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V/STOL CHARACTERISTICS IN RELATION TO TERMINAL REQUIREMENTS

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SYNOPSIS

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V/STOL aircraft, if they are to be used effectively in the air-transport system, will require special terminals and support facilities such as do not presently exist. The location and design of these terminals - or V-ports - will be governed by land and construction costs, convenience of the using public, acceptability to the neighboring communities, and the operational capabilities and limitations of the aircraft. This paper is concerned with the operational characteristics of V/STOL aircraft as they might influence the terminal requirements. In particular, consideration is given to take-off and landing characteristics, noise propagation, downwash characteristics, sensitivity to wind and instrument-flight factors. Two hypothetical V/STOL transports - one powered by a turboprop system and the other by a jet system - are described to serve as examples. The V/STOL aircraft characteristics are finally discussed in relation to a hypothetical terminal arrangement.

Author

INTRODUCTION

The V/STOL (vertical or short take-off and landing) class of aircraft appear to have a reasonably assured future in commercial air transport. A substantial research and development effort has already and will continue to improve their efficiency, reliability, and handling characteristics to the point where civil transport use should be practical. Wholesale supplanting of conventional aircraft operations is not, however, envisioned. Economic considerations suggest that the primary inroads of V/STOL aircraft will be in the short-haul market where the advantages of their city-center to city-center capability may offset their higher operating costs.

In order to exploit the unique capabilities of V/STOL aircraft in civil transport, special terminal facilities will be required. The size, arrangement, and location of these terminals, or V-ports, and support facilities will be dictated, in a large measure, by the operational capabilities and limitations of the aircraft. The purpose of this paper is to examine some of the operational characteristics of V/STOL aircraft in relation to the influence they may have on terminal facilities requirements. Primary consideration is given to take-off and landing performance, noise generation, downwash characteristics, and requirements and limitations imposed by all-weather operations.

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GENERAL CONSIDERATIONS

Although the economics of V/STOL operations are beyond the scope of this paper, some attention to this factor is needed insofar as it bears on the likely locations of V-ports. In a study for the Federal Aviation Agency,[1] the Stanford Research Institute has concluded that the initial and primary utilization of V/STOL aircraft will be in short-haul traffic - say up to 500 to 750 miles - between city centers, where convenience, the value of time saved, and reduction of airport to city-center transportation costs can balance the higher operating costs of V/STOL relative to conventional aircraft. Effective application of V/STOL aircraft, therefore, will require the establishment of terminals as close to city centers as possible - say 10 to 15 minutes by taxi.

The possibility exists, also, that V/STOL aircraft may operate from specially prepared areas of existing airports, apart from the conventional aircraft runways, to increase the capacity of the airports to meet growing traffic demands. The city-center V-port, however, appears to face the more stringent limitations, because of proximity to high buildings and dense population.

In order to compete successfully with conventional aircraft, the V/STOL aircraft must be capable of achieving an equivalent schedule reliability. In addition to adequate mechanical maintainability and reliability, this requirement means, of course, that the V/STOL aircraft must be able to operate to and from the V-ports with at least the same instrument flight minimums - ceiling and visibility - and winds as their counterpart conventional aircraft are capable of handling. For the purpose of this discussion it is assumed that, at the time that V/STOL aircraft enter commercial transport service, the FAA's Category II instrument landing system will be in use at most major airports, permitting landings of conventional airplanes with ceilings of 100 feet and visibility of 1/4 mile. Similar capability should, therefore, be expected of V/STOL aircraft and V-ports.

V/STOL AIRCRAFT CONFIGURATIONS

Although the term V/STOL technically includes helicopters, the considerations in this paper are directed to the type of aircraft which combine the capability of hovering flight with the ability to cruise at the high speeds of conventional airplanes. While this combination of talents requires some compromises in both flight regimes - hovering efficiency is less than for a helicopter, and cruising efficiency and payload fraction are less than for conventional airplanes - the aircraft, nevertheless, can perform missions of which neither of the other types are capable.

Many concepts of V/STOL aircraft have been proposed and a number of these have been incorporated in small experimental aircraft and tested in flight. Two of the types, a tilt-wing, turboprop and a lifting-engine jet are illustrated in figure 1 as they might appear as short-haul civil transports. Both types have been subjected to extensive study and appear to be promising to the extent that relatively large versions - 30,000 to 40,000 pounds - have been built for operational research. These two aircraft will be used as examples in the discussion of V/STOL characteristics.

Both aircraft are assumed to have design gross weights of 60,000 pounds, which should permit seating capacity of 50 to 60 and usable range of the order of 500 miles.

It should be noted that the airplanes in figure 1 are not intended to represent finalized designs, but only to illustrate principal features of the types and the approximate proportions they might be expected to have as short-haul transport aircraft.

Turboprop V/STOL

For hovering or vertical flight of the tilt-wing, turboprop airplane (fig. 1(a)), the wing, engines, and propellers are rotated as a unit, about a pivot in the fuselage, to a position 90° from the conventional position so that the propeller thrust is directed vertically upward. In the transition to cruising flight, the wing is gradually rotated down as the airplane accelerates until at a speed at which the lift of the wing alone is sufficient to sustain the aircraft, the wing and propellers reach the conventional cruise position. The reverse of this procedure is, of course, effected in deceleration from cruising flight. The wing is equipped with full-span high-lift flaps programed to deflect as a function of wing tilt, and serving to improve the flight characteristics and reduce the power requirement during the transition.

Control of the aircraft is obtained in the hover mode by differential pitch adjustment of opposite propellers for rolling, action of the ailerons immersed in the high-speed slipstream of the propellers for yawing, and a special controllable-pitch propeller mounted at the tail of the airplane for pitching. During transition the action of differential propeller pitch and ailerons is mixed to provide both roll and yaw control. Finally, when the wing has reached the cruise flight position, control is provided in the normal fashion by the usual aerodynamic control surfaces.

An important feature of the propeller-driven, tilt-wing aircraft arises from the interaction of the wing and propeller slipstream at slow forward speeds as in transition or short running take-offs and landings. This interaction results in a lifting capability which can be substantially greater than the combined lift of the propellers and wing if acting independently under the same power and speed conditions. This means, of course, that substantially less power is required at relatively slow forward speeds than for hovering.

For the example airplane it is estimated that an installed total power of 22,200 horsepower, would be required to allow for failure of one of the four engines during vertical take-off and landing on a hot day. To arrive at this figure, it was assumed that a margin of thrust over weight of 5 percent is required for control of hovering flight in take-off and that the engines have an emergency short time rating of 110 percent of rated take-off power.

As a matter of necessity, the four engines and propellers would be connected by cross-shafting and suitable gearing so that in the event of an engine failure, the remaining engines would drive all the propellers.

Jet V/STOL

The jet V/STOL type airplane illustrated in figure 1(b) would derive the greater part of its lift for hovering from groups of vertically alined turbofan engines mounted in pods on the wing tips. The two horizontal turbofan engines mounted on pylons under the wings are equipped with adjustable nozzles capable of vectoring their thrust vertically to contribute to hovering lift. The thrust of the lift engines is also vectorable to aid in accelerating or decelerating the aircraft in transition. In transition from hovering flight to cruise the thrust vector is rotated forward through a small angle, 10° to 20°, by deflection of the exhaust nozzles, to initiate forward acceleration. With a thrust available exceeding the airplane weight by 5 percent, a forward acceleration of as much as 10 ft/sec^2 can be developed while maintaining a vertical thrust component equal to the weight. When the airplane attains a forward speed such that the lift of the wings will support the airplane - say 100 to 120 knots - the lift engines are stopped, the doors of the engine compartments closed, and the nozzles of the two propulsion engines alined for forward thrust. The aircraft then proceeds as a conventional airplane.

