

NASA Technical Memorandum 81975

(NASA-TM-81975) ACOUSTIC FACILITIES FOR
HUMAN FACTORS RESEARCH AT NASA LANGLEY
RESEARCH CENTER: DESCRIPTION AND
OPERATIONAL CAPABILITIES (NASA) 15 p
HC A02/MF A01

N81-25765

Unclas
25906

CSCI 20A G3/71

Acoustic Facilities for
Human Factors Research at
NASA Langley Research Center
Description and Operational Capabilities

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JUNE 1981



NASA

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National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1981

INTRODUCTION

Over the last 15 years, a number of facilities have been developed at NASA Langley Research Center for aircraft noise research related to the physics of acoustics and noise reduction as well as to the effects of noise on humans. These facilities provide capabilities for

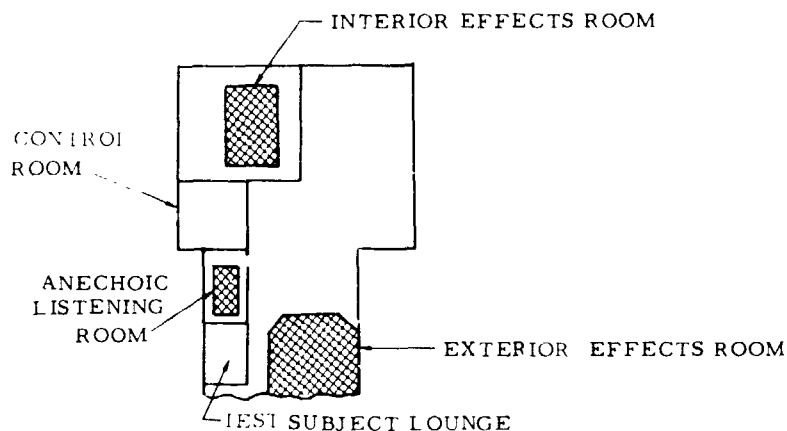
1. Studying generation, propagation, and control of noise associated with jet mixing regions and wakes and with interactions between aerodynamic flows and wings, flaps, struts, cavities, and rotating blades
2. Measuring and processing a wide variety of acoustics, vibration, and fluid dynamics data
3. Studying psychoacoustics and ride quality phenomena

In this document information is compiled about those facilities, devices, and items of special equipment which provide a unique test capability for psychoacoustics and related human factors research. The following are described: the exterior effects room, interior effects room, anechoic listening room, and aircraft noise synthesis system in the Langley Aircraft Noise Reduction Laboratory and the passenger ride quality apparatus. Each is designed to study the reactions of people to certain real-life situations. Design philosophy, physical layouts, dimensions, construction features, operating capabilities, recent calibrations, and example research applications are included. The intent is to indicate research potential rather than to provide detailed operating instructions.

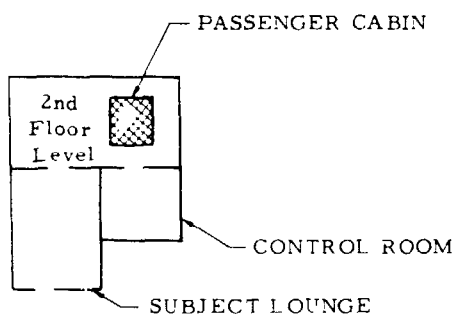
In some cases, the manufacturers' names and model numbers of current equipment are given to more clearly indicate the operational ranges and capabilities of the systems. This is not to be interpreted as an endorsement by NASA of a particular product, since in many cases equivalent equipment items are available and would probably produce equivalent results. Improvements will probably be made in the future as new equipment becomes available.

