NASA TECHNICAL MEMORANDUM

NASA TM X-72807

NASA TM X-72807

REVIEW OF SUBJECTIVE MEASURES OF HUMAN RESPONSE TO AIRCRAFT NOISE

By

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January 1976

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665

(NASA-TM-X-72807) REVIEW OF SUBJECTIVE MEASURES OF HUMAN RESPONSE TO AIRCRAFT NOISE (NASA) 28 p HC $4.00 CSCL 20A
N76-15779
Unclas
G3/53 08535

1. Report No.
NASA TM X-72807

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Review of Subjective Measures of Human Response to Aircraft Noise

5. Report Date
January 1976

6. Performing Organization Code
2630

7. Author(s)
Jimmy M. Cawthorn and William H. Mayes

8. Performing Organization Report No.
NASA TM X-72807

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, Virginia 23665

10. Work Unit No.
504-09-11-01

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, DC 20546

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes
This paper was presented as an invited lecture at the Third Interagency Symposium on University Research in Transportation Noise, November 12-14, 1975

16. Abstract

The history of research into human response to aircraft noise can be traced and the present state of the art can be assessed through an examination of the development of aircraft noise rating scales and indexes. This paper reviews the development, up to the present time, of single-event scales, multiple-event indexes, and their interrelation with each other. Research requirements for further refinement and development of aircraft noise rating quantification factors are discussed.

Future research is expected to place more emphasis on the human receiver of the noise and strive for increased realism in laboratory studies. Consistent with this forecast, the NASA Langley Research Center has built and now has operational a new Aircraft Noise Reduction Laboratory, one wing of which is devoted to human response to noise research. The laboratory has facilities for simulating an indoor home environment and an outdoor acoustic environment for subjective testing. The capabilities of this new laboratory, which is considered to be a national facility, are discussed along with its planned near-term use.

17. Key Words (Suggested by Author(s)) (STAR category underlined)
Noise
Aircraft Noise
Human Response to Noise
Subjective Response to Noise

18. Distribution Statement
Unclassified
Unlimited

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
27

22. Price*
$3.75

*Available from The National Technical Information Service, Springfield, Virginia 22161
STIF/NASA Scientific and Technical Information Facility, P.O. Box 33, College Park, MD 20740

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INTRODUCTION

This paper (which is an abbreviated version of reference 1) presents a historical review of research into human response to aircraft noise through an assessment of the development and current state of the art of aircraft noise rating scales and indexes. Also included is a review of current research needs and the role being played by Langley's new Aircraft Noise Reduction Laboratory in response to those needs. The laboratory is described and its capabilities are discussed along with examples of past, present, and future studies. The laboratory is regarded as a national facility and is available for use by outside interests such as university researchers.

It will be helpful to define some terms which will be used in the paper and also to provide some background on the problem definition of aircraft noise quantification. Regarding definition of terms, it is noted that there is a lack of standardization in terminology used for describing aircraft noise exposure. Therefore, the terms scale and index as used in this paper are defined as follows:

> Scale.- The physical parameters of sound plus factors which account for psychophysiological responses of an individual to a single-event noise exposure.

Index.- A scale plus factors associated with the cumulative effects of multievent noise exposures.

PROBLEM DEFINITION

In regard to the problem definition of quantification of aircraft generated noise exposure, the foremost requirement is that the descriptors used be closely correlated with people responses and with community acceptance. Moreover, as with other noise control activities, the characteristics of both the noise sources and the noise propagation path must also be considered. Experience has shown that for aircraft noise control many of these special characteristics are difficult to quantify in terms of their relationship to community noise exposure.

An aircraft is a complex source of acoustic energy consisting of noises associated with the propulsion system and aerodynamic/airframe interactions. For example, the propulsion system consists of many noise sources such as rotating blade interactions, combustion processes, and the mixing of the exhaust flow. Also, important characteristics of an aircraft as a noise source are associated with the aircraft's forward speed. The aircraft is a powerful, moving noise source with rapidly changing position and distance relative to the receiver of the noise. Thus, the path between the source and the receiver is continually changing and may not be closely repeated from operation to operation. In addition to the movement of the noise source, the path of the propagated noise is through an atmosphere which is nonhomogeneous in physical characteristics. Furthermore, these physical characteristics of the path are themselves frequently changing and, thereby, provide an erratic medium for the noise to propagate through.

The special physical characteristics associated with aircraft noise sources and paths may to some extent be sensed by the people who are receivers of the noise and may influence their subjective responses. The receiver is often a nonparticipant and nonbeneficiary of aircraft operations; consequently, he is frequently a hostile receiver with a reluctance to accept aircraft noise as part of his everyday environment. The receiver's response is also complicated by emotional, economic, political, educational, physical, and other related factors.

In quantifying the noise exposure, a major challenge is the task of obtaining a descriptor that adequately provides an evaluation of the complete impact of aircraft-generated noise exposure. Historically, proposed scales and indices have been numerous and many have found useful application in fulfilling specific needs. Single-event scales have been developed for important application in the acoustic evaluation of aircraft and in the noise certification of aircraft. Single-event scales also serve as a basic element of multiple-event indexes which may include the addition of terms to account for the total noise exposure. Multievent indexes have been developed for application as descriptors of community noise exposure for airport planning, land use planning, and airport noise regulation.

The development to date of the various scales and indexes has reflected progress; however, at the same time the increasing number of such scales and indexes has also led to a loss of credibility for any single one. The resulting multitude of descriptors has resulted in considerable confusion, yet among the many proposed there are several which are currently in the forefront of aircraft noise activity. It is primarily these several scales and indexes whose historical development will be traced in this paper.

HISTORICAL DEVELOPMENTS

Research efforts into the effects of noise on people and the response of people to noise began in the early 1930's time period and were highlighted with the introduction of jet aircraft in the 1950's. Measures to assess the effects of a single aircraft flyover were first developed to be followed by measures of community response to daily airport operations. The following will review the development of these measures – the single-event scales and the multiple-event indexes.

