# 12. NOISE PREDICTIONS AND ECONOMIC EFFECTS OF NACELLE MODIFICATIONS TO MCDONNELL DOUGLAS DC-8 AIRPLANES

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## SUMMARY

Techniques are described that were used for predicting the perceived-noise levels produced by DC-8 airplanes equipped with existing nacelles and with the modified nacelles selected for flight testing. For the landing-approach case with a DC-8 at maximum landing weight at a location 1 nautical mile from the runway threshold, the modified nacelles were predicted to produce a peak instantaneous perceived-noise level that would be about 11 PNdB less than that produced by an airplane equipped with the existing nacelles. The tolerances estimated for the predictions indicate that the reduction expected may be as small as 6 PNdB or as large as 14 PNdB. No change was predicted for the peak perceived-noise level during take-off.

The economic effects of modification to the existing nacelles, in terms of direct operating costs, were estimated by using a method of the Air Transport Association of America with engine-performance data from the test stand extrapolated to flight conditions and with the estimated effects of the modified nacelles on drag. This paper describes the basic assumptions used in the calculations and shows the effects that the nacelle modifications have on the various elements of the direct operating costs. The most significant cost increase is in the acquisition and depreciation of the modified nacelles. The total increase in direct operating costs was about 5.7 percent.

These noise predictions and estimated economic effects apply only to the specific engine and nacelle design considered. Substantial differences may exist in the effects of duct linings on other JT3D installations or on installations of other turbofan engines.

## INTRODUCTION

References 1 and 2 described the design, development, and testing of various acoustically treated inlet and fan-exhaust ducts for the JTSD engine. The tests were conducted on an engine test stand where far-field sound-pressure levels (SPL) and engine performance were measured for various configurations of treated inlet and fan-exhaust ducts and for the reference DC-8 inlet and fan-exhaust ducts. On the basis of these measurements, an inlet and fan-exhaust-duct configuration was selected for fabrication and testing in the flight-test program presented in reference 3.

This paper presents predictions of the flyover perceived-noise levels (PNL) produced by DC-8 airplanes equipped with nacelles modified to the configuration selected for the flight-test program. The estimated economic effects of airline operations with the modified nacelles are also presented. The noise predictions and estimated economic effects are based on the acoustical and engine-performance data obtained during the ground tests (ref. 2).

Economic effects were estimated in terms of changes to retrofit costs and to direct operating costs (DOC). In order to estimate DOC's, engine-performance data measured during the ground tests were extrapolated to flight conditions by standard methods. The basic method of calculating DOC's was patterned after that of reference 4. The effects of the modified nacelles on drag were also estimated by standard methods.

## SYMBOLS

| | |
|---|---|
| DOC | direct operating cost, cents/(seat-statute mile) |
| EPR | engine pressure ratio, $P_{t7}/P_{t2}$ |
| FAA | Federal Aviation Administration |
| $N_1$ | low-pressure rotor speed, revolutions/minute (rpm) |
| $N_1/\sqrt{\theta_{t2}}$ | referred low-pressure rotor speed, rpm |
| PNL | perceived-noise level, perceived-noise decibels (PNdB) |
| $\Delta PNL_{peak}$ | difference between peak value of instantaneous perceived-noise level of an airplane equipped with existing nacelle installation and peak value of instantaneous perceived-noise level of an airplane equipped with acoustically treated nacelles, PNdB |
| $P_{t2}$ | total air pressure at engine inlet, pounds/square foot absolute |
| $P_{t7}$ | total air pressure at inlet to primary-exhaust duct, pounds/square foot absolute |
| SPL | sound-pressure level, decibels (dB) re 0.0002 microbar |
| $T_{amb\ std}$ | standard-day ambient air temperature, 518.7° Rankine |

$T_{t2}$ total air temperature at engine inlet, degrees Rankine

$\theta_{t2}$ temperature ratio, $T_{t2}/T_{amb\ std}$

## DISCUSSION

### Noise-Prediction Techniques

A general description of the noise-prediction techniques used by McDonnell Douglas was given briefly in reference 5. The approach selected took the averaged 1/3-octave-band SPL's, measured on a 150-foot circular arc centered at the exit of the primary exhaust nozzle, and projected them to various sideline distances, that is, to lines drawn parallel to the engine axis at selected distances from 200 to 3000 feet. These sideline projections were made along radial lines, assuming the source of sound to be at the primary exhaust nozzle, by applying corrections to the observed SPL's to account for inverse-square loss and atmospheric absorption. Atmospheric-absorption corrections for the 1/3-octave-band SPL's were determined for an air temperature of 77° Fahrenheit and a relative humidity of approximately 62 percent by using data obtained from reference 6 and by incorporating the modifications of reference 7. No corrections were included for any absorption due to ground effects.

Initial estimates of the flyover SPL's for selected flight conditions were obtained by interpolating the SPL's for each band between the available ground-runup engine-power settings. For example, at the landing power setting of 5000 pounds of referred net thrust per engine, interpolations were made at the referred low-pressure rotor speed $N_1/\sqrt{\theta_{t2}}$ of 4680 rpm and an engine-pressure ratio (EPR) of 1.21. In order to obtain estimates of the SPL's at the take-off power setting (14 500 pounds of referred net thrust per engine at the selected flight condition), the data were extrapolated, beyond the 6300-rpm condition used as the highest engine-power setting in the ground-runup tests, to a referred low-pressure rotor speed of 6500 rpm and an EPR of 1.81.

