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TECHNICAL NOTE

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NOISE CONSIDERATIONS IN THE DESIGN AND OPERATION OF V/STOL AIRCRAFT

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SUMMARY

Available propulsion-system noise data have been applied to the problems of design and operation of V/STOL aircraft. In particular, considerations have been given to minimizing adverse community reaction for operations between airports and to minimizing detection due to noise for special missions.

For minimizing adverse community reaction, configurations incorporating low-blade-loading rotors, low-tip-speed propellers, or turbofan-type engines are judged to be most satisfactory. For minimizing detection, consideration must be given to minimizing the noise of the generating airplane, having maximum background noise in the vicinity of the observer, and operating the aircraft at minimum altitude.

INTRODUCTION

References 1 and 2 are examples of the many papers which have dealt with proposed configurations and operating practices of V/STOL aircraft. Based on available experience for other types of aircraft, it is believed that the noise problems of V/STOL aircraft will be closely related to their design as well as to the manner in which the aircraft are operated. In the present paper, discussions are included on the noise characteristics of the various propulsion systems and aircraft configurations of interest for V/STOL missions. Design variables and operating conditions affecting the noise generated by this type of vehicle are first discussed from the standpoint of minimizing adverse community reaction and then brief attention is given to the problem of avoiding detection for special missions.

RESULTS AND DISCUSSION

Effect of Design Variables and Operating Conditions

Assessment of community reaction.- For the purposes of assessing community reaction, the calculated quantity perceived noise level (in PNdb) rather than sound pressure level is used as a basis for comparison. (See ref. 3.) The use of this concept can be discussed with the aid of figure 1. Shown in the figure are sound pressure levels in various frequency bands for propeller and turbojet noise spectra having equal overall sound pressure levels of 100 decibels. It can be seen that the frequency content differs, the greater high-frequency content being associated with the turbojet spectrum. In the perceived-noise-level calculation procedure, the higher frequencies are weighted more than the lower frequencies. For the examples shown in figure 1, this results in a value of 113 PNdb for the turbojet spectrum as compared with a value of 107 PNdb for the propeller spectrum. In order to attach some significance to the difference in the perceived noise levels of the two spectra, a 6-PNdb difference corresponds roughly to a factor of 2 in distance, at least for distances significant for landing and climbout operations. For instance, in the example cited the turbojet aircraft would need to be about twice as far from an observer to be judged equally noisy. The use of the PNdb concept with regard to airport community reaction has been verified, particularly for spectra such as those for propeller and turbojet aircraft. (See ref. 3.) For the purposes of this paper, the PNdb concept is also applied to helicopter noise spectra for which very little experience is available.

Propulsion-system noise generation.- Because of their configurations and the speed ranges in which they are operated, the main sources of noise of V/STOL aircraft are the propulsion systems. As an indication of the types of V/STOL configurations considered and the relative noise-producing characteristics of each, figure 2 has been prepared. In this figure is presented a bar-graph comparison of the perceived noise levels of four types of possible V/STOL configurations; namely, the pure helicopter, two jet-engine lifting types (turbojet and turbofan), and the tilt-wing turboprop. It is assumed that each of these vehicles is capable of carrying a 9,500-pound payload. The data are estimated for an observer station on the ground with the vehicles in full transition in a 10° climbout condition at a distance of 500 feet. This distance of 500 feet was chosen for convenience; however, it is believed that the conclusion would not be markedly different for other distances significant for climbout operations. It can be seen from the extent of the bar graphs in the figure that there is a wide range of perceived-noise-level values depending upon the V/STOL configuration considered. There is also a range of noise levels for each configuration and the values depend on the range of performance variables. The effects of these variables (blade loading, jet-exhaust velocity, propeller-tip Mach number, etc.) on the perceived noise levels are shown in figures 3, 4, and 5 for the same operating conditions of figure 2 and are discussed in some detail in the following sections.