Single Event

The development of methods for the assessment of human response to aircraft noise can be traced back to early psychoacoustical experiments which were conducted in studies of the loudness of sounds. Equal loudness contours developed by Fletcher and Munson (ref. 2) in 1933 formed the basis for the standard "A," "B," and "C" weighting networks later incorporated into sound level meters. The "A" weighting which is illustrated in figure 1 was developed to approximate the response of the human ear for low levels with the lower frequencies being attenuated, allowing greater emphasis to be given to the higher frequencies where the ear is most sensitive.

Research into the quantification of the subjective attributes of sound (such as loudness, noisiness, and annoyance) has continued in both the United States and Europe by many researchers since the original work of Fletcher and Munson. During 1943, at the Harvard Psychoacoustics Laboratory under the direction of S. S. Stevens, equal loudness and equal annoyance contours were obtained (ref. 3). Under the sponsorship of The Port of New York Authority and the U.S. Public Health Service in 1959, Kryter introduced the concept of perceived noise level and developed equal noisiness contours and a calculation scheme based on previous contours and procedures developed by Stevens for calculating loudness (ref. 4). In the early 1960's, studies by Kryter and Pearsons (refs. 5, 6, and 7) resulted in further refinements to these equal noisiness contours. Illustrated in figure 2 are the currently accepted equal noisiness contours for use in computation of perceived noise level. Figure 2 shows the interrelation of sound level and frequency in that a given contour is judged to be subjectively equal across its frequency spectrum even though the band level changes significantly. That is, a low frequency sound (100 Hz) must be at a higher level of intensity to sound equally loud or equally noisy as a higher frequency sound (2000 Hz).

The describing parameter of the original equal loudness curves of Stevens was called the sone. In an effort to distinguish the new noisiness concept from loudness Kryter named the noisiness contour unit the "noy" and coined the term perceived noise level (PNL), as the name of the calculated annoyance descriptor. The calculation of PNL uses a frequency weighting scheme whereby sounds at frequencies at which the ear is most sensitive are weighted higher than sounds at the less sensitive frequencies of the ear. The PNdB unit translated the subjective noy scale into a dB-like scale; that is, a doubling of the subjective noy value increased the PNL value by 10 PNdB.

In the mid-sixties, as a result of a considerable amount of research sponsored by NASA and the FAA, corrections of PNL for pure tone components and noise duration were established and, thus, was produced the effective perceived noise level (EPNL) scale in units of EPNdB. EPNL became a "standard" when the FAA issued Federal Aviation Regulation Part 36 in 1969 (ref. 8), and designated EPNdB as the unit to be used in the certification of new subsonic transport category airplanes.

In the early 1970's interest was renewed for the use of L_A as a scale for monitoring purposes where a simplified scale was desired instead of the complicated computation procedure of EPNL. For example, in 1970, "Noise Standards" for the regulation of airport noise were enacted by the state of California using L_A as the basic noise measure (ref. 9).

In an effort to develop an easily obtained unit which would more closely represent human responses to aircraft noise the scale L_D has been proposed as an alternate to L_A (ref. 10). The D-level weighting is compared to the A-level weighting in figure 3. The L_D weighting is the inverse of the 40-noy curve and it has been proposed that L_D become a standard and be incorporated in commercial sound level meters.

Multiple Events

In the United States the evolution of methods for assessing the impact of multiple aircraft flyover events on an airport neighborhood community began in the early 1950's. The composite noise rating (CNR) concept was developed by Rosenblith, Stevens, and Bolt (of BBN) to predict the expected community response to a noise source (refs. 11 and 12). Modifications were made to the CNR procedure in the late 1950's which enabled the prediction of community response to a combination of a series of turbojet aircraft operations (ref. 13). After a series of modifications were made to the CNR procedure, both military and commercial aircraft operations were included in the CNR procedure in the early 1960's. The perceived noise level concept was used as the base descriptor of an aircraft noise source. Also included in the computations are factors for number of operations, time of day, season of year, and duration of runups. This work was performed by Galloway and Pietrasanta (BBN) and was published by both FAA and the DOD (ref. 14) in various forms as land use planning documents.

The noise exposure forecast (NEF) was introduced in 1967 by Bishop and Horonjeff (ref. 15) under the support of the FAA. The primary differences between the NEF and CNR is that in the NEF procedure the EPNL is used as the noise stimulus descriptor and a constant is subtracted from the computed level in order to make the numerical value significantly different from any other index so that there is no chance of confusing NEF with any other quantity.

While the CNR and NEF were being developed in the United States, a number of independent multievent airport community noise assessment measures were being developed in Europe and elsewhere. These included noise and number index, NNI (U.K.), isopsophic index, N (France), total noise load, B (The Netherlands), mean annoyance level, $\overline{Q}$ (Germany), and noisiness index, $\overline{NI}$ (South Africa). Additionally, the International Civil Aviation Organization (ICAO) formulated a measure of their own (weighted noise exposure level, WECPNL). These indexes are all similar in nature in that in their computation, they each employ terms relating to the aircraft flyover single-event noise levels, the number of flyover events, and a variety of constants.

In the late sixties and early seventies a concept which had previously been used with success (ref. 11) was suggested as a possible contender to form the basis of a unifying noise exposure index. This is the equivalent sound level (L_{eq}), based on L_A, which is computed as an energy averaged noise level integrated over a specified period of time. The L_{eq} came to the forefront as a noise scale largely as a result of the previously mentioned noise legislation enacted by the state of California in 1970 (ref. 9). L_{eq} is also used as the basis for calculating noise pollution level (L_{NP}) which was developed by Robinson in the United Kingdom (ref. 16). Noise pollution level was developed as an improved single number rating technique and accounts not only for the intensity of the intruding noise, but also for fluctuations in the noise level.

