Acoustics in Habitable Space Vehicles & Enclosures

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Presentation Outline

- "Crew compartment" term used to be inclusive of crewed or manned spacecrafts, modules, habitats, or other types of crewed enclosures
- Acoustics is a safety issue
- Effects of high noise
- What's required to ensure acceptable acoustic levels in crew compartments
  - Good set of acoustic requirements*
  - Noise Control, compliance & verification
  - Management relationship
- Conclusions

* **Emphasis on continuous noise**

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Acoustic Safety Issues

The acoustics environment in habitable space vehicles is important to crew & mission safety

- Importance of acoustic levels:
  - Crews hearing needs to be protected (not impeded or damaged)
  - Good communications are needed to support operations
  - Crew needs to hear alarms
  - Acoustics need to be at habitable level for crew comfort & efficient operations

  Limits used need to satisfy all of above

- High noise levels can cause:
  - Temporary or permanent hearing loss
  - Auditory pain
  - Headaches
  - Ringing in the ear
  - Irritability
  - Annoyance
  - Distraction
  - Impediment to or unacceptable communications
  - Inability to hear alarms or other cues
  - Errors in judgment
  - Other

Cartoons from Human Engineering Guide, 2nd Edition, Woodson, W. & Conover, D., 1970

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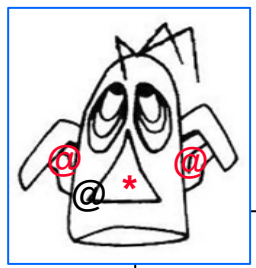

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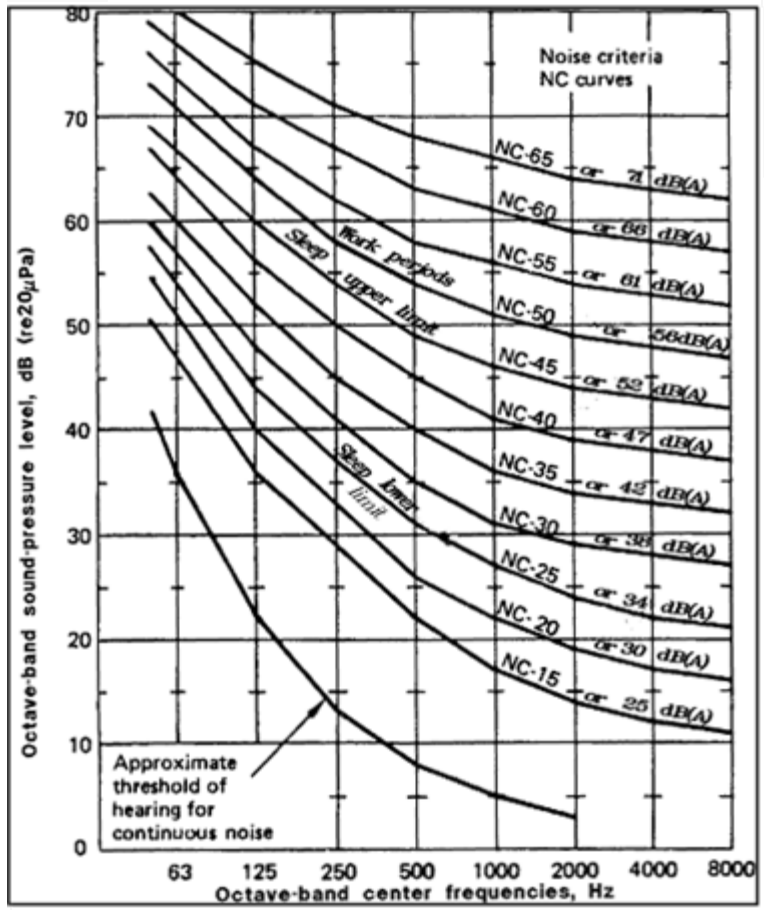
Continuous Noise, Background

- Based upon Apollo acoustic issues, NASA Design Standard 145 was established for manned spacecraft
  - ✓ NC curves used for criteria
  - ✓ NC-50 – "all systems" limit
  - ✓ NC-40 – sleep limit
- Space Shuttle Orbiter
  - ✓ NC-50 recommended at Shuttle SRR
  - ✓ Limits debated. NC-50 considered unnecessarily high and too difficult to meet
  - ✓ NC-55 set as "goal"
  - ✓ NC-55 set as limit late in program
  - ✓ Noise control efforts minimal until very high levels measured pre-delivery
  - ✓ Government Furnished Equipment (GFE) mufflers added in Orbiter prior to delivery (approach described in companion paper on noise control)



