Architecture

provides key services to customers and low cost access to space and a reduced integration/verification process for Payload operations as a service. The host payload will be designed to collect, analyze and distribute hyperspectral data from Low Earth Orbit (LEO). The facility was launched on June 3, 2017 on SpaceX-11 and has had no hardware failures after 1+ years of operations. It is currently fully operational and ready for hosted payloads.<sup>v</sup>

TBE applied its own corporate resources to analyze the need for advanced imagery services that could be uniquely provided by the ISS. They initially partnered with ISS architects and the JSC to build and launch a platform that would meet the needs of the customers they envisioned. Throughout the hardware design and building, operational planning, and launch and installation phases of their platform they worked with the operations experts in the POIC to understand the eventual reality of day-to-day operations. Beyond the platform itself they also had to prepare for the arrival of their first commercial customer DLR Earth Sensing Imaging Spectrometer (DESI) – yet another cooperative agreement with another ISS user.

*Payload Operations as a Service - Our model-based architecture for planning and operations tools enable rapid delivery of end-to-end payload operations services for both free-flying and ISS payloads<sup>16</sup>.*

*“All support provided by MSFC and the ISS Program was critical for MUSES success on-orbit.”*

*~ Paul Galloway, Multiple User System for Earth Sensing (MUSES), Program Manager*

TBE and the German Space Agency (DLR) partnered to build and operate DESIS from the TBE-owned MUSES Platform on the ISS. DLR developed the canister and instrument to meet MUSES Platform interface requirements and TBE provided integration services, flight hardware for integration, and a MUSES emulator for testing at DLR. The DESIS instrument was successfully launched on June 29, 2018 on SpaceX-15 and installed on the MUSES platform in August 2018.

Over years of design and development, working with corporate contracts and now commercial partners and vendors, MSFC learned its strength in operations and integration is a cornerstone of success for commercial aerospace endeavors. The early days of tele-science have been improved many times over and remote users can more easily interface with our

resources to achieve the results they seek. In the case of the MUSES Earth imaging platform, shown in figure 7, TBE can accommodate high-resolution digital cameras, hyperspectral imagers, and can integrate precision pointing and other analysis instruments.<sup>vi</sup> Although TBE provides a world-class control center of their own, they will connect to the ISS directly through the MSFC’s Payload Operations Integration Center (POIC) and utilize NASA’s multifaceted network of resources required to command and control their platform.



Fig. 7 MUSES Platform

Increasing partnerships and the requirements to be better, more efficient, and more customer friendly have been a driver for MSFC’s process improvements. The POIC engages with the commercial world and is meeting growing commercial demands by lending expertise in areas from concept, design and manufacturing, to safety analysis and onward to operations on the ISS. The integration with TBE, in the case of MUSES, allowed the company to further commercialize their platform and bring on their first user – or customer.

DESI, although they may have customers of their own, is a customer of TBE, who is now a customer of the MSFC. Partnerships are expanding and through the POIC’s commercial engagement the MSFC enables the collection of more science, better information transfer, and quicker, more efficient use of the data gathered, analyzed and applied to programs around the globe.

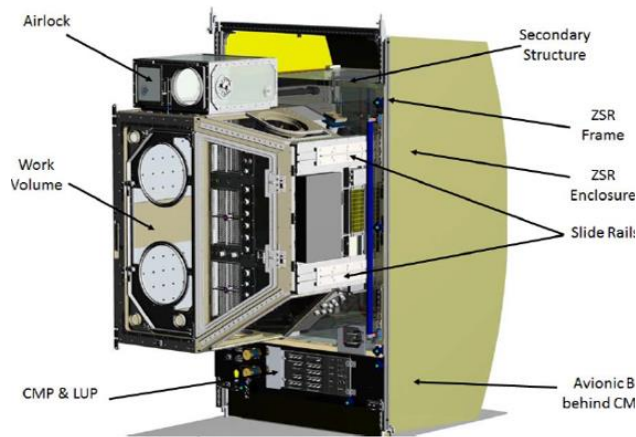
The LSG was developed to provide additional science and utilization capability beyond the existing ISS facilities. Like the original glovebox facility (the Microgravity Science Glovebox [MSG]), the LSG facility provides a sealed work volume for performing crew-operated investigations, which require isolation from the ISS cabin atmosphere. Payload facilities and resources have often been limited; the need and potential use of an additional glovebox was increasingly evident over years of documented lessons learned.