L_{eq} also led to the formulation of day-night level (L_{dn}) which is an energy averaged noise level integrated over a 24-hour period. The L_{dn} was developed to improve L_{eq} by adding a penalty for nighttime noises. As authorized in the Noise Control Act of 1972, the Environmental Protection Agency commissioned a task force to study various noise problems. Task Group 3, of that task force, was established under the chairmanship of Dr. Henning von Gierke to study the implications of identifying and achieving levels of cumulative noise exposure around airports. The report of Task Group 3 to the EPA (ref. 17) was issued in 1973, and it contained the recommendation that the EPA and other Federal Agencies should adopt L_{dn} as the measure for environmental noise (with L_A weighting as the base scale). It was further recommended that L_D weighting should be considered as a replacement for L_A as soon as practical – that is, when L_D is standardized and available in commercial sound level meters. Also, the EPA "levels document" (ref. 18) formulates the hypotheses that long term A-weighted sound levels (L_{eq} and L_{dn}) are the best descriptors of the effects of environmental noise in a simple, uniform, and appropriate way.

Meanwhile, the FAA conceived an alternative approach and in 1973, published a report (ref. 19) on the aircraft sound description system (ASDS). The ASDS describes exposure to aircraft noise by the amount of time that noise levels from aircraft operations exceed a threshold of 85 dB(A). In formulating the ASDS the FAA's stated goal was to present noise data to the community such that it would be both scientifically accurate and understandable to the layman. The FAA also announced that airports would be required to report their noise data in ASDS units (ref. 20). In 1974, the FAA published a four-volume report (ref. 21) which detailed the computational techniques for applying the ASDS concept.

Comparison of the recent procedures which have been developed (L_{eq}, L_{NP}, L_{dn}, and ASDS) with the earlier methods illustrates some differences in concept. As discussed previously, the earlier methods employ the same concept of an energy summation obtained by correcting a given noise level with a factor dependent on the number of operations while the L_{eq}, L_{NP}, and L_{dn} are computed as an energy average and ASDS is simply the amount of time that the aircraft noise levels exceed a predetermined level (i.e., 85 dB(A)).

RESEARCH NEEDS

In reviewing the state of the art of aircraft noise rating, there are several areas which have been identified as needing further research and understanding. These include the effects of low frequencies, background noises, duration, and impulsive noises. The importance of low frequency noise characteristics is emphasized as attention is focused on advanced aircraft using powered-lift systems which may generate considerable acoustic energy at frequencies below 50 Hz which is the lower limit of many aircraft noise descriptors. Of concern at these low frequencies is the need for the noise exposure descriptor to properly account for nonauditory response of people in both outdoor and indoor situations. The continuing population buildup near airports and the developement of short-haul aircraft operating in urban STOLports emphasizes the need for considering the background noise environment. For example, the presence of varying noise of surface transportation systems may influence the judgment of aircraft noise (ref. 22).

Also, there still remain questions regarding the effect of duration on the response of people to aircraft noise. The duration corrections which are currently being used were developed in controlled laboratory environments primarily using artifical sounds and there is some controversy as to the level of correction which is appropriate for real-life environments. And, as helicopters are further developed for commercial use, the subjective responses to impulsive noises such as blade slap need to be better understood. Also, there is a helicopter noise certification rule pending and there is some disagreement as to what scale is appropriate for this purpose.

Apart from the scales and indexes which are currently in the forefront of activity, further research may focus increased attention on descriptors such as Robinson's noise pollution level (L_{NP}) which applies a background noise correction to equivalent sound level (L_{eq}). Further research is believed needed to explore descriptor systems which are not based on energy averaging or energy summation approaches. For example, the approaches of the ASDS and of Rylander (refs. 23 and 24) should be given further critical study. These approaches, respectively, depend upon time summation and upon maximum-event noise level regardless of the number of events.

It is the opinion of the authors that what is required is the refinement of existing knowledge and the study of unknowns — not the development, per se, of additional noise rating scales and indexes.

LANGLEY AIRCRAFT NOISE REDUCTION LABORATORY

This section gives a brief description of the role being played at the Langley Research Center's Acoustics Division in responding to the identified research needs described in the preceeding section. A new Aircraft Noise Reduction Laboratory has recently been constructed and put into operation at Langley. Some of the main features of the laboratory are illustrated in figure 4. The laboratory has capabilities for studying both the basic properties and practical applications of aircraft noise reduction techniques using both theoretical and experimental approaches. The laboratory is intended to serve as a national facility and is intended for use in cooperative research programs with other Government agencies, universities, and industry. The laboratory provides research capability for directly addressing the problems of noise generated by aircraft, including fundamental research in the generation and physical measurement of noise, techniques for noise reduction, and human reactions to noise. The major experimental facilities contained in the laboratory concerned with noise generation and reduction include an anechoic room and a reverberation room connected by an acoustic duct. These facilities have a common quiet airflow capability and they are used for testing noise reduction materials, devices, and techniques. Two special rooms are contained in the laboratory for studying the subjective reactions of people to noise. The rooms are designed to simulate both indoor and outdoor community noise exposure situations. The indoor, or interior effects room, is shown in the photograph of figure 5. This room was designed and constructed to simulate a family or living room found in a typical residential dwelling both with regard to the wall transmission loss and the structural response due to external aircraft noise exposures. The appearance and physical makeup of the room, of course, can be adjusted to create the degree of realism or simulation required by a particular experiment. An ongoing in-house study on the effects of various background noise environments on response to aircraft noise flyovers is using the room as configured in figure 5. Another study, which was just recently completed, was concerned with activity interference of aircraft flyover noise and the room was configured as illustrated in figure 6. The noise stimuli are generated by the playback of tape recordings of actual aircraft flyovers or synethsized noises into hi-fidelity loud speaker systems located external to the room. The capability also exists for providing controlled vibratory inputs into both the floor and walls of the room.

Shown in figure 7 is a view of the exterior effects room which was designed for acoustically simulating the noises heard outdoors in the airport community. The room can accommodate up to 39 test subjects and has at each seat location a keyboard connected to a centralized digital computer for obtaining subjective response information. The room was designed to be acoustically semianechoic and contains 10 hi-fidelity loud speakers arranged in the ceilings and walls which provide the capability to simulate both aircraft motion and direction.

