Overview of Integrated Random Vibration Testing of the NASA Orion Crew Survival Suit

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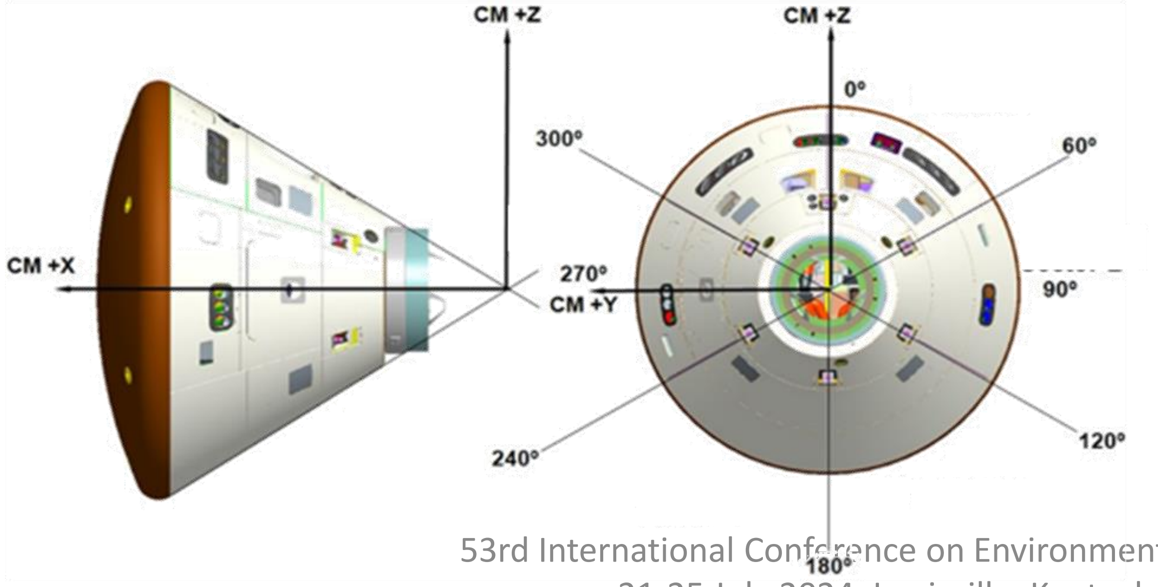
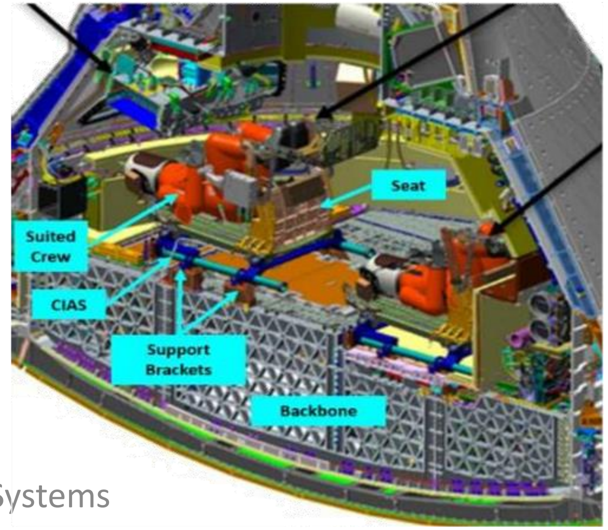
Grms: Acceleration Root Mean Squared