In contrast to the tilt-wing V/STOL aircraft, the lift produced by the jets and that generated by the wings are essentially independent. The forward speed must therefore be relatively high before the jet thrust can be substantially reduced. Yaw and pitch control in hovering are accomplished with controllable reaction jets at the tail utilizing bleed air from the engines. Roll control is obtained by differential modulation of lift-engine thrust.

For the airplane of figure 1(b), the installed thrust required to provide for hot-day hovering with one lift engine inoperative is indicated to be a total of 84,000 pounds - take-off rating - distributed 6,000 pounds each to the 10 lift engines and 12,000 pounds to each of the two cruise engines. It is assumed that the engines have an emergency rating of 110 percent of take-off rating and provision is included for 5 percent excess thrust in hovering at take-off weight and for bleed air to power the control nozzles.

TAKE-OFF AND LANDING OF V/STOL AIRCRAFT

Space requirements for take-off and landing of V/STOL aircraft are a primary factor in appraising terminal requirements. The character of the take-off and landing are determined not only by the aircraft characteristics but also by the mode of operation adopted, which, in turn, will be influenced by a number of factors including safety, passenger comfort, and adverse weather considerations.

Three basic take-off and landing procedures are theoretically available with V/STOL aircraft as illustrated in figure 2. The vertical climb and descent procedure appear attractive, on the surface, since it would, presumably, permit operations from small areas in the heart of a city, such as parks or squares, surrounded by high-rise buildings. This procedure is not, however, considered practicable, at least in the present state of the art. One limitation is the inherent difficulty of precisely controlling a protracted vertical flight path,[2] particularly under instrument flight conditions, which V/STOL transport operations will have to accommodate to - probably to within 100 feet from the ground, on occasion. Another problem with this type of operation lies in the added fuel consumption that would be involved because of the increased time required at hovering power levels. The vertical climb and descent type of operation will, therefore, not be considered further in this discussion, although advances in technology may, ultimately, make it feasible.

The vertical lift-off and touchdown technique, utilizing a sloping climb or approach path, with the vertical phase limited to heights of about 50 feet, which will be referred to hereafter as VTOL operation, appears to be a practical operational procedure for V/STOL transports as it has been for helicopters. This procedure with the V/STOL aircraft would require that part of the transition process between hover and cruise configuration be accomplished in the early part of take-off and the final stages of landing, and would involve substantial variations in power.

The third procedure illustrated in figure 2, commonly referred to as STOL (short take-off and landing) has also been considered as a possibility for V/STOL aircraft operations. It consists of a short run on the ground before lift-off or after touchdown with a flare stage between the ground run and the sloping climb or approach path. This procedure offers some advantages in that configuration changes in the initial stages of take-off or the final stages of landing are minimized - thus alleviating the pilot's task - and power requirements are less, at least to some degree, than for vertical or hovering flight.

The latter two procedures will be compared in examining the take-off and landing characteristics of V/STOL aircraft in the next section and later in relation to noise considerations.

Turboprop Aircraft

Estimated take-off and landing profiles (height versus distance) and power requirements for VTOL and STOL modes of operation of the example turboprop airplane are shown in figure 3. The landing weight of the airplane is assumed to be 90 percent of the take-off weight. Speeds at various stages in the operations are indicated along the profile curves. The results given are based on wind-tunnel data - not yet published - for a similar configuration, together with some assumptions as to operational limitations. For take-off, it was assumed that, for reasons of passenger comfort, where not limited by aircraft capabilities, the climb path should not exceed 10°, and that the longitudinal acceleration component imposed on the passengers (including the component of gravity along the flight path) should not exceed 0.3g. For the VTOL take-off it was assumed that the pilot would level off his flight path briefly at

25 feet after the vertical lift-off in order to increase speed and establish his course before initiating climbout.

For landing the final approach path angle of 6° assumed in figure 3(b) represents a compromise between obstacle clearance considerations, which call for as steep an angle as possible, and all-weather operating requirements which tend to call for moderate approach angles. Flight experience with helicopters and other aircraft has indicated that instrument approaches at 6° glide slope are feasible but that the task becomes more difficult as the approach path becomes steeper.[2] Furthermore, at a given approach speed the time available, after breaking through a low ceiling, for the pilot to become visually oriented and complete his landing is greater, the flatter the glide slope.

The final approach to landing was assumed, as indicated in figure 3(b), to be made at a constant speed of 45 knots with fixed airplane configuration (so as not to complicate the pilot's task in instrument approach) down to the point at which transition to the hover mode must be resumed for the VTOL operation or the initiation of flare for the STOL mode. The flight path in the VTOL landing is shown leveled briefly just before the vertical stage since it is believed this procedure would provide better control of the touchdown point.

The results in figure 3 indicate that the maximum power required for STOL take-offs and landings is substantially less than for VTOL - on the order of 35 percent less for take-off and 45 percent less for landing for the cases shown. The greater horizontal distances required to climb to or descend from a given height for the STOL relative to the VTOL operations is indicative of the larger take-off and landing area that would be required for STOL-type operation. The reduced power requirement for STOL take-offs and landings would mean that an STOL version of the aircraft would be lighter for a given payload, hence more economical than the VTOL machine. However, this advantage would have to be weighed against the increased costs of the larger take-off and landing areas that the terminals would have to provide for STOL operation.

The VTOL landing profile of figure 3(b) indicates that the deceleration and transition to hovering condition from the steady approach state takes place in about 100 feet of descent, hence, could, presumably, be accomplished visually after breaking out through a 100-foot ceiling. The horizontal distance covered during this interval is about 900 feet. The VTOL landing for the conditions indicated would therefore be compatible with the Category II minimums of 100 feet and 1/4 mile - that is, under these conditions, the pilot could perform the final transition and deceleration within sight of the touchdown point.

For the STOL landing, under the same weather minimums, the touchdown point would be in sight 10 or 12 seconds before flare initiation which would be sufficient time for the pilot to become oriented and make final path adjustments.

Jet Aircraft

Corresponding information on the take-off and landing characteristics of the example jet V/STOL aircraft to that just discussed for the turboprop airplane are presented in figure 4, and are based on similar assumptions as to operational procedures and limitations. The VTOL take-off and landing profiles are generally similar to those for the turboprop airplane. The most noteworthy difference between the results for the two airplanes is in the relation between VTOL and STOL operation. Although some reduction in maximum thrust requirement is indicated for the jet STOL take-offs and landings, the penalty in horizontal distance covered to or from a given height is greater in relation to the thrust reduction than was the case for the turboprop aircraft, for the reasons cited earlier. STOL operation for the jet aircraft appears less attractive from this standpoint than for the turboprop machine.

As in the case of the turboprop aircraft, figure 4(b) indicates that the landing in either VTOL or STOL mode could be made satisfactorily with Category II minimums.

NOISE CONSIDERATIONS

The noise problem which is plaguing some of the large airports serving jet transports, is likely to present even greater difficulties for V/STOL city-center operations because of the high power or thrust output required in take-off and landing, the need to locate the terminals as close to the heavily populated city-centers as possible, and the longer duration of noise because of the low speed of the aircraft. In the case of V/STOL operations the noise on the V-port itself may be an important consideration because of the relative nearness of the take-off and landing areas to the passenger terminal and boarding gates. This noise aspect as well as the fly-over noise that may be imposed on the surrounding city will be discussed in this section.