A recent study on the assessment of noise from light aircraft was performed in this room under a research grant to the University of Utah. A calibration of the room is now underway for a planned in-house study concerned with the subjective aspects of impulsive noise characteristics of a helicopter due to blade slap.

The acoustic stimuli used for the two rooms just discussed are provided from magnetic tape recordings of the flyovers of existing aircraft, synthesized noise of future type aircraft, and/or special noises as may be required for a particular experiment. The present capability for synthesizing aircraft noises is being updated and will include the capability indicated in figure 8. The synthesis system is designed to accept the inputs of various aircraft flight parameters, acoustical parameters, and modifiers indicated on the figure.

As is indicated in figure 9, the synthesis system will allow research studies to be performed of the subjective effectiveness of various noise reduction schemes that may be proposed for existing aircraft as well as those of future aircraft still in the design stage. While this loop can be entered at any point, for convenience consider beginning with the prediction which is provided by the Acoustics Division's Aircraft Noise Prediction Office. The prediction programs are used to generate noise signatures representing standard aircraft and aircraft/engine design modifications. Analog tape recordings of simulated aircraft flyovers are synthesized from the predicted noise signatures. These tape recordings can then be used as the noise source for subjective response testing in the psychoacoustic research areas of the laboratory (exterior effects room and interior effects room). The subjective response testing serves two purposes: It can be part of the "editorial" process of critiquing the validity of the prediction program, and also, proposed aircraft/engine acoustical modifications can be subjectively assessed without the expense of hardware fabrication.

The results of subjective response tests with synthesized noise can play an important role in the planning and design of source noise reduction experiments and aircraft operations research performed by other researchers which in turn can lead to significant improvements in the predictive methods.

CONCLUDING REMARKS

In closing, this paper has presented a historical review of human response to aircraft noise research through a review of a number of aircraft noise rating scales and indexes. Consideration has also been given to future research needs to improve the rating procedures. A description of Langley's new Aircraft Noise Reduction Laboratory was given along with examples of research studies which have been and will be conducted therein.

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Volume III - Data Tables
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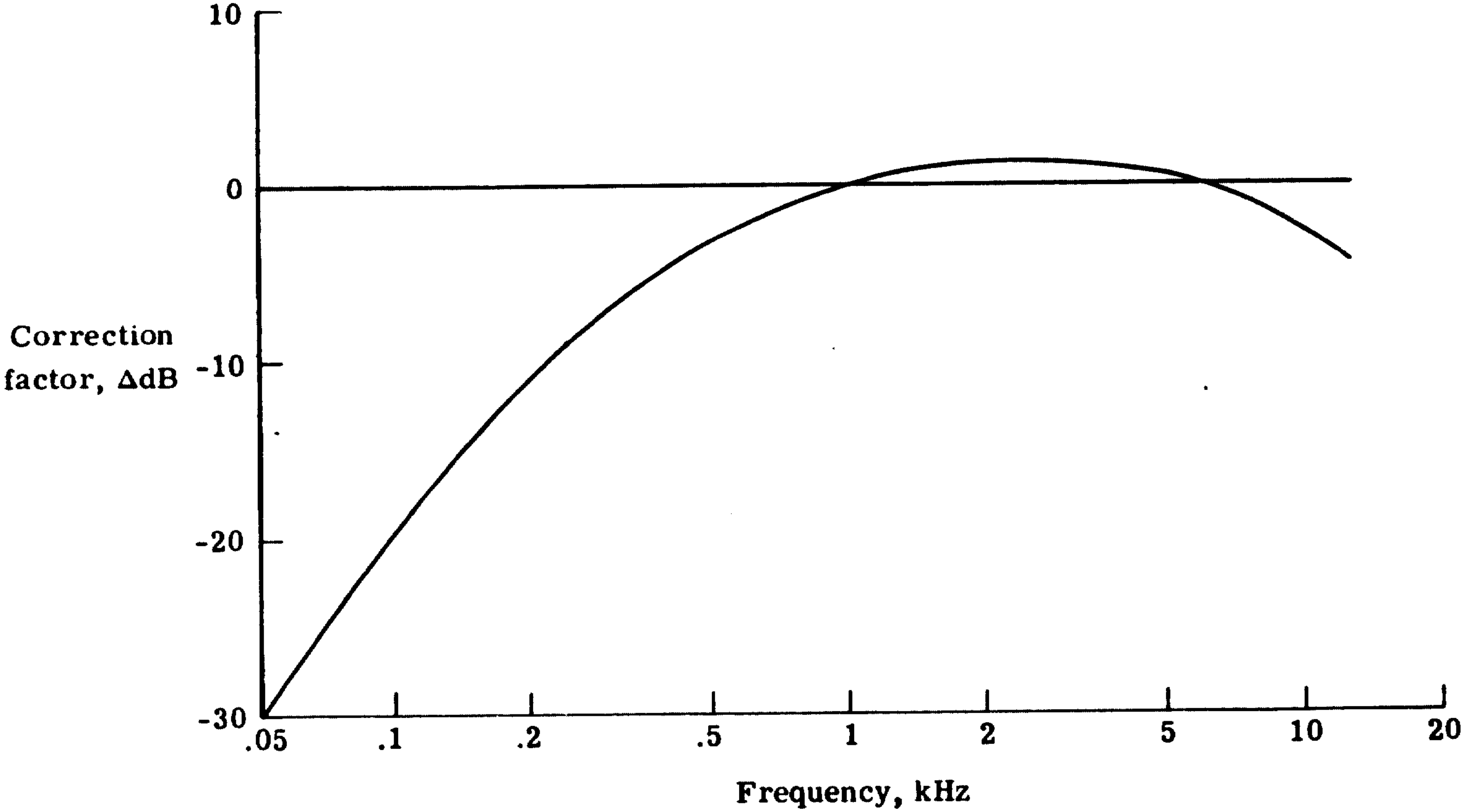

Figure 1.- A-level weighting correction factors.

