Experiences with Extra-Vehicular Activities in Response to Critical ISS Contingencies

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ISS External Infrastructure

• ISS primary utilities (power, thermal) located externally
  – Power routing and conversion
    • Route primary power from solar arrays/batteries to various internal and external loads
    • Convert primary power (~160 VDC) to stable secondary power (~120 VDC)
  – Primary thermal control system
    • Transfer heat from internal loads to external cooling loop via heat exchangers
    • Transfer heat from external loads to external thermal cooling loop via coldplates
    • Reject heat via radiators
  – Command and Data Handling
    • Multiplexer/Demultiplexers (MDMs) controlling external hardware such as cooling loops, solar arrays, robotics
Complications with Infrastructure

- Most hardware located on Integrated Truss Structure facing into velocity vector
  - Potential damage/loss due to Micro-Meteoroid/Orbital Debris (MM/OD)
- Most hardware on the Contingency EVA list has limited or no redundancy
  - Example: Loss of single Pump Module or Flex Hose Rotary Coupler results in loss of 1 of 2 external thermal control loops. Loss of 1 loop requires shutting down half of USOS primary power system due to lack of cooling. USOS becomes zero fault tolerant for survival.
- Maintenance and Supportability of these systems was reduced during ISS design and development
  - In recent years, internal and external jumper cables has led to a somewhat improved redundancy risk posture
- Drove development of “Critical Contingency EVA” List
Critical Contingency EVA List

• Started as listing of EVA tasks that, by hardware design or system implementation, would be difficult for EV crew to remove/replace or could impede ISS assembly
• As ISS grew in size, list grew from “Big 8” to “Big 9” to “Big 14” to “Big 11” to now the “Big 13”
  – These are the number of types of Orbital Replacement Units (ORUs) – there are generally 2 or more of each type
• First CCE was performed in Fall 2010 to replace a failed external cooling loop pump
  – Quick turnaround EVA response only theory prior to this event
• Lessons learned from those EVAs (3 were required) demonstrated the need for additional pre-failure analysis prior to future contingency EVAs
  – Spawned development of Failure Response Assessment Team (FRAT)
Current CCE List
(in order of priority)

1. Pump Module (PM) R&R
2. Flex Hose Rotary Coupler (FHRC) R&R
3. Interface Heat Exchanger (IFHX) R&R
4. Solar Array Wing (SAW) Bearing Motor Roll Ring Module (BMRRM) R&R
5. SAW Electronics Control Unit (ECU) R&R
6. Ammonia Tank Assembly (ATA) R&R
7. Nitrogen Tank Assembly (NTA) R&R
8. Main Bus Switching Unit (MBSU) R&R
9. External (EXT) Multiplexer/Demultiplexer (MDM) R&R
10. DC-to-DC Converter Unit (DDCU) R&R
11. External Remote Power Control Module (RPCM) R&R
12. Ammonia (NH3) Leak Isolation and Recovery
13. Micrometeoroid/Orbital Debris (MMOD) penetration pinpoint and repair
Solar Array CCE ORUs

#4. BMRRM – in back

#5. ECU

SAW

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S1, S0, P1 Truss CCE ORUs

#1. PM
#2. FHRC
#3. IFHX (under MMOD shields) (US Lab shown, typical for Node 2, Node 3)
#6. ATAs on back of truss behind PMs
#7. NTA
#8. MBSU

Airlock

#12. NH3 Plumbing – throughout trusses
S0 Truss CCE ORUs

#8. MBSUs

#9. MDM

#10. DDCU

#11. RPCMs

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Sparing

- Spares for most Contingency EVAs are already externally staged
  - Spare IFHX, DDCU, and BMRRM are internal

- P3 Truss
  - ELC 1
    - PM, NTA, ATA
  - ELC 3
    - ATA

- ESP 2
  - Forward side of Airlock
    - PM, MBSU (2), FHRC

- S3 Truss
  - ESP 3
    - FHRC
  - ELC 2
    - PM, NTA
Lessons from 2010 PM R&R

• Much of the “Big 14” (2006 – 2008) work was useful in generating EVA response plans and procedures but had not been taken far enough

• Assumptions made pre-failure for procedures and analysis need to be more thoroughly documented, reviewed, and accepted

• As much engineering analysis as possible should be performed pre-failure
  – Trade off between cost/schedule and risk if work is not done
  – Earlier approach only identified needed analysis, did not have funding to perform analysis

• Pre-failure planning must include protections to be put in place after the failure to better posture ISS for the Next Worse Failure (e.g. a failure of the only other functioning coolant loop)
FRAT Organization