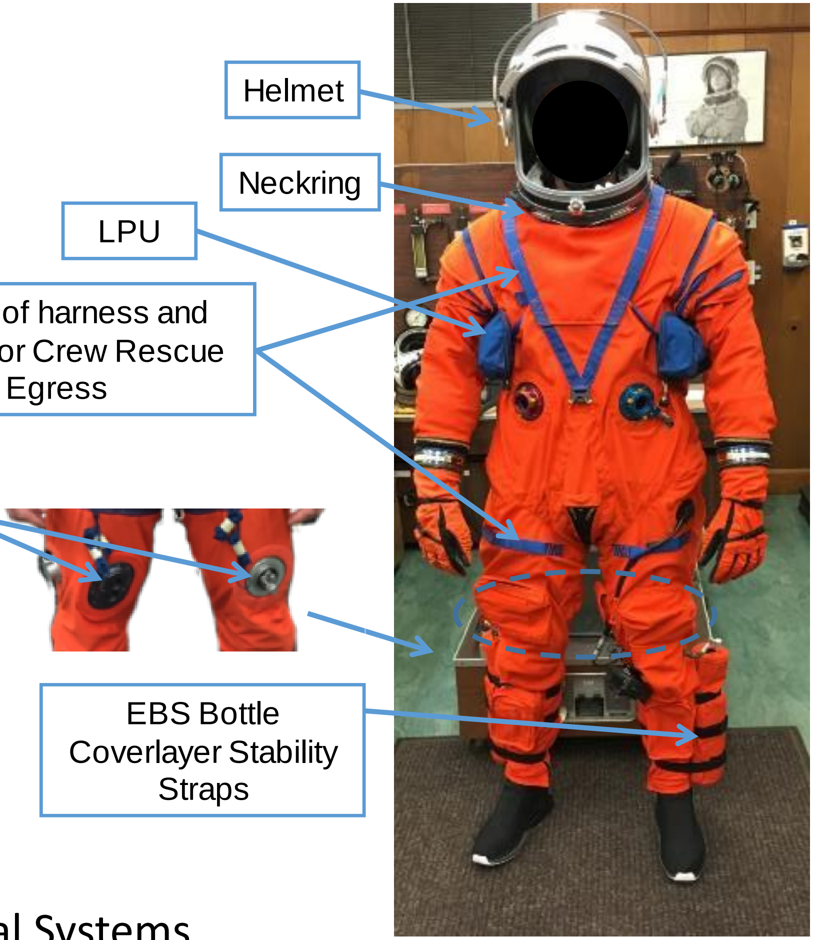
Background - Orion Crew Module Overview

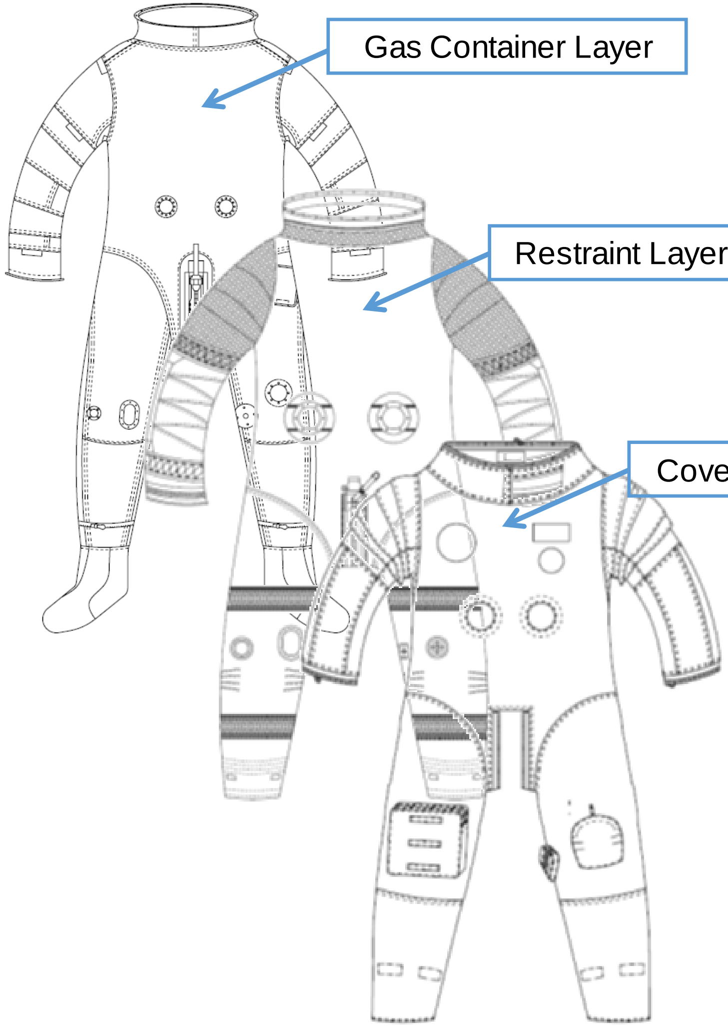
- Artemis 1 Mission Launched/Landed Successfully Fall 2022
  - Un-manned Mission
  - Carried one manikin, mass simulators, and radiation torso simulators
  - Traveled around Moon, returned to Earth
- Orion Crew Module
  - Supports 4 Crew Members
  - Seats mounted to Crew Impact Attenuation System (CIAS)
  - Launch Scenarios consider Nominal Ascent and Abort Cases
- Artemis 2 Mission Planned for Fall 2025
  - Four astronauts will venture around the Moon in Orion on Artemis II





