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INTEGRATION PROCESS FOR PAYLOADS IN THE FLUIDS AND COMBUSTION FACILITY

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Abstract

The Fluids and Combustion Facility (FCF) is an ISS research facility located in the United States Laboratory (US Lab), Destiny. The FCF is a multi-discipline facility that performs microgravity research primarily in fluids physics science and combustion science. This facility remains on-orbit and provides accommodations to multi-user and Principal investigator (PI) unique hardware. The FCF is designed to accommodate 15 PI's per year. In order to allow for this number of payloads per year, the FCF has developed an end-to-end analytical and physical integration process. The process includes provision of integration tools, products and interface management throughout the life of the payload. The payload is provided with a single point of contact from the facility and works with that interface from PI selection through post flight processing. The process utilizes electronic tools for creation of interface documents/agreements, storage of payload data and rollup for facility submittals to ISS. Additionally, the process provides integration to and testing with flight-like simulators prior to payload delivery to KSC. These simulators allow the payload to test in the flight configuration and perform final facility interface and science verifications. The process also provides for support to the payload from the FCF through the Payload Safety Review Panel (PSRP). Finally, the process includes support in the development of operational products and the operation of the payload on-orbit.

Overview

The ISS FCF is a multidiscipline research facility that provides accommodations to investigate combustion and fluids phenomenon in a sustained microgravity environment. Investigations performed in a microgravity environment provide unique insight into the behavior of fluids and combustion science. The combustion portion of the FCF supports investigation and observation of laminar flames, turbulent combustion, droplet and spray combustion, and other types of combustion research. The fluids portion of the FCF supports investigation and observation of multiphase flows, boiling, condensation, colloid physics, surface tension controlled flows, and other types of fluid physics research.

Both the crew and ground operations personnel operate the FCF. The crew sets up and prepares the FCF payloads for semi-automated operations. Experiment setup involves installation of multi-user hardware, PI-unique hardware and samples as well as reconfiguration of the diagnostics. The crew also performs maintenance and upgrades to the facility.

Data collected over the course of PI experiment runs is processed and stored within the FCF. A portion of this data may be downlinked in near real-time for decision making and/or engineering analysis. The crew removes PI-unique hardware and restores and/or reconfigures the facility for continuing PI experiments.

The facility is comprised of three powered, Active Rack Isolation System (ARIS)-equipped International Standard Payload Racks (ISPRs). The FCF is incrementally launched with the Combustion Integrated Rack (CIR) as the initial deployment. The intermediate deployment consists of the Fluids Integrated Rack (FIR) in conjunction with the CIR. The CIR and the FIR operate independently until the Shared Accommodations Rack (SAR) is added. At this

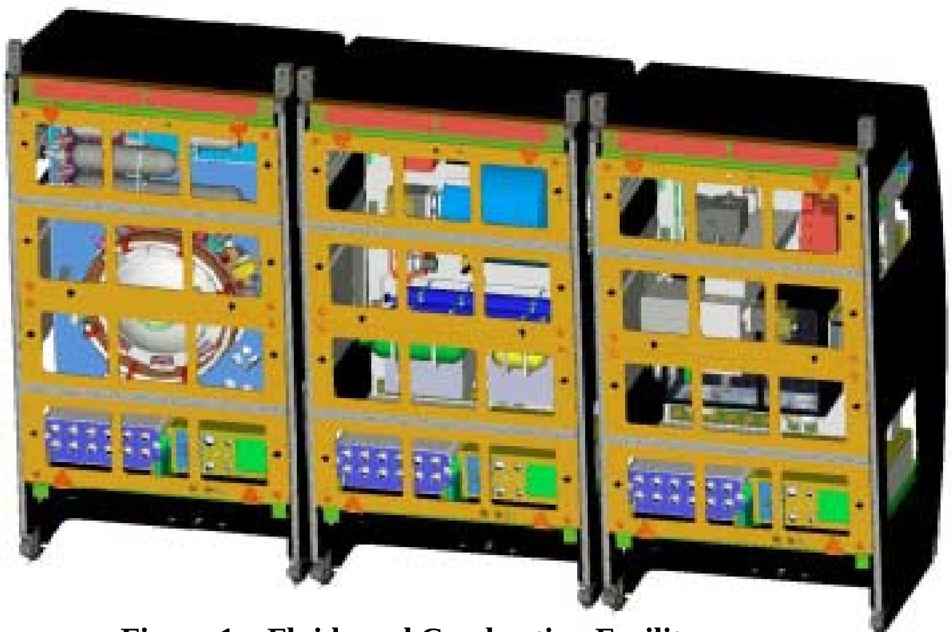


Figure 1 – Fluids and Combustion Facility

point the FCF is fully deployed as shown in Figure 1, Fluids and Combustion Facility. The FCF is designed to operate with a maximum of 15 PI's per year. This includes NASA sponsored experiments, commercial investigations and international experiments.