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Continuous Noise, Background (continued)

- Space Shuttle Orbiter (continued)
  - Acoustic levels achieved with GFE mufflers is shown in Figure 1 (in green)
  - These levels were adopted as specification limits
  - Limit curve sums to 68 dBA
  - Payload limits set 10 dB below specification limits in all octave bands (sum to 58 dBA)

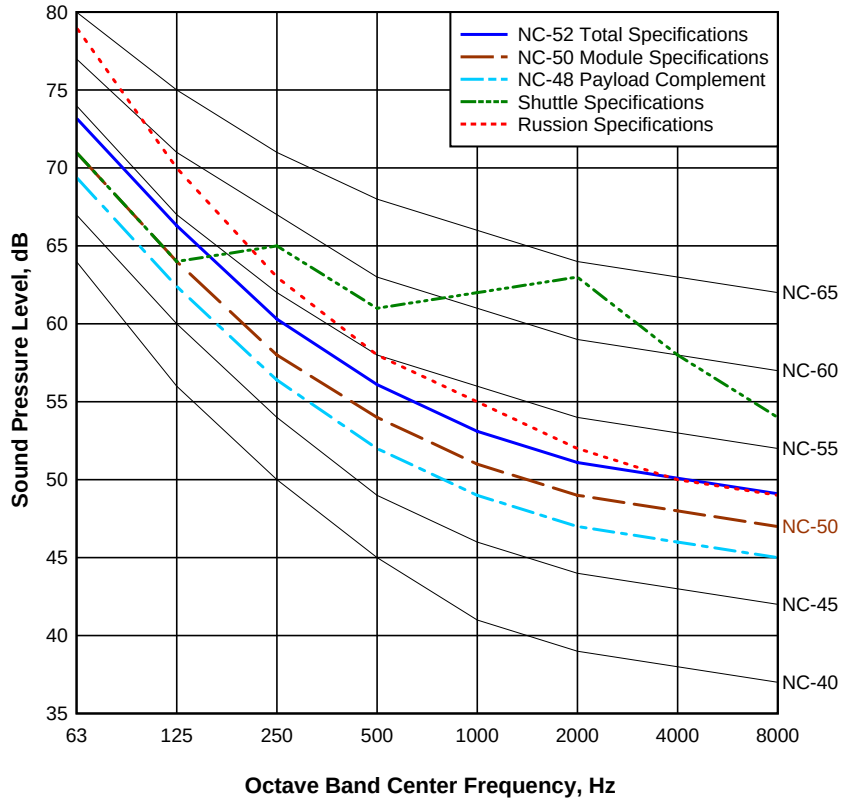

Figure 1. Noise Criteria curves and specifications

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Continuous Noise, Background (continued)

- International Space Station (continued)
  - NC-50 recommended for all systems
  - NC-50 adopted for U.S. segment modules (equivalent to 58 dBA) _ _
  - Russian Segment curve in Fig. 1 (equivalent to 60 dBA) -----
  - Payload complement limit set at NC-48 ----
  - Individual payloads set at NC-40
  - Acoustics has been one of the top habitability issues in ISS