Ground Noise

The noise levels created by the aircraft at the maximum power or thrust settings utilized during take-off and landing (figs. 3 and 4) have been estimated in terms of Perceived Noise decibels (PNdB) at various lateral distances from the airplane track, for both the turboprop and the jet aircraft, and for the STOL and VTOL modes of operation. The computations of jet noise were based on standardized procedures[3] for predicting sound-pressure levels and for converting to the Preceived Noise scale. The turbofan engines were assumed to have a bypass ratio of 1.3:1 and the primary jet and fan exhausts were conservatively treated as separate. For the turboprop aircraft, the noise estimates were based on the measured sound-pressure spectrum of a large transport airplane corrected to the dimensions and operating conditions of the V/STOL aircraft propellers by means of the propeller noise charts of Hubbard.[4]

The estimated ground or side-line noise levels are given in figure 5(a) for take-off and in figure 5(b) for landing. The noise level of 105 PNdB is shown as a reference level. This choice of reference is somewhat arbitrary inasmuch as no criteria for acceptable noise levels for city-center V/STOL operations have been established. A perceived noise level of 112 PNdB is currently in force at New York Port Authority airports as the limit for noise imposed on the surrounding communities in take-off of conventional airplanes, but in other areas, limits have been set as low as 105 PNdB for night operations.

Furthermore, since the duration of noise from V/STOL aircraft will be longer - perhaps two to three times - than for conventional airplanes, because of the speed difference, the level of acceptable noise is likely to be substantially less for the V/STOL's.[5]

For the turboprop airplane the STOL noise levels are somewhat less than the VTOL for both landing and take-off because of the lower power required. In all cases, however, the 105 PNdB level is reached at distances between 450 and 550 feet from the airplane, so that to keep the noise down to this level at the passenger terminal, the take-off and landing area would have to be at least this order of distance away.

The jet aircraft produces a much higher level of noise than the turboprop, both in landing and take-off. The STOL noise levels are, again, less than for VTOL operation, but in no case is the 105 PNdB level reached even at 1,000 feet from the airplane. The implication, of course, is that the dimensions of a V-port to accommodate the jet V/STOL would tend to be considerably larger than for turboprop aircraft, if terminal noise is an important consideration, unless suitable means can be found to greatly reduce the noise output of the turbofan engines without undue weight penalty, or effective acoustic shielding of the terminal building and gates could be provided.

Fly-Over Noise

The fly-over noise levels - i.e., the noise produced at ground level beneath the aircraft in flight - has been computed for extensions of the take-off and landing profiles and the corresponding power or thrust conditions of figures 4 and 5. The estimates were made in accordance with the same basic procedures as for the ground noise. The perceived noise levels on the ground (or at the same elevation as the V-port runway, if above ground level) are shown for take-off as a function of distance from the take-off starting point in figure 6(a), and for landing as related to distance from the stopping point in figure 6(b).

In this case - fly-over noise - the STOL procedure creates the greater noise level, particularly near the take-off or landing area, because the lower height at a given distance from start of take-off or end of landing more than offsets the effect of any reduction in power or thrust realized with STOL as compared to VTOL operation. The landing noise is generally higher than for take-off because of the lower flight-path angle of landing approach (6°) relative to take-off climb angle (10°). The turboprop noise reduces to the 105 PNdB level at the ground at a little over a mile from take-off start and about $1\frac{1}{2}$ miles from the stopping point in landing.

The jet aircraft noise is again substantially greater than for the turboprop aircraft. The greater difference between landing noise and take-off noise for the jet aircraft results from the low-speed fixed-configuration approach assumed for instrument landing, which requires a relatively high thrust level for the jet aircraft throughout the final approach. (See fig. 4(b).) For take-off, on the other hand, it was assumed that the transition and acceleration to higher speeds, hence lower thrust-required and less noise, could be performed in the climbout. In take-off, the jet noise remains above the 105 PNdB level for about $1\frac{1}{2}$ miles from the starting point. In landing, this noise level would be reached 2 to 3 miles from the landing point.

It should be noted that, if the aircraft must fly over high buildings in the take-off climbout or landing approach, the noise levels imposed on the upper parts of the buildings would be considerably higher than those indicated in figure 6. For example, in the case of the turboprop VTOL landing, the top of a 30-story building (300 feet) under the airplane path and about a mile from the take-off point would be subjected to a noise level of about 117 PNdB as compared to the 110 PNdB's indicated for ground level. In take-off at the same point, the noise level would be 111 PNdB. For this reason, then, if for no other, the choice of V-port location and/or V/STOL operating procedures should be such as to avoid, insofar as possible, the need to climb out or approach over tall buildings close to the terminal.

PROPELLER AND JET WASH CONSIDERATIONS

The downward-directed propeller slipstream or jet-exhaust of V/STOL aircraft has received considerable attention from the standpoint of the erosion of unprepared surfaces that they might cause,[6] and the attendant possibilities of engine and propeller damage by the debris thrown up. For commercial applications, it is unlikely that V/STOL aircraft will operate from other than paved surfaces, and therefore this problem should not be of great importance.

However, there are other problems associated with the slipstream or jet exhaust of V/STOL transports which may be important in considerations of terminal requirements. One of these problems lies in the considerable distance below the aircraft to which these high-velocity flows persist. This factor is illustrated by the curves on the left side of figure 7 which show estimated slipstream velocity of the turboprop aircraft and exhaust velocity of the jet airplane as functions of distance below the aircraft. The propeller-slipstream curve was determined from model propeller test results[6] adjusted to the size and power of the example V/STOL propellers. The jet-velocity curve and the jet-temperature curve shown in the right part of figure 7 were obtained from measurements with a full-size jet engine of about the same thrust output as the propulsion engines of the example jet V/STOL airplane. A velocity level of 75 mph - the hurricane wind level index - is indicated on the figure for reference. (Note the logarithmic velocity scale.)

The jet velocity greatly exceeds the slipstream velocity - about 7 times - close under the aircraft, but dissipates much more rapidly with distance below the aircraft until they are equal at a distance of about 100 feet and a velocity of about 100 mph; at greater distances the propeller slipstream velocity is considerably higher than that of the jet. The 75-mph level is reached at about 125 feet below the airplane for the jet exhaust but not until about 200 feet for the propeller slipstream. The temperature of the exhaust stream of the jet engine is indicated to be about 140° F at a distance of 100 feet below the aircraft.

These results indicate that the downwash characteristics should be taken account of, as in the case of noise, in considering V-port location and take-off and landing paths relative to the building arrangement of the city. An even more serious problem may lie in assuring protection of terminal buildings, parked aircraft, and boarding or disembarking passengers in a busy V-port, and could impose restrictions on take-off and landing procedures. More will be said about this factor later.

In the case of the jet V/STOL aircraft, the very high jet velocities - order of 1,000 mph - and the high exhaust temperatures - about 800° F - to which the runway surface might be subjected in the early stage of VTOL take-off or final stage of VTOL landing, introduces the possibility of damage, at least to some types of surfaces, with repeated exposure. Short running take-offs or landings would eliminate or substantially reduce the likelihood of damage, because of the much shorter exposure of any area of the surface. Special run-up areas with blast resistant surfaces or grating-covered pits would have to be provided for check-out of lift engines when needed.

SENSITIVITY TO WIND

Because of the necessarily low flight speeds of V/STOL aircraft in the take-off and landing operations, the effects on these operations of even moderate wind velocities and variability can be large. Probably the most important aspect of wind, insofar as terminal facilities requirements are concerned, is the sensitivity of the V/STOL aircraft to cross-wind component - i.e., wind component perpendicular to the available flight path. For example, an aircraft approaching for a landing at an along-track speed of 45 knots with a cross-wind component of only 10 knots would have a heading of about 13° from the direction of travel. In VTOL mode of operation, the heading offset from track direction or "crab" angle would increase as the aircraft decelerated further until it reached 90° at the hover stage. These effects on aircraft heading would considerably complicate the pilot's already sizable task of precise control of approach path on instruments and might cause some difficulty in the final transition to hovering after breakout, particularly in minimum ceiling and visibility conditions. For the STOL type of operation under the same conditions - 45-knot approach and 10-knot cross wind - a severe "decrab" or heading change of 13° might have to be made very precisely just before touchdown.