Helicopter rotors: It is generally realized that for conventional helicopters the exhaust noise of the reciprocating engines is one of the main noise sources. However, it is believed that in a properly designed turbine-powered helicopter, the engine noise can be reduced to the point where it can be assumed that the main source of noise is due to the shedding of vortices from the rotor. (See ref. 4.) The data of figure 3 indicate the nature of this rotor-noise problem and the variables that are significant in noise generation. Perceived noise levels are plotted as a function of blade loading for a range of rotor-tip speeds. It can be seen that the perceived noise levels decrease with decreasing tip speed and with decreased blade loading. The shaded region indicates combinations of rotor-tip speeds and blade loadings that are of current practical interest. For such designs a sizable reduction in tip speed might not be feasible because of the proximity to stall. A more promising approach to reducing the noise would be to decrease the blade loading by the use of additional rotor solidity.

Measurements have indicated that helicopter rotor noise fluctuates in amplitude at a rate corresponding to the blade passage frequency. (See ref. 4.) In the application of the PNdb concept to helicopter rotor noise, no attempt has been made to account for this phenomenon. It is thus believed that the PNdb values for the helicopter of figures 2 and 3 may be lower than they would be if this amplitude modulation effect were properly accounted for.

Jet engines: In the case of the jet-powered V/STOL aircraft, the noise is due to the mixing of the jet exhaust with the ambient air and the nature of this problem is illustrated in figure 4. (For example, see refs. 5, 6, and 7.) Perceived noise levels are shown on the vertical scale as a function of the average jet-exhaust velocity. Data are included for a range of velocities significant for conventional turbojet engine operation (nonafterburning), turbojets with afterburning, and the turbofan engine. It can be seen from the curve that jet velocity has a very strong influence on jet-exhaust noise production and accounts for a wide range of noise levels. Also, it can be seen that the higher noise levels are associated with the high jet-exhaust velocities of the turbojet engines with and without afterburning.

The portion of the curve corresponding to the turbojets without afterburning has been fairly well established, based on present-day operating experience. The use of suppressors of the type now available results in noise reduction of the order of 4 PNdb. (See refs. 3, 7, 8, and 9.) The present trend, however, is toward the turbofan engine with its large potential noise reduction due to its inherent low jet-exhaust velocity. (See refs. 6 and 7.) Experience with the earlier version of the turbofan engine indicates that the PNdb values are generally higher than those presented in figure 4. These higher noise levels are believed to be due to the combined effects of fan noise and incomplete mixing of the primary and secondary air. (See ref. 6.) Recent advances have been made toward improving the noise characteristics of these engines (ref. 7), and it is believed that the noise levels will finally approach those represented by the turbofan curve shown in figure 4.

Propellers: In the case of turbopropeller aircraft, particularly for the case where compressor and accessory noises are minimized, the main noise source is the propeller. The nature of the propeller-noise problem is illustrated in figure 5. Perceived noise levels are plotted as a function of propeller-tip Mach number M_t for various numbers of blades. The curves have been estimated assuming four propellers of 17-foot diameter absorbing a total of 8,500 horsepower. (See ref. 10.) It is seen that noise may be reduced by either reducing the propeller-tip Mach number or by increasing the number of blades, or both. Most of the proposed high-powered vehicles incorporate four-blade propellers, and it is felt that an increase in the number of blades would result in relatively small noise reductions in addition to lending added complexity. Noise reduction might be more practically achieved by reducing propeller-tip Mach number.

It should be realized that substantial noise reductions for any of the propulsion systems discussed are usually accompanied by performance penalties and these would have to be evaluated for any particular configuration under consideration.

Ground noise patterns.- In order to discuss some of the operational practices that are useful in controlling the noise patterns on the ground, a tilt-wing V/STOL airplane incorporating a turbopropeller propulsion system and capable of carrying a 9,500-pound payload will be used as an example in figures 6, 7, and 8. Such an aircraft as this would have the capability for a wide variety of take-off profiles, two of which are illustrated for comparison in figure 6. As illustrated, the pilot would have the option of throttling back in power and tip speed and still be able to climb at a 10° geometric angle or of maintaining full take-off power and climbing at a 20° geometric angle. In the 20° climb-out condition, the airplane would not be in full transition to the forward flight configuration in order that the floor angle in the cabin could be maintained at an acceptable value for the passengers.