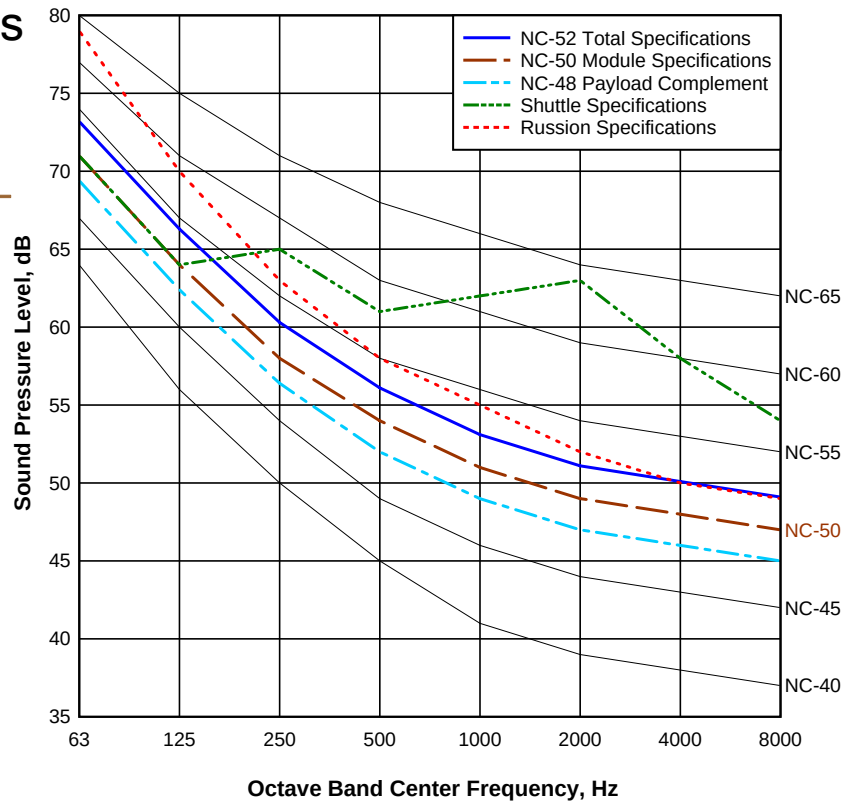

Figure 1. Noise Criteria curves and specifications

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Factors Needed to be Considered in Acoustic Requirements

- Type of mission
- Mission duration
- Number and characteristics of crew occupants
- Size, function, number, and type of hardware systems that make up the crewed vehicle, module, or enclosure, and the supplementary hardware such as payloads and supplementary Government Furnished Equipment (GFE) and their significance relative to the total system noise contributions
- Whether single or dual shift operations will be used
- The distance between crewmembers that is required for good communications and the relative orientation between communicating crewmembers and their work tasks during that time
- The quality of the communications, including the degree of speech intelligibility needed
- Whether shirtsleeves is considered nominal operational condition, with suited operations as required for contingencies or Extra-Vehicular Activity (EVA)
- Crew members should have direct voice communications during continuous noise operations
- Communications headsets or speakers should be compatible with background noise and relied upon for critical mission tasks or communications
- The size and the shape of the interior surface and equipment areas, the surface absorption properties and the reverberation characteristics in the crew compartment
- The operating pressures of the crew compartment and the gaseous composition
- The external environment and the type of vehicle or enclosure external physical support, if planetary

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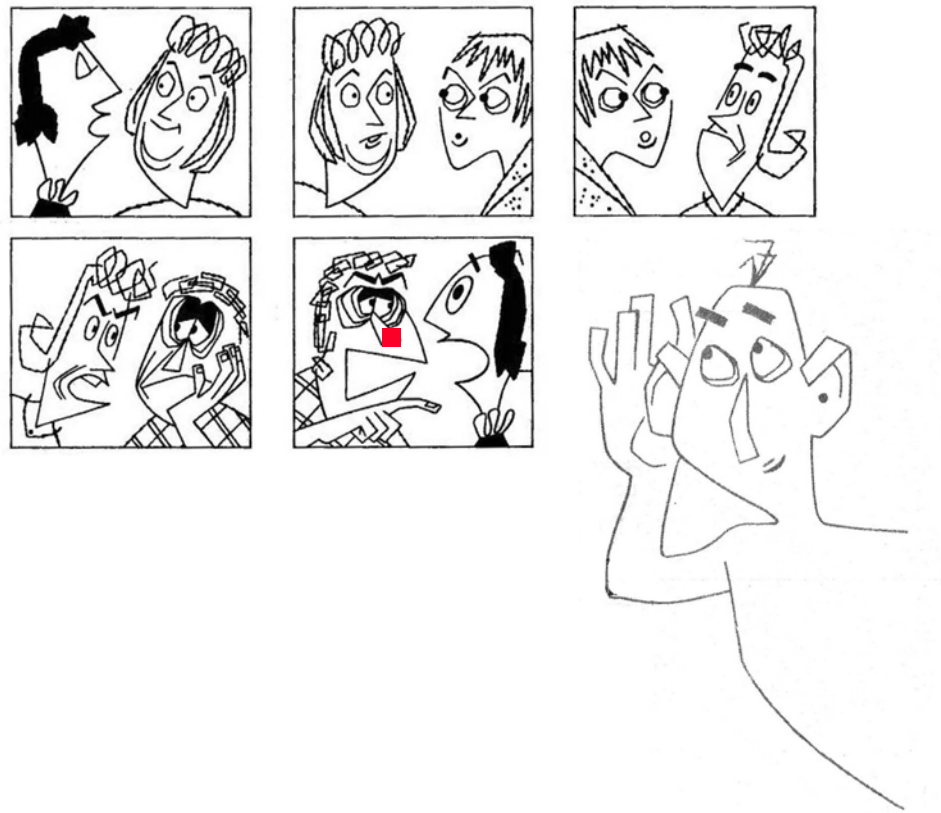
Acoustic Limits Need to Accommodate Good Communications