As indicated earlier, effective utilization of V/STOL aircraft will probably require operations under any wind velocities in which conventional airplanes would operate - possibly two to three times the 10 knots assumed above - and from practically any direction. The implication of the foregoing considerations is that the V/STOL terminal should be located and arranged so as to permit landings and take-offs in essentially all directions to avoid cross-wind difficulties.

Beneficial effects of wind can also be realized, of course, in V/STOL operations, if the aircraft can be operated directly into the wind. In take-off or landing the horizontal distance required to reach or descend from a given height could be substantially reduced with even a moderate headwind. For example, the horizontal distances to or from 100 feet, indicated for the no-wind STOL take-off and landing of the turboprop aircraft in figure 3, could be as much as 25 percent shorter with a 10-knot headwind. Alternatively, the aircraft could take-off or land in the same distances as for no wind conditions, but with higher airspeeds to take advantage of possibly better handling characteristics or to allow for gustiness.

TERMINAL NAVIGATION FACILITIES

Inasmuch as V/STOL aircraft can operate in the same manner as conventional airplanes, en route navigation would be accomplished by means of the same facilities on the same airways. The V/STOL aircraft could, if necessary, also share the approach and departure corridors to the terminal area and the holding areas of the conventional air traffic. However, much of the potential advantage of V/STOL transport operations, in relieving the growing airspace congestion in terminal areas of large cities and in reducing travel time between city centers, could be lost if they must be mixed with heavy conventional traffic in the terminal area. Reeder has suggested[7] that, to make more effective use of V/STOL capabilities, the approach corridors and holding patterns of conventional aircraft could be raised to moderately higher minimum altitudes than at present so as to permit the establishment of separate V/STOL approach and departure corridors underneath. In any case, terminal area traffic control of the V/STOL operations, along with control of conventional traffic, would, presumably, be exercised from facilities apart from the individual V/STOL terminal, up to the point at which the aircraft enters the final landing approach path, or from the point at which visual contact with the ground is lost in take-off.

For the final stages of approach to the V/STOL terminal, under instrument flight conditions, navigation or guidance must be provided with facilities associated with the particular V-port. These would include means for vectoring the aircraft into final approach path, thence along course toward the landing point, and finally down the selected glide slope to the point at which visual flight conditions are reached. The exact nature of the equipments and procedures that will serve these functions is not known at present. Their capabilities should probably provide for safe landing operations with Category II weather minimums, glide slopes of at least 6° - variable glide slope may be desirable to accommodate to various situations - and final approach paths in any direction. Because of the low-speed capability and steeper approach angles of the V/STOL aircraft, the dimensions of the final approach pattern can be much smaller than those of conventional high-performance transports - on the order of one-half -[2] so that the range of terminal navigation facilities could, presumably, be substantially less than for conventional airports. It is understood that the FAA is currently developing a variable glide slope, omnidirectional landing guidance system for helicopters which could possibly be adapted to meet V/STOL requirements.

In addition to electronic guidance for the instrument stages of approach to the V-port, a suitable landing-area light system must be provided for orientation and guidance in the visual stage of landing at night or in limited visibility operations. Again, the complete character of the system required for V/STOL operations has not yet been defined. Flood lighting of the landing area might be feasible, possibly with perimeter lights outlining the area. In addition, it may be necessary or desirable to provide approach lights outside the perimeter in linear array pointing to the desired touchdown point. If omnidirectional landing capability is required, a number of such arrays would be needed, radiating from the touchdown area at suitable azimuthal intervals to permit selective lighting in accordance with the wind direction.

HYPOTHETICAL V/STOL TERMINAL

In order to better visualize the possible influences on terminal requirements of some of the V/STOL characteristics discussed in the preceding sections they will be considered in relation to the hypothetical V-port illustrated in figure 8.

This terminal has been given relatively large proportions - covering some 30 acres in overall area - to represent what might be required to accommodate a reasonably high frequency of service for a large city. Eight loading gates are shown, each about 125 feet long to provide maneuvering space for V/STOL transports of the proportions illustrated in figure 1. This number of gates, assuming an occupancy time of 15 minutes, should be capable of serving about 150 aircraft movements a day, which Stanford Research Institute[1] has estimated might be required, for example, at each of two V-ports in New York City. This traffic flow would probably require that, in peak periods at least, landing and take-off operations be performed simultaneously, hence on separate areas of the V-port. This situation has been catered to in the layout in figure 8 where the landing and take-off tracks could be separated by 400 or 500 feet leaving space along the perimeter of the surface for taxiing operations, as indicated by the dotted lines.

It is assumed in the hypothetical arrangement that the V-port could be located on the bank of a river or lakefront, indicated by the irregular line, possibly with a considerable portion of the port extending beyond the bank on suitable support structure or land fill. With this arrangement, take-offs or landings - VTOL or STOL - could be made into the wind for at least a 180° range of wind directions with little concern for obstacle clearance, noise, or downwash. The take-off or landing track could be 600 or 700 feet from the terminal building and gates so that noise levels from turboprop aircraft would be less than 105 PNdB. The noise from jet aircraft under the same circumstances could be much higher - 115 to 120 PNdB - and possibly unacceptable.

Problems associated with the foregoing factors - clearance, noise, and downwash - would be encountered, with the V-port arrangement shown, primarily with a moderate-to-strong wind blowing off-shore for the take-off case or in the reverse direction for landing, as illustrated. The straight, long-dash lines indicate the into-the-wind take-off and landing tracks for these conditions, with the points shown by black circles, at which the aircraft, in VTOL operation, would be at the indicated heights relative to the V-port surface. The terminal building and gates are shown alined radially to the landing area in order to minimize the likelihood of direct overhead passage of incoming or departing aircraft. The straight-in approach or straight-out take-off paths would, nevertheless, be sufficiently close so that noise levels would be rather high, even for the turboprop aircraft, and impingement of high-velocity downwash on parked aircraft or passengers would be a possibility. Furthermore, with the approach and departure paths for this case, the obstacle clearance slope would be likely to be relatively steep, with the possibility of excessive noise levels in high-rise buildings.

There may be feasible alternatives to straight into-the-wind paths, such as the curved paths shown in figure 8. The landing path indicated requires the assumption that the pilot could follow an approach path on instruments with, possibly, a strong cross wind until sighting the ground at a height of 100 feet. He would then turn, holding altitude, until lined up with the wind and the touchdown point and complete his landing. The take-off would follow a corresponding procedure. These paths would keep the aircraft further away from the terminal buildings and would, presumably, avoid the necessity of flying over high-rise areas of the city. Whether or not such procedures would be practicable cannot be stated with assurance at this time, and the intent, here, is only to illustrate the nature of operational procedures that might have to be considered to cope with the problems indicated.

CONCLUDING REMARKS

In order for V/STOL aircraft to achieve substantial stature as an element of the air transport system, it appears that they must be capable of operating from terminals very close to city centers and under adverse weather conditions as severe as those under which competitive conventional transports could operate in the same time period. In addition, there are, at least in the present state of the art, limitations on the steepness of approach and departure paths, particularly in instrument flight conditions. The operating characteristics of V/STOL aircraft have been examined to a limited extent, in the light of these requirements and limitations to obtain an indication of their possible influences on V/STOL terminal requirements.

