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HUMAN RESPONSE TO VIBROACOUSTIC ENVIRONMENTS OF SPACE VEHICLES

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ABSTRACT

To insure efficient utilization of the system, space station design and operations will require special habitability considerations for the occupants and crew because of the relatively long duration missions. Of particular concern is the environment in which the personnel will live and work, and how it affects both the performance and comfort of the occupants. Current criteria do not consider possible effects of reduced gravity, long duration, and confinement. Preliminary to developing space station vibroacoustic habitability criteria, the adequacy of criteria for other space vehicles has been reviewed. In this paper, responses to the noise and vibration environments of both Skylab and Shuttle are discussed. Some astronauts have reported sleep interference, communication interference, distraction, and general annoyance as noise related complaints. In addition, information from the Russian Salyut missions, as well as similar earth based situations (e.g., submarines), is reviewed.

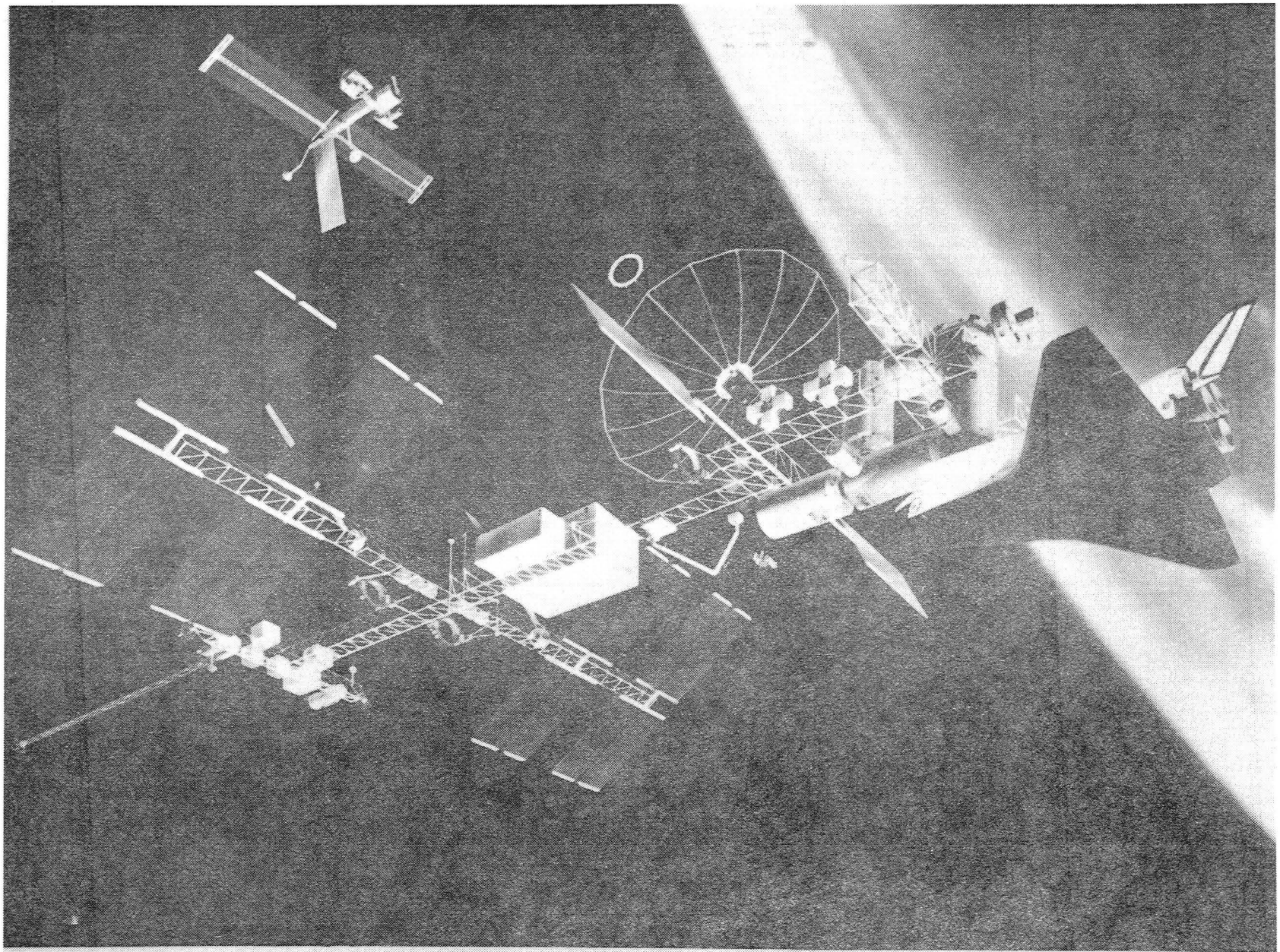


Figure 1.- A space station concept.

INTRODUCTION

The U.S. plans to launch a Space Station in 1992. While the station may not be initially habitable, the existing plans are to have an operational habitat module within three to five years of the first launch. (Shuttle will be used to carry some or all of the modules and the station will be assembled in space). An example of a space station configuration is shown above.

Although the U.S. has had a space station in the 1970's (Skylab), there are several features which will make this one different. Unlike Skylab, the space station will be designed for a long mission life and continuous use during that time with regular changes of crews after various durations. The goal is to have a permanent manned presence in space.

The space station will also differ from Skylab in other ways. Crew size will be larger (up to six or eight people, eventually), and atmospheric pressure will be near normal. Skylab, in comparison, had atmospheric pressure about one-third of that of earth. Often, non-career astronauts will work in the Space Station versus the highly trained astronauts of Skylab. Since the non-career personnel may not be as motivated to overlook or compensate for unpleasant or possibly compromising factors of long duration stays in space, it is expected that habitability issues will receive closer attention in the design of Space Station.

One habitability issue that has been noted in almost all previous space missions has been noise. While not usually loud enough to be harmful to the hearing mechanism, noise during orbit has resulted in some complaints of annoyance, communication interference, and sleep disturbance. The noise is produced by the life support equipment (e.g. fans), avionics, attitude thrusters, and other equipment. Although less of a problem, some vibration can be felt under certain circumstances and may also give rise to complaints. If vibroacoustic (noise and vibration) effects are not considered in the design of Space Station, mission productivity and efficiency likely could be compromised. Results from studies indicate that tolerance of noise and vibration diminishes with increasing mission duration when combined with other factors such as confinement, monotony, and fatigue.

TABLE I.- PREVIOUS SPACE STATION ANALOG STUDIES

PROJECT	CREW SIZE	DURATION	NOISE LEVELS	NOISE COMPLAINTS	COMMENTS
BEN FRANKLIN	6	30 DAYS (650 FT)	60–80dB	12 (6 DAYS)	COMPLAINTS DECREASED WITH DURATION
TEKTITE I II	4 5	60 DAYS (50 FT) 14–30	NOT REPORTED	10	NOISE LEAST ACCEPTABLE FACTOR
GENERAL ELECTRIC	4	30 DAYS	NOT REPORTED	YES	SLEEP DISTURBANCE
MCDONNELL DOUGLAS	4	90 DAYS	69–77dB	YES (BIWEEKLY)	SLEEP COMMUNICATION
SMEAT	3	56 DAYS	50–70dBA	YES	ERGOMETER ANNOYING

PRIOR SPACE STATION ANALOG STUDIES

The above chart summarizes results from several Space Station analog studies. The chart identifies the projects, indicates the crew size and study duration as well as the range of measured noise levels, and the occurrence of noise complaints. The last column under comments provides a summary of the study with respect to noise effects. Each of these studies is reviewed in more detail on the following pages.

