

Risk of in-mission and long-term Hearing Loss and Performance Decrements from In-flight Exposure to Environmental and Physiological Conditions (Hearing Loss Risk) Revision B.1

Human System Risk Board (HSRB)

HSRB CR SA-07566
Approved: 2/13/2025

Risk Custodian Team

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Risk Record

- ❖ This revision:
 - Provides Level of Evidence (LOE) score and assumptions for Design Reference Missions (DRMs)
 - Provides updated evidence for:
 - The prevalence of acoustic requirement, noise hazard level, and flight rule exceedances
 - The incidence and prevalence of on-orbit hearing shifts
 - The prevalence of post-mission hearing shifts
 - The long-term health effects of crewmembers
- ❖ This information (including changes incorporated based on today's discussion) will be released via Change Request (CR).

This information was previously reviewed/dispositioned at:

Meeting	Date	Outcomes/Direction
SMOCB/ HSEICB	4/1/2024	Approved to present to HSRB

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1. Risk Title and Risk Statement

- ❖ **Risk Title:** Risk of in-mission and long-term Hearing Loss and Performance Decrements from in-flight exposure to acoustic, other environmental, and physiological conditions
- ❖ **Risk Statement:** Given the environmental (e.g., noise, atmospheric pressure and composition, and microgravity) and physiological (e.g., cephalic fluid shifts) conditions in spaceflight, there is a possibility that the auditory system will experience temporary or permanent reductions in hearing sensitivity or that crew performance will be impacted

2. Risk History

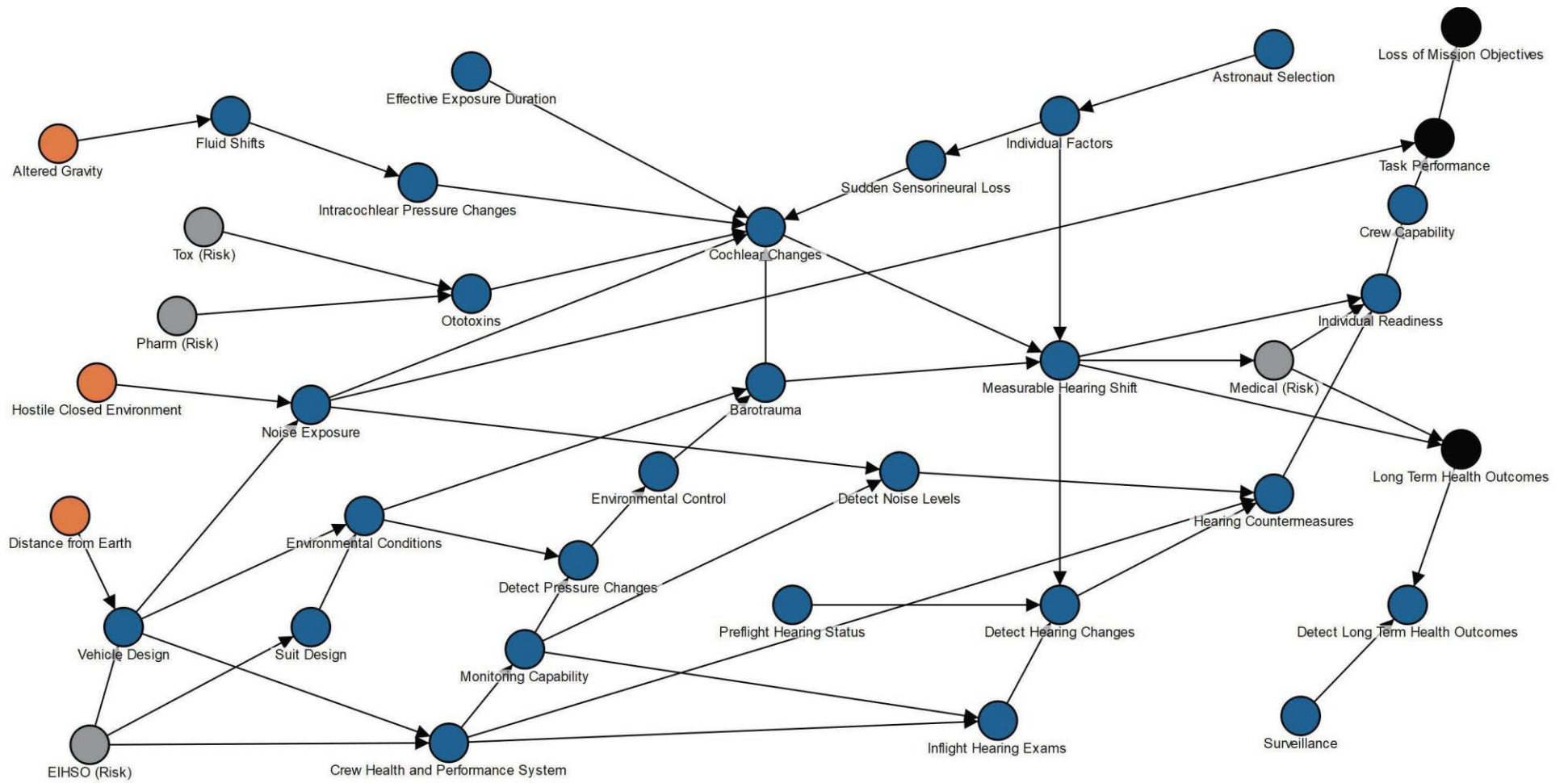
Meeting	Date	Outcome/Direction
HSRB Risk Presentation	02/13/2025	<u>Decisional</u> – CR SA-07566 HSRB DAGtionary Updates and DAG Corrections; CR approved with modifications. Rev B.1
HSRB Risk Presentation	07/18/2024	<u>Decisional</u> – CR SA-06901 Updates to the Hearing Loss Risk, Rev B
HSRB Risk Presentation	04/11/2024	<u>Informational</u> – CR kickoff.
HSRB Risk Presentation	02/23/2023	<u>Decisional</u> – CR SA-05752 HSRB Risk Matrix Format LxC Change from 3x4 to 5x5; CR Approved with Mods, Rev A.2
HSRB Risk Presentation	05/13/2022	<u>Decisional</u> – CR SA-05096 HSRB Directed Acyclic Graphs Errata Changes; CR Approved out of board, Rev A.1
HSRB Risk Presentation	07/30/2020	Decisional – CR approved with Mods Rev A; new DRMs and evidence
Risk Evaluated via CR	06/10/2020	CR Evaluation period ended 6/25/20
HSRB Risk Presentation	06/04/2020	Informational – CR kickoff.
HSRB Risk Presentation	04/25/2019	<u>Informational</u> – Timely data update on Audiology Evidence Base. Four related actions were issued including a formal risk update.
HSRB Risk Presentation	11/19/2014	Decisional – Approve Baseline with Mods
Risk Evaluated via CR	10/16/2014	<u>Decisional</u> – Requesting approval for baseline risk per JSC 66705

3. Executive Summary

- ❖ International Space Station (ISS) Noise Hazard Level [85 A-Weighted decibel (dBA)] has been exceeded during 38% of acoustic measurements
- ❖ ISS Flight Rule (72 dBA LEQ*_{16hrs}) has been exceeded for 21% of crew-worn dosimetry acoustic measurements
- ❖ HSRB metric for Hearing Loss is based on incidence of mission-associated hearing threshold shifts seen among inflight and postflight hearing assessments
 - Inflight, on-orbit hearing assessments (OOHA) show few high frequency shifts (9.0%), but frequent low frequency shifts (40.4%) among United States On-Orbit Segment (USOS) crewmembers. Postflight, hearing assessments (within 10 days of landing) are improved for high frequency shifts (6.7%). However, residual threshold decrements may persist below the 'shift' criteria. Risk posture may change with longer missions. Low frequency shift data are still being collected and processed.
 - Russian data show persistent hearing shifts in both high and low frequencies among Russian On-Orbit Segment (RSOS) crew
- ❖ Efforts in Hearing Conservation are risk mitigations for mission ops and Long-Term Health (LTH)
 - Risk posture will change if acoustic monitoring is reduced
 - Risk posture will change if future space vehicles/habitats do not meet acoustic requirements
- ❖ High value risk mitigation targets:
 - Continue acoustic monitoring and hearing assessments to understand their relationship and monitor risk levels
 - Employ an effective systems engineering process, so vehicles meet acoustic requirements
 - Understand cause of low-frequency hearing threshold shifts, using higher-fidelity hardware/software system (KUDU wave) for OOHA's
 - Understand why Russian data suggests hearing loss more often than USOS data

*Average Noise Level

4. Directed Acyclic Graph (DAG)



Directed Acyclic Graph (DAG) (Narrative)

- From a health perspective this DAG centers around Cochlear Changes which are changes inside the inner ear that can lead to issues with hearing. These culminate in effects on Individual Readiness and Crew Capability. This can be influenced by changes in:
 - Noise Exposure which includes Noise Intensity Level, Noise Exposure Duration, and Noise Spectrum which can also disrupt sleep and lead to degraded performance.
 - Monitoring crew health: Eustachian Tube Dysfunction (ETD) (specifically dilatory and baro-challenge-induced ETD), and ability of CM to manually pressurize middle ear (Valsalva) prior to an EVA or altered pressure event.
 - Ototoxins in the environment or in medications
 - Sudden Sensorineural Hearing Loss which is dependent on Individual Factors and has been recorded in some astronauts.
 - Intracochlear Pressure caused by Fluid Shifts in Altered Gravity environments. In this case the Effective Exposure Duration accounts for the cumulative effect that the exposure will have for different Design Reference Missions.
 - Barotrauma that can result from changes in pressure represented here by Environmental Conditions. This can result in Inner Ear Barotrauma that affects Cochlear Changes or Middle Ear Barotrauma that affects Measurable Hearing
 - Shifts without affecting the cochlea. This is affected by Suit Design.
- From a performance perspective, Noise Exposure leads directly to Task Performance showing that the noise environment can affect performance by impacting effective communications without degrading astronaut health.
- Vehicle Design and the Crew Health and Performance System enable Noise Monitoring and In-Flight Hearing Exams if these are designed into the system. When designed into the system, they enable Detect Noise Levels and Detect Hearing Changes. Inflight Hearing Exams must be coupled with Pre-Flight Hearing Status to enable detection of changes. Detection of either inappropriate Noise Levels or actual hearing changes can prompt crews to use Hearing Countermeasures such as hearing protection, which must also be designed into the Crew Health and Performance System to enable risk mitigation.
- From the Barotrauma perspective, Environmental Monitoring Capability enables us to Detect Pressure Changes. Standards require that crew have Environmental Control over the rate of depressurization that can minimize the likelihood of experiencing Barotrauma. A method to help reduce the risk of barotrauma includes the assessment of Eustachian tube function (tympanometry) and appropriate medications. Reduced barotrauma risk can help prevent a measurable hearing shift. EVA risk has direct link to barotrauma.
- Measurable Hearing Shifts and Hearing Countermeasures both affect Individual Readiness and Crew Capability. In some cases, Measurable Hearing Shifts can lead to medical problems like Hearing Loss both In-Mission as well as Long Term Health Conditions.