GENERAL LAYOUT AND DESIGN

The exterior effects room, the interior effects room, and the anechoic listening room are designed for psychoacoustics research to evaluate annoyance of humans due to noise and noise-induced vibrations. They are located in the human factors wing of the Langley Aircraft Noise Reduction Laboratory (ANRL), Building 1208 (see fig. 1(a)), along with a control room and a lounge. The lounge serves as a briefing and debriefing room for the test subjects. From the control room, recorded or synthesized flyover noise can be input to the



(a) Psychoacoustics test area in building 1208.



(b) Passenger ride quality apparatus in building 1293B.

Figure 1.- General layout of facilities.

test areas, test subjects can be monitored, the test program can be controlled (in real time), and data can be acquired. The control room equipment is designed for maximum flexibility to allow amplifiers, tape recorders, computer control systems, closed circuit TV monitors, and test signal patch panels to be used for tests in any of the above test areas. For all test areas, there is access to data processing and analysis equipment including a COPE terminal, a DEC PDP 11/70 computer, a Spectral Dynamics 360 digital signal processor, a Nicolet Model 660A dual-channel fast Fourier transform analyzer, multichannel analog-to-digital and digital-to-analog converters, one-third-octave-band and narrow-band analyzers, and selectable high- and low-pass filters.

The human factors portion of the Aircraft Noise Reduction Laboratory is constructed on piling systems separate from those of the physical acoustics portion and is isolated structurally by means of a vibration break. Special provisions are made for controlling environmental noise from air-conditioning systems and other sources. For instance, individual air handling units are provided in the air-conditioning system which is designed for low system noise, and vibration isolation and double wall construction are provided to isolate noise from card punches and other computer equipment.

The passenger ride quality apparatus is located in the Langley Structural Dynamics Research Laboratory (Bldg. 1293B). Hydraulic actuator systems and a reaction mass are located on the first floor, and a control room, subject briefing lounge, and simulated passenger cabin are located on the second floor (see fig. 1(b)). Test signals are played from tape recordings to represent noise and vibration situations inside various transportation vehicles. Limited data analysis equipment is available in the adjacent control room. Because of the nature of the equipment and test procedures, no special building noise control features or procedures are required.

In all human factors test areas, hazards to the human subjects have been either eliminated or reduced to acceptable levels. Each speaker system is double fused to limit the overall noise exposure of the subjects to a maximum level of 95 dB(A) as a precaution against damage to hearing and to the speaker equipment. Shaker systems are limited to accelerations of $\pm 0.5g$.

The number of subjects who can participate in a given test varies from facility to facility. One or two can be accommodated in the anechoic listening room, four to six in the passenger ride quality apparatus, and up to eight in the interior and exterior effects rooms. The exterior effects room has a greater seating capacity, but as a practical matter the number is limited to eight to simplify transportation of test subjects.

DETAILS OF DESIGN AND OPERATION

Exterior Effects Room

The exterior effects room (EER) is a test area in which subjects are exposed to the types of noises that would be experienced outdoors where aircraft speed, altitude, flight direction, and lateral position can influence the character of the observed noise signatures. A group of subjects can be tested together as a panel, or jury (see fig. 2). While listening or performing a group activity, this panel rates test noises on absolute scales or as paired comparisons. Example research programs along with experimental designs and test protocols are given in references 1 to 3.

The test noises are presented through a system of loudspeakers in the ceiling and walls. Six are distributed over the ceiling and an additional four are located in the walls near the corners of the room. By properly phasing the signals to the speakers, the noise signatures can represent an aircraft flying in a particular direction and at a particular altitude and offset distance, either with or without neighborhood background noise superposed. The loudspeakers, which are Altec 604E models, have a continuous power rating of 50 watts and a usable frequency range from 20 Hz to 20 000 Hz. All loudspeaker channels are powered by Altec 9440A 200-watt amplifiers.