Need for Integration Process

In order to accommodate a high volume of payload flow through the on-orbit facility and the associated ground system, a well-defined process is necessary. Establishment of such a process will allow a consistent, cost-effective, and concise approach to ensure both FCF and ISS requirements are satisfied.

As a payload carrier, FCF is responsible for systematically ensuring that each flight to the ISS and FCF presents the highest quality and amount of science return in the safest and most efficient manner.

The increment and planning period structure defined by ISS and the aggressive payload throughput of the facility have resulted in a significant overlap of work. During each phase the payload will require information and assistance from the facility in order to complete planning, to design required analyses and to perform testing to ensure compatibility with the on-orbit hardware. To complete this work the payload will require regular interaction with the FCF team to understand the operational resources, design interfaces and verification requirements. Additionally, the payload will require a FCF ground system to which their hardware can be tested prior to launch.

In order to meet the needs identified in the previous paragraph, the ISS requirements for data delivery, and the need for repeatability; it was determined that a structured payload integration process was required.

Process Overview

In defining and developing the integration process the first step taken was to understand the end-to-end system required that would allow for groundbreaking research in the areas of fluid physics and combustion science. The system that is currently being developed consists of three layers: Principal Investigator (PI), FCF and ISS. It became clear that an understanding of each layer and how they fit into the overall system was necessary. In understanding the PI layer, GRC drew on its history of flying experiments aboard the Shuttle and Mir. To understand the ISS level, GRC drew upon its interaction with the ISS Payloads Office, particularly in the development of the ISS payload requirements and integration process. Understanding of the FCF layer was provided by the direct interaction with the FCF development team. The system was then defined at a top level as shown in Figure 2.

The FCF Payload Planning Process is the set of activities developed to address the above responsibilities. The process includes resource

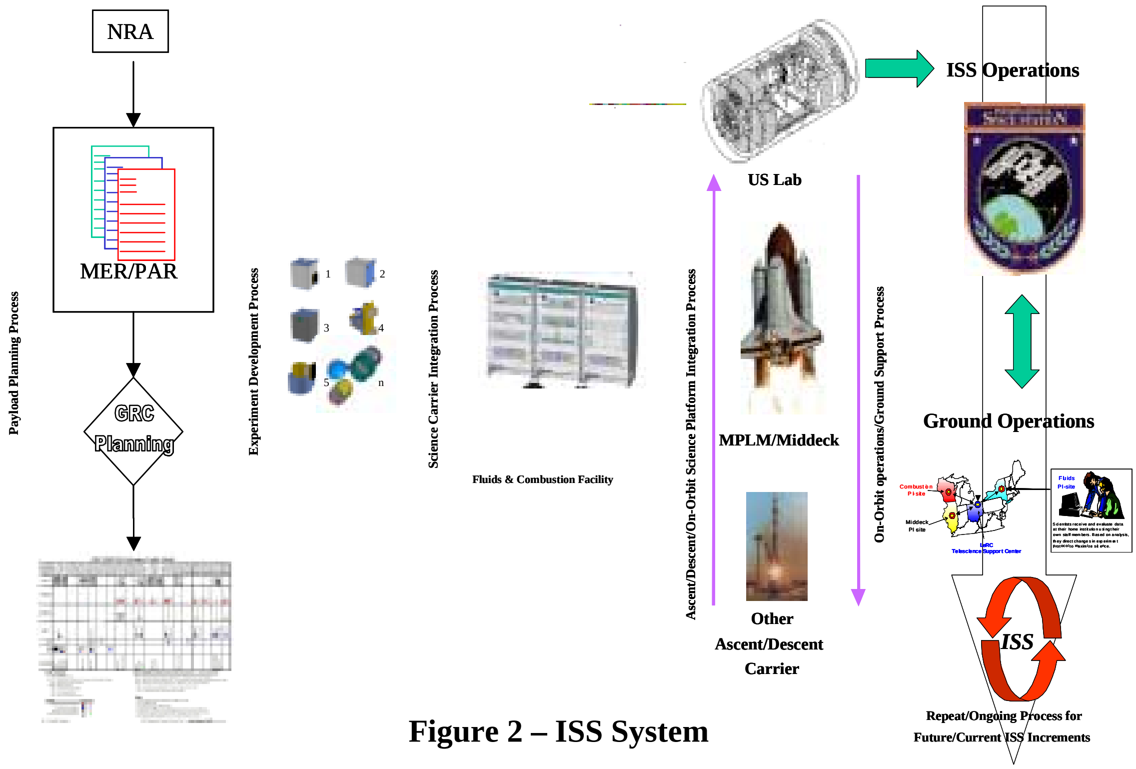


Figure 2 – ISS System

guideline development, collection and management of payload resource requirements data, and resource analysis that results in a payload being manifested on the FCF for a particular ISS increment or increments.