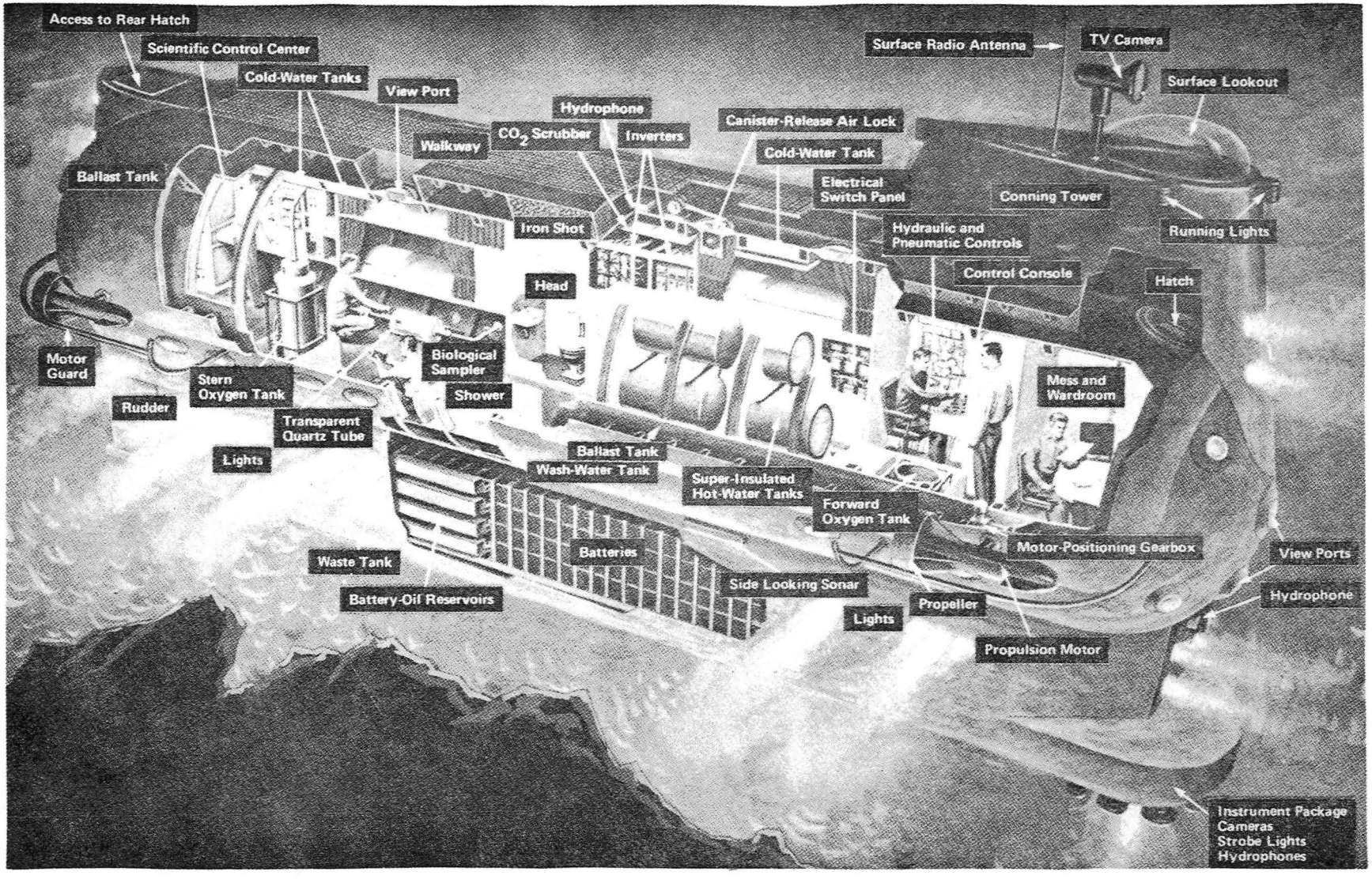


Figure 2.- The Ben Franklin underwater habitat.

BEN FRANKLIN SUBMERSIBLE

The Ben Franklin was a submersible used in a 1969 study (ref. 1) to investigate the underwater habitat as a Space Station analog. The submersible drifted from Florida to Nova Scotia in 30 days at an average depth of 650 ft. with a six-man crew performing oceanographic observations. Noise measurements were recorded every third day in the wardroom, galley, and scientific areas. The noise levels were generally between 60 and 80 dB, and the galley area was slightly noisier then the other two areas. Noise complaints were requested on six different days throughout the mission. A total of twelve complaints were recorded. In addition, one volunteered complaint was observed. The number of complaints peaked during the middle of the mission and then decreased as the mission continued. The complaints were concerned with sleep and relaxation interference due to intermittent equipment noise and with concentration interference when other crew members were moving around the vehicle.

TABLE II.- MEAN ENVIRONMENTAL ASSESSMENT SCORES FROM TEKTITE CREW MEMBERS

KEY N=41
1=POOR
2=FAIR
3=VERY GOOD
4=EXCELLENT
X=NOT APPLICABLE

	SLEEP	FOOD		RECREATION		SOCIAL INTER-ACTION	WORK				HYGIENE		OVER ALL	AVER AGE
		EATING	PREPA-RATION	EXER-CIZE & ACTIVE REC'N	GAMES BOOKS ENTER TAINMENT		SCIENCE INSIDE	MAINTE-NANCE INSIDE	ACCESS TO OUTSIDE	WORK OUTSIDE	WASTE ELIM.	WASHING SHOWER - ING		
IS THERE ENOUGH ROOM?	3.12	2.76	2.46	2.32	2.83	2.80	1.69	2.15	2.51	X	2.61	3.12	2.98	2.62
IS THE LIGHTING OF THE AREA SATISFACTORY?	3.27	3.41	3.20	3.26	3.34	3.16	2.72	3.08	3.08	2.77	3.30	3.32	3.18	3.16
IS THE LOCATION OF THE AREA SATISFACTORY?	3.12	2.98	2.90	2.67	2.89	3.00	1.95	2.31	2.71	3.06	2.79	3.18	X	2.82
IS THE LAYOUT OF THE AREA SATISFACTORY?	3.03	2.78	2.63	2.50	2.77	2.89	1.86	2.07	2.49	X	2.81	2.97	2.87	2.66
IS IT QUIET ENOUGH?	2.22	2.59	2.63	2.38	2.37	2.38	2.20	2.34	2.24	X	2.47	2.62	2.31	2.40
IS THERE A LACK OF ODOR?	3.15	3.00	2.83	3.18	3.19	3.11	2.73	3.14	2.68	X	2.38	2.83	2.90	2.92
IS THE TEMPERATURE SATISFACTORY?	3.48	3.59	3.35	3.37	3.45	3.63	3.37	3.45	3.34	3.56	3.57	3.63	3.59	3.49
IS THE HUMIDITY SATISFACTORY?	3.60	3.66	3.62	3.47	3.57	3.66	3.51	3.61	3.47	X	3.61	3.62	3.68	3.59
IS ENOUGH TIME ALLOWED?	2.80	3.32	3.24	2.86	2.86	3.25	2.88	2.64	3.19	3.26	3.21	3.38	X	3.07
ARE THE TIMES AVAILABLE OK?	3.36	3.24	3.24	3.21	3.00	3.06	3 21	2.84	3.57	3.60	3.37	3.42	X	3.26
IS THERE GOOD SELECTION & VARIETY?	X	2.75	X	2.30	2.67	X	2.48	X	X	X	X	X	X	2.58
HOW DOES THE HIBITAT EFFECT THE ACTIVITY IN GENERAL?	3.16	3.10	2.79	2.47	2.75	2.97	2.32	2.55	3.20	3.46	2.66	3.27	X	2.90
AVERAGE	3.12	3.08	2.95	2.82	2.98	3.07	2.54	2.74	2.91	3.26	2.94	3.18	3.07	2.96

