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EVALUATION OF NOISE PROBLEMS ANTICIPATED WITH FUTURE VTOL AIRCRAFT

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ROBERT T. ENGLAND

MAY 1967

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Foreword

This report was prepared by the Biodynamics and Bionics Division, Biomedical Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, under Project 7231. "Biodynamics of Aerospace Operations," Task 723104, "Biodynamic Environments of Aerospace Flight Operations."

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This technical report has been reviewed and is approved.

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Abstract

The potential noise problems anticipated with future VTOL aircraft are analyzed and discussed in general terms, and a brief review of the basic principles of noise generation of various types of propulsion systems proposed for VTOL is included. Primary consideration is given to the noise environments produced in areas adjacent to VTOL sites, since they could cause the most serious noise problem limiting the usefulness of VTOL aircraft. Contours of perceived noise levels are compared for different takeoff and landing profiles of 3-4 passenger, 60 passenger, and 25 ton-lift-crane VTOL aircraft. Criteria and methods for assessing the response of communities to noise from V-port operations are discussed along with the problem of detection of military VTOL aircraft by means of noise. Recommendations are given on the requirements for future research on these noise problems with emphasis on the need for considering noise as an integral part of the design, selection, and test of VTOL aircraft.

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SECTION I.
Introduction

Noise is a problem not expected to interfere seriously with the military mi sion of future VTOL aircraft. However, the potential use of the same basic aircraft design . commercial-civilian operations makes the analysis of potential noise problems and operational restrictions an important step in the analysis of the merits of any particular VTOL design. Such an analysis should almost antomatically answer any questions about noise of the same type aircraft used for special, noise-sensitive, military missions. This report deals exclusively with the noise situation expected from commercial VTOL operations.

The high level of noise created by the propulsive system of future VTOL aircraft, especially during takeoff and landing, is a serious problem yet to be faced squarely in their design and development. Aircraft noise is not a new problem in today's jet age, but VTOL aircraft pose a new set of noise problems which must be dealt with effectively before there can be any hope for regularly scheduled flights in and out of small downtown or suburban V-ports.

Each type of VTOL aircraft will present some of its own special, noise-induced problems requiring steps to insure such features as structural integrity, adequate crew and passenger protection, and satisfactory communication. The most serious and over-riding noise problems for VTOL aircraft will be those caused by noise radiated into communities or areas surrounding the V-port.

Noise has been a very real and increasing problem threatening the existence and future development of airport facilities for conventional (CTOL) fixed-wing aircraft. Aircraft are powerful noise sources and all too frequently this noise radiates into adjacent communities disrupting activities and annoying people. The same problem will plague the development and operation of VTOL aircraft designed to provide short-haul passenger service between V-ports located in population centers. Close to such ports the community noise problem will probably be worse than that experienced at our busiest airports today unless positive steps are taken to develop quiet, future VTOL aircraft. Three factors tend to make the small downtown or suburban V-port more of a community noise problem than conventional airports: (1) the high aircraft power settings necessary during landing and takeoff of VTOL aircraft, (2) the very small separation between aircraft and exposed communities, and (3) the relatively low background noise environments at many of these locations.

The purpose of this report is to describe the nature and magnitude of the community noise problem associated with VTOL aircraft and to point out the need for considering noise as an integral part of the design, selection, and test of VTOL aircraft.

SECTION II.

Principles of Noise Generation

One of the first steps in assessing any noise problem is to measure or estimate the physical quantities which describe the noise-generating characteristics of the source under its various operating conditions. For a VTOL aircraft the propulsive system is the primary source of noise because of the aircraft's configuration and speed range. Its acoustic power output and directivity pattern as a function of frequency for each phase of flight must be known to determine how much and what kind of noise radiates into adjacent communities. Although considerable experience and predictive capability exist for analyzing noise from CTOL fixed-wing aircraft and conventional helicopters, the complex noise fields of future VTOL aircraft cannot be described accurately or fully with present-day knowledge for many of the less orthodox propulsive systems; this is especially true for the transition phase between vertical and horizontal flight.

Despite the lack of detailed data and predictive methods, sufficient information exists to show the nature and scope of the potential VTOL noise problem and, more importantly, to provide guidelines for action to prevent or minimize the problem before it develops.

The measure of noise used in this report is the so-called perceived noise level, which is expressed in units of PNdB. This concept for rating the relative "noisiness" of complex sounds has been widely accepted and used in this country and abroad in studies of traffic, industrial, and aircraft noise. The perceived noise level of a given sound is a calculated quantity based on a system of weighting the measured or estimated sound pressure levels in frequency bands and combining these weighted band levels to arrive at a single number (the perceived noise level in PNdB) that will describe the relative noisiness of that particular sound. Hence, using perceived noise levels in this report, rather than sound pressure levels or sound power levels, gives a direct and simplified measure of the relative subjective noisiness of different VTOL aircraft. In addition to the levels, the duration and repetition of noise must be known to describe the total noise exposure at any given location and to estimate human reaction to this exposure.

DISK-LOADING

The noisiness of a particular VTOL aircraft will depend highly on the disk-loading of its propulsive system as shown in figure 1 (ref 1). Noise considerations obviously favor low disk-loading, with rotor-type propulsive devices being the quietest and straight jet engines the noisiest. Other types of propulsive systems being conceived today will lie somewhere between these extremes. Note on this same figure the perceived noise levels typical for city traffic, residential areas, etc.

ROTORS

The main source of noise from VTOL aircraft with shaft-driven rotors will be the vortices shed from the rotors. Engine noise, although sometimes a problem with conventional, piston-engine helicopters, can be kept low, compared to the rotor noise, using properly designed engines (e.g., turbines). Some fundamental noise characteristics of helicopter rotors are illustrated in figure 2 (ref 2). The perceived noise level at a fixed distance depends on blade loading and rotor-tip speed with low blade loading and low tip speeds favoring low noise generation. Consequently, one approach to reduce noise would be to decrease blade loading by increasing rotor solidity. In some designs it might be feasible to reduce tip speed depending on aircraft stall characteristics.

