Innovation Award

Multilateral Medical Operations Panel's Acoustics Sub-Working Group for the International Space Station

February 21, 2020

Christopher Allen
Dick Danielson

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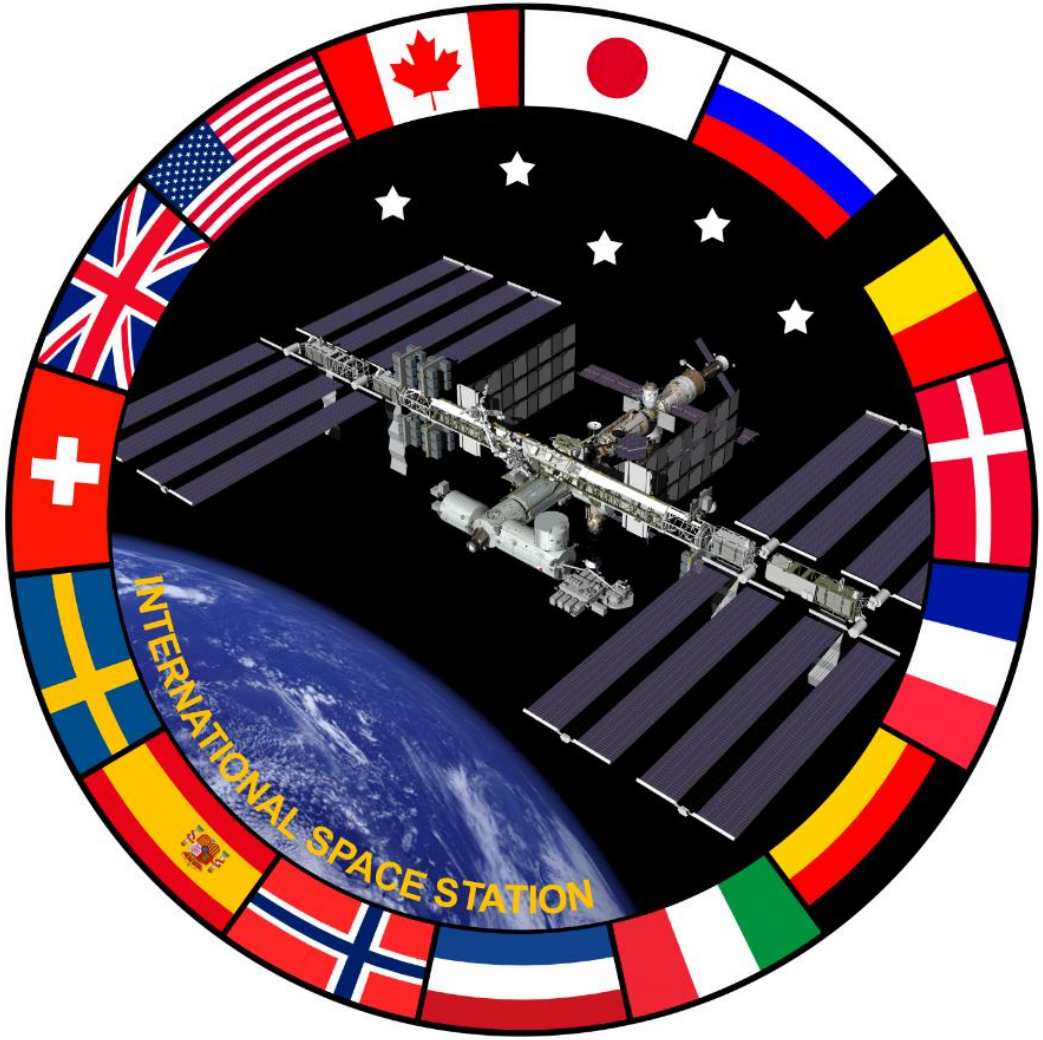
EXCELLENCE IN HEARING LOSS PREVENTION AWARD

International Space Station:
Multilateral Medical Operations Panel (MMOP)
Acoustics Sub-Working Group



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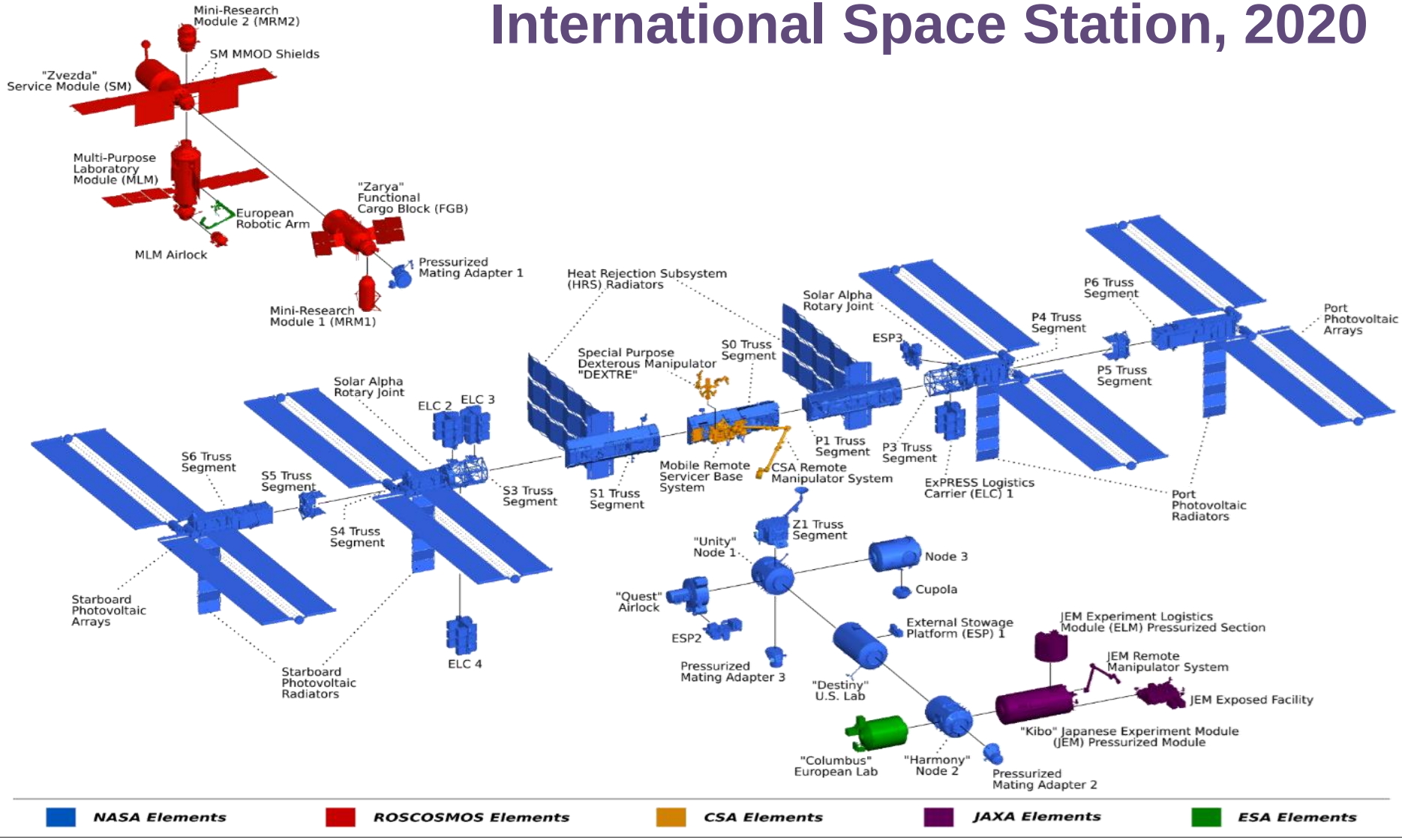
International Space Station, 2020