Although it represents a high degree of roll-up, the figure allowed the FCF integration team the ability to clearly see the how the system works with FCF as the carrier of the PI hardware to the ISS.

Payload Planning

In order to properly establish an early interface to the FCF payload projects to convey resource availability, a payload planning function was developed. The payload planning function has four primary responsibilities:

1) Provide a rolled-up set of the FCF required resources to ISS
2) Perform an integrated FCF resource analysis
3) Develop an FCF traffic model
4) Provide the initial integration process interface to payload project teams

Resource Development

The allocation of resources down to the facility level has been problematic and unclear in the early stages of increment development for ISS. The primary document for conveying the available utilization resources for future increments is the ISS Operations Summary Document. In order to provide an FCF payload with a resource "envelope" or guideline, the GRC payload planning group worked with the Microgravity Research Program Office (MRPO) to develop a representative percentage of the resources to apply to the Microgravity Science Division (MSD). This percentage was determined to be 9.5% of the total utilization resources presented in the Operations Summary Document. The appropriate percentage of the MSD allocation is then determined for the FCF and can be used for planning purposes. Nominally, resource allocation to MSD would not be received until after payloads are manifested at the L-24 milestone. This early resource analysis performed by the planning group allows a payload project and the FCF project to obtain an early picture of what resources will be available for the increment or increments on which they will be flying.

Resource Analysis

Once the planning group has developed the available resources, they are then able to analyze the feasibility of flying a specific payload complement during a given increment. The analysis consists of totaling up resource requirements data submitted to the planning group from the payload project, performing a roll-up with facility requirements, and then comparing the required resources to the theoretical available resources. The categories compared are: upmass, launch stowage, on-orbit stowage, crew time, energy and downmass. This analysis is then used in the development of the GRC/MSD ISS Utilization Traffic Model.

Traffic Model

The GRC/MSD ISS Utilization Traffic Model is a one page summary diagram that identifies the launch and return flights for all payloads managed or sponsored by GRC/MSD. It is the primary strategic and tactical planning tool to forecast and track the long-term usage of the FCF. The FCF portion of the traffic model is developed as a system including both fluids and combustion payloads. An example of the traffic model is shown in Figure 3. This traffic model will be continually validated against projected ISS resource allocations and each update is published and reviewed with the GRC MSD management.

Initial Process Interface

In order to meet the early need for planning data, the payload project interfaces with the planning group as early as L-54. This early interface allows an introduction to the entire integration process. Therefore, the payload planning representative serves as the early integration interface or integration manager. With the assistance of other integration personnel, the planning representative provides an integration process overview to the payload project team at a kickoff meeting. This early interaction between the project team and the FCF integration team allows the payload project to have a single point of contact throughout the payload's entire lifecycle. Additionally this early interface allows interaction early in the design phase for

