InSPIRE-II Halo PDR

15 January 2014
DARPA, NASA, NRL
AFS, MIT SSL
Outline

- Introduction and System Overview
- Mechanical Design
- Electrical Design
- Software Changes
- ISS Operations Plan
- Programmatic Risks
- Safety and Integration
- Schedule
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InSPIRE-II Introduction

Objective Statement: Develop a cost-effective facility for maturing adaptive GNC technology in support of on-orbit, robotic satellite assembly in a risk-tolerant, dynamically-authentic environment

- Hardware upgrades to SPHERES Facility on ISS include Universal Docking Ports (UDP), Halos, and Satlets/Any-angle docking ports
- Purpose:
  - Enable testing of on-orbit robotic assembly and servicing
  - Address challenge of aggregating resources (sensors and actuators)
  - Enable testing of various techniques for reconfigurable control and responses to changing system dynamics
- Space applications may include but are not limited to:
  - Remote or autonomous robotic servicing of retired, obsolete, or failed satellites
  - Assembly of spacecraft modules into fully-functional satellites on-orbit
  - Assembly of large spacecraft on-orbit, such as space-based telescopes
## Halo System Requirements

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To be filled in throughout presentation
Halo System Overview

- Enables each satellite to **interface with six external objects simultaneously** through rigid mechanical and electrical interfaces called “Halo ports” (HPs)
- Supports **VERTIGO Goggles**, multiple **UDPs**, and other future peripherals through USB and Ethernet
- Peripherals added to and removed from the Halo by the astronaut as necessary for each test
- Utilizes processing power of **VERTIGO Avionics (VA) Stack**
- Provides power to all attached peripheral devices
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• Mechanical Design
  • Applicable Requirements
  • Design Overview
  • Design Details

• Electrical Design

• Software Changes

• ISS Operations Plan

• Programmatic Risks

• Safety and Integration

• Schedule
# Applicable Mechanical Requirements

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Halo Mechanical Design Overview
# Halo Mechanical Design Overview

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Mass [kg]</th>
</tr>
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<tr>
<td>X-dim [cm]</td>
<td>Y-dim [cm]</td>
</tr>
<tr>
<td>43.4</td>
<td>16.3</td>
</tr>
</tbody>
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<thead>
<tr>
<th>Part</th>
<th>Material</th>
<th>Rationale</th>
</tr>
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<tbody>
<tr>
<td>Sleeve</td>
<td>6061-T6 Aluminum</td>
<td>Strong, yet cheap and lightweight – ideal for clamping the SPHERE (as used on RINGS)</td>
</tr>
<tr>
<td>Struts, battery holders and port housings</td>
<td>3D Printed Ultem</td>
<td>Recently Flight Approved, can be designed to have adequate strength in key locations, lightweight, easy to manufacture</td>
</tr>
</tbody>
</table>
Halo Mechanical Design Overview

- Mounts on SPHERES with VA Stack
- Interfaces with VA Stack 50-pin connector
- Produces 6 identical 50-pin connectors at 6 rigid HPs around the SPHERES
- Supports 6 PCBs: Motherboard, Power board, and 4 boards at the 4 angled ports
- HPs angled at 45 degrees so that:
  - Multiple peripherals can be attached
  - Two Halo-equipped SPHERES can dock
- The 3 subassemblies include:
  - Halo Mounting Assembly
  - Halo Expansion Port Side
  - Halo Back Side
Halo Subassemblies

Back Side

Support Sleeve

Expansion Port Side
Halo CAD: Mounting Assembly

- Halo mounted to SPHERES with sleeve and struts
- Similar to press-fit design used for RINGS
- Sleeve also used for alignment
- 4 battery holders integrated into struts
- Wires between front and back halves of Halo routed along struts and sleeve
Halo CAD: Expansion Port Side

- Provides male 50-pin Samtec connector to interface with VERTIGO Avionics Stack
- Connector mates to VA Stack using ribbon cable (similar to RINGS)
- Houses Halo Motherboard at HPG and 2 Halo Port boards at HP1 and HP5
- Includes external USB and Ethernet connectors
- LEDs on each side of HPs are lit when each port is powered
Halo CAD: Back Side