TEKTITE I AND II

The Tektite studies were performed in 1970 as reported in references 2 and 3. The Tektite was a submersible with four compartments, each 12 ft. diameter by 7 ft. high: bridge, environmental control room, crew quarters, and wet lab. In Tektite I, a crew of four marine scientists worked for 60 days at a depth of 50 ft. off the Virgin Islands. Tektite II was at the same location, but 10 crews of five people each rotated for mission durations of 14 to 30 days. Noise levels were not reported. However, results of an environmental assessment form, shown above, filled out by the aquanauts four days before the end of their respective missions revealed that noise was the least acceptable factor. In addition, during debriefing, 10 complaints about noise were recorded. In particular, equipment noise was found to be distracting for several activities including leisure.

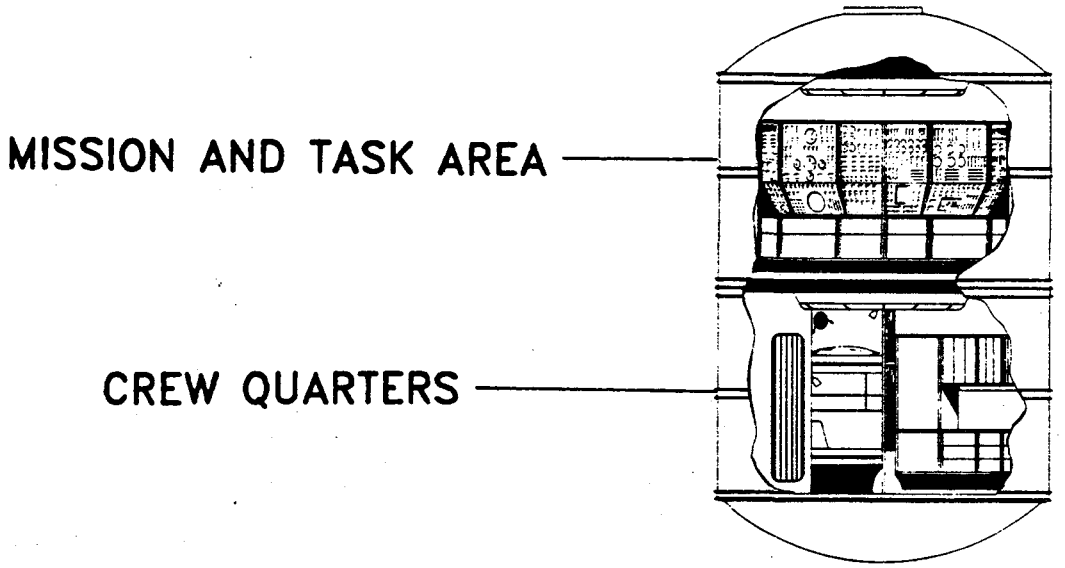


Figure 3.- The General Electric space station simulator.

GENERAL ELECTRIC SIMULATOR

In addition to the underwater studies, there have been at least three major habitability studies using space station simulators. The results of a study by General Electric was reported in 1964 (ref. 4). This study involved the use of a pressurized test chamber (7 psia, 50 percent oxygen and 50 percent nitrogen) in which there were two components each 8 ft. long and 12.5 ft. in diameter. Four men lived in this chamber for 30 days under simulated space mission conditions. No mention was made of noise measurements being conducted during the study, although noise complaints were discussed during a post-test debriefing. The only consistent complaint of the debriefing was related to the lack of good sound insulation in the sleep area. This contributed to sleep loss and thus fatigue.

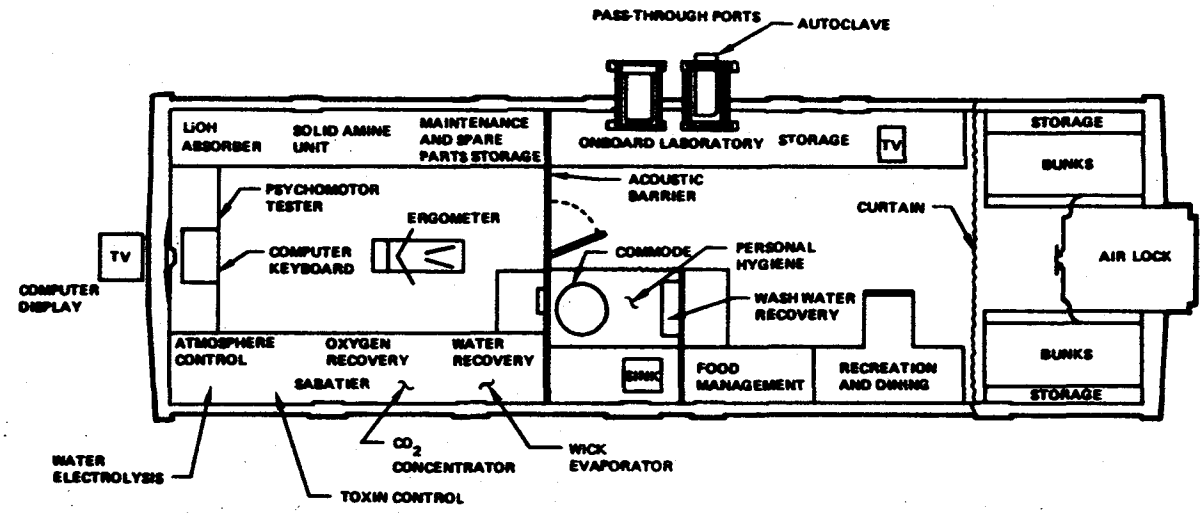


Figure 4.- The McDonnell Douglas space station simulator.