The indications are that V/STOL aircraft, particularly with VTOL capability, should be able to operate from reasonably compact terminals with Category II weather minima, assuming availability of appropriate guidance facilities, and that flight patterns and procedures are not unduly complicated by other factors. The large heading deviations from track that can result from operations of V/STOL aircraft in even moderate cross winds leads to the desirability, if not necessity, of the terminal providing for essentially omnidirectional take-offs and landings. Such a requirement could lead to difficulties in selecting terminal locations which would best serve the traveler and still not have some directions blocked by structures which the aircraft could not clear by adequate margins. The landing approach will probably be more critical in this respect than take-off, since glide slopes for instrument flight are expected to be limited to somewhat shallower angles than the climbout paths.

One of the factors which will influence the clearance requirements is the noise generated by these aircraft. For example, in landing, a clearance of over 800 feet above noise-sensitive structures, such as apartment or office buildings, would have to be provided for to keep noise levels to about 105 PNdB with the example turboprop aircraft. The jet V/STOL would require even greater clearance from noise considerations.

Noise will also require consideration in the layout of the terminal proper, as will the high-velocity downwash of the V/STOL aircraft, which could be as much as 75 mph at 200 feet below the aircraft.

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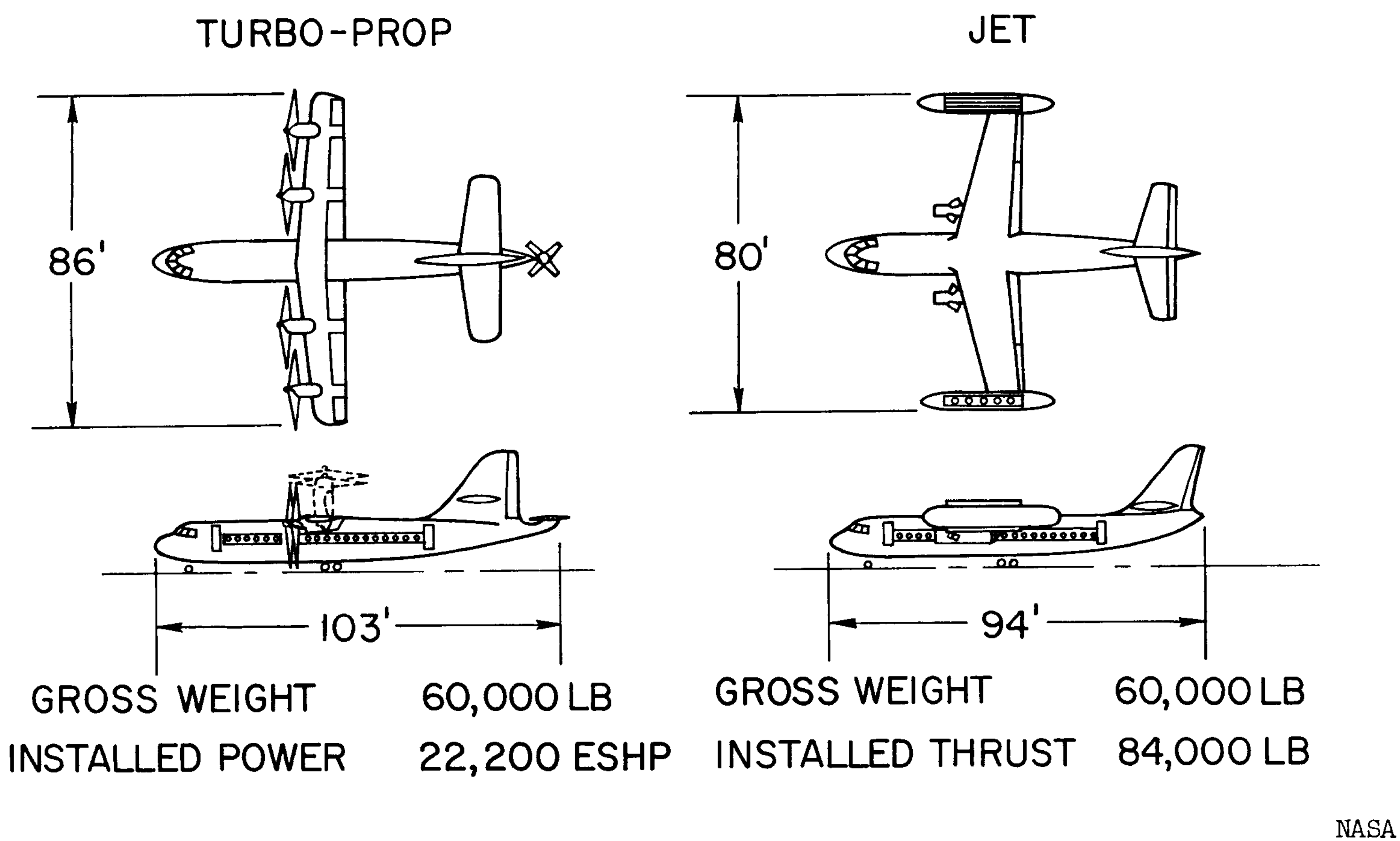

Figure 1.- Example V/STOL transports.

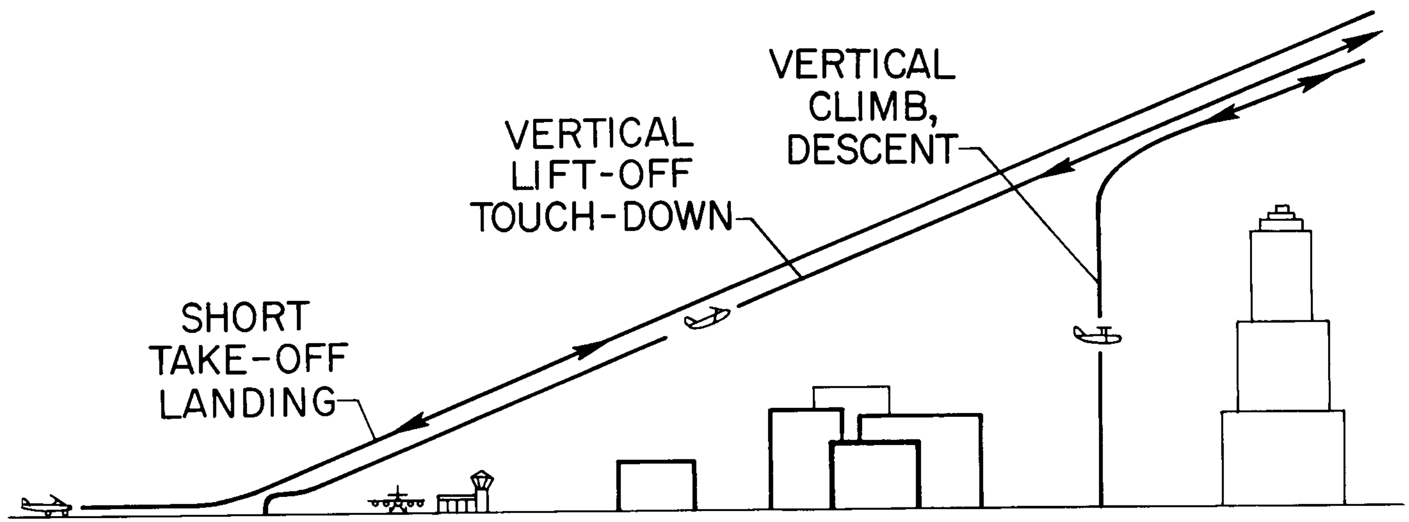

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Figure 2.- V/STOL take-off and landing modes.