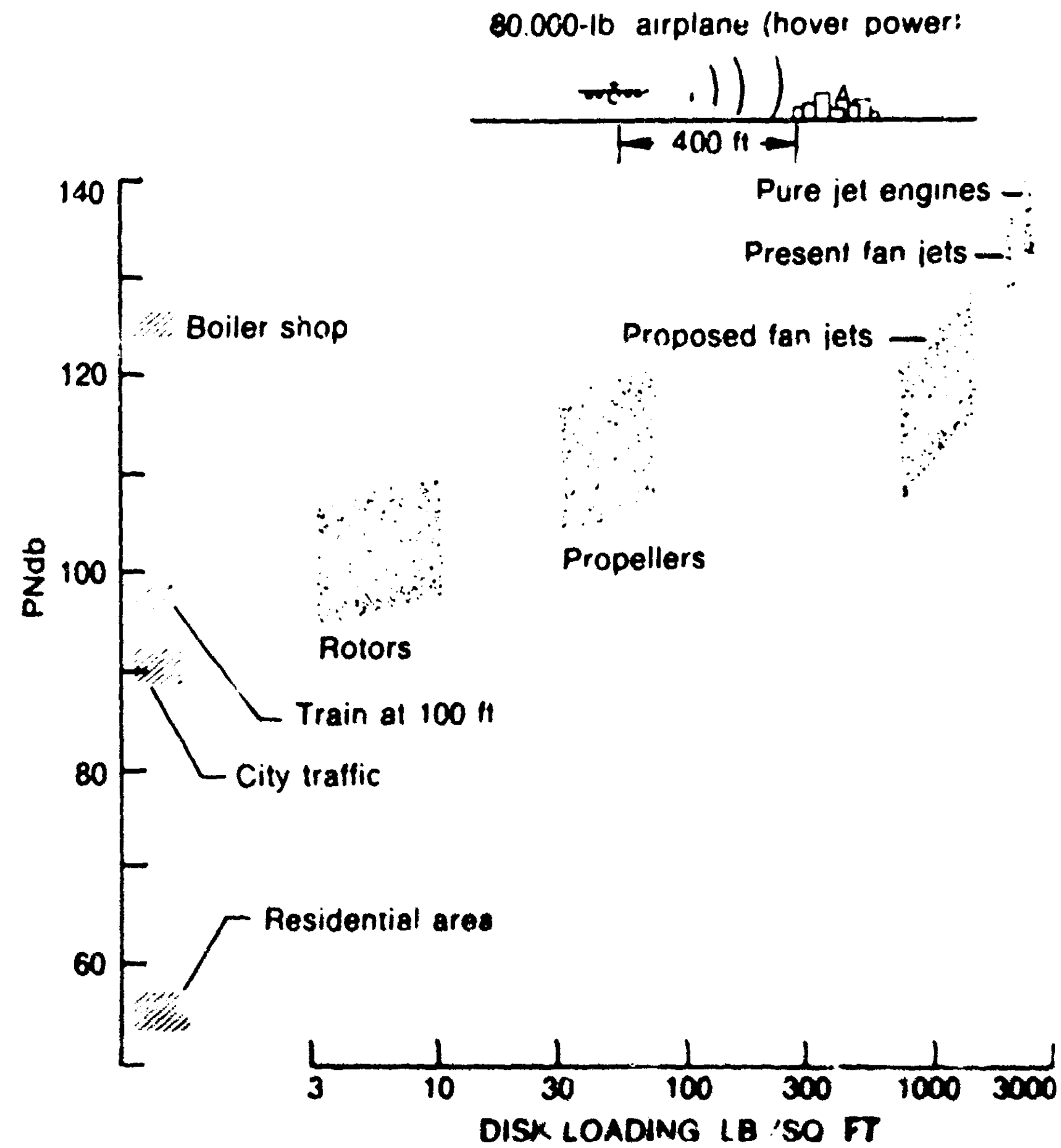

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Figure 1. Effect of Disk Loading on Perceived Noise Levels (Reference 1).

PROPELLERS

The primary source of noise from VTOL aircraft with turboprop propulsion will be the propeller itself, particularly if engine compressor noise is minimized. Propeller noise is produced by the aerodynamic pressure field of the rotating blades and is characterized by discrete-frequency components (associated with the blade passage frequency) superimposed on a broad vortex noise spectrum. The dependence of propeller noise on propeller tip Mach number and the number of blades is illustrated in figure 3 for four propellers, 17 feet in diameter, absorbing a total of 8,500 hoursepower (ref 2). Noise can be minimized by decreasing propeller tip speed or increasing the number of blades or both. Since it would probably be impractical to increase the number of