MCDONNELL DOUGLAS SIMULATOR

Another major habitability study was performed in 1970, by the McDonnell Douglas Astronautics Company (ref. 5). Four crew members lived for 90 days in a 12 ft. diameter, 40 ft. long simulator with an oxygen and nitrogen atmosphere at 10 psia. Cabin noise was measured before the test and three times during the test at numerous locations. The sleep quarters had a 69 dB overall sound pressure level, which met criteria requirements of NCA (noise criteria)-50. The crew quarters met criteria for NCA-60 with an overall A-weighted level of 64 dB. The equipment quarters exceeded the NCA-60 requirement with an A-weighted level of 77 dB. For the most part these were acceptable ambient noise levels. However, random crew and equipment sounds were audible above the background levels and were major irritants during sleep. Both habitability questionnaires completed every two weeks, and post-test debriefings, contained comments indicating some communication difficulties among crew members in addition to sleep disturbance. Interestingly, one crew member, rather than adapting to the noise with mission duration, became noise sensitized and annoyed by the noise level as the mission continued.

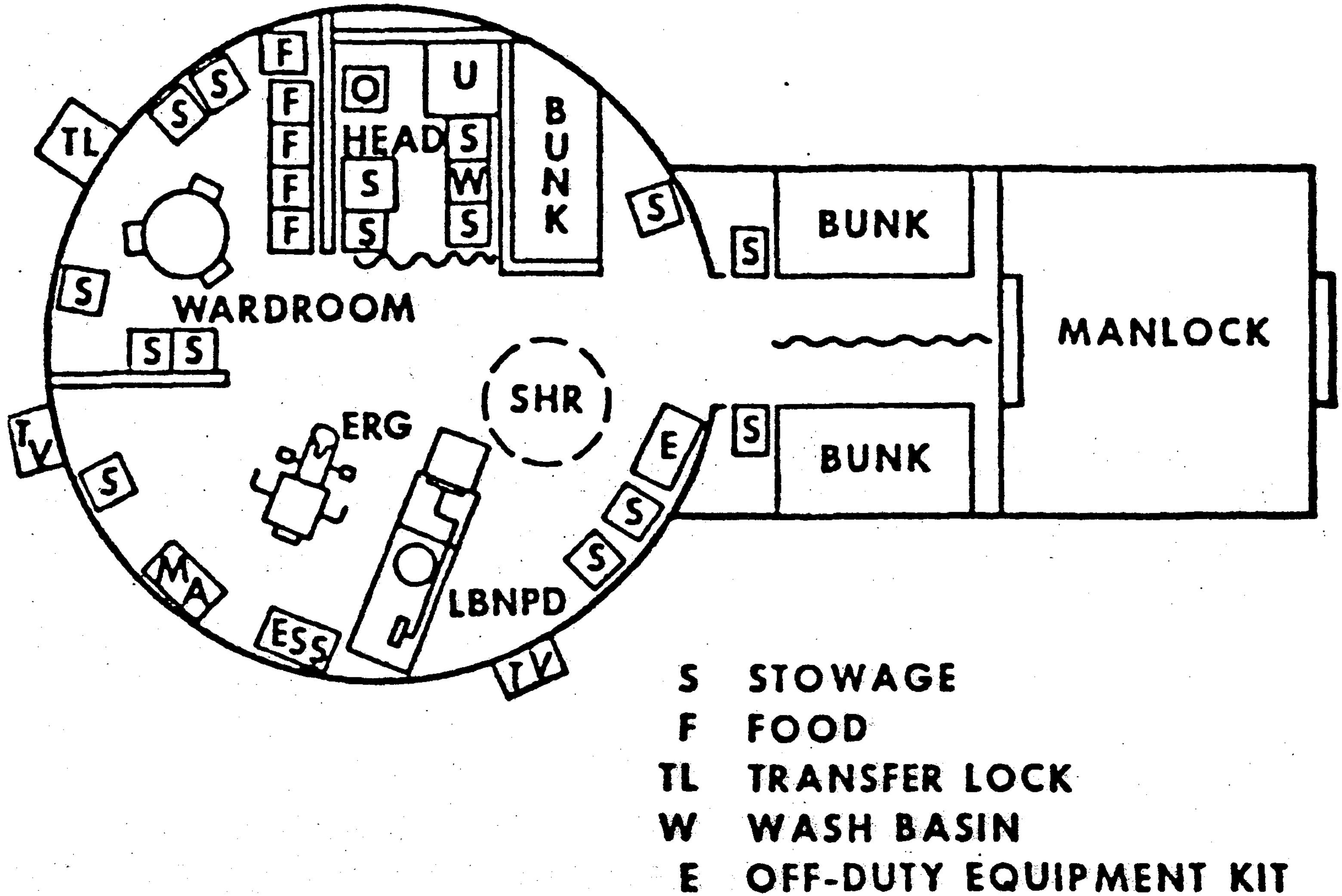


Figure 5.- The Skylab Medical Experiments Altitude Test Chamber.

SKYLAB MEDICAL EXPERIMENTS ALTITUDE TEST

The third major space habitability study, called the Skylab Medical Experiments Altitude Test (SMEAT), was conducted in 1972 (ref. 6). SMEAT was a full scale simulation of a 56-day Skylab mission in a test chamber with an atmosphere of 70 percent oxygen and 30 percent nitrogen at 5 psia. Three men served as crew members in a 20 ft. diameter, two-level chamber. The main chamber contained the living quarters, wardroom, sleep stations, and experiment area. The second level was used for equipment storage and some additional experiments. Noise was measured at six locations several times before the test and nine times during the test. In addition, the noise levels of three particular pieces of equipment were measured two to four times during the test. A questionnaire was completed three times before the test and five times during the test. The results indicated that the noise was predominantly low frequency and was loudest in the wardroom (60-70 dB, A-weighted). The sleep areas were the quietest (50-60 dB, A-weighted), and the ergometer was the loudest and most annoying piece of equipment.