OCSS Suit Overview

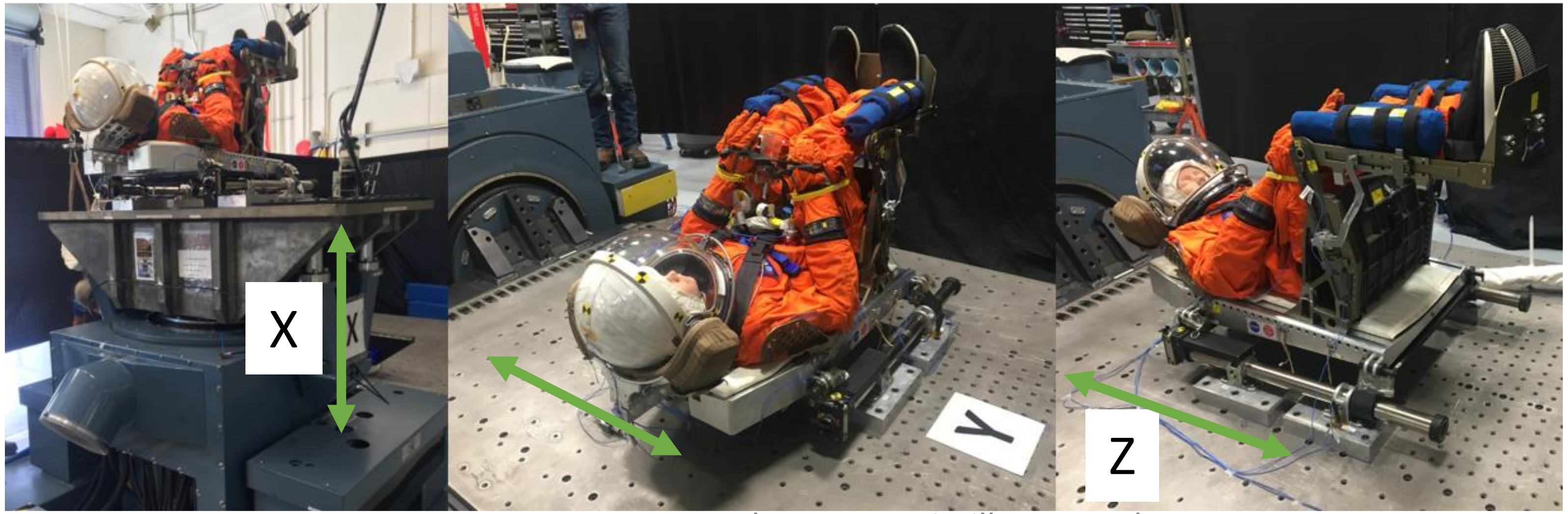




OCSS: Orion Crew Survival Systems
LPU: Life Preserver Unit
DSC: Dual Suit Controller
EBS: Emergency Breathing System

Vibration Testing

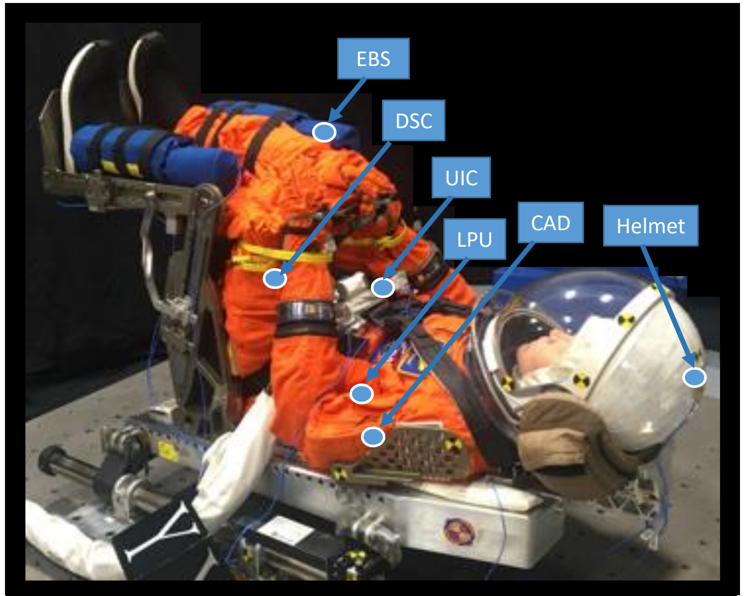
- Vibration Testing for crew and hardware assessment
  - 2017 - Human Vibration Test Series
  - 2019 - Development Test
    - Medium Manikin / Development Level Seat
  - 2020 - Qualification Test
    - Medium & Large Manikin / Qualification Level Seat
- Qualification testing performed at the NASA Kennedy Space Center Vibration Lab
  - Flight-like as possible – included CIAS, Seat, Suited Manikin, and Umbilical Bundle
- Comparisons performed to assess similarity between Manikin and human response to these conditions
  - Previous testing showed good comparisons in frequency content and energy transfer using measurements at the chest and Helmet regions