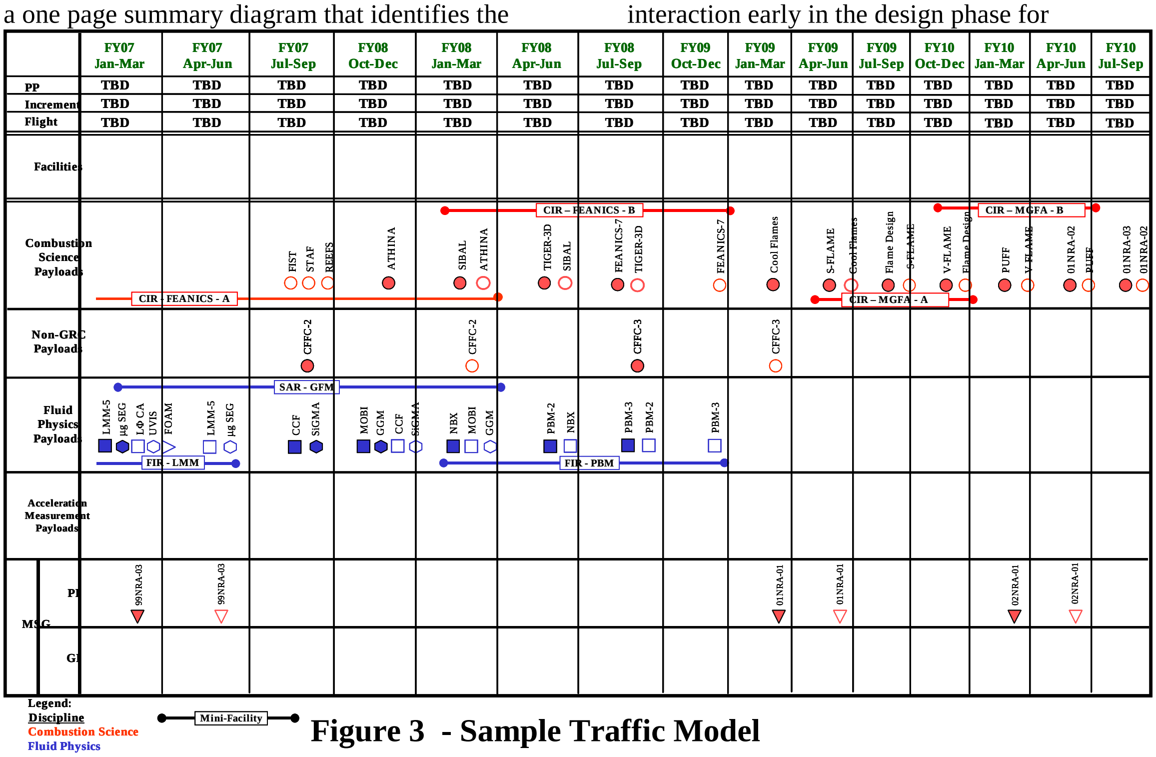


Figure 3 - Sample Traffic Model

communication of design requirements to the payload project. The complete content of the kickoff meeting will be discussed in a latter section.

Integration Process Ground Rules

The development of the integration process was conducted at GRC by a diverse team. The purpose of the diversity was to ensure that all entities responsible for designing, utilizing and operating the FCF would be represented. The participants in the integration process development team included Payload Project Managers, Science Discipline Interface Managers, FCF Rack Managers, Operation Personnel and Integration Process Developers.

The initial product of this team was the development of integration process ground rules. The purpose of the ground rules was to establish a set of guidelines or criteria against which each to the processes, documents and/or requirements could be compared against for validity and acceptability. The ground rules developed were:

1. Minimize the amount of documentation required to integrate an FCF payload

2. Provide the payload with comprehensive source for all requirements (FCF,MRPO,ISS,STS)

The primary concern of payload projects as discussed in the development team was the amount of documentation in place with ISS and the impact that would have on the payload's integration into the FCF. In order to allay this fear, it was determined that the best effort would be made to combine documents/requirements as possible.

3. Keep consistency with ISS and EXPRESS Rack documentation structure where possible

Because of FCF functions as a carrier for payloads and as well as a payload itself to ISS, it was determined that maintaining consistency with ISS documents and data structures was important for requirements and data traceability during roll-ups.

4. Provide payload projects with a single point of contact for resolution of all FCF and ISS matters

To match the ground rule of minimum documentation and a comprehensive set of requirements, it was determined that a single point of contact would simplify the integration process. This allows the payload to consistently know where to look for inputs and know where to submit required information. This interfaces is discussed in a latter section.

5. Provide the payload project with autonomy in the ISS safety process as applicable

A strong sentiment among the process development team from the payload side was the need for freedom of operation in the safety submittal and approval process. The PSRP also agrees with this method. Details of this implementation are in a latter section.

Payload Interfaces

In defining the methods by which the FCF integration team would interface with the payload, it was determined that a lead for each payload would be necessary. This individual, known as the Integration Manager, would then be solely responsible for the successful integration and operation of the payload in the FCF. The Integration Manager would transition from the payload planning representative, as mentioned earlier, around the L-42 timeframe. The primary responsibilities of the Integration Manager are to act as the single point of contact with the payload project for integration issues; provide detailed technical guidance in the area of FCF interface and integration including access to the FCF engineering discipline team; preparation and submittal of integration, training and operations documentation; design review support and execution in the area of FCF interface and integration; and liaison to the FCF Increment Manager on the payloads behalf.

Because of the number of payloads flying within the FCF during any one increment as evidenced in earlier figures, a single point of representation for FCF on a specific increment is required. The FCF Increment Manger acts as the individual responsible for the overall increment programmatic interface and reporting. In this role, the FCF Increment Manager acts as the interface to the ISS for FCF including all payloads within the increment. This individual is appointed at approximately I-30, in time to solidify the efforts for the given increment in support of the manifest request and during the manifesting process. The individual also represents the FCF to the ISS Payload Mission Integration Team (PMIT) forum.

Additional personnel with whom the payload project will have occasional interaction include the Increment Engineer, Science Discipline Interface Managers and the Utilization Scientist. The Increment Engineer has the responsibility for ensuring technical compliance with all FCF and ISS requirements via verifications prior to submittal to ISS. The FCF Increment Engineer acts as the competent technical authority for the integration engineers. The Science Discipline Interface Managers continue as payload advocates during the development of FCF upgrades and in general FCF integration/interface forums. The Utilization Scientist works directly with the Principal Investigators for each payload during the development of science priorities internal to the FCF and with the ISS Increment Scientist for development of science priorities on ISS.

Interaction between the FCF Ground Processing Team and the FCF Operations Team will be coordinated through the Increment Engineer.

