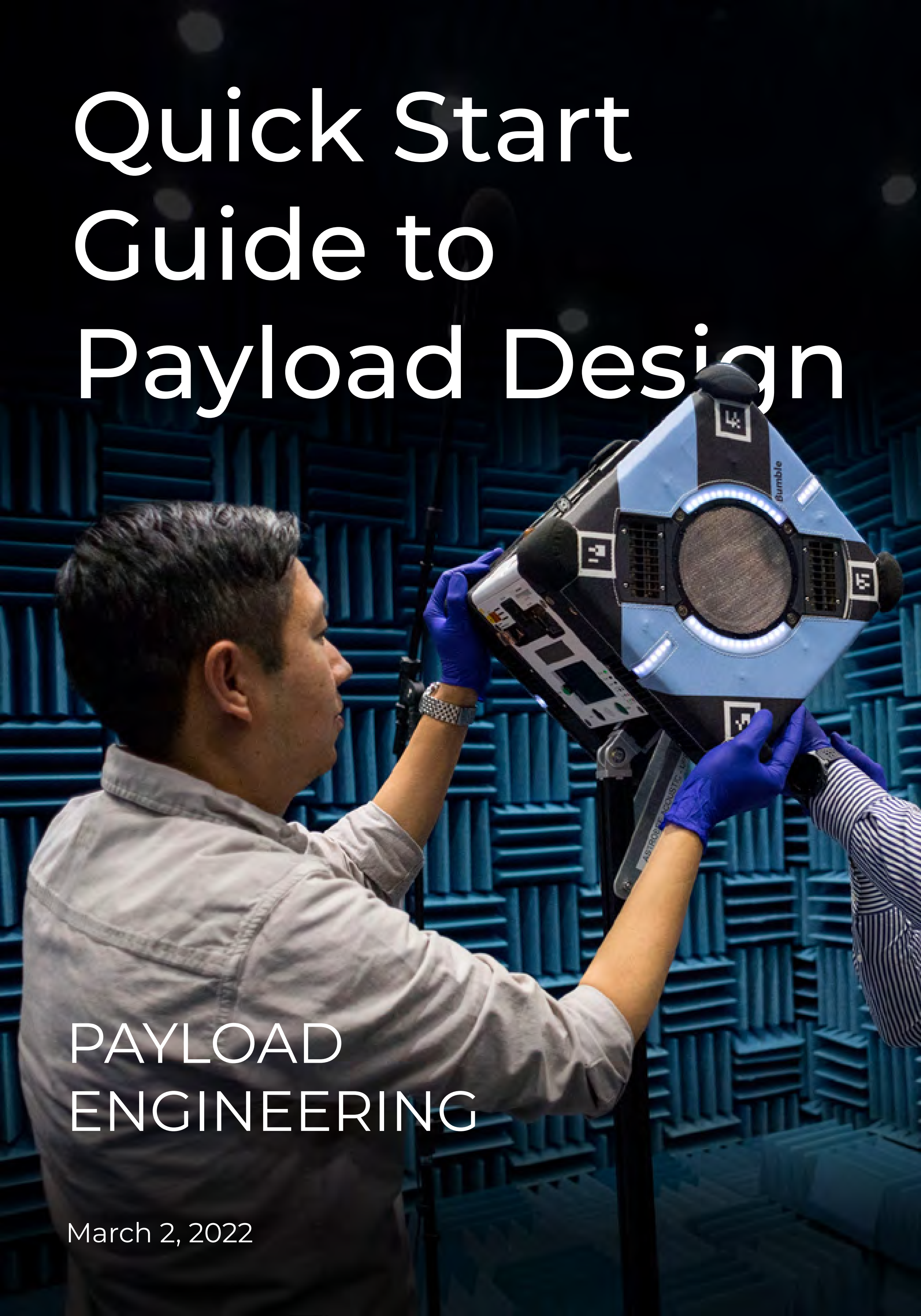
Quick Start Guide to Payload Design



PAYLOAD ENGINEERING

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Payload Engineering

Building a better mousetrap

While engineering designs vary as widely as payload purposes, they are all subject to the physical, chemical, and mathematical principles understood by NASA discipline experts who support the ISS Program. ISS hardware, software, and operations are organized functionally into systems and sub-systems with leading experts that provide support in each of these areas.