NOISE CHARACTERISTICS OF HELICOPTER ROTORS

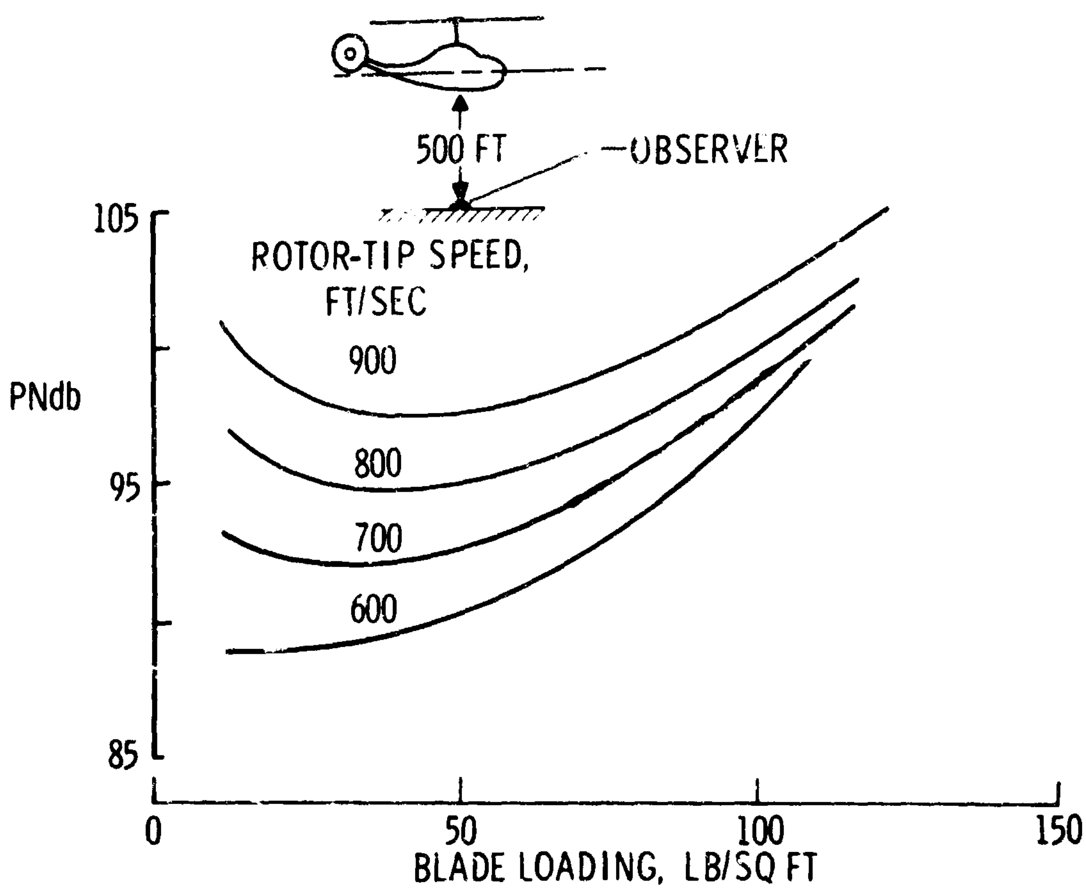

Figure 2. Noise Characteristics of Helicopter Rotors (Reference 2).

blades beyond four or six, the best approach for minimizing propeller noise is to keep rotor-tip speed to an absolute minimum.

JET ENGINES

The noise produced by turbojet and turbofan engines comes from the turbulent mixing of the hot, high-velocity, exhaust gases with the surrounding ambient air. It is broad-band noise and its maximum energy typically occurs in the range from 150 to 600 Hz, depending mainly on the effective diameter and velocity of the exhaust flow. The noise outputs of jet engines are highly dependent on jet exhaust velocity, as illustrated in figure 4 (ref 2). Turbofan or bypass-type engines are considerably less noisy because of their lower average jet exhaust velocities. Some jet engines, particularly when operating at reduced power, emit noticeable, high-frequency, periodic

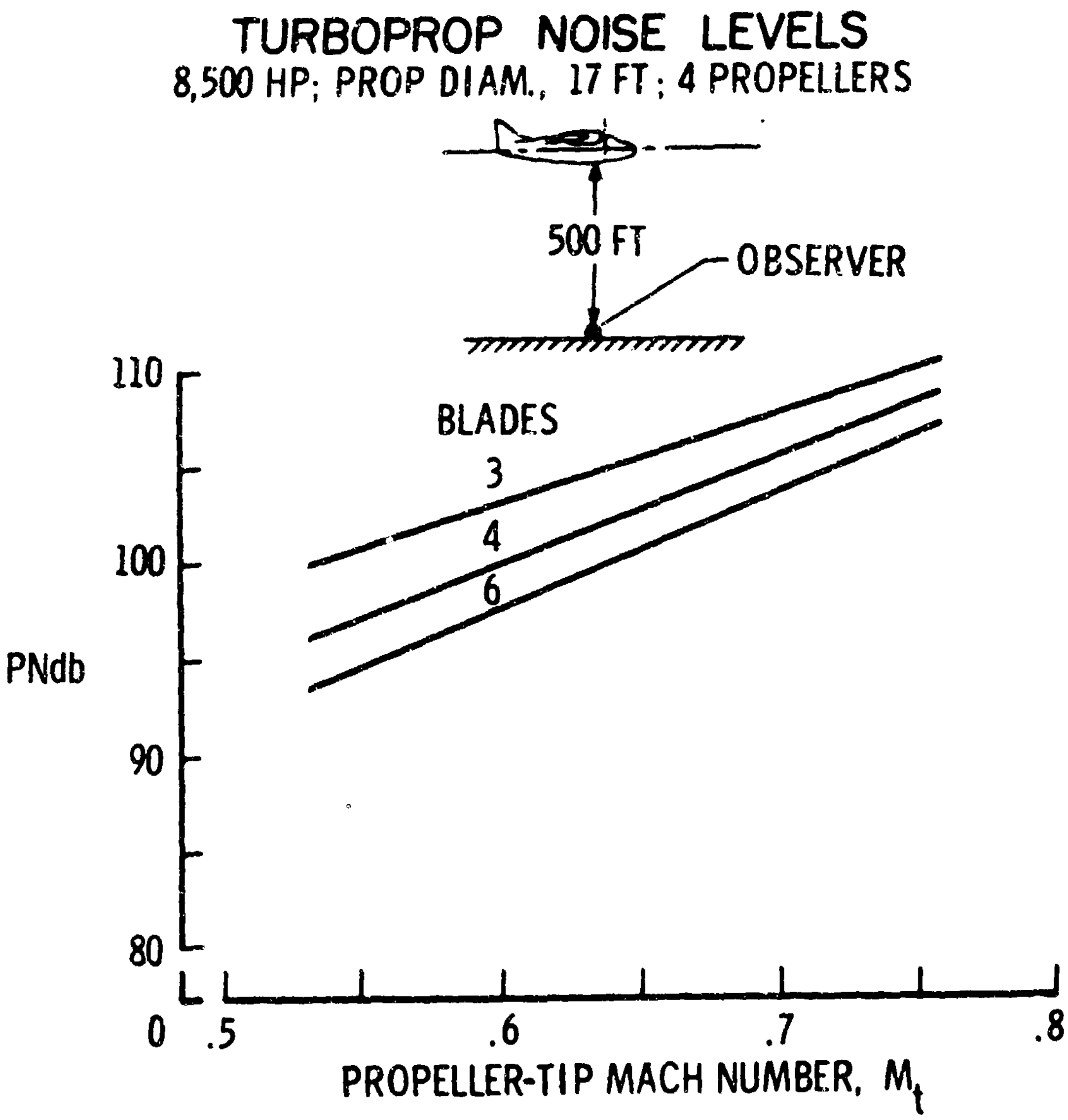

Figure 3. Turboprop Noise Levels as a Function of Propeller-Tip Mach Number and the Number of Blades (Reference 2).

noise associated with the engine compressor. Although usually not a major problem, the noise can be very annoying and must be considered in the overall problem. It is radiated primarily toward the front (i.e., in the direction of the intake) and is consequently of primary concern during approach maneuvers.