Multilateral Medical Operations Panel (MMOP)

Coordinator of medical system support for all ISS crewmembers, through a network of several MMOP Working Groups

Acoustic Challenges

- Collaborative interactions among partners with dissimilar standards, scientific evidence and levels of bureaucratic review
- Concurrence on acoustics limits and requirements
- Protection of crew health and performance using conservative Damage Risk Criteria and acoustic requirements
- Multiple ISS research and operations payloads, which contribute to crewmember noise exposure
- Missions are long-duration (6 months or more)
- Crew-time is a critical resource
- Mass, volume, and power-usage must be minimized

MMOP Acoustics Sub-Working-Group

- Disciplines: Acoustical engineering, noise control engineering, audiology, industrial hygiene, otolaryngology, psychoacoustics, hearing conservation, flight medicine, biomedical engineering

- Provides guidance regarding acoustics and hearing issues
  - **Pre-flight activities**: Acoustic limits, design of modules and payloads, nose control engineering, verification of requirements, acoustic modeling to integrate hardware
  - **In-flight:** Acoustic monitoring of equipment and crew exposures, recommendations for in-flight mitigations and hearing protection, audiometric monitoring with On-Orbit Hearing Assessments
  - Provides ISS program managers with updates on ISS acoustic environments and risks
  - Revises ISS Requirements and Acoustic Flight Rules
  - Develops organization of subgroup, and processes for decision-making / problem resolution

Team Members of
ISS MMOP Acoustics Sub-working Group

(2017 Face-to-Face Meeting, Tsukuba Japan)

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JSC Acoustics Office
Acoustics and Noise Control Lab

- Performs hardware acoustic verification testing
- Develops noise controls
- Develops flight-certified acoustic materials
- Provides acoustic demonstrations
- Validate acoustic modeling techniques

JSC Audiology
and Hearing Conservation Clinic

- Provides clinical and research support for flight and occupational hearing loss prevention programs
- Consultant for auditory issues in human spaceflight
- Reviews hearing status of former astronauts in Lifetime Surveillance of Astronaut Health Program

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ISS Acoustics Working Group (AWG)

- The AWG is a JSC advisory group, chaired by the Acoustics Office Lead, and supported by the following organizations
  - Acoustics Office
  - Audiology and Hearing Conservation
  - Astronaut Office
  - System Engineering & Integration
  - Safety
  - ISS Program
  - Ad-hoc members as-needed
- The AWG reviews significant acoustic issues, waivers, exceptions, Safety Non-Compliance Reports (NCRs).
- The AWG builds consensus in the acoustics community and advises the ISS Program

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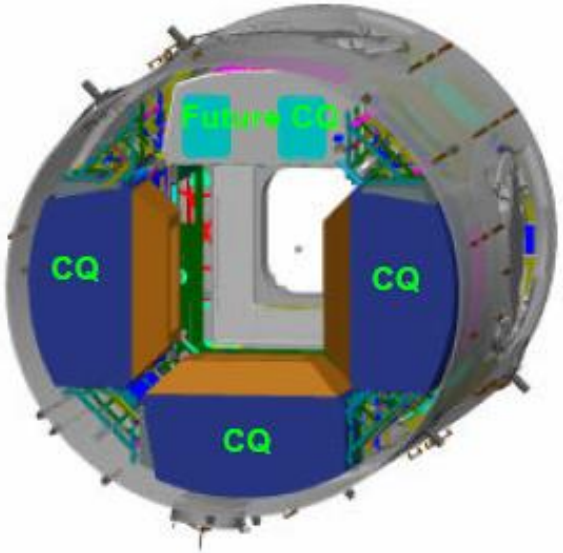
Innovations in the ISS Environment



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Goals of ISS Acoustics Team

*Control **NOISE impacts on Crew Health and Mission Safety***

Consider effects of spaceflight sound levels on:
*Risks for developing hearing loss *(permanent, temporary)*
*Interference with speech intelligibility and communications due to noise
*Possible reduction in Alarm Audibility due to noise
*Possible disruptions of crew sleep due to noise
*Possible interference with crew task performance due to noise

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INNOVATION DETAILS
Examples of International Partner Major Efforts

- **Hearing Conservation**
  - Flight Rules
  - Hearing Assessment Updates
  - Hearing Protective Device Availability and Use Guidelines
- **Noise Control of Integrated Modules**
  - Updates to Russian Segment Requirements
  - Remedial Action Plan for Russian Service Module
  - Acoustic Modeling of Module Systems and Hardware
  - Disposition of Exceptions
- **On-orbit Monitoring and Mission Support**
  - Review of Acoustic Monitoring and Hearing Assessment Data
  - Coordination of Mission Operations regarding Acoustics Issues

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Noise Constraints Flight Rule

- **Uses Noise Damage Criteria based on consensus of World Health Organization, NIOSH & scientific evidence**

  Uses 3 dB exchange rate, based on "Equal Energy", consistent with other IP's

- **Separates noise exposures into appropriate risk events**
  - **Work-day ($L_{eqA,16}$)**, re: hearing loss risks and communication interference
  - **Night-time ($L_{eqA,8}$),** re: sleep disturbance
- **Allows task-based predictions of high noise activities and work locations (and guidance for use of hearing protection), using new mechanisms developed by JSC**

Flight Rule: Noise Level Constraints

A. IF THE 16-HOUR CREW WORK PERIOD NOISE EXPOSURE LEVEL (LAEQ16) AS MEASURED BY THE ISS AUDIO DOSIMETER OR AS PREDICTED USING THE "NOISE HAZARD INVENTORY" EXCEEDS: ®[032113-00603C]

1. 72 DBA, CREWMEMBERS SHALL BE DIRECTED TO WEAR APPROPRIATE HEARING PROTECTIVE DEVICES DURING ACTIVITIES WHERE HIGH NOISE EXPOSURE LEVELS ARE PRESENT. THESE ACTIVITIES AND EXPOSURES WILL BE IDENTIFIED IN THE "NOISE HAZARD INVENTORY."

2. 60 DBA, THE FLIGHT SURGEON WILL RECOMMEND TO THE AFFECTED CREWMEMBER USE OF APPROPRIATE HEARING PROTECTIVE DEVICES, BASED ON THE INDIVIDUAL NEEDS OF THE CREWMEMBER AND THE LEVELS AND DURATIONS OF THE NOISE EXPOSURE.

Mandated HPD Use	*Recommended HPD Use*	
Exposure Sound Level (dBA)	*Exposure Sound Level (dBA)*	*Exposure Duration (hours)*
72	*60*	*16*
75	*63*	*8*
78	*66*	*4*
81	*69*	*2*
84	*72*	*1*
85		*HAZARD - NOT ALLOWED*

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B13-152
NOISE LEVEL CONSTRAINTS

Night-time ($L_{eqA,8}$)

B. IF THE 8-HOUR SLEEP PERIOD NOISE EXPOSURE LEVEL (LAEQ8), AS MEASURED BY THE ISS ACOUSTIC DOSIMETER, EXCEEDS 50 DBA, THE FLIGHT SURGEON WILL INFORM THE AFFECTED CREWMEMBER OF STEPS TO MITIGATE THE NOISE.