NASA's Pressurized Payloads Interface Requirements Document (SSP 57000) is the principle source for interface design requirements for all NASA-developed payloads operating in the pressurized volume of the ISS. Payload developers must verify the applicable requirements in this document to ensure the safety of the ISS crew, transport vehicles, on-orbit ISS systems hardware, and neighboring payloads. This document also provides design guidance that ensures the basic operation of the payload and affects the payload's mission success. It is your responsibility as payload developer (PD) to design in accordance with the design guidance.

NASA is equipped with laboratories and other facilities designed to support payload projects throughout their lifecycles. Although each of these experts fulfills an important role within the ISS Program — such as ensuring safety or providing necessities for the crew — all of them have something to offer you as a (PD) to help you achieve payload mission success.

The following content draws from the expertise and experience of individuals across the organizations mentioned above. The sections within this chapter highlight specific considerations that should concern you while completing the engineering design, development, and verification activities associated with your payloads.

> You are encouraged to coordinate closely with your Payload Integration Manager (PIM) and reach out to experts in areas relevant to your payload.

CONSIDERATIONS FOR PAYLOAD DESIGN

This section describes several aspects of space flight that you will need to take into account during the payload development process.

Keep in mind that payloads that use less of the station's limited resources are more easily accommodated. Keeping resource usage to only what is absolutely required and finding ways of reducing the use of resources improves a payload's opportunities for mission success.

Crew

Pressurized payloads share the ISS environment with the crew, whether they are passive/autonomous (not requiring crew time) or active (requiring crew time). ISS engineering experts are available to assist with the design approach and verification process to prepare the payload for crew interaction. Your PIM will conduct a payload Kickoff meeting where these requirements are introduced. The PIM is the liaison between you and various ISS experts.

Consider the number of crew absolutely required to complete your payload operations.

Thermal

The ISS offers payloads different types of thermal control: active, passive, and conditioned stowage.

The **Active Thermal Control System (ATCS)** is an internal system (inside the ISS) that uses a closed-loop (series of tubes) that circulates chilled water and pulls excess heat from racks and payloads. In this system, there are two temperatures available: a 4°C Low Temperature Loop (LTL) and a 17°C Moderate Temperature Loop (MTL).

The **Passive Thermal Control System (PTCS)** is also an internal system that removes heat using forced cabin airflow across the payload.

When designing your payload, consider the thermal requirements and what would be ideal: ATCS or the PTCS.

Conditioned Stowage provides for the specific temperature needs for scientific samples and other temperature-sensitive payload items. This resource consists of several active devices, such as freezers, refrigerators, and incubators as well as passive assets like Coldbags and Ice Bricks. These options are available on ISS, plus during launch and return. Standard conditioned stowage temperatures are -32°C and +4°C. All other temperatures are considered a unique re- quest.

Conditioned stowage is one of the most limited resources on ISS. To ensure that your payload is accommodated for conditioned stowage, keep sample dimensions as small as possible.

Electrical

The ISS Electrical Power Distribution and Control (EPDC) system provides power to the ISS and payloads. Your PIM will discuss its intricacies during your Kickoff meeting and throughout the development process and will facilitate interactions with the Electromagnetic Effects (EME) and the Electrical Power System (EPS) Teams. The EME Team provides Power Supply and EMI Filter design guidance for compatibility with the ISS system and other payloads. The Electrical Power System (EPS) Team provides guidance on power interface requirements.

Engaging the help of the EME team early and often is an important practice to ensure success in electrical design. The EME team can help you understand the EPDC requirements and offer proven methods to meet them in addition to providing test facilities equipped to support electrical and EMI testing.

When designing your payload, take into consideration the following design factors:

Power Interface Design

Two-fault tolerant controls and verifications are required to ensure crew safety through the following approaches:

Redundant or Designed for Minimum Risk (DFMR) Bonding of all crew accessible surfaces (including cables) that can be energized after a failure or electrical fault (i.e., test for a minimum of class H bond <0.1 Ohm or use of double insulation).

Electrical isolation between primary power and chassis and secondary power.

EME Team can provide support and guidance on design and verification of all classes of bonding required for your payload.

Power Quality Testing

The EPS combines critical (ISS core systems) and non-critical loads (payloads) in the same power feed; therefore, additional systems-level requirements are in place to protect the system. It is important to involve the EME and EPS Teams early in the design of the payload.

Electromagnetic Compatibility (EMC) Design

When designing your payload, keep in mind that there are electromagnetic standards that must be met. Early communication with you PIM and the EME team will help lead to a successful design.

