Unpressurized Logistics Carriers for the International Space Station – Lessons Learned

William W. Robbins, Jr.
Space Station Program Office
Johnson Space Center, Houston, Texas 77058

Abstract

The International Space Station has been in development since 1984, and has recently begun on orbit assembly. Most of the hardware for the Space Station has been manufactured and the rest is well along in design. The major sets of hardware that are still to be developed for Space Station are the pallets and interfacing hardware for resupply of unpressurized spares and scientific payloads. Over the last ten years, there have been numerous starts, stops, difficulties and challenges encountered in this effort. The Space Station program is now entering the beginning of orbital operations. The Program is only now addressing plans to design and build the carriers that will be needed to carry the unpressurized cargo for the Space Station lifetime.

Unpressurized carrier development has been stalled due to a broad range of problems that occurred over the years. These problems were not in any single area, but encompassed budgetary, programmatic, and technical difficulties. Some lessons of hindsight can be applied to developing carriers for the Space Station. Space Station teams are now attempting to incorporate the knowledge gained into the current development efforts for external carriers. In some cases, the impacts of these lessons are unrecoverable for Space Station, but can and should be applied to future programs.

This paper examines the progress and problems to date with unpressurized carrier development, identifies the lessons to be learned, and charts the course for finally accomplishing the delivery of these critical hardware sets.

Body

The Space Station Program recognized early in development that routine resupply would be necessary to support the Station hardware. However, each year of Station development was a "critical" budget year, and consideration of hardware requirements for resupply was often deferred. As can be expected, the result of not investing early is having to pay more in later years. Following are several key events which occurred over the years. Examination of these events may help to understand how the program got to where it is today, and how future programs may be able to develop operational support capabilities more efficiently.

Lesson#1: Establish standard hardware interfaces as a top-level requirement in the hardware specification, and flow *that requirement down to the lowest level of the specification tree.*

The design specification for the Space Station was written in the 1980s. It included numerous requirements for controlling interfaces. However, the focus was on interfaces between assembly hardware, interfaces between tools and Station hardware, and interfaces between crewmembers and Station hardware. It was silent on interfaces between ORUs and their next higher assembly. Therefore, there were no requirements on standardizing connector interfaces, bolt patterns, installation guide patterns, etc. Each major hardware developer was allowed the freedom to design their ORUs with no regard for resupply. Most of the basic design work was performed during the late 1980's. As design work progressed, concerns about hardware weight became predominant. Designers optimized their ORU designs for weight, which led to more point design installation schemes. The installation hardware was tailored to optimize the assembly interface. Installation to a carrier was not required as a design consideration. In the meantime, very little work had been performed on unpressurized carrier design. The Program felt no urgency about carrier design, in part because resupply was not planned to begin until after the Station was completely assembled. With annual budgets always tight, design work on unpressurized carriers was deferred, and did not begin in earnest until after basic design work on the core Station was mature.

Several trade studies had been performed in the 1980s to determine sizing of unpressurized carriers, and to develop design concepts. However, no specification or interface control document had been issued to constrain ORU developers. Therefore, ORU designs were optimized for cost, weight and operating performance. This led to some ORUs which will be a logistics challenge for the life of the program. The most significant example is the Pump Module. This ORU is an electro-mechanical device which circulates ammonia through thermal radiators. It is installed on the Station truss, in an unpressurized environment. It has multiple functions incorporated in the design to pump, regulate and monitor the ammonia. In early design concepts, these functions were broken down to separate ORUs. This would have allowed for replacement of relatively small ORUs upon failure. The penalty for this approach was the added weight needed for modularizing these functions. The design organizations had an overall problem with the weight of the launch elements for assembly, and the decision was made to combine the functions of smaller ORUs into a large ORU. The ability to resupply the ORU upon failure was not a required consideration. The resulting design is an 870 pound ORU which provides 50% of the heat rejection capability of the operating systems. Upon failure, 50% of the operating systems must be shut down. The predicted failure rate is such that a Pump Module can be expected to fail about every second year. The Pump Module is too large for most Shuttle cargo carriers, requiring a large cross bay carrier such as the SpaceLab Pallet (SLP). This leads to a requirement that a spare Pump Module must be stored on board the station (with the resulting cost of a thermal conditioning system) and be resupplied as soon as possible. The effect is that the Station program is driven to developing a large cross bay carrier which can be manifested relatively quickly, often causing other planned payloads to be removed. This is a costly operational impact which will be borne for the life of the program. It might have been avoided had there been design requirements for cargo resupply in place.