C. PROPOSED SLEEP LOCATIONS, OTHER THAN CERTIFIED "CREW QUARTERS" WITHIN A VEHICLE/MODULE, SHALL BE EVALUATED FOR ACOUSTIC EXPOSURE CHARACTERISTICS PRIOR TO EXTENDED USE AS A CREW SLEEP LOCATION. AN EVALUATION SHALL INCLUDE SOUND LEVEL METER OR ACOUSTIC DOSIMETER MEASUREMENTS TO CHARACTERIZE THE ACOUSTIC LEVELS WITHIN THE VEHICLE/MODULE AND DETERMINE WHETHER OR NOT USE OF APPROPRIATE HEARING PROTECTIVE DEVICES WOULD BE NECESSARY. ®[032113-00603C]

D. IF THE CREW PERCEIVES NOISE LEVELS TO BE EXCESSIVELY HIGH, ACOUSTIC MEASUREMENTS SHALL BE TAKEN. THE FOLLOWING IS THE ORDER OF PREFERENCE FOR ACOUSTIC MEASUREMENTS IN THIS CASE: ®[032113-00603C]

1. SOUND LEVEL METER

2. ACOUSTIC DOSIMETER

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Noise Exposure Estimation Tool

DAILY (LEQ16) NOISE EXPOSURE ESTIMATION TOOL (NEET)

Calculation of Equivalent A-weighted Sound Pressure Level
(reference, Engineering Noise Control, Bies and Hanson, pp. 108, eq 4.23)

This spreadsheet may be use to estimate the 16-hour work period noise exposure level LEQ16 (dBA) based on crew location (e.g. module) or task/activity performed on ISS. Simply fill in the yellow shaded cells for the Task or Location (using the drop-down list) and the estimated exposure time (duration) in hours for each job task/activity or crew location. (Cummulative time should NOT be greater than 16 hours)

Note: This spreadsheet will provide you with the hearing protection requirement.
(using the 3-dB Trading Rule)

VERSION 1.12

Task or Location	Duration (hrs)		Lp (dBA)
T2 - High Speed	1.0	HPD Required	84.5
ARED	1.5	HPD Recommended	66.3
Node 2	2.0	HPD Recommended	63.8
Node 1	1.0	No HPD Needed	60.2
MRM1	2.0	HPD Recommended	65.3
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
US Segment	8.5	No HPD Needed	59.5

LEQ16 (dBA)

72.8

HEARING PROTECTION MAY BE REQUIRED FOR SOME OF THE ACTIVITIES, TASKS OR LOCATIONS

Total Time

16.0 Total time is correct

NOTE: Total time must equal to 16 hours

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Noise Exposure Estimation Tool

DAILY (LEQ16) NOISE EXPOSURE ESTIMATION TOOL (NEET)

Calculation of Equivalent A-weighted Sound Pressure Level
(reference, Engineering Noise Control, Bies and Hanson, pp. 108, eq 4.23)

This spreadsheet may be use to estimate the 16-hour work period noise exposure level LEQ16 (dBA) based on crew location (e.g. module) or task/activity performed on ISS. Simply fill in the yellow shaded cells for the Task or Location (using the drop-down list) and the estimated exposure time (duration) in hours for each job task/activity or crew location. (Cummulative time should NOT be greater than 16 hours)

Note: This spreadsheet will provide you with the hearing protection requirement.
(using the 3-dB Trading Rule)

VERSION 1.12

Task or Location	Duration (hrs)		Lp (dBA)
T2 - High Speed + Plugs	1.0	HPD Recommended	70.3
ARED	1.5	HPD Recommended	66.3
Node 2	2.0	HPD Recommended	63.8
Node 1	1.0	No HPD Needed	60.2
MRM1	2.0	HPD Recommended	65.3
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
US Segment	8.5	No HPD Needed	59.5

LEQ16 (dBA)

63.7 No hearing protection is required, but may be recommended for some activities, tasks or locations

Total Time

16.0 Total time is correct

NOTE: Total time must equal to 16 hours

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Crew Noise Exposure and Hearing Protection Use

- Noise Hazard Inventory is an increment specific operations product
- Implements JSC Flight Rule B13-152 (communicates to crew)
  - Hearing protection requirement (mandated use) is based on the crewmembers' predicted 16-hour noise exposure level (LEQ16) while performing projected activities when LEQ16 > 72 dBA
  - Hearing protection recommendations are made based on activity levels and durations when predicted LEQ16 > 60 dBA
  - Crewmember-specific hearing protection recommendations may be provided separately by the JSC Audiologist according to "On-Orbit Hearing Assessment" results or other information
  - Recommendations for reducing noise levels in crew sleep stations are made based on 8-hour noise exposure levels (LEQ8) in sleep stations when LEQ8 > 50 dBA
- Noise exposure level predictions of combinations of activities are performed using the "Noise Exposure Estimation Tool"
- Crewmembers can use hearing protection whenever they want to for comfort →*Hearing protection is always available for their use*

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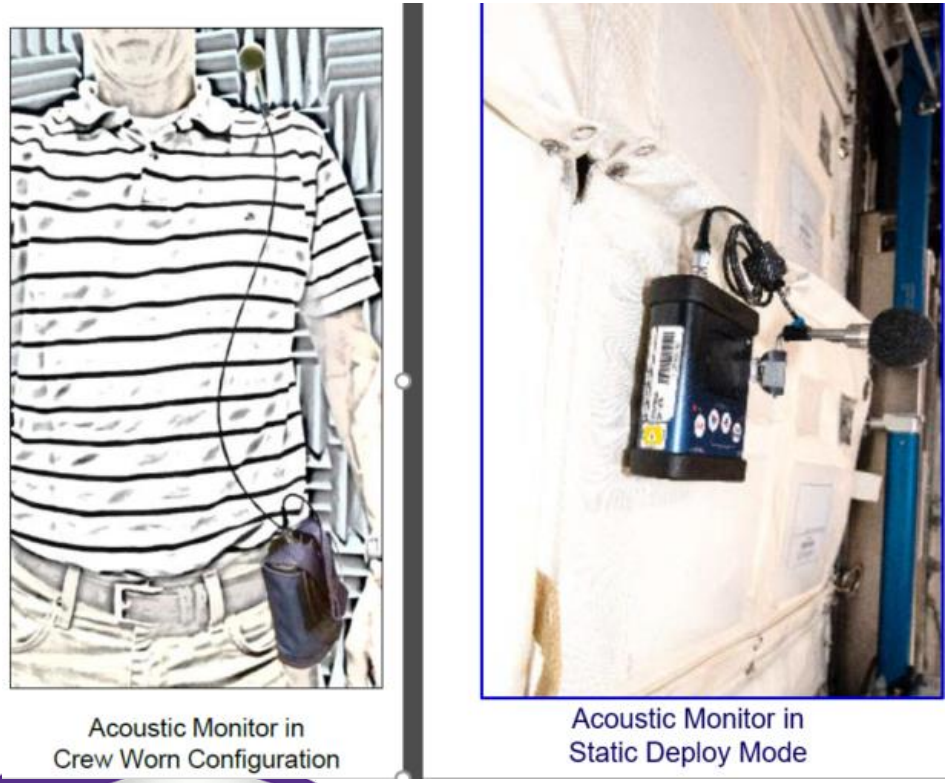
Significant contributions from Canadian Space Agency (CSA)