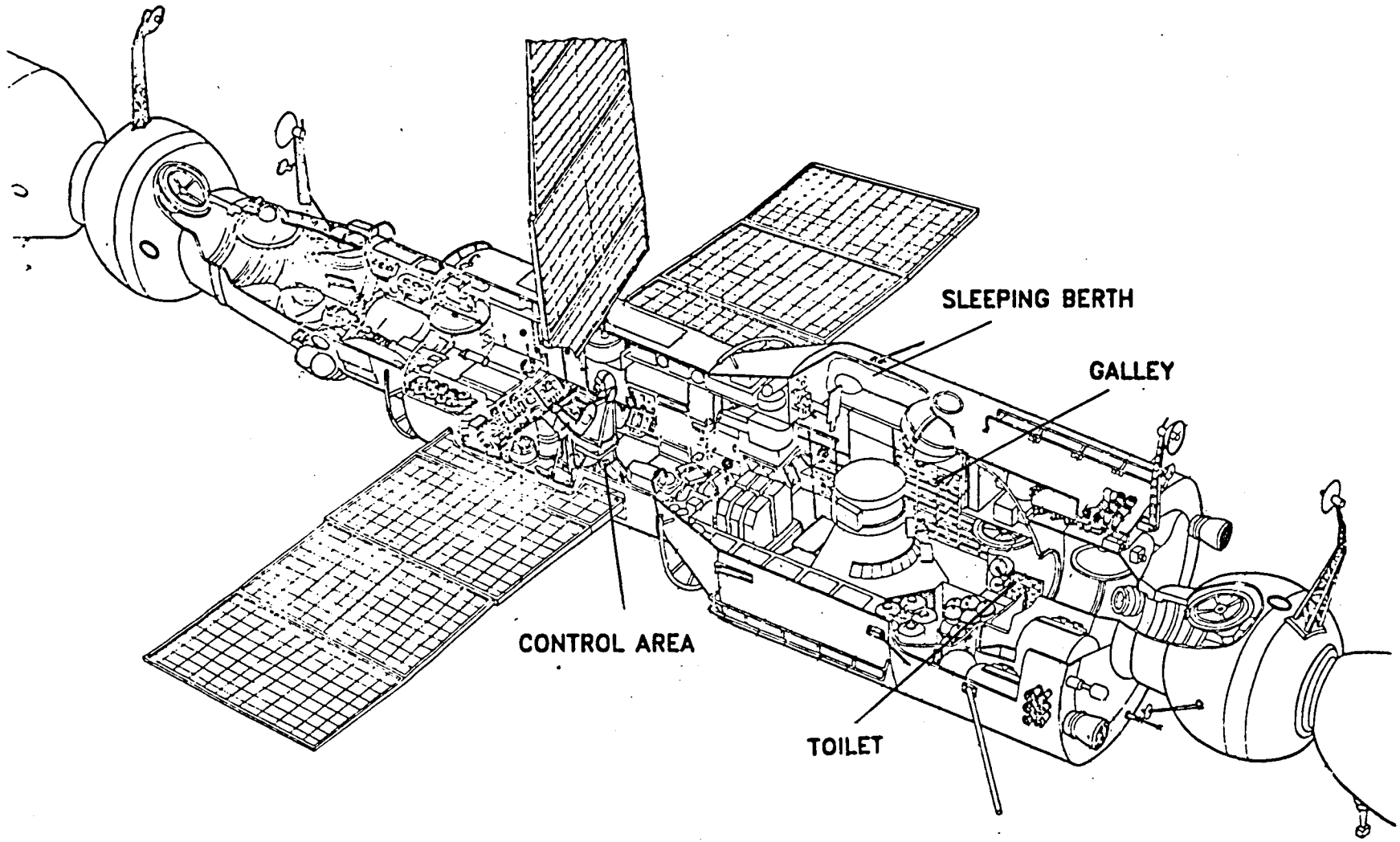


Figure 6.- The Salyut 6 space station.

SALYUT 6

The Russians have also been concerned with the effects of noise on cosmonauts. They, too, have performed chamber tests, although their major focus has been on hearing thresholds. A 1965 habitability chamber study (ref. 7) was conducted in which subjects were exposed to either 60-65 dB or 74-76 dB noise continuously from 8 hours to 60 days. Based on this study, recommendations were made that noise not exceed 60-65 dB for sleeping and resting compartments. The importance of noise characteristics was noted also. Background life support noise was monotonous and irritating. A change in noise characteristics while maintaining the same loudness was suggested.

More recently, noise problems have been experienced in Salyut 5 and 6 (shown above). Although actual noise levels were not reported, reference 8 indicated that they were comparable to permissible levels on earth. However, the unique living conditions in a spacecraft with weightlessness and the continuous montonous aspect were found to be important considerations in determining noise effects. Fatigue and sleep disturbance were found likely to occur after long durations in the presence of such continuous noise at low and moderate intensity. Reference 9 indicated that some noise control retrofit measures on-orbit had been necessary for Salyut 6. Some instruments were muffled and the location of some life support equipment was changed. Interestingly, noise was listed as an important flight factor which helped determine mental state and work capacity of Salyut 6 cosmonauts (ref. 10).

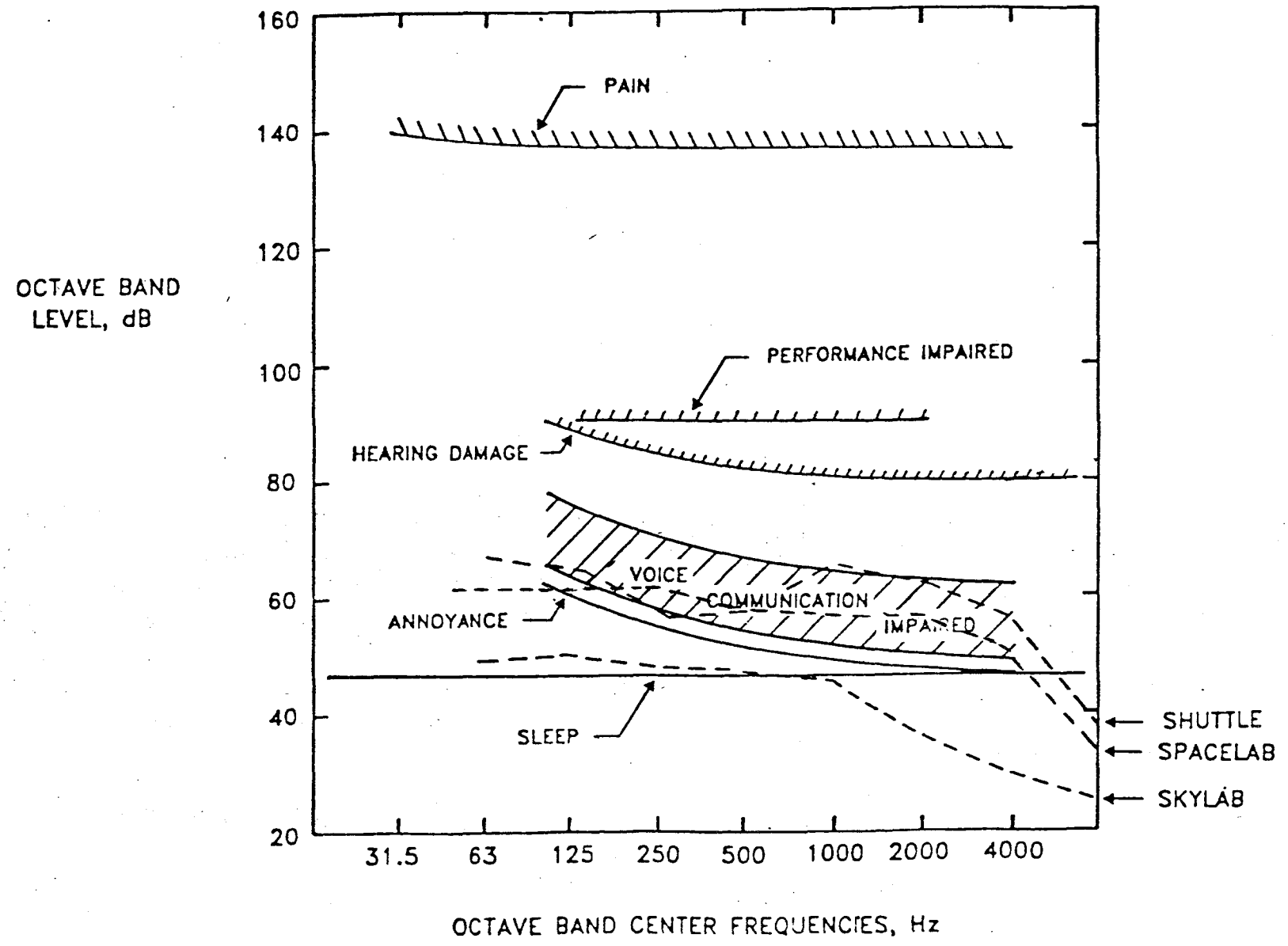


Figure 7.- Examples of U.S. spacecraft noise levels and thresholds for certain noise effects.

