RESEARCH APPROACHES TO ALLEVIATION OF AIRPORT-COMMUNITY NOISE

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ABSTRACT

The material of this paper relates to the problem of noise in communities near commercial airports due to landing and take-off operations and contains a description of some of the related NASA sponsored research toward its alleviation. The objectives of the paper are to identify some of the significant factors involved, and to present pertinent research information from NASA in-house and contract studies. Data are included to illustrate the significance of such factors as aircraft engine type, compressor configuration, nacelle location and design, power reductions during climbout, steep angle landing approach profiles, and compatible land usage, with regard to noise alleviation and human response implications.

INTRODUCTION

This paper deals with the airport-community noise problem and the various physical factors involved in it. Particular attention is given to those factors which are amenable to research and for which some recent results are available. Following the manner in which research has been conducted, it is convenient for the purpose of discussion to break the problem down into its constituent parts. These individual items form the bases for the brief discussions of the paper. The main objectives of this paper are to identify significant parts of the problem, and to describe several possible approaches which point to an overall solution.

Some of the ingredients of the airport-community noise problem can be discussed with the aid of figure 1. Noise in communities surrounding airports is largely due to the power plants during aircraft operations. In this paper, consideration is given to noise exposures arising from aircraft during landing approach to the airport, transient ground operations on the airport, and take-off and climbout operations from the airport.

The type of noise-exposure time history resulting from airport operations is illustrated in figure 2. This is a measured noise-level time history for a climbout of a turbojet aircraft over a point on the ground about 3 miles from the start of roll. It can be seen that the noise increases gradually to a maximum value and then decreases gradually to the ambient noise level. For the example shown, the aircraft noise is measurable above the background noise for a period of about 1 minute, the maximum noise levels are about 35 dB above the ambient noise level and they occur near the time that the aircraft is overhead. For a roll-by on the ground or a fly-over during landing approach the main

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features of the noise-level transient would be the same; however, such details as the total time duration, the maximum noise level, the ambient noise level, and the spectral content of the noise are variables. A transient noise exposure such as this can be made more acceptable either by reducing the noise-level amplitudes, reducing the duration of exposure, or by altering the spectral content of the noise. (See ref. 1.)

Some of the various approaches to noise alleviation from the research standpoint and which are included in the NASA research program are listed in figure 3. Such items as the operating cycle of the engine and details of its interior component design to minimize noise generation (refs. 2 and 3), design of the engine nacelle so as to minimize the noise radiating from it, and the significance of aircraft overall configuration involving such special features as engine location and thrust-to-weight ratio have been studied (see refs. 2 to 4). Additional studies have related to such operational considerations as steep angle landing approaches and climbouts and the associated employment of engine power reduction (ref. 2), and to community compatibility with airport operations (refs. 5 and 6). This paper is devoted to brief considerations of the above individual items that have been studied in-house or in NASA supported noise-research programs. Noise reduction at the source, aircraft design, aircraft operations, and airport—community compatibility will be treated in that order.

NOISE REDUCTION AT THE SOURCE

Sources of Engine Noise

By way of review, the principal noise sources to be dealt with on current aircraft engines of the types in commercial use are indicated with the aid of the schematic diagrams of figure 4 (see ref. 7). The top figure represents a turbojet engine, whereas the bottom figure represents a turbofan engine. The main sources of noise for each engine and the general direction in which each radiates are also shown. The main source of noise radiating in the forward direction from the turbojet engine is the compressor, whereas the exhaust jet is the main source of noise radiating in the rearward direction. The turbofan engine has, in addition, noise from the fan section of the engine which radiates both forward and rearward from the inlet and fan discharge nozzles, respectively. The jet noise which has a continuous spectrum tends to be less intense for the fan engine for a given thrust level. On the other hand, the noise from the rotating machinery, that is, fan and compressor, and which consists of both discrete tones and random noise (continuous spectrum) is most intense for the fan engine. Other noise sources such as the turbine, the burning of fuel, cavity resonances, and turbulence induced in the internal flows may under some conditions be important, but are generally considered secondary to those listed in figure 4.

Jet Exhaust Noise

It is well known that the noise generated by jets is associated with eddy convection in the jet mixing region. When the eddy convection velocity exceeds the ambient speed of sound outside of the jet, the mechanism exists for so-called Mach wave radiation to occur (see ref. 8) in addition to the conventional mixing noise. Mach wave radiation can be defined with the aid of figure 5. Two sketches of jet exhaust flow are shown and are similar except for the maximum value of jet velocity. The top sketch represents a situation where the eddy convection velocity V_c is lower than the velocity of sound a_o in the ambient air. The bottom sketch represents the case where V_c is greater than a_o. Weak shock waves can be detected radiating into the ambient medium even though no shock waves exist in the jet exhaust flow. A theory has been developed in reference 8 which explains the nature of this phenomenon. The eddy has associated with it a pressure field, the presence of which is felt at the jet boundary. If the eddy moves at a speed which is supersonic with respect to the ambient medium, then the disturbance at the boundary does likewise. Shock waves are generated in the same manner as in the case of a solid body moving through air at supersonic speeds. Mach wave radiation has been observed not only for subsonic jets but also for choked flows from converging nozzles and supersonic flows from converging-diverging nozzles. Although the significance of Mach wave radiation is not fully evaluated at present, its occurrence is believed to be objectionable.

One of the main objectives of research on exhaust noise reduction is to find acceptable methods of producing less noise per unit thrust. The fan or bypass engine offers the possibilities for lower exit velocities and hence lower noise levels. The data of figure 6 are included to show the relative perceived noise levels associated with various engine types. Maximum perceived noise levels at a sideline distance of 200 feet were estimated by the methods of references 9 and 10. These perceived noise level data were arbitrarily normalized to a thrust of 21,000 pounds for comparison and for convenience have been plotted as a function of bypass flow ratio, referred to those of the turbojet engine.

Data for current turbojets are plotted at the zero location of the abscissa scale and fall in the narrow hatched region. Current turbofans are represented by the larger hatched region and are seen to have somewhat lower perceived noise levels. Proposed high bypass ratio engines are represented by the stippled region at the right and it is seen that by means of an increase in bypass flow ratio substantially lower perceived noise levels may be realized. It should be noted that the lower boundary of the stippled region is well defined but the upper boundary is not well defined. The vertical extent of the stippled region represents some of the uncertainties regarding the importance of jet stream turbulence, combustion noise, compressor noise, fan discharge noise, and turbine noise for these proposed engines. Research effort is being directed to minimize the noise from these sources so that the full potential of these engines can be realized.

Compressor and Fan Noise

The fan and compressor sections of current fan engines are important sources of noise. Because of the fact that the trend in commercial aircraft engines is toward higher bypass flow ratios, it follows that noise from the rotating components of these future engines may be relatively more intense. Considerable effort has been directed toward the study of the noise generation by compressors and fans and in ways of reducing this noise. One of the more obvious ways in which such noise can be reduced at the source is by including the proper spacing between stationary and rotating components of the engine. The reason for this and some example research findings are presented in figures 7, 8, and 9. Figure 7 contains schematic diagrams which illustrate some of the main features of the aerodynamic wake of the stator vanes and the resulting load fluctuations on the rotor due to such wakes.

There is a velocity deficiency in the wake as indicated by the dark shaded regions. The velocity deficiency is strongest near the stator vane where the wake is narrowest. As the wake broadens out at greater distances, the velocity deficiency decreases. Thus, a rotor blade passing through the wake of the stator vane will encounter different flow conditions depending on the portion of the wake that it encounters. As the rotor blade passes through the wake, it experiences a momentary change in angle of attack due to the variation in in-flow velocity, and thus there is an associated fluctuation in the blade loading. The detail nature of this fluctuating load has not at present been defined and hence one can only guess at the nature of it. The sketches at the bottom of the figure are artist's conceptions of these load fluctuations as a function of spacing between the stator and the rotor. It is believed that the blade load fluctuations are of shortest duration and of greatest magnitude when the clearance between the stator and rotor is relatively small. As the clearance increases, the amplitudes reduce and the durations increase. Since it is believed that the noise from the rotating components is related to the blade load fluctuations, there is a suggestion that an increased spacing would be beneficial with regard to noise generation.

Experiments which confirm this beneficial effect of spacing have been performed on a small laboratory compressor and some sample results are given in figure 8. At the left of the figure is a polar diagram showing the noise radiation pattern of the discrete tone corresponding to the fundamental frequency of the rotor. Data for two spacing conditions are included as indicated by the sketches on the right. The data represented by the circle points relate to a spacing of a fraction of a chord length between inlet guide vanes and rotor blades. The square data points relate to a clearance condition of about six chord lengths. It is obvious that noise reductions were obtained at all azimuth angles.

The maximum reduction values obtained for the above modification and for others studied in the model test are shown in bar graph form in figure 9. At the left of the figure are sketches indicating the configuration of the study and the bars indicate maximum noise reduction obtained for the various configurations compared to the first one listed for which data were included in figure 8. The maximum noise reduction of the fundamental frequency as obtained by moving the inlet guide vanes to a clearance of about six chord lengths is represented by the second bar from the top and is seen to be of the order of 12 dB. A further small reduction was obtained by removing completely the inlet guide vanes and likewise an additional noise reduction increment was obtained by removal of the downstream stator vanes. From the above data it can be concluded that the strongest interactions were experienced between the rotor and the inlet guide vanes, the other interactions being of relatively little importance.

NACELLE DESIGN

One obvious approach to reducing the noise during the landing approach operation is to add acoustical treatment to the engine nacelle to absorb the noise before it can radiate into free space. Some thoughts about the manner in which nacelle treatment might be employed and the potential of noise reductions of such nacelle treatment are discussed in figures 10, 11, and 12. Shown in the upper right of figure 10 is a schematic diagram of a noise-level time history for a fan-powered aircraft in landing approach. It can be seen that two noise peaks are evident and these are associated with the inlet and the fan discharge ducts, respectively. The data of the bar graph are estimates of the perceived noise-level reduction that might be obtained during the landing approach operation by treating various portions of the engine nacelle. These estimates were based on studies made for NASA by the Douglas Aircraft Company under a research contract. Acoustic treatment of the inlets only would probably not reduce the maximum noise levels but would essentially eliminate the first peak of the noise time history. The resulting perceived noise-level reduction would be a modest one. Likewise, if the discharge ducts alone were treated, this would essentially eliminate the second peak in the noise time history and a somewhat larger but still modest perceived noise-level reduction would result. If, however, the inlet and the fan discharge ducts were both treated, a rather substantial overall noise reduction would be anticipated as shown by the bar at the bottom. The results of this figure have been estimated based on laboratory experience with acoustic absorptive-type materials believed to be suitable for use in engines.