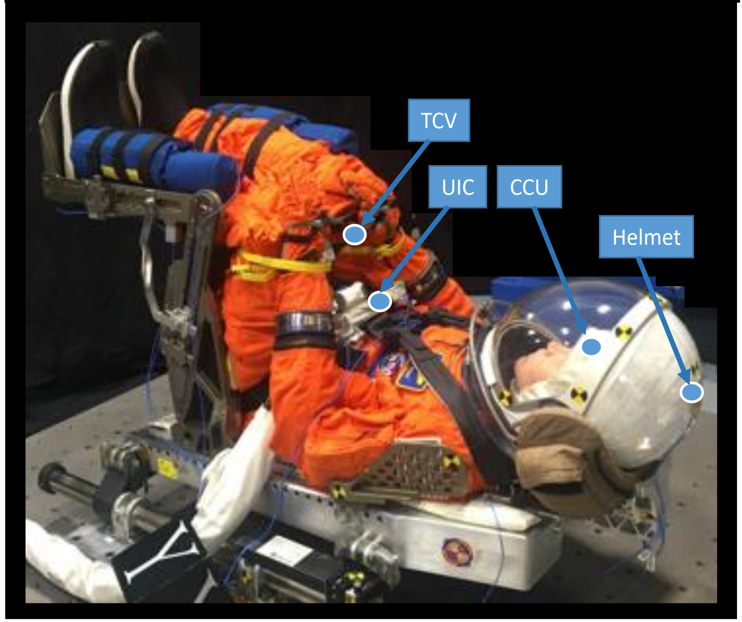


Data Collection

- Accelerometers placed on key Suit components and across regions of the body
- Number of sensors reduced in Qualification Test
  - Regions not expecting response
  - Availability for better Shaker Table control
- Test Criteria to survive the events without damage to fit/form/function
  - Visual inspections of each component between tests
  - Ability to pass functional tests after all vibration exposures

Suit Component	Instrumented in Dev Test	Instrumented in Qual Test	Justification
CommCap/Manikin Head (CCA)	No	Yes	Not tested in Development Test
Thermal Control Valve (TCV)	No	Yes	Not tested in Development Test
Umbilical Interface Connector (UIC)	Yes	Yes	Repeat data for comparison between Tests
EBS Bottle Reducer	Yes	No	Exempt based on Development Test and heritage
Helmet	Yes	Yes	Repeat data for comparison between Tests
Dual Suit Controller (DSC)	Yes	No	Similar hardware, mounting method, and location to TCV
Crew Active Dosimiter (CAD)	Yes	No	Soft mounted - Very low response in Development Test
Life Preserver Unit (LPU)	Yes	No	Soft mounted - Very low response in Development Test





TCV: Thermal Control Valve

Qualification Test Sequence

Flight Event Profile	Axis	Test	Purpose
Ascent Profile	Y	Random Survey (Low Level)	Pre Health Check
		Ascent Profile (Lowered)	Fixture Evaluation
		Ascent Profile including Test Factor	Full Level of Test
		Random Survey (Low Level)	Post Health Check
	Z	Random Survey (Low Level)	Pre Health Check
		Ascent Profile (Lowered)	Fixture Evaluation
		Ascent Profile including Test Factor	Full Level of Test
		Random Survey (Low Level)	Post Health Check
	X	Random Survey (Low Level)	Pre Health Check
		Ascent Profile including Test Factor	Fixture Evaluation
		Ascent Profile	Full Level of Test
		Random Survey (Low Level)	Post Health Check
Abort Profile	Y	Random Survey (Low Level)	Pre Health Check
		Abort Profile including Test Factor	Full Level of Test
		Random Survey (Low Level)	Post Health Check
	Z	Random Survey (Low Level)	Pre Health Check
		Abort Profile including Test Factor	Full Level of Test
		Random Survey (Low Level)	Post Health Check
	X	Random Survey (Low Level)	Pre Health Check
		Abort Profile including Test Factor	Full Level of Test
		Random Survey (Low Level)	Post Health Check

Medium Manikin (Ascent Profile)

Large Manikin* (Abort Profile)