5. Risk Summary

Risk Title: Risk of in-mission and long-term Hearing Loss and Performance decrements from in-flight exposure to acoustic, other environmental, and physiological conditions Risk Custodian Team: M. Robinette, C. Allen, C. Coble									
Risk Statement: Given the environmental (e.g., noise, atmospheric pressure and composition, and microgravity) and physiological (e.g., cephalic fluid shifts) conditions in spaceflight, there is a possibility that the auditory system will experience temporary or permanent reductions in hearing sensitivity or that crew performance will be impacted.									
Primary Hazard: Hostile closed environment		Secondary Hazard(s): Altered gravity		Countermeasures (are elements of a Hearing Conservation Program): Monitoring: Acoustic monitoring, audiometry (preflight/post-flight), On-Orbit Hearing Assessments Prevention: Standards (selection and NASA Std. 3001), system-specific acoustic requirements and verifications, personal protective equipment (PPE), training, Intervention: Acoustical noise controls and PPE					
Contributing Factors: Environmental Factors (mission duration = Noise Exposure, microgravity, and ototoxins), Cohort Factors (age, sex, and genetics), and physiological factors (Sudden Sensorineural Hearing Loss, intracochlear pressure)									
State of Knowledge: Countermeasures have been found to be effective in dealing with risk of hearing loss, but risk posture will change if monitoring is reduced. Audiometric shifts may indicate physiological auditory change: 1) High Frequency - Noise-induced high freq. loss with progression to low freq. 2) Low Frequency (impedance) – Conductive (stiffness of middle ear) or Sensorineural. According to current data, the mitigations in place are effective. There have been 0 cases of persistent high frequency shifts among United States On-Orbit Segment (USOS) crewmembers after their International Space Station (ISS) missions, but Russian data suggest more frequent shifts. Low frequency shifts have been observed but their significance is uncertain. Sudden sensorineural losses (30 decibels (dB) or greater) could affect mission ops.									
LxC Drivers: Ops Likelihood, all DRM: Likelihood of in-flight hearing loss is high. Based on the USOS evidence from 6-month ISS missions, there is a > 1 % likelihood of inflight threshold shift of ≥10 dB in the high frequency range averaging 2k, 3k, and 4k hertz (Hz), via pre/post flight audiometry) and inflight tests. Ops Consequence per DRM: LEO Short, LEO Long: No significant impact on performance and ops. Lunar Short, Lunar Long, Lunar Orbital + Surface (Short, Long): Auditory errors due to hearing loss, when complicated by delayed communications, reduce crew performance and ops. Increased noise levels in Gateway phase II vehicles/habitats (and lunar ops) could cause minor impact to performance and ops - requiring additional resources such as increased acoustic and hearing monitoring and remedial actions and countermeasures. Mars Preparatory: Auditory errors due to hearing loss, when complicated by delayed communications, reduce crew performance and ops. Mars Planetary: Auditory errors due to hearing loss, when complicated by delayed communications, reduce crew performance and ops. Increased noise levels in Mars vehicles/habitats and planetary operations could cause significant hearing loss with substantially longer durations, resulting in reduced performance and loss of some mission objectives. LTH Likelihood per DRM: LEO, Lunar Short (for missions >30 days): Increased noise levels and longer missions can increase risk of hearing shifts and accelerate hearing loss due to age-related factors or if Sudden Sensorineural Hearing Loss occurs concurrently. LTH Consequence per DRM: LEO Short, Lunar Orbital (<30 days), Lunar Orbital + Surface (<30 days): Negligible impact on quality of life, hearing returns to near baseline. Others, especially Mars Planetary (1-3 years): Moderate impact on quality of life if hearing does not return to baseline.				DRM Categories	Mission Type and Duration	LxC Ops	Risk Disposition Ops	LxC LTH	Risk Disposition LTH
				Low Earth Orbit (LEO)	Short (<30 days)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
					Long (30d - 1 year)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
				Lunar Orbital	Short (<30 days)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
					Long (30d - 1 year)	4x2	Accepted With monitoring	2x3	Requires characterization
				Lunar Orbital + Surface	Short (<30 days)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
					Long (30d - 1 year)	4x2	Accepted With monitoring	2x3	Accepted With monitoring
				Mars	Preparatory (<1 year)	4x2	Accepted With monitoring	2x3	Requires characterization
					Planetary (1- 3 years)	4x3	Accepted With monitoring	4x3	Requires characterization
Risk Disposition Rationale per DRM: Ops – Accepted requiring inflight monitoring for all missions to ascertain that extended exposure to the mission environment does not cause reduced hearing sensitivity. LTH – Accepted with monitoring for missions LEO and Lunar missions <30 days. Longer missions require characterizations if vehicles/habitats do not meet all of program’s acoustic requirements									

6. LxC Quick look

Previous (approved February 2023)

DRM Categories	Mission Type and Duration	LxC Ops	Risk Disposition Ops	LxC LTH	Risk Disposition LTH
Low Earth Orbit (LEO)	Short (<30 days)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
	Long (30d - 1 year)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
Lunar Orbital	Short (<30 days)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
	Long (30d - 1 year)	4x2	Accepted With monitoring	2x3	Requires characterization
Lunar Orbital + Surface	Short (<30 days)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
	Long (30d - 1 year)	4x2	Accepted With monitoring	2x3	Accepted With monitoring
Mars	Preparatory (<1 year)	4x2	Accepted With monitoring	2x3	Requires characterization
	Planetary (1- 3 years)	4x3	Accepted With monitoring	4x3	Requires characterization



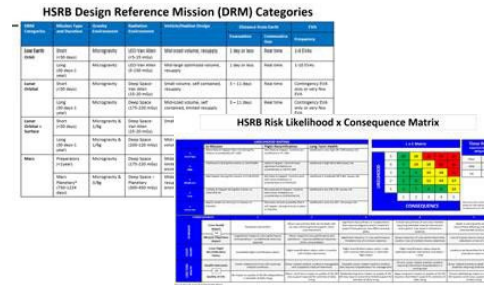
Current (approved February 2025) No changes

DRM Categories	Mission Type and Duration	LxC Ops	Risk Disposition Ops	LxC LTH	Risk Disposition LTH
Low Earth Orbit (LEO)	Short (<30 days)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
	Long (30d - 1 year)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
Lunar Orbital	Short (<30 days)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
	Long (30d - 1 year)	4x2	Accepted With monitoring	2x3	Requires characterization
Lunar Orbital + Surface	Short (<30 days)	4x1	Accepted With monitoring	1x2	Accepted With monitoring
	Long (30d - 1 year)	4x2	Accepted With monitoring	2x3	Accepted With monitoring
Mars	Preparatory (<1 year)	4x2	Accepted With monitoring	2x3	Requires characterization
	Planetary (1- 3 years)	4x3	Accepted With monitoring	4x3	Requires characterization

7. Assumptions

All LxC assessments:

- Assume that NASA Standards 3001 have been met
- Countermeasures equivalent to current ISS countermeasures are in use
- Based on the HSRB LxC Matrix and the HSRB DRM Categories
- Additional assumptions are documented below
 - [List additional for all DRMs](#)



DRM Categories	Mission Type and Duration	Assumptions
Low Earth Orbit (LEO)	Short (<30 days)	
	Long (30 d-1 yr.)	Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months.
Lunar Orbital	Short (<30 days)	NASA STD 3001 Continuous noise limit is not met.
	Long (30 d-1 yr.)	Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months.
Lunar Orbital + Surface	Short (<30 days)	NASA STD 3001 Continuous noise limit is not met.
	Long (30 d-1 yr.)	Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months.
Mars	Preparatory (<1 year)	Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months.
	Planetary 1 – 3 yrs)	Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months.

Current countermeasures in use:

- **Prevention:** Standards (selection and NASA Std. 3001), system-specific acoustic requirements and verifications, personal protective equipment (PPE), training,
- **Intervention:** Acoustical noise controls and PPE
- **Monitoring:** Acoustic monitoring, audiometry (preflight/post-flight), On-Orbit Hearing Assessments

8. HSRB Risk Likelihood x Consequence Matrix

LIKELIHOOD RATING			
	In-Mission	Flight Recertification	Long Term Health
5 Very High	More likely to happen than not during the mission or probability (P) >10%	Very likely to happen. Controls are insufficient or P> 10%	Likelihood is very high OR >10% excess risk
4 High	Likelihood is during the mission or 1%<P≤10%	Likely to happen. Controls have significant limitations or uncertainties or 1%<P≤ 10%	Likelihood is high OR 6-10% excess risk
3 Moderate	May happen during the mission or 0.1%<P≤1%	Not likely to happen. Controls exist with some limitations or uncertainties or 0.1%<P≤1%	Likelihood is moderate OR 3-6% excess risk
2 Low	Unlikely to happen during the mission or .01%<P≤0.1%	Not expected to happen. Controls have minor limitations or uncertainties or 0.01%<P≤0.1%	Likelihood is low OR 1-3% excess risk
1 Very Low	Nearly certain to not occur in-mission or P≤0.01%	Extremely remote possibility that it will happen. Strong controls in place or P≤0.01%	Likelihood is very low OR < 1% excess risk

Ops: LEO short & Long, LO Short, LOS Short

LTH: LEO short & Long, LO Short, LOS Short

L x C Matrix						
LIKELIHOOD	5	10	16	20	23	25
	4	7	13	18	22	24
	3	4	9	15	19	21
	2	2	6	11	14	
	1	1	3	5	8	12
		1	2	3		
CONSEQUENCE						

Ops: Op long, LOS Long, Mars Prep

Ops & LTH: Mars Planetary

LTH: LO Short, LOS Short, Mars Prep

Time frame
Expected Need for Mitigation

Near	0 < 2 Years
Mid	2-7 Years
Far	> 7 Years

Risk Score Card values are constant across all risks and prioritize consequence over likelihood.

