28. PROCEDURES FOR ESTIMATING THE EFFECTS OF DESIGN AND OPERATIONAL CHARACTERISTICS OF JET AIRCRAFT ON GROUND NOISE

By James H. Farrell

Conesco Division of Flow Corporation

SUMMARY

Procedures have been developed for estimating the effects of design and operational characteristics of jet aircraft on ground noise including various engine-cycle parameters, aircraft-design characteristics, and aircraft-flight characteristics. Parametric plots have been prepared to show how these different interrelated factors influence noise; and, when possible, assessments have been made of the accuracies and limitations of the graphs, nomographs, and equations that have been developed. This paper presents a review of these studies.

INTRODUCTION

One very important aspect of the noise-control problem is that it is a system problem, and any noise reduction, if it is to be attempted at an early design stage, requires knowledge of how various design and operation factors of the engine-airplane system are combined to influence the noise level on the ground. Along with this fact is the consideration that because of the complexity of the problem, noise control will involve the efforts of people who are not experienced acousticians, and it is important that acoustical data and design procedures be put in a form easily understood and used by engineers who do not have acoustical experience.

The present program was organized with these two important considerations in mind. Specifically, it was concerned with the study of how various factors inherent in the design and operation of any engine-airplane system are combined to influence the noise level on the ground. The aim of the program was to identify the various factors of importance and to develop quantitative descriptions of how they are related to noise. A further aim of the program was to develop and present simplified and easy-to-use parametric charts, nomographs, and formulas that might enable designers and others to relate quickly and directly the important engine and airplane design parameters to noise.

A detailed report of the program is presented in reference 1; this paper is a synopsis of that report.

SYMBOLS

A	exhaust nozzle area, compressor flow area, humidity-absorption coefficient
C_D	drag coefficient
C_L	lift coefficient
$C_{\hat{L}}$	maximum lift coefficient
CPR	overall cycle pressure ratio
F_n	net thrust of aircraft
FPR	fan pressure ratio
H	distance of closest approach
PNdB	unit of perceived noise level (PNL)
PNL	perceived noise level
P_r	nozzle pressure ratio
Q	log of ratio of perceived noise to thrust, $\mathrm{PNdB}_o - 10 \log F_n$
S	wing reference area, initial distance between observer and aircraft
S’	ground-roll distance
S_o	distance to observer from starting roll position
SFC	specific fuel consumption
T	net thrust of aircraft
T_t	nozzle total temperature
T_4	turbine inlet temperature

V or V_0	aircraft velocity
W	weight of aircraft
β	bypass ratio
Y	flight-path inclination

INFLUENCING FACTORS

The factors that influence the noise at specific ground locations are as follows: First, the engine-noise source can vary in sound-power level, spectrum shape, and directionality pattern, depending upon the engine-design characteristics. Second, the distance between the noise source and the ground observer depends upon aircraft-design characteristics and the chosen flight paths, and third, the noise-attenuation characteristics of the air depend upon such things as temperature and moisture content. This program has been concerned with the interrelation of these factors, and an effort has been made to show how the existing knowledge of jet-engine noise can be used to develop explicit relations among these factors. The work has been primarily analytical, and much experimental verification is needed to establish accuracies. The program has included the following efforts:

(1) Noise-prediction procedures for jets and compressors have been established. This program has involved

(a) A review of "SAE" method of predicting jet-exhaust noise and the development of a direct method for estimating jet perceived noise levels (PNL)

(b) The development of a procedure for calculating the initial perceived noise levels (PNL_0) of combined jets in fan engines

(c) The modification of several suggested compressor noise-prediction methods into one unified method

(2) An analytical investigation of noise as a function of engine-cycle parameters for jet and fan engines has been performed, The parameters considered include:

Nozzle parameters:

Exhaust velocity
Density
Total temperature
Pressure ratio
Weight flow
Nozzle area

Fan parameters:

Tip velocity
Weight flow

Cycle parameters:

Cycle pressure ratio
Fan pressure
Turbine inlet temperature
Bypass ratio

Parametric plots have been prepared that show how jet and fan noise vary as these different parameters are changed.

