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Paper Session I-B - Report on the International Space Station's Planning for Critical Assembly Phase Failures

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Report On The
International Space Station's
Planning For Critical Assembly Phase Failures

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Abstract

During the early assembly missions the International Space Station could experience failures that will leave it single fault tolerant or could seriously reduce it's power generating capability. These failures or reduction in power generating ability could endanger the crew, the station or completely bring ISS assembly to a halt until corrected. Recent analysis and planning have been completed that looked at critical hardware failures and recommended work around strategies, manifesting of spares or on-orbit stowage of spares. The implementation of this analysis will allow ISS assembly to continue with minimum impact. This report describes how the analysis was brought about, the analysis process and finally the implementation strategy recommended and being put into place.

Introduction

On July 3, 1997, the International Space Station Program Office was conducting reviews of program requirements in preparation for the fiscal year 1998 budget submittal. The Deputy Program Manager for Operations, and the Deputy Program Manager for Development, directed the Logistics and Maintenance Team to review and update requirements for the procurement of spares. This initiated a four month programmatic study which resulted in new approaches to supporting the Space Station hardware.

A great deal of work had been done prior to this effort to plan for Station maintenance, and to procure the necessary spares and logistics products. However, this planning had been done based on analyses that were not yet mature. Also, maintenance planning was conducted within an assumed set of available resources. The quantity of maintenance that can be performed, and the timeliness of maintenance is tied directly to available resources such as upmass, on board stowage, crew time, and spares quantities. In this effort, better analyses came to the forefront, changing the level of risk associated with assembly and activation of Station elements. Commensurate with the new analyses, old assumptions about what resources could be made available were revised.

The end result was a viable, coherent approach to supporting Station during the early assembly phase. This approach was characterized by maximizing the use of Shuttle performance, aggressive on board sparing, protection of key resources for spares resupply, and identification of new workaround hardware. As this approach is implemented, the level of risk associated with assembling, activating, and operating the Station during assembly will be dramatically reduced.

Executive Summary

This effort grew from a spares requirements review into a revision of the total support approach for the Station. It incorporated people and resources from across the Station Program, Shuttle advise and assistance, and institutional support from three NASA centers.

Process

The Assembly Stage Critical Failures Planning Team was formed to develop an overall Assembly Critical Failures Operations Plan for supporting ISS during the assembly phase and post assembly. There were four sub-teams formed to assess on-orbit failures, develop spares requirements and operational workarounds, develop new manifest requirements, and to identify new hardware and associated costs. These teams had both serial and parallel tasks in order to develop the operational support plan for ISS for the assembly phase, and carrying into the post assembly phase.

Assembly Failures Solution Set

The major challenge of determining how to implement the new spares and hardware requirements led to an intense effort called the Assembly Failures Solution Set. The stated purpose of the Assembly Failures Solution Set was to define logistics carriers, on board internal/external stowage locations, environmental protection services, and EVA/EVR requirements to accomplish spares deliveries and on board stowage during assembly

The Solution Set conducted an iterative set of sessions by which multiple disciplines exchanged information to arrive at design and operations plans. This was a combined effort between three sub-teams, Launch Package Integration, Element Management, and Specialized Expertise.

Results

The teams met the original objectives as stated. All ORU’s that are required to be pre-positioned had flights identified for their delivery that were before or on their need dates. All ORU’s and workaround hardware that needed to be launched on the next flight after a failure had flights identified for their pre-positioning with few exceptions. Those exceptions had plans developed for them that would meet the support requirements. Special planning considerations were identified that will facilitate timely delivery of critical spares following an on board failure.

Pre-positioned ORUs were stored internally as much as possible, avoiding significant expense. A Spares Warehouse concept was developed for those ORUs that had to be stored externally.

Concepts for operational workaround hardware were developed, assessed and refined such that engineering groups can now perform the actual design and development work.

Workplan

The approach developed here requires extensive follow on work by a myriad of organizations both within the Station Program, and at Center Institutions. Some of the key tasks are updates to maintenance plans, manifest changes, production diversion planning, on board stowage planning, launch package integration, and new hardware development. Numerous organizations have been assigned tasks to complete this work, and the necessary integration structure is being put in place. Accomplishment of this work will extend more than two years into the assembly phase.

Conclusions

The Assembly Stage Critical Failures Planning Team was successful in establishing an approach and plan that satisfies the need to support critical assembly hardware.

This report is a snapshot of the new requirements, approach and planning for supporting the International Space Station during assembly. The real work for the Program is to successfully put the new support in place, and use it to ensure successful assembly and operation of the International Space Station.