Innovations in Acoustic Monitoring



Acoustic Monitor in Crew Worn Configuration

Acoustic Monitor in Static Deploy Mode

Analyzed Effects of Impulse Noise on Crew Noise Exposure

Nakashima, Limardo, Boone, Danielson. (2019) Influence of impulse noise on noise dosimetry measurements on the International Space Station. Intl Journal of Audiology https://doi.org/10.1080/14992027.2019.1698067

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Significant contributions from Russian members of MAS

Innovations in Noise Reduction

Developed Service Module Remedial Action Plan

Air Conditioning System Noise Controls

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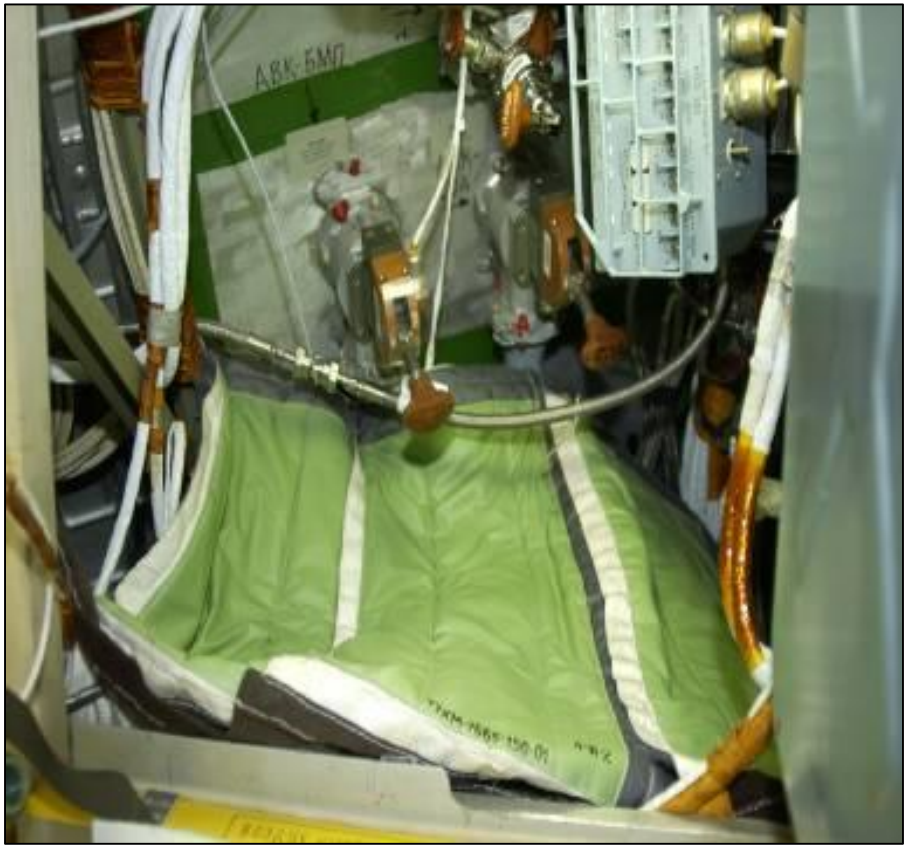
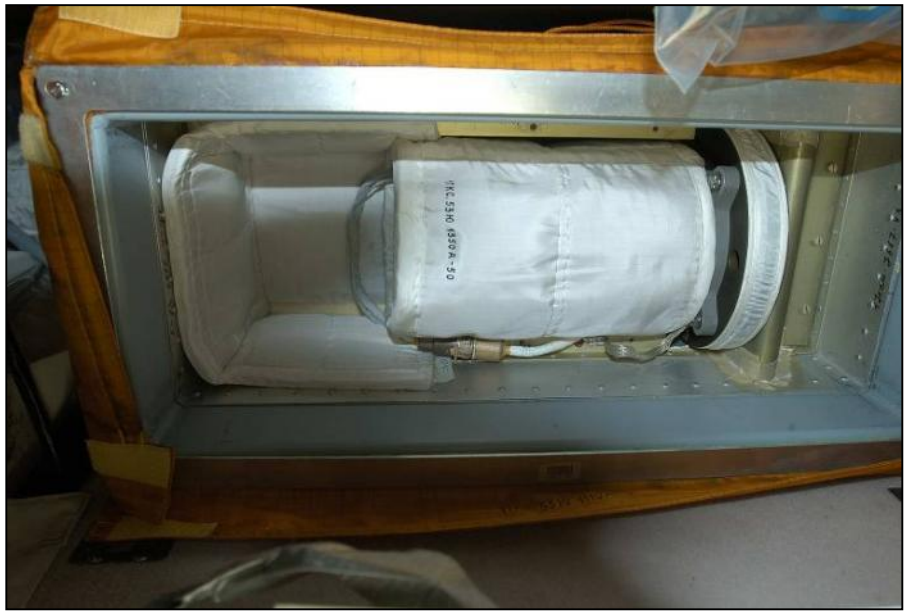
SM CO2 Removal System Noise Controls

Adapter, shock absorber, and soft soundproof cover installed



Upon crew initiative, additional soundproofing device installed

SM Ventilation System Noise Controls



Development of Russian “Quiet Fan”

Fan type	MO-2-5008	17КС.53Ю 5014А-0
Test condition	H=4 mm H20 (0.16 in H2O)	
Capacity, Q, l/s	47.0 (100 cfm)	83.4 (177 cfm)
Current, I, mA	470	470
Rot. speed, n, rpm	3120	2010
Iso. noise levels, dBA	61-64	48
Duct noise level, dBA		42

SM Fans

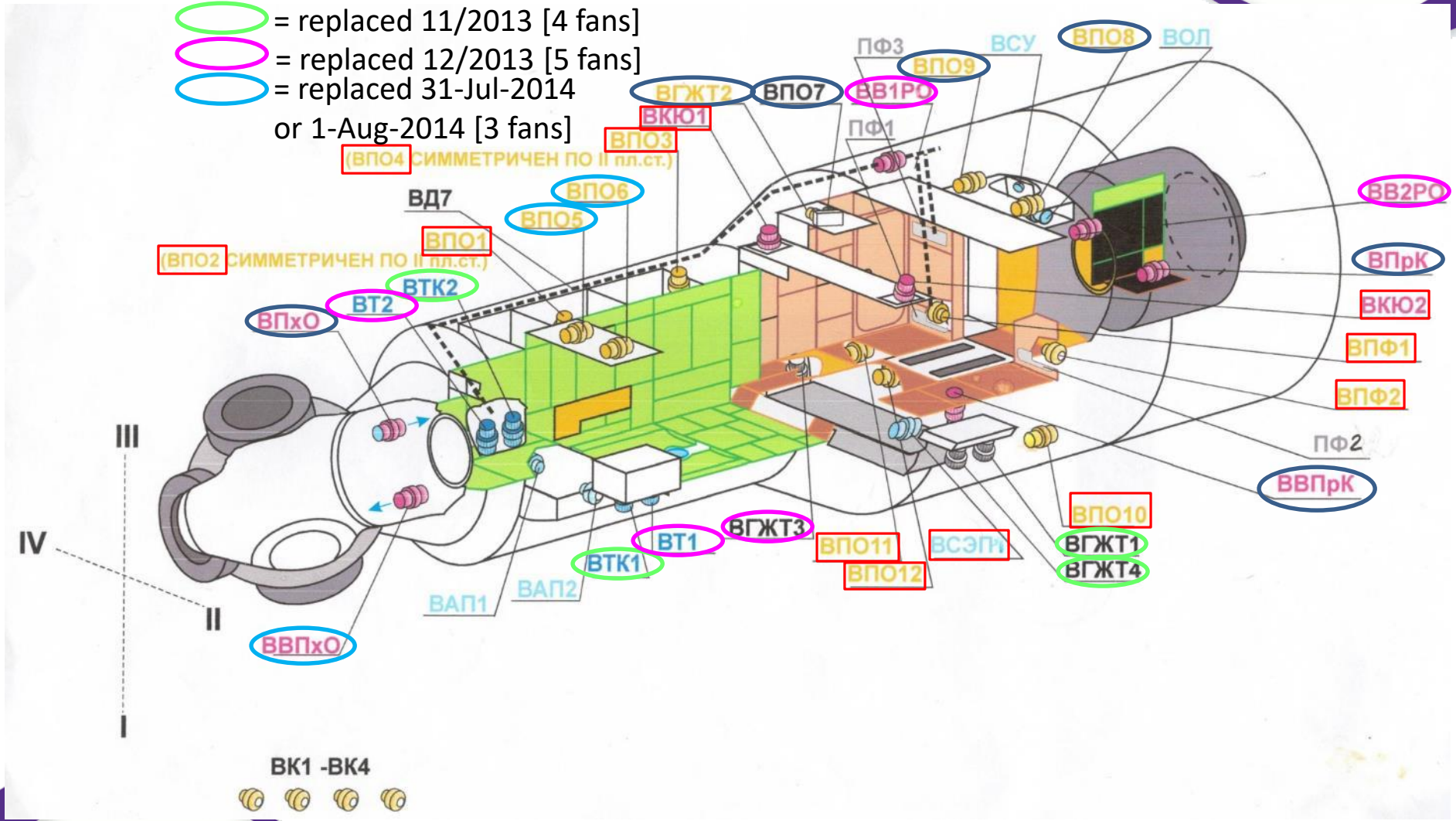
= vibration isolation acoustic-lined duct