- Houses Halo Power board at HP3 and Halo Port boards at HP2 and HP4
- Contains master power switch on the side of HP3
- LEDs on each side of HPs are lit when each port is powered
- Thumb screws easily accessible by astronauts
- Does not interfere with battery insertion and removal
Halo CAD: Halo Port

- HPs provide 9 cm by 11 cm flat face for flush mounting; HPG and HP3 are 12 cm by 11 cm
- Each HP provides 4 male thumb screws protruding outwards from Halo for mounting peripherals
- HPs provide mechanical connection identical to VA Stack with Samtec connector and 4 female mounting holes
- Connector is not centered so astronauts can easily recognize correct mounting configuration
# Keep Out Zone Definitions

<table>
<thead>
<tr>
<th>Category</th>
<th>Req. #</th>
<th>Item</th>
<th>“Keep Out” Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumables</td>
<td>STR-6.1</td>
<td>Battery doors</td>
<td>7 cm radius from hinge</td>
</tr>
<tr>
<td>Consumables</td>
<td>STR-7.1</td>
<td>CO₂ Tank</td>
<td>15 cm diameter, 20 cm distance</td>
</tr>
<tr>
<td>Consumables</td>
<td>STR-8.1</td>
<td>Pressure regulation knob</td>
<td>15 cm diameter</td>
</tr>
<tr>
<td>Operations</td>
<td>STR-10.1</td>
<td>SPHERES Control Panel</td>
<td>Clear</td>
</tr>
<tr>
<td>Operations</td>
<td>STR-9.1</td>
<td>Pressure gauge</td>
<td>LOS</td>
</tr>
<tr>
<td>Performance</td>
<td>STR-4.1</td>
<td>Thrusters</td>
<td>18 deg. cone</td>
</tr>
<tr>
<td>Performance</td>
<td>STR-5.1</td>
<td>Ultrasound (US)</td>
<td>90 deg. cone</td>
</tr>
<tr>
<td>Performance</td>
<td>STR-5.2</td>
<td>Infrared (IR)</td>
<td>120 deg. cone</td>
</tr>
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**Consumables:** to maximize efficiency in replacing consumables during the test session, the crew should be able to handle the consumables without taking off the expansion item (i.e., the Halo or any peripheral)

**Operations:** areas must be kept clear because they are essential to the crew during the entire test session

**Performance:** blocking thrusters, ultrasound, or infrared will degrade the performance of the system
Keep Out Zone Visualization: Thruster Plumes

Keep out zone violation:

- Limits thrusting capability
- Possibly misdirects forces

- Ideally no plume impingement, however requirement depends on dynamics required for testing
- Cannot reduce thrust below a TBD threshold that enables testing of robotic assembly

Note: Grey sphere is meant to show the size of the cross-section of the plumes at an arbitrary radius and does not reflect the extent of the plume.
Keep Out Zone Visualization: Ultrasound and Infrared

**Keep out zone violation:**

- Should not block the entire cone, but allowed to block portions of the FOV so long as STR-5.1 and STR-5.2 are met

- The ultrasound receivers (4 on each face of the satellite) can receive pulses from anywhere in direct LOS up to 4m away

- The IR transceivers (2 on each face of the satellite) can transmit/receive IR flashes to/from any unblocked location in their 120° FOV
Keep Out Zone Visualization: Batteries, CO₂ Tank and Pressure Knob

**Keep out zone violation:**
- Crew must remove Halo to install or remove consumables
- These areas should not be permanently blocked by any expansion item

The crew must be able to:
- Insert, screw in, unscrew and remove the tank from the bottom of the satellite
- Adjust the regulator knob on the top of the satellite
- Open the battery doors fully with room to install and remove a battery pack
SPHERES Keep Out Zones vs. Halo

- +/- Z plumes completely unimpinged
- +/- Y plumes (not pictured) completely unimpinged
- +/- X plumes only slightly impinged
  - Will not degrade capabilities beyond acceptable limits
  - Degradation similar to that with VERTIGO Goggles

Thruster plumes shown in yellow
SPHERES Keep Out Zones vs. Halo

- Battery doors completely unimpinged
- CO\textsubscript{2} tank completely unimpinged
- Pressure knob completely unimpinged
- US/IR FOVs on +/- Y and +/- Z faces (not pictured) completely unimpinged
- US/IR FOVs on - X face (not pictured) slightly impinged
- US/IR FOVs on + X face (not pictured) completely impinged