CONSEQUENCES		1	2	3	4	5
IN MISSION	Crew Health Impact	Temporary discomfort	Minor injury/illness that can be dealt with by crew without ground support, minor crew discomfort	Significant injury/illness or incapacitation that requires diagnosis and/or treatment support from ground, may affect personal safety	Critical injury/illness of one crew member requiring extended medical intervention and support, may result in temporary disability	Death or permanently disabling injury/illness affecting one or more crewmember (LOCL/LOC)
	Mission Objectives Impact	Insignificant impact to crew performance and operations – no additional resources required	Minor impact to crew performance and operations – requires additional resources (time, consumables)	Significant reduction in crew performance, threatens loss of a mission objective	Severe reduction of crew performance that results in loss of multiple mission objectives	Loss of mission due to crew performance reductions or loss of crew
FLIGHT RECERT	Crew Flight Recertification Status	Immediate flight recertification status	Flight recertification status within 3 months with limited intervention	Flight recertification status within 1 year with nominal intervention or restricted flight status	Flight recertification status requires extended medical intervention and takes > 1 year	Unable to be Recertified for Flight Status, premature career end
LONG TERM HEALTH	Health Outcomes	Career related short term self-resolving medical conditions	Career related medical conditions manageable with outpatient medical treatments	Treatable career related medical condition that requires hospitalization for management	Chronic career related medical condition requiring intermittent hospitalization or nursing care	Career related premature death or permanent disability requiring institutionalization
	Quality of Life	No impact on quality of life OR independence in activities of daily living	Minor, short-term impact on quality of life OR rare support required for activities of daily living	Moderate long-term impact on quality of life OR may require some time-limited support for activities of daily living	Major long-term impact on quality of life OR requires intermittent support for activities of daily living	Chronic debilitating impact on quality of life OR requires continuous support for activities of daily living

Assumptions for Long Term Health Risk Matrix:

- Long Term Health extends from the end of the past mission time period and covers an astronaut's lifetime.
- Conditions considered within the LTH Risk Matrix are those that 1) are related to the astronaut career, 2) are beyond those expected as part of natural aging, and 3) include acute, chronic and latent conditions.
- Quality of Life is defined as impact on day-to-day physical and mental functional capability and/or lifetime loss of years

9. Risk Postures:

Low Earth Orbit (< 30 Days) Operations

4x1

Accepted with Monitoring

- **LxC Drivers for Likelihood:** Likelihood of in-flight hearing loss is high. Based on the USOS evidence from 6-month ISS missions, there is a > 1 % likelihood of inflight threshold shift of ≥ 10 dB in the high frequency range averaging 2k, 3k, and 4k Hz, via pre/post flight audiometry) and inflight tests.
- **LxC Drivers for Consequence:** To date, hearing threshold shifts have not had significant impact on performance and ops on ISS missions
- **Rationale for Risk Disposition:** Accepted, based on in-flight monitoring of acoustic environment and hearing sensitivity. If acoustic exceedance or hearing shifts occur, can take corrective actions.
- **DRM Specific Assumptions:**
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Low Earth Orbit (< 30 Days) Long Term Health

1x2

Accepted with Monitoring

- **LxC Drivers for Likelihood:** To date, hearing thresholds shifts have not been sustained beyond 30 days.
- **LxC Drivers for Consequence:** Negligible impact on quality of life, hearing returns to near baseline.
- **Rationale for Risk Disposition:** Accepted, with continued monitoring of hearing sensitivity during career and post-career surveillance
- **DRM Specific Assumptions:**
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Low Earth Orbit (30 d – 1 yr) Operations

4x1

Accepted with Monitoring

- **LxC Drivers for Likelihood:** Likelihood of in-flight hearing loss is high. Based on the USOS evidence from 6-month ISS missions, there is a > 1 % likelihood of inflight threshold shift of ≥ 10 dB in the high frequency range averaging 2k, 3k, and 4k Hz, via pre/post flight audiometry) and inflight tests.
- **LxC Drivers for Consequence:** To date, hearing threshold shifts have not had significant impact on performance and ops.
- **Rationale for Risk Disposition:** Accepted, based on in-flight monitoring of acoustic environment and hearing sensitivity. If acoustic exceedance or hearing shifts occur, can take corrective actions.
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Low Earth Orbit (30 d – 1 yr) Long Term Health

1x2

Accepted with Monitoring

- **LxC Drivers for Likelihood:** To date, hearing thresholds shifts have not been sustained beyond 30 days.
- **LxC Drivers for Consequence:** Negligible impact on quality of life, hearing returns to near baseline.
- **Rationale for Risk Disposition:** Accepted, with continued monitoring of hearing sensitivity during career and post-career surveillance
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations or induce permanent changes in cochlear function.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Lunar Orbital (< 30 Days) Operations

4x1

Accepted with Monitoring

- **LxC Drivers for Likelihood:** Likelihood of in-flight hearing loss is high. Based on the USOS evidence from 6-month ISS missions, there is a > 1 % likelihood of inflight threshold shift of ≥ 10 dB in the high frequency range averaging 2k, 3k, and 4k Hz, via pre/post flight audiometry) and inflight tests

- **LxC Drivers for Consequence:** Auditory errors due to hearing loss, when complicated by delayed communications, reduce crew performance and ops. Increased noise levels in new vehicles/habitats (and lunar ops) could cause minor impact to performance and operations - requiring additional resources such as increased acoustic and hearing monitoring and remedial actions and countermeasures.
- **Rationale for Risk Disposition:** Accepted, based on in-flight monitoring of acoustic environment and hearing sensitivity. If acoustic exceedance or hearing shifts occur, can take corrective actions.
- **DRM Specific Assumptions:**
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Lunar Orbital (< 30 Days) Long Term Health

1x2

Accepted with Monitoring

- **LxC Drivers for Likelihood:** To date, hearing thresholds shifts have not been sustained beyond 30 days.
- **LxC Drivers for Consequence:** Negligible impact on quality of life, hearing returns to near baseline.
- **Rationale for Risk Disposition:** Accepted, with continued monitoring of hearing sensitivity during career and post-career surveillance
- **DRM Specific Assumptions:**
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Lunar Orbital (30 d – 1 yr) Operations

4x2

Accepted with Monitoring

- **LxC Drivers for Likelihood:** Likelihood of in-flight hearing loss is high. Based on the USOS evidence from 6-month ISS missions, there is a > 1 % likelihood of inflight threshold shift of ≥ 10 dB in the high frequency range averaging 2k, 3k, and 4k Hz, via pre/post flight audiometry) and inflight tests.
- **LxC Drivers for Consequence:** Auditory errors due to hearing loss, when complicated by delayed communications, reduce crew performance and ops. Increased noise levels in new vehicles/habitats

could cause minor impact to performance and operations - requiring additional resources such as increased acoustic and hearing monitoring and remedial actions and countermeasures.

- **Rationale for Risk Disposition:** Accepted, based on in-flight monitoring of acoustic environment and hearing sensitivity. If acoustic exceedance or hearing shifts occur, can take corrective actions.
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months. NASA STD 3001 Continuous noise limit is not met.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Lunar Orbital (30 d – 1 yr) Long Term Health

2x3

Requires Characterization

- **LxC Drivers for Likelihood:** Likelihood may increase (0.1% to 1%) if longer missions and increased noise levels in new vehicles/habitats increase risk of hearing shifts and accelerate hearing loss due to age-related factors or if Sudden Sensorineural Hearing Loss occurs concurrently.
- **LxC Drivers for Consequence:** Moderate impact on quality of life if hearing does not return to baseline. New vehicle may present increased risks of hearing shifts and accelerate hearing loss due to age-related factors.
- **Rationale for Risk Disposition:** Accepted, with continued monitoring of hearing sensitivity during career and post-career surveillance. Requires characterizations if vehicles/habitats do not meet all of program's acoustic requirements.
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations or induce permanent changes in cochlear function.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Lunar Orbital + Surface(< 30 Days) Operations

4x1

Accepted with Monitoring

- **LxC Drivers for Likelihood:** Likelihood of in-flight hearing loss is high. Based on the USOS evidence from 6-month ISS missions, there is a > 1 % likelihood of inflight threshold shift of ≥ 10 dB in the high frequency range averaging 2k, 3k, and 4k Hz, via pre/post flight audiometry) and inflight tests.

- **LxC Drivers for Consequence:** Auditory errors due to hearing loss, when complicated by delayed communications, reduce crew performance and ops. Increased noise levels in new vehicles/habitats could cause minor impact to performance and operations - requiring additional resources such as increased acoustic and hearing monitoring and remedial actions and countermeasures.
- **Rationale for Risk Disposition:** Accepted, based on in-flight monitoring of acoustic environment and hearing sensitivity. If acoustic exceedance or hearing shifts occur, can take corrective actions.
- **DRM Specific Assumptions:** NASA STD 3001 Continuous noise limit is not met.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Lunar Orbital + Surface (< 30 Days) Long Term Health

1x2

Accepted with Monitoring

- **LxC Drivers for Likelihood:** To date, hearing thresholds shifts have not been sustained beyond 30 days.
- **LxC Drivers for Consequence:** Negligible impact on quality of life, hearing returns to near baseline.
- **Rationale for Risk Disposition:** Accepted, with continued monitoring of hearing sensitivity during career and post-career surveillance
- **DRM Specific Assumptions:**
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Lunar Orbital + Surface (< 30 d – 1 yr) Operations

4x2

Accepted with Monitoring

- **LxC Drivers for Likelihood:** Likelihood of in-flight hearing loss is high. Based on the USOS evidence from 6-month ISS missions, there is a > 1 % likelihood of inflight threshold shift of ≥ 10 dB in the high frequency range averaging 2k, 3k, and 4k Hz, via pre/post flight audiometry) and inflight tests
- **LxC Drivers for Consequence:** Auditory errors due to hearing loss, when complicated by delayed communications, reduce crew performance and ops. Increased noise levels in new vehicles/habitats could cause minor impact to performance and operations - requiring additional resources such as increased acoustic and hearing monitoring and remedial actions and countermeasures.