A subsequent research program is expected to involve the application of these devices to a full-scale fan engine for acoustic and performance evaluation. The manner in which such treatment might be applied to an actual engine as a result of the Douglas Aircraft Company studies is shown schematically in figure 11. The dark shaded areas are those to which sound absorptive material might be applied for evaluation testing. Configurations other than that of figure 11 are also being studied.

With regard to the inlet treatment problem, another approach that offers possibilities of practical application is that of producing a sonic block in the inlet upstream of the rotating engine components. Such a condition is obtainable by means of a choked flow inlet as illustrated schematically in the sketch in figure 12. Such a device has been tested during ground operation of a small turbojet engine and samples of the data obtained in such tests are shown at the bottom of the figure. The data are in the form of 1/3 octave band spectra obtained at a point 20 diameters from the inlet and at an angle of about 25° off the center line. The dashed line spectrum is seen to have peaks in it at high frequencies which correspond to the fundamental and second harmonic of the first rotor. The corresponding noise spectrum obtained for choked flow conditions which occurred at a slightly higher engine rotational speed indicates that the peaks associated with the rotor frequencies are now greatly reduced in amplitude. It has been estimated that the successful application of inlet choking to a fan-type engine plus adequate treating of the fan discharge ducts might produce overall noise reductions of the order of the maximum values indicated in figure 10. It should be pointed out that the performance penalties associated with the use of such techniques as inlet choking and the acoustic treatment of inlets and fan exhaust ducts have not to date been evaluated by testing.

AIRCRAFT DESIGN

Shielding of Noise by the Aircraft Structure

There has been considerable speculation about the effectiveness of the wing and fuselage structure of aircraft for shielding engine noise from the ground observer. In order to document the situation for aircraft of the current transport type, some special experiments were performed with the use of a microphone suspended a few thousand feet above the ground by means of the Goodyear airship "Mayflower." The objective of the experiment was to measure the differences in the noise time histories for a fan-powered (CV-990) transport aircraft flying above and below the measurement equipment, in both the landing approach and climbout configurations. The results obtained for the climbout power conditions are given as an example in figure 13. It can be seen that characteristic sound pressure level time histories having the same gross features as those obtained on the ground (see fig. 2) were also obtained during these tests. Furthermore, it can be seen that the measured values for the case where the airplane flew below the noise measuring equipment were generally lower than for the airplane flying above the measuring equipment. The maximum differences noted for these two conditions were about 5 dB or the same order of magnitude predicted on the basis of small-scale laboratory tests (ref. 4). These results suggest the extent to which the wing of the aircraft is effective in shielding the engine noise. An inspection of the data records suggests that the shielding effects noted relate mainly to the jet noise and the fan discharge noise, whereas the inlet noise reduction was minimal. The problem of obtaining substantial shielding effects from the aircraft structure involves consideration of the overall design concepts for the aircraft.

The information of figure 14 relates to the differences in the noise radiation patterns shown at the bottom of the figure as obtained from three different nozzle configurations (see ref. 4). The pattern at the lower left relates to a conventional circular nozzle and is seen to be radially symmetrical. The middle nozzle has a narrow rectangular shape and results in a radiation pattern which also tends to be rectangular, the radiation being stronger in the direction of the short dimension. The radiation pattern on the right is of particular interest because it was obtained with the use of a flow attachment surface. The jet was allowed to issue from a rectangular nozzle and to flow along a surface external to the nozzle. The result is a radiation pattern which is asymmetrical, with respect to the horizontal, the strongest radiation being directed upward. The latter concept, if it could be incorporated successfully into an aircraft, would result in most of the jet exhaust noise being radiated upward from the aircraft rather than downward and would obviously be attractive from the standpoint of noise alleviation.

The photograph of the aircraft model in figure 15 is included as an artist's conception of how such an aircraft might look. Note that the engines are above the wing, the exhaust nozzles are narrow rectangles in cross section rather than being circular. The jet flow attaches itself to the upper surface of the wing and flows over the wing and flap. It is believed that a configuration such as this would have attractive aerodynamic performance features as well as acoustic benefits. No aircraft of this type is known to be operational. One of the problems in such a configuration is the proper handling of the high-temperature exhaust gases. This problem may be alleviated as high bypass ratio engines become available. The principle illustrated is believed to be most directly applicable to small rather than large aircraft.

AIRCRAFT OPERATIONS

Take-Off and Initial Climb

There has been much discussion also about the use of steeper initial climb rates in order to increase the distance from the aircraft and thus reduce the noise on the ground. In the diagram at the top of figure 16 are shown schematically two altitude-distance profiles. The lower profile is representative of the operation of a current, long-range, fan-powered aircraft. The upper profile, on the other hand, represents a hypothetical high-performance aircraft of about the same gross weight but with twice the installed thrust and with advanced-design fan engines.

At the bottom of the figure, a diagram shows the estimated 100 PNdB contours on the ground for the associated take-off operations. These contours are plotted at appropriate longitudinal and lateral distances with reference to the runway. The reference rectangle of dashed lines is drawn at a 1/2-mile distance in all directions from the runway, and therefore is representative of the size of some commercial airports.

The current airplane, because of its lower thrust-to-weight ratio, has a longer take-off run, a slower climb rate, and thus an associated ground-noise contour that is relatively long and slender. The hypothetical high-performance aircraft, on the other hand, has a shorter take-off run, a more rapid climbout, and an associated ground-noise pattern that is relatively short in the take-off direction as indicated by the shaded area. The shaded area is included to show the range of results obtainable, depending on the exhaust conditions of the proposed engine. For a high-velocity exit (duct heating), the outer extremes of the area apply, whereas for a high-bypass-ratio engine without duct heating, the inner extremes apply. For this latter condition, the perceived noise levels above 100 PNdB all occur within the airport boundaries.

With regard to current aircraft, there has been some question about the effectiveness of the power cutback procedure illustrated in figure 16 and what the optimum schedule might be for such a climbout operation. In an attempt to answer this question, the data of figure 17 have been obtained for a turbojet-powered aircraft supplied and operated by FAA personnel. The data apply to the three different profiles illustrated in the sketches at the top of the figure and are examples of the types of data obtained in this study. The left-hand plot at the bottom shows a comparison of the perceived noise levels on the ground track for a profile using take-off power all the way with one involving a power cutback. It can be seen that the ground noise levels are lower for the power cutback case. It follows that the beneficial effects of reduced power more than offset the detrimental effects of reduced altitude.

In the lower right-hand figure a comparison is made between a full-power climbout and one involving a 10-second power reduction followed by a return to take-off power as is sometimes practiced. It is obvious that noise reduction occurs only so long as the power is reduced. After return to climb power, it can be seen that higher noise levels than normal would be experienced mainly because of the relatively lower altitudes.

Landing Approach

Operational procedures are equally important for the landing approach situation. The nature of this phase of the problem and some sample measurement results are given in figure 18. Shown in the sketch at the top are two altitude distance profiles that have been evaluated for comparison. The solid line profile represents a conventional 3° approach, whereas the dashed line profile represents a two-segment approach, variations of which may have some useful applications in the future. In this latter case the initial approach angle is about 6°, and there is a transition to the standard 3° approach profile at some arbitrary distance from the end of the runway.

At the bottom of the figure are shown comparative noise levels for the two above profiles as a function of distance from the end of the runway. At the greater distances the noise-level values associated with the steep approach path are markedly lower mainly due to the increased altitude of the aircraft although somewhat lower power settings are also involved. As the two profiles converge at the shorter distances, the noise levels are about equal. For these latter conditions the altitude of the aircraft and the power settings are very nearly the same in both cases. The two-segment profile is beneficial in reducing noise only when it results in an increase in altitude or a power reduction or both.

COMMUNITY COMPATIBILITY CONSIDERATIONS

It is obvious that normal activities in many communities near airports are not, for one reason or another, compatible with the noise exposures from airport operations. Some changes in the noise characteristics of the power plants or in the manner of aircraft operation, as have been discussed, might be beneficial in reducing noise. Of equal importance to the overall compatibility problem are possible changes in the community itself to better adapt itself to its environment (see fig. 19). Some of the possible considerations in such a community undertaking could be: zoning, tax incentives, financial assistance, building and housing codes, land acquisition, eminent domain, and urban renewal. Each of these considerations is not discussed, but it should be pointed out that they have already been used successfully to bring about desired changes in some specific situations. A study sponsored by NASA has recently been completed for the purpose of gathering together the lastest information relative to the application of these procedures to communities with airport noise problems (see ref. 5). The use of such instruments by the proper authorities as part of a sound overall plan for community development could be very beneficial and would complement other efforts to minimize noise exposures.

CONCLUDING REMARKS

In summary it may be useful to refer to figure 20 in order that the individual items discussed herein may be seen fitted together in the appropriate manner and in the proper perspective. It should be mentioned that the overriding consideration is that people react unfavorably to noise and thus some remedial action is called for. It goes without saying that the nature of this remedial action will be determined in large measure by economic or safety considerations or both. These factors have thus been given a central place in the summary diagram of figure 20. The material dealt with in this paper fits into the outlying three categories of the figure. Data relating to noise reduction at the source, aircraft design and operational factors, and community consideration have all been briefly discussed. Before any of these ideas or procedures or devices that have promise of noise alleviation are generally accepted, they must be evaluated under realistic operating conditions. In future NASA research emphasis will be given to full-scale hardware studies with the objectives of evaluating performance penalties, operating problems, and safety considerations as well as the potential for noise alleviation (ref. 11).