= replaced with low-noise fan in week preceding 7-Dec-2012 [7 fans]

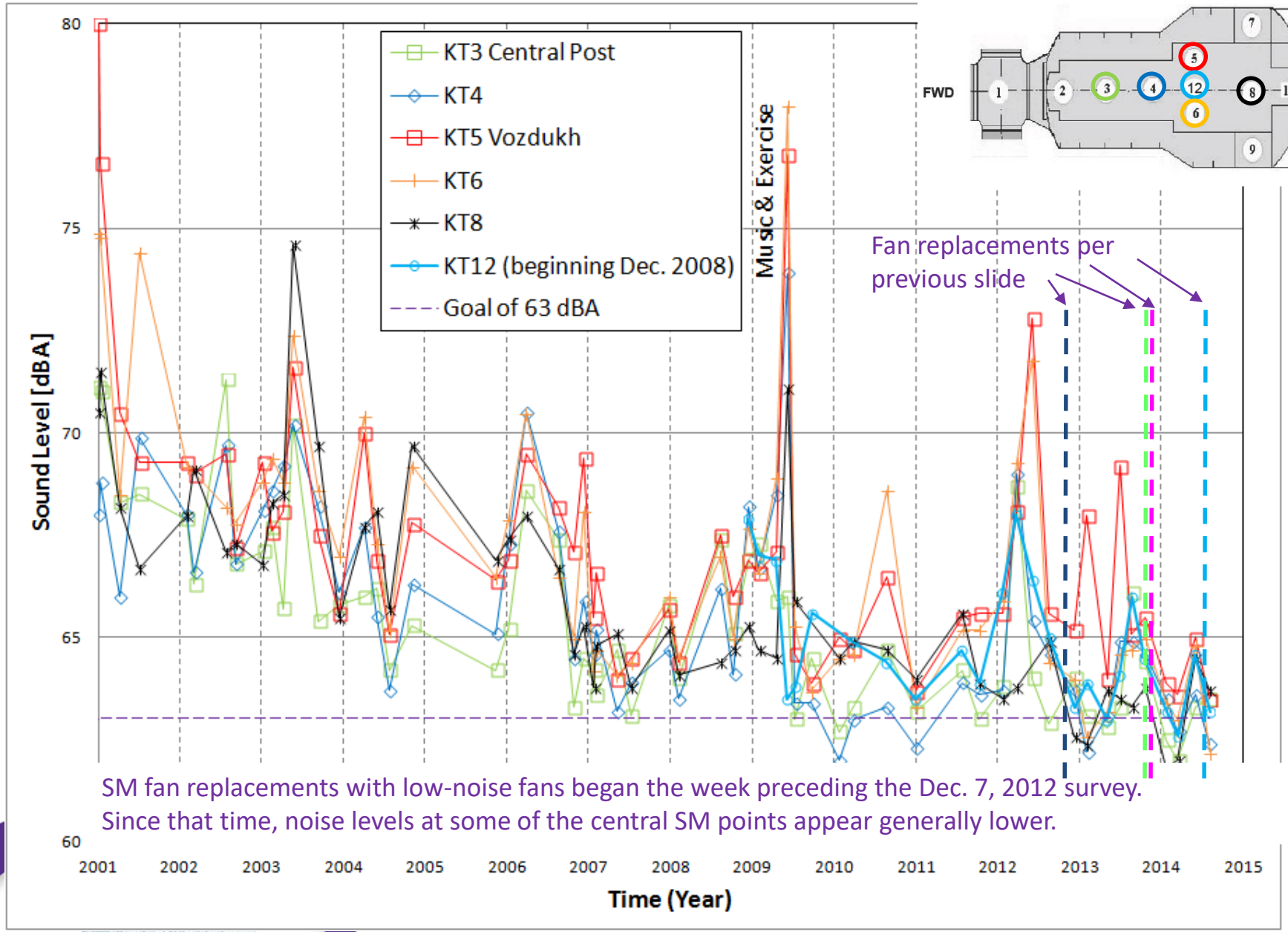
= replaced 11/2013 [4 fans]

= replaced 12/2013 [5 fans]

= replaced 31-Jul-2014
or 1-Aug-2014 [3 fans]