Normally this involves consideration of the following factors:

- Speech interference level
- Percentage of word & sentence intelligibility
- Signal-to-noise ratio
- Reverberation
- Distance between speaker & listener
- Crew compartment pressures



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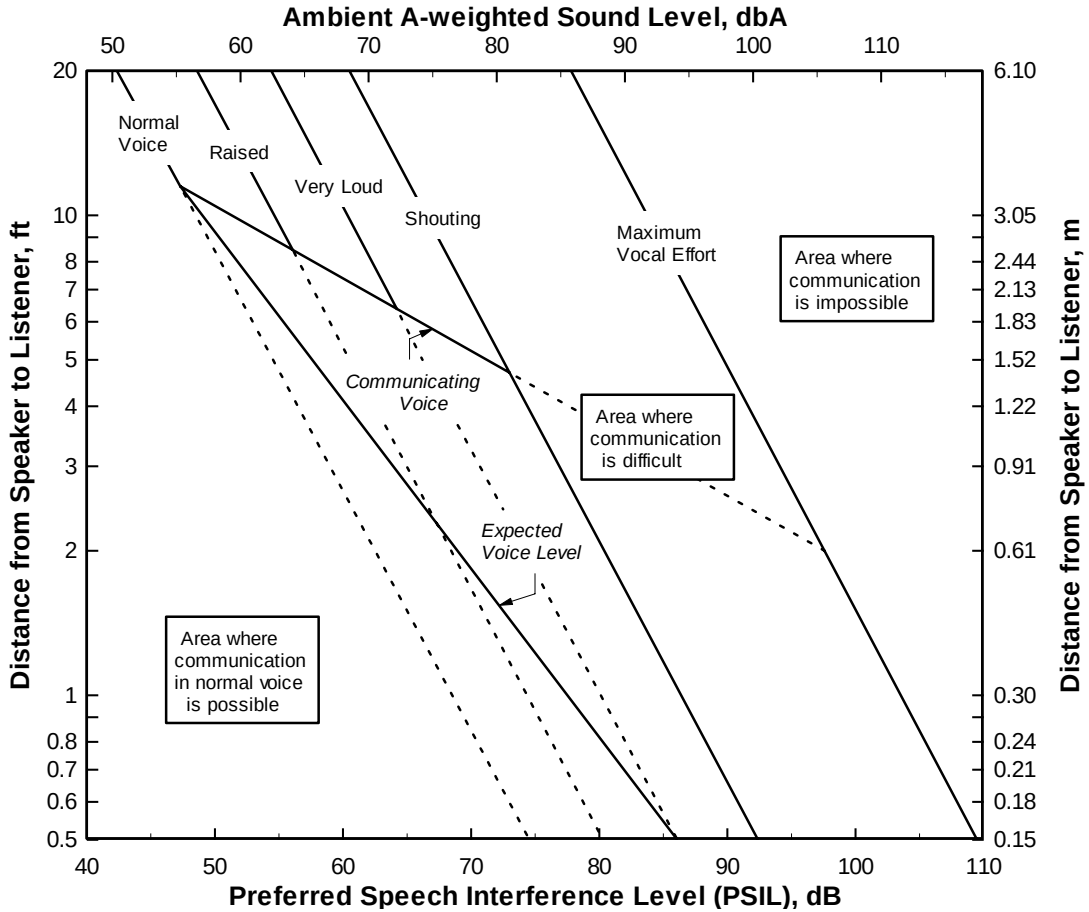
Speech Interference



PSIL= Ave. of 500 Hz + 1 KHz + 2 KHz readings

Figure 2. Effectiveness of voice communications as function of the preferred speech interference level or the dBA noise level and the distance from speaker to listener

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Intelligibility vs. NC Curves