- **Rationale for Risk Disposition:** Accepted, based on in-flight monitoring of acoustic environment and hearing sensitivity. If acoustic exceedance or hearing shifts occur, can take corrective actions.
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months. NASA STD 3001 Continuous noise limit is not met.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Lunar Orbital + Surface (< 30 d – 1 yr) Long Term Health

2x3

Accepted with Monitoring

- **LxC Drivers for Likelihood:** Likelihood may increase (0.1% to 1%) if longer missions and increased noise levels in new vehicles/habitats increase risk of hearing shifts and accelerate hearing loss due to age-related factors or if Sudden Sensorineural Hearing Loss occurs concurrently.
- **LxC Drivers for Consequence: Consequence:** Moderate impact on quality of life if hearing does not return to baseline. New vehicle may present increased risks of hearing shifts and accelerate hearing loss due to age-related factors.
- **Rationale for Risk Disposition:** Accepted, with continued monitoring of hearing sensitivity during career and post-career surveillance. Requires characterizations if vehicles/habitats do not meet all of program's acoustic requirements.
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations or induce permanent changes in cochlear function.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Mars Preparatory (<1 yr.) Operations

4x2

Accepted with Monitoring

- **LxC Drivers for Likelihood: Likelihood** of in-flight hearing loss is high. Based on the USOS evidence from 6-month ISS missions, there is a > 1 % likelihood of inflight threshold shift of ≥ 10 dB in the high frequency range averaging 2k, 3k, and 4k Hz, via pre/post flight audiometry) and inflight tests.
- **LxC Drivers for Consequence:** Auditory errors due to hearing loss, when complicated by delayed communications, reduce crew performance and ops. Increased noise levels in new vehicles/habitats could cause minor impact to performance and operations - requiring additional resources such as

increased acoustic and hearing monitoring and remedial actions and countermeasures.

- **Rationale for Risk Disposition:** Accepted, based on in-flight monitoring of acoustic environment and hearing sensitivity. If acoustic exceedance or hearing shifts occur, can take corrective actions.
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Mars Preparatory (<1 yr.) Long Term Health

2x3

Requires Characterization

- **LxC Drivers for Likelihood:** Moderate impact on quality of life if hearing does not return to baseline
- **LxC Drivers for Consequence: Consequence:** Increased noise levels and longer missions can increase risk of hearing shifts and accelerate hearing loss due to age-related factors or if Sudden Sensorineural Hearing Loss occurs concurrently.
- **Rationale for Risk Disposition:** Accepted, with continued monitoring of hearing sensitivity during career and post-career surveillance. Requires characterizations if vehicles/habitats do not meet all of program's acoustic requirements.
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations or induce permanent changes in cochlear function.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Mars Planetary (730-1224 d) Operations

4x3

Accepted with Monitoring

- **LxC Drivers for Likelihood: Likelihood** of in-flight hearing loss is high. Based on the USOS evidence from 6-month ISS missions, there is a > 1 % likelihood of inflight threshold shift of ≥ 10 dB in the high frequency range averaging 2k, 3k, and 4k Hz, via pre/post flight audiometry) and inflight tests.
- **LxC Drivers for Consequence:** Auditory errors due to hearing loss, when complicated by delayed communications, reduce crew performance and ops. Increased noise levels in Mars vehicles/habitats and planetary operations could cause significant hearing loss with substantially

longer durations, resulting in reduced performance and loss of some mission objectives.

- **Rationale for Risk Disposition:** Accepted, based on in-flight monitoring of acoustic environment and hearing sensitivity. If acoustic exceedance or hearing shifts occur, can take corrective actions.
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations, induce permanent changes in cochlear function, or result in acute debilitating symptoms in missions > 6-months.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

Mars Planetary (730-1224 d) Long Term Health

4x3

Requires Characterization

- **LxC Drivers for Likelihood:** May increase (to >1%) if longer missions and increased noise levels in new vehicles/habitats increase risk of hearing shifts and accelerate hearing loss due to age-related factors or if Sudden Sensorineural Hearing Loss occurs concurrently.
- **LxC Drivers for Consequence:** Increased noise levels and longer missions can increase risk of hearing shifts and accelerate hearing loss due to age-related factors or if Sudden Sensorineural Hearing Loss occurs concurrently. Resultant hearing impairment may increase need for hearing amplification technology.
- **Rationale for Risk Disposition:** Accepted, with continued monitoring of hearing sensitivity during career and post-career surveillance. Requires characterizations if vehicles/habitats do not meet all of program's acoustic requirements.
- **DRM Specific Assumptions:** Low frequency hearing loss, while similar to Ménière's disease, will not result in vestibular aberrations or induce permanent changes in cochlear function.
- **DRM Specific Evidence/Level of Evidence:** 2-Moderate

10. Overall Assessment of the Evidence

Evidence:

- ❖ International Space Station (ISS) Noise Hazard Level (85 dBA) has been exceeded during 38% of ~461 crewmember crew-worn acoustic measurement sessions
- ❖ 21% of noise exposures have exceeded ISS Flight Rule (based on conservative World Health Org. criteria)
- ❖ Hearing threshold shifts in US crewmembers show recovery within 30 days and no longer meet our shift criteria. However, a residual (high frequency) loss may remain and can lead to an accelerated threshold shift in the future.
- ❖ Hearing Conservation countermeasures have been found to be effective in dealing with risk of hearing loss, but risk posture might change if monitoring is reduced
- ❖ Potential risk of Sudden Sensorineural Hearing Loss manifests more significant impact on ops performance and long-term health than small hearing threshold shifts

Limitations of evidence base:

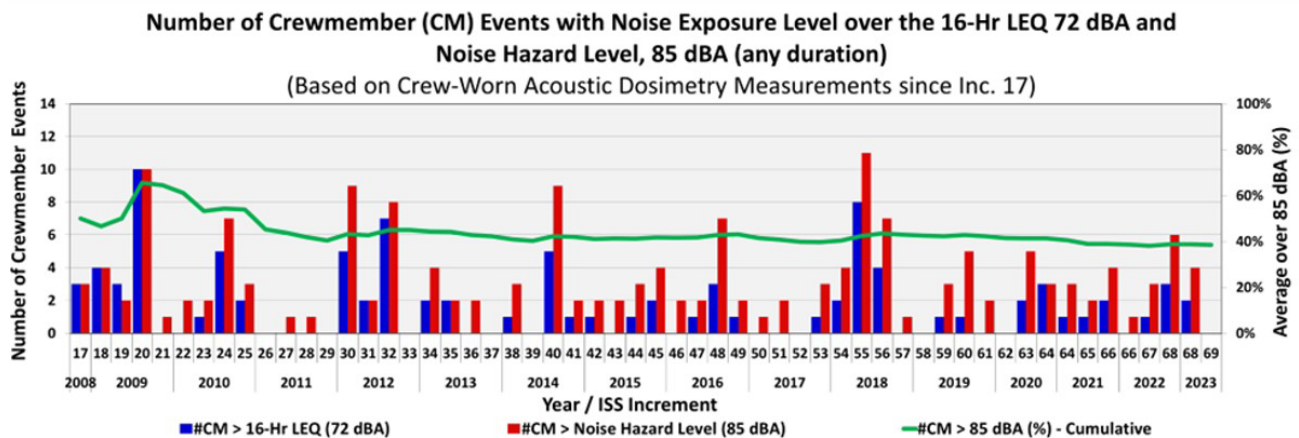
- ❖ Limited understanding of low-frequency hearing shifts
- ❖ Effects of microgravity on hearing loss are not well understood, may be minimal
- ❖ Risk that future vehicles/habitats will not meet standards (some currently do not); can be problematic with longer duration missions
- ❖ RSOS data suggests high incidence (56%) of shifts persisting for at least 10 days post-flight, which is difficult to interpret (and a limitation) at this time

11a. State of Knowledge – New Evidence

ISS Crew-worn Acoustic Dosimetry Flight Rule Exceedances

Daytime Noise Exposure Levels over 72 dBA and Hazard Level Exceedances of 85 dBA or higher

- ⑩ ISS Noise Hazard Level (85 dBA) has been exceeded during 38% of ~461 crewmember crew-worn acoustic measurement sessions
- ⑩ Flight Rule B13-152 (which limits crew noise exposure over a 16-hour work period to be less than 72 dBA) has been exceeded in 21% of ~461 crewmember crew-worn acoustic measurement sessions



On-Orbit Incidence of High Frequency Hearing Shift

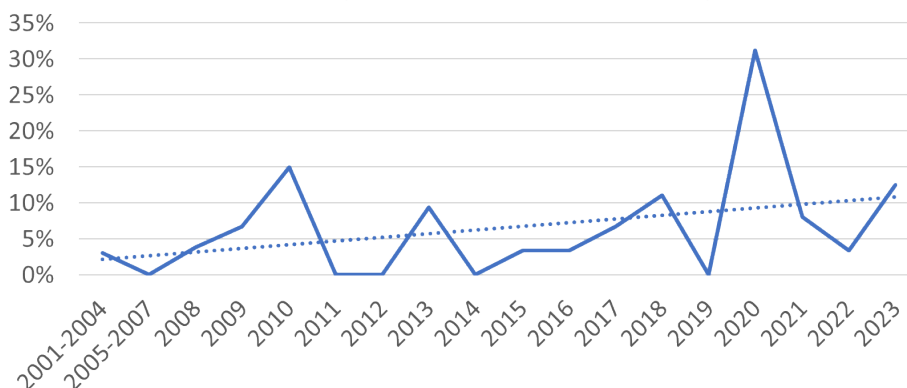
High Frequency Hearing Shift

- Definition: average change of 10 dB or more at 2000, 3000, and 4000 Hz in either ear

On-Orbit Hearing Assessment (OOHA)

- High frequency hearing shift rates are trending upward (US data only)
- 9.0% of OOHA's indicate a high frequency shift
- 21.3% of US crewmembers have experienced a high frequency shift on at least one of their OOHA's

Percent of OOHA's with a High Frequency Shift
(Ave of 2000, 3000, 4000 Hz)