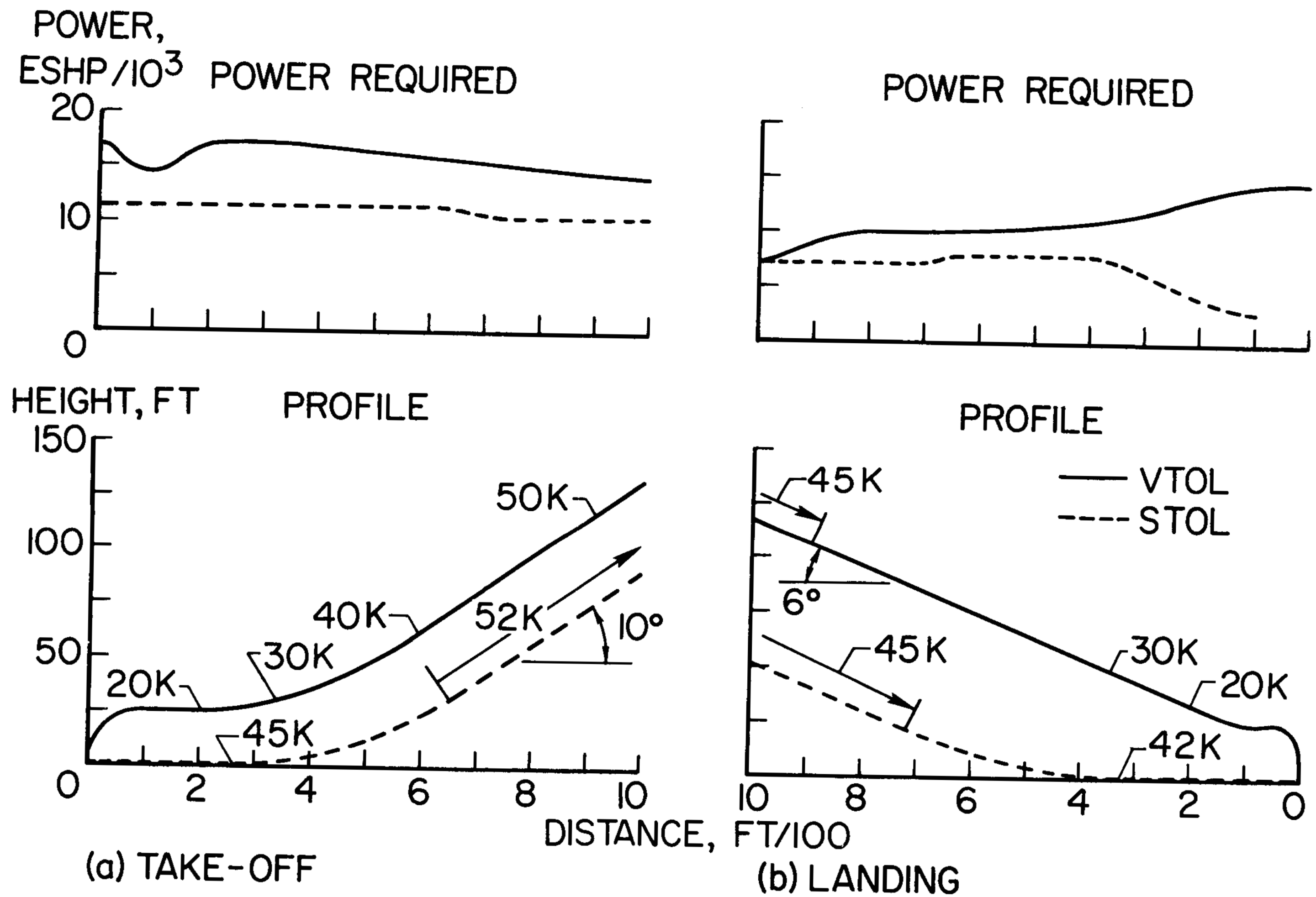

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Figure 3.- Take-off and landing performance turboprop V/STOL.

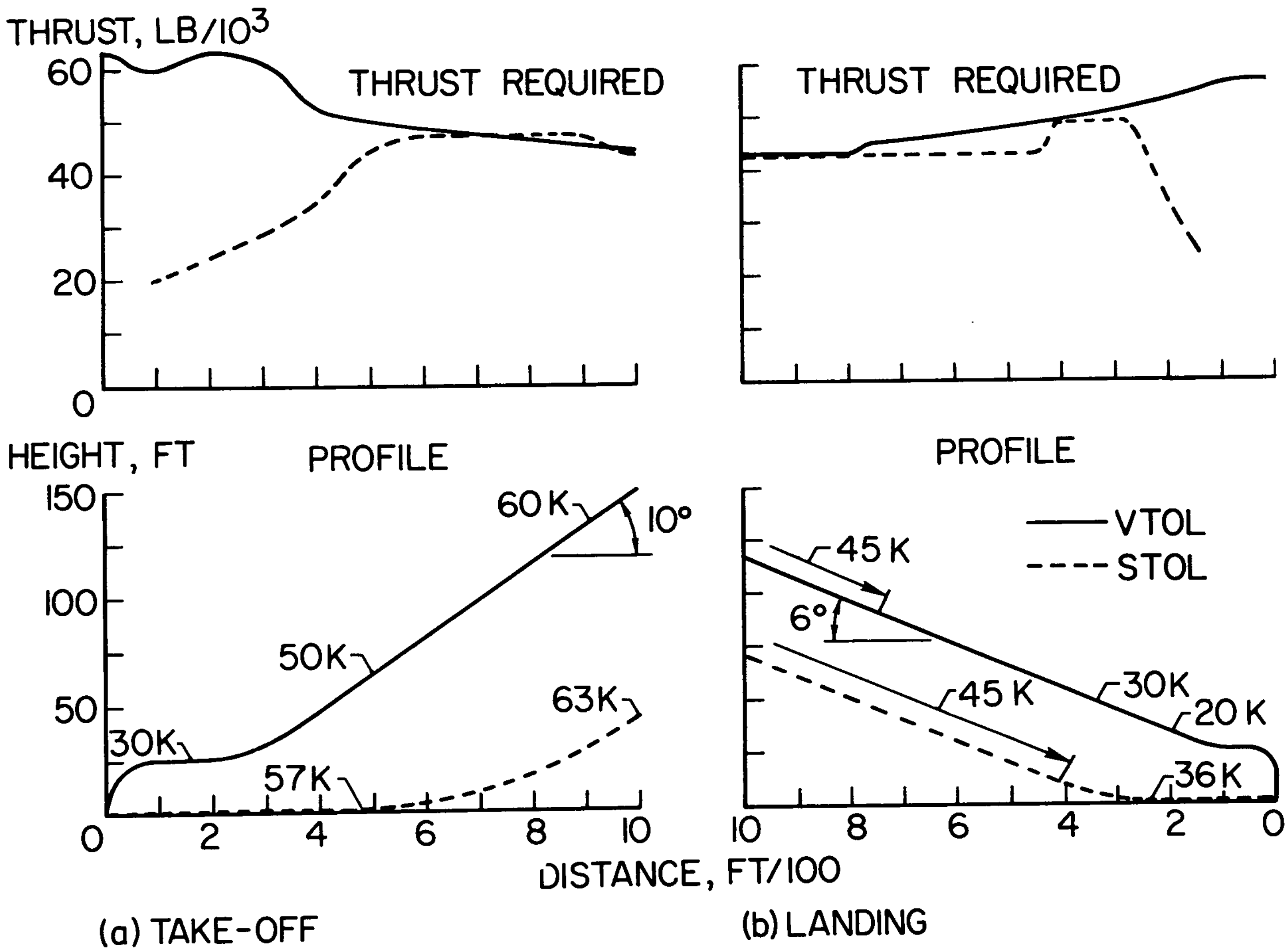

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Figure 4.- Take-off and landing performance jet V/STOL aircraft.