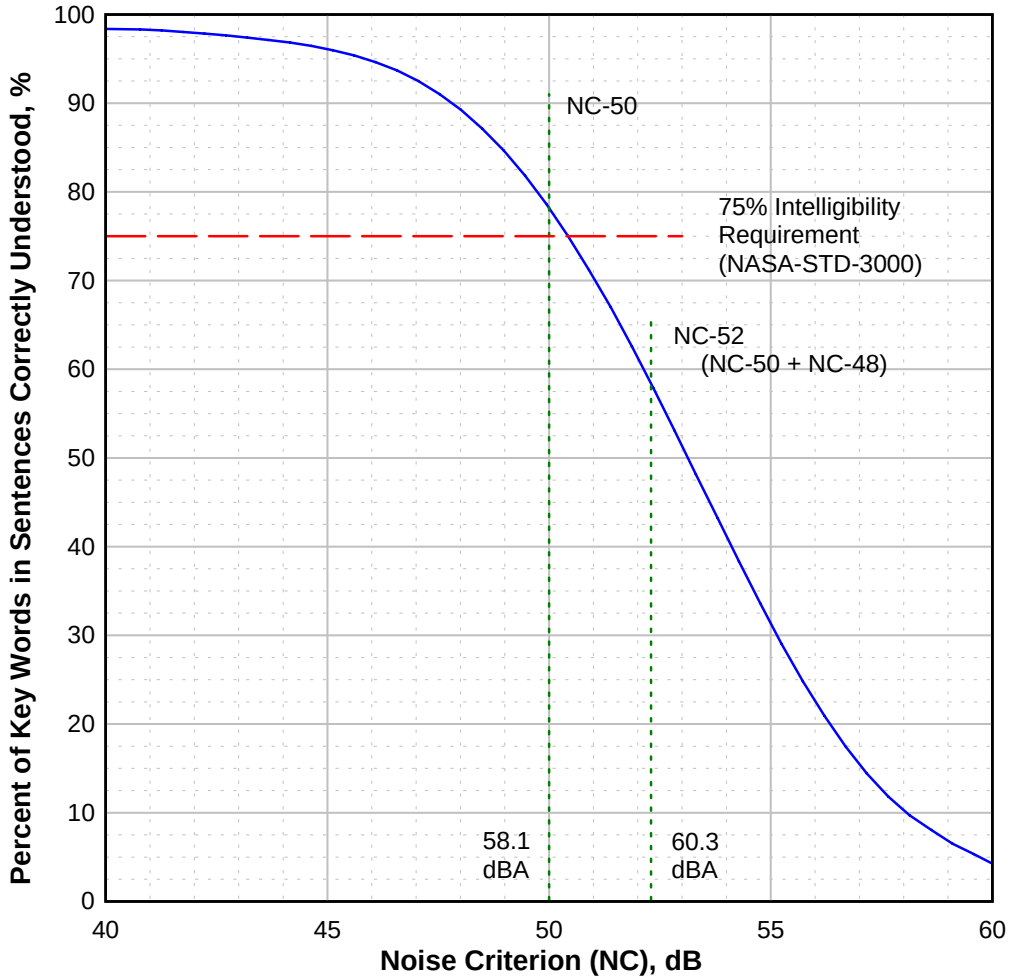

Figure 3. Percent intelligibility level versus the NC criterion for male crew-to-crew communication at distances from five feet to eight feet

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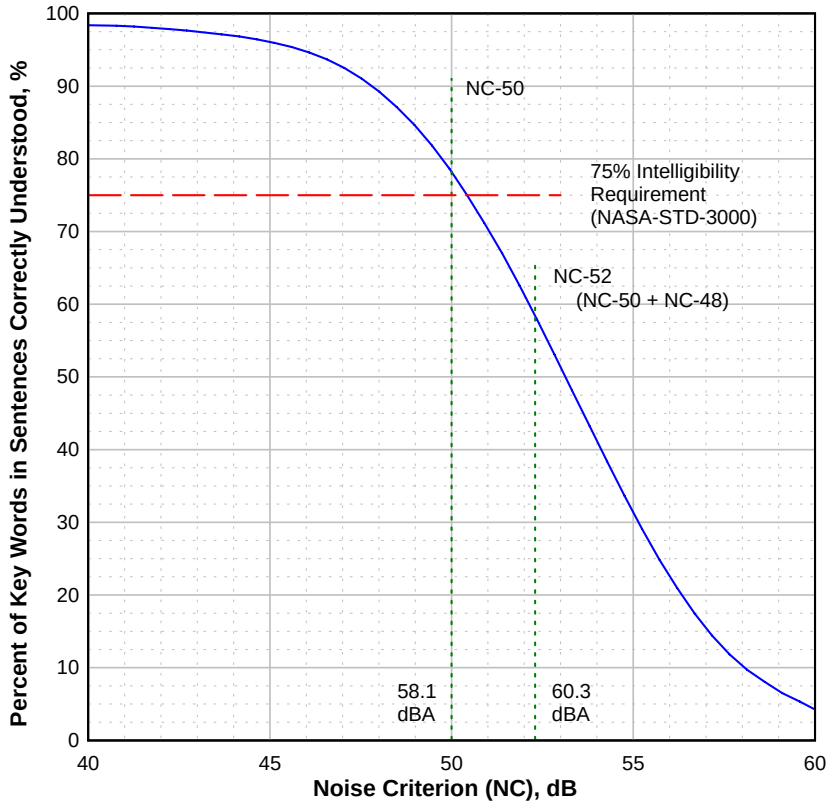
What is the Right Continuous Noise Limits for Communications