As work on unpressurized carriers begin to progress, a specification for an Unpressurized Logistics Carrier (ULC) was released in 1991. This specification designated a standard grid pattern, and required all cargo developers to adapt to this pattern. However, by this time, most unpressurized ORUs had been through Critical Design Review (CDR), such that 90% of the drawing were complete. Design organizations threatened major cost impacts to revise the installation interfaces to meet the ULC specification. In order to avoid those cost impacts, which would have certainly broken the Station budget, relief was provided to the ORU developers. The ORU designs were not required to change, and interfacing hardware would be developed to adapt the ORUs to the ULC. Development of the interfacing hardware was deferred, since budget was not available, and the hardware would not be needed until resupply operations began, which was several years away. The program management recognized that interfacing hardware would add cost, but that cost was being deferred from what was considered a problem year financially. In addition, the complexity that would be required of the interface hardware was not well understood, which further reinforced the decision to defer the work.

Lesson#2: Establish a management structure which creates a strong link between carrier designers and core hardware designers.

Work did continue on the ULC design. By 1994, the ULC was reaching the Preliminary Design Review (PDR) stage, meaning that 10% of the drawings were complete. However, the design work on station was somewhat compartmentalized, by virtue of the compartmentalized management structure that had been in place until 1993. Although the management structure was integrated and streamlined in 1993, the design work that had been performed on the ULC was largely unrecognized by the rest of the program. At this time, the ULC design was thought to be immature, and there was no management insight into whether the ULC design would meet the needs of the program. In reality, the ULC design had progressed well, and was resulting is a flexible carrier system with robust capabilities. However, in 1994 the station program was again in severe money trouble, and every opportunity was examined to save cost, even if that resulted in significant cost penalties in later years. The ULC was identified as deferrable work. The SLP was an existing carrier available to the program. It was recognized as being less capable than the ULC, but judged adequate for use in the first two years of assembly. The decision was made to archive the PDR level design work on the ULC, and restart work in 1996. This had an additional effect, the impact of which was under recognized. Since all funding for ULC development was halted, the ULC design organization was dismantled. Therefore, there was no organization which could coherently address carrier issues, and plan for carrier requirements.

Lesson#3: Costs are controlled only by the program understanding the operational and design requirements, and being willing to invest early in carrier hardware design.

In 1995, the program recognized that interfacing hardware would be needed for ORUs and assembly hardware being carried on the SLP. Further, the program still planned to resurrect ULC design work in 1996 or 1997. So, the program authorized design work to begin on interfacing hardware, and the term Cargo Handling Interface Adapter (CHIA) began. The program Prime Contractor, Boeing, began design work. In parallel, they estimated the cost of completing CHIA design, fabrication and test. The approach was to develop CHIA which could be used with the SLP, and would lead to use on the ULC. Commonality was embedded into the design work. Once the cost estimates were compiled, they totaled $80 million, not including the Boeing fee. Again, budget pressure was enormous. The program elected to stop the Boeing work. Further, the program decided to expand the use of the SLP through the entire assembly phase, and to develop the necessary CHIA. Management of this effort was assigned to a government project office at Marshall Space Flight Center. The total effort was estimated to cost $50 million, and had the attraction of further deferring ULC design work.

Lesson#4: Create a contractual structure which supports open flow of information.

However, this put the government in the position of requiring detailed ORU design data for CHIA development. Boeing had the data, or could develop the data, but it was not yet a contractual deliverable. Boeing wanted to get paid for producing the data, and providing engineering support to explain the data. The program would not agree to the costs Boeing proposed. This stalemate continued for over a year. During this time, Boeing bought out or merged with their subcontractors, one of which was McDonnell Douglas Aerospace (MDA), which was the government contractor for the CHIA, as well as the manager of the SLP. This now created a situation where Boeing was responsible for building the ORUs, building the interfacing hardware to the SLP, and for engineering support of the SLP. Boeing now was responsible for each component of the resupply system, however, it was through different contracts managed under different NASA centers. This made NASA an intermediary, such that Boeing organizations did not communicate with each other, but through various NASA offices. These artificial divisions continued to stymie design progress, and continued to threaten continually higher costs.