The 105-PNdb ground noise contour patterns for take-off have been calculated for the two cases illustrated in figure 6, and these results are plotted in figure 7 along with comparable data for a conventional propeller-driven transport airplane having a gross weight of about 130,000 pounds. (See ref. 3.) The 105-PNdb contour was arbitrarily chosen as a basis for comparison and may not necessarily be an acceptable level in all communities near airports for this type of operation on a round-the-clock basis. Regardless of the PNdb level chosen to be acceptable, it is felt that the conclusion would not be significantly changed. It can be seen that the reference contour line for the conventional airplane extends out laterally from the flight track approximately 1,600 feet in each direction and extends about 12,000 feet from the point of lift-off. The contours for the V/STOL aircraft extend out to about the same distance laterally but both are foreshortened considerably in the longitudinal direction. It can also be seen that the extent of the ground pattern for the V/STOL aircraft is minimized when the climbout is made at the lower angle. This latter result arises because of the lower horsepower required and because of the additional beneficial effects of a reduction in tip Mach number from 0.76 to 0.61.

Similar data are plotted in figure 8 for the landing approach configuration of the V/STOL aircraft at a 6° geometric angle. Data are shown for a given power rating but for two different propeller-tip Mach numbers M_t, and the results are again compared with available data (ref. 3) for a conventional present-day propeller transport aircraft. It can be seen that at the higher tip Mach number the ground contour extends farther laterally and longitudinally than the corresponding ground contour for the conventional aircraft. At the lower propeller-tip Mach number, however, the resulting ground contour encompasses less area than that for the conventional airplane and extends a shorter longitudinal distance.

Based on a knowledge of the basic noise characteristics of the various V/STOL aircraft of figure 2 and the manner in which they would be operated (ref. 2), some ground noise contours have been calculated for both the landing and take-off conditions. The results for these calculations for the 105-PNdb ground noise contours are presented in table I. In these calculations, a 6° approach angle and a 10° climbout angle were assumed. The sketch at the top of table I includes a runway and it has been assumed that landing and take-off are accomplished in the same direction. The dimension l is the total longitudinal distance covered by the 105-PNdb contours and the dimension w is the maximum lateral extent. The distances l and w are given in the table for the various V/STOL configurations considered. It will be noted from the results of reference 2 that for the approach angles considered for the V/STOL configuration the associated approach speeds are considerably lower than those for present-day propeller and jet transport aircraft. In the calculations for table I, 3 PNdb have been added to the perceived noise levels for a given operating condition for each halving of the approach speed in an attempt to account for the associated longer duration of noise exposure. Also included in table I are the distances associated with the operation of a conventional propeller airplane of reference 3. These distances are considered to be representative of current experience.

It can be seen from table I that the smaller distances are associated with the V/STOL turboprop and helicopter and that the larger distances are associated with the jet-powered vehicles. The data also indicate that the noise patterns associated with V/STOL aircraft do not exceed in extent those of a conventional present-day propeller transport aircraft. This result suggests that from a noise standpoint, V/STOL aircraft could probably operate satisfactorily into and out of conventional airports. If, however, operations are proposed for smaller area short-haul terminals, then the ground distances involved may constitute a serious problem in land acquisition.

It should be noted that in the case of operation of V/STOL aircraft which are sensitive to wind direction so that take-off and landing operations may have to be accomplished in many directions, the term w may not be significant and the term l would apply in all directions. An additional problem, not discussed in this paper but which may be of concern in the operation of V/STOL aircraft, is the generally higher noise levels anticipated within the terminal areas.