The variability of the observed signals at various locations in the room is shown in figure 3. Data are given in one-third-octave-band format for a pink noise input to the speaker system with the speakers adjusted individually to generate the same sound pressure level at a central location. The range of

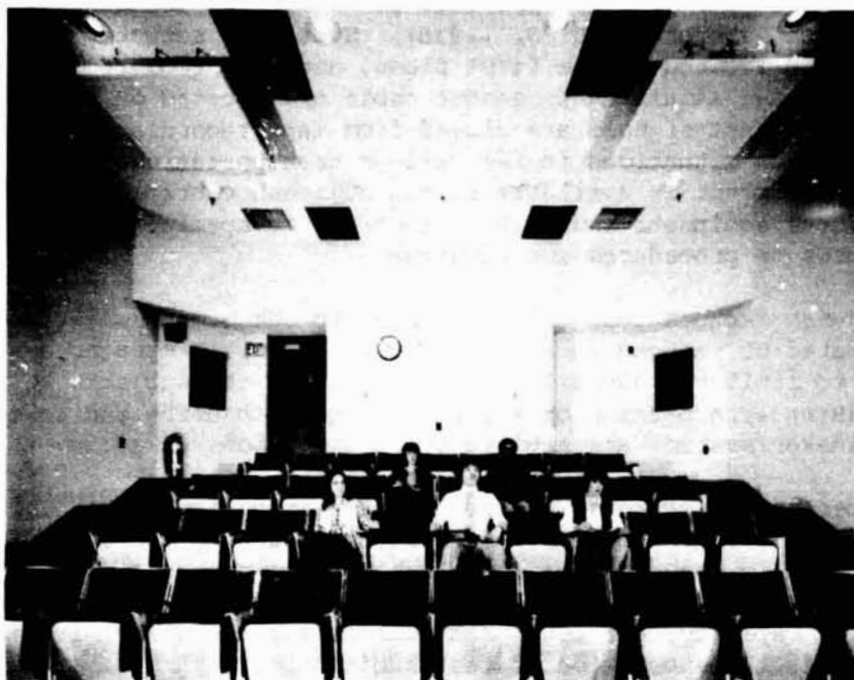


Figure 2.- Exterior effects room. L-81-2908

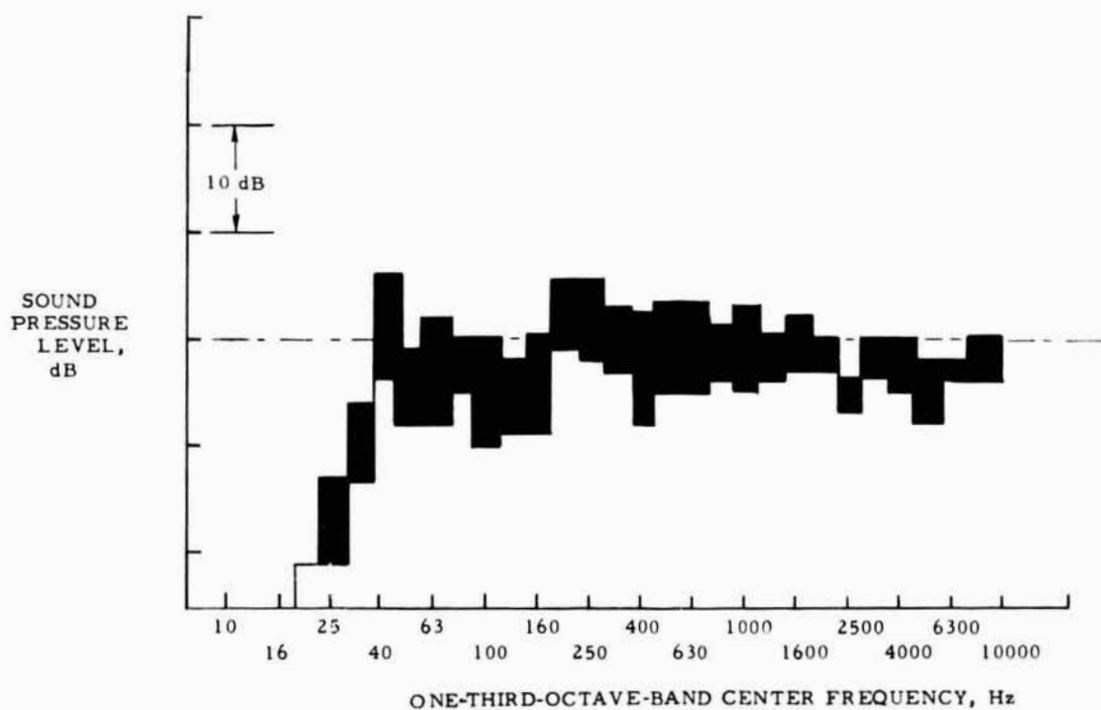


Figure 3.- Ranges of measured one-third-octave-band levels at observer locations in the exterior effects room.

levels for each one-third-octave band represents the variability at 10 widely spaced locations near the center of the room. Maximum variations of ± 5 dB are observed in individual one-third-octave-band levels. More uniform exposures over small areas are achieved by means of equalization techniques.

Dimensions of the test area are nominally $4.2 \times 8.5 \text{ m} \times 9 \text{ m}$ and its volume is about 320 m^3 . Ceilings and floor are of reinforced concrete and walls are double-plastered 8-inch cinder block with specially designed acoustic doors. A nominal transmission loss for the walls of 40 dB is provided to minimize possible disturbances to testing within the room due to activities outside and vice versa. A representative ambient noise level is 35 dB(A) in the test area, the bulk of the acoustic energy being at frequencies below 75 Hz.

Acoustical absorptive treatment of the interior surfaces is concentrated on the walls which have a perforated vinyl septum covering 5-cm-thick fiberglass blankets with 5 cm of backup air space. Some absorption is also provided by the cushioned carpeting and by the 39 upholstered chairs. The ceiling is smooth cement plaster on expanded metal lath. It is suspended from the reinforced concrete structure on a metal suspension system. The resulting reverberation times vary from about 0.50 seconds at the lower frequencies to about 0.20 seconds at the higher frequencies. For the audible frequency range above 250 Hz, the reverberation times do not exceed 0.30 seconds.