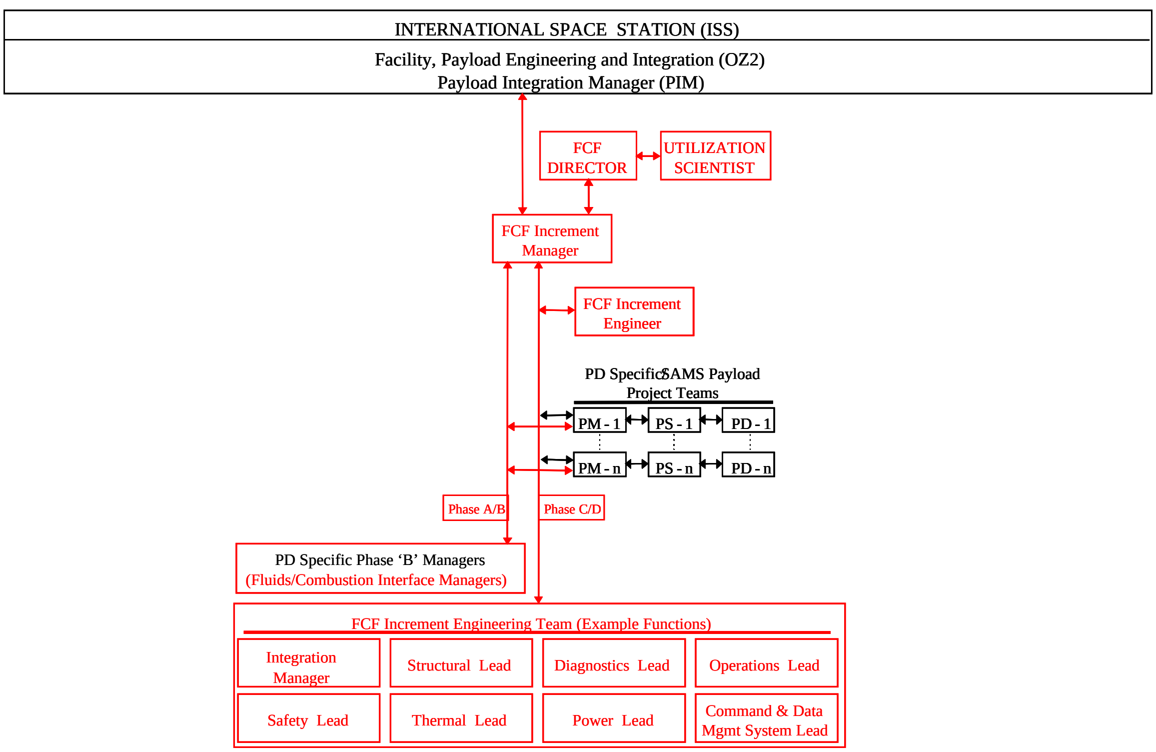
A figure showing the general integration interface structure is shown in Figure 4.

Requirements Flow and Documentation

The primary integration process ground rule was to develop a comprehensive source of all requirements for the payload and to minimize the amount of documentation required of the payload project. Figures 5 and 6 represent the flow/distillation of requirements from levels above the payload into a unique set of payload required documents.

As the figures show, the integration process has been developed such that the payload project is required to refer to only one document to obtain all payload technical and interface requirements from the FCF. This document is the Interface Definition Document (IDD). The IDD contains all interfaces and requirements for integrating to