Pre and Post Test Random Survey
- Differences in response can indicate damage

Lower Level Test
- Check for anomalous behavior

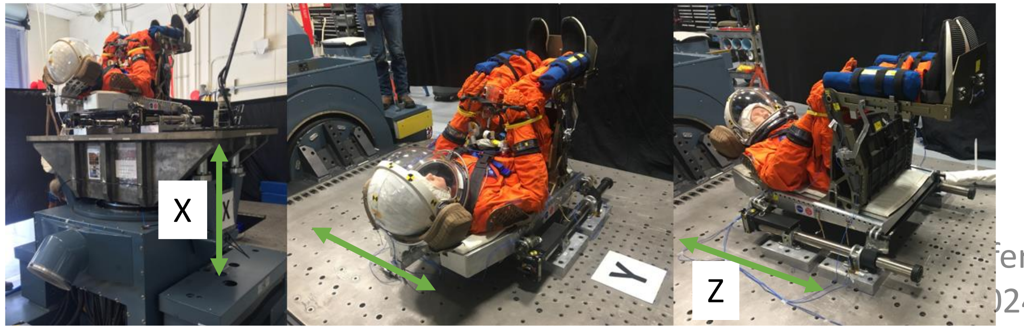
Full Level Test – as required

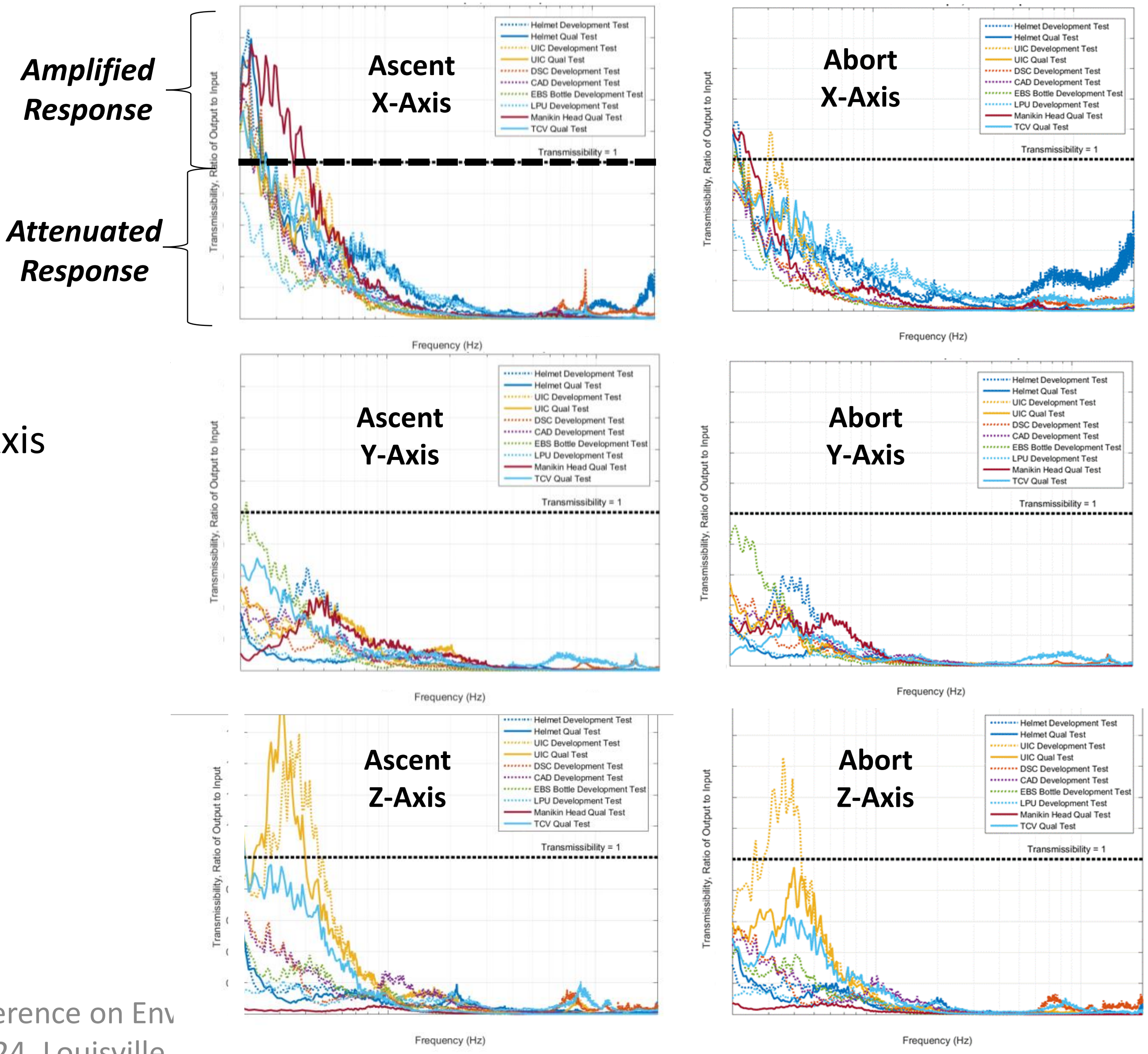
For higher level Abort cases, the Lower Level Test was removed from the sequence
- Minimize damage to hardware
- No anomalous behavior found in Ascent Cases