(3) Several simplified calculational methods have been developed for determining PNL for various situations including:

(a) Jet and compressor noise PNL from overall sound-pressure level

(b) PNL of the combined jet and compressor noise from individual PNL values

(c) Prediction of the variation of PNL with distance for jet, compressor, and jet combined with compressor noise

(4) An analytical investigation has been made of aircraft separation distances and, hence, noise as a function of design and flight characteristics. The parameters considered include wing loading $\frac{\text{Weight}}{\text{Wing reference area}}$; drag-weight ratio $\frac{\text{Drag}}{\text{Weight}}$; power loading $\frac{\text{Thrust}}{\text{Weight}}$; and maximum lift coefficient of wing $C_{\hat{L}}$.

Parametric plots have been made relating these parameters to ground noise.

(5) Both graphical and analytical procedures have been developed for establishing ground noise at specific points or over specific areas when an aircraft is in flight. The graphical procedure allows direct comparisons of ground PNL contours for different flight paths.

(6) To show what can be done with some of the methods that have been developed, PNL contours, magnitudes of ground areas as functions of PNL, and annoyance levels have been calculated for several flight paths, and the results have been compared.

To illustrate the work, consider the following examples from the program.

Engine-Cycle Parameters and Noise

Engine-cycle parameters can be related to jet-exhaust noise by use of the SAE method of predicting jet noise. In this method, the engine-reference noise level is a function of the exhaust density, the exhaust nozzle area, and the relative velocity between the jet exit velocity and the aircraft speed. The three variables – density, nozzle area, and jet velocity – can be related to such parameters as nozzle-pressure ratio, nozzle total temperature, overall cycle pressure ratio, turbine inlet temperature, and engine size (represented by either area, thrust, or weight flow); thus, the engine-reference noise level can be given directly as a function of these variables. Once the reference noise level is known, perceived noise levels can be determined. Figure 1 shows a plot of sideline perceived noise levels as functions of pressure ratio, total temperature, area, and aircraft velocity. This particular graph is plotted for an area of 5 square feet. If there is a total temperature of 1200° F, a pressure ratio of 2.5, and the aircraft is traveling at 300 ft/sec, then the reference PNdB is 130. As can be seen, such graphs can be conveniently used by engine designers, and the values obtained are within 1/2 dB of what would be obtained by a calculation using the SAE method.

In the case of compressor noise, there is no standard calculational procedure available for determining sideline noise; however, several empirical methods have been combined to give results that are accurate to about ±6 dB, and which can give qualitative information on noise trends. Figure 2 shows how such variables as bypass ratio, fan pressure ratio, turbine inlet temperature, and specific aircraft velocities are related to a noise parameter Q which has been defined as the log of the ratio of perceived noise to thrust and which is an expression of the amount of perceived noise per pound of thrust. Figure 2 is for an aircraft velocity of 200 ft/sec; other graphs for three other velocities have been developed.

Even though figure 2 is representative of trends, some interesting results are obtained by relating the cycle variables to noise and an important factor such as specific fuel consumption. Specific fuel consumption is directly related to the parameters: bypass ratio, flow-pressure ratio, cycle pressure ratio, and turbine inlet temperature. Figure 3 shows a sample graph of the noise parameter Q as a function of specific fuel consumption for various combinations of engine parameters. It can be seen that a low Q is generally associated with a low specific fuel consumption. From a consideration of several such graphs, it appears that in optimum high-bypass-ratio designs, the compressor noise per unit flow, the jet noise Q, and the specific fuel consumption all tend to be minimized and, thus, on an equal thrust basis, high-bypass-ratio designs are favorable for both noise and economy.

Airframe Design and Noise

Aerodynamic design of an airframe can indirectly influence the amount of noise received on the ground in several ways: (1) by affecting the flight path relative to the observer, and hence the distance between the observer and the noise source, (2) by affecting the engine-power requirement at various modes of take-off and landing operations, and hence the noise-source intensity, and (3) by affecting the aircraft speed characteristics which, in turn, affect both the noise source characteristics and the exposure time of the observer to the noise.