Battery doors, CO\textsubscript{2} tank, and pressure knob keep out zones shown in orange

Optics Mount or UDP on +X face will replace sensors
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Halo Electrical Design Overview

- HP2 Board
- HP1 Board
- Power board
- Motherboard
- HP4 Board
- HP5 Board

4 Batteries

6 PCBs shown in green
Halo Battery Selection

- Selected Battery: Nikon 16650 Lithium Ion Battery
  - 4 in parallel gives adequate voltage and max current
  - Small size integrates well into Halo structure
  - Sufficient current and capacity to support intensive CONOPS
- Already on ISS for VERTIGO Avionics Stack

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Capacity (Wh)</th>
<th>Capacity (Ah)</th>
<th>Mass (kg)</th>
<th>Volume (cm³)</th>
<th>Max Current (A)</th>
<th>Specific Capacity (Wh/kg)</th>
<th>Capacity Density (Wh/cm³)</th>
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<tr>
<td>11.1</td>
<td>112</td>
<td>10</td>
<td>0.648</td>
<td>460</td>
<td>7.6</td>
<td>172.84</td>
<td>0.24</td>
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Halo Printed Circuit Boards

PCBs Include:

1. Halo Motherboard
   - Supports 50-pin connector to interface with VA Stack
   - Contains USB hubs, Ethernet switch, and PIC
   - Routes all wires to the proper HPs
   - Contains all circuitry for HPG

2. Halo Power Board
   - Parallelizes batteries
   - Creates 5V and Ground lines from Batt+ and Batt-
   - Routes power to the proper HPs
   - Contains all circuitry for HP3

3. Halo Port (HPₙ) Boards
   - Takes data lines and power lines from Motherboard and Power board
   - Supports 50-pin connector to interface with peripherals
Halo Motherboard Block Diagram (Detail)

- External USB Connectors (QTY 2)
- External Ethernet Connector (QTY 1)
Halo Motherboard Block Diagram (Detail)

- VERTIGO
- Avionics
- Interface
- Connector
Halo Motherboard Block Diagram (Detail)

- PIC32 Processor Block
Halo Motherboard Block Diagram (Detail)

- Ethernet Switch Block
Halo Motherboard Block Diagram (Detail)

- USB Hub Block (QTY 2)
Halo Motherboard Block Diagram (Detail)

- Halo Port 1 (HP1) and Halo Port 5 (HP5) Connectors
- Halo Port 2 (HP2), Halo Port 3 (HP3), Halo Port 4 (HP4) Connector
- Halo Port Goggles (HPG) Connector
Motherboard Components (1 of 3)

Microchip PIC32MX795F512L

- Key Features
- 512+12(1)KB Program Memory, 128KB Data Memory
- Embedded USB, Ethernet
- 5 independent I²C buses to provide flexible interfaces to ethernet switch and USB hub
Micrel KS8999 9-Port Ethernet Switch

- Interfaces (1) VERTIGO Avionics Box, (6) Halo Ports, (1) PIC Processor, (1) External Ethernet Connector

Key Features

- Integral Physical Layer Transceivers (PHY) and Media Access Control units (MAC)
- Can operate as a standalone 8-port-switch, or provide more customized operation via PIC processor.
Motherboard Components (3 of 3)

Microchip USB2517i

- USB 2.0 Hi-Speed 7-Port Hub Controller (QTY 2 required)
- Upstream ports are (2) VERTIGO Avionics USBs
- Available downstream ports are:
  - (12) Halo Ports (2 USB channels per port)
  - (2) External USB Connector
Halo Power Board Block Diagram
HP_N Board Block Diagram

Data lines (in/out):
- USB VD6
- USB VD3
- Ethernet

Power lines (in):
- SW Batt +
- Batt -
- 5V Regulated
- Ground

LED

VERTIGO 50 pin connector
Halo Electrical Interfaces (1/3)

• With VERTIGO:
  • Connected through 50-pin Samtec connector coming out of the VA Stack
  • Communicates through USB, Ethernet, UART (looped back)
  • US/IR lines passed through