Post-Flight Incidence of High Frequency Hearing Shift

High Frequency Hearing Shift

- Definition: average change of 10 dB or more at 2000, 3000, and 4000 Hz in either ear

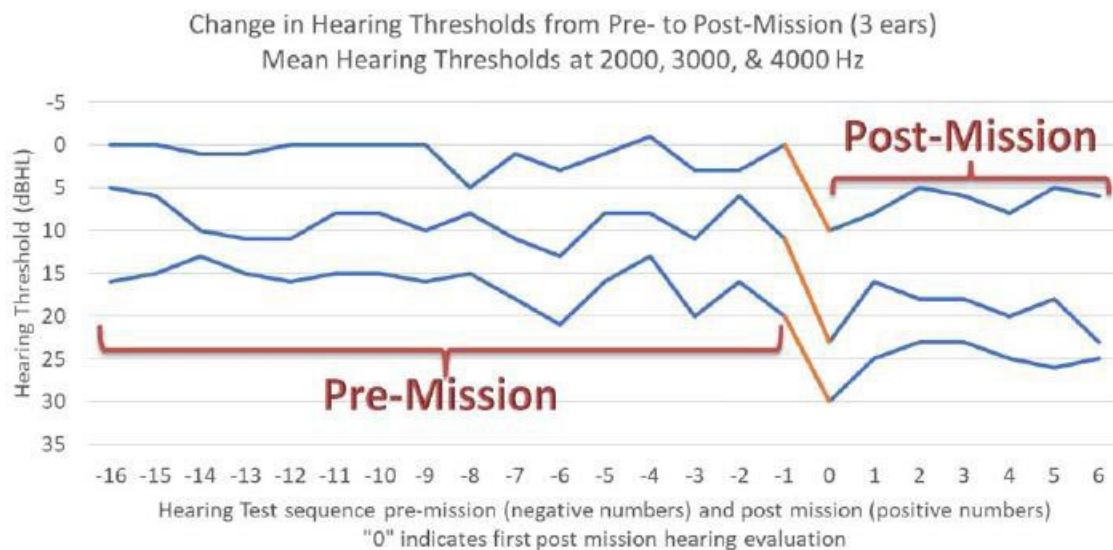
Conventional Audiometry

- 6.7% of post-flight hearing assessments (1st test, average: 4.7 days after landing) indicate a high frequency shift
- 0% of follow-up hearing assessments (2nd test, median: 27 days after landing) indicated a mission related high frequency shift

Residual High Frequency Hearing Loss

Post-flight high frequency hearing shifts are expected to resolve

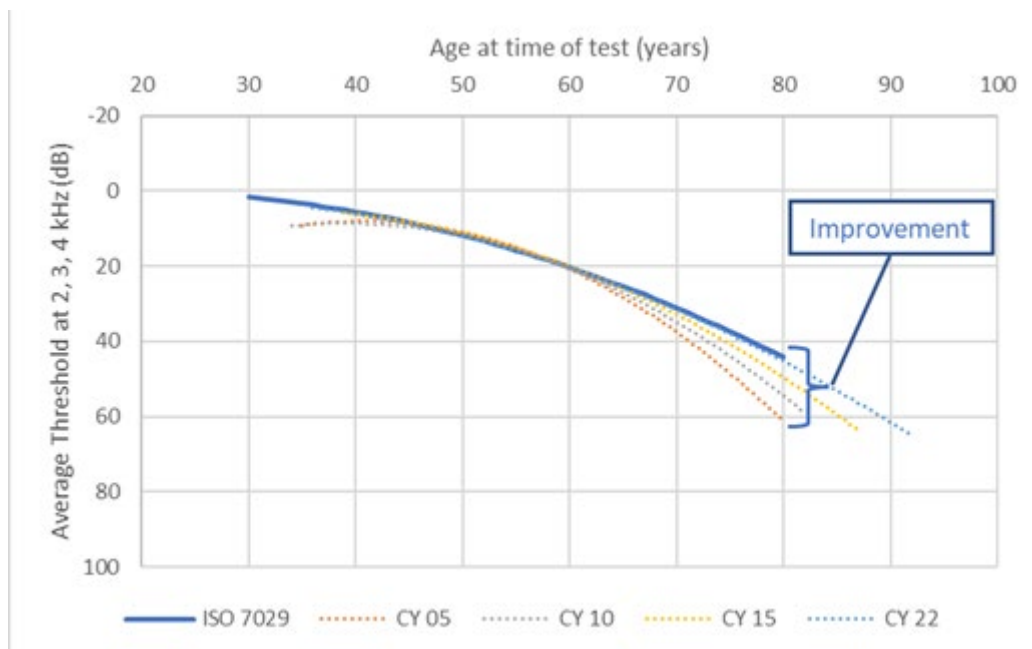
A residual decrement in mean thresholds may persist



High frequency hearing shifts identified within 10 days of landing are expected to resolve. However, a residual decrement in mean hearing thresholds may persist. The example below shows the average hearing threshold (at 2000, 3000, and 4000 Hz) of three ears for 16 tests prior to their ISS mission and 7 tests after their mission. All of these ears demonstrated a 10 dB (or greater) threshold shift from pre-mission to post-mission. Follow-up testing showed improved thresholds for all ears that no longer met the shift criteria of 10 dB change on average at 2000, 3000, and 4000 Hz. However, the average thresholds post-mission were markedly lower than pre-mission thresholds.

Long-term hearing health is improving

Mean hearing thresholds (trendline) of male astronauts (current and former) show improvement
CY2005 –CY2022



Graph showing the OSHA high frequency shift rates by calendar year (or year group) for US crewmembers.

Long-term hearing health (mean hearing thresholds) appears to be improving with time. The mean hearing thresholds (at 2000, 3000, and 4000 Hz) of male astronauts (current and former) tested at the JSC Clinic in calendar years 2005, 2010, 2015, and 2022 were evaluated. Calendar year 2020 was not used due to the low participation rate during Covid restrictions on travel and access to the JSC Clinic. Data were plotted as a function of age at time of test. A trend line (2nd order polynomial) was applied to each calendar year group. The trendlines suggests that thresholds below age 65 show no difference between year groups, while thresholds above age 65 show improvement with time. For example, an 80-year-old male astronaut would have mean hearing thresholds that are approximately 15-20 dB better in 2022 than an 80-year-old male astronaut in calendar year 2005. This suggests that current and future astronauts will have better hearing than their predecessors. The assumption is that the efforts employed by the JSC Hearing Conservation Program (on ground) and Acoustic flight rules (during space flight) to protect hearing and reduce noise exposure, have improved the long-term hearing health of crewmembers. Current (2022) threshold trends approximate expected hearing thresholds of the general population (based on ISO 7029).

On-Orbit Low Frequency Shift Rates

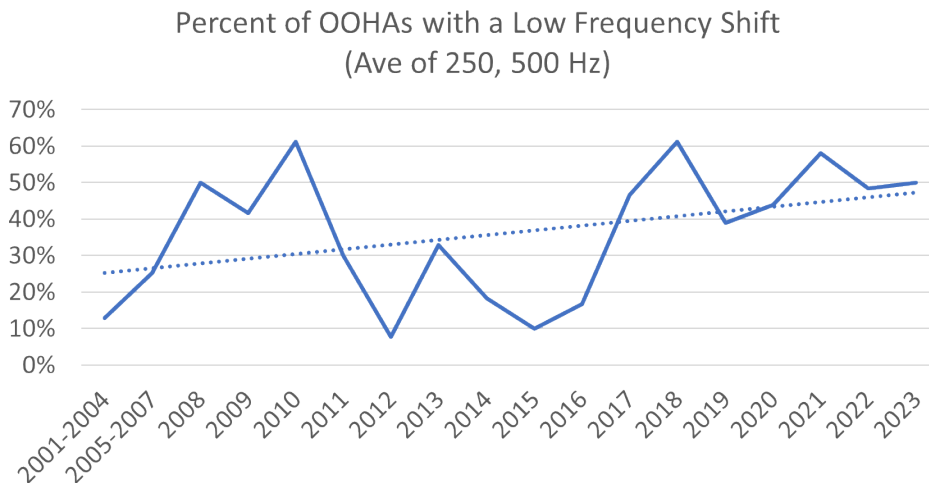
Low Frequency Hearing Shift

- Definition: average change of 10 dB or more at 250 and 500 Hz in either ear

On-Orbit Hearing Assessment (OOHA)

- Low frequency hearing shift rates are trending upward (US data only)
- 40.4% of OOHAAs indicate a low frequency shift
- 62.7% of US crewmembers have experienced a low frequency shift on at least one of their OOHAAs

Graph showing the OOHAs low frequency shift rates by calendar year (or year group) for US crewmembers



Long-term health effects of low frequency hearing loss are not known. While similar to cochlear Ménière's, the limited duration of low frequency shifts linked with 6-month ISS missions, may limit, or reduce permanent cochlear changes. Longer duration missions have the potential to incur permanent deleterious changes in cochlear function and audition.