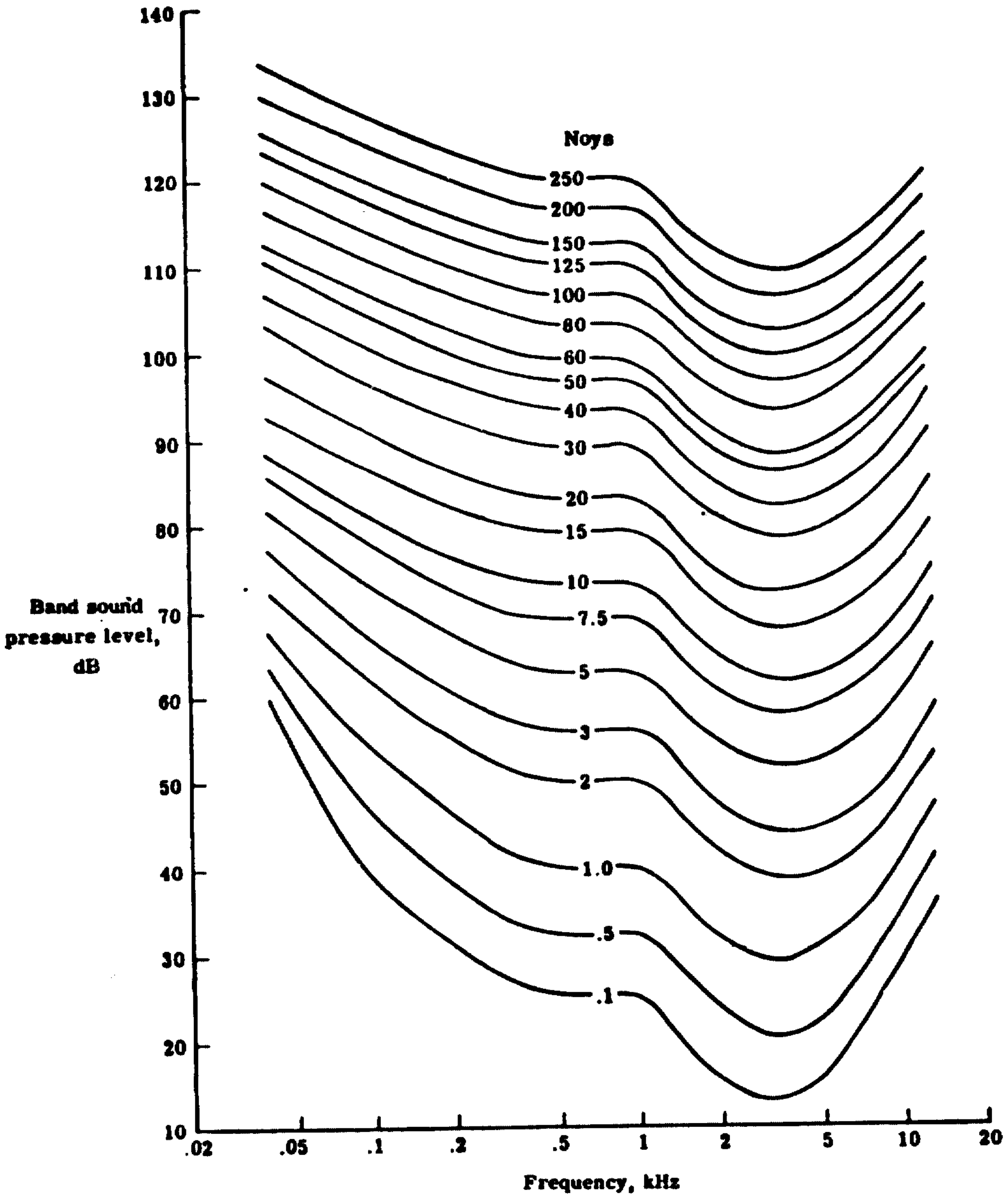

Figure 2.- Contours of equal noisiness sensitivity of the human ear.