NOISE LEVELS WITHIN U.S. SPACECRAFT

In the U.S. space program, noise has been identified as a problem, although usually mior, for almost every mission from Gemini through today's Shuttle flights. The above figure shows a comparison of measured noise levels within Skylab, Shuttle, and Spacelab with various noise threshold curves at which certain objective and subjective events may occur (ref. 11). Although these noise threshold curves are not design criteria, they do indicate the noise levels at which a problem is likely to occur. The spacecraft data in figure 7 indicate that for Skylab some sleep disturbance would be likely. However in both Spacelab and Shuttle, communication interference and annoyance, as well as sleep disturbance would be indicated. In general, these suspected effects did occur within these spacecraft.

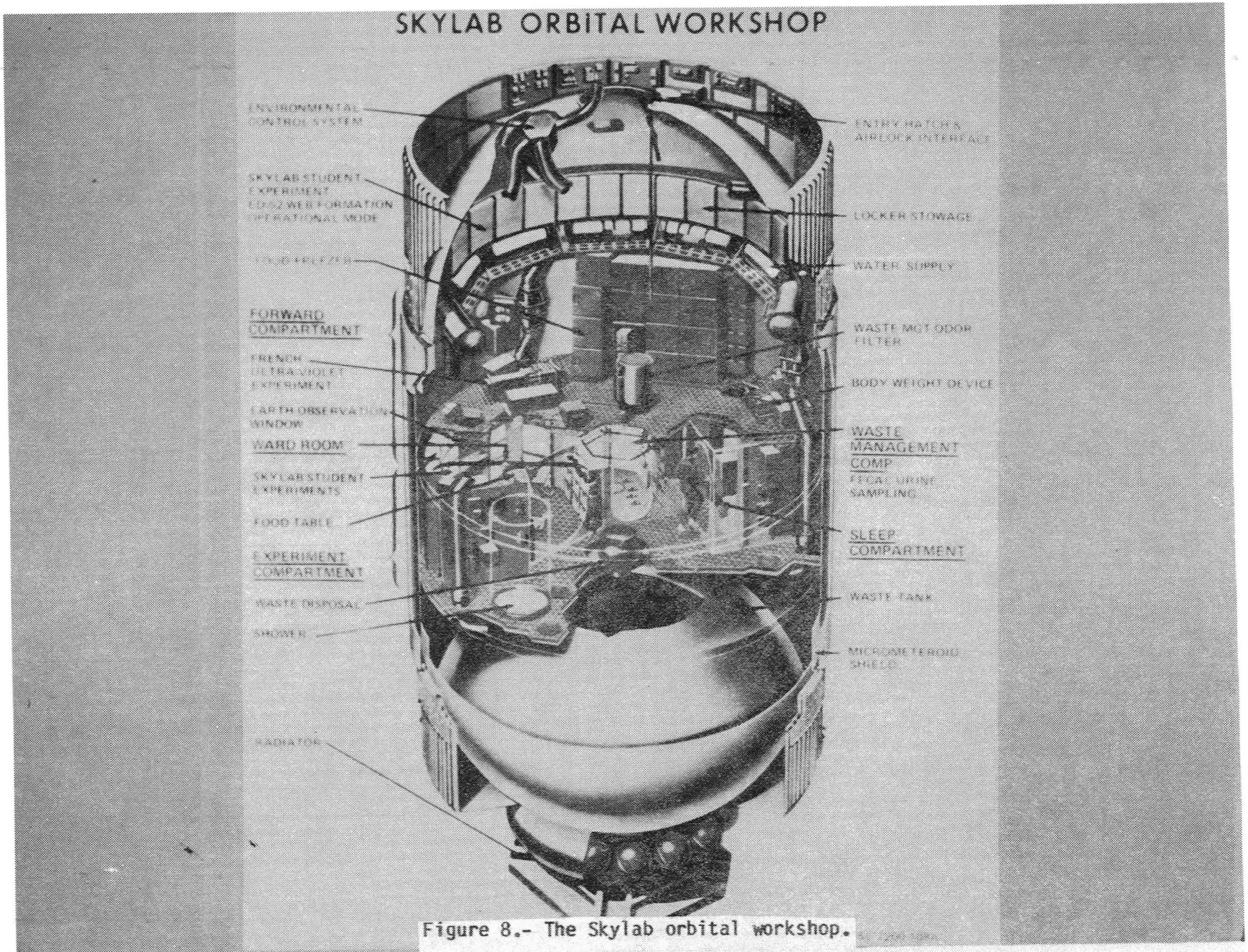


Figure 8.- The Skylab orbital workshop.

SKYLAB

Skylab had three missions of 28, 59, and 84 days, respectively, during 1973. Each mission had a crew of three which lived in the orbital workshop shown above. Noise measurements were made at eight locations during each mission and the resulting measurements were described in references 12 and 13 as generally meeting criteria. Reference 12, presented results of a habitability study of Skylab crew quarters which included noise assessment. The report noted that background noise was low, probably due to the 5 psia atmosphere, and because of this low noise level other intermittment noises disturbed the crew's sleep. Reference 13 also indicated occurrence of some sleep disturbance as well as communication interference both among crew members and with ground control. Shouting was sometimes necessary because voices did not carry and to overcome some interference caused by reverberation of other noises. Pump noise was often cited as an irritant. More comments and complaints were made by the crew of the third and longest mission, suggesting that the ability to cope with noise effects may diminish with mission duration.