11b. State of Knowledge – Evidence Base

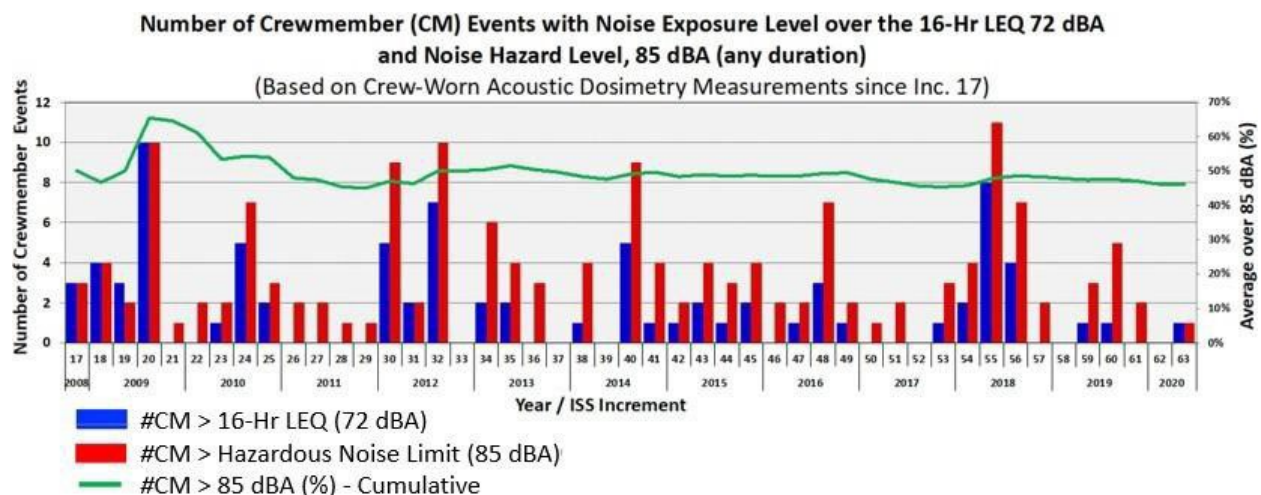
Crew-worn Acoustic Monitoring

- ❖ **Noise Levels are reported in A-weighted decibels (dBA)**
- ❖ **Crew-worn Acoustic Monitoring sessions are scheduled approximately every 60 days**, done in conjunction with On-Orbit Hearing Assessments.
- ❖ **Crew has possession of Acoustic Monitor for 24 hours**
 - **Worn during Workday (16-Hr LEQ):** Average of noise levels during all (not just certain) activities on that day.
- ❖ **Key Metrics**
 - *Flight Rule Limit: 72 dBA average, 16-Hr LEQ*
 - *Noise Hazard Level Exceedance: 85 dBA (for any duration)*



Crew-worn Acoustic Dosimetry

- ❖ ISS Noise Hazard Level (85 dBA) has been exceeded during 38% of ~461 crewmember crew-worn acoustic measurement sessions
- ❖ Flight Rule B13-152 (which limits crew noise exposure over a 16-hour work period to be less than 72 dBA) has been exceeded in 21% of ~461343 crewmember crew-worn acoustic measurement sessions

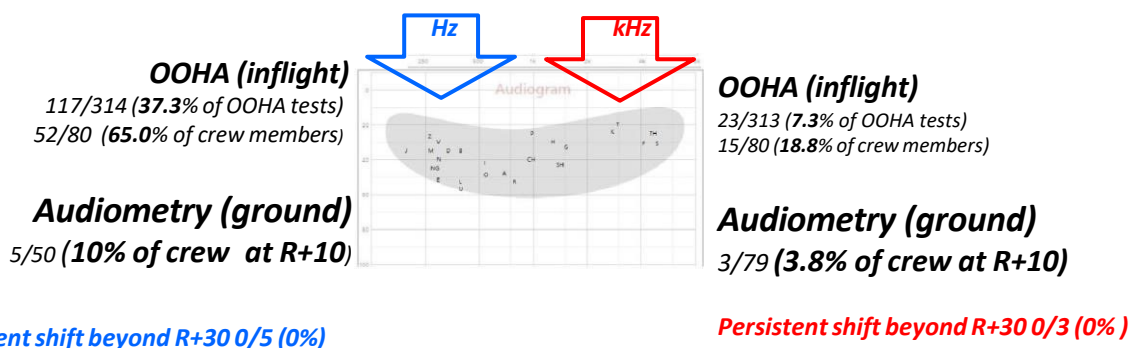


USOS OOHA and Audiometry

ISS Increments 2 -61 Mission-Associated Shifts Since Pre-flight
(Similar to 2019 review by HSRB)

Low frequency shifts
≥10 dB average of 250 and 500

High frequency shifts
≥10 dB average of 2, 3, and 4



Russian Audiometry



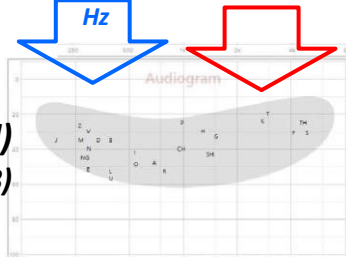
Russian Audiometry: Frequent Hearing Shifts

ISS Increments 2 - 57

Mission-Associated Shifts Since Pre-flight

Low frequency shifts
 ≥ 10 dB average of 250 and 500 Hz

High frequency shifts
 ≥ 10 dB average of 2, 3, and 4 kHz



Audiometry (ground)

18/61 (29.5% of crew at R+3)

4/61

(6.6% had not returned in 14 days)

Audiometry (ground)

48/61 (78.7% of crew at R+3)

34/61

(55.7% had not returned in 14 days)

Source: Dr Edouard Matsnev, IBMP (2018) MMOP Acoustics Sub-Working Group Face-to-Face Meeting

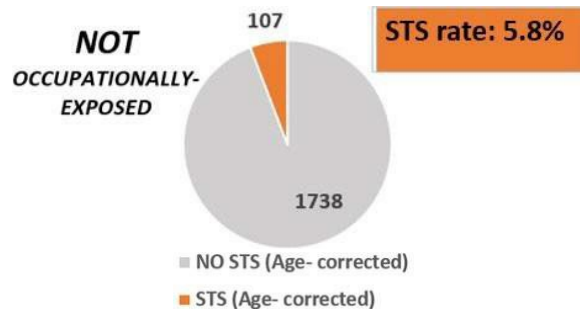
Threshold Shifts & Hearing Conservation Programs

Fewer significant threshold shifts [Shuttle Transportation System (STS)] seen among Johnson Space Center (JSC)/ White Sands Test Facility (WSTF) employees when enrolled in hearing conservation programs (HCP) (*with acoustic and hearing monitoring, training, required use of PPE)

* Enrolled in Hearing Conservation Programs



Not enrolled in Hearing Conservation Programs
 (Wellness, Test Support, Long Term Surveillance of Astronaut Health (LSAH))



Source: R. Danielson (2019) SD Occ Health Program Review: 2018 Data

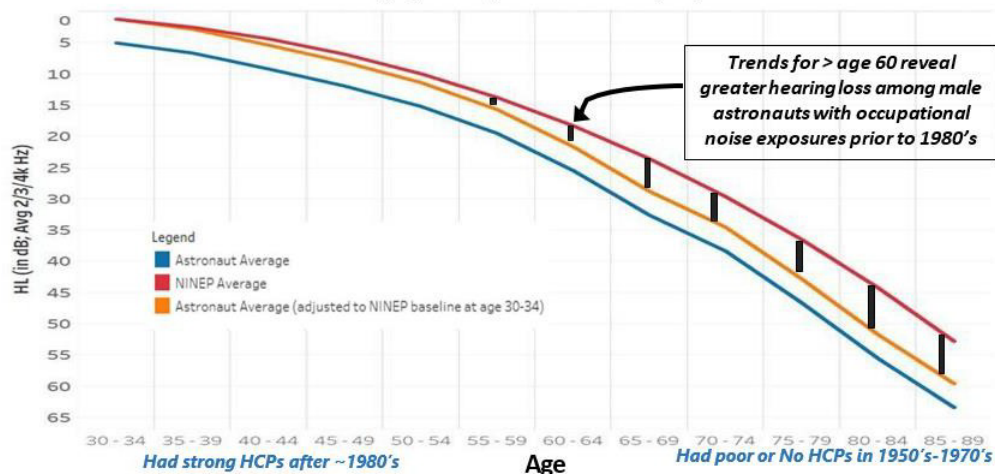
Hearing Conservation Programs

Efforts in hearing conservation programs are a risk mitigation for long-term health

Hearing Trends (smoothed), by Age: Male Astronauts vs. "Non-Industrial Noise-Exposed Population (NINEP)"

Averaging Hearing Thresholds at 3k, 3k, 4k Hz

Per ISO 7029 Annex A



Sensorineural Hearing Loss

- ❖ Sudden Sensorineural Hearing Losses (SSNHL) (30 dB to Total Loss) Can Occur in Terrestrial Populations, Could Affect Mission Ops

Population	
Reported in Literature (Slightly more likely in men. Incidence increases with age)	27 per 100,000
** Astronaut cases (2001-2020)	3 OF 194 Active Astronauts
** LSAH patients (2001-2020)	1 of 325 Former Astronauts
** JSC employees (2001-2020)	4 Patients (contractor/civil servant)

- If promptly identified, SSNHL is considered by Ear, Nose and Throat doctors (ENTs) to be a true otologic emergency
- Most widely accepted mode of therapy of SSNHL: Oral doses of oral corticosteroid, but evidence lacking due to absence of well-controlled studies
- **Of the 7 cases treated w/steroids, hearing loss improved (by ≥ 30 dB or completely) in 4 cases

* Alexander and Harris (2013). Incidence of sudden sensorineural hearing loss. *Otology & Neurotology* 34:1586-1589.

* Shemirani and Schmidt (2009). Sudden sensorineural hearing loss: an evaluation of treatment and management approaches by referring physicians. *Otolaryngol Head Neck Surg*;140: 86-91.

** JSC cases (2001-2020), per Electronic Medical Record review

12. Metrics

- ❖ Ongoing review of acoustic dosimetry trends (over time); peer-reviewed and published annually
- ❖ Ongoing review of Noise Survey data (revealing sources of elevated noise levels)
- ❖ Ongoing reviews of continuous noise levels of spaceflight vehicles/habitats
- ❖ Ongoing reviews of noise levels produced by certain intermittent sources (e.g., exercise device, toilet)
- ❖ Ongoing review of crew members' OSHA and Audiometry data
 - Hearing Threshold Shifts (≥ 10 dB)
 - Hearing Threshold Shifts that also result in Hearing Loss (≥ 25 dB with respect to normal hearing)
- ❖ Ongoing comparisons of LSAH audiometric data (including individual former astronauts at time of their periodic physical exams) with NINEP audiometric data
- ❖ Three dashboards created using IMPALA data and updated in real-time as a visualization tool to determine any long-term shifts post-flight.
 - Dashboard 1 reviews audiogram shifts by name and mission for both high and low frequency (low frequency does not currently include 250 Hz) as well as for US and USOS crew. This dashboard also reviews inflight OOHAs by (crewmember, mission, date), (crewmember and mission), and (all missions) to tease the data out for different users.
 - Dashboard 2 outlines the percent of OOHAs with and without a shift over time by side, year, shift size by year, and shift size by year and side for both high and low frequencies.
 - Dashboard 3 is the newest visualization looking at high frequency hearing shifts (low frequency will be added after getting 250 Hz results into IMPALA) and showcases those with a shift at R+3/first exam and if any of those crew had a shift persist to their R+10/second exam or beyond.