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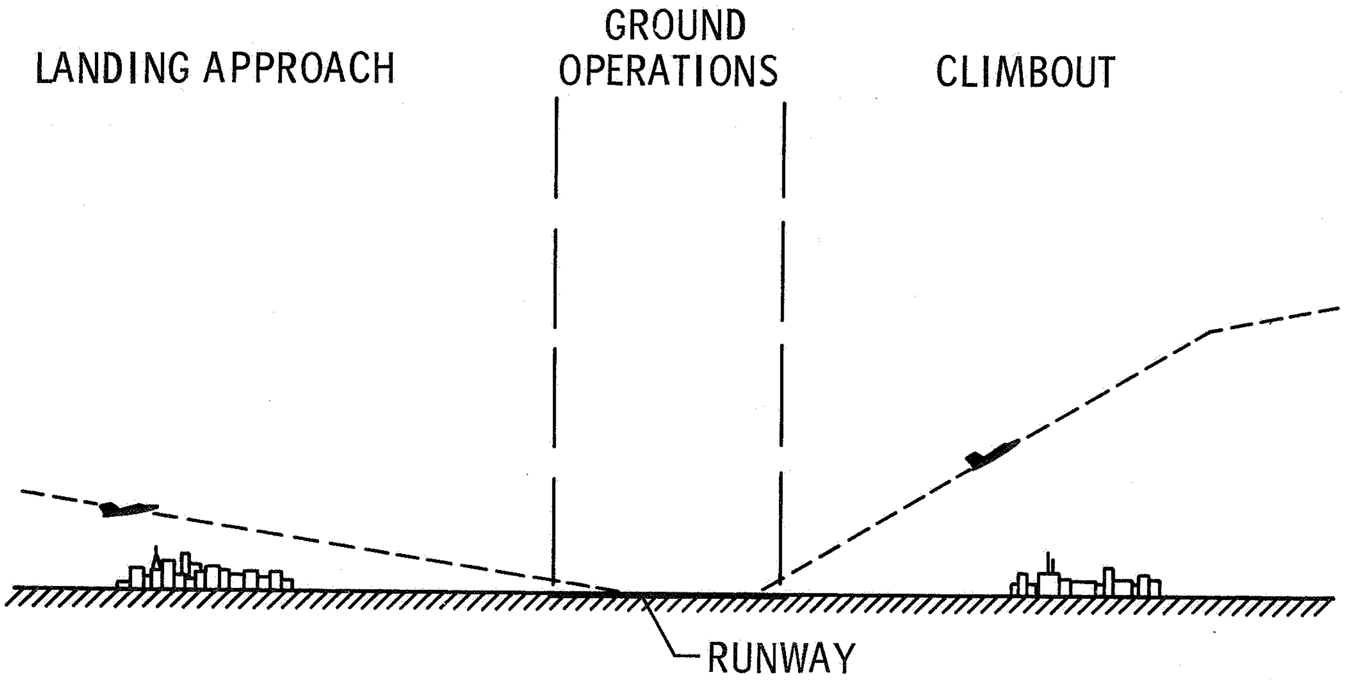

Figure 1.- Aircraft operations which result in noise in communities near airports.

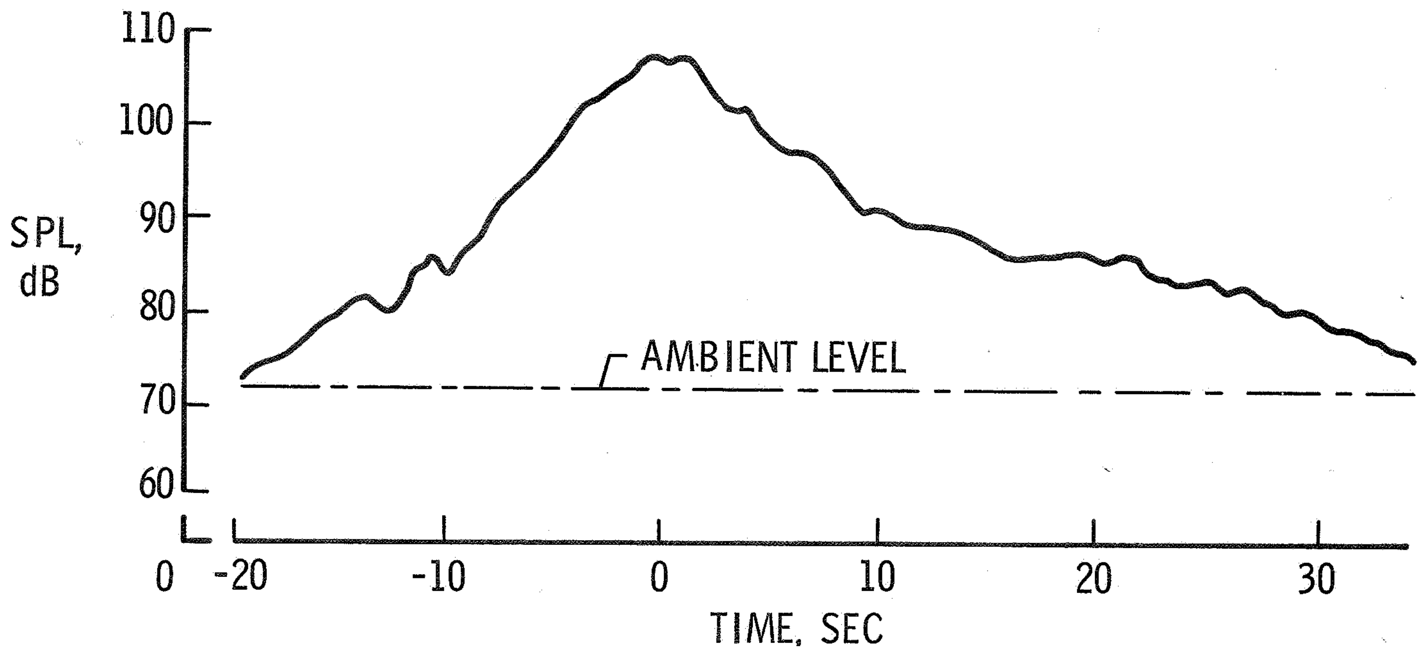

Figure 2.- Sample noise-level time history for the take-off of a 4-engine turbojet-powered aircraft as observed at a point about 3 miles from start of roll.

- ENGINE DESIGN
- NACELLE DESIGN
- OVERALL AIRPLANE DESIGN
- OPERATING CONSIDERATIONS
- COMMUNITY CONSIDERATIONS

Figure 3.- Approaches to noise abatement.

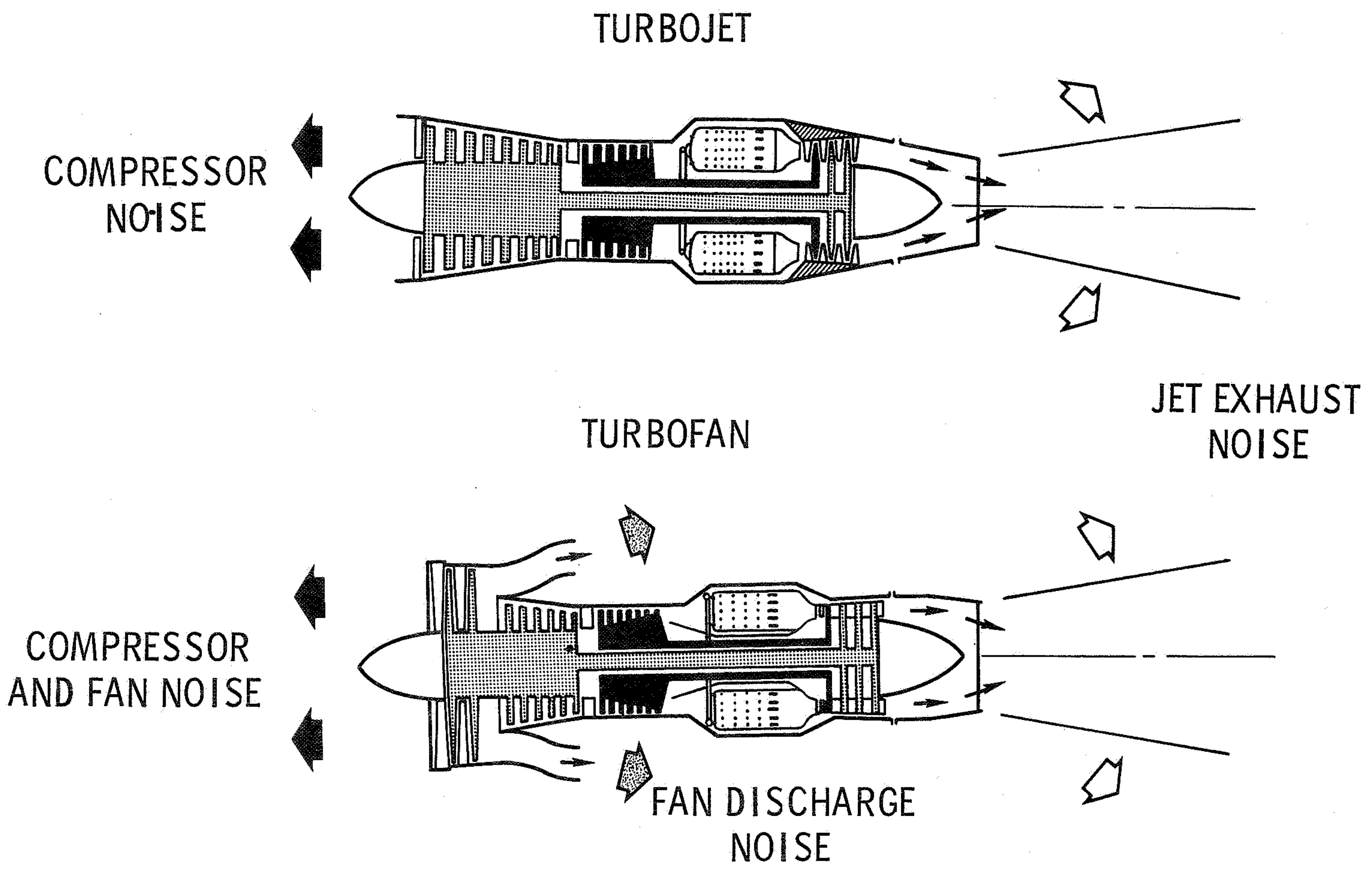

Figure 4.- Sources of noise in turbojet and turbofan engines.

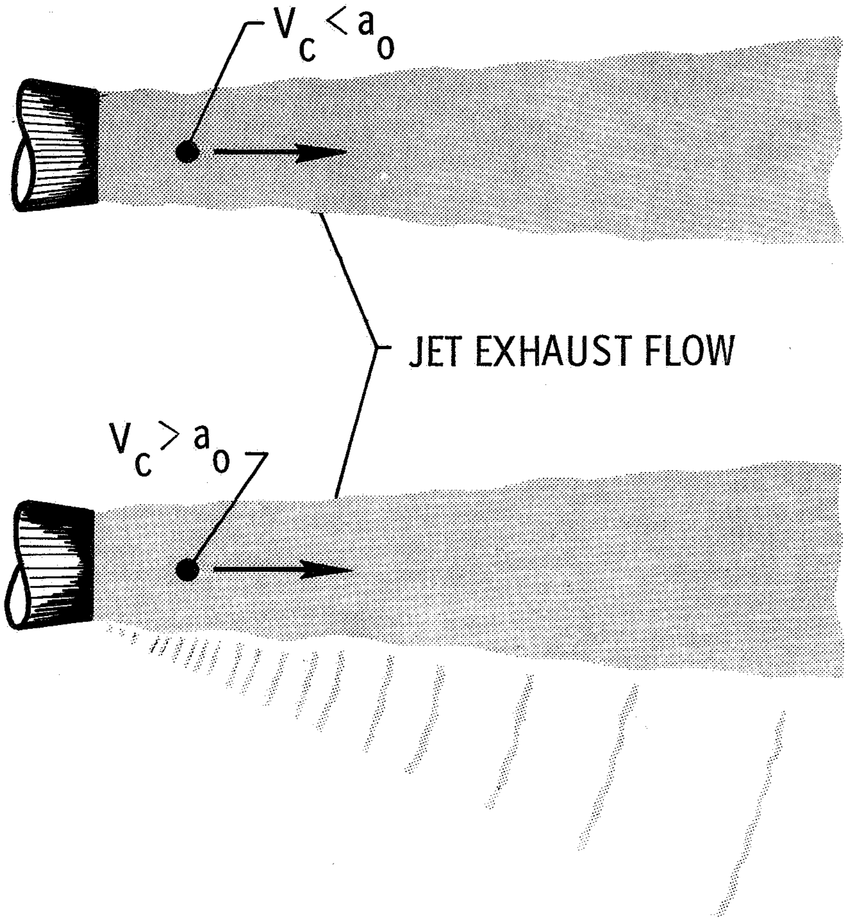

Figure 5.- Mach wave radiation from jet exhaust flows.