Designing for electromagnetic compatibility up front will reap dividends later in the process by reducing costs and schedule impacts from later design changes due to EMI issues.

> Review this paper, Electromagnetic Compatibility Considerations for International Space Station Payload Developers, for specific guidance.

Some PDs prefer to buy Commercial-Off-The Shelf (COTS) products for their payloads. If a COTS product is being considered, EME experts can help based on experience with previous payloads.

Electromagnetic Interference (EMI) Testing

EMI testing occurs near the end of the payload development lifecycle. This testing is a requirement for flight.

> Be sure to account for EMI early in your payload design to ensure it will pass testing and move forward to flight.

If stated in the Payload Integration Agreement (PIA), NASA can provide testing services. Otherwise, testing can be performed at a commercial facility. Talk to your PIM about testing options.

Electrical Power Distribution and Control (EPDC) Design

In coordination with your PIM, the EME, Safety, and EPS Teams will provide assistance with initial requirements for payload development and design. It is important to engage with these teams early in the design phase.

In a microgravity environment, there is no convective cooling: objects and structures using electricity that heat up on the ground likely will get much hotter on orbit.

Example: Laptop chargers are familiar COTS products that tend to heat up while charging during ground operations. While on-orbit, they can heat up to temperatures that exceed touch temperatures, potentially endangering the crew. Additional fans provide a solution.

The ISS electrical system has a 32-volt shock limit, which is lower than what most payload developers expect.

> By engaging with the EME Team early and not waiting until the Phase I safety review, cost and schedule impacts can be reduced or eliminated.

Example: If a PD up-converts from the 28 *volts provided by the ISS, the PD could unwittingly introduce a situation requiring a two-fault tolerance. If this requirement is not taken into account early on, the payload's electrical system will have to be modified.*

Also consider the materials used in the electrical system. Polyvinyl Chloride (PVC) insulation is not permitted for use on the ISS based on its flammability risk.

> Teflon-coated wiring is optimal.

Battery Design and Testing

Your PIM will assist in connecting you with the Safety Team for assistance with the battery selection process. It is important to understand the full implications of what is required to implement a design using battery power and the time required to do so.

> ! NASA can build batteries, or COTS batteries can be used after testing.

All batteries, regardless of type, have potential risks:

- Lithium ion (Li-ion) produce a lot energy by operating a higher capacity, but unique circuitry that leads to the potential of thermal runaway. Thermal runaway propagation-resistant batteries are required if the capacity is over 80 watt-hours. With Li- ion batteries, rigorous safety hazard mitigation and safety plan documentation are requirements.

- Alkaline and electrolyte batteries can leak and have venting issues.

- Nickel cadmium batteries are easier to work with and do not have thermal runaway issues. The drawback is that they may not be powerful enough for some applications.

Capacitor Component Testing/Screening

When using capacitors, it is important to understand the hazards associated with wet electrolytic capacitors — particularly aluminum electrolytic and wet tantalum types — since they present the possibility for toxic material to reach the crew. Engage the Safety team early in the design phase.

> Avoid aluminum electrolytic capacitors. Electrolytes tend to react with the dielectric material, creating a short. When activated after being off for some time, the capacitor may fail quickly. Similarly, tantalum capacitors can have unexpected failure modes. Treating them for moisture problems via sealing them or baking them out tends to help avoid shorts. Ask your PIM for recommendations on appropriate capacitors for your payload.

EEE Parts and Ionizing Radiation

The EEE part selection and the effects of ionizing radiation are closely monitored for ISS hardware.

> Select parts from known manufacturers with an emphasis on quality and reliability.

> ! Your PIM can help you navigate interactions with the experts on what EEE parts may work for your payload.

For COTS parts, it is good practice to ask about qualification testing and their current Failure-in-Time (FIT) rate when considering manufactures.

> A FIT rate of approximately 20 is a good rule of thumb when selecting parts.

Ionizing radiation for internal payloads is a recognized but minor concern. If your payload is sensitive to radiation, the options for parts should include redundancy and proton testing.

> Consider performing a "burn- in" on the payload or a particular electronics assembly by simply letting it run, perhaps for a few weeks. This is a cost-effective method to identify longevity problems in the design.