Another factor changed the situation in late 1997. Brazil had approached NASA about entering the Station partnership by making a hardware contribution in return for on board resources to conduct science. NASA negotiated to have Brazil develop the ULC and interfacing hardware to carry ORUs and scientific payloads. This work was intended to have the ULC become available late in the assembly phase. As Station technical teams examined the missions which the SLP was baselined, they saw opportunities for efficiency by using the ULC. This was because the ULC was expected to be designed specifically for carrying Station cargo, as opposed to the SLP which had been designed as an experiment platform and pressed into service as a cargo carrier.

Lesson#5: As the quantity of hardware increases, so does the complexity of the task. The organizational structure to manage technical issues must be able to deal with the complexities of the task.

The requirements for interfacing hardware were becoming more complex. By early 1998, Station teams realized that many ORUs would need to be able to be carried on multiple carriers. The SLP might be the only carrier available early in the program, but the ULC would be carrying the same types of cargo items. Some of the ORUs were small enough to be carried on a sidewall mounted in the Shuttle payload bay, offering great flexibility for delivering an ORU when no unpressurized carrier was part of that flight's complement. Another carrier had also entered the scene, the Integrated Cargo Carrier (ICC) from SpaceHab, Inc. The ICC is a carrier which mounts across the Shuttle payload bay, as do the SLP and ICC, and is capable of carrying large scientific payloads, and/or large ORUs. By now, some ORUs could potentially be carried on a SLP, ULC, ICC or sidewall carrier. This drove new requirements for interfacing hardware, since each carrier had a different grid pattern, and most ORUs had unique mounting hardware.

As can be imagined, the design work was not meeting the needs of the Station program. The artificial divisions created by having the government in between contractor design organizations were inefficient and expensive. Further, it was becoming apparent that the program needed a focal point for integrating the development of carriers and interfacing hardware. Design work was being managed out of multiple Station organizations, with no one responsible for overall integration. The potential was increasing for a further proliferation of unique hardware interfaces.

Lesson#6: Better to fix the problem late than not at all.

The Station program made two major changes to bring order to this situation. First, the Boeing work on interface hardware was moved from the SLP contract to the Station Prime contract. This put the developers of interfacing hardware on the same contract as the ORU developers, without the government in between. This effectively eliminated the artificial barrier which had prevented the interface hardware designers from getting detailed design data from the ORU design organizations. The second change was that the Station program named an office to integrate the requirements and design work on all external carriers and interface hardware. An organizational structure was developed to facilitate integration of operational requirements with hardware design. This was the first appearance in years of such a design integration function for external carriers. Finally, there was a forum to integrate requirements, identify issues and recommend solutions.

The year 1999 begins a recovery for external carrier development and interface hardware. This is not an easy recovery, nor a cheap one. Parallel actions are occurring to begin the recovery.

Detailed operational scenarios have been developed for the end-to-end handling of ORUs. These scenarios identify the steps that occur in ORU handling from Shuttle launch through the astronaut accessing the ORU, taking it to a worksite, removing and replacing the failed ORU, a returning it to a mounting location for return to ground. These scenarios are used to identify hardware requirements for handling, translation, and temporary storage.

The total picture is being assessed for the projected traffic of ORUs to and from orbit. This effort involves using ORU predicted failure rates to project total upmass/downmass requirements, and to characterize the requirements. This information is being used to determine the types and quantities of carriers required, and how often they will fly. By careful examination of how often different ORU types can be expected to fly, and how time critical their resupply will be, major costs of hardware development can be avoided. For example, the largest ORUs in the Solar Array Wing may need to be resupplied only once in the life of the program, or not at all. However, because their failure would be a major impact to the Station operability, they would have to be resupplied expeditiously. Since they have the potential to fail early in assembly when the only carrier available that is large enough to carry them is the SLP, interface hardware for the SLP will have to be developed. However, since this resupply will be infrequent or not at all, there is no need to spend design money to make the interface hardware common to other carriers, such as the ULC.

The Station program has had many setbacks to developing an efficient fleet of unpressurized carriers. Each setback was caused by budget problems, a poor management structure, or usually both. The bottom line to developing a successful operations capability is having the right budget in place at the right time, and an effective management structure in place to avoid wasting any of that precious budget on false paths.

Biography

William W. Robbins, Jr. has led the Maintenance, Resupply and Crew Provisioning team for the International Space Station Program since 1994. Previously, he spent four years with the NASA Mission Operations Directorate as the Logistics Technical Lead. During his active duty with the US Army, he performed Integrated Logistics Support for Air Defense Artillery weapon systems. He received his Bachelor of Business Administration from Texas A&M University.