Jet-powered VTOL propulsive designs that deflect or modify the flow from jet engines will also modify the character and level of the generated noise. The flow modifications will usually decrease the total acoustic power generated, but the effect on perceived noise level at a given location could be to either increase or decrease noisiness depending on the acoustic power spectrum and directivity of the particular propulsive system.

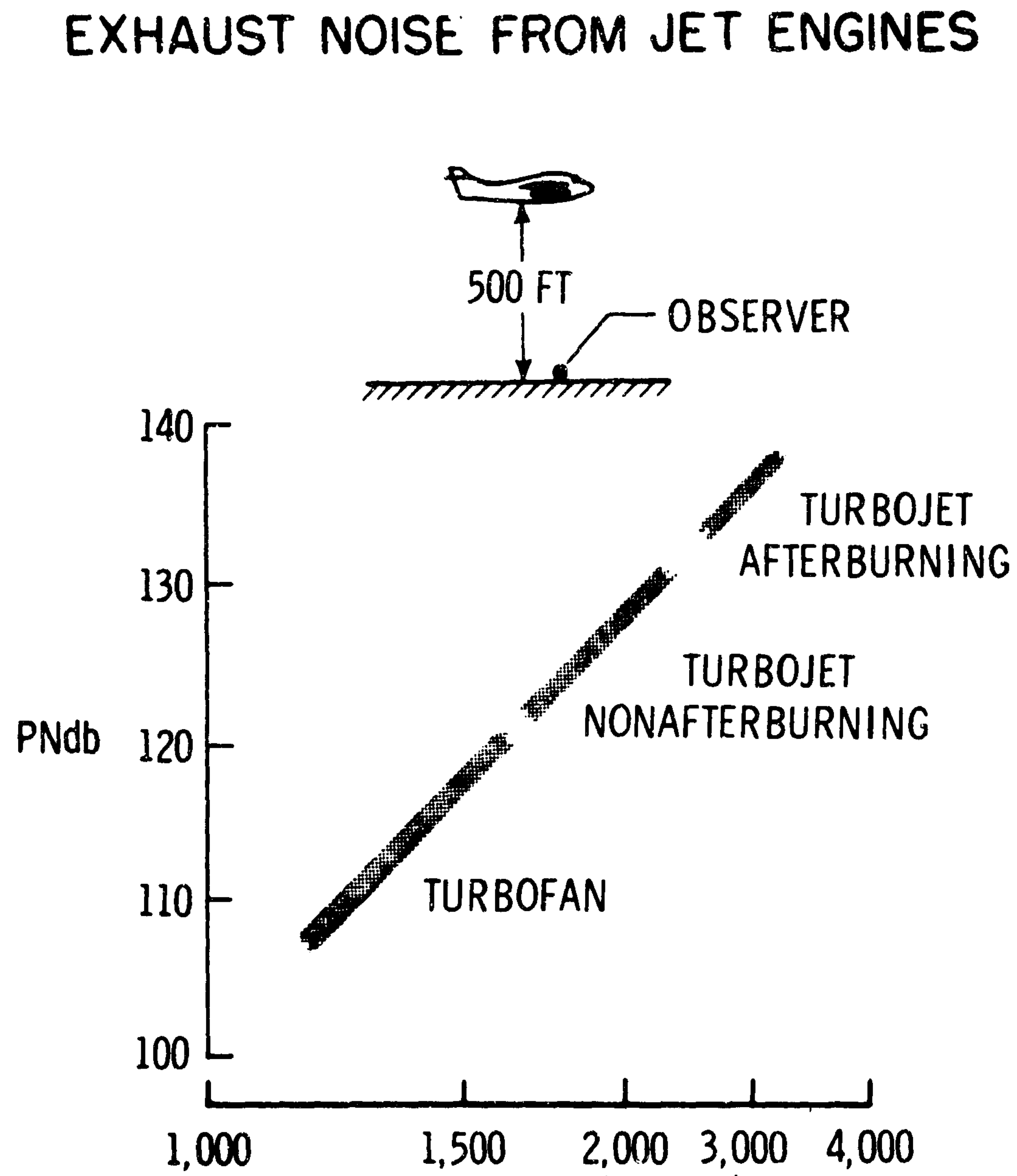

Figure 4. Exhaust Noise from Jet Engines as a Function of Jet Exhaust Velocity (Reference 2).

Any reductions in noise to be achieved by adopting "quiet" systems of propulsion might very well come at the expense of decreased performance, increased cost, or both. These trade-offs among performance, noise, cost, and other factors emphasize the necessity for considering noise as a major, integral, and unavoidable factor in the design and operation of VTOL aircraft.

Although data and adequate predictive methods are lacking for estimating noise from many of the less orthodox propulsive systems considered for VTOL aircraft (e.g., ducted fans, wing rotors, integrated propulsion/airframe systems), the noise produced by most if not all of these propulsive systems will lie between the extremes set by the quietest, helicopter-type VTOL aircraft and the noisiest, straight-jet-lift-type VTOL aircraft.

Perceived noise levels are plotted on figure 5 as a function of distance to the aircraft for a variety of specific VTOL aircraft proposed for (60-passenger) short-haul service (ref 3, 4, 5). Distance to the aircraft is equal to the shortest distance to the flight path. These estimates show the wide range of noise levels that can be expected from different types of VTOL aircraft having the same function (i.e., to transport 60 passengers). These curves also confirm that helicopter-type aircraft will be least noisy, while straight jet types will be the noisiest. Figure 5 also shows two curves for comparison indicating the perceived noise levels of busy multi-lane highways and urban streets.