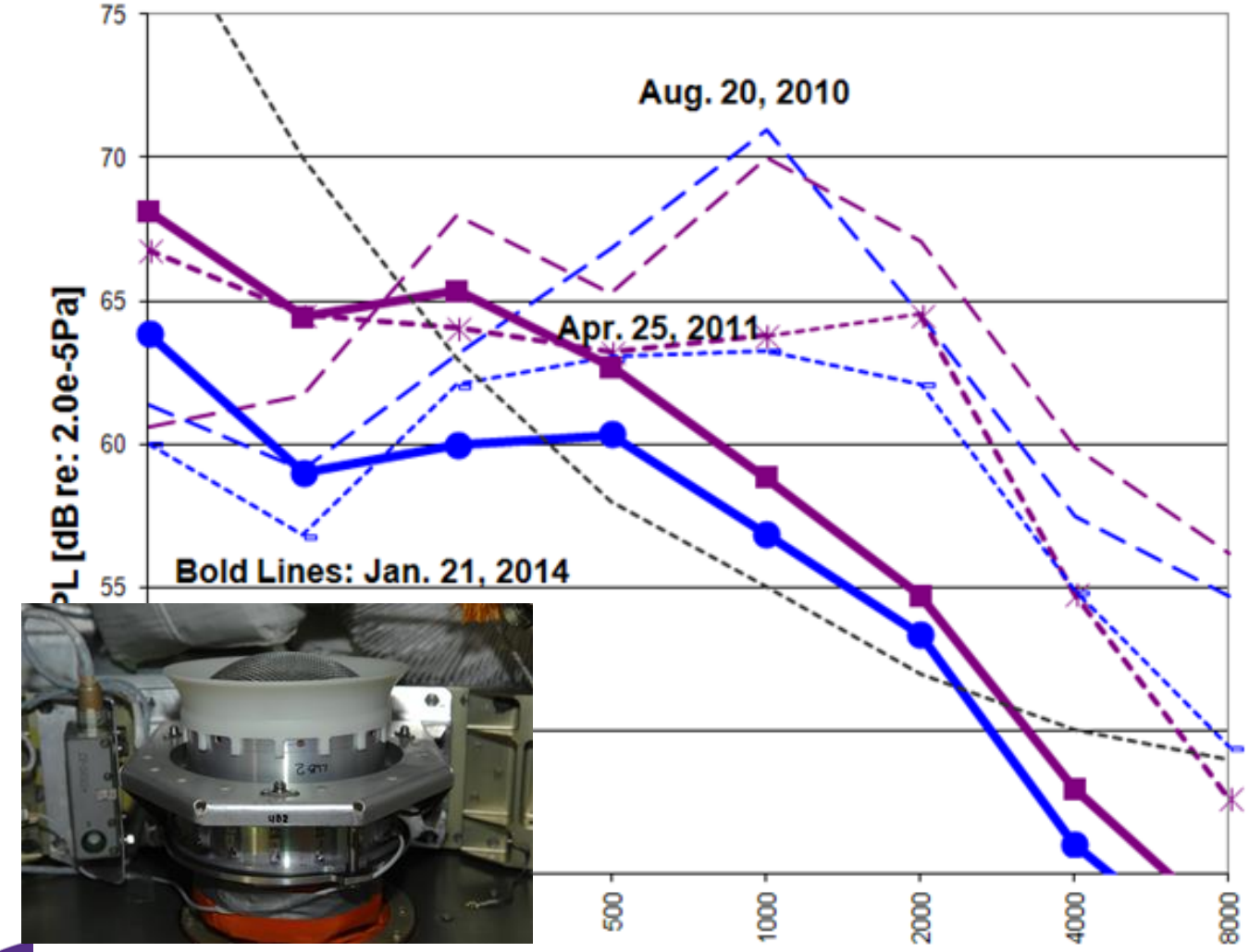


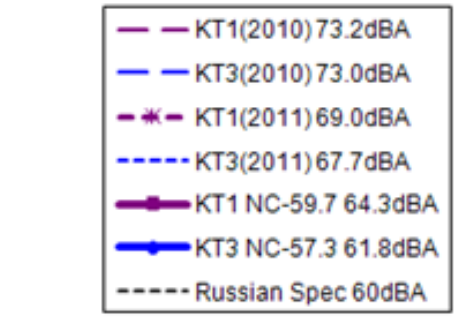
SM Central Control Points vs. time

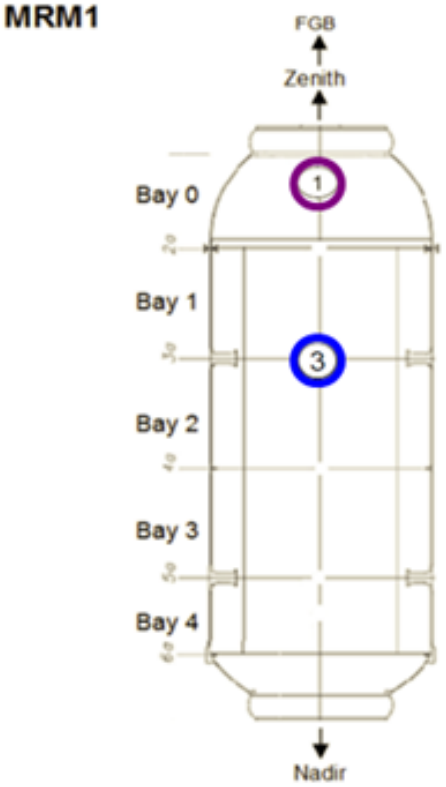


SM fan replacements with low-noise fans began the week preceding the Dec. 7, 2012 survey. Since that time, noise levels at some of the central SM points appear generally lower.

MRM1 Noise Reductions from Quiet Fan Installations







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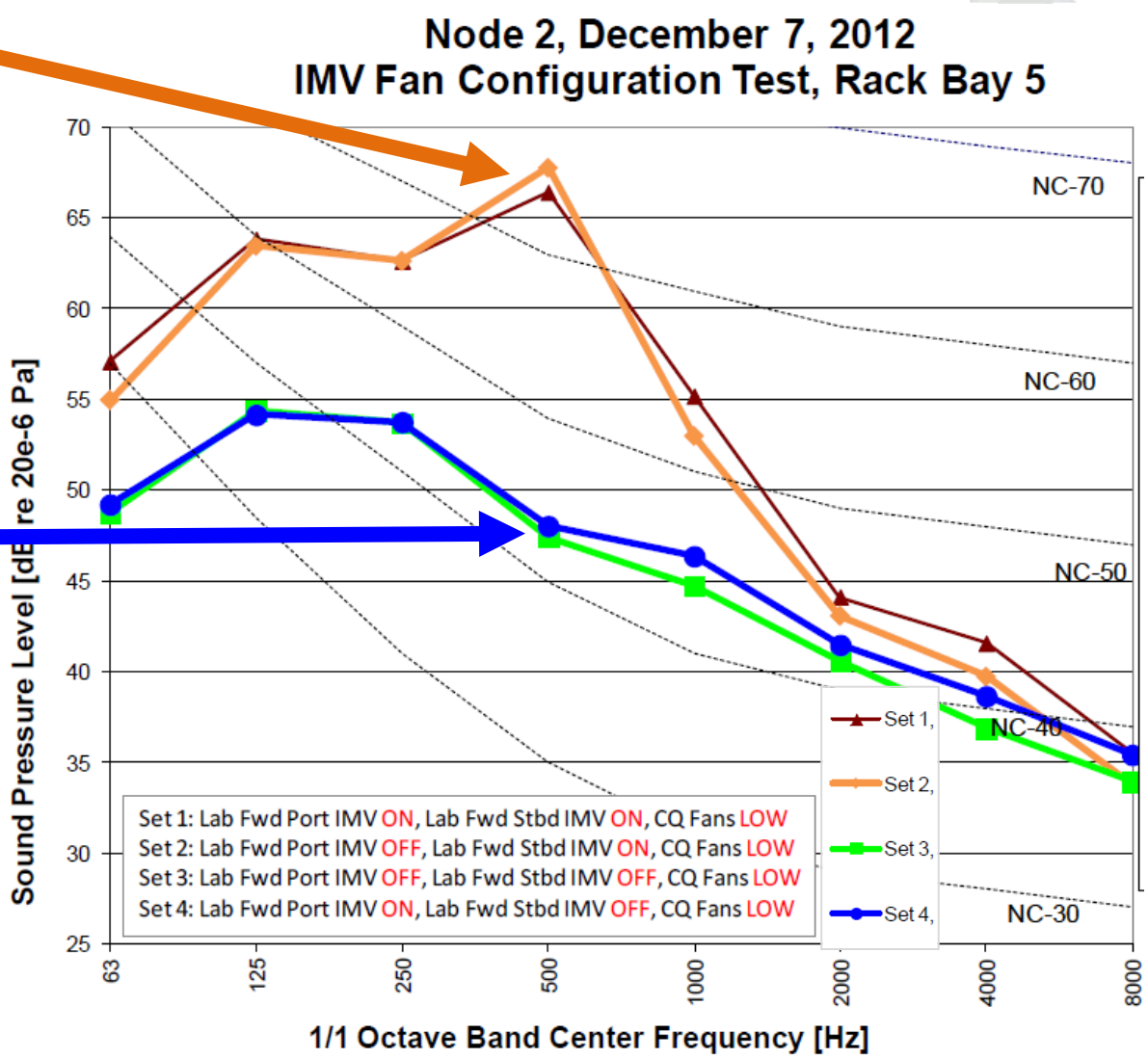
Significant contributions from the Japanese Exploration Agency (JAXA)