Interior Effects Room

The interior effects room (IER) is a test area in which subjects are exposed to the types of noises and noise-induced vibrations that would be experienced inside a building. The orientation and distance from the sources, as well as the characteristics of the structure itself, can influence the character of the observed signatures. Human subjects can be tested individually or as a group to subjectively evaluate noises, vibrations, or a combination of noises and vibrations. Example experimental designs and test protocols are given in reference 4.

The interior dimensions of the IER are about $2.4 \text{ m} \times 3.5 \text{ m} \times 4.9 \text{ m}$ (41 m^3). It was constructed of common building materials to represent conventional house construction regarding the sizes and spacings of framing members, wall sheathing, and interior finish. The IER is similar in size, furnishings, and appearance to the living room of a house (see fig. 4). Relative transmission losses are similar to the average values indicated in reference 5 for various types of home construction. Values vary from about 15 dB at 100 Hz to 25 dB at 8000 Hz.

The IER has a separate air handling unit and is contained within a large outer room, $3.7 \text{ m} \times 7.1 \text{ m} \times 8.3 \text{ m}$. The outer room provides isolation from external noise sources which might interfere with tests in the IER and prevents the noise generated within the IER from propagating to adjacent test areas. The IER is suspended within the outer room over an open basement to provide seismic isolation and to allow vibration to be generated. The outer room is constructed of reinforced concrete. A number of movable acoustic absorption panels within the room control the reverberation time. Each of the panels, $1.22 \text{ m} \times 2.44 \text{ m} \times 0.10 \text{ m}$, is constructed of bonded glass fiber in a wooden frame and is covered with steel cloth for abrasion protection. The resulting reverberation times in both the IER and the outer room are about 0.5 seconds.