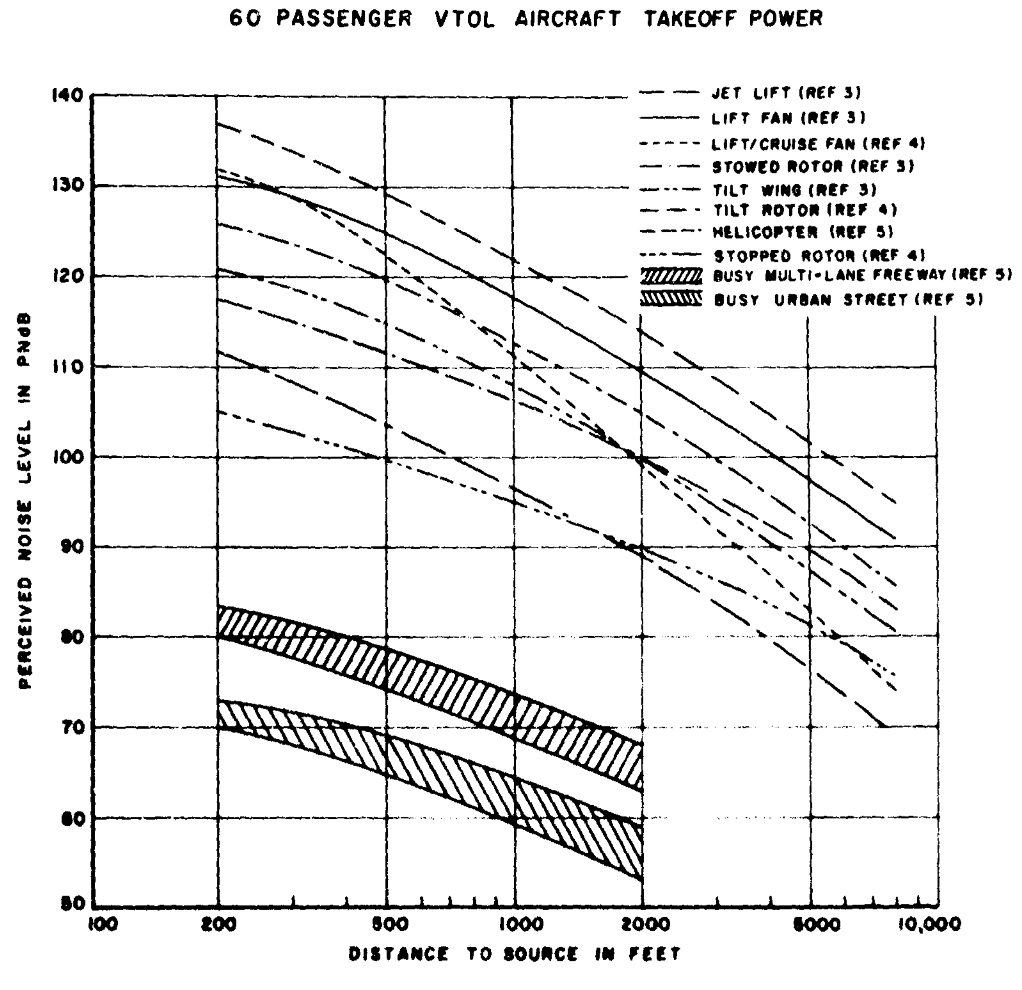

Figure 5. Perceived Noise Levels as a Function of Distance for 8 Types of VTOL Aircraft and 2 Traffic Situations (References 3, 4, and 5).

SECTION III.

Perceived Noise Levels Around V-Ports

One procedure, currently used to evaluate the effect of aircraft noise in communities adjacent to present-day airports, requires the development of perceived noise contours for each type or class of aircraft (ref 6). These contours represent the maximum perceived noise levels produced at points on the ground when each aircraft takes off on some given flight profile; similar contour sets can be calculated for landings. These contours then form the basis of a procedure for estimating the probable response of community residents to the total complex noise exposure resulting from the many and varied operations at that airport. This procedure and its relevance to the V-port noise problem are discussed in a later section. Here we are considering only the relative shape and size of perceived noise contours produced on the ground by various VTOL aircraft flying certain flight profiles.

Perceived noise contours have been calculated for three different sizes of VTOL aircraft: a 3-4 passenget aircraft; a 60-passenger aircraft; and a crane-type, 25-ton-lift aircraft. The contours on figure 6 show the points on the ground exposed to perceived noise levels of 95 PNdB for "quiet" type VTOL aircraft and for the "niosy" type VTOL aircraft. The lower limit of the perceived noise levels on figure 5 was used to define quiet, 60-passenger, VTOL aircraft; the upper limit was similarly used to define noisy, 60-passenger, VTOL aircraft. Contours for the small 3-4 passenger aircraft and the lift crane aircraft were obtained by scaling those estimates made for the 60-passenger aircraft on the basis of gross weight ratios, assuming a constant thrust:weight ratio for all three sizes. The following flight profile was assumed for all aircraft and is also shown on figure 6: 25° take-off angle with the ground; cruise altitude of 1500 feet; 10° landing angle with the ground. Additional assumptions were: (1) noisy (jet-type) aircraft would reduce power at cruise altitude and hence reduce noise, while the quiet (helicopter-rotor-type) aircraft would maintain essentially constant power upon reaching cruise altitude with no significant change in noise output; and (2) landings and takeoffs required substantially the same aircraft power settings.

The shaded areas of figure 6 show the relative size and shape of the geographic areas exposed to levels equal to or greater than 95 PNdB. The 95 PNdB level was selected because it represents the estimated upper limit of noise that would probably be tolerated on a regular basis at a downtown or urban type V-port.* In other words, the smaller shaded areas indicate the amount of land that must function as a buffer around a V-port to isolate quiet aircraft operations from the surrounding area. The larger shaded areas show how much more area is affected or required for isolating noisy aircraft. V-ports with special, noise-controlling construction would not affect areas as large as those shown on figure 6. The advantages and necessity of designing VTOL aircraft to be as quiet as possible are obvious.

Figure 6 shows that the only difference in takeoff and landing contours stems from the difference in flight profile (25° takeoff, 10° landing), since we assume that landing requires approximately as much aircraft power as takeoff. For some types of VTOL aircraft this condition

*Selection of a specific PNdB level as design criterion or as upper "permissible" or "tolerable" limit is always subject to debate, and arguments for higher or lower limits can be brought forward depending on the individual situation and on the individual arguing the case. The "upper limits probably tolerable" and calculated distances using such limits, which are presented in this report, should not be taken as sharp lines or boundaries, but rather as trend curves and approximate distances involved. The criteria used are based on the best unbiased data available and are recommended for planning purposes.