Noise Levels Decreases and Airflow Increases After Clogged Fans Are Cleaned

Before Cleaning

After Cleaning

ISS025E012160



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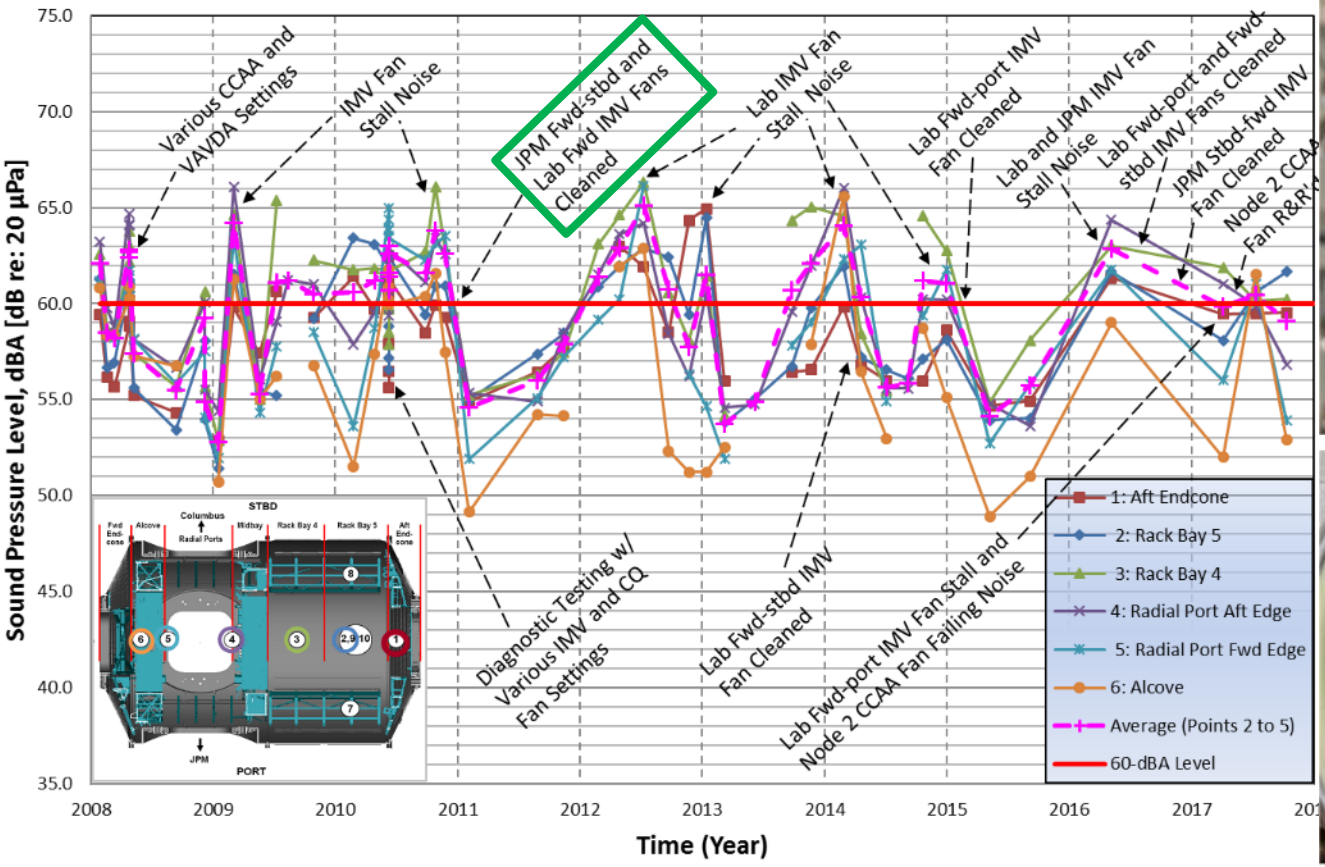
Node 2 Sound Levels vs. Time



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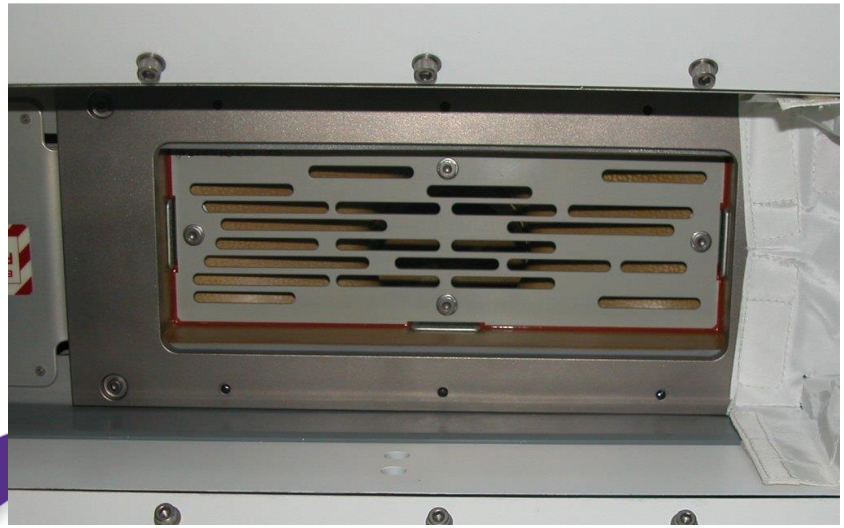
Innovations in Noise Reduction

Significant contributions from the European Space Agency (ESA)

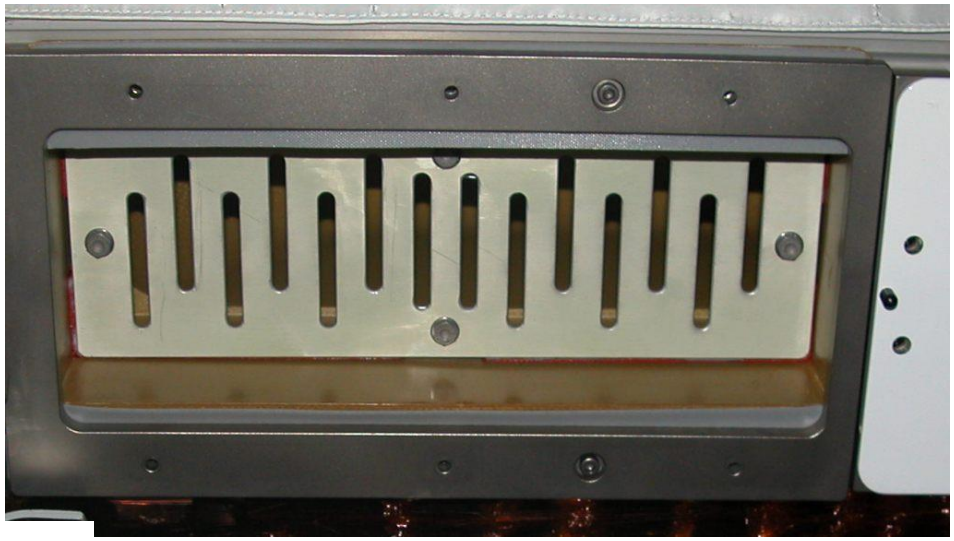
Old and New Node 2 Cabin Air Diffuser Plates Changed Out