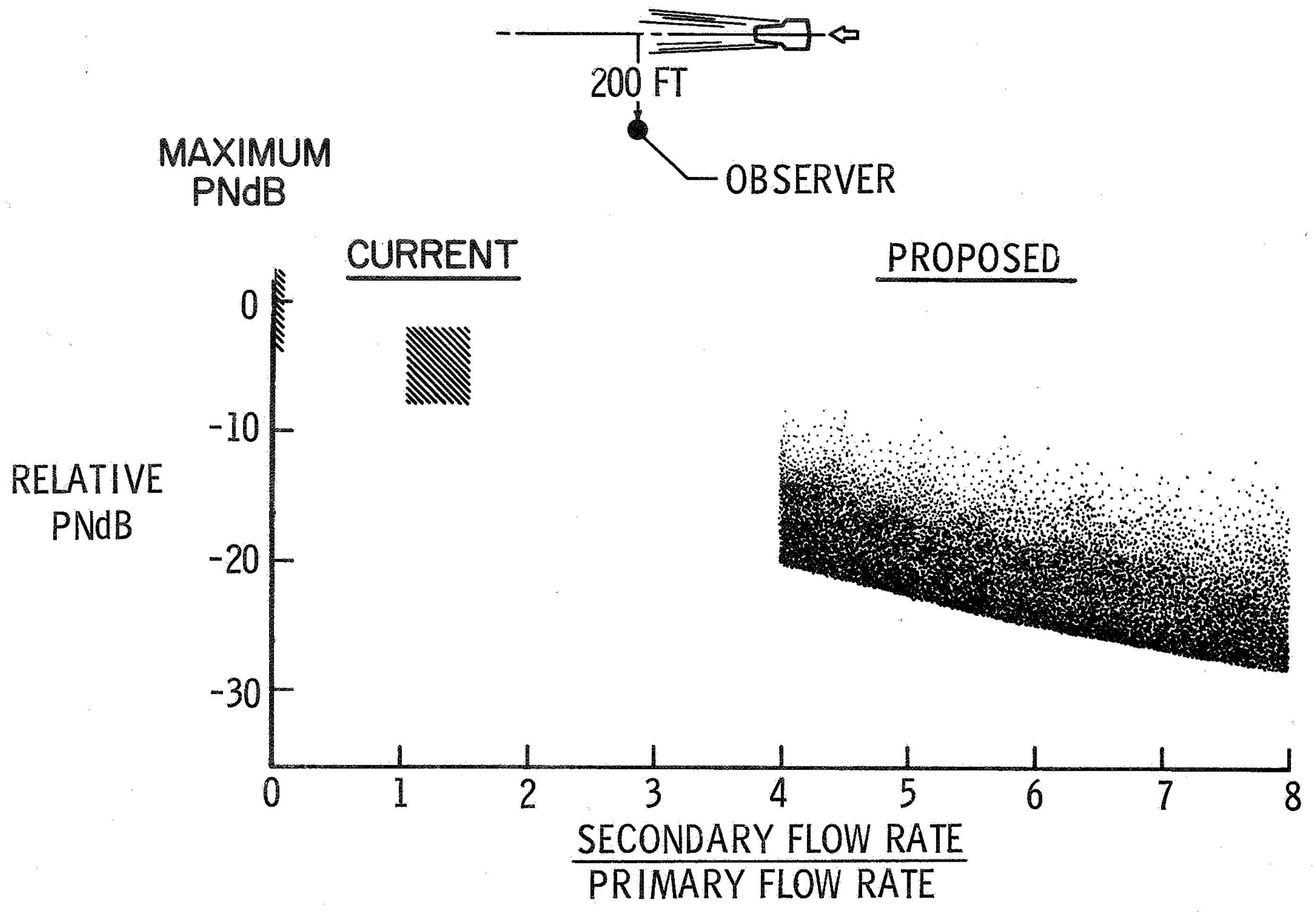

Figure 6.- Effect of engine bypass ratio on perceived noise level for a given level of thrust.

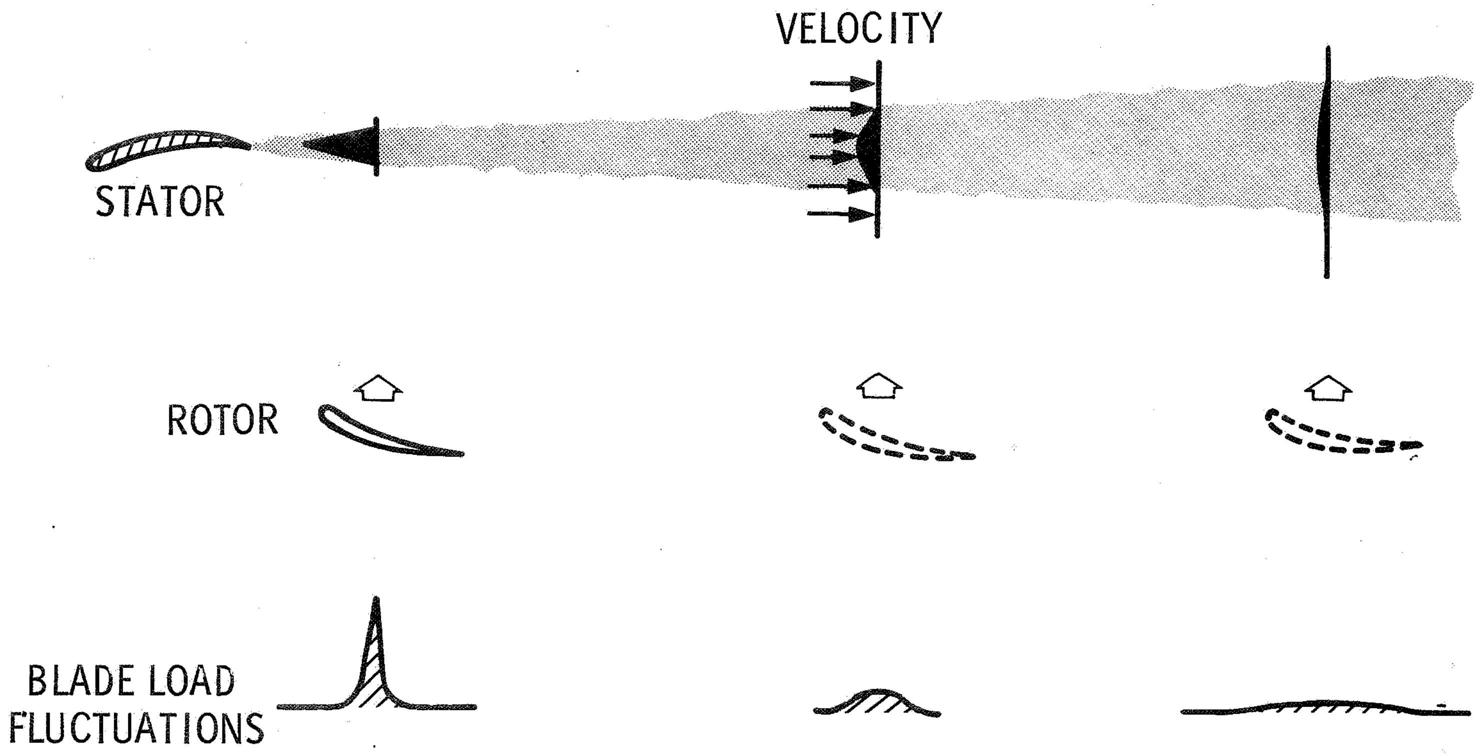

Figure 7.- Nature of inlet-guide-vane rotor interactions.