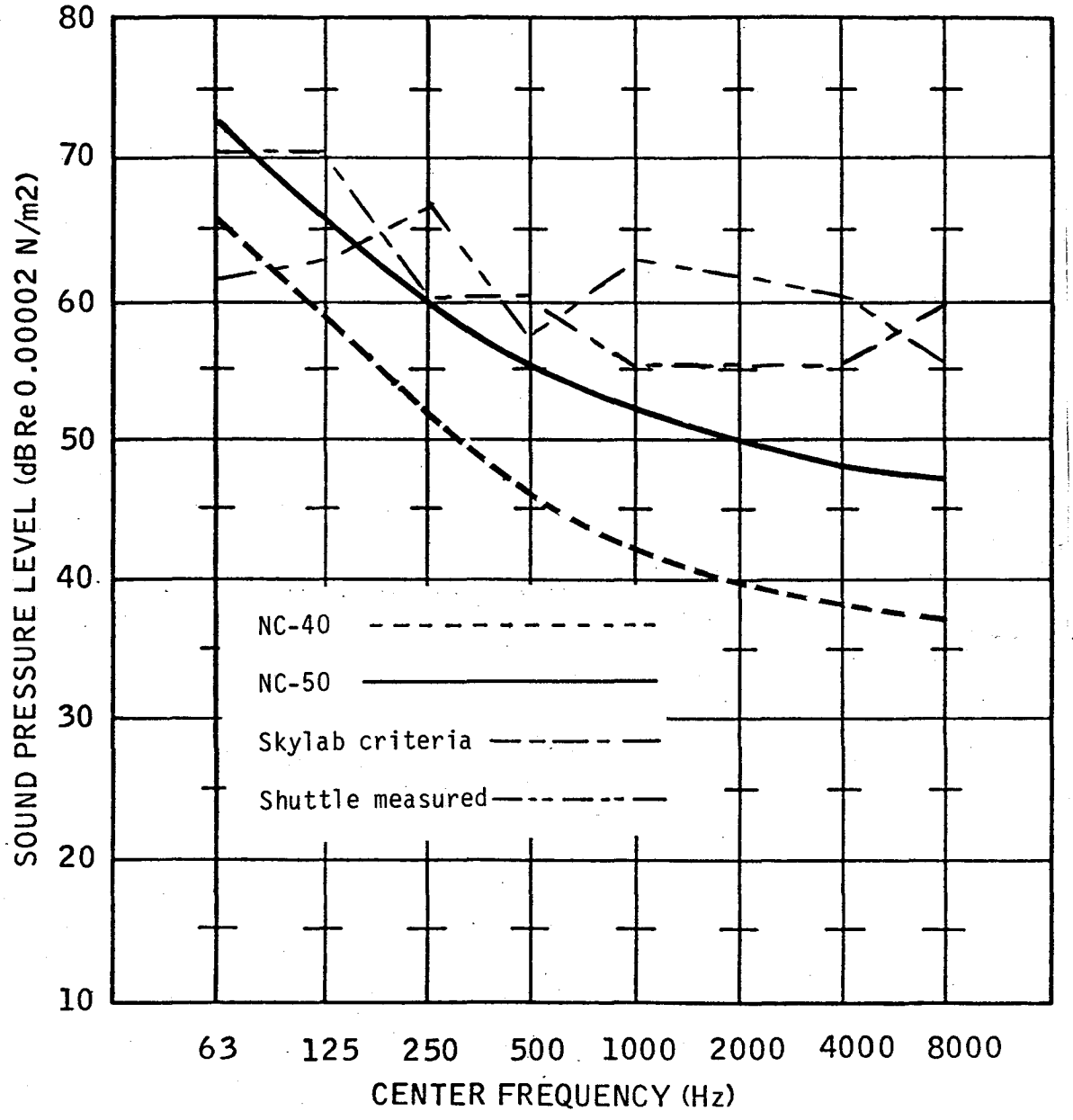
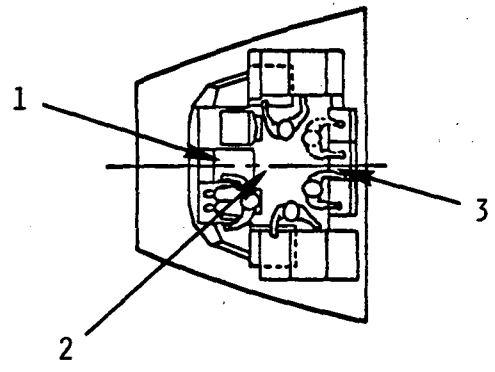


Figure 9.- Measured shuttle noise levels compared to Shuttle and Skylab noise criteria for octave band center frequencies.

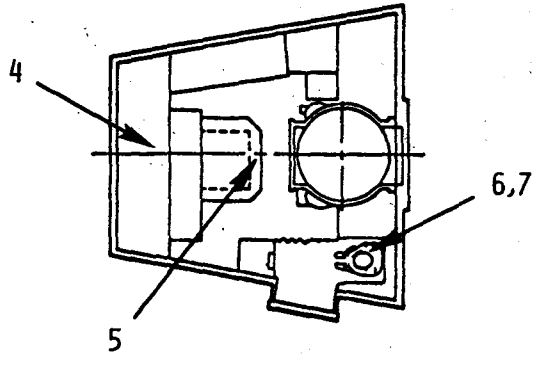
SHUTTLE NOISE CRITERIA

The Shuttle had more stringent noise criteria applied to it as a result of the SMEAT study and re-evaluation of the Skylab criteria (shown in figure 9). Rather than one criteria curve for all habitable areas, two criteria curves were selected for Shuttle. The NC-50 curve was used for work areas while the NC-40 curve was used for sleep areas. (There is no criteria for intermittent noises, only continuous noise.) As shown in figure 9 above, the noise measurements made in the middeck of Shuttle (STS 1) failed to meet the criteria. Noise in the flight deck also exceeded criteria for most frequencies. Noise measurements were also made on other Shuttle missions: STS 2, STS 4, and STS 5. The results were similar to those of STS 1.

FLIGHT DECK



MID DECK



DESIGN STANDARD: NC-50 (L_A = 55 DB)

POSITION	LOCATION	L_A, DB	LEVEL ABOVE STANDARD, DB
1	SEATS (SLEEP)	61	6
2	FLOOR BEHIND SEATS (SLEEP)	64	9
3	BETWEEN AFT WINDOWS	67	12
4	FORWARD AVIONICS BAY, FLOOR LEVEL	80	25
5	CENTER OF DECK	68	13
6	WCS OPERATION, SEAT LEVEL	87	32
7	WCS AIR INLET	75	20
--	VARIOUS AIR INLETS AND OUTLETS	68-77	13-22

Figure 10.- Measured Shuttle (STS 2) noise levels in A-weighted overall sound pressure level for various locations.

MEASURED SHUTTLE NOISE LEVELS

A sample of some of the overall A-weighted noise levels measured at various locations during the orbital flight of STS 2 and the amount those levels exceeded the criteria is given in figure 10. This figure indicates that the measured levels exceed the NC-50 criteria at all locations. The criteria were substantially exceeded at several locations such as positions 4 and 6.

TABLE III.- SHUTTLE ASTRONAUT QUESTIONNAIRE RESPONSES

A. DISTURBANCE BY NOISE

EFFECT	NUMBER OF "YES" RESPONSES	COMMENTS
SLEEP	5	NEED BETTER ISOLATION.
COMMUNICATION (UNAIDED)	7	HAVE TO SHOUT BETWEEN DECKS. WIRELESS UNITS UNDESIRABLE.
WORK CONCENTRATION	3	MORE QUIET WOULD AID CONCENTRATION.
RELAXATION	6	

B. NOISE SOURCES

EQUIPMENT	LOCATION
CABIN FANS	MD, FD
AVIONICS FANS	MD
TELEPRINTER	MD
WMS	MD
TREADMILL	MD
CAMERAS	FD
PUMPS	FD
RCS	--

ASTRONAUT QUESTIONNAIRE RESPONSES

Prior to deriving Space Station noise and vibration habitability criteria, a review of the current criteria used for Shuttle is being conducted. As part of this review, information about the vibroacoustic environment was obtained from several Shuttle astronauts.

Astronauts from three Shuttle missions were contacted either by a mailed questionnaire or by telephone. The most recent missions of at least a 6-day duration were chosen: STS 9/Spacelab 1, STS 11 or STS 41-B, and STS 41-C. Eight astronauts, out of the 16 from these missions, provided responses. In general, some communication and sleep disturbance were reported by several of the astronauts. A summary of part of the data is provided in the accompanying table. The responses were compared to noise level measurements made during orbit at particular locations. The locations at which complaints or minor problems occurred were often in areas which exceeded the Shuttle noise criteria (NC-50 and NC-40).