* Development Test Series used Medium Manikin

Results – Component Response

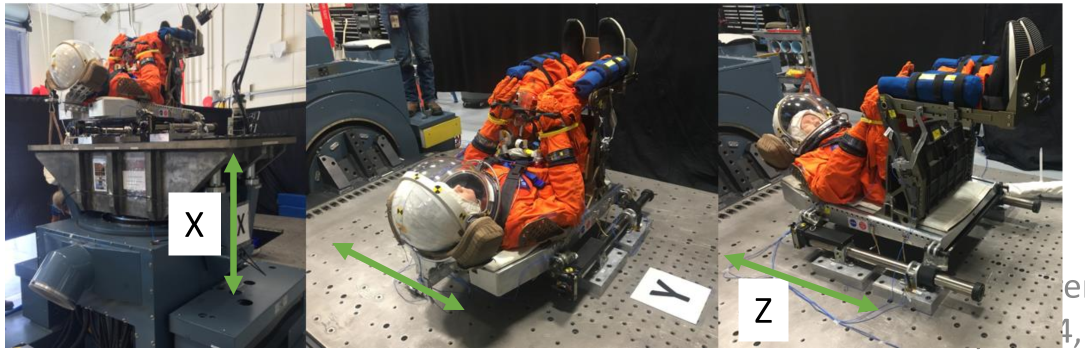
- Transmissibility – Ratio of Output to Input
  - Indicates areas of Amplification or Attenuation
  - Frequency Range and Transmissibility removed
- No official requirement for amplification limit
- **X-Axis**
  - Low frequency amplification seen in components during Ascent X-axis
    - Drove decision to instrument in subsequent test
  - Less amplification seen in the higher level Abort X-Axis
- **Y-Axis**
  - Mostly attenuated across frequency range
  - Similar behavior across Ascent and Abort
- **Z-Axis**
  - Umbilical Interface Connector (UIC) amplified
  - Drove decision to instrument in subsequent test