Old NOD2OS3 (upstream), 11% Open area

Old NOD2OS5 (downstream), 10% open

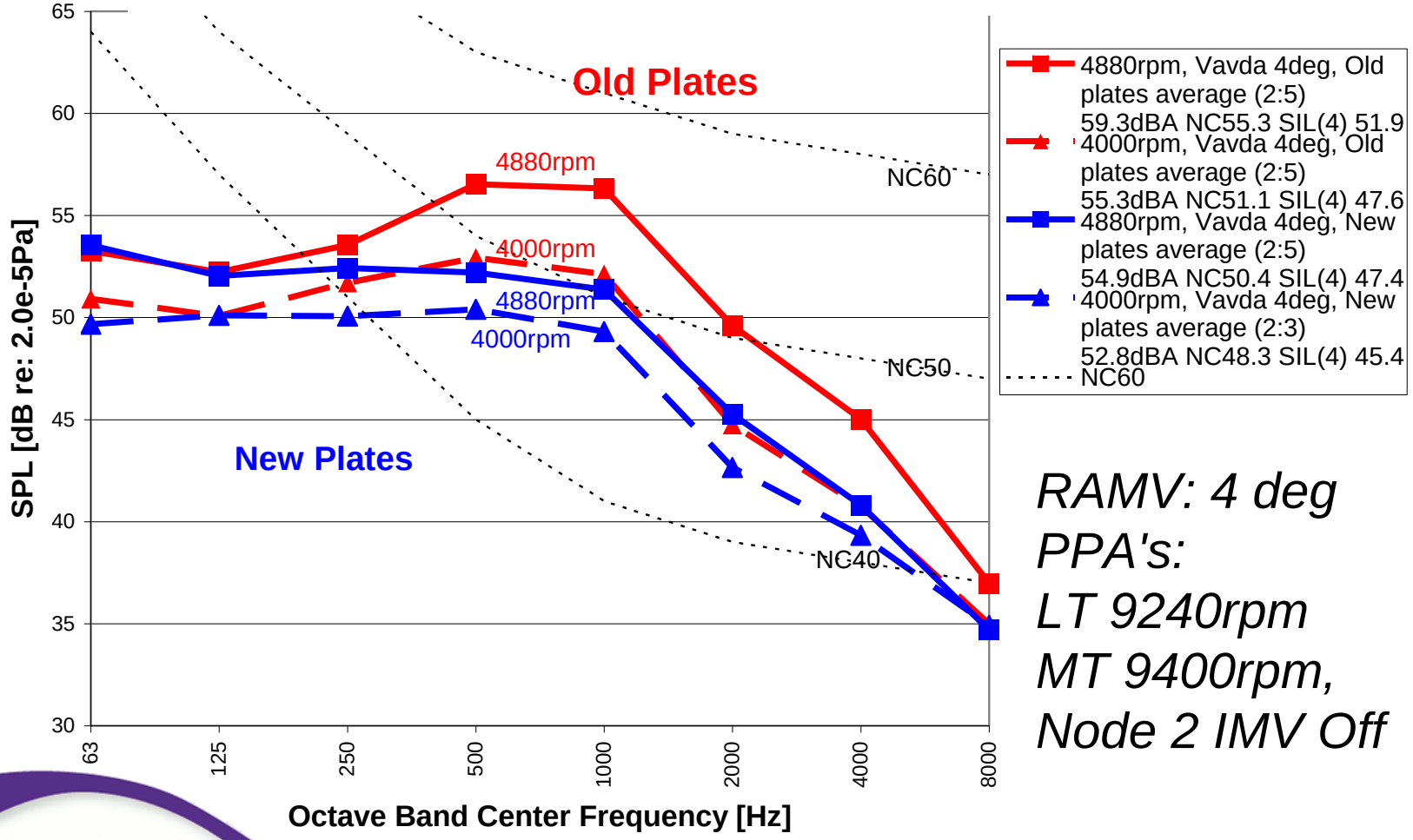


New NOD2OS3 (upstream), 22% open area



New NOD2OS5 (downstream), 18% open

Acoustic Levels of Old vs. New Node 2 Cabin Air Diffuser Plates



RAMV: 4 deg
PPA's:
LT 9240rpm
MT 9400rpm,
Node 2 IMV Off

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Significant contributions from NASA

On-Orbit Hearing Assessments (OOHA) Performed In-Flight on ISS

OOHA with basic software, ear monitors, ANR headset

(Undergoing tests now) OOHA with "Boothless Audiometer" w/tympanometry

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Analyses of Hearing Assessments

In 2018, MAS formed an Auditory Health and Performance Focus Group with experts in audiology, otolaryngology, and psychoacoustics

- Addressing auditory and non-auditory effects of noise
- Standardizing methods for reporting OOHA and audiometry results, using similar metrics

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Summary

- The MAS has collaborative interactions among partners with dissimilar standards, scientific evidence and levels of bureaucratic review
- Concurrence has been reached on acoustics limits and requirements
- A hearing conservation program has been agreed-upon, including self-administration of hearing tests (OOHA); noise monitoring and dosimetry, and hearing protection use guidelines, without having on-site technical support.
- Acoustic modeling, based on ground measurements, is used to control noise levels of the integrated module environments, even with significant changes in spaceflight hardware topologies/configurations.
- Noise problems have been successfully identified and remotely remediated (e.g., clogged fans, malfunctioning equipment, upgrades of noisy fans to quieter units).

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Significance of this Award

What does this Award mean for the future of MAS?

- Acknowledgement by ISS Program Managers that acoustic issues warrant continued efforts by subject matter experts and hardware developers during design of payloads and future spacecraft.
- Highlights that noise control is less costly and much easier to do proactively rather than retrofitting systems in the development of spaceflight hardware, as it is in industry
- Highlights to our NASA management that our efforts are seen as effective and important by external peers. This is an affirmation for future collaborative efforts among International Partner members of MAS

What Future Work Lies Ahead for the MAS?

- Sustained efforts and improvements in acoustic monitoring, acoustic modeling, and innovative approaches to hearing assessments (e.g. on-orbit tympanometry) and hearing protection
- Recognition of new technologies and instrumentation (e.g., Noise Hazard Level Alerting)
- Study the non-auditory effects of noise (e.g., sleep disturbance, individual and team productivity)
- Examine potential to extend work with International Partners and commercial companies for the acoustic environments of the Gateway, Human Landing System, and Lunar & Mars habitats
- Collaborate in acoustics and hearing conservation efforts in areas other than space flight

Lessons Learned

What can others learn from MAS's innovation experience?

- Stick-to-itiveness, slow and steady collaborative progress, is important. Most of our accomplishments took many years to coordinate and implement.
- Recognize what is important to partners when negotiating. Respect their point of view. Work through translation issues to make sure concepts are clear and understood, to find common ground.
- Autonomous monitoring of noise exposures would provide valuable insight regarding early detection of operational auditory risks (e.g., among military and industrial hearing conservation programs)

- *Chris' personal lesson: That Noise Control Engineering is important to Hearing Conservation efforts and is recognized within the NHCA community*

CONTACT INFORMATION

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