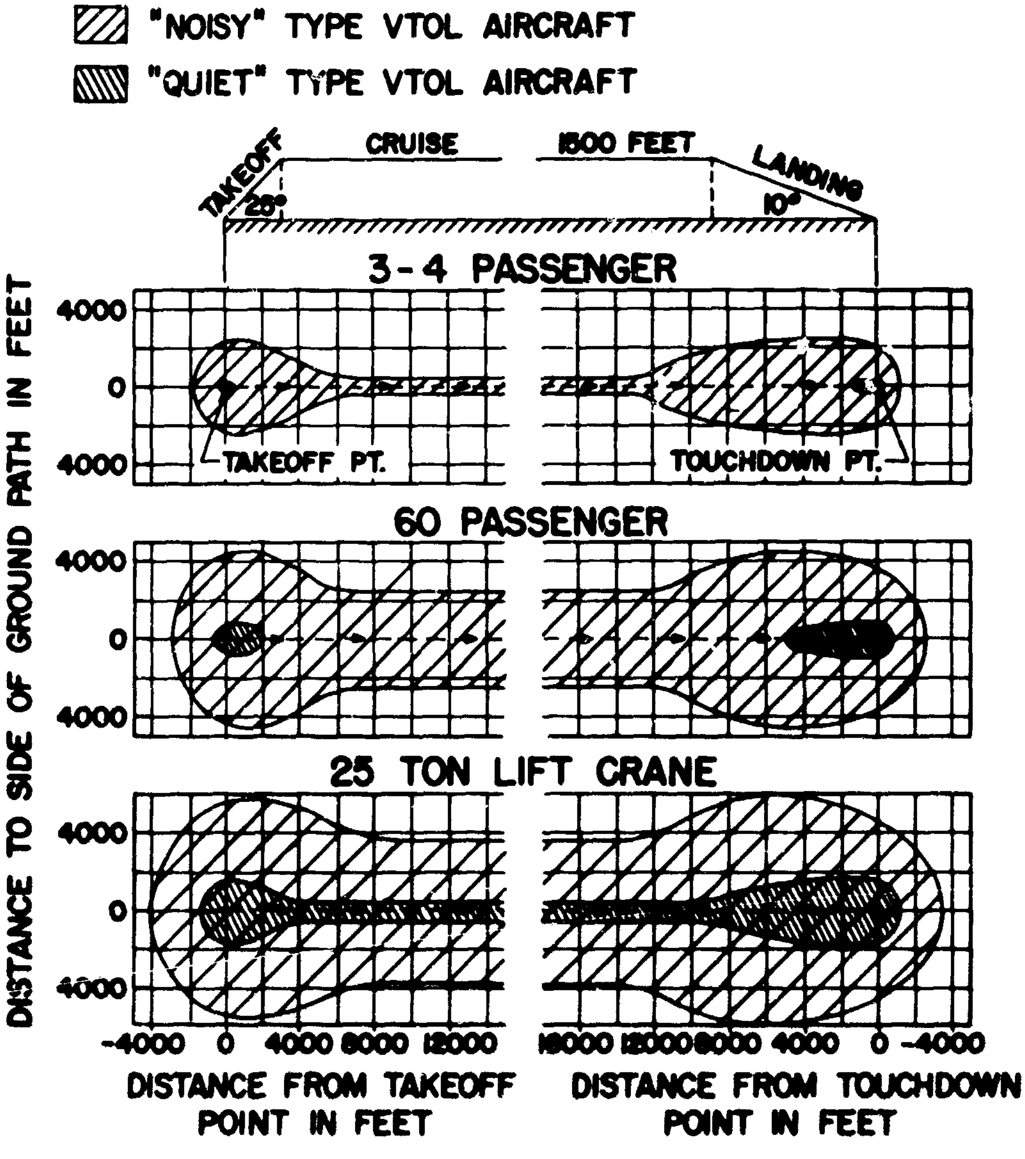

Figure 6. Contours showing Areas Exposed to Perceived Noise Levels Equal to or Greater than 95 PNdB for Takeoff, Cruise and Landing of 3 Sizes of VTOL Aircraft.

will probably not be true, therefore the landing contours shown in figure 6 would be somewhat oversize.

The small V-port located in a suburban area presents a more severe noise problem. Experience with present-day helicopter operations indicates that levels as low as 75 PNdB in suburban areas can cause adverse community response, particularly during early morning or late evening hours or when produced on a frequent schedule. To illustrate how much more serious the noise problem will be at such suburban locations, perceived noise contours for 80 PNdB were calculated and are shown in figure 7. These contours are based on the same set of assumptions used for figure 6. The main conclusion to be drawn from these contours is that VTOL operations at a