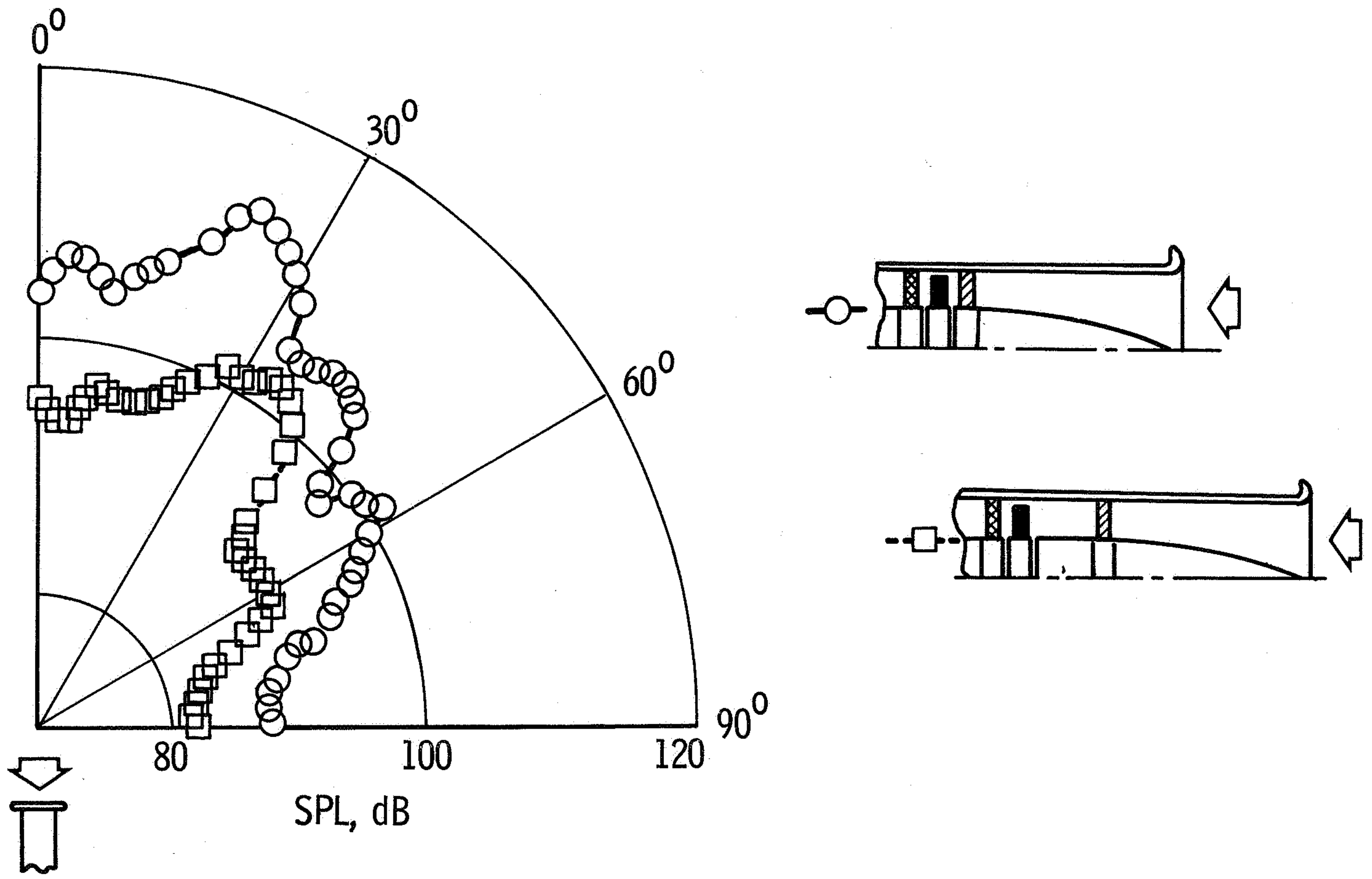

Figure 8.- Effect of inlet-guide-vane rotor spacing on the noise radiation patterns from a single-stage compressor.

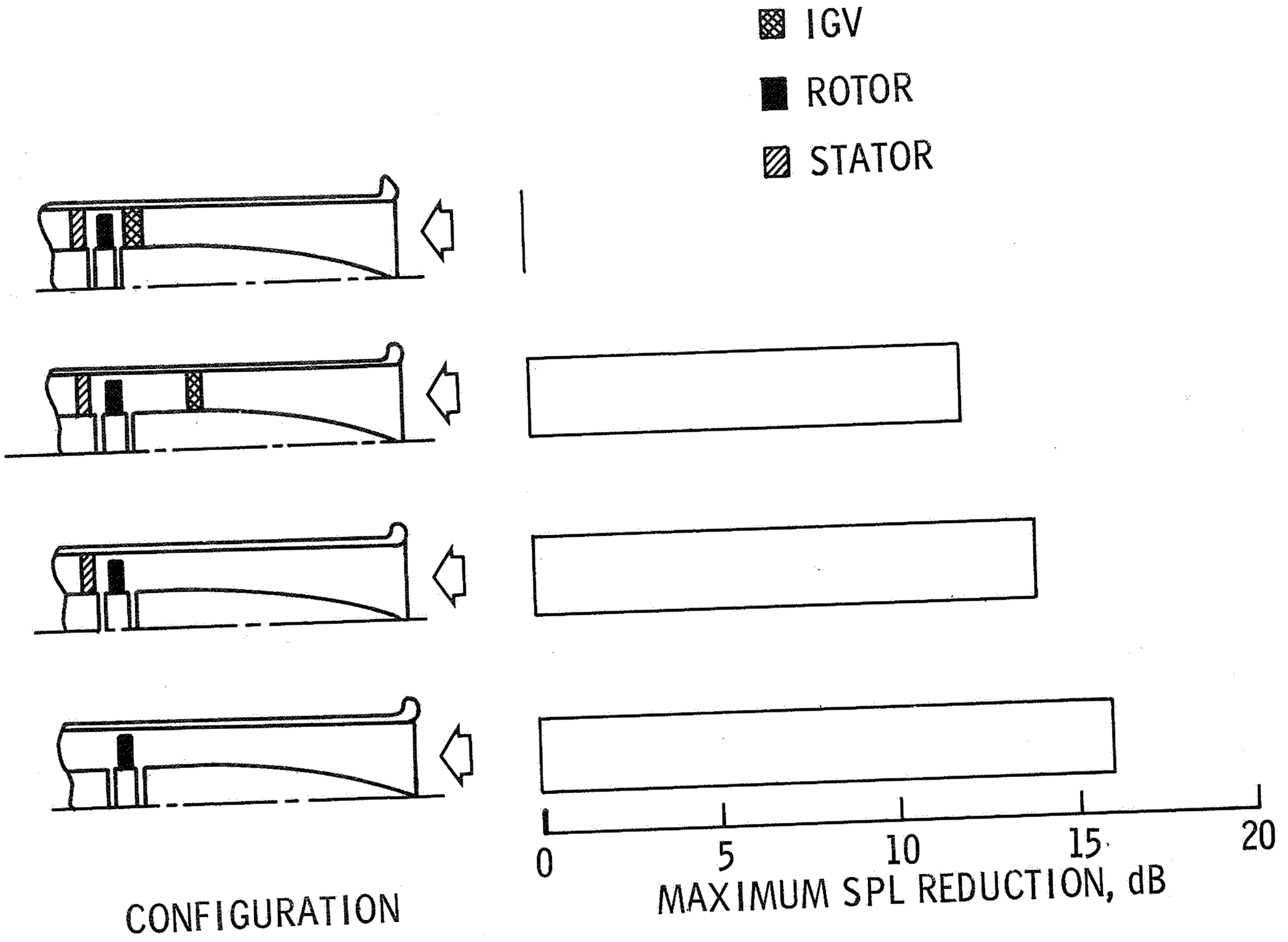

Figure 9.- Maximum noise-level reductions for various configurations of a single-stage compressor.

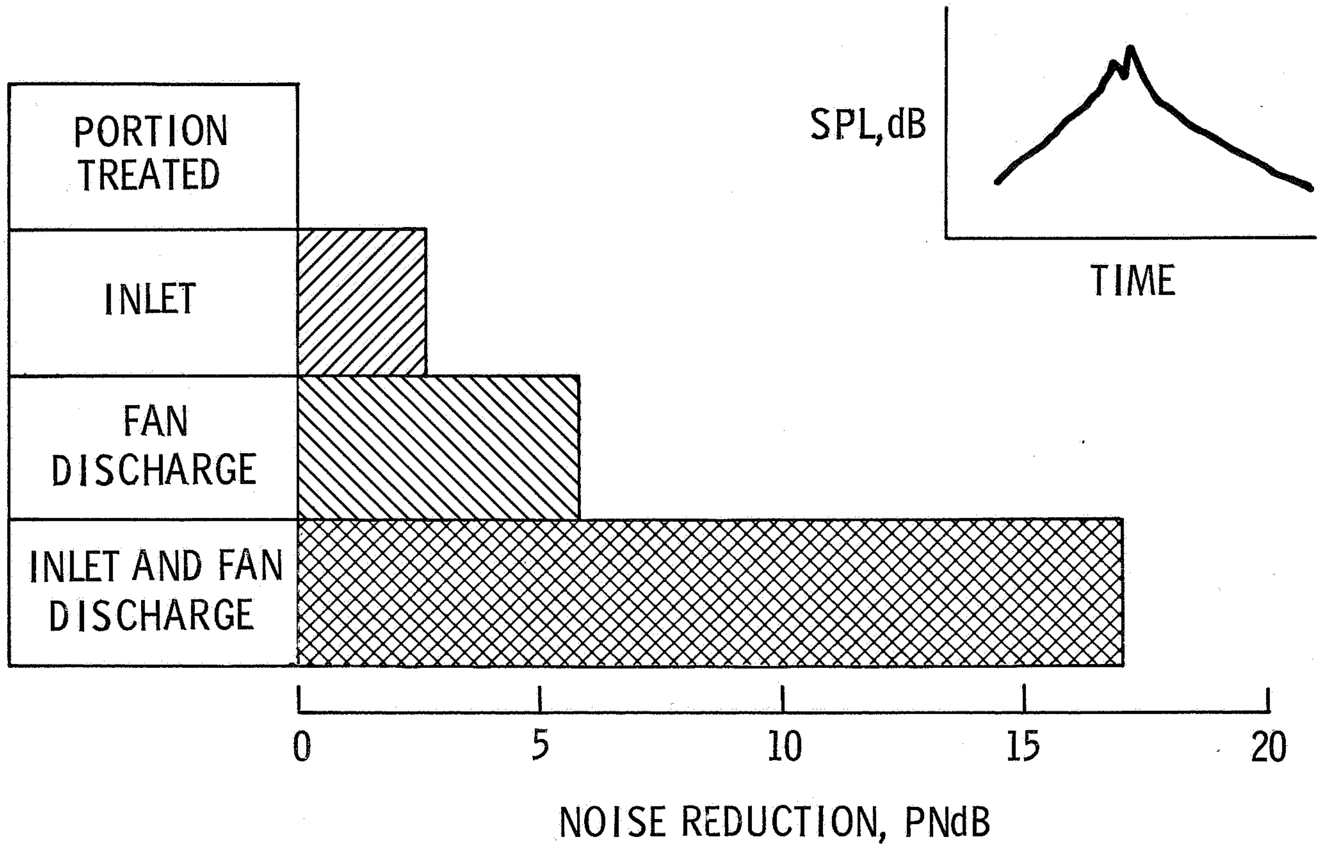

Figure 10.- Noise reduction potential of engine nacelle acoustic treatment (based on Douglas Aircraft Co. studies).

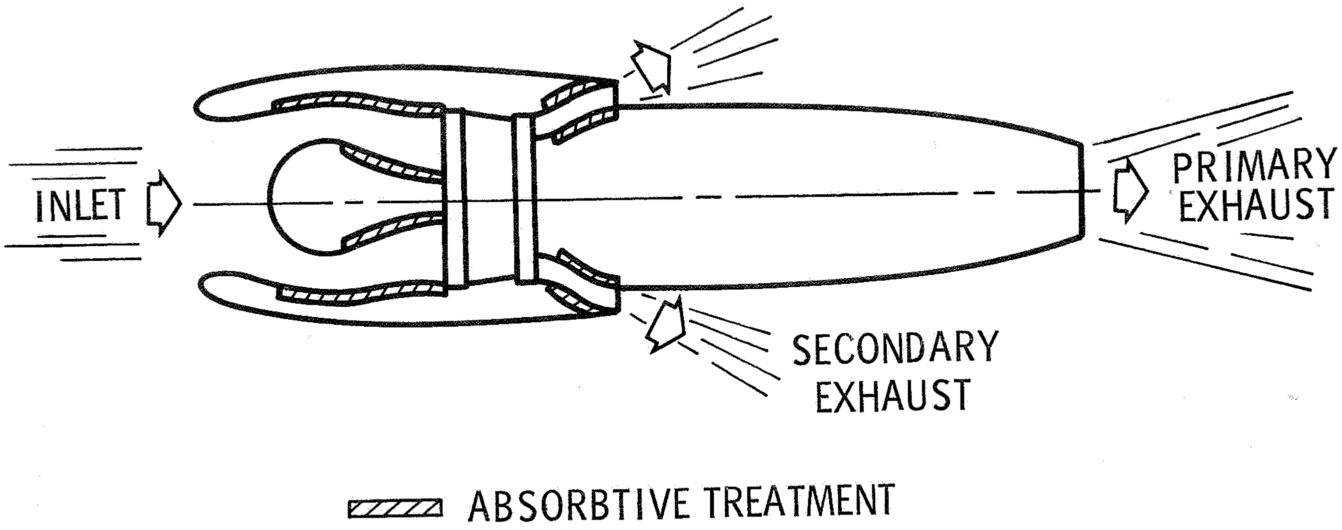

Figure 11.- Schematic diagram showing regions of a turbofan engine nacelle which are amenable to acoustic treatment (based on Douglas Aircraft Co. studies).