Detailed Report

Background

The L&M Team had developed an analytical process for determining spares quantities which took into account support factors such as hardware failure rates, failure effects, the resupply cycle, and on board storage. The quantitative analysis focused on the assembly complete operations phase, and the results were reviewed for application to the assembly phase. The support factors were modeled, resulting in an ORU availability value. ORU availability values were compiled to the subsystem level, providing an indication of the operational availability. As the L&M Team changed the support variables, such as spares quantities or on board storage, the effect on availability values was assessed. As this process continued iteratively, the mix of variables, including spare quantities, was optimized to improve operational availability.

In order to further optimize and validate the recommended quantities, system operators from Mission Operations Directorate (MOD) were consulted. This was to add a qualitative assessment of spares quantities to the quantitative results. As the meetings with MOD progressed, issues surfaced about the ability to support the station during early assembly. The assembly stages from Flights 2A through 12A have limited failure tolerance and redundancy, especially in the power and thermal systems. After and 12A and 13A, a second Photo-Voltaic (PV) Array is active, and the External Active Thermal Control System is operational. Until then, however, the Station is dependent on two power channels, and two thermal loops. The solution to supporting the early assembly phase is not simply spares quantities, but the ability to resupply spares quickly when needed, and to store ORUs on board during early assembly stages.

The months of July and August were spent in developing recommendations for spares quantities, and assessing the supportability of the early assembly phases. Periodically, the L&M Team briefed the results to program management, usually the Deputy Managers for Development and for Operations. As the criticality of the assembly support issues became apparent, the Deputy Manager for Development directed the team to determine how to solve this issue.

Purpose

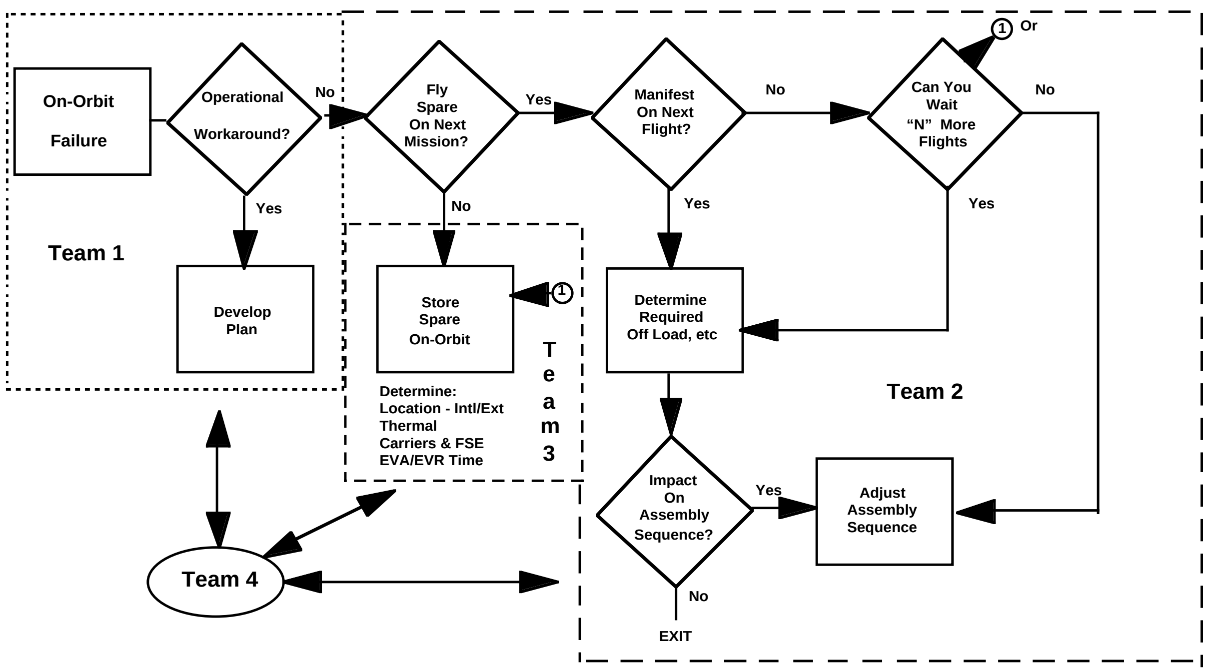
The Assembly Stage Critical Failures Planning Team was formed to develop an overall Assembly Critical Failures Operations Plan for supporting ISS during the assembly phase and post assembly. The Team was tasked to assess on-orbit failures, develop spares requirements and operational workarounds, develop new manifest requirements, and to identify new hardware and associated costs.

Team Structure

The team was co-chaired by the L&M Manager and the Vehicle Deputy Manager. There were four sub-teams formed.

- Team 1 - Failure Assessment
- Team 2 - Manifesting & Assembly Sequence Impacts
- Team 3 - Vehicle Hardware Impacts
- Team 4 - Spares/Costs

These teams had both serial and parallel tasks. The Failure Assessment Team had to work ahead of the other teams, as they were responsible for identifying the spares that needed to be stored on board, and spares that had to be delivered to orbit immediately after a failure. The other teams began their work in parallel with Team 1, but needed the Team 1 results to perform complete assessments. The team tasks and work processes are shown in Figure 1.