The LSG enables the science community, and ISS crewmembers, to conduct more life sciences’ oriented experiments in cell, insect, aquatic, plant, and animal developmental biology in a contained environment that is maintained at a slightly negative pressure relative to the ISS habitable volume. The

enclosed volume of the glovebox is approximately 18 cubic feet (one-half cubic meter), which is almost twice the size of MSG.<sup>vii</sup>

While the MSG supports only single crewmember operations, two crewmembers can use the LSG workspace at the same time, using glove ports that extend into the environmentally controlled work area. LSG includes some familiar and expected resources and doubles the ISS program's capacity for glovebox services to PDs. Air circulation, through activated charcoal filters, allows for chemical absorption. The requisite clean workspace, and a separate high-efficiency air filter, removes particles and aerosols that can potentially contaminate or preclude the desired science. The LSG can also be used with Laboratory Support Equipment - including the Bar Code Reader and an incubator.

The LSG unit comes complete with a vacuum cleaner, a video monitor, two video cameras, and internal illumination, including two spotlights. Temperatures inside the LSG can be regulated to 18-27°C (+/-1°C) allowing further use of the design components collected based on anticipated science scenarios, lessons learned, and the growing needs of commercial PDs.



LSG with Airlock attached and Work Volume (WV) Extended (extends approx. 31.6").

Fig. 8. Life Sciences Glovebox

The facility includes experiment-generic equipment, tools, and sample kits, a Cryosystem Vial Freezer (a -180°C freezer, accessed through the Habitat Access Door), and a Passive Dosimeter (a repositionable sensor located inside the work volume of the LSG to measure biologically active space radiation during an experiment). All of those features

will meet the growing commercial payload demands for on-orbit analysis.<sup>viii</sup>

One of the early users of the LSG facility will be the Center for Advancement of Science in Space (CASIS). NASA awarded them the responsibility of stimulating interest and managing the U.S. National Lab as a platform for basic and applied research onboard the ISS. They support the US government-funded National Laboratory established in 2011, with principal research facilities located in the United States portion of the ISS. They inspire, solicit, and enable science projects from academia, government, and commercial venues. The CASIS commercial connections continue to grow and enable space science projects, demos, and experiments. As an integration organization, they have worked with companies like COBRA PUMA Golf to design material science vibration testing experiments. Their efforts will lead to improvements in the company's manufacturing and product development. More recently, the CASIS and the United Nations partnered on a unique opportunity to take advantage of the ISS's vantage point and develop a hyperspectral imager capable of improving life on Earth. All of the CASIS ISS payload endeavors have been closely coordinated with POI personnel to combine operational requirements with science objectives.<sup>ix</sup>

*The Center for the Advancement of Science in Space (CASIS) and Teledyne Brown Engineering (TBE) today announced a sponsored program up to \$4.5 million, offering researchers the ability to propose flight project concepts for the International Space Station focused on remote sensing and Earth observation. Within this opportunity, up to \$1 million will be available for researchers to support sensor development. Prospective awardees will utilize the Multi-User System for Earth Sensing (MUSES) platform, developed and managed by TBE. This funding opportunity will run through December 7, 2018.*

*~ Press Release KENNEDY SPACE CENTER (FL), August 20, 2018*

One of upcoming CASIS commercial partnerships will capitalize on the resources provided by the LSG facility to advance pharmaceutical science. Celestial Immunity is an experiment proposed by Sanofi Pasteur, the vaccines division of the multinational pharmaceutical company Sanofi. The experiments will seek to utilize elderly and younger donor peripheral blood mononuclear cell (lymphocytes and monocytes) stocks to evaluate

whether gravity-regulated immune pathways are affected by age. They will be evaluating multiple immunomodulators that target unique immune cell populations and signaling pathways to gain a broad understanding of the impact of gravity on overall human immune function and to potentially uncover novel immune pathways.<sup>x</sup>

The POIC managed LSG facility will be launched aboard the JAXA HTV7 mission and installation is expected in October 2018. The goal of the facility is to provide a growing pool of commercial users, like those organized by CASIS, with opportunities to continue research on the ISS.

“In an ongoing effort to foster commercial activity in space, NASA has selected 13 companies to study the future of commercial human spaceflight in low-Earth orbit, including long-range opportunities for the ISS.

The studies will assess the potential growth of a low-Earth orbit economy and how to best stimulate private demand for commercial human spaceflight. The portfolio of selected studies will include specific industry concepts detailing business plans and viability for habitable platforms, whether using the space station or separate free-flying structures. The studies also will provide NASA with recommendations on the role of government and evolution of the space station in the process of transitioning U.S. human spaceflight activities in low-Earth orbit to non-governmental enterprises.”<sup>xi</sup>

NASA chose NanoRacks as one of the 13 companies to provide commercial users with access to the ISS laboratories. The company already has a variety of facilities on station from the NanoLabs to the CubeSat deployers. To date their CubeSat deployment campaign has launched more than 180 small satellites as part of their mission to provide a commercial gateway to space.