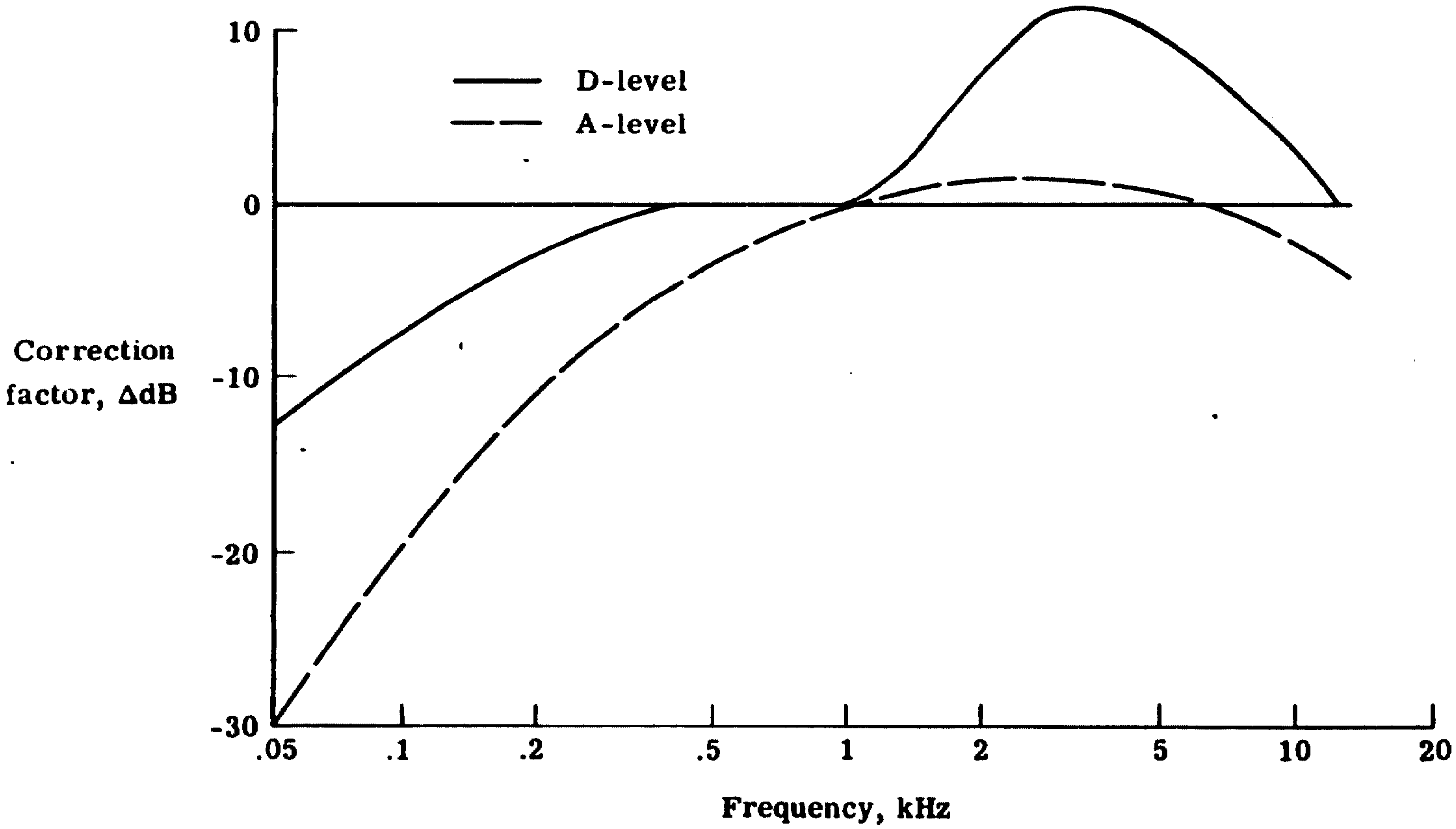

Figure 3.- Comparison of D-level and A-level weighting correction factors.

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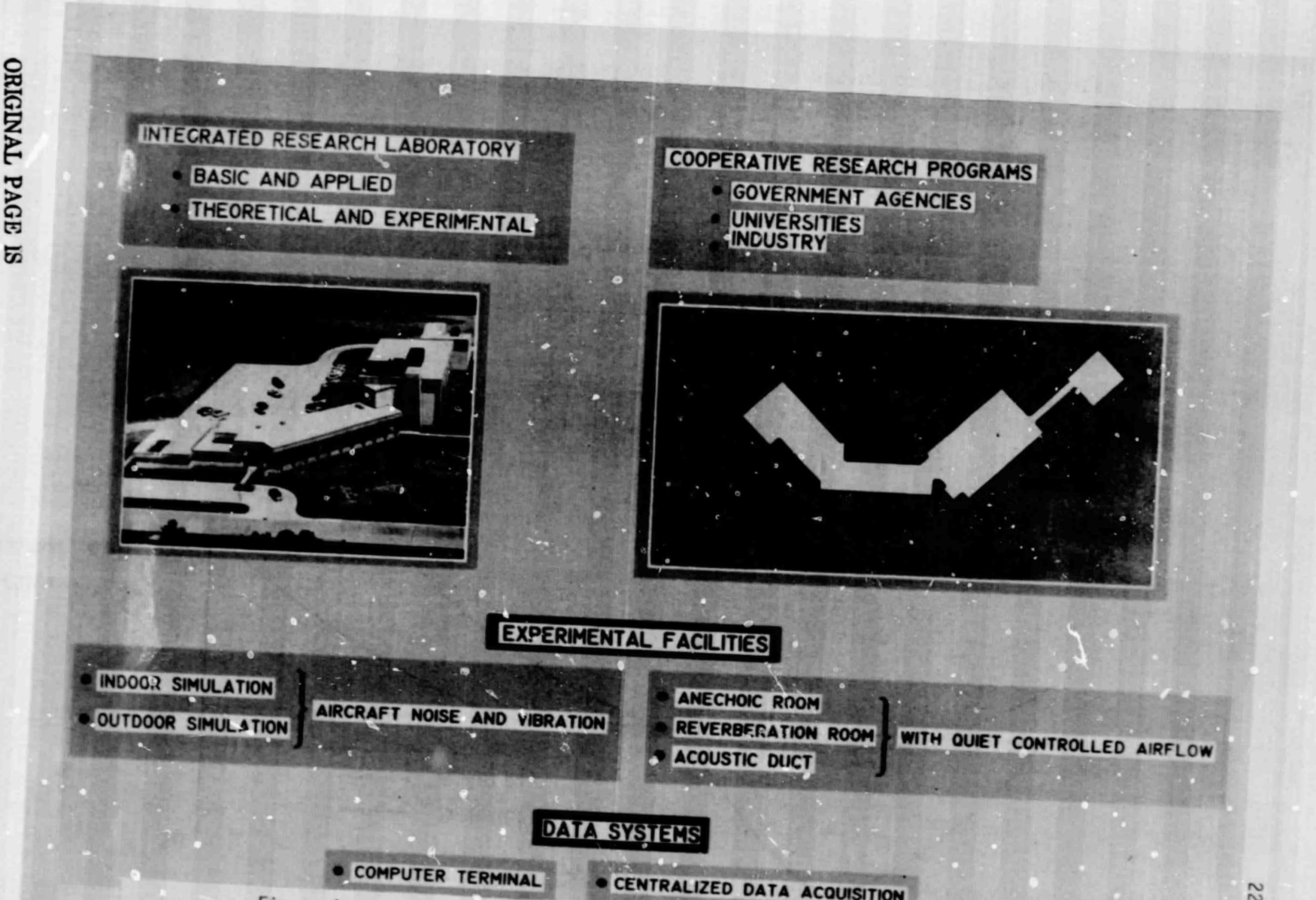

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- BASIC AND APPLIED
- THEORETICAL AND EXPERIMENTAL

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- UNIVERSITIES
- INDUSTRY

EXPERIMENTAL FACILITIES

- INDOOR SIMULATION
- OUTDOOR SIMULATION

} AIRCRAFT NOISE AND VIBRATION

- ANECHOIC ROOM
- REVERBERATION ROOM
- ACOUSTIC DUCT

} WITH QUIET CONTROLLED AIRFLOW

DATA SYSTEMS

- COMPUTER TERMINAL
- CENTRALIZED DATA ACQUISITION

Figure 4.- Langley Research Center Aircraft Noise Reduction Laboratory (ANRL).