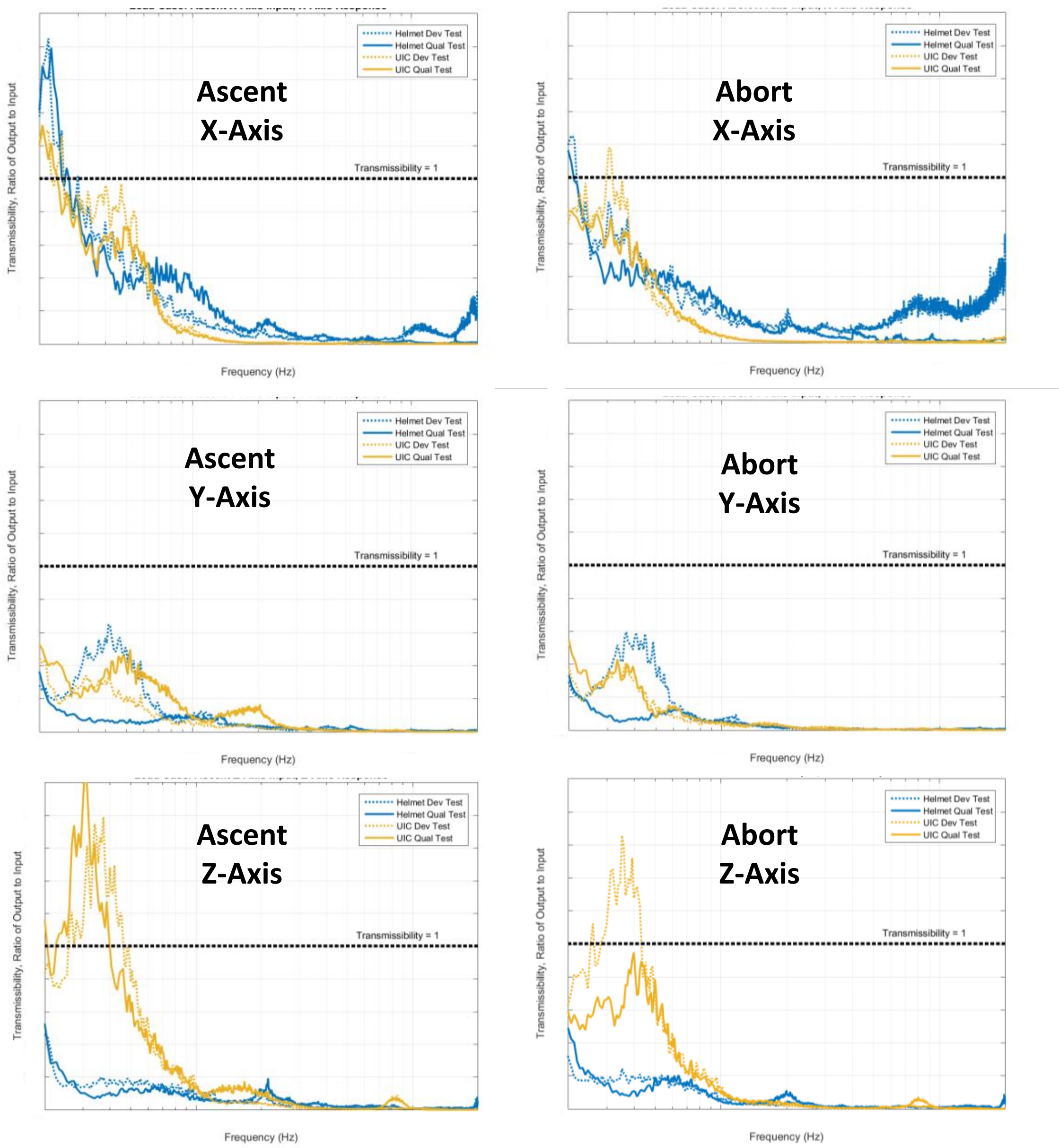




Results – Comparison Development/Qual Tests

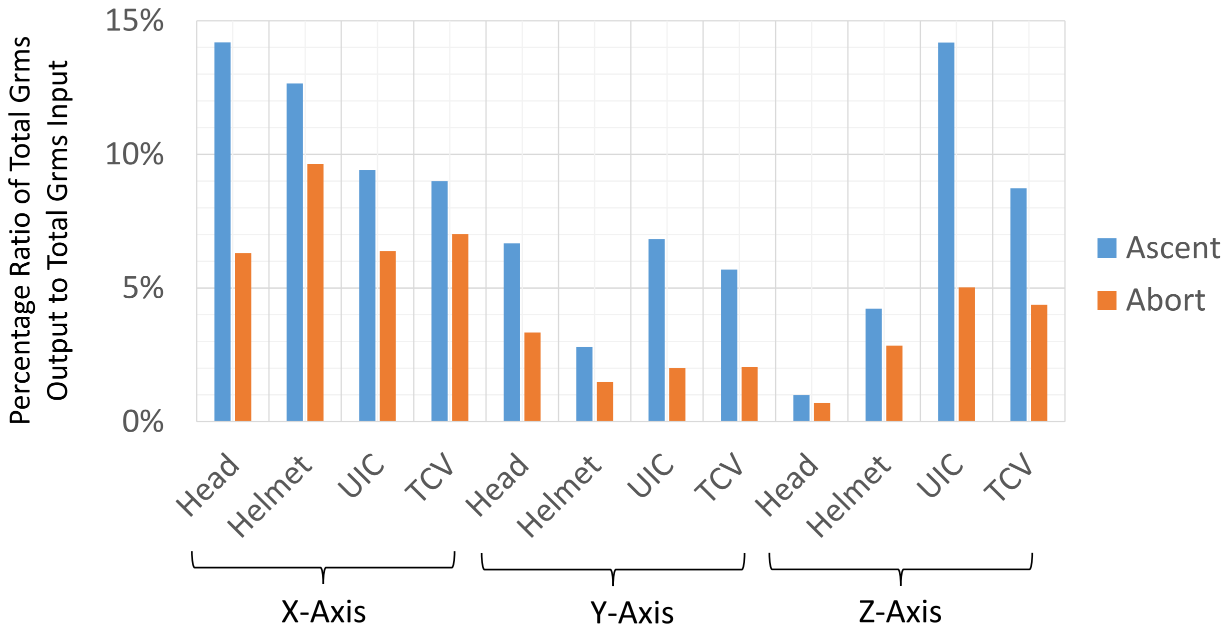
- Comparison performed to assess quality of test setup and repeatability
  - No official requirement for matching of the test data
  - Looking for similar amplification and frequency range of amplified regions in Ascent and Abort
- Some differences expected in response
  - Slight variations in test set up, seatbelts, positioning
  - Sensitivity of the components to direction (e.g. Helmet Y-Axis)
  - Nonlinear nature of softgood mounting
  - Abort tests used different manikin sizes across Tests
- **Ascent X-Axis** – Helmet and UIC had good matches
- **Ascent Z-Axis -** Similar behavior but Qualification (Qual) exceeded Development (Dev)
- **Abort Z-Axis** - Similar frequency range, but different level