• With SPHERES:
  • No direct connection
  • US/IR lines passed through VA Stack
  • All other communications must be processed by VA Stack

VA Stack 50-pin Samtec connector
Halo Electrical Interfaces (2/3)

- With Peripherals at HPG:
  - Provides identical electrical interface to the VA Stack (only change is UART pins are empty)
  - 2 USB lines, 1 Ethernet line, and 11.1V unregulated and 5V regulated power lines
  - HPG has 4 USB lines (2 dedicated)

HPG 50-pin Samtec connector
Halo Electrical Interfaces (3/3)

- With Peripherals at HP1-5:
  - Provides identical electrical interface to the VERTIGO Avionics Stack (only change is UART and US/IR pins are empty)
  - 2 USB lines, 1 Ethernet line, and 11.1V unregulated and 5V regulated power lines
  - HPN has 2 USB lines (from USB hubs)
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System Requirements Recap
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SYS-1 to be further addressed in Safety section of presentation

Further discussion required for SYS-5
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• **Software Changes**
• ISS Operations Plan
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Software Changes

- No expected changes to SpheresCore
  - Mass and inertia, US receiver configuration, and control gains will be updated in Halo-specific code to reflect new physical properties of satellites with Halos
- GogglesCore restructured to enable multiple devices to be easily inserted
  - Simplify process for creating new classes in GogglesCore
  - Create new generalized classes rather than camera-related classes
  - “spheres” and “DataStorage” classes will remain; “cameras”, “rectifier”, “videoStreamer”, and “videoBuffer” modified to be more general
- VERTIGO Daemon generalized so it is structured for multiple generic objects to plug in through USB or Ethernet (not solely video)
Outline

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- ISS Operations Plan
  - Assembly Sequence
  - Test Session Plans
  - CONOPS
- Programmatic Risks
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Halo Assembly Sequence (1/3)

- Step 1) Mount the VERTIGO Avionics Stack onto the SPHERES Expansion Port V2
Halo Assembly Sequence (2/3)

- Step 2) Slide the SPHERES with VERTIGO Avionics Stack into the sleeve of the Halo
Halo Assembly Sequence (3/3)

• Step 3) Connect the tethered connector on the back side of HPG with the connector on the VA Stack so that the latching mechanism engages
Test Session Plans

- Total time for Halo Test Session Setup: 2.5 hours
- Total time for Halo Test Session Experiments: 3.5 hours

Halo Test Sessions:

<table>
<thead>
<tr>
<th>Event/Activity/Task/Session Description</th>
<th>Template Date(s) &amp; Flexibility</th>
<th>Crewtime per Event (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPHERES Halo Checkout</td>
<td>2-4 weeks after unstow</td>
<td>6</td>
</tr>
<tr>
<td>SPHERES Halo Science 1</td>
<td>4-8 weeks after Checkout</td>
<td>6</td>
</tr>
<tr>
<td>SPHERES Halo Science 2</td>
<td>6-10 weeks after Science 1</td>
<td>6</td>
</tr>
<tr>
<td>SPHERES Halo Science 3</td>
<td>6-10 weeks after Science 2</td>
<td>6</td>
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## Halo Test Session Setup

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<tr>
<th>Step</th>
<th>Source</th>
<th>Astronaut Time</th>
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<tbody>
<tr>
<td>1.0 Charge 10 Batteries</td>
<td>Existing ISS Camera Charging Procedures</td>
<td>15 min</td>
</tr>
<tr>
<td>2.0 Upload Code and Disk Image to ISS</td>
<td>VERTIGO Procedures</td>
<td>0 min (Behind the scenes)</td>
</tr>
<tr>
<td>3.0 Check Flash Disk Consistency</td>
<td>VERTIGO Procedures</td>
<td>40 min</td>
</tr>
<tr>
<td>4.0 SPHERES Work Area Setup</td>
<td>SPHERES Proc: 1.001</td>
<td>45 min</td>
</tr>
<tr>
<td>5.0 VA Stack and Halo Attachment</td>
<td>VERTIGO Procedures and New Halo Procedures</td>
<td>30 min</td>
</tr>
<tr>
<td>6.0 Load SPHERES and VA Stack programs</td>
<td>SPHERES and VERTIGO Procedures</td>
<td>20 min</td>
</tr>
</tbody>
</table>