Figure 5.- ANRL Interior Effects Room configured as living room for background noise studies.

Figure 6.- ANRL Interior Effects Room configured for activity interference studies.

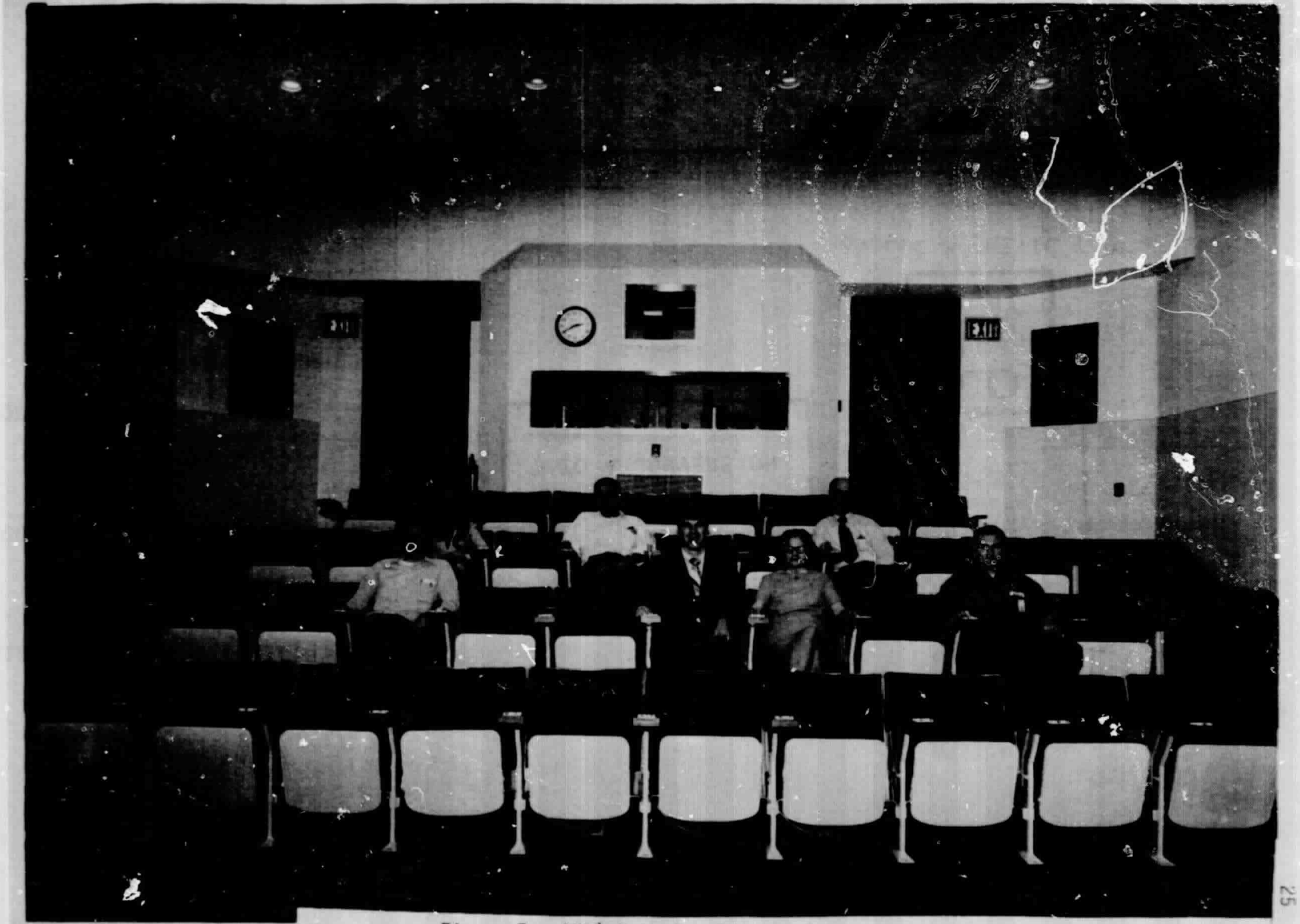

Figure 7.- ANRL Exterior Effects Room.