STRUCTURES AND MECHANISMS

When developing your payload, it is important to engage NASA's Structures and Mechanisms (S&M) experts early in the design phase. These experts will help you deter- mine how your payload and structural loads will play a factor in moving forward with the ISS Safety and Review Panel (ISRP). When designing your payload, fault tolerance requirements and options should be understood to ensure the hardware is created with enough flexibility to operate on the ISS.

> Work with the S&M experts prior to entering the safety review process to determine whether your payload would be designated as 'Safety Critical.'

Structural Loads

Structural loads may arise from mechanical, pressure-related, vibration-related, inertial, and thermal forces applied to structural elements. All payloads must limit their disrupting effects on the microgravity environment. Keep the following information in mind during the design phase of your payload:

The three categories of disruption are Quasi-Steady, Vibratory, and Transient.

Quasi-Steady Launch and Landing Loads

Quasi-Steady refers the state that the vehicle experiences when traveling through the atmosphere. In this state, the turbulence experienced occurs slowly and quickly reaches equilibrium therefore creating a seemingly steady state. Acceleration loads need to be considered for your payload.

Payloads in their launch, on-orbit, or landing configurations must provide positive margins of safety when exposed to accelerations.

Vibratory Loads

Your payload should be designed to withstand vibrational loads. If your payload is vibration-sensitive, the ISRP will recommend Protoflight Random Vibration Hardmount Testing.

> Vibration testing and analysis are recommended to verify the function of any payload that includes electronics, close tolerance moving devices, or optical equipment.

> Whenever possible, leave tolerances loose to enable on-orbit operations, such as payload installation.

> Structures can change shape compared to their ground measurements when in microgravity.

Fracture Vulnerability

All payload equipment is evaluated for potential breakage that could cause harm to the crew, ISS, or visiting vehicles.

> Fracture control analysis should be performed concurrently with the stress analysis early in the development of the payload.

Primary structural elements may be classified as low-risk, non-Fracture Critical as long as the working stresses are low, use of proper materials, and satisfactory fatigue life are demonstrated.

> To decrease the potential of payload fracture, consider the parts and mate-

rials used in the design. There should be no welds, castings, forgings, or additive manufacturing. Materials prone to shattering, such as glass, ceramics, etc., must be contained.

The containment of hazardous materials/fluids must be 2-fault tolerant (yielding three levels of containment). Otherwise, the primary container will become Fracture Critical.

Mechanisms

If your payload has mechanisms, addressing considerations early in the design process is crucial. Your PIM and S&M experts will help you through this process with the first step of developing a mechanical fault tolerance strategy.

Focus your efforts on incorporating mechanical redundancy wherever possible and determining whether to implement a Design for Minimum Risk (DFMR) strategy. (DFMR is a process that allows Safety Critical mechanisms to achieve fault tolerance through rigorous design, analysis, testing, and inspection practices rather than through true physical redundancy.)

Mechanical fault tolerance is always preferred, either in the form of like or unlike redundancy. Some examples of incorporating like mechanical fault tolerance include dual rotating surfaces for hinges and secondary sliding surfaces.

MATERIALS

The JSC Materials and Processes team consists of experts to assist you in the selection of materials for your payload. This team differentiates payloads into the Simple or Complex categories described below.

Payloads will need to meet the verification requirements set by the JSC Materials and Processes team. Contact your PIM for guidance.

Simple Payloads

Simple Payloads are those that have minimal ISS vehicle interfaces and little to no structural hardware (i.e. welded seams). Examples of a simple payload include container kits, syringe kits, consumable re-supply kits, and Commercial-Off-The-Shelf (COTS) hardware such as cameras, syringes, filters, sample container bags to name a few. The primary concerns for simple payloads are flammability and toxic off gassing.

COTS hardware can be accepted through the COTS certification process. Contact your PIM for assistance with this process.

Complex Payloads

Complex Payloads are those that do not meet the criteria of a Simple Payload. These primarily include structures and will need to comply with the Structures and Mechanisms requirements.

All materials used for Safety Critical structural components require certification as to their composition and properties.

Structural payloads should avoid using complex materials processes such as additive manufacturing, welding, brazing, structural adhesive bonding, forging, casting, and structural soldering in Safety Critical structural components.

Payload Guidance

For Complex Payloads, the Materials and Processes Technical Information System (MAPTIS) contains a collection of verified test data on standard design materials that will be crucial when designing your payload. MAPTIS provides letter rating on flammability, fluid compatibility, stress corrosion, toxic off gassing, and vacuum outgassing.

MAPTIS experts are available when you request assistance through your PIM.