**Total Time: 2.5 hours**
# Halo Test Session Experiments

<table>
<thead>
<tr>
<th>Step</th>
<th>Source</th>
<th>Astronaut Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Power on SPHERES, VA Stack, and Halo</td>
<td>SPHERES Procedures, VERTIGO Procedures, New Halo Procedures</td>
<td>30 min</td>
</tr>
<tr>
<td>2.0 Quick Checkout SPHERES</td>
<td>Embedded as Test</td>
<td>10 min</td>
</tr>
<tr>
<td>3.0 Quick Checkout Halo</td>
<td>New Halo Test</td>
<td>20 min</td>
</tr>
<tr>
<td>4.0 Run Tests</td>
<td>2.001: 2 &amp; 3</td>
<td>50 min</td>
</tr>
<tr>
<td>5.0 Change SPHERES Consumables (C02 Tanks and SPHERES Batteries)</td>
<td>2.002</td>
<td>20 min</td>
</tr>
<tr>
<td>6.0 Change VA Stack and Halo Consumables (Batteries)</td>
<td>VERTIGO Procedures and New Halo Procedures</td>
<td>25 min</td>
</tr>
<tr>
<td>7.0 Download Data from VA Stack to Laptop</td>
<td>VERTIGO Procedures</td>
<td>35 min</td>
</tr>
<tr>
<td>8.0 Shutdown experiment</td>
<td>SPHERES Procedures, VERTIGO Procedures, New Halo Procedures</td>
<td>20 min</td>
</tr>
</tbody>
</table>

**Total Time: 3.5 hours**
Halo CONOPS

- 4 ISS Test sessions requested
  - Minimize risk of loss of crew time
  - Iterative & Incremental testing to prove out the system and reduce risks
  - Presume successful operations, but provide contingencies for unforeseen circumstances

- Halo Test Session #1: SPHERES Halo Checkout
  - 2-4 weeks after unstow
  - Hardware checkout and crew familiarization
  - Description: Turn on, test all Halo ports with UDPs and Goggles, begin inertia characterization, execute position and attitude maneuvers, most basic science test-move/dock/reconfigure/move/undock

- Halo Test Session #2: SPHERES Halo Science 1
  - 4-8 weeks after Checkout
  - Description: Tune controllers, test Resource Aggregated Reconfigurable Control (RARC) using UDPs and VERTIGO Goggles, incrementally test Robotic Assembly Architectures beginning with the first (beehive)

Arch. 1: Beehive
Integrated
Distributed
Prox Ops
Halo CONOPS

- **Halo Test Session #3: SPHERES Halo Science 2**
  - 6-10 weeks after Science 1
  - Description: Advance algorithms, incrementally test Robotic Assembly Architectures 3 and 7 (integrated and external tugs)

**Arch. 3: Integrated Tug**
Integrated
Centralized
Prox Ops

**Arch. 7: External Tug**
External
Centralized
Prox Ops

- **Halo Test Session #4: SPHERES Halo Science 3**
  - 6-10 weeks after Science 2
  - Description: Incremental advancements in algorithms, expand to include CONOPS with resource aggregation, reconfigurable control, vision-based navigation and mapping, and robotic assembly of modules
Outline

• Introduction and System Overview
• Mechanical Design
• Electrical Design
• Software Changes
• ISS Operations Plan
• Programmatic Risks
• Safety and Integration
• Schedule
# Programmatic Risks

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Risk</th>
<th>Mitigation Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>ECOs from safety reviews</td>
<td>Plan ahead for potential safety concerns using past experiences; keep margin in schedule</td>
</tr>
<tr>
<td>B</td>
<td>Compressed schedule</td>
<td>Routine progress meetings to work through problematic areas; enter reviews well-prepared; leave margin in schedule</td>
</tr>
<tr>
<td>C</td>
<td>Ground environmental testing schedule slip</td>
<td>Work to plan testing ahead of time and leave margin in the schedule</td>
</tr>
<tr>
<td>D</td>
<td>ISS Orange satellite not functional</td>
<td>Plan for Orange satellite debugging before HW gets on station; utilize 2-sat CONOPS</td>
</tr>
<tr>
<td>E</td>
<td>Challenges with modifying VERTIGO software</td>
<td>Begin incremental code changes early; update code to more advanced levels as testing requires</td>
</tr>
</tbody>
</table>