Team 1, What can go wrong & how can I fix it?

Team 2, Is there a flight to put the "fix" on?

Team 3, How do I deliver it to orbit, and keep it safe until I need it?

Team 4, Is there a spare available, and what does this effort cost?

Figure 1

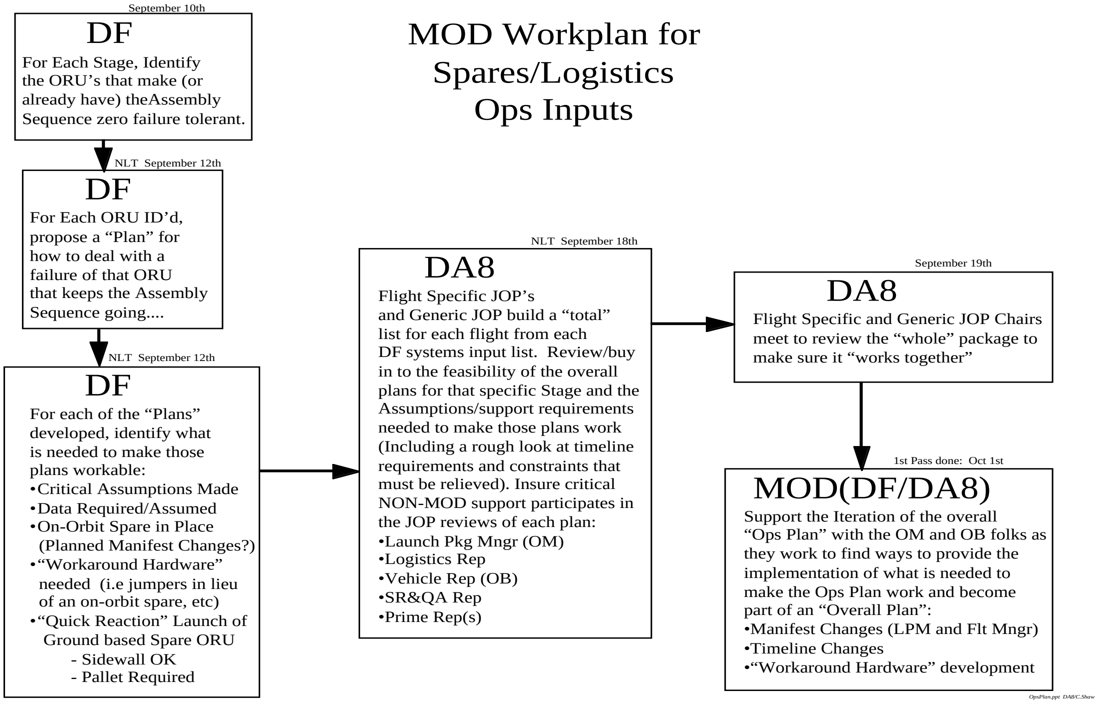
The Teams were also tasked to work concurrently to develop the operational support plan for ISS for the assembly phase, and carrying into the post assembly phase.

Team 1 - Failure Assessment

Team 1 was composed of MOD system operators and Flight Directors and was chaired by a MOD Flight Director Lead. Team 1 tasks were to:

- Assess possible hardware failures during the assembly sequence
- Propose the initial plan to deal with failures and continue the assembly sequence
- Identify what is needed to make plan the workable
- Work concurrently with other teams to develop the overall Assembly Critical Failures Operations Plan

The Team 1 approach and process are shown in Figure 2.



MOD Workplan for
Spares/Logistics
Ops Inputs

September 10th

DF
For Each Stage, Identify
the ORU's that make (or
already have) theAssembly
Sequence zero failure tolerant.

NLT September 12th

DF
For Each ORU ID'd,
propose a "Plan" for
how to deal with a
failure of that ORU
that keeps the Assembly
Sequence going....