Figure 4 - Payload Project Interfaces



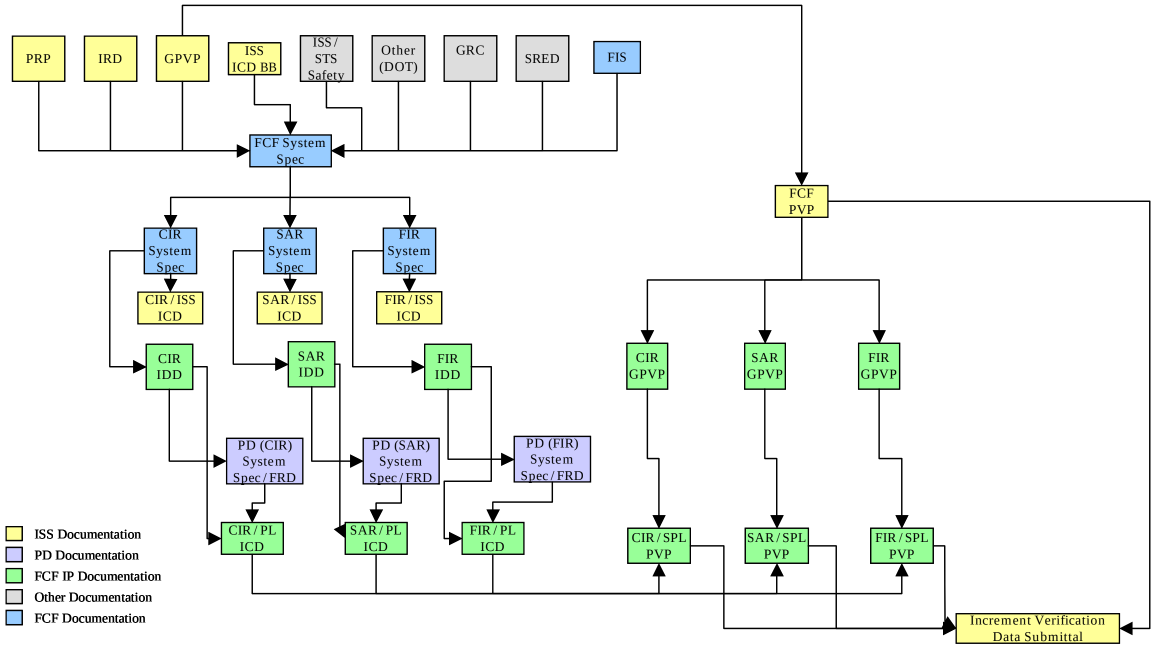


Figure 5 - Requirements Flow (Part 1)

a specific FCF rack. The payload project team, with the guidance of the Integration Manager, selects from the IDD those interfaces and requirements that are applicable to their specific payload via an applicability matrix. The Integration Manager then develops a payload specific Interface Control Document (ICD) which is jointly signed by the Integration Manager and the payload Project Manager. The payload project is then required to show payload compliance to the interfaces and requirements in the ICD by the Payload specific Verification Plan (PVP). The PVP is derived from a generic plan in a similar process as the ICD is from the IDD based on the interfaces and requirements selected in the applicability matrix. These verifications, where required by ISS, are then rolled up into a single submittal for the specific rack and total FCF.

A payload, in conjunction with the Integration Manager, also develops an Integration Agreement (IA). The IA consists of the main volume and the data sets. This structure is identical to the previous ISS structure with the exception of tailoring for FCF and payload project unique roles, responsibilities, resources

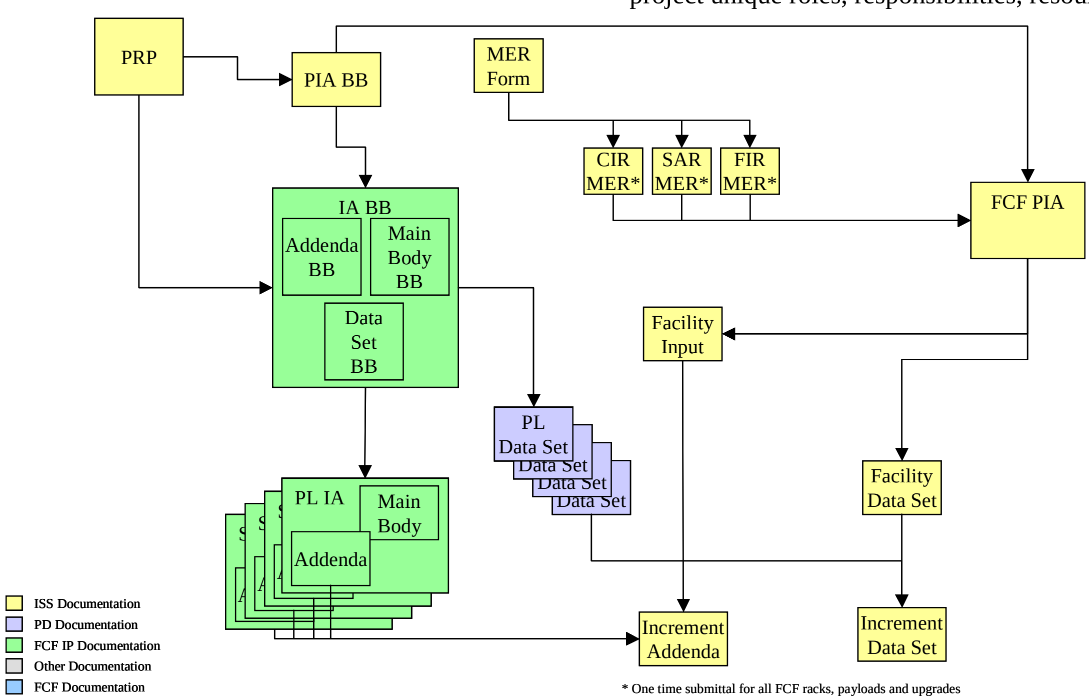


Figure 6 - Requirements Flow (Part 2)

and provisions. As with the verifications, detailed payload increment requirements are rolled up and submitted to ISS as a specific rack or total FCF submittal. The payload data sets will also be rolled up with the FCF data sets but, it is currently envisioned that the payloads will have the capability to submit the required information directly to PDL; the FCF integration team will be able to view and roll up the data within PDL; and the data can then be submitted as a specific rack or FCF combined data set.

Integration Template

In order to provide a payload project with a schedule of deliverables to the FCF integration team and to track upcoming design and flight milestones a top level integration template was developed. The template, Figure 7, serves as the starting point for development of a payload unique integration schedule.