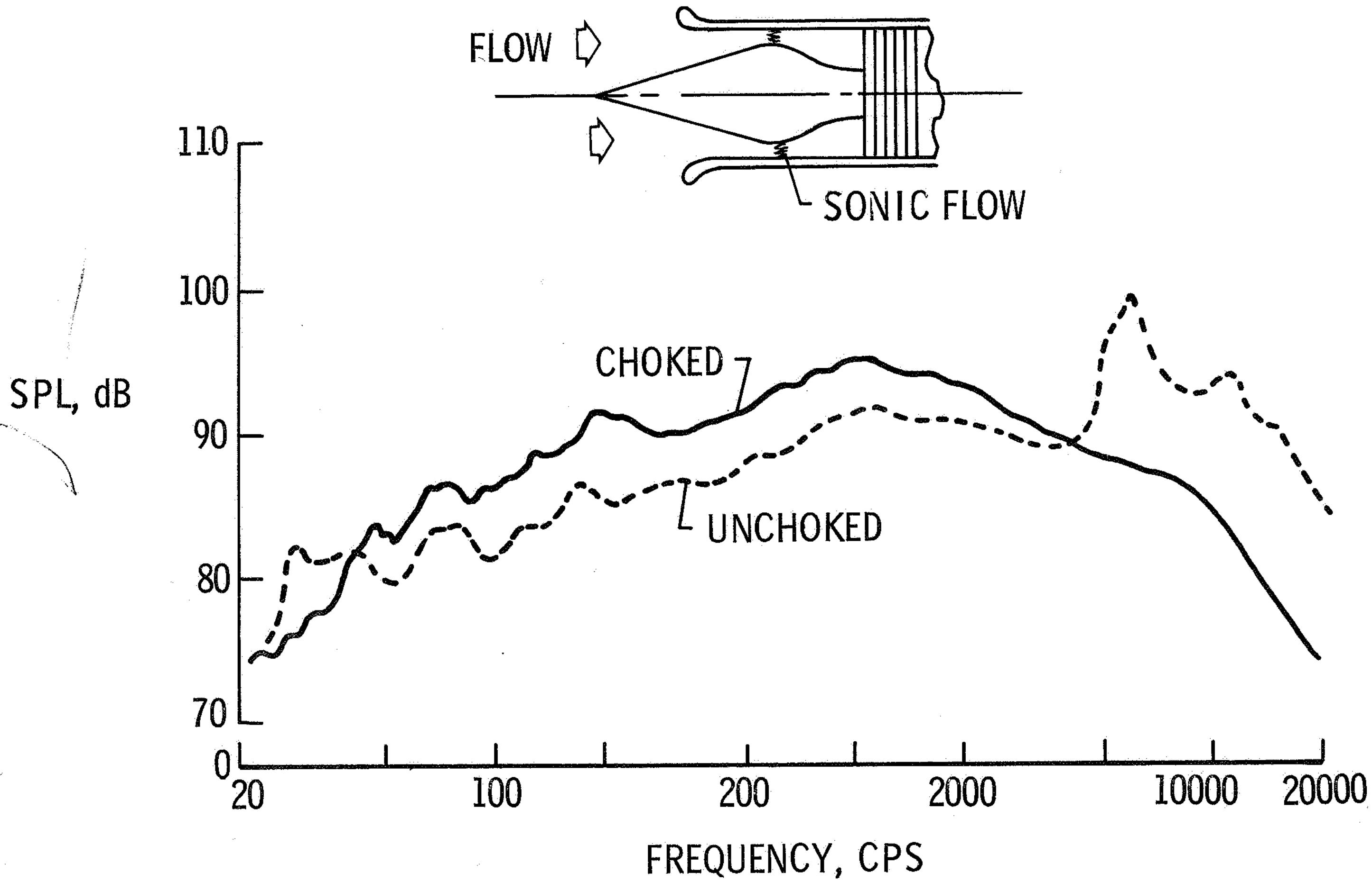

Figure 12.- Effects of inlet flow choking on the one-third octave band spectra of noise measured at a distance of 20 diameters and at an angle of 20° from the axis in front.

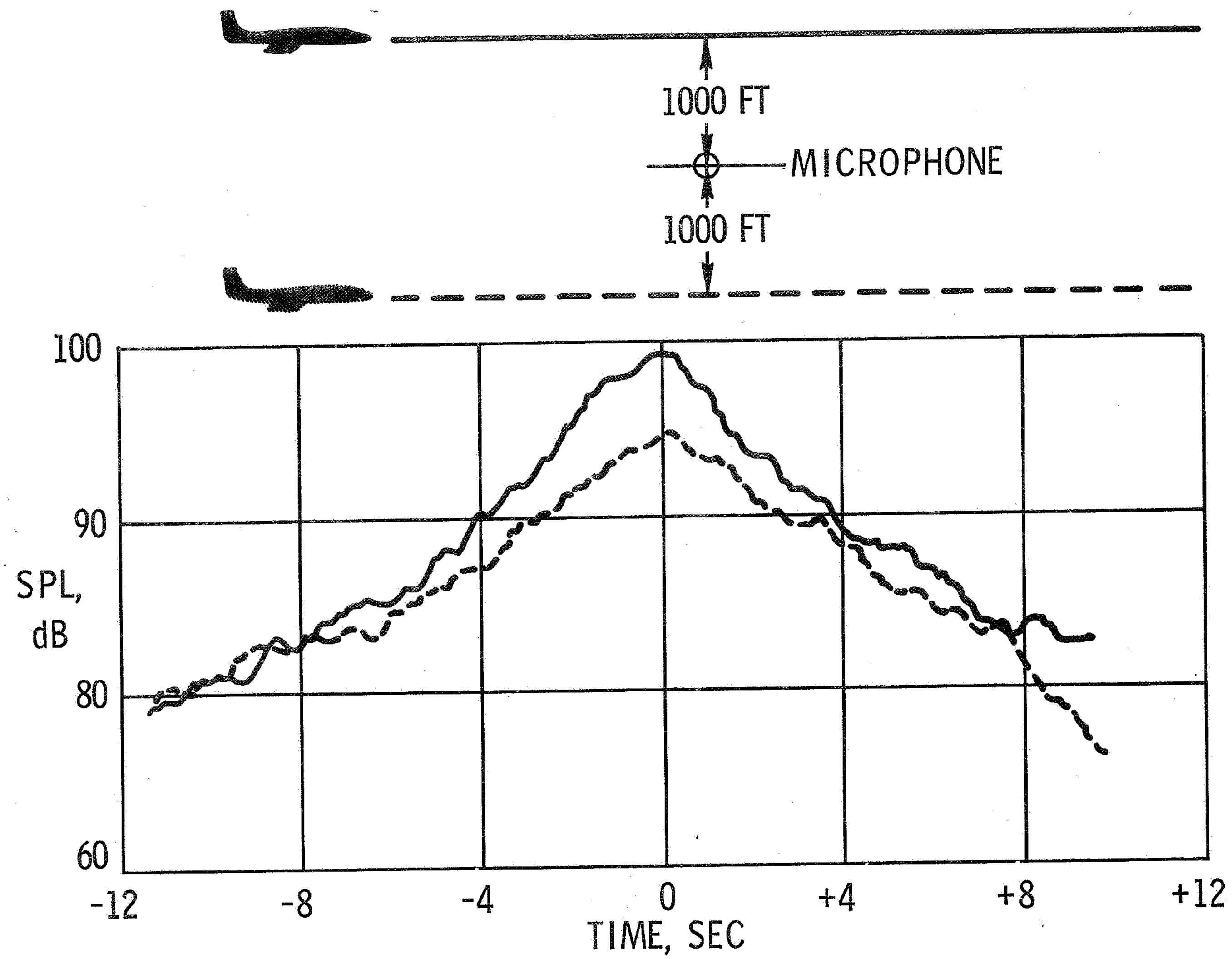

Figure 13.- Comparison of the noise-level time histories measured 1000 feet above and below a 4-engine fan-powered transport aircraft for take-off power conditions. (Microphones were supported at about 2500 feet altitude by means of the Goodyear blimp.)