Airframe design parameters that are of special importance in noise studies include the gross weight W, wing reference area S, coefficients of lift and drag C_L and C_D at various airplane flap configurations, and the thrust T. Once these parameters or their limiting values are adequately defined, it is generally possible to establish the limits in flight path, power setting, and speed within which the airplane can operate.

For a powerplant operating at a specific power setting during take-off, the most important variable which determines the noise level experienced by an observer on the ground is the minimum separation distance between the observer and the flight path. This minimum separation distance is denoted by the symbol **H**. If the observer is directly under the flight path and the climb angle of the aircraft is not very steep, the minimum separation distance is almost exactly equal to the altitude of the aircraft when directly overhead.

Figure 4 is a schematic diagram of a take-off where the climb angle is given by γ, the closest approach distance between the observer and the plane is given by H, and the equivalent ground-roll distance is given by S'. Equivalent ground-roll distance can be empirically related to such aircraft-design parameters as weight, thrust, wing area, and maximum lift coefficient, whereas the climb angle y is related to thrust, drag, and weight. It is thus possible to express the distance of closest approach in terms of the distance between the observer and the starting roll position S_o and various airframe-design parameters. If an observer is considered to be at the 3-mile point (so that S_o is known), then the distance of closest approach can be expressed solely in terms of design parameters, and it is now possible to calculate the maximum noise level at the 3-mile point, only the airframe parameters and the engine characteristics being known. This procedure has been followed, the following assumptions being made: (1)the climb-out path of the airplane follows a constant angle of attack, (2) there is a constant speed procedure, and (3) the powerplant design is fixed. Under these conditions, the effect of airframe-design parameters on noise is due simply to their effect on separation distance. For example, figure 5 shows the effect of power loading T/W on the relative PNL (APNdB) for several values of wing loading. This effect is very strong, and increasing the thrust-weight ratio from 0.25 to 0.35 can mean a noise reduction of approximately 5 to 7 PNdB for both jet and compressor noise.

Although the engine noise may be known and the effect of airframe-design parameters on noise may be known, the picture is incomplete if the effect on ground noise of various aircraft maneuvers is not determined. Two methods have been developed for determining the PNdB of an aircraft at selected positions on the ground. The first method is graphical and gives a quick and simple procedure for determining the time history and magnitudes of PNL at selected ground points. The second method is an analytical method and gives the same answers, but in a form suitable for computer applications. Of central importance in the graphical method is the concept that the aircraft noise field may be considered as fixed and that the ground observer can be considered as moving relative to the stationary aircraft and its noise field. Thus, different observer points and flight paths may be represented by properly oriented flight paths drawn on noise contour maps of the airplane. The analytic method utilizes the concept of the angle of maximum radiation and distance of closest approach to determine the maximum PNL that a ground point experiences. By means of these concepts, a computer program has been written and used to determine the contours of constant PNL produced by various take-off procedures.

The graphical procedure is most useful for showing how variations in the airplane flight path can influence the noise at a specific ground location, whereas the computer analysis is most useful for calculating contour plots of noise levels for various assumed take-off and landing procedures. The graphical procedure is illustrated in figure 6, which shows a typical take-off flight path. To visualize the development of the two-dimensional tracking plot, it is necessary to imagine how a fixed point on the ground appears to an observer in the airplane. In figure 6, at the start, the ground-observation point will be in line with the runway and several miles from the start of the ground roll. Thus, the ground point appears, to the observer, to be approaching along the airplane axis. At rotation, the airplane pitches upward, which causes the ground point to rotate down, as seen by the observer. Thus, the pitch maneuver, if negotiated quickly, can be projected on the plot as an instantaneous rotation of the ground point at constant range. The airplane then continues to climb at a constant rate, and this flight path is a straight line parallel to the axis of the airplane on the noise plot.