Detection of Aircraft by Means of Noise

The detection of aircraft by means of noise is of particular concern for vehicles such as V/STOL aircraft which might be used in special tactical missions. Recently, some studies have been made to determine how far a propeller airplane could be detected by hearing. (See ref. 11.) Based on this experience some estimates have been made of the detection distances of a four-engine V/STOL turbopropeller aircraft of 6,000 horsepower and having a propeller-tip Mach number of 0.53. The basic concepts involved are illustrated in figure 9. The noise levels in the various frequency bands are shown for the airplane at various distances and also for two assumed background noise spectra at an observer station - one associated with the noise of a residential area of a city and the other (the lower curve) with that of a quiet countryside (ref. 11). The data for the top dashed curve were estimated for the aircraft at a distance of 500 feet. The data for the aircraft at the other distances were calculated based on the values for 500 feet and by including atmospheric propagation losses (ref. 12).

It can be seen that the atmospheric losses attenuate the high-frequency parts of the spectra at a more rapid rate than the low-frequency parts.

For the purposes of this discussion it is assumed that detection is possible when any portion of the airplane noise spectrum lies above the background noise spectrum. For the conditions of a background noise corresponding to a residential city area, this detection distance is approximately 50,000 feet, and it appears that the frequency band of 300 to 600 cps is most significant in this particular case. For some special cases where the noise has distinctive characteristics, detection may be possible at greater distances. It should be noted that this detection distance is a function of the three main variables; namely, the background noise conditions at the observer station, the noise characteristics of the airplane, and the noise propagation phenomena involved. The manner in which detection distance is affected by each of these variables, zero wind being assumed, is shown in figures 10 and 11.

As previously noted, the atmospheric propagation losses are a significant part of the detection problem. There are also significant effects of terrain, and these effects are illustrated in figure 10. Shown in the figure are combinations of altitude and horizontal distance for which detection is possible, that is, areas within the curved boundaries. It has been found that when the elevation angle measured from the observer to the airplane is 7° or greater, atmospheric effects are significant and this determines the shape of the boundary curve, in this case above an altitude of about 3,000 feet. At lower elevation angles, terrain effects become significant and they determine the shape of the lower portion of the boundary curve (ref. 11). The dashed-line boundary corresponds to conditions of open terrain, whereas the solid-line boundary corresponds to conditions of heavily wooded terrain. The shaded region between these curves is thus an indication of the order of magnitude of the effects of the type of terrain. The effects of terrain, therefore, are such that they greatly reduce the distances over which detection is possible for low elevation angles.

The manner in which the background noise level and engine operating conditions may affect the detection distances is indicated in figure 11. Boundary curves are shown for areas where detection is possible for the case in which the condition of heavily wooded terrain is assumed. The lower boundary curve indicates the detection distances for the aircraft at the high-speed cruise condition for a background noise corresponding to a residential area of a city. For the same background noise level, reducing the power and propeller-tip Mach number results in the middle boundary curve. It can be seen that this low-speed cruise condition generally results in large reductions in the detection distances at a given altitude. Assuming this low-speed cruise condition and an increase in the background noise level of about 10 db to a level representing city traffic leads to further reductions in the detection distances, as indicated by the boundary curve at the left.

The manner of operation of the aircraft and the background noise conditions at the observer station are seen to have rather large effects on the detection distances for the intermediate range of airplane altitudes. However, if the airplane is operated at minimum altitude, the range of detection distances is seen to be relatively small for the wide range of operating conditions and background levels assumed.

It should be noted that the actual detection distance in the presence of wind will be either less than or greater than those indicated in figure 11, depending on whether the observer is upwind or downwind, respectively, of the generating aircraft. (See ref. 11.)

CONCLUDING REMARKS

Operating procedures and design concepts in the interest of noise reduction for several V/STOL aircraft have been discussed from the standpoint of minimizing adverse community reaction for operations between airports and avoiding detection for special missions. For minimizing adverse community reaction, configurations incorporating low-blade-loading rotors, low-tip-speed propellers, or turbofan-type engines are judged to be most satisfactory. For minimizing detection, consideration must be given to minimizing the noise of the generating airplane, having maximum background noise in the vicinity of the observer, and operating the aircraft at minimum altitude.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 18, 1960.