![](chart.png)

[Chart showing risk likelihood and impact]
Outline

• Introduction and System Overview
• Mechanical Design
• Electrical Design
• Software Changes
• ISS Operations Plan
• Programmatic Risks
• Safety and Integration
  • Top Level ISS Integration and Safety Requirements
  • Planned Analyses
  • Venting/Stored Energy Analysis
  • Structural Analysis
• Schedule
## Top Level ISS Integration and Safety Requirements

<table>
<thead>
<tr>
<th>ID</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISS-1</td>
<td>The system shall meet the requirements detailed in <strong>SSP 30233</strong>: Space Station Requirements for Materials and Processes</td>
</tr>
<tr>
<td>ISS-2</td>
<td>The system shall meet the requirements detailed in <strong>SSP 57000</strong>: Pressurized Payloads Interface Requirements Document</td>
</tr>
<tr>
<td>ISS-3</td>
<td>The system shall meet <strong>Form 1298 standard hazards</strong> primarily for sharp edges, corners, protrusions</td>
</tr>
<tr>
<td>ISS-4</td>
<td><strong>Environmental testing</strong> must be performed for EMI/EMC, vibration, touch temperature, acoustics, and offgasing</td>
</tr>
<tr>
<td>ISS-5</td>
<td><strong>Analysis</strong> must be performed for consideration of thermal environment, structural (launch) loads, crew induced kickloads, and sharp edges, pinch points and holes</td>
</tr>
</tbody>
</table>
Halo Safety Overview

- The team has reviewed the design and identified standard and unique hazards.
- A Safety TIM with the PSRP has been scheduled for Feb 18th. Documentation submittal due by Feb 4th.
- While referred to as a TIM, the goal will be to prepare a Safety Data package closely resembling a Phase 0/1/2, with the aim of advancing directly to a Phase 0/1/2 review in the April timeframe.
- The PSRP Safety Verification process is migrating to an online system for submitting HR’s and verification documentation.
- The team is familiarizing themselves with the new online system.
Halo Standard Safety Overview

The Halo design will adhere to NASA Safety and Integration Regulations for ISS Payloads Operations

- **SSP 30233** (Materials), **SSP 50835** (Common IRD), **SSP 57000** (Press. P/L IRD), **NSTS 1700.7B** (Safety), **SSP 52000** (ExPRESS)

- Standard Safety Form 1298 Hazards
  - Stowage Structural Failure
  - Sharp Edges, Corners, Protrusions
  - Shatterable Materials
  - Flammable Materials
  - Materials Offgassing
  - Non-ionizing Radiation (EMI)
  - Electro-Magnetic Compliance (EMC)
  - Touch Temperature
  - Electrical Power Distribution
  - Rotating Equipment
  - Mating/Demating Powered Connectors
  - Contingency Return and Rapid Safing
  - Hole Sizing

- We will be performing testing for:
  - EMI/EMC
  - Vibration
  - Touch temperature
  - Acoustics
  - Offgas

- We will be performing analysis for:
  - Thermal
  - Structural (launch) loads
  - Crew induced loads (kickloads)
  - Sharp edges, pinch points, holes
Venting/Stored Energy Analysis

- As per section F.3 of the Form ISS_OE_1298 Flight Payload Standardized Hazard Control Report calculated MEVR to verify no stored energy hazard exists in the event of depressurization/repressurization of the surrounding volume

<table>
<thead>
<tr>
<th>a) Provides an internal volume to effective vent area ratio that results in a differential pressure loading of no greater than 0.01 psid.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Note: Maximum Effective Vent Ratio (MEVR) for a 0.01 psid pressure differential is defined as:</td>
</tr>
<tr>
<td>$ MEVR = \left( \frac{\text{Internal volume (in}^3\text{)}}{\text{Effective vent area (in}^2\text{)}} \right) \leq 2000 \text{in} $</td>
</tr>
</tbody>
</table>