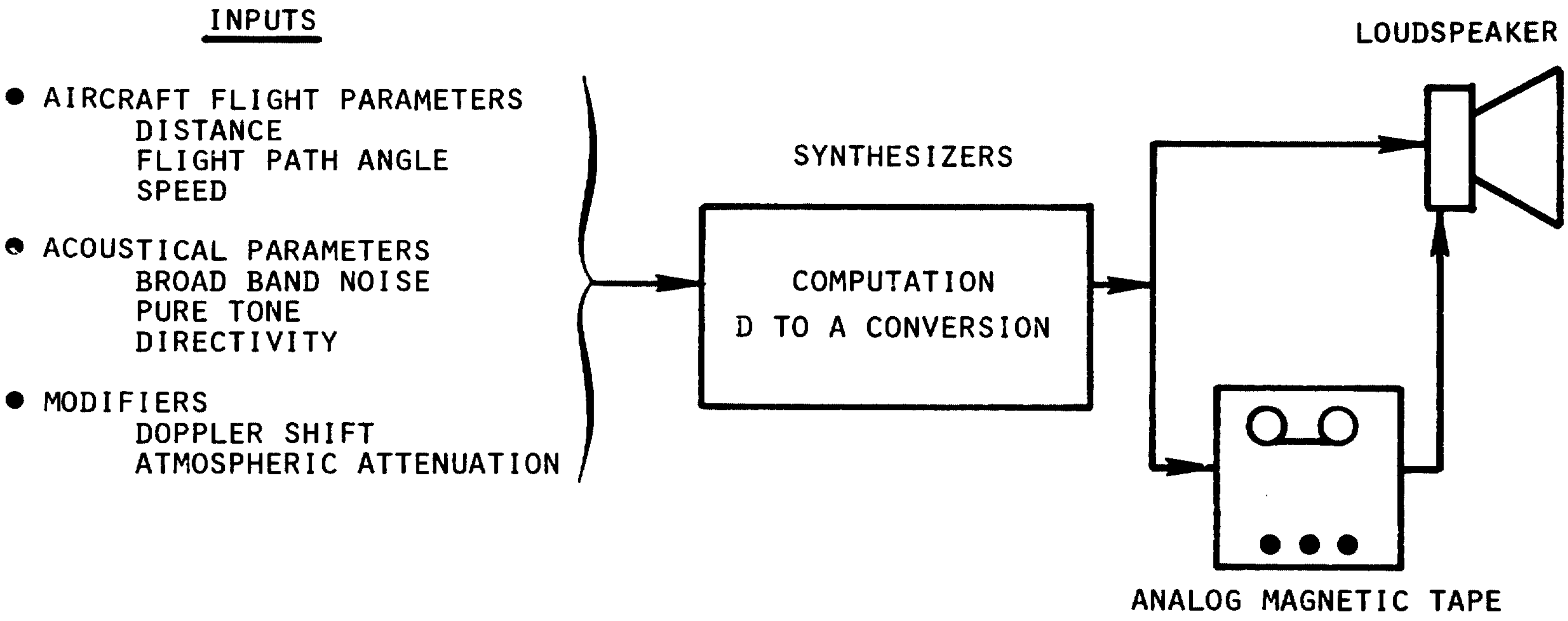

Figure 8.- Schematic of Langley aircraft noise synthesis capability.

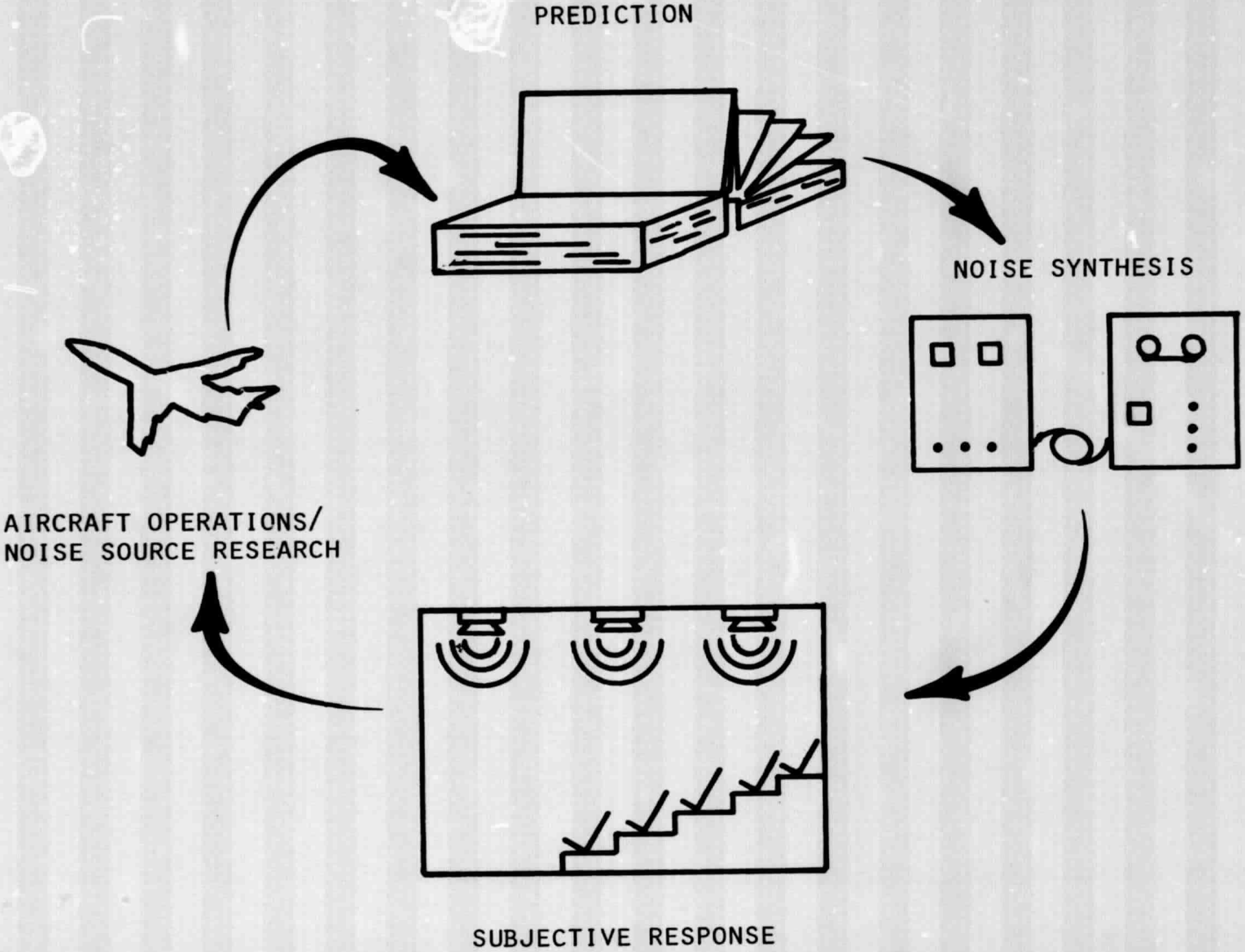

Figure 9.- Integration of Langley acoustics research.