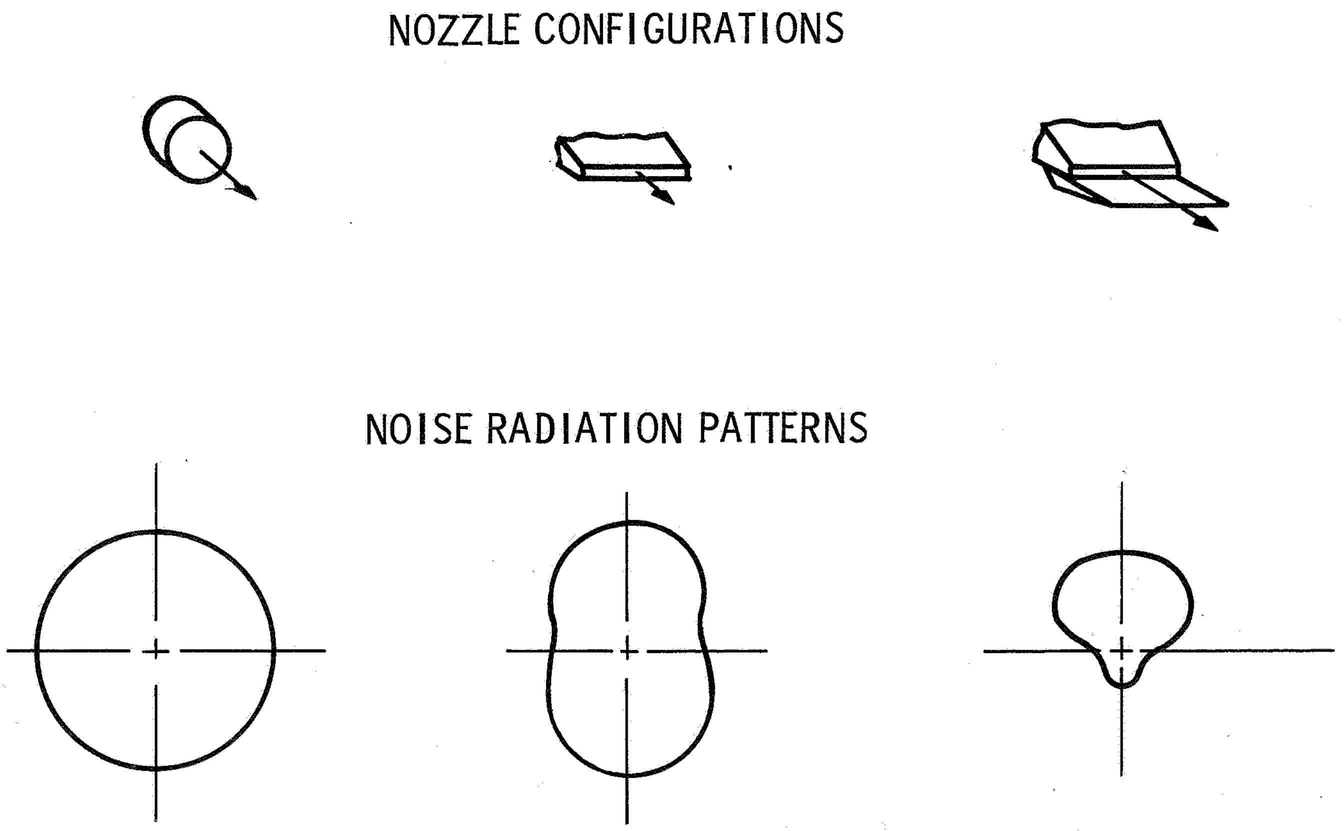

Figure 14.- Noise radiation patterns from three nozzle configurations.

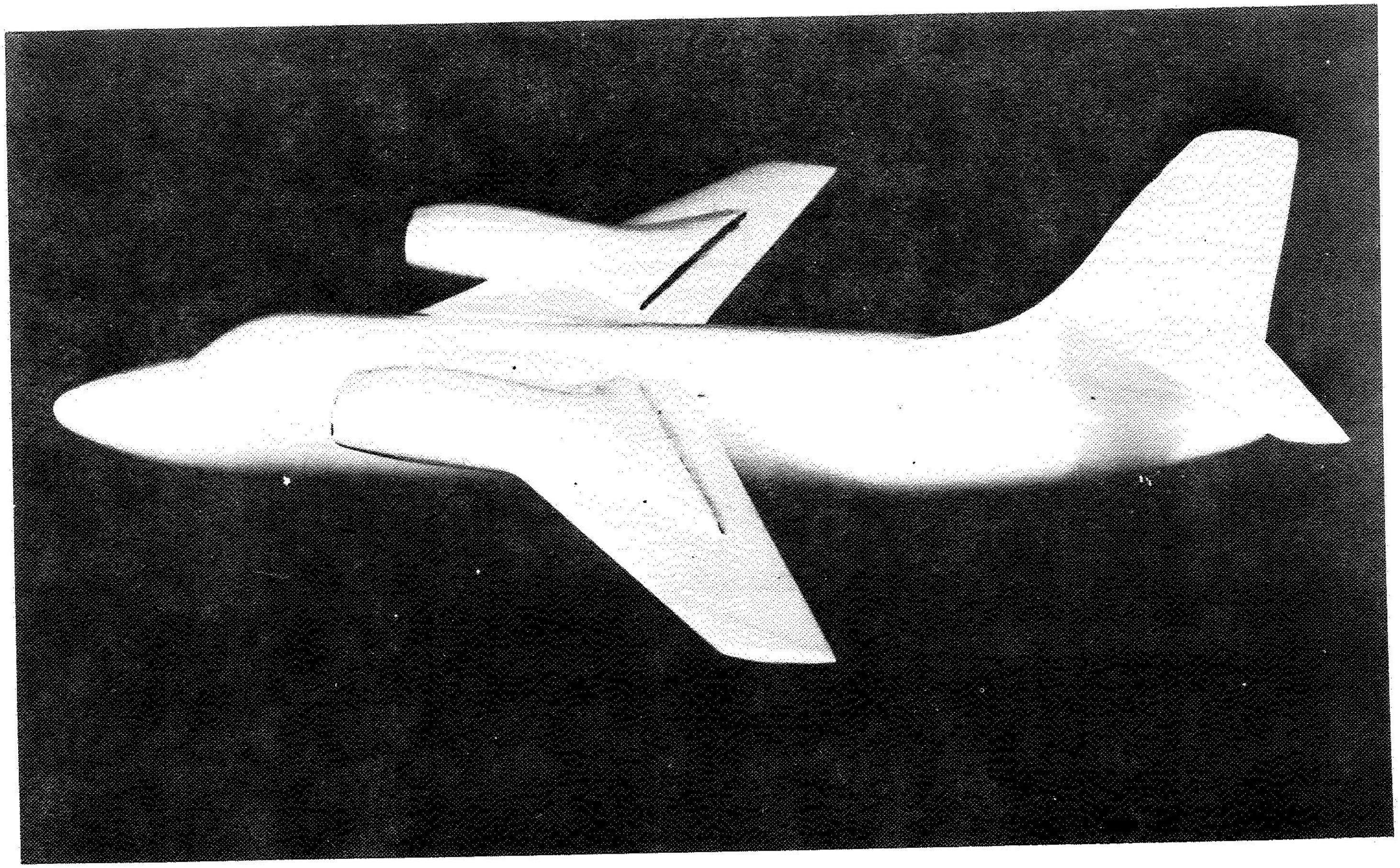

Figure 15.- Photograph of model of proposed jet flap airplane.

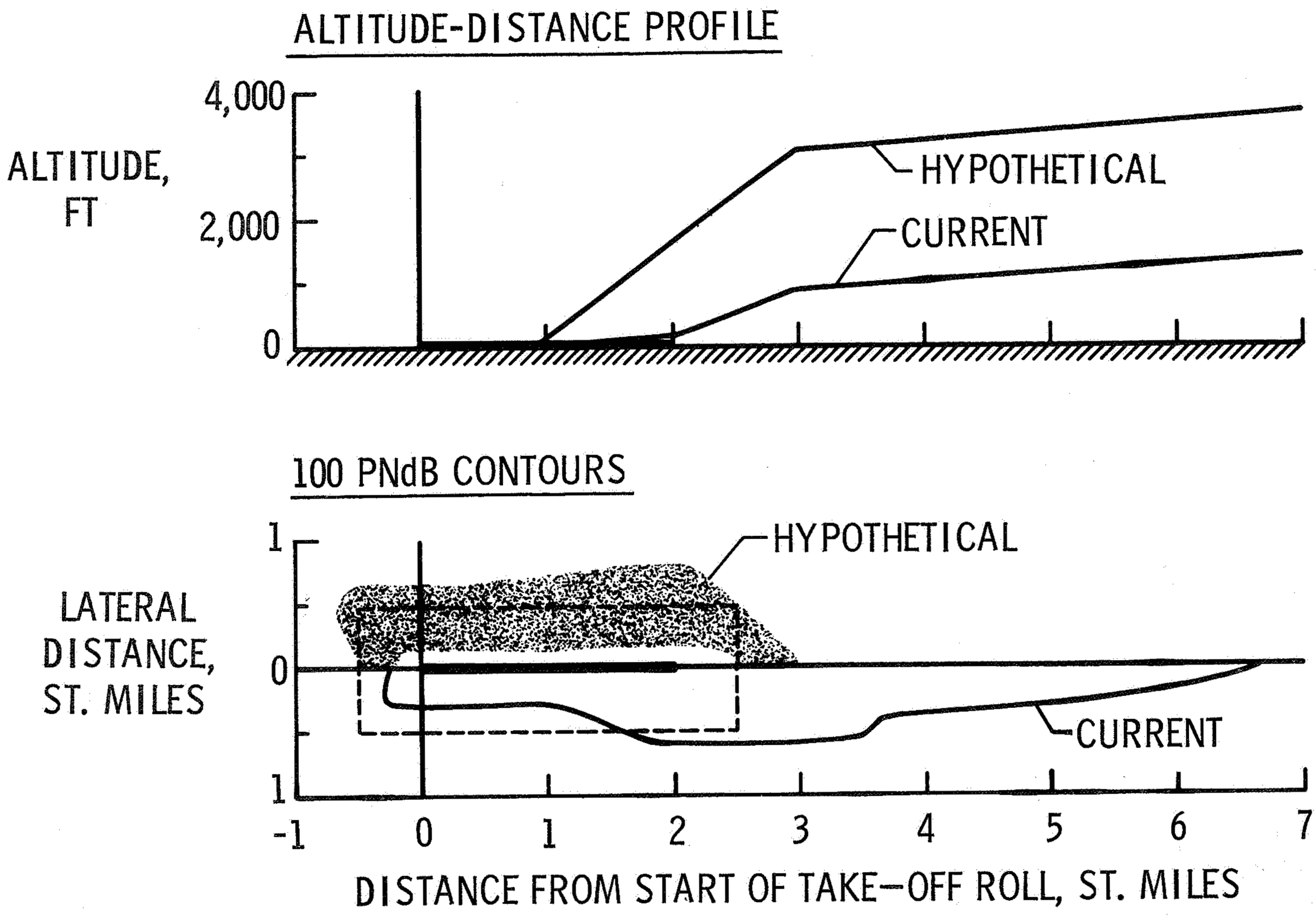

Figure 16.- Comparison of the altitude distance profiles and the associated ground noise contours for two aircraft having different values of thrust-to-weight ratio.