NLT September 12th

DF
For each of the "Plans"
developed, identify what
is needed to make those
plans workable:
•Critical Assumptions Made
•Data Required/Assumed
•On-Orbit Spare in Place
(Planned Manifest Changes?)
•"Workaround Hardware"
needed (i.e jumpers in lieu
of an on-orbit spare, etc)
•"Quick Reaction" Launch of
Ground based Spare ORU
- Sidewall OK
- Pallet Required

NLT September 18th

DA8
Flight Specific JOP's
and Generic JOP build a "total"
list for each flight from each
DF systems input list. Review/buy
in to the feasibility of the overall
plans for that specific Stage and the
Assumptions/support requirements
needed to make those plans work
(Including a rough look at timeline
requirements and constraints that
must be relieved). Insure critical
NON-MOD support participates in
the JOP reviews of each plan:
•Launch Pkg Mngr (OM)
•Logistics Rep
•Vehicle Rep (OB)
•SR&QA Rep
•Prime Rep(s)

September 19th

DA8
Flight Specific and Generic JOP Chairs
meet to review the "whole" package to
make sure it "works together"

1st Pass done: Oct 1st

MOD(DF/DA8)
Support the Iteration of the overall
"Ops Plan" with the OM and OB folks as
they work to find ways to provide the
implementation of what is needed to
make the Ops Plan work and become
part of an "Overall Plan":
•Manifest Changes (LPM and Flt Mngr)
•Timeline Changes
•"Workaround Hardware" development

Figure 2

The Team 1 process provided results which fell into four categories:

- Spares that should be stored on-orbit
- Spares that should be carried to orbit on the next flight after a failure
- Spares that should be carried to orbit on the next flight after failure (oversized)
- Workarounds or special hardware that can delay the need for a spare

Team 2 - Manifesting & Assembly Sequence Impacts

Team 2 consisted of personnel from the Mission Integration Team, and was led by the Assembly and Manifest Lead. Team 2 was tasked to:

- Assess the initial output from Team 1 to determine the impact to flight manifests and whether an on demand spare must be flown on the next/soonest available flight
- Assess the recommended spares list to determine the impact to flight manifests in terms of:
    - Orbiter performance
    - Hardware off-load required
    - Interface with the Shuttle program to implement changes
    - Develop a “Fly on Next Flight After Failure” scenario
- Work concurrently with other teams to develop the overall Assembly Critical Failures Operations Plan

As Team 1 developed their inputs, Team 2 identified candidate flight manifests, and assessed stowage availability. Team 2 also reviewed the external spares, and determined which could be transported and stored internally. Although previous assessments had been done in this area, these assessments were based on using existing internal racks, trays, etc. Team 2 expanded the list, by adding external spares that could be carried internally if additional Flight Support Equipment (FSE) were developed.

Team 3 - Vehicle Hardware Impacts

Team 3 consisted of personnel from the Vehicle Team, and was led by a Vehicle Subsystem Manager.

Team 3 was tasked to:

- Assess the output from Team 1 for development and cost of new hardware requirements to implement operations workarounds, on-orbit spares storage, and ORU carriers/FSE.
- Assess the recommended spares list to determine the impact to the on-orbit vehicle, carriers, FSE, etc.
- Work concurrently with other teams to develop the overall Assembly Critical Failures Operations Plan

Team 3 was responsible for defining logistics carriers, on board external stowage locations, environmental protection services, and EVA/Robotics requirements to accomplish spares deliveries and on board stowage during assembly. In addition, Team 3 assessed the proposed workaround hardware from Team 1 for technical feasibility.

Team 3’s tasks required design engineering expertise to support this effort. The need and criticality of performing a complete assessment in this area led to a follow-on effort, the Assembly Failures Solution Set, described in section 3.4.

Team 4 - Spares/Costs

As the first three teams worked, Team 4 was responsible for identifying changes in recommended spares quantities, production diversion requirements, and compiling costs. Team 4 was led by Phil Shannahan. Team 4 was tasked to:

    - Consolidate outputs from Teams 1,2, and 3 for cost and cost phasing to implement

the overall plan
- Continue to assess the recommended spares list to refine cost requirements the ORU level, and at subindentures below the ORU level
- Visit Original Equipment Manufacturers and vendors to refine costs
- Work concurrently with other teams to develop the overall Assembly Critical Failures Operations Plan

The Assembly Failures Solution Set

"This is clearly worthwhile, we need to deal with these disconnects, I can't think of a better use of time than locking these people in a room." Deputy Program Manager for Development, October 8, 1997

Throughout the month of September, the Team developed maintenance and operational workaround plans for assembly failures that would threaten crew/station survival, or would disrupt assembly. The team developed a set of assembly critical failures, on board spares requirements, operational workaround hardware proposals, and identified flight margins. These results were briefed to the Deputy Program Managers for Development and Operations on October 9. The consensus was that if the ISS program didn't put in the place the ability to get these spares to orbit when needed, and in some cases to keep them on board, then ISS assembly could very well fail.

The next big step in this effort was to define how to implement these requirements. The response to the team's proposal was the quote above.

The stated purpose of the Assembly Failures Solution Set was to define logistics carriers, on board internal/external stowage locations, environmental protection services, and EVA/EVR requirements to accomplish spares deliveries and on board stowage during assembly. This was a continuation of the work performed by Team 3 the prior month.