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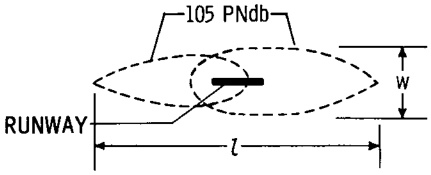
TABLE I

EXTENT OF GROUND CONTOURS



CONFIGURATION	l, MILES	w, MILES
HELICOPTER	1.2	0.3
TURBOPROP	1.5	.6
TURBOFAN	3.0	.8
TURBOJET	4.0	1.0
CONVENTIONAL PROP	4.5	.7

COMPARISON OF PERCEIVED NOISE LEVELS FOR TWO SPECTRA HAVING EQUAL OVERALL SPL

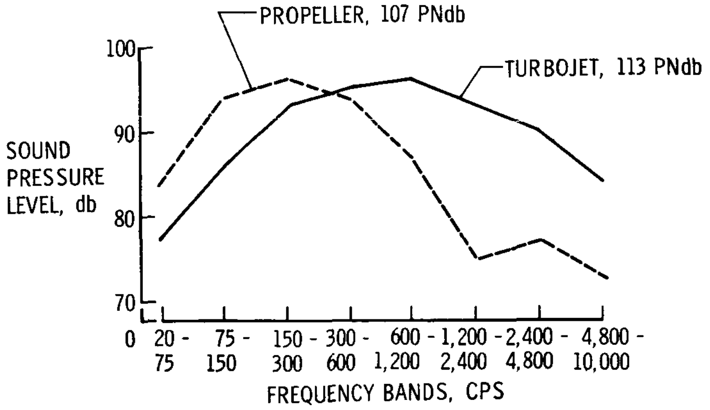


Figure 1