Materials Flammability

The flammability of materials is an important consideration when designing your payload. The basic requirement for flammability is that the materials be nonflammable. The materials that you are envisioning for your payload may be tested for acceptability.

Something to keep in mind that some flammable materials can be accepted by configuration analysis, such as containment or low quantity.

Standard flammability test data typically used for ground applications in air environments are not conservative enough for the oxygen-enriched ISS pressurized environment. Consult your PIM to determine the appropriate expert to assist in choosing your material.

Common nonflammable materials are listed below. Talk to your PIM about any specific material you want to use.

- Teflon (Tetrafluoroethylene (TFE), Fluorinated ethylene propylene (FEP), and Perfluoroalkoxy (PFA))
- Nomex (HT 9040 and some additional grades, but not all)
- Polycarbonates (Lexan, Macrolon), 1/8 inch or thicker
- Kapton and other polyimides
- Ultem
- Painted metal

Common flammable materials are listed below. These materials are not expressly prohibited and may be acceptable within the total payload configuration. Be sure to discuss any materials you want to use with you PIM and materials experts.

- Paper
- Polyethylene
- Polypropylene
- Acrylonitrile butadiene styrene (ABS)
- Nylon
- Hook-and-loop fasteners (such as VELCRO® or similar products)
- Polyvinyl Chloride (PVC)
- Polyethylene terephthalate (PET)
- Cotton
- Polyester
- Wool

Complete lists of nonflammable and flammable materials are avail- able. Please contact your PIM to discuss with the material experts.

Off Gassing and Outgassing

When materials release gases into the environment, this is referred to as off gassing. Should toxic off gassing occur on the ISS, it may create a toxic environment for the crew.

Toxic off gassing is frequently confused with toxic hazard ratings. The toxic hazard rating pertains to fluids only and the hazard that would occur if the entire amount of fluid were released into the ISS cabin atmosphere.

There are times that "off gassing" and "outgassing" terms are frequently confused. Off gassing typically occurs inside the pressurized vehicle whereas outgassing occurs outside the vehicle in a vacuum.

When navigating off gassing requirements, keep in mind that unmodified COTS hardware that contains less than 20 pounds (total mass) of polymeric materials need not be tested for off gassing, with some exclusions.

Outgassing may result in contamination of the vehicle transporting your payload or the ISS. There is potential that your payload's surface or near-by payloads could be contaminated. You can find an extensive list of outgassing data in MAPTIS.

Fluid Compatibility and Stress Corrosion

Your payload materials must be compatible with any fluids with which they come into contact.

> A few of the materials that are permitted to come into contact with the Internal Thermal Control System (ITCS) coolant loops include internal metallic materials made of stainless steel, materials with a nickel base, or titanium alloys. Aluminum alloys containing greater than 5 percent copper are not permitted.

Additional requirements to keep in mind with respect to materials and the ISS:
Payload materials that provide structural support need to meet stress and corrosion requirements.

Water-soluble volatile organic compounds are strictly controlled within the environment of the ISS. The release of methanol, ethanol, isopropyl alcohol, n-propyl alcohol, n-butyl alcohol, acetone, ethylene glycol, and propylene glycol are restricted in the ISS pressurized elements because the water recycling system can remove only limited quantities of these com- pounds from water condensate.

RADIO FREQUENCY AND SPECTRUM MANAGEMENT

If you are planning using radio frequencies in your payload design, it is important to engage the spectrum management team early. Your PIM will assist in helping you reach the experts.

> ! Your PIM will guide you through the licensing processes (should your payload require it). They may seem a bit complex but they are necessary to minimize potential technical anomalies, interventions, and risks to mission success.

INFORMATION TECHNOLOGY FOR YOUR PAYLOAD

There are several options for telemetry, Health & Status monitoring, and commanding for your payload from the ground. Your PIM will connect you to the experts that will help determine which options will work best for your payload.

> Separate your ISS interfaces from your science software as much as possible to facilitate pre-approvals with your software integration.

REQUIREMENTS VERIFICATION

Success with requirements verification can be achieved by following the best practices throughout your payload's lifecycle:
Stay in close contact with the PIM
Openly communicate preliminary pay- load design data
Engage NASA experts early and often
Keep stakeholders apprised of payload design changes

> ! You have access to support throughout the entire process of building your payload. Working together with experts will facilitate your success in meeting your scientific objectives while verifying that the crew and the ISS remain safe.