Concerns/comments

- Basis for some data is male-to-male communications
- Basis for Speech interference is steady-state noise level ground testing
- Crew compartment communication situations vs. literature
- % intelligibility required
- NC-55 original Shuttle spec. limit per Fig. 3, gives 31% word intelligibility
- ISS's NC50 + NC48, per Fig. 3 gives 58% word intelligibility
- NC-50 per Fig. 3 gives 78%



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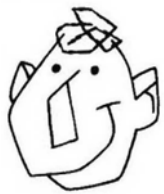
Recommended Extended Continuous NC Limits



-total continuous noise in crew compartments be limited to NC-50. (Sum of all sources). ***NC curves covering requirements are now proposed to be extrapolated to include the 16 kHz octave band, as shown in Fig. 4. This is to better cover the audible range at the higher frequencies.*** ***Limits for each octave band are provided in Tab. 1.***

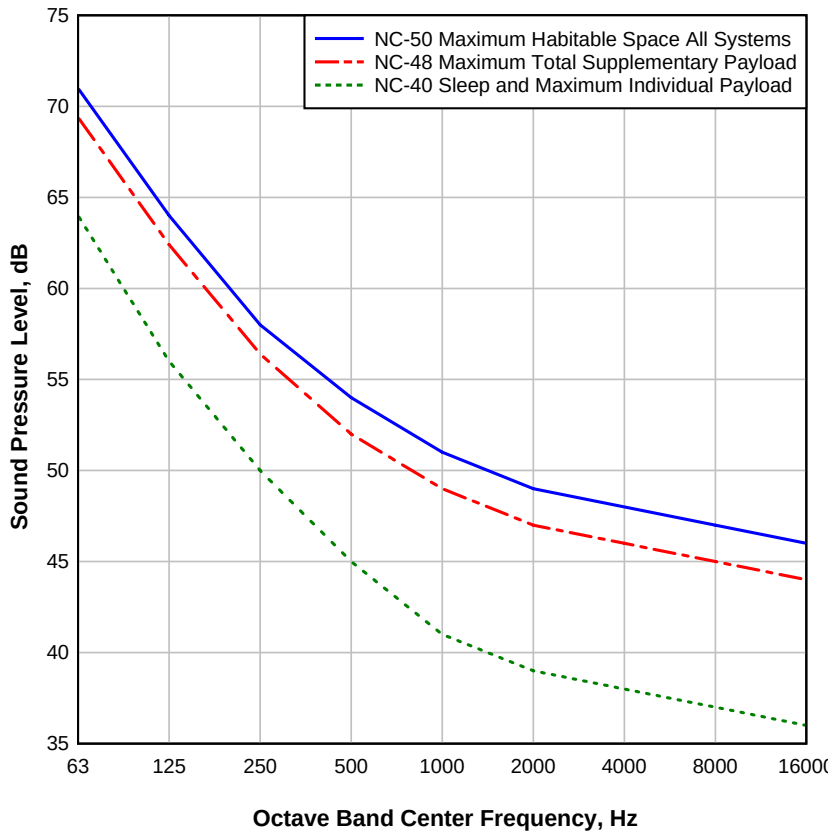


Figure 4

-Other contributors such as payloads & GFE should have sub allocated limits compatible with NC-50 as total, "all systems" limit

Tab. 1

Octave-Band (Hz)	63	125	250	500	1k	2k	4k	8k	16k	NC
Work Areas	71	64	58	54	51	49	48	47	46	50
Sleep Areas Maximum	64	56	50	45	41	39	38	37	36	40
Sleep Areas Minimum	54	44	37	31	27	24	22	21	20	25