13. Risk Mitigation Framework - Color Changes

How do we know when this risk's posture moves from yellow → green?

- ❖ If evidence that future vehicles/habitats are meeting acoustic requirements
- ❖ If ISS Noise Hazard Level (85 dBA) is not exceeded (in more than 50%?) crewmember crew-worn acoustic measurements
- ❖ If Flight Rule B13-152 (72 dB LAEQ_{16hrs}) is not exceeded (in more than 25%?) crewmember crew-worn acoustic measurements

14. Risk → Standards → Requirements Flow

Risk	Risk of Hearing Loss and Performance Decrements Due to Acoustics Issues in Space (Hearing Loss Risk)	
Standards	NASA-STD-3001: NASA Space Flight Human-System Standard Vol. 1, Crew Health Rev. C – September 2023	
	[V1 3001] Selection and Recertification	[V1 3003] In-Mission Preventive Health Care
	NASA-STD-3001: NASA Space Flight Human System Standard Vol. 2, Human Factors, Habitability, and Environmental Health, Rev. D – September 2023	
	[V2 3006] Human-Centered Task Analysis [V2 6001] Trend Analysis of Environmental Data [V2 6007] Rate of Pressure Change [V2 6073] Launch, Entry, and Abort Noise Exposure Limits [V2 6074] Ceiling Limit for Launch and Entry [V2 6075] Ceiling Limit for Launch Abort V2 6076: Launch, Entry, and Abort Impulse Noise Limits [V2 6077] Hazardous Noise Limits for All Phases Except Launch, Entry, and Abort [V2 6115] 24-Hour Noise Exposure Limits [V2 6078] Continuous Noise Limits [V2 6079] Crew Sleep Continuous Noise Limits [V2 6080] Intermittent Noise Limits [V2 6081] Alarm Maximum Sound Level Limit [V2 6082] Annoyance Noise Limits for Crew Sleep [V2 6083] Impulse Noise Limit [V2 6084] Narrow-Band Noise Limits [V2 6085] Infrasonic Sound Pressure Limits [V2 6106] Noise Limit for Personal Audio Devices	[V2 6087] Acoustic and Noise Monitoring [V2 6088] Individual Noise Exposure Monitoring [V2 7043] Medical Capability [V2 7070] Sleep Accommodation [V2 9053] Protective Equipment [V2 9054] Protective Equipment Use [V2 9056] Use of Hearing Protection [V2 9057] Hearing Protection Provision [V2 9058] Hearing Protection Interference [V2 11009] Continuous Noise in Spacesuits

15. Proposed Standards Updates

❖ NASA Standard 3001

- No updates needed, but need to flow to requirements

❖ MED Volume A

- No updates needed

❖ MED Volume B

- MedB 1.8 Hearing Assessment revision has been approved by Multilateral Medical Operations Panel (MMOP), now accumulating signatures
- Principal change: Replacing “EarQ system” with “KUDUwave system” for OOHAs

16. High Value Risk Mitigation Targets

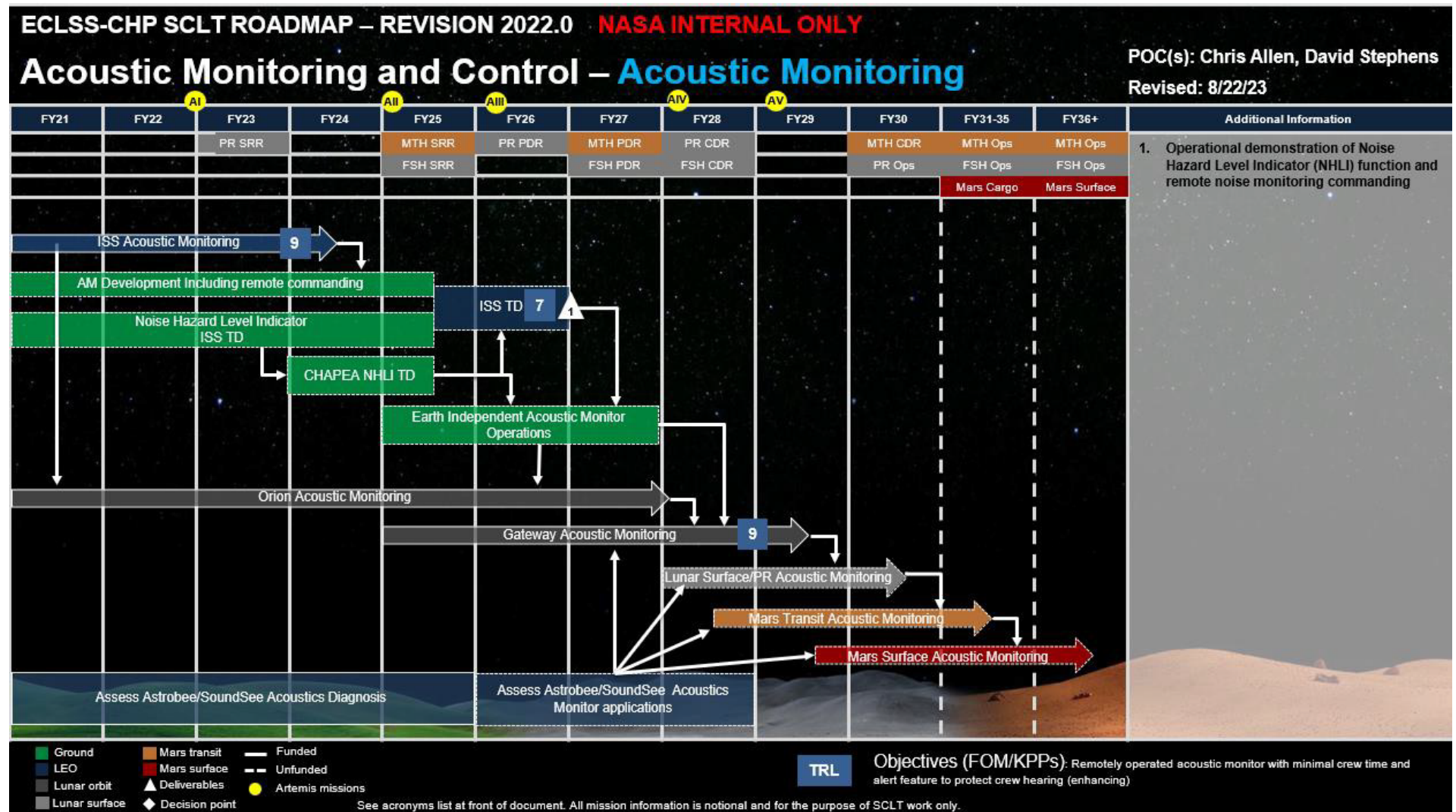
- ❖ Continue acoustic monitoring and hearing assessments to understand their relationship
 - Continue noise dosimetry and acoustic monitoring on ISS (SF)
 - Optimize performance and efficiency of KUDUwave audiometer and tympanometer system (SD)
- ❖ Ensure that acoustic requirements are met in new vehicles/habitats by employing an effective human systems integration process (e.g., an Acoustic Noise Control Plan) (SF)
 - Ensure noise and hearing monitoring in place for new vehicles/habitats (SD and SF)
 - Develop low noise ventilation and high-pressure-rise fans and technology (SF and GRC)
- ❖ Plan OOHAs for future long duration missions (SD)
- ❖ Understand cause of low-frequency hearing threshold shifts, using higher-fidelity hardware/software system (KUDUwave) for OOHAs (SD)
- ❖ Characterize the development and resolution of low frequency hearing loss, potential impacts to longer duration missions (greater one year), and potential long-term health impacts (SD)
- ❖ Understand why Russian data suggest more hearing loss than USOS data (SD)
- ❖ Characterize risk of hearing loss due to causes other than noise exposure (SD)
- ❖ Understand effect of reduced atmospheric pressures on acoustic environments in Artemis vehicles (SF)

17. Conclusions

- ❖ ISS Noise Hazard Level (85 dBA) has been exceeded during 38% of crew-worn dosimetry measurements
- ❖ ISS Flight Rule (72 dB LAEQ_{16hrs}) has been exceeded for 21% of crew-worn dosimetry measurements
- ❖ Continuous Noise Level Requirement has been significantly exceeded for Commercial Crew Transport Vehicles (both commercial providers) and for the Orion Multipurpose Crew Vehicle
- ❖ HSRB metric for Hearing Loss is based on incidence of mission-associated hearing threshold shifts seen among inflight and postflight hearing assessments
 - Few hearing threshold shifts seen among USOS in high frequencies, but very common in low frequencies in On-Orbit Hearing Assessments (OOHAs).
 - Currently, no threshold shifts persist among USOS crew beyond L+30 after 6-month missions, but risk posture will change with longer missions.
 - Russian data show persistent hearing shifts in both high and low frequencies among RSOS crew
- ❖ Efforts in Hearing Conservation are risk mitigations for mission ops and Long-Term Health
 - Countermeasures have been found to be effective in dealing with risk of hearing loss
 - Risk posture will change if acoustic monitoring is reduced
 - Risk posture will change if future space vehicles/habitats do not meet acoustic requirements