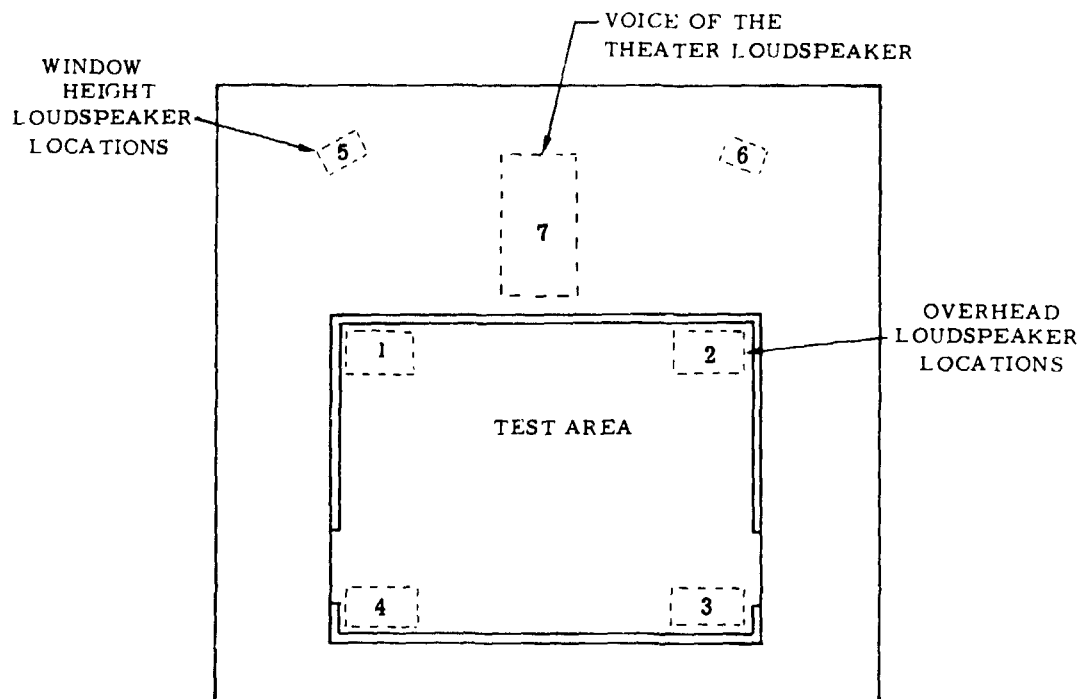
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Figure 4.- Interior effects room.

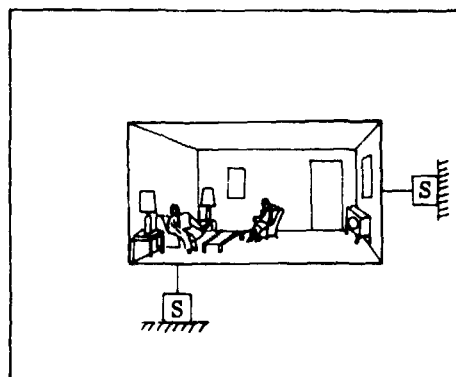
Loudspeaker systems used to produce aircraft and road traffic noise stimuli are located in the outer room to simulate residential environmental noise. The locations of the loudspeaker systems are indicated in figure 5(a) by the dashed rectangular areas. Loudspeakers 1 through 4, mounted above the ceiling of the test room, reproduce aircraft noise stimuli. They are Altec 9846-8A speaker systems with a usable frequency range from 35 Hz to 20 000 Hz and with a continuous power rating of 50 watts. Loudspeakers 5 and 6 which reproduce traffic noise stimuli are mounted at window height approximately 2 m from one wall of the test room. They are Altec 9844A speaker systems having a continuous power rating of 60 watts and usable frequency range from 35 Hz to 20 000 Hz. Loudspeaker 7 is an Altec Voice of the Theater A4 system with a continuous power rating of 100 watts, which can be used for aircraft noise reproduction as an alternative to use of loudspeakers 1 through 4.