The integration schedule is the working agreement between the FCF integration team and the payload project team for delivery of products, hardware or data. The delivery dates on the schedule are closely tied to the delivery dates of FCF products to ISS. The interdependence of the schedules requires close scrutiny and discussion between the payload project team and the FCF integration team to ensure that shortfalls in payload deliveries do not impact the FCF deliveries to ISS.

An important event noted on the template is the Integration Kickoff meeting. As referenced earlier in the paper, the kickoff meeting occurs early in the payload development phase typically after the payload has completed the Science Concept Review (SCR). At this meeting the payload will receive a comprehensive presentation of the end-to-end integration process. Additionally, the payload will receive a set of applicable documents including the FCF Payload Accommodations Handbook, IA blank book, IDD and the FCF GPVP.

As the payload progresses through the design phase, the FCF integration team, through the Integration Manager, provides support to the payload project at payload reviews to ensure complete coverage of issues that affect the design or implementation of the carrier interfaces. This support includes the development of draft IAs, ICDs and PVPs.

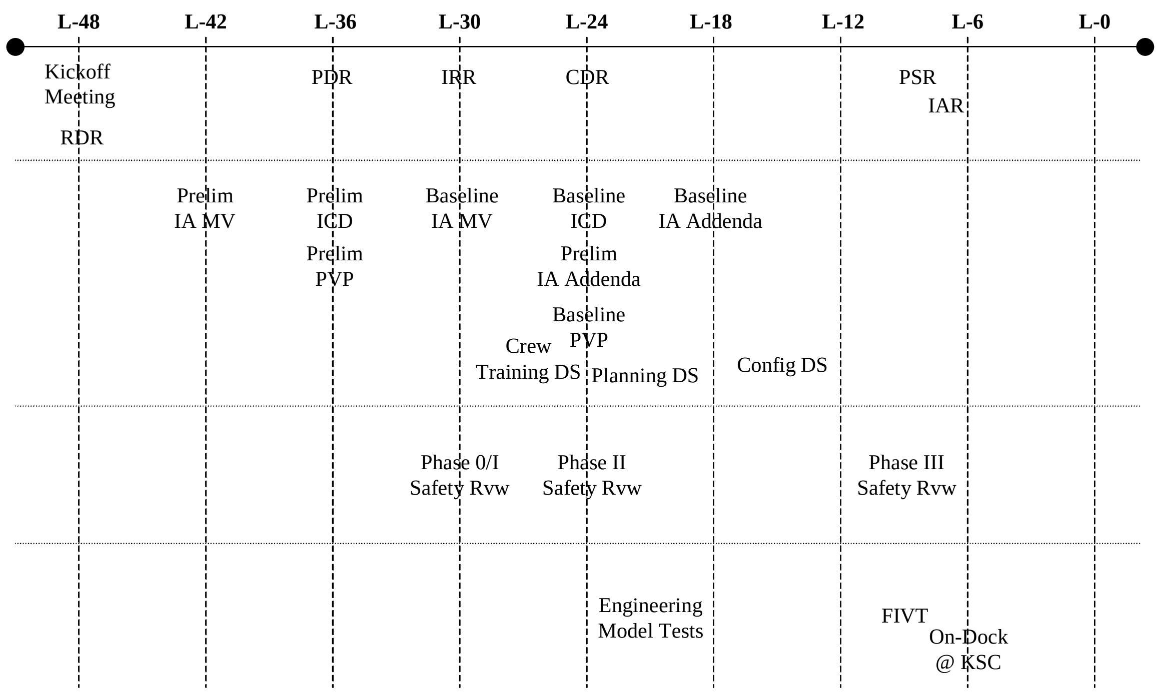


Figure 7 - Integration Template

Figure 8 - FCF Ground Processing

Finally, there are two FCF unique reviews that are part of the integration template: Increment Requirements Review and the increment Acceptance Review. These reviews are in place to identify and assess compliance with all increment-unique requirements imposed on the FCF by the payloads. The reviews are chaired by the Increment Manager and require participation by the payload projects that have payloads operating within the FCF for the given increment.

Safety Process

The payload safety process closely follows the process in place by the Payload Safety Review Panel (PSRP).

The payload project has complete responsibility for compliance of their payload with all safety requirements enforced by the ISS Program. The FCF imposes no additional requirements on the payload. Development of the safety data packages and safety specific verifications are the responsibility of the payload project. Additionally, the payload project team is responsible for presentation to the PSRP of the phase 0,1,and 2 payload safety data packages. The FCF integration team acts in a support role during the package development and during the presentation of the referenced phase. The FCF integration team collates all phase 3 data packages into a single FCF submittal to the PSRP. This package represents a picture of all FCF operational configurations and the associated safety controls for those configurations. The FCF integration team then presents this integrated assessment to the panel with the payload projects' support.