- Venting/Stored Energy Analysis Preliminary Results:
  - Used SolidWorks 2012 CAD package to measure volumes and areas
  - Total internal volume (conservative) was calculated as: $\sim 100 \text{ in}^3$
  - The total exposed surface area of Mounting holes: $\sim 2.24 \text{ in}^2$
  - Substituting into the MEVR equation: $100/2.24 = 44.64 \text{ in} \ll 2000 \text{ in}$
Structural Analysis

- **Worst Case Scenario analyzed:**
  - During launch typically experiences up to a 6G load factor
  - As an added factor of safety, a launch load factor of 12G in each axis (corresponding to the HTV expected loads according to Table 3.1.1.2.1.1.2-1 of the SSP 50835 Common Interface Requirements Document) is used
  - Onboard the ISS, a payload may be subjected to a 125 lbf (56.7 kgf) push-off load in any axis imparted on it by a crewmember

<table>
<thead>
<tr>
<th>TABLE 3.1.1.2.1.1.2-1</th>
<th>LAUNCH AND LANDING LOAD FACTORS ENVELOPE WITHOUT PRE-DETERMINED ORIENTATION (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nx (g)</td>
</tr>
<tr>
<td>Launch (2)</td>
<td>+/-11.6</td>
</tr>
<tr>
<td>Landing (3)</td>
<td>+/-12.5</td>
</tr>
</tbody>
</table>

**Notes:**
1) The values assume that the stowed hardware orientation is not pre-determined.
2) The launch load factors and rotational accelerations are an envelope of the launch Nx, Ny, and Nz values from Table 3.1.1.2.1.1.1-1.
3) The landing load factors and rotational accelerations are an envelope of the landing Nx, Ny, and Nz values from Table 3.1.1.2.1.1.1-1.
Structural Analysis: Preliminary Results

- Used SolidWorks 2012 Simulation Von Mises Stress Analysis Tool with tetrahedral elements for meshing
- Verified positive safety margins with factors of safety of 1.25 (yield) and 2.0 (ultimate)
Structural Analysis: Preliminary Results (Cont’d)

- 125 lbf Crew Kick Load Analysis
  - Max Stress: 7.2 ksi
  - Max Displacement: 4.026 mm
- Factor of Safety (Yield): 1.5
- Margin of Safety > 0
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## Schedule

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety TIM Package Due</td>
<td>4-Feb-14</td>
</tr>
<tr>
<td>Safety TIM</td>
<td>18-Feb-14</td>
</tr>
<tr>
<td>Critical Design Review</td>
<td>1-Mar-14</td>
</tr>
<tr>
<td>Phase 0/I/II SDP Due</td>
<td>4-Mar-14</td>
</tr>
<tr>
<td>Phase 0/I/II Safety Meeting</td>
<td>17-Apr-14</td>
</tr>
<tr>
<td>Phase III SDP Due</td>
<td>TBD</td>
</tr>
<tr>
<td>Phase III Safety Meeting</td>
<td>TBD</td>
</tr>
<tr>
<td>Crew Training Materials</td>
<td>TBD</td>
</tr>
<tr>
<td>Three (3) Flight Qualified units</td>
<td>1-Jul-14</td>
</tr>
<tr>
<td>Final Acceptance Tests Data Package</td>
<td>1-Jul-14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew Procedures</td>
<td>1-Jul-14</td>
</tr>
<tr>
<td>Simulation Update</td>
<td>1-Aug-14</td>
</tr>
<tr>
<td>SpheresCore Updates</td>
<td>1-Sep-14</td>
</tr>
<tr>
<td>Interface Control Document</td>
<td>1-Sep-14</td>
</tr>
<tr>
<td>Launch (Orbital 3)</td>
<td>3-Oct-14</td>
</tr>
<tr>
<td>ISS Checkout</td>
<td>20-Oct-14</td>
</tr>
<tr>
<td>ISS Sci 1 (SW Developed)</td>
<td>1-Dec-14</td>
</tr>
<tr>
<td>ISS Sci 2</td>
<td>1-Feb-15</td>
</tr>
<tr>
<td>ISS Sci 3</td>
<td>1-Apr-15</td>
</tr>
<tr>
<td>ISS Science Report</td>
<td>TBD</td>
</tr>
</tbody>
</table>
QUESTIONS?