*NanoRacks provide everything you need to get your research and discovery mission underway on the ISS... and beyond... 700+ Payloads launched to date.*

*~ <http://nanoracks.com/>*

In the past, small satellites of a certain class have been launched by rockets as piggyback satellites. When a rocket can launch extra weight other than its main satellite, piggyback satellites are given their seats in the rocket and are thrown into the orbit after the main satellite is successfully deployed. The advantages of launching satellites from the space station by robotic arm compared to piggyback on a rocket include the option to choose the best timing of

the small satellite’s ejection without affecting the main satellite’s timing. With limited space for small satellites to piggyback on rockets, the space station provides the additional benefit of having regularly scheduled cargo resupply flights on which the small satellites can more readily travel.<sup>xii</sup>

The NanoRacks ISS CubeSat Deployment (NRCSD) program provides the commercial sector the ability start a satellite program, build constellations, and run low-cost technology demonstrations. NRCSD, shown in figure 9 deploying small satellites, is a self-contained CubeSat deployer system that mechanically and electrically isolates CubeSats from the ISS, cargo resupply vehicles, and the ISS crew. The NRCSD design is compliant with NASA ISS flight safety requirements and is space qualified.<sup>xiii</sup>



Fig. 9. CubeSat Deployment

The POIC shares in the CubeSat program success and continues to learn lessons along with NanoRacks and their commercial customers. A dedicated specialist team provides support for pre-flight ISS integration, on-orbit operations, and post-flight or re-flight phases. The POIC teams, from Safety and Planning, to the commanding and operations positions (DMC/PRO/OC), and the JSC FCT along with NASA’s International Partners enable the CubeSat campaigns to succeed and grow. A new generation of CubeSats will soon be launched using the largest permanent commercial addition to the ISS – the NanoRacks Airlock – Bishop.

NanoRacks as a commercial venture does not stop with innovative uses for the ISS external environment. They provide other commercial PDs services inside their laboratories. The Research Platform 3, Centrifuge, Plate Reader, Microscope, and other facilities enable their customers to explore and develop repeatable microgravity research experiments. NanoRacks’ Platform-3 opens doors to low-cost biological microgravity research opportunities in the US National Lab onboard the

ISS. Their modular designs provide a plug-and-play platform interfacing with the ExPRESS rack computer and data downlink systems and provide the ability to share results with other users or protect for proprietary storage and transfer of experiment results.

As a facilitator for commercial companies, NanoRacks teaches potential users how to interface with station hardware, understand the NanoRacks platforms, and how to build a NanoLab Payload. They enable creativity and science objectives to expand through experimentation and reaction to both expected and surprising results. The POIC is reliably at their side to ensure that crew procedures are written to exacting standards, stowage locations are secured and managed, operations are executable and collected science is meticulously distributed as designed or required.

The emergent list of NASA Programs, ISS partners and commercial engagements continues to grow. NASA recently selected 16 companies to provide a diverse range of competitive task-order contracts for serving the research and engineering products and services needs of the ISS. Research, Engineering, and Mission Integration Services (REMIS) is a multi-award contract with indefinite-delivery/indefinite-quantity, firm-fixed price and cost-plus-fixed-fee line item numbers. The contract began on September 6, 2018 with a five-year base period and work statements include the ability to solicit spaceflight and ground hardware and software, sustaining engineering functions, engineering services, payload facility integration, and research mission integration and operations services on a commercial basis, with minimal involvement of the government.

The contract was developed for use by NASA's International Space Station Program (ISSP), but may be utilized by other NASA organizations or federal government agencies through a mutual agreement with the ISSP.<sup>xiv</sup>

The selected companies represent a cross-section of states including Alabama, Colorado, Florida, Maryland, Ohio, Indiana, Texas, Virginia, and Wisconsin.

## 5. Conclusion

A qualitative characteristic of the POI is to react quickly and enable the success of all payload endeavors. Payload investigators and supporting organizations around the world depend on the operations and integration expertise provided by the POI. Notwithstanding the increase in commercial investigations, the POI is dedicated to all payload customers and their needs. When payload facility anomalies occur, the expertise of the diverse MSFC workforce can assist the POI to evaluate for safe