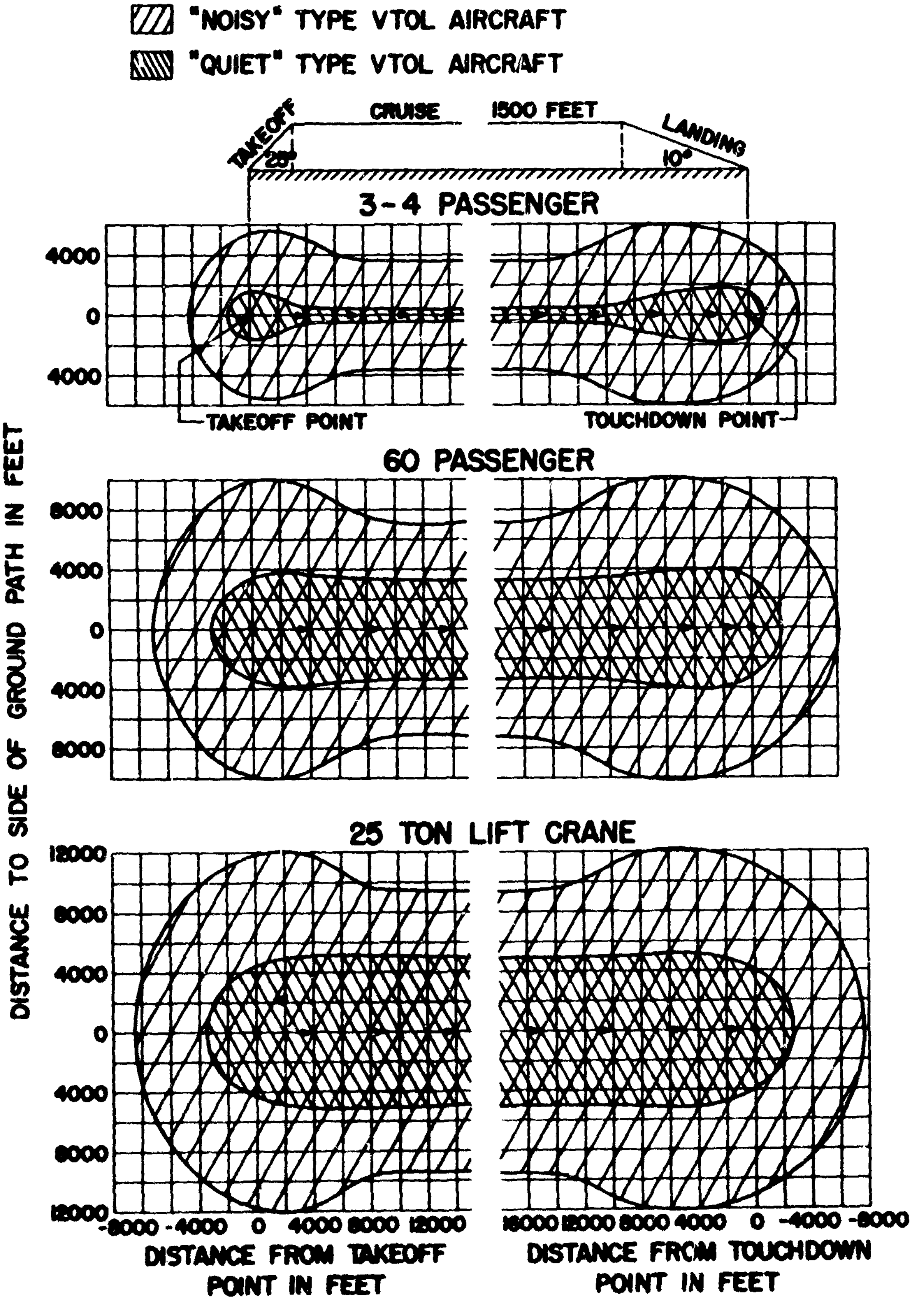

Figure 7. Contours showing Areas Exposed to Perceived Noise Levels Equal to or Greater than 80 PNdB for Takeoff, Cruise and Landing of 3 Sizes of VTOL Aircraft.

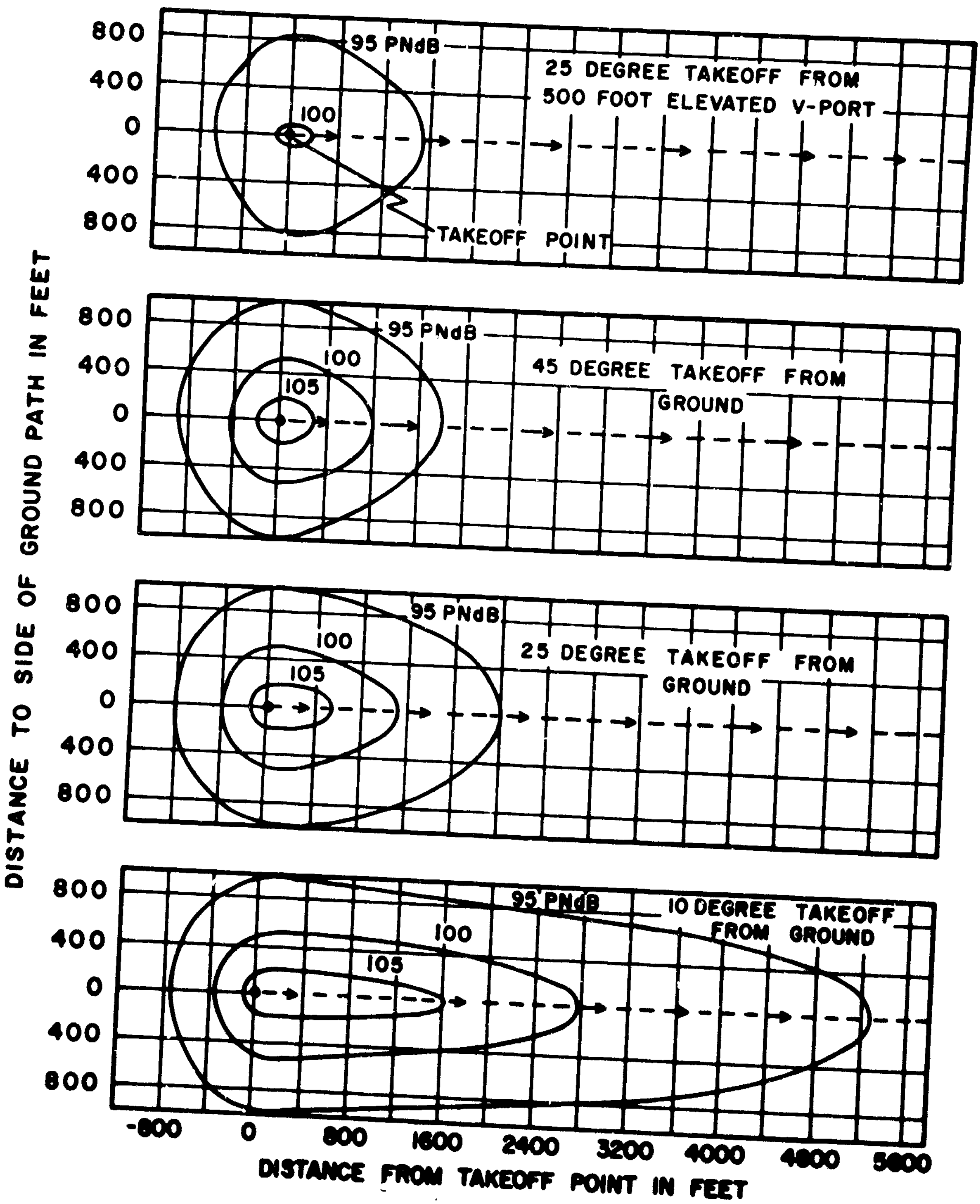

Figure 8. Perceived Noise Level Contours of 60 Passenger VTOL Aircraft for 4 Takeoff Profiles (Quiet, Helicopter-Type Aircraft).

suburban V-port will expose large areas to noise levels that probably would not be acceptable on a regular basis. Once again the necessity for developing quiet VTOL aircraft is apparent.