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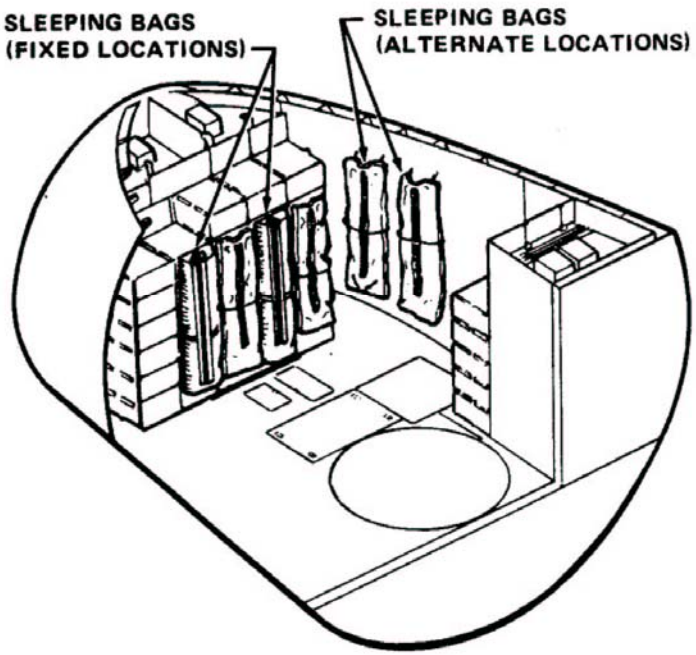
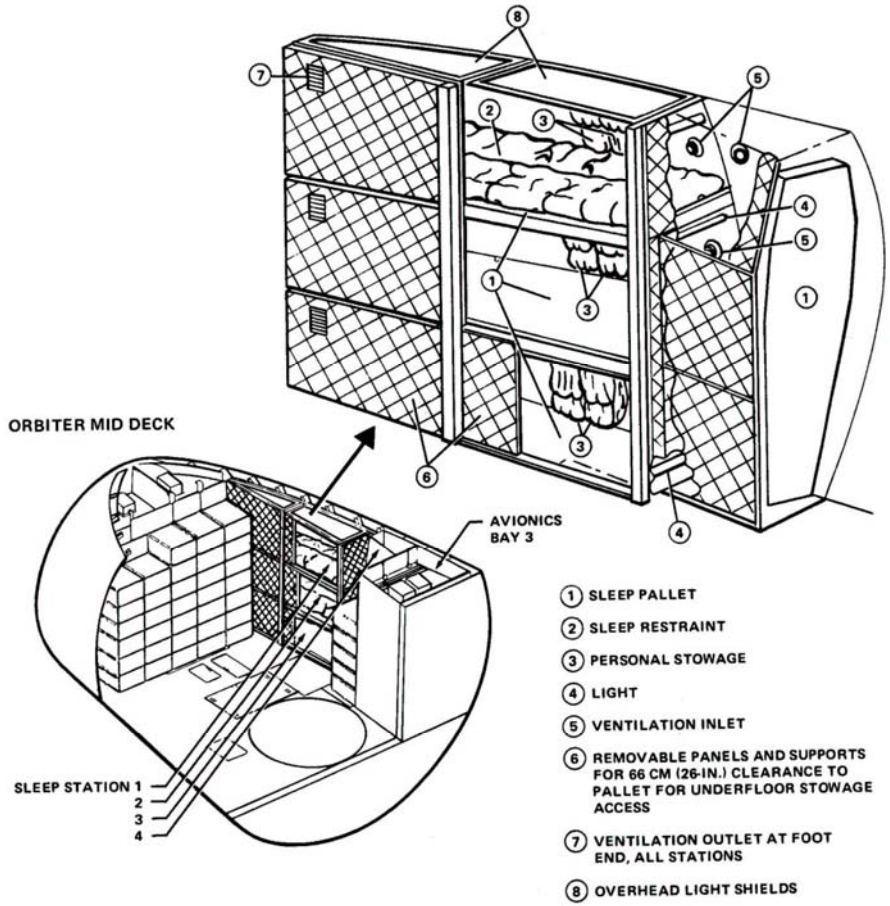
Sleep Limits, Background

Shuttle Sleep Stations

Shuttle Sleeping Bags



Shuttle Bunks(3+1)



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Sleep Limits, Background

Shuttle & ISS Sleep Stations

Shuttle Bunks(4 Horiz.)