recovery, adjust for planning constraints, contribute to troubleshooting plans, and address possible impacts and work-around scenarios. The trend from operating mostly NASA funded payload experiments to the challenge of meeting commercial customer requirements has been met in many ways and the multiple lessons learned have been applied to the entire operations and integration system managed by the POI. A long list of opportunities for creativity and growth including the sensitivity of patents and proprietary data, communication limitations from space to ground, integration and operational conflicts, and management of finite resources like power, water, and bandwidth in an ever growing national lab have been introduced and mitigated. In most every case, lessons were learned and over time, solutions were developed and applied. The ISS culture has been evolving through the RISE initiative and the POI functions have had to stay ahead of and meet the needs of our commercial customers. The greatest challenge was to address the influx of commercial payloads with inherently shorter planning and development templates. Initially, using lessons learned from a past performance, the POI disciplines banded together to update tools for configuration management and applied the latest technology to the HOSC provided services. Several MSFC organizations also collaborated with the POIC to identify, and build, process improvements. The improvements range from new streamlined planning processes, to new methods of reviewing and baselining operational products, to training a budding new Cadre.

*“When the International Space Station was established, we could not have anticipated all of the benefits it would provide ...”*

*“We’re excited to receive this input from the commercial market and aerospace experts to help shape a future thriving space economy in which companies contract with each other to conduct research and activities in low-Earth orbit.”*

*~ Sam Scimemi, Director of the International Space Station division at NASA Headquarters.*

*<https://www.nasa.gov/press-release/nasa-invests-in-concepts-for-a-vibrant-future-commercial-space-economy>*

The inherent need for change, as the ISS moved from the assembly phase to utilization, challenged the POI to meet the increase to a nominal 100 (and sometimes more) number of payload hours in any given week. While systems enhancements and new technologies were developing the POI created advancement opportunities for senior employees to leadership positions, occasions to shift their knowledge and experience to SME positions, and temporary assignments to support the dedicated PREP room objectives. The mobility of our mature workforce has served the program well and provided opportunities for new employees. The staffing challenge created by new positions was compounded by the requisite need to duplicate some console position to increase the capacity to operate the increasing number of payload activities on the crew and ground timelines. The necessity was real and more flight controllers were needed to maintain optimal situational awareness and technical execution standards. Careful considerations were applied to organizational designs. The POI met the challenge to hire and train new flight controllers with diverse roles and responsibilities. Simulations to test the division of duties and the newest communication and information sharing tools continue to be used, and evolve, today while even more tools, training programs, and efficiency efforts are advancing.

The increase in flight control personnel has improved support and provided increased flexibility for the academic, government, space industry, and commercial payload teams and enabled them to maximize their science objectives. The POI is expanding commercial engagements by providing effective and efficient support to the NASA partners who continue to build station hardware like MUSES and the LSG. Key facilities, as a service to customers, are available and low cost access to space is becoming more readily available for Payload operations. Non-profit, non-government organizations like CASIS and commercial companies like NanoRacks and TBE are now able to attract other innovative space science investigators to conceptualize, design, and build hardware adding to the research capabilities of the ISS.

*My job as an operations engineer for NanoRacks is to ensure the successful execution of experiments on the International Space Station. Behind every one of these experiments lies the hard work, dedication and passion of those who've spent often times years of effort into their project. Whether it is an educational experiment for elementary schools or a million-dollar satellite deployment, the joy and wonder that comes from working in space is what ties this special community together. To see the efforts of many come to fruition, to share in their joy when success is achieved or frustration when problems occur, the highlight for me is to be a part of that journey.*

*~ Kyle Warner, Operations Engineer  
NanoRacks, LLC. – TX | [nanoracks.com](http://nanoracks.com)*

MSFC organizations from the POI to the project offices and beyond to the SLS, ECLSS and Propulsion disciplines have all felt the impact of commercial expansion in space and throughout the ISS. New vehicles, new science facilities, and new research are the motivation to succeed with the next best tool, product, or flight controller who will safely operate experiments on the ISS and other crew vehicles. The future is bright, research continues 24 hours a day, and new initiatives are being envisioned as the existing teams grow, meet, and engage the commercial reality that is now part of the payload culture.

## Figures:

- Figure 1 – ISS Research Participation
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- Figure 7 – Multi-User System for Earth Sensing (MUSES.)
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## Quotes:

1. Katie Presson/POM
2. Katie Presson/POM
3. Tim Horvath/POM
4. Damon Self / Specialist OC Team Lead
5. Tim Horvath/POM
6. Paul Galloway, Multiple User System for Earth Sensing (MUSES), Program Manager
7. Sam Scimemi, Director of the International Space Station Division at NASA Headquarters
8. Kyle Warner, Operations Engineer Nanoracks, LLC

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Teledyne's Multi-User System for Earth Sensing (MUSES) and Lessons Learned from First Hosted Payload Integration Paul Galloway, Teledyne Geospatial Solutions July 26, 2018

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POIC Share Knowledge

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