Four-track tape recorders are used to play the recordings of both aircraft and traffic noise through 200-watt amplifiers in all loudspeaker channels. The system is flexible so that the speakers can be phased to produce stereophonic and quadrophonic signals as well as conventional monophonic playbacks.

In addition to the capability to generate noises representative of those observed inside of buildings, noise-induced vibration can also be simulated. This is accomplished through the use of shakers attached to the floor and side-walls, as indicated schematically in figure 5(b). The floor shaker rests on a 450 000-kg reaction mass and is attached to a 1.2 m x 2.4 m section of the floor of the test room. It is an electromagnetic type, rated at a force of 9000 N. It has a stroke of ± 1.3 cm, an acceleration of $\pm 0.25g$ in the vertical direction only, and a frequency range from 10 Hz to 2000 Hz (its response is



(a) Plan view showing loudspeaker arrangement.



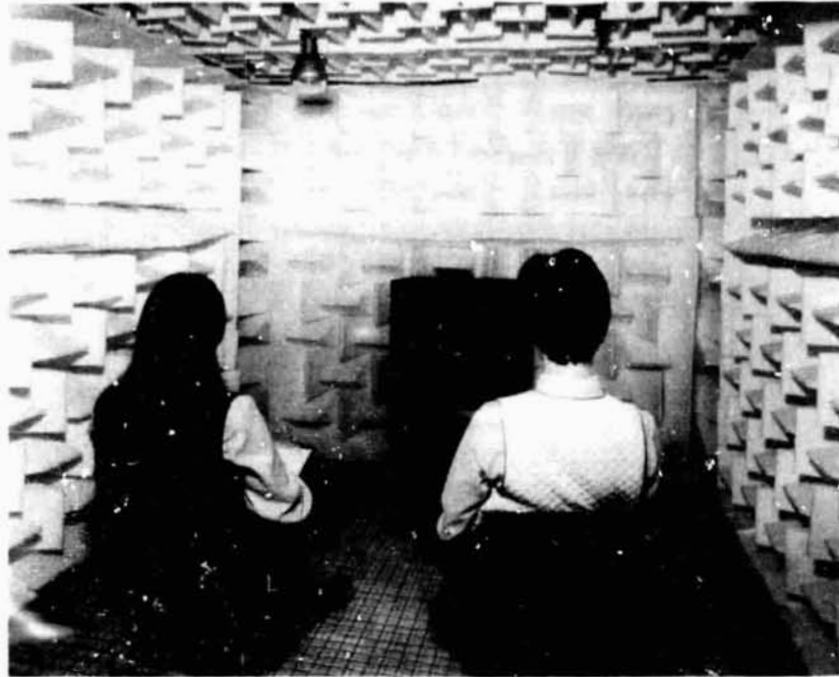
(b) Side view showing mechanical shaker arrangement.

Figure 5.- Layout of interior effects room test area.

essentially flat in the range from 10 Hz to 100 Hz). Several small (0.5 to 2 N) shakers can be attached at a number of positions on the wall panels. Wall shakers can be operated in phase to represent low frequency noise excitation or with arbitrary phase to represent high frequency noise excitation.

Anechoic Listening Room

The anechoic listening room is a test area in which two subjects can be exposed to noises in an essentially echo-free environment while engaging in basic listening tasks (see fig. 6). This area is designed to permit precision



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Figure 6.- Anechoic listening room.

calibration of acoustical instruments as well as to support human factors research for free field speech interference and for response to impulsive noise sources.

The test room is installed within an outer concrete room. The test room was prefabricated, the basic sidewall framework being of steel support panels filled with 10 cm of fiberglass. The test room is vibration isolated and there is a 10-cm air space between the walls of the test room and outer room. A separate air handling unit is provided to minimize the noise transmission from adjacent work areas. The ambient noise level is about 15 dB(A) with most energy being below 75 Hz.