The Solution Set was led by Logistics & Maintenance lead for Maintenance and Resupply and a representative from Element Management. The 7A Launch Package Manager represented Mission Integration and led the integration of the Launch Packages. Three sub-teams were formed:

- Launch Package Integration - Flight 7A Launch Package Manager. Composed of:
    - Launch Package Teams
    - Flight Management & Integration Teams

- Element Management - External Stowage Element lead. Composed of:
    - Element Managers
    - Flight Elements & Systems

- Specialized Expertise - Logistics Spares Lead. Composed of:
    - Mission Operations Directorate/Joint Operations Panel (MOD/JOP)
    - Vehicle Integrated Performance and Resources (VIPER)
    - Crew Office
    - Logistics Carriers
    - Hardware Allocation

Manifests, flight margins
Resource Management
Spares availability
EVA/EVR
NH3 Servicer
Orbiter Capabilities & Constraints
S&MA

The Solution Set conducted an iterative set of sessions by which the disciplines exchanged information to arrive at design and operations plans. This was a combined effort between the three sub-teams. The sub-teams identified potential storage sites, assigned spares and workaround hardware to specific flights, identified logistics carriers and FSE, and developed actions for implementation. The intended result was a workable set of plans, by flight/stage, that addressed the end to end process of transporting spares to orbit, transferring them to Station, and where applicable, storing them on board.

Guidelines

The Solution Set needed an approach that would yield the desired results while minimizing cost and minimizing Program changes. Therefore, a set of guidelines was developed. These guidelines were intended to help focus on least cost/least impact solutions.

Store as Much Inside as Possible

Many spare external ORUs needed to be stored on-orbit. Storing external ORUs internally avoids significant cost and effort over developing external storage accommodations. Since the internal environment is benign, no utilities are required for thermal conditioning. The need is avoided for special Flight Support Equipment (FSE) to interface the ORU to a support structure, since internally most ORUs can be packed into trays or lockers. Also, EVA time to transfer external pre-positioned spares from the Shuttle bay to an external storage location can be avoided by bringing the spare to orbit internally, and transferring it to the Station internal storage volume.

With this in mind, a concerted effort was made to find ways to maximize the number of external ORUs that could be stored internally. Where external ORUs had to be stored externally, the need for external accommodations was pushed out as late as possible, to delay the need for funding the development of external storage hardware.

Pre-Position as Much as Possible

The assessment from MOD/JOP had showed that many critical spare ORUs could be stored on the ground until a failure had occurred. Those ORUs would then need to be manifested on the next flight in order to restore the failed string prior to further assembly and activation activities. However, if the spare could be stored on-orbit, it allowed the crew to restore the failed string almost immediately. This reduced system down time, and eased the strain of having numerous candidate spares that could need to be manifested on very short notice.

Minimize Impact toExisting Hardware

Due to the state of design and manufacture of Station hardware, any design or configuration change would be extremely costly. Redesign was considered a last resort. In that vein, the teams tried to use current carriers and FSE as much as possible.

Stay Within Current Schedules/Assembly Sequence

The assembly sequence is an agreed-upon baseline that impacts international agreements if changed. The hardware manufacture and delivery schedules are also tied to the assembly sequence, and changes to those could incur cost. Changes to the assembly sequence were avoided as much as possible, and plans were initiated that would help avoid disrupting the assembly sequence in the event of a failure. Hardware delivery schedules were looked at as opportunities for “borrowing” a flight asset to use as a spare until an operations spares could be procured and manufactured. This option was especially attractive when hardware deliveries were scheduled ahead of the ground assembly and integration dates.

Develop an Viable Approach for Program Implementation

The Solution Set did not want to establish new standing boards and programmatic overhead in order to prepare for assembly critical failures. Therefore, the intent was to bring together all the necessary disciplines to identify and assess potential approaches, and determine the most viable approach. The disciplines could then identify the top-level requirements associated with this support approach. The support approach and the requirements set could then be handed off to the appropriate existing Program teams for implementation.

External Storage Sites

Part of the process was the identification of potential external storage sites on a stage basis. This helped the teams know how external storage volume could potentially be available, and at what stage that volume could become available. That provided the basis for the teams to trade potential external storage approaches to determine the most technically feasible approach.

Element managers reviewed the design configurations of their elements, and assessed the availability of potential stowage sites by stage. This review was of elements delivered from flights 2A through 12A.

- Node 1 -
Has numerous attach points for small items, available on 2A -
WIFs - Some needed only for assembly operations 2A - 7A. One had no identified use. Load limits on WIFs would be a concern if used for stowage of large spares.
Light interfaces & camera interfaces - Power connections available, could only be used for small spares due to loads.
EVA installed handrail locations and slide wire brackets could be modified as ORU attach points.

- Lab Module -
Has the Lab Cradle Assembly, available after 8A, could handle a SLP/ULC.
Also has static flight fittings which could handle small items, available after 5A.