Concerning application to Space Station, crew members felt that current noise levels might prove unsatisfactory over a longer duration. One crew member said that lower noise levels were "critical" for long duration missions. The effects would most likely be evident in communication and sleep interference which could lead to fatigue and compromised performance. Some felt better facilities for sleep should be provided with more isolation. This would be especially important in the multiple workshift operation mode. Changes in noise level as well as the high continuous background noise level were particularly disturbing.

A summary of the major findings from all the astronaut responses are listed below.

1. Although not a large problem, noise effects have been found in Shuttle flights.
2. The effects were largely communication and sleep interference.
3. Several noise sources were identified, with the primary sources being the equipment and life support air circulation fans in the cabin.
4. Vibration is not a significant problem in the Shuttle.
5. Lower background noise levels were desired for longer duration and multiple workshift operations such as those for Space Station.

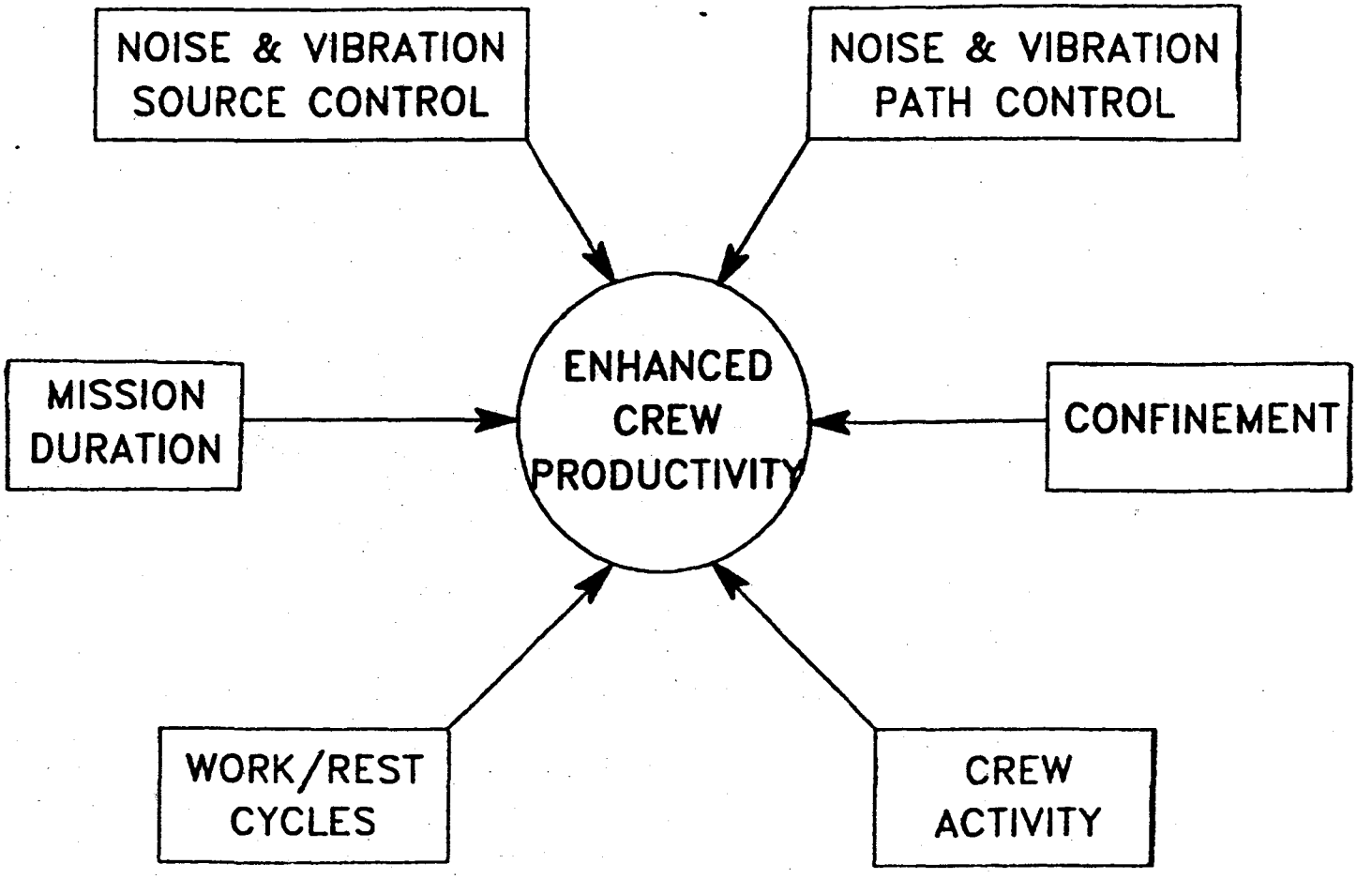


Figure 11.- Possible strategies for meeting vibroacoustic criteria.

POSSIBLE STRATEGIES FOR MEETING CRITERIA

The appropriate vibroacoustic criteria in terms of level can be met by various source and path control measures. Alternatively, the exposure to uncontrollable levels could be limited. That is, instead of requiring that one or two criteria curves be applied to all areas of Space Station, the exposure limits may be guided by the crew's activities. Some activities may require lower noise levels than others. For example, sleep and difficult fine motor tasks would probably require lower levels than other activities. However, the effects of vibroacoustics on communication, hearing, sleep, performance, and comfort must all be considered. Regardless of the form of the criteria, the effects of confinement and time in terms of mission duration, and even weightlessness, must be included. The appropriate vibroacoustic environment should act to enhance crew productivity.

SUMMARY

To insure efficient utilization of the system, space station design and operations will require special habitability considerations for the occupants and crew because of the relatively long duration missions. Of particular concern is the environment in which the personnel will live and work, and how this environment will affect both the performance and comfort of the occupants. It was pointed out that current criteria do not consider the potential effects of reduced gravity long duration, and confinement. This paper has reviewed and discussed existing noise criteria as applied to space vehicle interior noise environments measured in other orbital vehicles as well as ground-based simulators. This review included information from the Russian Salyut missions. In addition, astronaut responses to Skylab and Shuttle vibroacoustic environments were discussed. It was concluded that Space Station habitability criteria should be developed and should account for the effects of noise and vibration on performance, comfort, communication, sleep, and hearing. Alternative strategies for meeting these criteria were discussed. The payoff to the development of appropriate criteria and control strategies would be the enhancement of crew performance and productivity.

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16. Abstract

To insure efficient utilization of the system, space station design and operations will require special habitability considerations for the occupants and crew because of the relatively long duration missions. Of particular concern is the environment in which the personnel will live and work, and how it affects both the performance and comfort of the occupants. Current criteria do not consider possible effects of reduced gravity, long duration, and confinement. Preliminary to developing space station vibroacoustic habitability criteria, the adequacy of criteria for other space vehicles has been reviewed. In this paper, responses to the noise and vibration environments of both Skylab and Shuttle are discussed. Some astronauts have reported sleep interference, communication interference, distraction, and general annoyance as noise related complaints. In addition, information from the Russian Salyut missions, as well as similar earth based situations (e.g., submarines), is reviewed.

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