As can be visualized, because of the axial symmetry of the noise field around the aircraft, any straight-line flight path will resolve itself into a straight line parallel to the aircraft axis on the noise plot, and each such segment of straight-line flight will have a corresponding distance of closest approach. The effects of a power cutback are also shown in figure 6. As can be seen, before the track reached the point of closest approach and the point of maximum PNL, a rotation at constant slant range has been shown. This rotation corresponds to the downward pitch of the aircraft at power cutback. In this illustration, it has been assumed the power cutback would lower the PNL values of the contour by 10 PNdB. This effect is indicated by the dashed-line sections showing the after-cutback values of the PNL contours. From such a diagram, if the flight velocity is known, the complete time history of the observation point can be constructed.

CONCLUDING REMARKS

The illustrations presented give some idea of what can be accomplished with existing theory. Obviously, what has been done is only a beginning, and it is to be hoped that those engineers who are actively concerned with engine or airframe design or with operational problems will extend the approaches presented in the report so that the prediction of ground noise becomes part of the routine of aircraft design or of flight analysis.

REFERENCE

1. Lee, Robert; Farrell, James; Henry, George; and Lowe, Albert: Procedures for Estimating the Effects of Design and Operational Characteristics of Jet Aircraft on Ground Noise. NASA CR-1053, 1968.

PERCEIVED NOISE LEVEL AS FUNCTION OF PRESSURE RATIO, TEMPERATURE, AREA, AND VELOCITY

AREA = 5 SQ FT

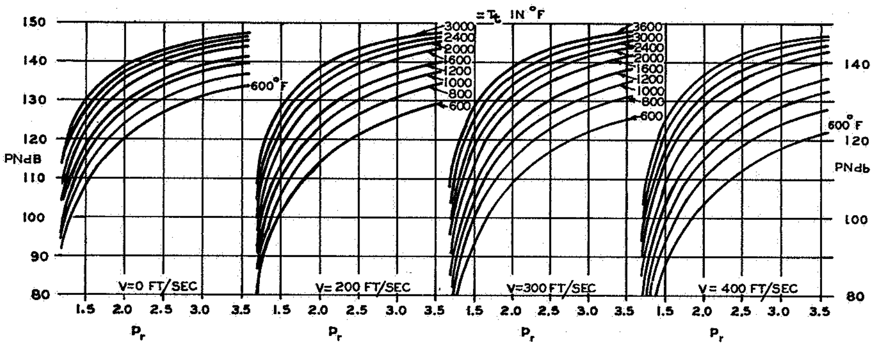

Figure 1

Q AS A FUNCTION OF BYPASS RATIO, FAN PRESSURE RATIO, TEMPERATURE, AND OVERALL CYCLE PRESSURE RATIO

AIRCRAFT VELOCITY, 200 FT/SEC

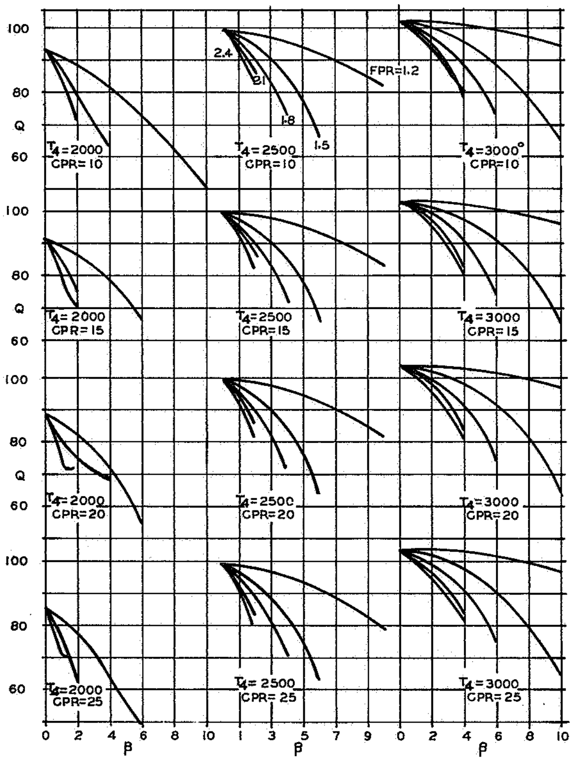

Figure 2

Q AS A FUNCTION OF SPECIFIC FUEL CONSUMPTION FOR VARIOUS OVERALL CYCLE PRESSURE RATIOS, FAN PRESSURE RATIOS, BYPASS RATIOS, AND TEMPERATURE