- Z1 Truss Segment-
Has attach points used to deliver the S-Band RF Group, available after 4A. CBM inter-

face could handle a small carrier. Available after 12A.

- P6 Segment -

Two sites available along the P6 Long Spacer, one about 25 feet along the spacer, the other about 10 feet along the spacer, below the EETCS Radiator. Both have volume to accommodate a carrier. Available from 4A to 12A.

- Airlock-

Static flight fittings and trunnion pins. Available after 7A.

- S0 Truss Segment -

Keel pins could accommodate a carrier. Available after 8A. Other truss elements assessed by similarity to S0.

Flight by Flight Planning

A series of sessions was held in which each flight was considered for delivery of spares to orbit. Each session was led by the launch package integration team. The objective was to be able to deliver each spare before or on it's need date that had been identified by Team 1 (MOD/JOP).

The sessions were held sequentially, starting with flight 2A, and continued until all spares requirements were met. As many spares as practical were designated on each flight. The spares that could not be carried on that flight were rolled over to the next flight. This allowed the teams to get as many spares to orbit as early as possible.

Each flight was planned within the limits that were identified by the multiple disciplines that were participating. Some of the limitations were available upmass, available stowage capability, and EVA accessibility by stage.

Results

The teams met the original objectives as stated. All ORU's that are required to be pre-positioned had flights identified for their delivery that were before or on their need dates. All ORU's and workaround hardware that needed to be launched on the next flight after a failure had flights identified for their pre-positioning with the exception of the following:

- Direct Current Switching Unit
- Pump & Flow Control Subsystem
- Interface Heat Exchanger
- Control Moment Gyro Electrical Assembly
- Ammonia Servicer, Jumpers and Kit

Preparations are being made such that these ORUs can be launched on the next flight after an on board failure occurs. The action for planning and conducting the preparations for launching after a failure was assigned to the Launch Package Managers.

In addition, there were some ORUs that are too large for integrating onto an existing flight. These are ORUs have a critical impact upon failure, but also have a very low likelihood of failure. For these ORUs, the Assembly & Manifest Team is preparing a generic flight configuration that can be substituted for a planned assembly flight relatively quickly. The configuration of

Flight 7A.1, which includes a MPLM and a SLP, will be the basis for this generic flight. This will allow these oversized ORUs to be transported to orbit in a timely manner. Additional cargo would be added to the flight in order to fully utilize the upmass capability.

All ORUs that were pre-positioned can be stored internally with the following exceptions:

- DC to DC Converter Unit Coldplate
- Thermal Control System Pump Module
- Flex Hose Rotary Coupler
- Pump & Flow Control Subsystem
- Ammonia Servicer, Jumpers and Kit

These items are too large to fit through the hatches for IVA translation.

On Board Requirements

The assessment by Team 1 (MOD/JOP) resulted in the identification of spares that needed to be pre-positioned on-orbit, spares that must be delivered to Station on the next flight after a failure, and a set of hardware that was needed in order to perform operational workarounds in the event of a failure.

On Board Pre-positioned Spares

The spares that Team 1 identified for on board pre-positioning were arrived at through a series of JOP sessions which assessed the impact of on board failures by flight. Team 1 identified the need for a pre-positioned spare when the potential failure could endanger Station survival, the ability of the crew to remain on board, or interrupt the assembly sequence before a spare could be delivered on the next Shuttle flight. This was based on their review of system capabilities, demands, redundancies, and the ability to work around a failure.

Many of the spares that were identified were needed due to power demands. The Team 1 assessment showed that as the assembly build progresses, power demands will increase to the point that both power channels are required for operations. This occurs at the 7A.1 stage, requiring on board spares be available in the event of a failure.

Spares Warehouse

Spares that had to be pre-positioned were accommodated using internal stowage through most of early assembly. However, some large power and thermal ORUs were identified as being required on board prior to 12A. These ORUs are too large to store internally, and require external storage. No external storage capability exists in the Station baseline. The teams evaluated the potential external storage sites identified earlier. The Airlock sites were the most promising. The Airlock is installed in time to the meet the need date, and has external volume and attach points that can potentially support a storage facility. The available volume and attach points are not affected by subsequent assembly, and should be available for the life of the program. Also, external power feeds are available nearby which can be tapped to provide power for heater strips that would keep ORUs within required temperature limits.

A spares warehouse concept was developed to provide the capability to store large external ORUs on board, with the power for heaters as needed. This concept calls for a set of beams to be mounted on the Airlock launch trunnions. These beams would extend past the crewlock such that a pallet can be mounted on the beams. Payload Retention Latch Assembly (PRLA) interface would be incorporated on the beams that would be similar to the PRLAs in the Shuttle payload bay. These PRLA type interfaces would secure the pallet to the beams. Power for heaters would be by a cable from a external power feed to the pallet. In this configuration, any pallet which is designed to ride across the cargo bay will also fit on these beams. See Figure 3.