RANGE OF NOISE LEVELS OF V/STOL CONFIGURATIONS

PAYLOAD = 9,500 LB

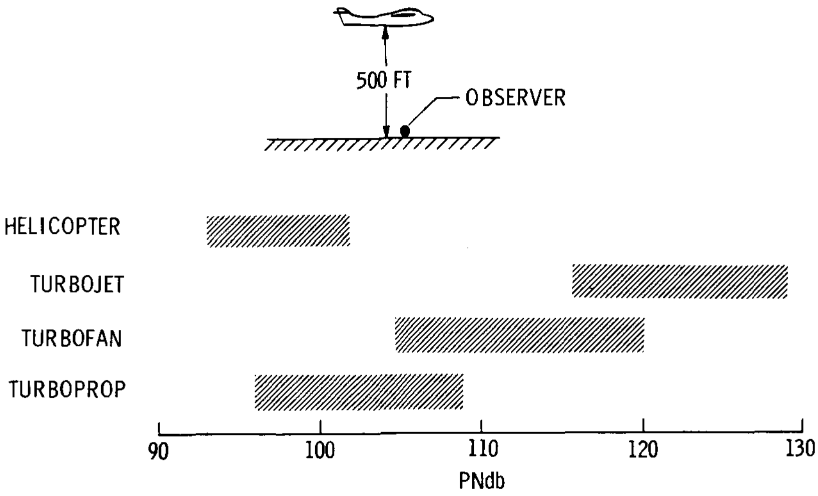


Figure 2

NOISE CHARACTERISTICS OF HELICOPTER ROTORS

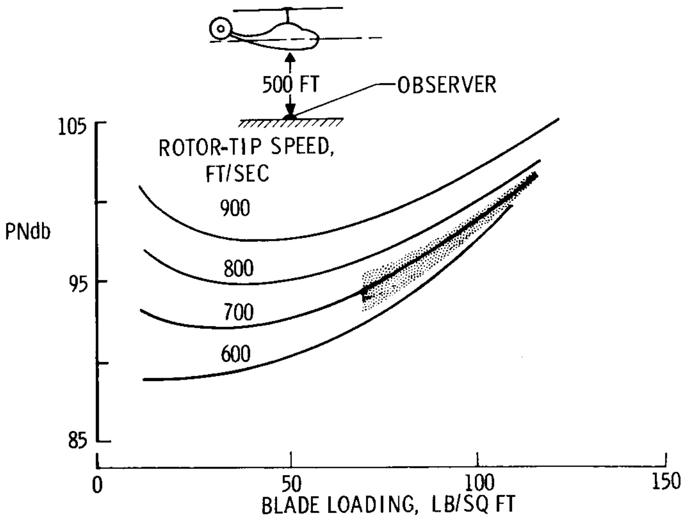


Figure 3

EXHAUST NOISE FROM JET ENGINES

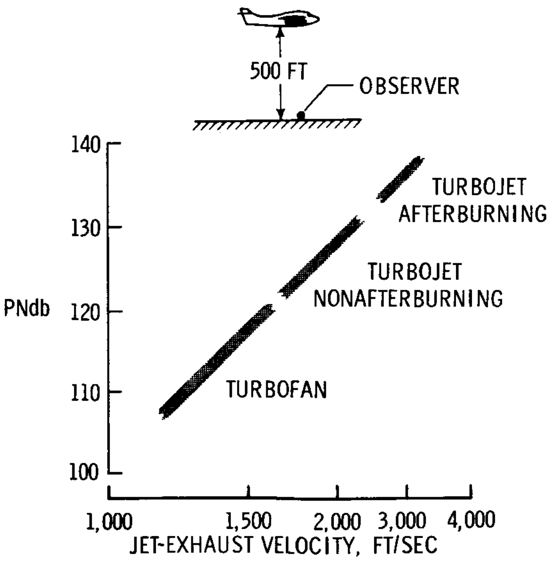


Figure 4

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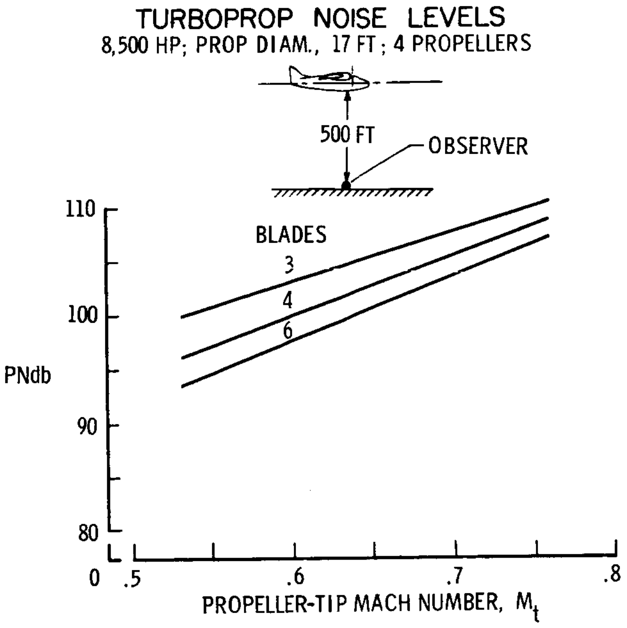