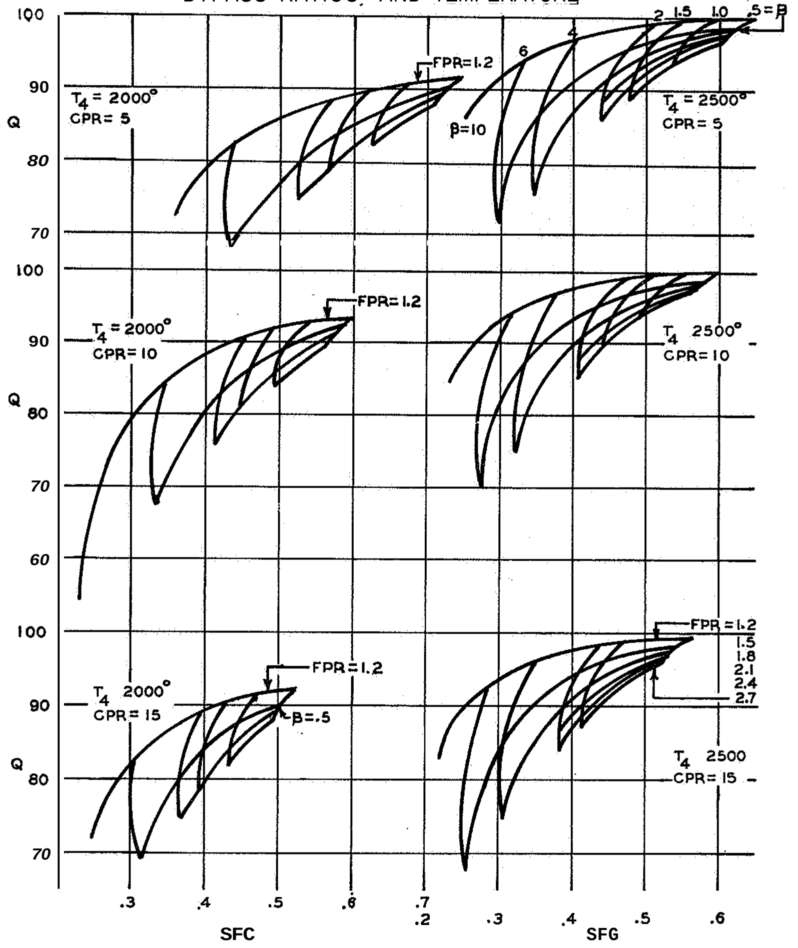

Figure 3

TAKE-OFF SCHEMATIC

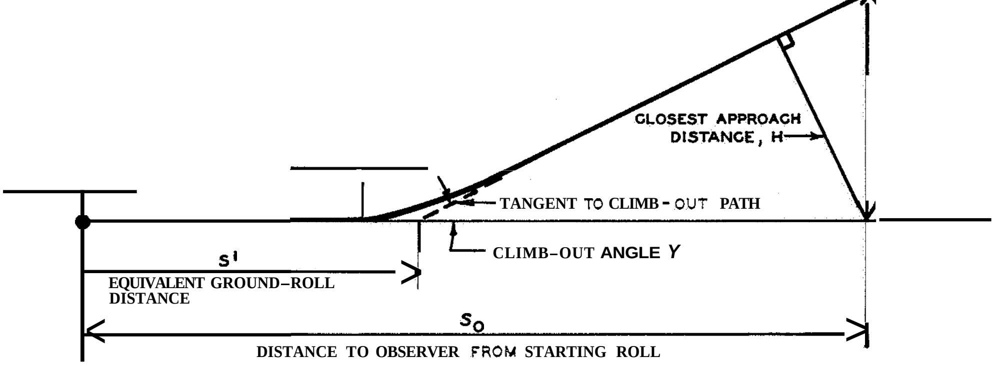

Figure 4

APNdB AS A FUNCTION OF POWER LOADING