Workaround Hardware

In some cases, an operational workaround is more practical than providing a spare. In these cases, Team 1 developed an operational and functional concept for the hardware necessary to perform the workaround. Team 3 performed an initial assessment of the workaround hardware to determine that it’s development is viable.

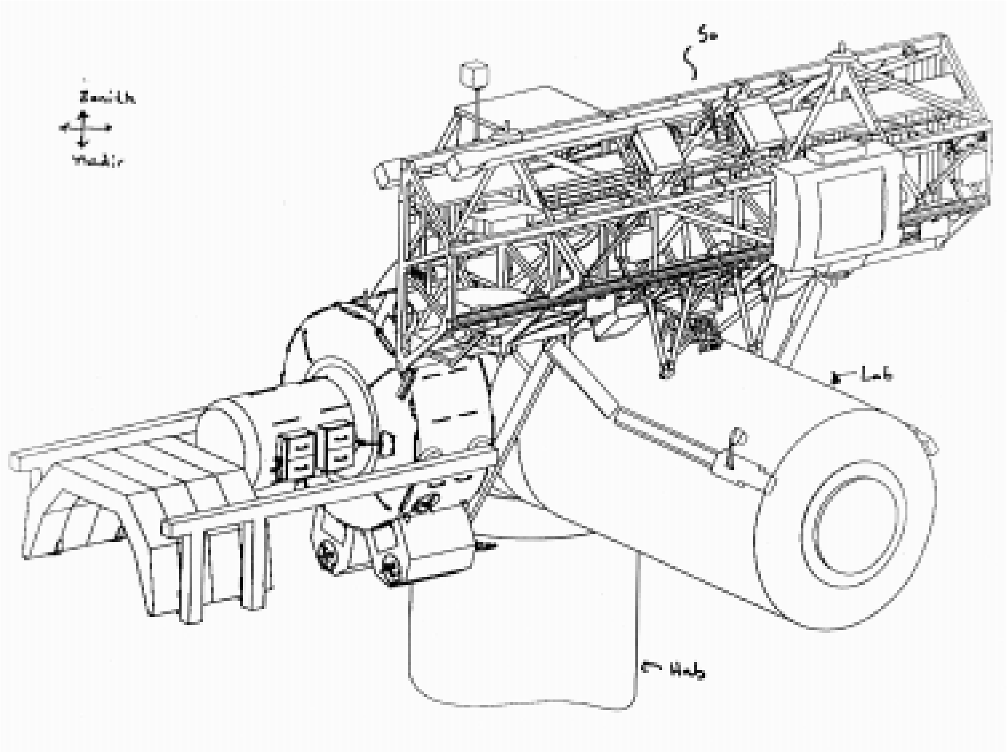


Figure 3 Spares Warehouse Concept

An example is the Ammonia Servicer, Jumpers and Kit. A Photo-Voltaic (PV) Radiator failure while P6 is mounted on Z1 can not be restored through radiator replacement prior to UF2. The most likely failure scenario for the radiator is a failure of a loop through Micro Meteoroid/Orbital Debris (MM/OD) penetration. There is no known method for manipulating such a massive ORU until the Space Station Remote Manipulator System (SSRMS) can be operated from the Mobile

Base System (MBS).The MBS is not delivered until UF2. A failure of the PV radiator would require that power channel to be shut down, which, beginning with stage 7A.1, would leave inadequate power to operate ORU heaters and the Lab. The US Segment would also be zero fault tolerant for power.

The proposed workaround is to provide a set of ammonia jumpers that connect to the radiator interfaces and run to an EETCS radiator. This would allow the EETCS radiator to provide cooling to the PV Array, allowing that power channel to continue to operate. An ammonia servicer is also needed for this workaround, in order to charge the jumpers with ammonia, and replenish ammonia that was lost as a result of the MM/OD strike of the PV Radiator loop.

Fly on Next Flight After Failure

Not all of the critical failures identified by Team 1 must be restored immediately. Some can be lived with temporarily. In these cases, Team 1 identified the period in which the spare must be delivered to orbit on the flight following a failure. In the case of the power system, these failures left the US segment zero fault tolerant for power, but did not immediately endanger the station hardware or crew. However, activation of the next element would require both power channels be available. Therefore, a spare would be delivered on the next Shuttle along with the next assembly element, and installed prior to the element being installed and activated.

Where Team 1 identified a spare in this category, every effort was made to pre-position the spare early. This gave the Station crew the ability to restore the system prior to the next the Shuttle flight. This reduces the risk to an assembly and activation flight by having full system capability available prior to Shuttle launch.

Essential planning considerations were identified for this category of spares.