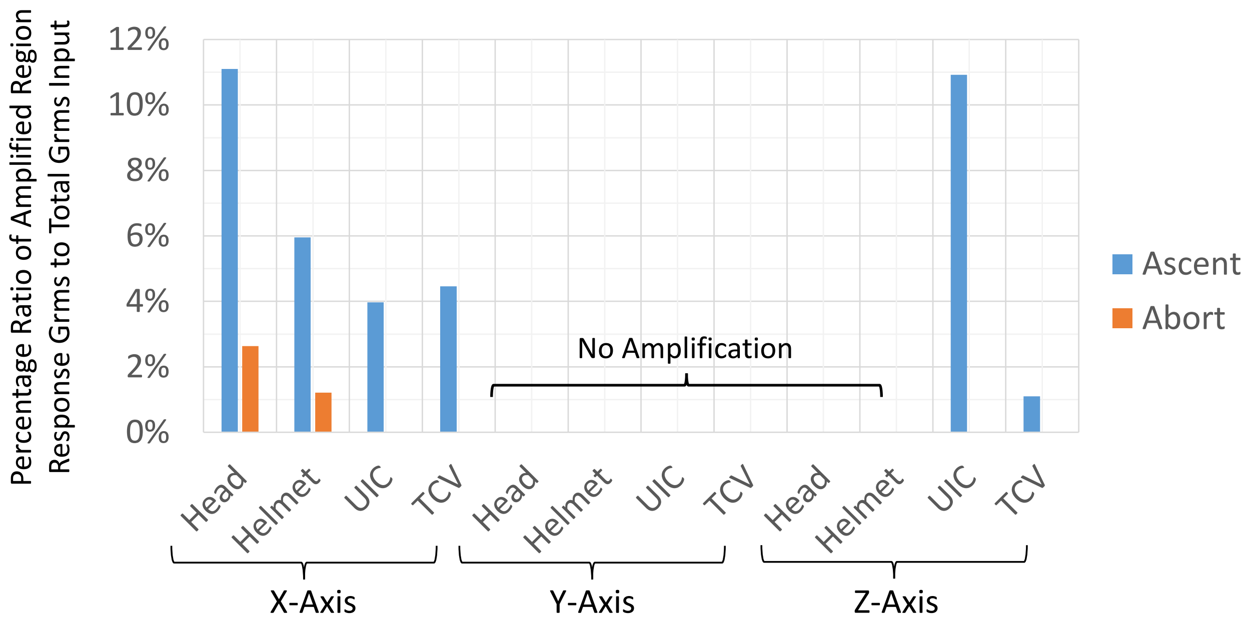




Results – Grms Ratio

- Grms response values represent total energy
- Ratio of Grms output to input represents the percentage of total energy reaching each component





Conclusions and Discussion

- OCSS Suit hardware is capable of withstanding expected flight vibration conditions
- Energy input to the system is attenuated before reaching the Suit component level
  - Amplified regions were seen, but only in low frequency region
  - Total response Grms was less than 15% of the total input Grms for any component across all cases
  - On-axis amplified response regions all remained under 12% of the input Grms
- Component Response trends showing consistency
  - Similar trends in the frequency regions that are attenuated or amplified
  - Similar magnitudes of amplification or attenuation
- Similarities between Development Test and Qualification Test enough to confirm planning decisions for Qualification Test
  - The two components measured (Helmet and UIC) showed similar behavior across the tested frequency range for X, Y, and Z, ascent and abort Cases
  - Qualification Test response magnitudes were similar or lower than the Development Test
  - Responses at the suit level measured in the Qualification Test were considered to fall within the family of the Development Test responses
- Trends in attenuation seen in the suit components is likely driven mostly by the soft mounting and less by the differences in manikin mass and size
  - Each future Artemis crew member will be unique and have varying anthropometry, so it will be beneficial that the attenuation trends of the suit components are expected to occur in all actual flight cases despite variations.
- While a spaceflight system and set of environments unique to Orion was tested, the general trends are likely to be consistent with similar flight systems and Suits
  - Potentially allow for reduced scope and cost of testing

Known Test Limitations

- Seat and Suit hardware as close to flight-like as possible using up-to-date designs at the time of test
  - No major deviation in mass, CG, mounting position, or component stiffness.
- Variations in setup (softgood and manikin positioning)
- Limitations in the size of the DAS used in the test facility
  - limited the number of channels available for hardware instrumentation
- Number of test cases limited to approximately 20 runs per Test Series
- Repeatability of manikin and softgood materials in the load path
- Using manikins to represent humans as the transfer media between the vibration input and the Suit hardware

CG: Center of Gravity
DAS: Data Acquisition System

Forward Work

- Correlate tested response data of suited manikins with human vibration analysis models that are currently used to integrate with structural finite element models.
- Potential to study possible acute human injury related to low frequency amplification of components mounted to the body, as was seen across some of the components in this set of test cases.

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Questions?

Thank you!