18. ECLSS-CHP SCLT Roadmaps

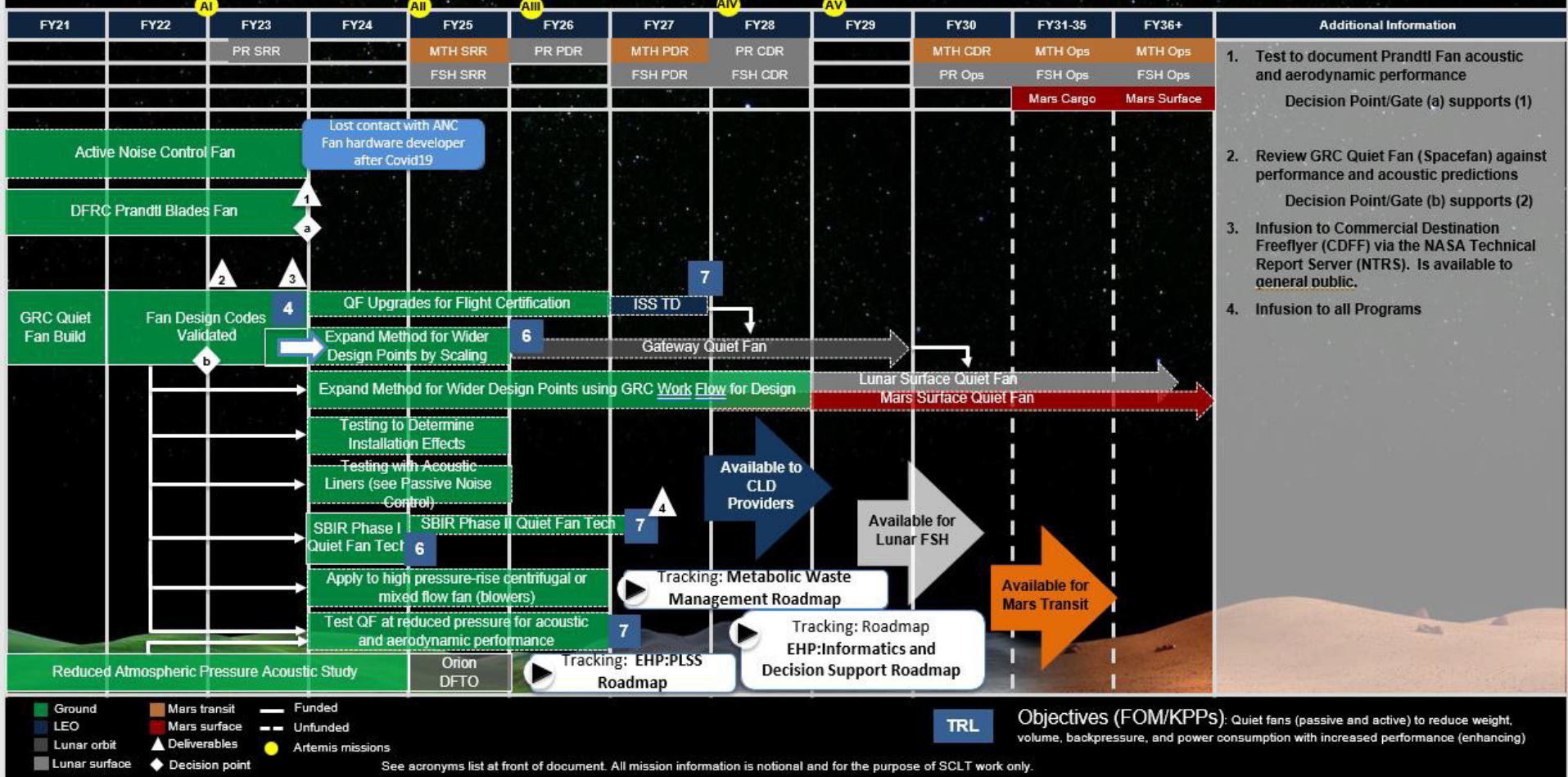
These Roadmaps are current as of 4/11/2024 (board presentation date) and are owned by the SCLT, not the HSRB.



Acoustic Monitoring and Control – Quiet Fans

POC(s): Chris Allen, David Stephens

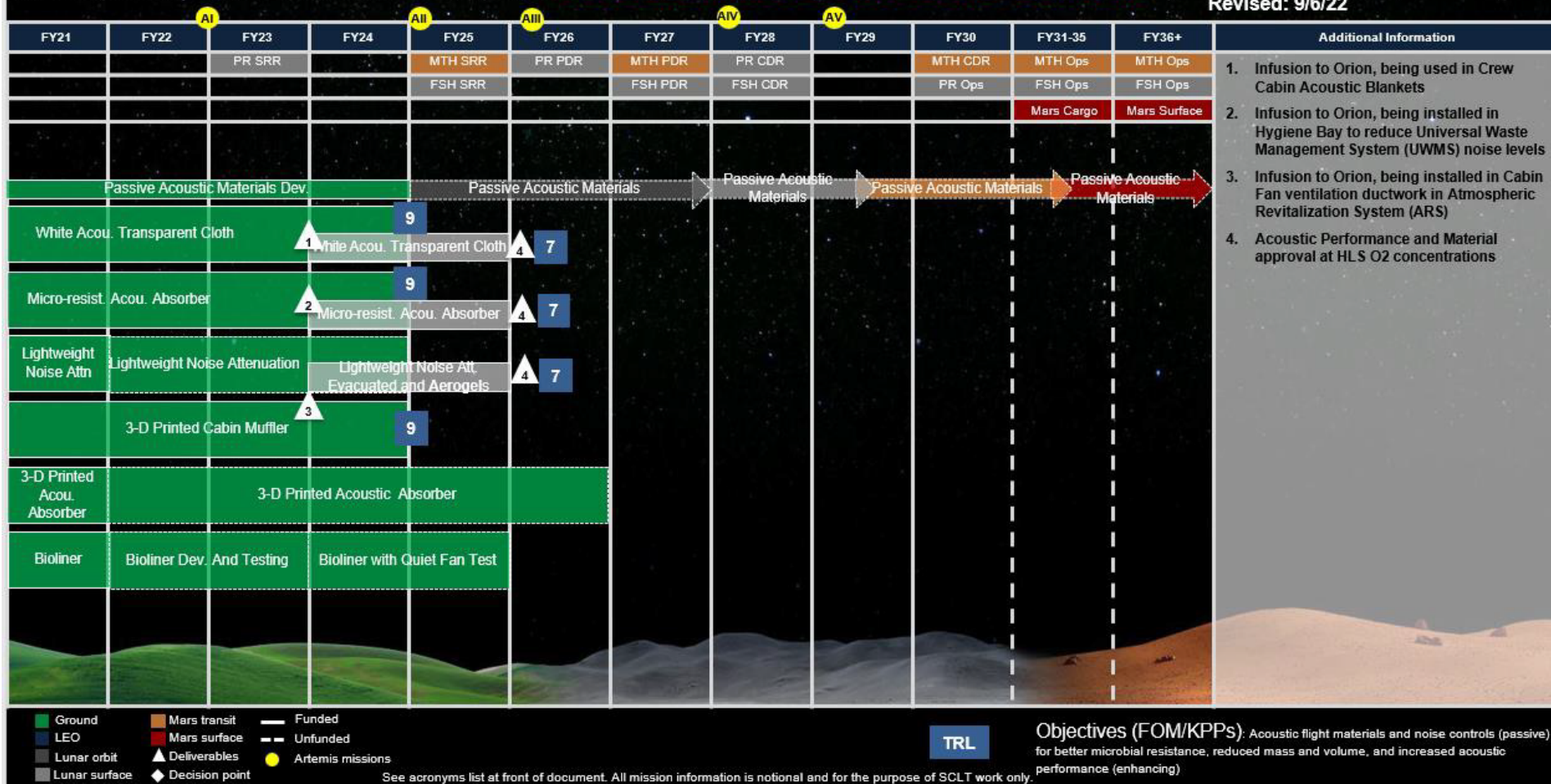
Revised: 9/6/22



Acoustic Monitoring and Control – Acoustic Materials and Noise Controls

POC(s): Chris Allen, David Stephens

Revised: 9/6/22



19. References

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- ❖ Limardo J Allen CS Danielson RW and Boone AJ. International Space Station (ISS) crewmember's noise exposures. *Proceedings of INTER-NOISE 2018*, #1898, 2018.
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- ❖ International Organization for Standardization. *ISO 7029 Acoustics- Statistical distribution of hearing thresholds as a function of age*. 2017. Geneva, Switzerland.
- ❖ Berglund B, Lindvall T, Schwela DH. *Guidelines for community noise*. World Health Organization, April 1999 ANSI S3.44- 1996 (R 2006) *Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment*. . American National Standards Institute. Melville, NY.
- ❖ Alexander TH, Harris JP. Incidence of sudden sensorineural hearing loss. *Otology & Neurotology* 2013; 34:1586-1589.
- ❖ Shemirani ML, Schmidt M, Friedland DR. ML. Sudden Sensorineural Hearing Loss: An Evaluation of Treatment and Management Approaches by Referring Physicians. *Otolaryngol Head Neck Surg*; 2013; 140: 86-91.
- ❖ Rabinowitz PM, Galusha D, Dixon Ernst C, Slade MD. Audiometric "Early Flags" for occupational hearing loss. 2007; *Journal of Occupational and Environmental Medicine* 49:1310-1316
- ❖ Kirchner DB, Evenson E, Dobie RA. MD, Rabinowitz P, Crawford J, Kopke R, et al. Occupational Noise-Induced Hearing Loss: ACOEM Task Force on Occupational Hearing Loss. *Journal of Occupational and Environmental Medicine*. 2012; 54(1):106–108.

20. Acronyms

Acronym	Meaning	Acronym	Meaning
BAA	Broad Agency Announcement	LEQ	Average Noise Level
CHP	Crew Health and Performance	LOE	Levels of Evidence
CR	Change Request	LSAH	Long Term Surveillance of Astronaut Health
DAG	Directed Acyclic Graph	LxC	Likelihood x Consequence
dB	decibel	MMOP	Multilateral Medical Operations Panel
dBA	A-Weighted decibel	MORD	Medical Operations Requirement Document
DRM	Design Reference Mission	NASA-STD-3001	NASA-STD-3001, Space Flight Human-System Standard
ENT	Ear, Nose and Throat	NINEP	Non-Industrial Noise-Exposed Population
HCP	Hearing Conservation Program	OOHA	On-Orbit Hearing Assessments
HLS	Human Lander System	PPE	personal protective equipment
HMTA	Health and Medical Technical Authority	R	Return
HPD	Hearing Protection Device	RSOS	Russian On-Orbit Segment
HSIR	Human System Integration Requirements	SD	Space Medicine Operations
HSR	Human System Requirements	SF	Human Systems Engineering & Integration
HSRB	Human System Risk Board	SRD	System Requirements Document
Hz	Hertz	SSNHL	Sudden Sensorineural Hearing Loss
ISS	International Space Station	STS	Shuttle Transportation System
JSC	Johnson Space Center	USOS	United States On-Orbit Segment
kHz	kilo Hertz	WSTF	White Sands Test Facility
LAeq	Equivalent Continuous Sound Level		