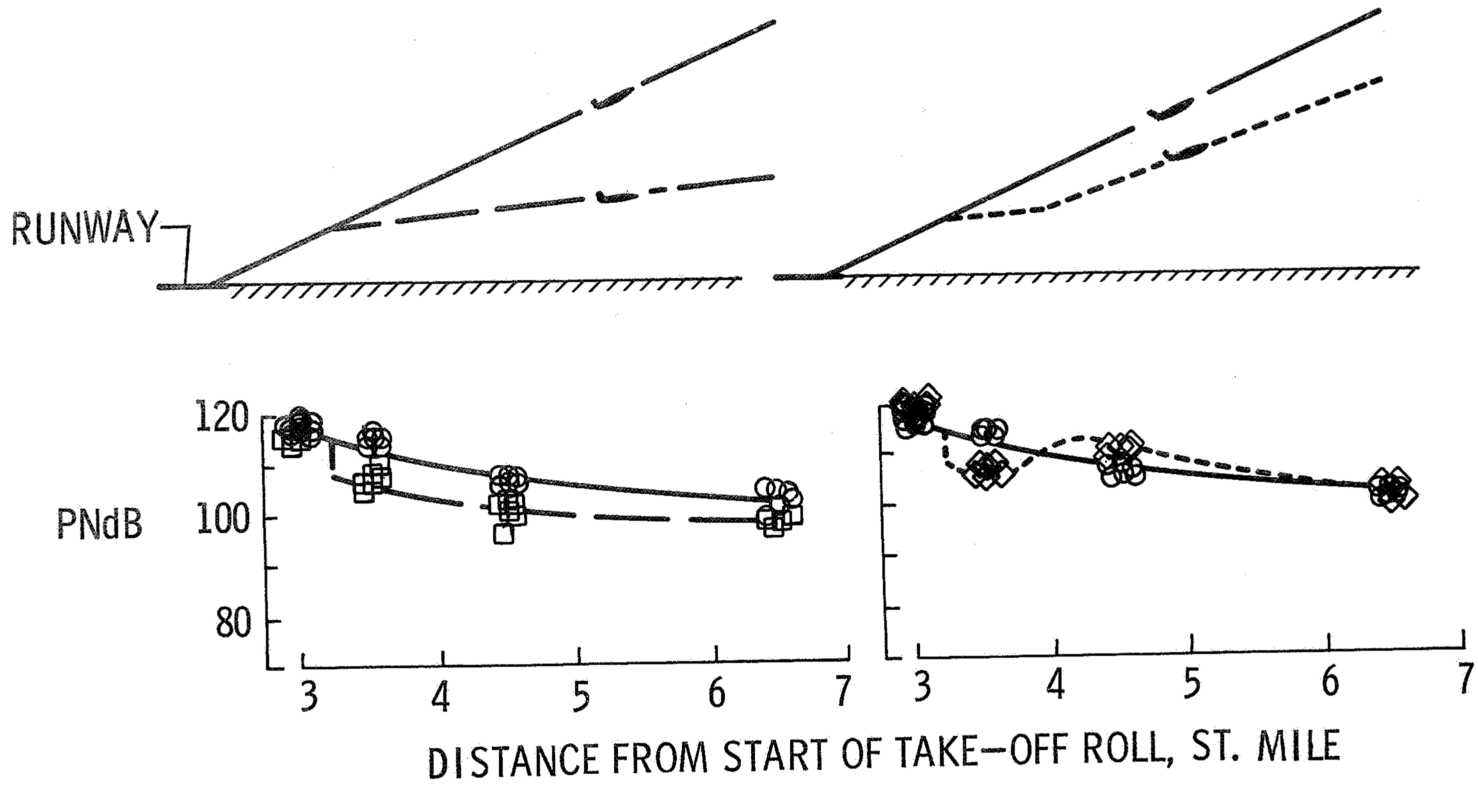

Figure 17.- Effects of power reduction on the ground noise levels during climbout of a four-engine turbojet-powered airplane.

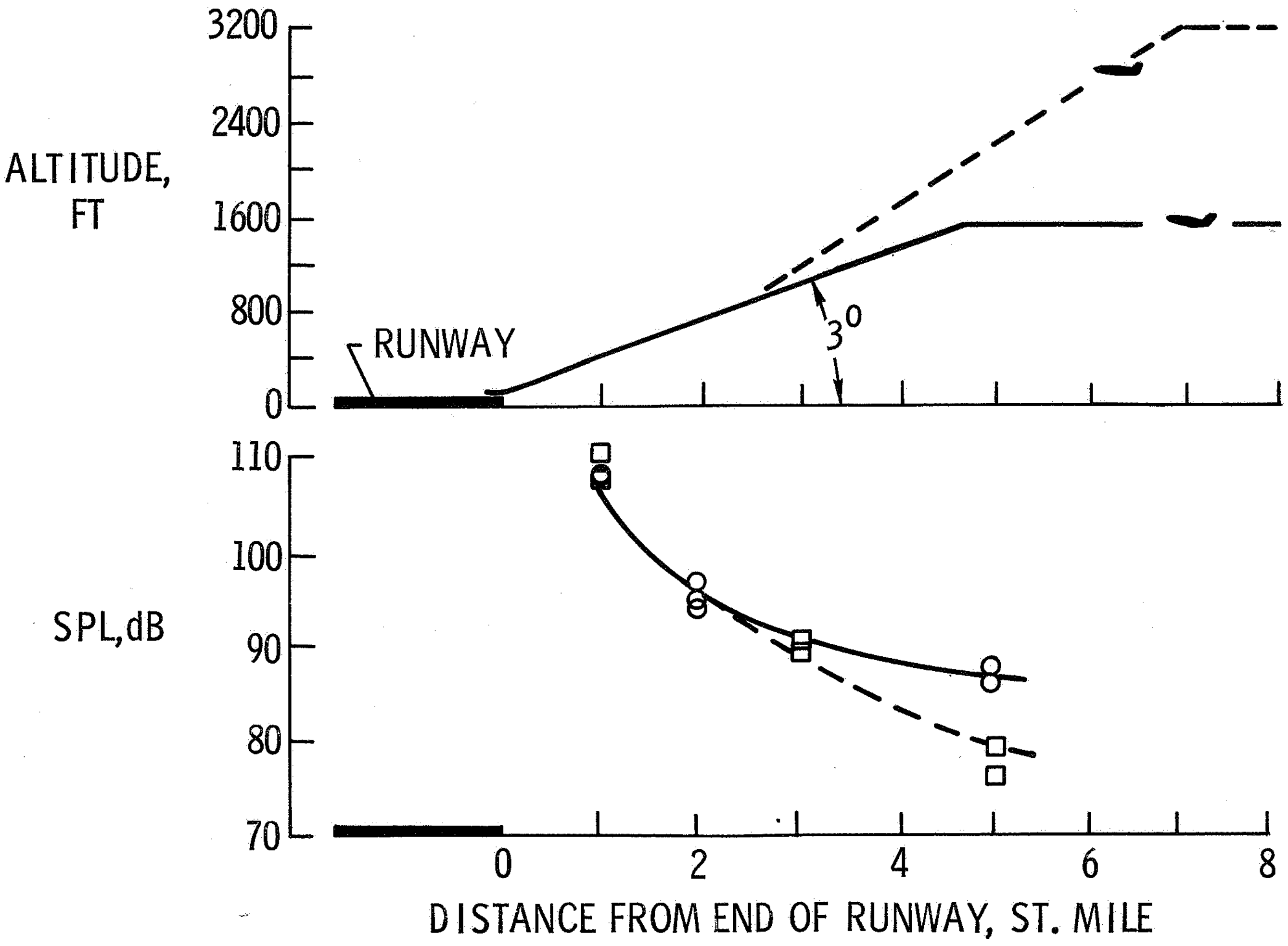

Figure 18.- Effects of steep angle approaches on the ground noise levels for a four-engine turbojet-powered airplane.

- TAX INCENTIVES
- FINANCIAL ASSISTANCE
- ZONING
- BUILDING AND HOUSING CODES
- LAND ACQUISITION
- EMINENT DOMAIN
- URBAN RENEWAL

Figure 19.- Community considerations.

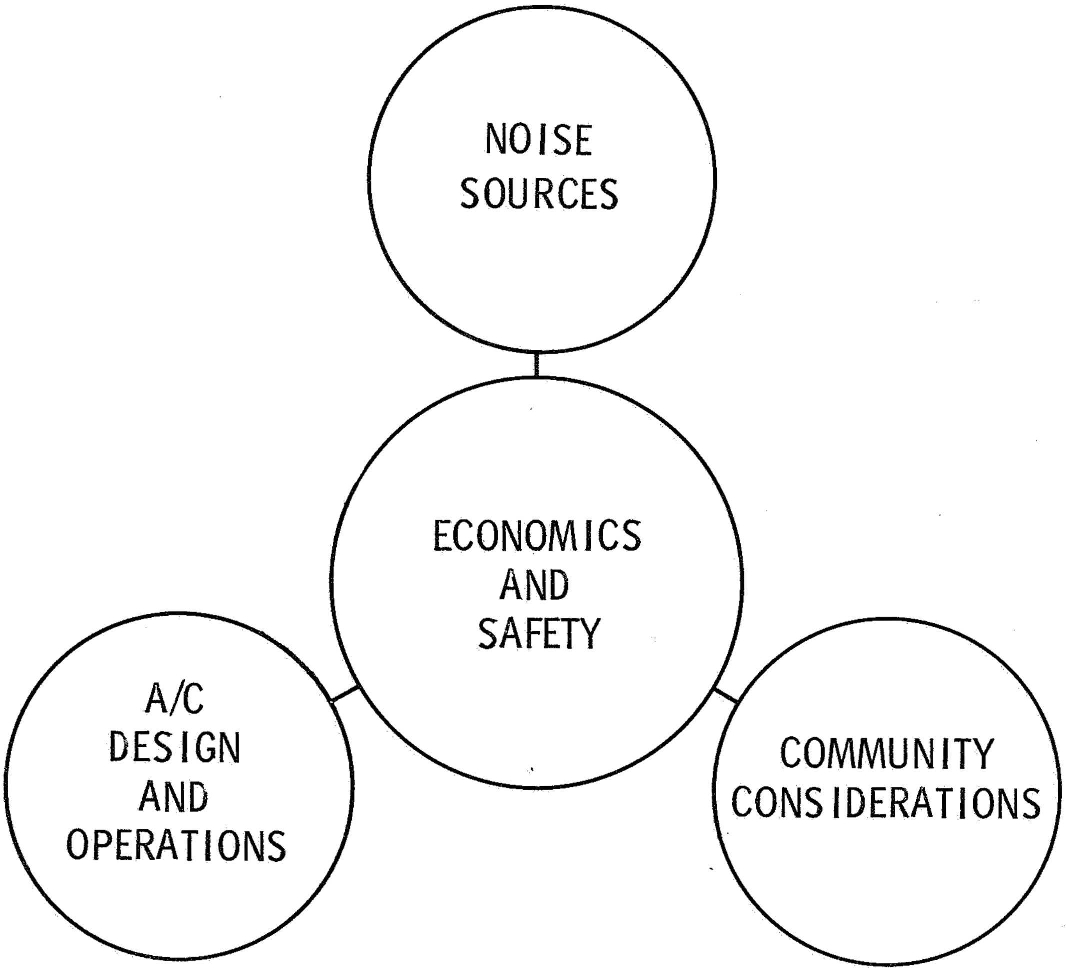

Figure 20.- Significant factors in the airport-community noise problem.

NASA-Langley, 1966