Failure Response Assessment Team

Constraints Assessment Team
Co-Chairs: Vehicle Office and Safety Office
Later merged with Ops Products & Analysis Team

Ops Products & Analysis Team
Co-Chairs: Flight Operations Directorate and Vehicle Office

System Configuration and Requirements (Next Worse Failure) Team
Co-Chairs: Flight Operations Directorate and Vehicle Office

FRAT Products

- Integrated Operations Product Template (IOPT) Process
  - All possible analysis needed for an EVA, notating which *can* be done pre-failure, which *should* be done pre-failure, long (hours) the generic analysis will take if performed pre-failure, and how long the failure-specific analysis would take if performed post-failure

- Pre-failure analysis
  - Subset of IOPT analysis funded and performed in advance of a failure

- Pre-failure planning products
  - Operational procedures, training, post-failure timelines for each ORU created to guide the response from initial failure until execution of the EVA(s)

- Post failure response
  - Briefing to real-time teams to transition from generic FRAT work to post-failure specific work
  - Tailoring of generic pre-failure analysis, assumptions, and decisions to actual situation
  - Finalizing, uplinking, and executing operational products and EVA(s)
Pre- or Post- Failure?

- Engineering Analysis Item

  - Is it possible to perform the analysis prior to the failure?
    - No
    - Yes

  - If the analysis is performed after the failure, could it delay the first EVA by more than ~2 days?
    - No
    - Yes

  - If the analysis is performed after the failure and results differ from assumptions, could this delay the first EVA by more than ~2 days?
    - No
    - Yes

- Perform analysis prior to failure
- Perform analysis after failure
Overall FRAT Project Flow

Pre-Failure

1. Create engineering analysis lists, Draft EVA timelines, Initial operations assessments, Post-Failure timelines, train crews with best available information.
2. Perform, deliver funded analysis
3. Perform NBL Development runs, update EVA timelines, update crew training
4. Integrate delivered analysis into EVA-related products, final product, EVA procedure reviews

Post-Failure

1. Resolve open issues ISS Program
2. "Shelve" all final products
3. Review pre-failure decisions, analyses to ensure applicability
4. Implement pre-failure plans, crew training
5. Perform necessary post-failure analyses
6. Perform EVA(s)

Next Worse Failure Assessments, Recommendations

Reassess readiness based on Program/Vehicle changes

Assess, implement lessons learned for future EVAs
Summary

- Initial “Big 14” work was put to the test for the first time in 2010. Deficiencies were found in some of the planning and approaches to that work.
- Failure Response Assessment Team created in 2010 to address deficiencies
  - Identify and perform engineering analysis in operations products prior to failure; incorporate results into operations products
  - Identify actions for protecting ISS against a Next Worse Failure after the first failure occurs
  - Better document not only EVA products but also planning products, assumptions, and open actions
- Pre-failure investments against critical failures best postures ISS for swift response and recovery
  - A type of insurance policy
  - Has proven effective in a number of contingency EVA cases since 2010
    - Planning for MBSU R&R in 2012
    - Second PM R&R in 2013
    - EXT MDM R&R in 2014
- Current FRAT schedule projects completion of all analysis in 2018
Backup Data
Acronym List

• BMRRM – Bearing Motor Ring Roll Module
• CCE – Critical Contingency EVA
• DDCU – DC-to-DC Converter Unit
• ECU – Electronics Control Unit
• ELC – External Logistics Carrier
• EMU – Extra-vehicular Mobility Unit
• EPS – Electrical Power System
• ESP – External Stowage Platform
• EV – Extra-Vehicular
• EVA – Extra-Vehicular Activity
• EXT – External
• FHRC – Flex Hose Rotary Coupler
• FOD – Flight Operations Directorate
• FRAT – Failure Response Assessment Team
• GJOP – Generic Joint Operations Panel
• IFHX – Interface Heat Exchanger
• IOPT – Integrated Operations Product Tempalte
• ISS – International Space Station
• ITS – Integrated Truss Segment
• LSAR – Logistics Support Analysis Record
• MBSU – Main Bus Switching Unit
• MDM – Multiplexer/Demultiplexer (similar to computer)
• MHA – Maintenance Hazard Analysis
• MM/OD – Micrometeoroid/Orbital Debris
• NASA – National Aeronautics and Space Administration
• NBL – Neutral Buoyancy Laboratory
• NH3 – chemical formula for Ammonia
• ORU – Orbital Replacement Unit
• PM – Pump Module
• R&R – Remove and Replace
• RPCM – Remote Power Control Module
• SAW – Solar Array Wing
• USOS – United States Orbital Segment
• VDC – Volts, Direct Current
Photo References

• All photos are NASA downlink images
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