One means of reducing the area of land exposed to given noise levels is to select the optimal flight profile as illustrated on figure 8. The perceived noise contours for takeoff of a 60-passenger aircraft (quiet helicopter type) are shown for four different flight profiles: takeoff from ground at 45°, 25°, and 10° angles with the ground and takeoff from an elevated V-port (500 feet above ground) at 25° with the ground plane. The aircraft power settings were assumed to be constant for all profiles. Aircraft using steeper takeoff angles expose less land area to a given noise level. Takeoff from a 500-foot tower or building considerably reduces the noise levels on the ground in the immediate area of the elevated V-port when compared with the nonelevated takeoff from the same ground point. These reductions in noise level are substantial only within a radius of approximately the tower height. At locations greater than this radius, the advantages of elevating the takeoff point rapidly diminish. Elevated V-ports, if sufficiently high, do offer one means of reducing the community exposure to the highest VTOL noise levels. Of course, if such an elevated facility were considered for a downtown location in the proximity of other tall structures, such as office buildings, the exposure of the occupants would have to be considered. Such other structures probably should be separated from the elevated V-port by a distance at least equal to 1.5 times the elevation of the V-port.

Since we assumed a 1500-foot cruise altitude, some of the contours shown in figures 6 and 7 touch the ground during the cruise portion of the flight. If a sufficiently large number of such flights pass over the same geographic areas on a regular basis, then the response of communities in such areas must be considered as part of the VTOL aircraft noise problem. Moving the flights to higher altitudes would appear to be an easy solution to reduce the noise; however, the effects on cost, performance, and traffic control are other considerations.

SECTION IV.

Reaction of Community to Noise

One procedure for evaluating the response of residents to aircraft noise is based on developing perceived noise level contours for each type or class of aircraft. Although this procedure is now applicable only to residential noise problems, CTOL aircraft, and helicopters, much of its logic and methodology bears directly on the potential community noise problems with VTOL aircraft. Following are some of the factors that must be considered in estimating community response (reference 6 contains a detailed description of the procedure).

The reaction of a community to a given pattern of noise stimuli depends on many factors. The magnitude, duration, and repetition frequency of perceived noise are all important. Starting with the perceived noise levels for each class of aircraft, correction factors can be added which take these operational factors into account (e.g., number of flights per day, time of day) obtaining a composite noise rating (CNR). The CNR is a measure of the probable response of residents located at that point. The relationship between CNR and response was empirically established through actual studies of community exposure and reaction patterns at conventional airports.

A procedure similar to the one described above will have to be developed and applied to V-port operations in order to fully evaluate the community noise problems for each proposed V-port or for characteristic classes of V-ports (or for that matter to evaluate the impact of VTOL aircraft operations at conventional airports).

The present very general discussion of the potential community noise problems to be expected from some future VTOL concepts indicates clearly that noise is likely to develop into a major problem area unless long-range planning not only with respect to the aircraft as such but with respect to the V-port and the overall transportation system is properly executed.

SECTION V.

Noise and Military VTOL Aircraft

Military VTOL aircraft noise problems will be somewhat different from those of their civil counterparts. Military missions will not generally require landings and takeoffs on a regular basis in densely populated urban or suburban areas – at least not under peace-time conditions. Consequently, the military VTOL aircraft will not pose the difficult community noise problems associated with civil V-ports.

Many of the noise-induced problems concerning crew and passenger protection, structural reliability, communications, etc., however, will be substantially the same as for civil VTOL aircraft.

For some missions, enemy detection of the noise from military VTOL aircraft will be of concern. Three major factors determine the distance at which aircraft can be aurally detected: (1) the spectrum and directivity of the noise produced by the aircraft, (2) the effect of the atmosphere and ground cover in attenuating this radiated noise, and (3) the background noise present at the listener. These factors must be considered in the design and selection of special VTOL aircraft when absence of detection is important to the military mission requiring the aircraft.

SECTION VI.

Conclusions and Recommendations

The main purpose of this report has been to identify and define the character and magnitude of the potential noise problems associated with future VTOL aircraft. We have primarily focused on the radiation of noise into communities adjacent to civil V-ports, since this problem will be the most difficult and demanding of solution.

Noise must be fully considered along with aircraft performance, economy, safety, traffic control, etc., in the design, development, and testing of VTOL aircraft; otherwise, noise considerations will ultimately impose stringent limitations on the usefulness of VTOL aircraft.

A thorough and adequate analysis of the noise problems presented by future VTOL aircraft will require additional or new research in several areas. The physical acoustical characteristics of propulsive systems considered for VTOL aircraft must be better defined. Theoretical and experimental studies of the noise fields produced by ducted fans, tilt-wing props, jet-lift systems, supersonic propellers, etc., are required; data are needed especially on the noise radiation during the transition phase between vertical and horizontal flight. Research is also required to improve and expand present methods for evaluating subjective response to the problem of evaluating VTOL noise. The spectral and temporal patterns will be somewhat different from those of present-day aircraft and consequently human response to such noise will differ.

The basic laws of noise generation by the various propulsive devices for lift and thrust have been studied and are known. Major technological breakthroughs will not result from additional research on noise generation nor can significant relief from the predicted noise situations be expected from additional research on noise control and on human reaction to noise exposure. Available knowledge must be used in the planning and design of the overall transportation system. It is not fair to place the whole burden of noise on the aircraft alone; ground facilities must be considered part of the system. Although no miracles can be expected, continued noise research will continue to help in the design of quieter aircraft, to find the best compromise, and to sharpen our engineering prediction. Such research must be an essential continuing part of progress in aviation technology. The noise problems which exist today at some airports were clearly predictable at the time the airports were built or at the time the introduction of the new aircraft was planned. In spite of certain gaps or uncertainties in our knowledge, the future noise problems of VTOL aircraft based on designs presently discussed are known today. These problems can only be solved if they are realized today and realistically considered in the overall design and through an active continuing research effort.

Some VTOL propulsive systems are inherently more noisy than others. However, proper design and selection of propulsive systems can minimize noise generation, although undoubtedly at a cost in terms of performance, money, and other factors. Careful analysis must be made of the tradeoffs involved; the price of quieter propulsive systems must be paid if VTOL aircraft are to contribute their maximum usefulness to the transportation problems of tomorrow.

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13. ABSTRACT

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