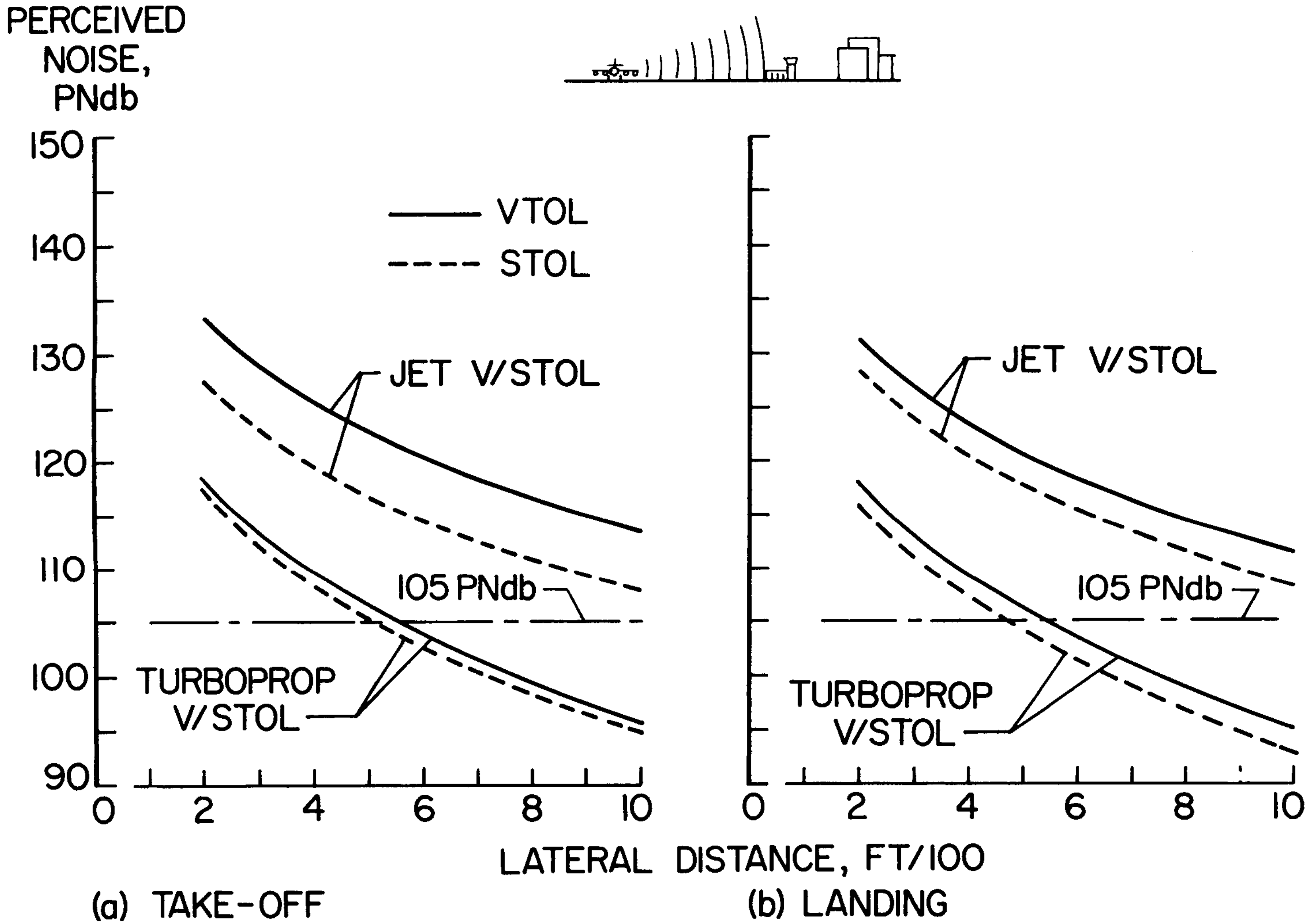

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Figure 5.- Ground noise V/STOL aircraft.

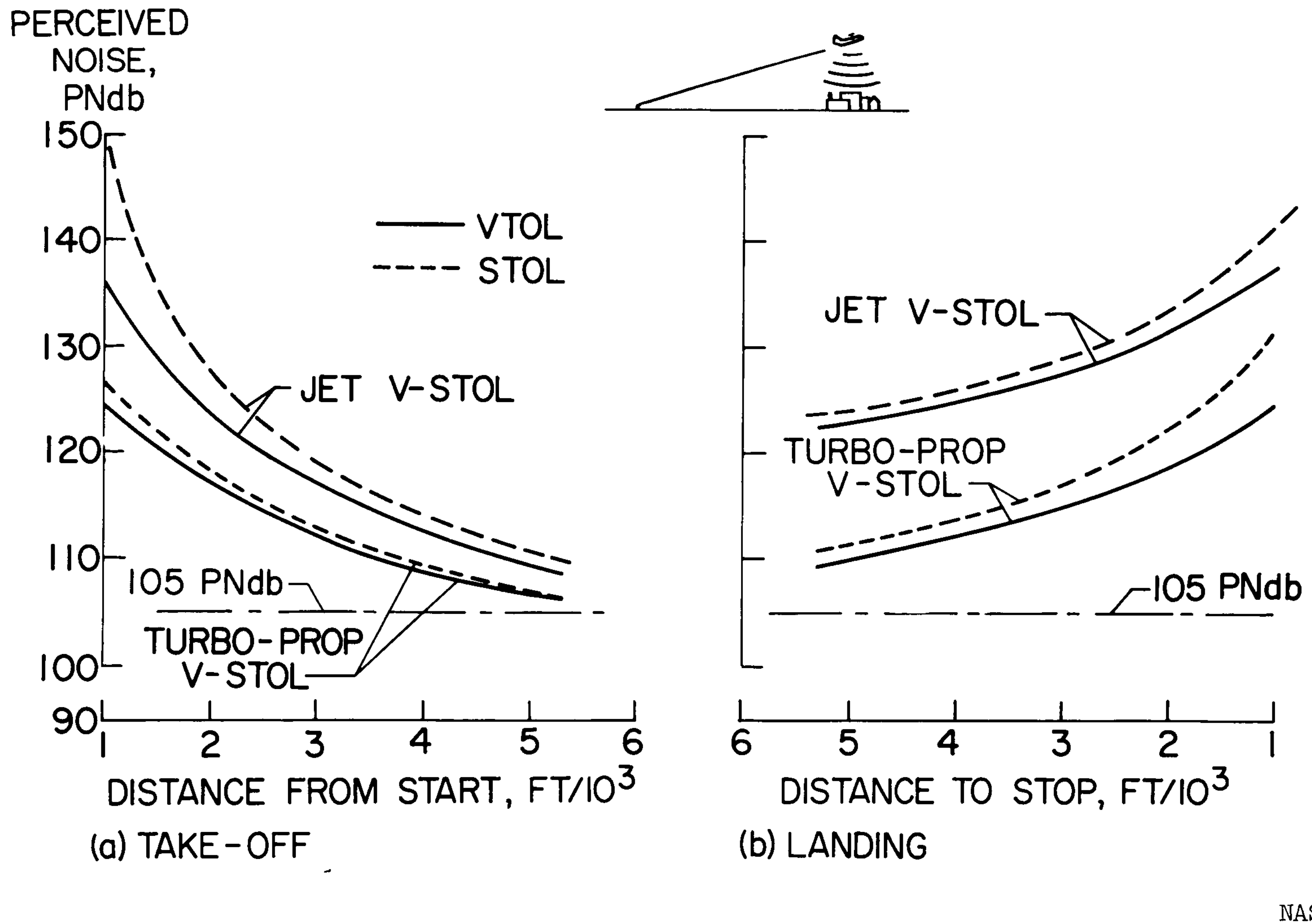

Figure 6.- Fly-over noise V/STOL aircraft.