The inside surfaces of the test room are covered with wedges of polyurethane, fully reticulated (open cell) foam, 40 cm deep and 20 cm by 20 cm at the base. Test subjects walk on a network of tension cables just above the floor wedges. Entrance is through a 1-m wide door supported by resilient mounts. The dimensions of the test room are about 3.7 m \times 2.5 m \times 2.1 m (20 m³).

For listening tasks involving low frequencies such as those produced by helicopters and wind turbines, a special speaker system is provided. It is a

combination of high and low frequency units. The high frequency unit is an Altec 604E loudspeaker having a usable frequency range of 100 Hz to 10 000 Hz. The low frequency unit is a subwoofer having a 37.5-cm-diameter driver and a flat response within ± 1 dB in the frequency range from 30 Hz to 100 Hz.

Aircraft Noise Synthesis System

An aircraft noise synthesis system is used to simulate aircraft flyover noise at an observer position on the ground. It is available for use in the IER, the EER, and the anechoic listening room. The system consists of a general purpose minicomputer, a software program, a digital-to-analog converter, and a programmable attenuator. Typically, the system is used to generate subjective test stimuli in which some noise characteristics, such as duration or tonal content, are independently varied while the remaining characteristics, such as broadband content, are held constant. The system may also be used to provide representations of the predicted noise characteristics of existing or planned aircraft over a range of operating conditions.

In generating flyover noise, the synthesis software takes into account the time-varying aircraft position relative to the observer; specified reference spectra consisting of broadband, narrow-band, and pure-tone components; and directivity patterns, Doppler shifts, atmospheric effects, and ground reflections. An updated noise spectrum at the observer position is calculated for each 0.08-second increment of the flyover. These spectra are converted from the frequency domain into digital waveforms in the time domain by inverse Fourier transformation. After completing the waveform generation for the entire flyover, the digital waveforms are converted to an analog signal by a digital-to-analog converter. The overall time-dependent amplitude of the analog signal is controlled by a programmable attenuator in order to maintain the full dynamic range throughout the flyover.

The synthesis system software is currently being modified to provide improved performance and capability. These modifications include the addition of a more complete flight trajectory, increased capacity for narrow-band and pure-tone components, and improved modeling of directivity, atmospheric effects, and ground reflection.

Passenger Ride Quality Apparatus

The passenger ride quality apparatus (PRQA) is a device for studying passenger comfort during simulated operations of various types of vehicles, particularly aircraft. Subjective ratings are obtained for various interior vehicle environments involving vibration, noise, and combinations of noise and vibration. A basic understanding of human behavior under such circumstances is expected to lead to the development of valid ride quality criteria for a wide range of vehicles. Example research programs along with experimental designs and test protocols are given in references 6 to 8.

The PRQA consists of a passenger cabin mounted on a hydraulically powered motion table with provisions for controlling the vibration and noise environments

of the human test subjects. The cabin is approximately one-fourth as wide as a full-size cabin of a B707 or DC-8 aircraft (see fig. 7). The cabin has two rows



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Figure 7.- Cabin interior of passenger ride quality apparatus.

of either first-class-type or coach-type aircraft seats for a maximum capacity of six test subjects. Access to the cabin is provided through bulkhead doors at each end. The inside of the cabin simulates the interior of a commercial aircraft. Included are overhead consoles with lights, ventilation, and indirect ceiling lighting. Observation windows are provided in the front and rear bulkheads for monitoring the subjects during tests. Visual cues in the form of projected still or motion pictures are provided to the test subjects for viewing through the side cabin windows.