ISS TeSS

ISS Kayuta

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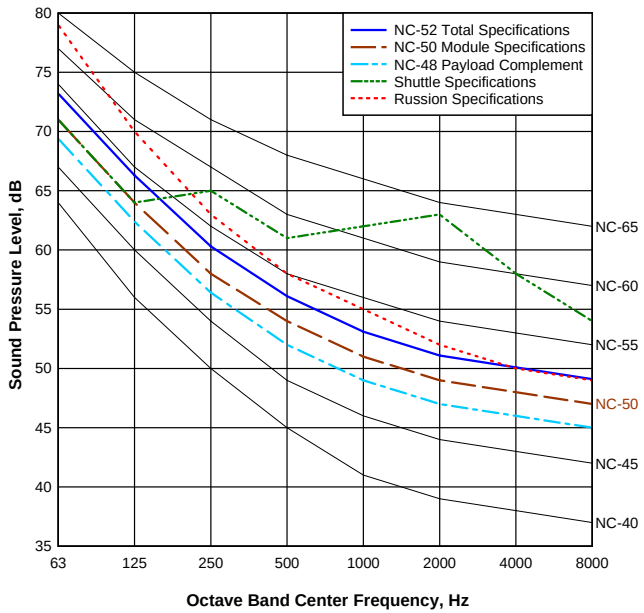
Recommended Sleep Station Limits

- *Where the crew compartment design permits, the crew quarters or other sleeping area should be an accommodation that is separated from areas of work activity, higher noise level sources, and intermittent noise sources. The crew sleeping area should not exceed NC-40, as shown in Fig. 4 and listed in Tab. 1. A minimum noise limit of NC-25 is recommended (Tab.1). The sleep station design should minimize effects of such internal or external bumps or dings to the structure or having a structural borne noise transmitted to it. To preclude any awakening of sleeping crewmembers, impulse or transient noises in the sleeping area should be limited to less than 10 dB above the background noise*



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Recommended Intermittent Limits for Hardware

Supplementary hardware in the ISS is limited in intermittent A-weighted acoustic emissions to the levels and the durations defined in Tab. 2 with measurements taken 0.6 m from the loudest point on the hardware. Use of this table is recommended.

Tab. 2

Maximum Noise Duration (per 24-hours)	A-weighted Overall Sound Pressure Level [dBA]
8 Hours 7 Hours 6 Hours	49 50 51
5 Hours 4.5 Hours 4 Hours	52 53 54
3.5 Hours 3 Hours 2.5 Hours	55 57 58
2 Hours 1.5 Hours 1 Hours	60 62 65
30 Minutes 15 Minutes 5 Minutes	69 72 76
2 Minutes 1 Minute Not Allowed	78 79 80

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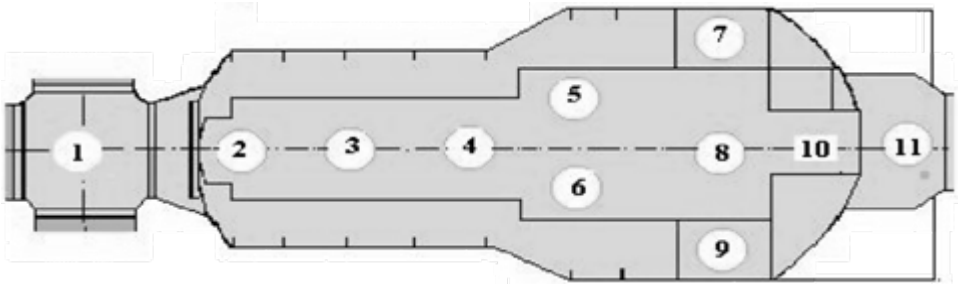
ISS Exercise Equipment in Service Module



Recommend separate isolated areas for exercise, if feasible

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Ultrasonic Limits

Ultrasonic levels in the crew compartment are of concern or exceeds any recommended Threshold Limit Value or TLV as shown in Tab. 3

One-third Octave Band Center Frequency [kHz]	Ceiling Values [dB]	Eight Hour Time-weighted Average [dB]
10	105	89
12.5	105	89
16	105	92
20	105	94
25	110	--
31.5	115	--
40	115	--
50	115	--
63	115	--
80	115	--
100	115	--

Tab. 3

Infrasonic Limits

***Infrasound in the crew compartment or habitat should be limited to less than 150 dB within the frequency range of 1 Hz to 20 Hz* [20].**

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Conclusions

- Need a “good set” of stringent requirements for overall, composite levels and “properly apportioned” individual hardware
- Acoustic requirements need to be treated as “requirements” by hardware suppliers, not “goals” and acoustics accepted as technical discipline
- Acoustics needs to be dealt with/implemented early in development to preclude significant impacts and late dilemma
- Noise control is required to ensure compliance (see companion presentation by Dr. Grosveld, later this session)
- A small experienced team can perform oversight, consult, and work on key problem areas
- Management needs to understand & support acoustic requirements and implementation

FINIS

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