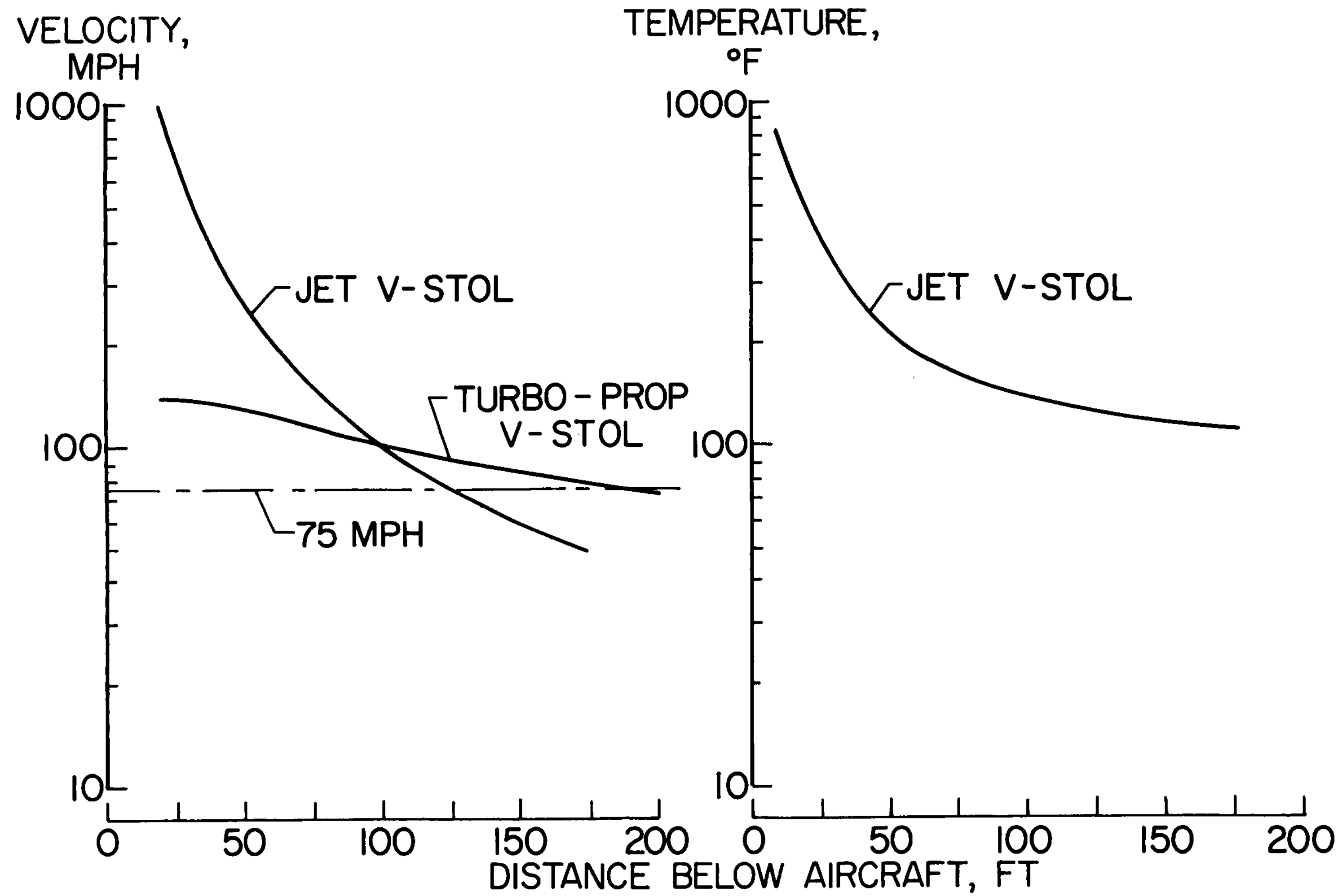

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Figure 7.- Propeller-and-jet-wash characteristics.

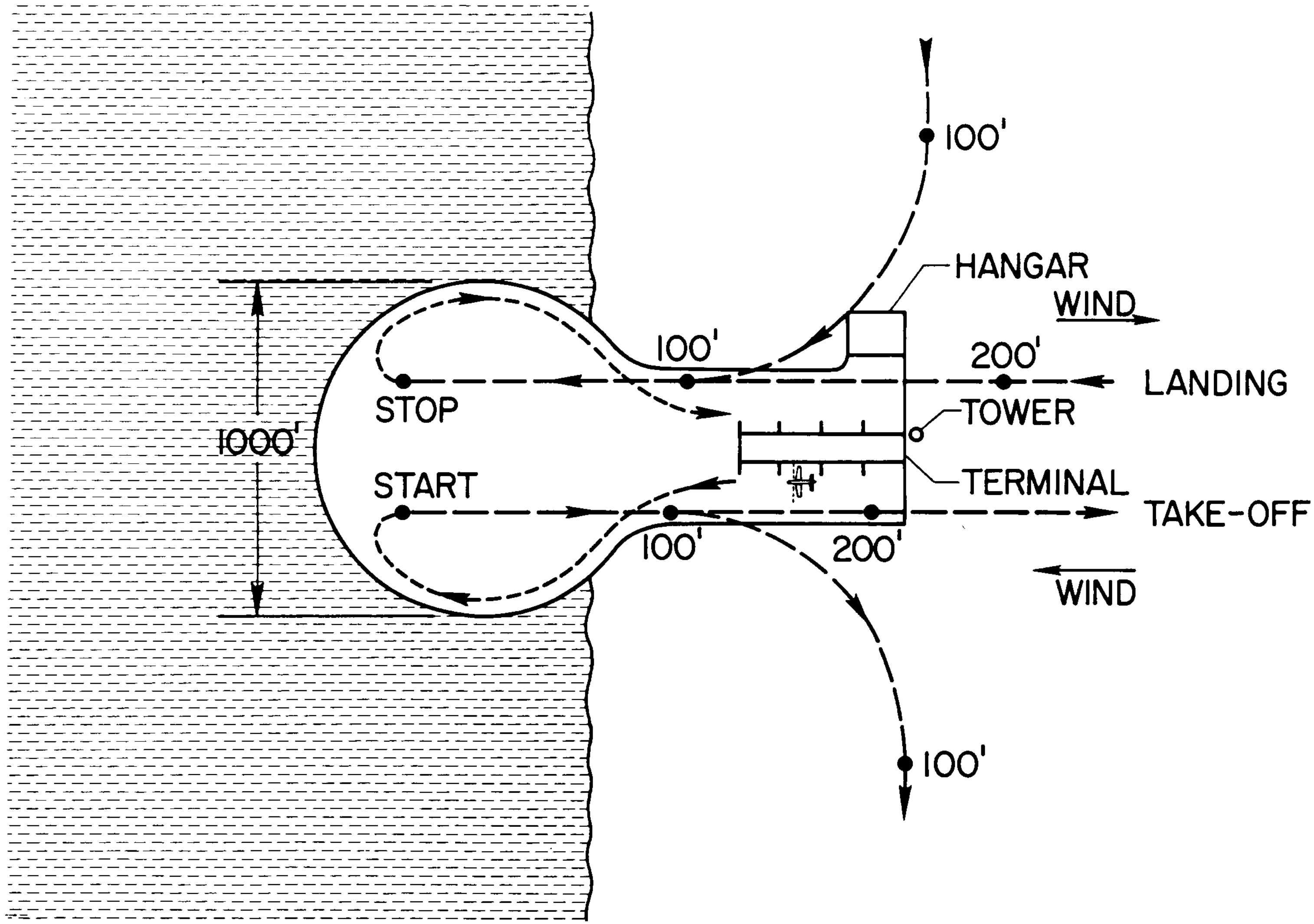

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Figure 8.- Hypothetical V/STOL port.

NASA-Langley, 1965