The motion system consists of a 2.1-m square table driven by three vertical and one horizontal hydraulically powered servo-controlled actuators (see fig. 8). Each of these actuators is equipped with load limiters and hydraulic cushions on each end. The PRQA cabin can be attached to the motion table in two different orientations, 90° apart; therefore, the horizontal motion can be fore-and-aft or side-to-side and the angular motion can be rolling or pitching. The system has an operating range from 0 to 30 Hz and a capacity of 2250 kg. In the vertical or horizontal degree of freedom, the motion amplitudes are limited to ± 7.6 cm and to $\pm 0.5g$. In the roll or pitch degree of freedom, the motion amplitudes are limited to ± 0.1 rad and an acceleration of 6 rad/sec^2 . Simultaneous motion in two or more degrees of freedom reduces the allowable single-degree limits. The

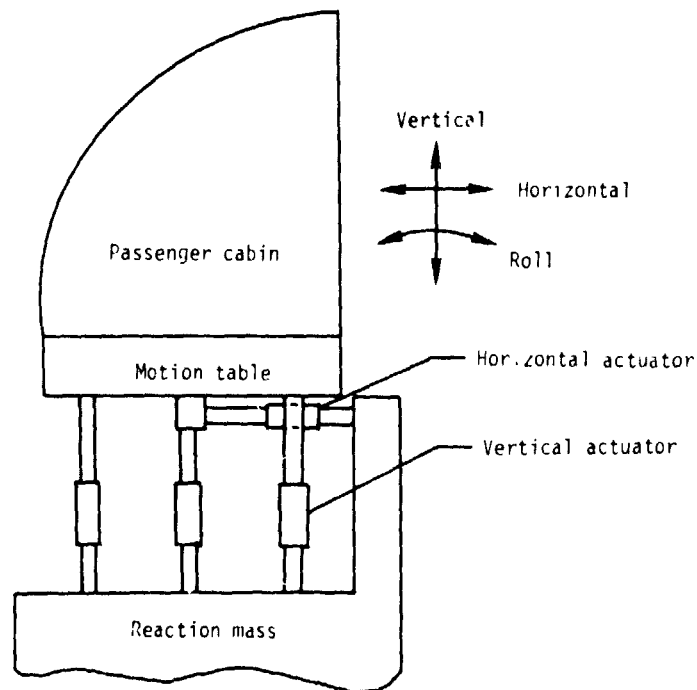


Figure 8.- Schematic diagram of actuator mechanisms for passenger ride quality apparatus.

actuators are mounted to a steel pad fastened to a 41 000 kg reinforced concrete reaction mass. With the system mounted on this base, the neutral position of the table is level with the second floor. A platform allows access to the cabin from the control room. A mechanical system restrains horizontal displacement along an axis perpendicular to the roll axis (or pitch axis) and prevents yaw of the table. A mechanical stop system is provided as a backup in the event of failure of any actuator or any part of the mechanical restraint system.

The hydraulic power is supplied to the system by two 120 L/min variable volume pumps driven from a single motor. In order to isolate the noise, these units are housed in the basement of the building and are controlled from the master control console for the PRQA.

The control station for the PRQA is located in the control room adjacent to the cabin. Normal controls for the power supply, as well as an emergency shutoff, are located at this station. The control console provides for programming single cycles or a predetermined number of cycles of an electrical analog of natural and inverted sine, haversine, triangular, square, sawtooth, and ramp functions. There are also provisions for accepting random vibration signals from external sources.

A sound reproduction system is also included to simulate the interior noise of various transportation vehicles. To equalize the interior noise field, a

multiple speaker system is used. A 37.5-cm Altec 411-16A low frequency speaker is mounted in the front and in the rear door; 2 Altec 802D drivers plus a JBL HL91 horn and lens are located in the overhead rack; and 12 small speakers are distributed throughout the cabin, 8 under the seats and 4 in the overhead rack. A pink noise calibration signal to the speaker system produces equal overall levels within ± 1 dB at the six subject locations.

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April 27, 1981

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