- If a failure occurs on board, it may bump an ORU that was manifested for pre-positioning.
- The Shuttle Program should plan on providing power for any sidewall carrier, and the FSE designer should have heater elements as a standard design feature.
- Both Programs will have to do enough cargo analysis to ensure that any one of the identified spares can fly (loads and thermal analysis).
- When an ORU is flown after failure, the maintenance will be performed while the Orbiter is present, requiring an additional EVA. The Program will have to accept using the unscheduled EVA, or add the consumables to add an EVA to the flight.

Reconfigure Flight After Failure

A limited set of ORUs were identified that have a critical impact to Station upon failure, which, due to their size and mass, would require reconfiguration of a flight to deliver to Station. Fortunately, these ORUs have a very low probability of failure. Below is the listing of ORUs that fall into this category.

- Ammonia Tank Assembly
- Nitrogen Tank Assembly
- Thermal Radiator Rotary Joint ORU’s
- Solar Array ORU’s

The Solar Array Wing is an example of the planning that addresses failures of these ORUs. The Wing consists of two Blanket Boxes and a Mast Canister. These are delivered and deployed on

Flight 4A. The most likely failure mode is a failure to deploy upon activation on 4A. If this occurs, it is not a situation that can be effectively dealt with spares. The configuration of the Station, with P6 mounted on Z1, precludes handling of these oversized ORUs. The element would either have to brought to ground for refurbishment, or left in place until additional handling equipment can be brought to orbit to manipulate the ORUs. Either case would require the redesignation of an upcoming flight to correct the problem. Once deployed, the probability of failure is minimal.

The Assembly & Manifest Team is conducting the planning to reconfigure a flight on relatively short notice for these contingencies. The general approach is to pre-plan a flight configuration such as 7A.1, with a SpaceLab Pallet and a MPLM. The Program would use the opportunity to also deliver additional ORUs and other cargo as necessary.

Workplan

Following is a summary of the forward work required to implement the findings of this study.

Maintenance Planning

Maintenance planning will be updated to reflect the changes of this study. Tool lists, technical data, training plans, etc., will be reviewed and modified to ensure that all on board resources are available as needed. The updated maintenance planning will be documented in the IDRD, Annex 2, On-Orbit Maintenance Plan. Annex 2 is published by Planning Period, and updates through Planning Period 3 will cover the Assembly Critical Failures Planning.

Manifest Revisions

The On-Orbit Maintenance Plan is the Program input to IDRD Annex 1, Station Cargo Manifest. Annex 1 and 2 will be updated to reflect manifesting of spares and workaround hardware. Annex 1 is published by flight, and will be updated for those flights through Planning Period 3 affected by Assembly Critical Failures Planning.

Hardware Utilization Board

Requirements for diverting production assets for use as spares have been submitted to the Hardware Utilization Board (HUB). The HUB is responsible for identifying specific assets by serial numbers, and providing that information for incorporation into maintenance planning and manifest development. Where an asset is not available, the HUB is responsible for raising that as an issue to the Program.

Stowage Plans

nternal stowage of spares and workaround hardware was assessed from a volumetric standpoint to determine that the approach is viable. The Cargo Integration Team is conducting more detailed assessments to determine definite stowage locations and accommodations.

Hardware Development

The new hardware concepts have been assigned to Vehicle team leads for implementation. Each lead is responsible for the Design, Development, Test & Evaluation (DDT&E) of their hardware items, including gaining approval for necessary changes to the Program baseline. Each lead is responsible for the technical, budgetary and schedule management of their hardware.

Conclusions

The Assembly Stage Critical Failures Planning Team was successful in establishing an approach and plan that satisfies the need to support critical assembly hardware. The support begins with Flight 2A, maximizes the spares available on board to respond to critical failures, identifies new workaround capabilities, and supports through the 12A stage. The appropriate Program teams have been assigned the tasks necessary to implement the new requirements, and the necessary integration structure is being put into place.

This is an on-going process. Launch Package Managers are responsible for integrating the new spares and hardware onto their flights, and reporting and resolving issues. Subsystem managers are responsible for new hardware development to meet manifest schedules and reporting and resolving issues. The L&M Team is responsible for implementing maintenance planning and assessing the impacts to on-orbit supportability as hardware and manifests change. The L&M Team is also responsible for providing an integrated picture to Program Management of progress as it is made in implementing this new support plan.

This report is a snapshot of the new requirements, approach and planning for supporting the International Space Station during assembly. The real work for the Program is to successfully put the new support in place, and use it to ensure successful assembly and operation of the International Space Station.

tions Directorate as the Logistics Technical Lead. As the Maintenance and Resupply lead Mr. Robbins is responsible for all facets of on-orbit maintenance planning and resupply. During his active duty with the US Army, he performed Integrated Logistics Support for Air Defense Artillery.