Figure 5

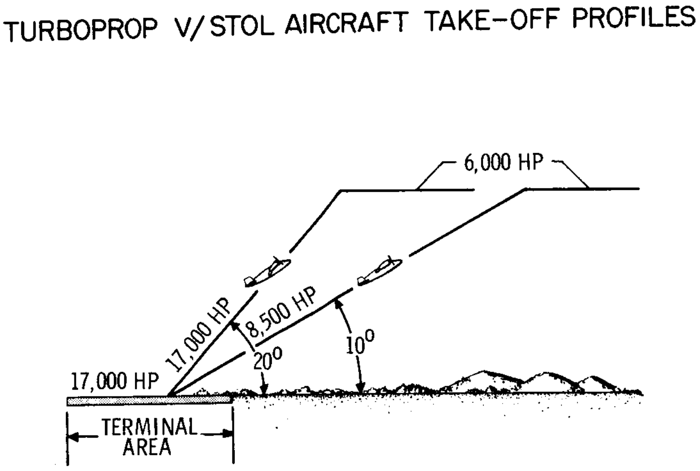

Figure 6

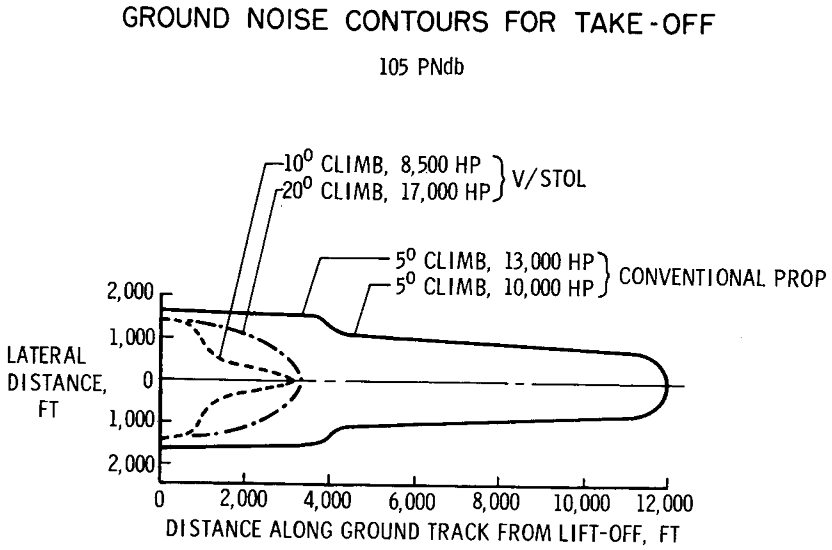

Figure 7

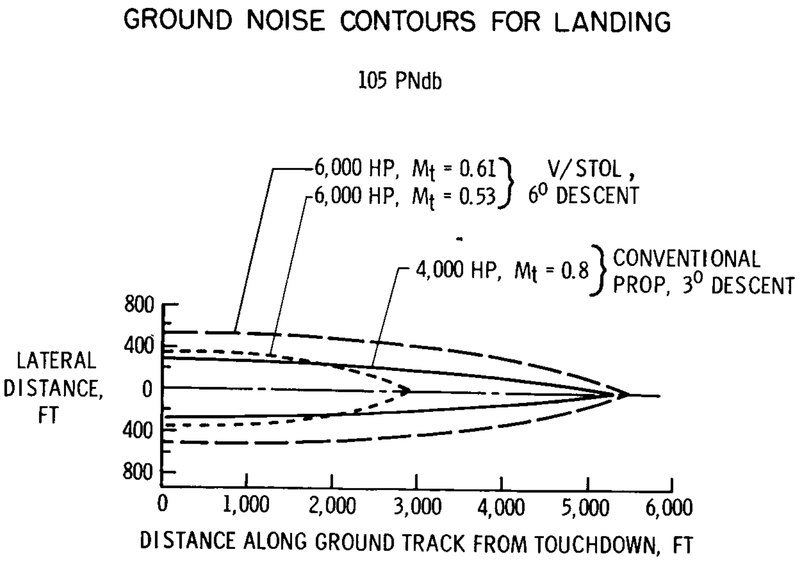

Figure 8

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NATURE OF DETECTION PROBLEM FOR
V/STOL TURBOPROP AIRPLANE