Ground Processing

The payload ground processing for FCF consists of four phases as discussed in the following text and shown graphically in Figure 8.
he first ground processing phases begins early on in the payload development and may continue through early flight hardware development depending on the payloads needs. In this phase a suite of FCF simulators is made available to the payload project team. The simulators include science diagnostics or FCF rack simulators. The payload project can use these simulators to test scientific phenomena measurement capabilities or to test payload equipment operation with FCF supplied resources such as power or cooling.

The second ground processing phase consists of testing the payload engineering model or in some cases the flight unit in an FCF rack Experiment Development Unit (EDU). The EDU provides a functional equivalent of the FCF rack but does not contain flight interfaces. The EDU is made available to the payload during the payload engineering model test phase. This early system test availability allows the payload project time to make any corrections or modifications prior to proceeding with flight unit fabrication.

The third phase of ground processing occurs after the payload project has turned over the flight unit to the FCF integration team. This phase is the payload final interface verification testing and occurs in the FCF Ground Integration Unit (GIU) at GRC. The GIU is a flight equivalent unit and contains all interfaces that are in the flight rack. These verifications serve as closure for many of the items in the PVP. This is the only ground processing phase which all payloads must complete.

The fourth and final phase consists of the payload processing at the Kennedy Space Center (KSC). Because there will not be a FCF simulator at KSC, this is not anticipated to be an extensive test phase to avoid nullifying verifications performed at GRC. It is understood that some payloads may require a brief aliveness test or maintenance of some consumables prior to launch.

Operations

The operations process includes all documentation, hardware, and personnel support to assure that the FCF and its payloads operate as planned. This process begins with flight and

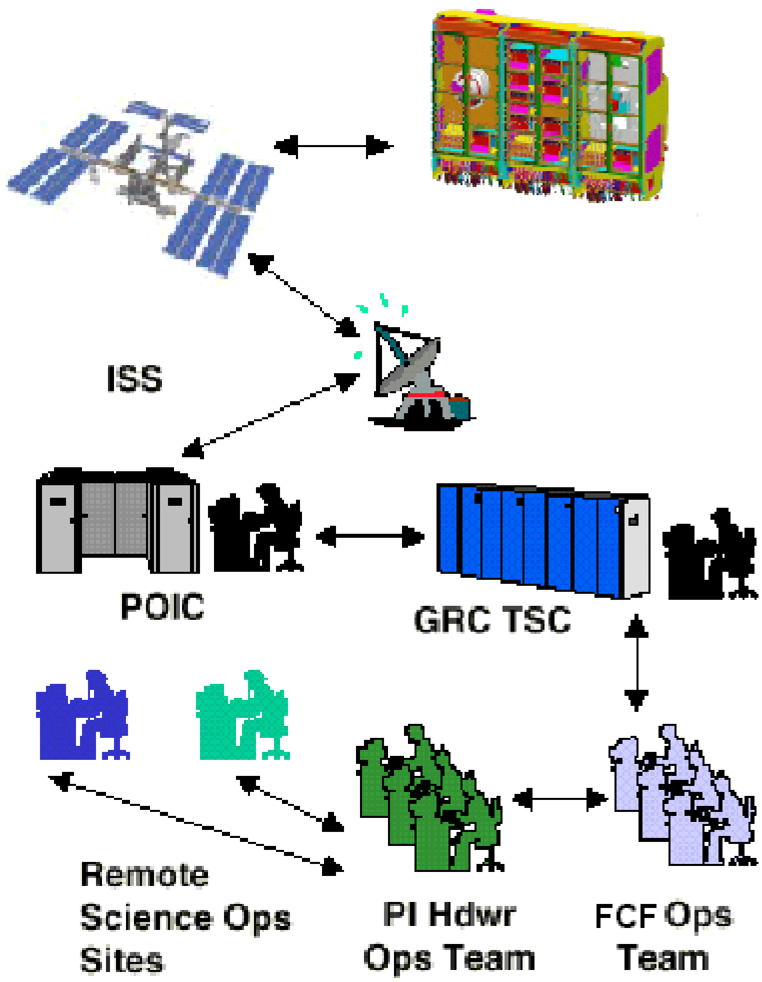


Figure 9 - FCF Operations

ground operations planning, crew training and procedure development and approval. All FCF operational data for an increment's set of FCF payloads is individually submitted by the payload projects and organized by the FCF integration team into a single facility submittal to ISS.

Payload operations are conducted through the GRC Telescience Support Center (TSC). The FCF Operations team is located at the GRC TSC and is responsible for overall operation of the FCF. The payload projects have the option to maintain a presence with the GRC TSC or be remotely linked receiving data on a workstation and voice loops at a chosen site. During science operations, the payload project team works closely with the FCF operations team and, in some cases, may be given the capability to send FCF commands to ensure the highest quality scientific return and to minimize delays with the FCF team in the loop.