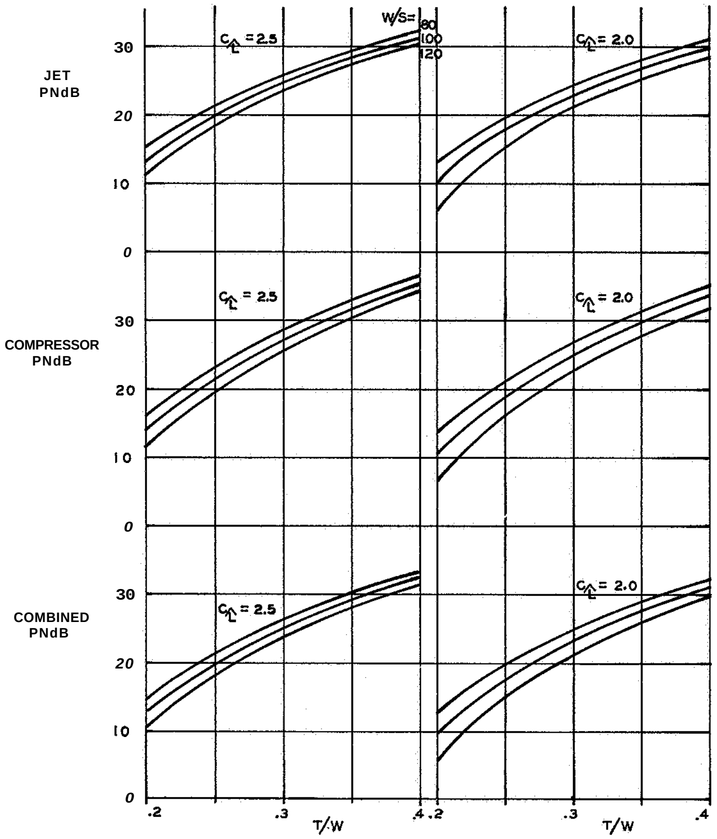

Figure 5

GROUND-TRACK PLOT OF AIRPLANE TAKE-OFF

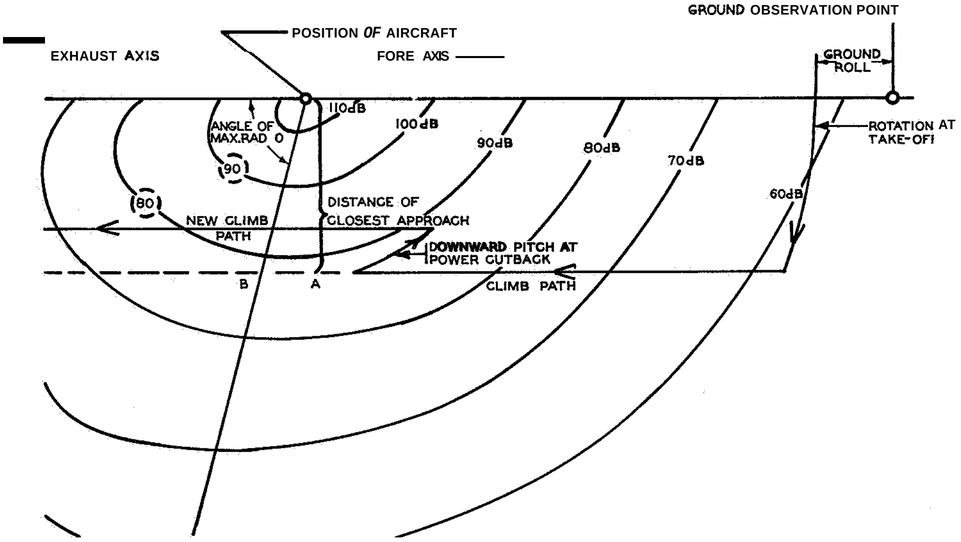

Figure 6