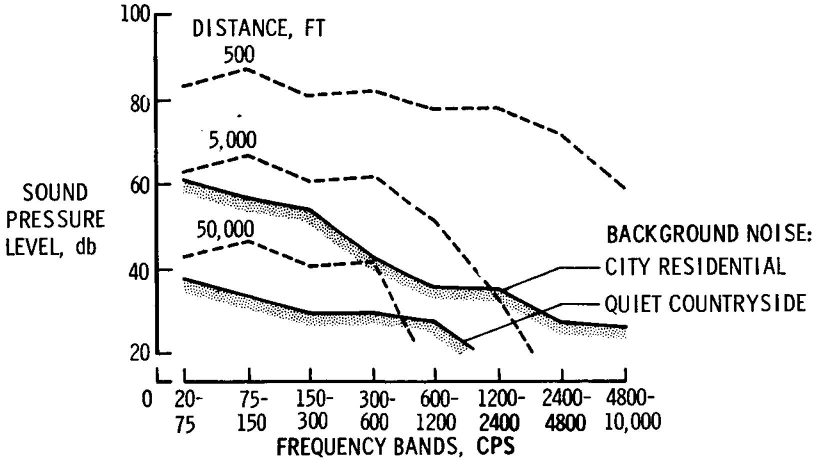

Figure 9

DETECTION DISTANCE FOR V/STOL TURBOPROP AIRPLANE

EFFECT OF TERRAIN

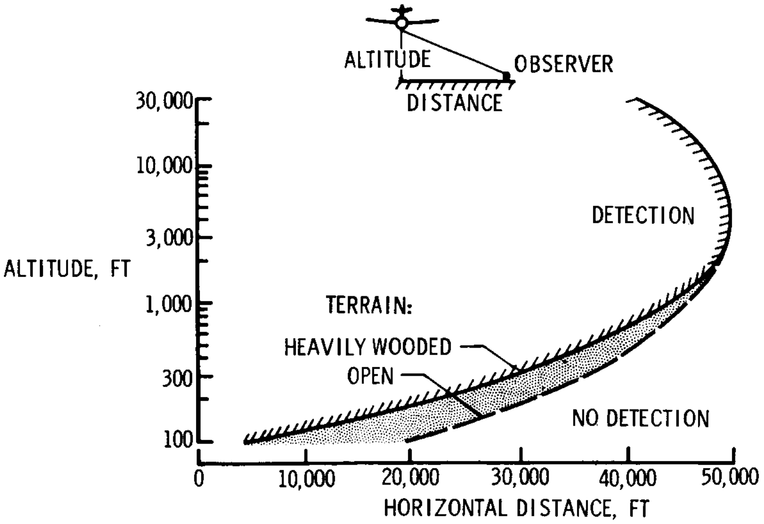

Figure 10

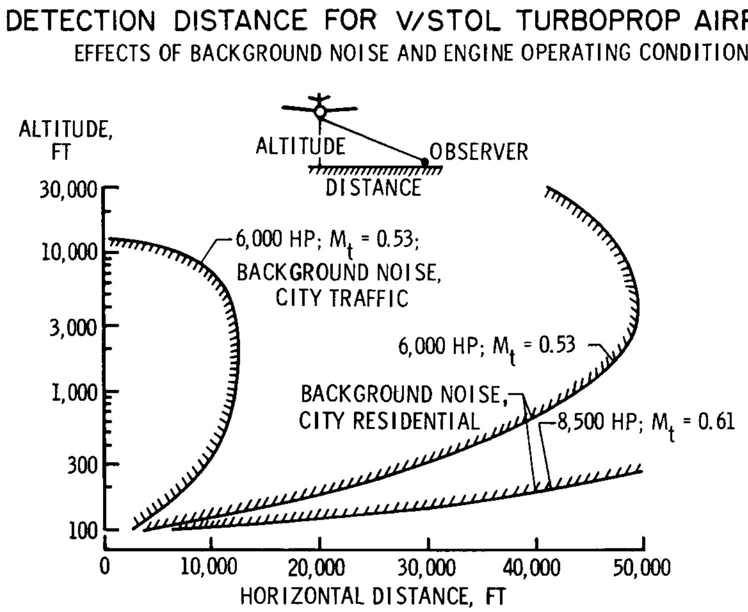

Figure 11

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