Estimates of the variation of the SPL with time during a flyover were next made by assuming that the projected sideline SPL's were representative of an airplane flying in straight and level flight over an observer on the ground. These estimates were made for each of the twenty-three 1/3-octave bands and for each of the nine engine-power settings used for the ground-runup tests. By assuming a constant airplane speed (a Mach number of 0.25 or about 280 feet/second), estimates were obtained for 0.25-second intervals of the variation of the 1/3-octave-band SPL's with time during the simulated flyover.

The critical problem in making the interpolations and extrapolations from the ground-runup data was in the selection of the appropriate parameter or parameters. The problem was complicated by the requirement to produce the correct shape, as well as the amplitude, of the flyover noise spectrum to obtain correct perceived-noise levels. High-frequency noise (for example, frequencies greater than 800 Hz) from the existing, unsuppressed JT3D nacelle is, presumably, related to fan-blade tip Mach number and, hence, was assumed to be a function of $N_1/\sqrt{\theta_{t2}}$. The low-frequency noise (for example, frequencies less than 800 Hz) was assumed to be a function of jet-exhaust velocity (or relative jet-exhaust velocity), since previous studies of turbojet engine noise had indicated that the jet-exhaust-velocity parameter produced reasonable correlation between predicted and measured values within this frequency range.

Two problems arose with attempts to utilize the exhaust-velocity parameter. First, the definition of the jet velocity was that derived from the thermodynamic fully expanded velocity determined from the EPR, the turbine-discharge total temperature, and the airplane Mach number. Exhaust velocity, determined in this manner, was representative only of the primary nozzle; the velocity of the air exhausted from the fan-discharge ducts was neglected.

The second problem was that predictions of the flyover SPL spectra from ground-runup SPL measurements of the reference JT3D-powered DC-8 airplanes did not always agree well with measured flyover SPL spectra. At some thrust settings, the predicted SPL's were higher than the measured values; at others, they were lower. Many attempts, using other engine parameters, were made to determine a method that would produce acceptable spectral estimates over a range of engine-power settings.

After considerable experimentation involving comparisons of predictions from ground-runup measurements to actual flyover SPL's (using data from JT3D- and JT8D-powered airplanes; for example, DC-8's and DC-9's), the parameter selected for making spectral estimates for each of the 1/3-octave bands between 50 and 8000 Hz was $N_1/\sqrt{\theta_{t2}}$. Empirical corrections were applied to the initial estimates of the flyover SPL's, for the 1/3-octave bands between 50 and 630 Hz, so that the predicted SPL's at the time associated with the maximum value of the instantaneous PNL for the existing JT3D-powered airplane would be close to previously measured values. In order to determine these empirical corrections, comparisons were also made with "composite" spectra consisting of the maximum 1/3-octave-band SPL's noted during a flyover.

The predicted flyover SPL's were adjusted to account for the difference in level owing to four engines by adding 6 dB to all 1/3-octave-band SPL's. Finally, the perceived noisiness of the predicted flyover SPL's, for a given flight condition, was determined by making use of the tables from reference 8 to convert the SPL's to noisiness values. A large-capacity digital computer was programed to carry out the computations described.

## Selection of Noise-Rating Unit

Probably, most of the airplane noise analyses that have been conducted in the past have been in terms of "composite" PNL's. Composite PNL's are computed from the maximum SPL readings in 1/1- or 1/3-octave bands, irrespective of the times of occurrence of the maximum values. Composite PNL's are the most readily obtainable and require the least sophisticated data-reduction system. "Instantaneous" PNL's are calculated from SPL spectra determined at discrete, closely spaced intervals of time from the beginning to the end of a flyover noise cycle. Both instantaneous and composite PNL's can be determined from the conversion tables in reference 8.

In recent years, it has been suggested that corrections should be applied to the PNL to account for the varying duration of flyover noise exposures and for the presence of intense discrete-frequency components in the spectrum. Proposed techniques for incorporating these effects have been based on instantaneous PNL. (See refs. 9 to 11.)

Noise reductions predicted for the suppression systems are generally larger with peak instantaneous PNL's than with composite PNL's. This fact is due to the relatively greater low-frequency SPL's from the jet-exhaust noise in the composite spectrum than in the spectrum obtained at the instant of the peak PNL. The contribution of these low-frequency sounds to the annoyance of the total spectrum is relatively more important for the sound from the modified nacelles than that from existing nacelles. However, reductions in peak instantaneous PNL's will probably fall between those that would be estimated by using composite PNL's and those estimated by using PNL's with tone and duration corrections.

Instantaneous PNL's were specified to judge the noise-reduction benefits to an airport community because, at the present time, methods for calculating the tone and duration corrections have not been standardized. Specifically, to determine compliance with noise-reduction goals, the difference (referred to as $\Delta PNL_{peak}$) between the peak values of the instantaneous PNL's of the existing and the modified nacelles was calculated for selected altitudes and engine-power settings.

The PNL's used for rating the noise-suppression systems were calculated from the SPL's estimated for an outdoor location. PNL's calculated for interior locations within homes may be more relevant to judgments of the actual effectiveness of noise-suppression systems for airplanes. Typical wall transmission-loss data determined for residential structures (ref. 12) were used to obtain estimates of indoor PNL's.

## Limitations and Accuracy of Predictions

The limitations of the flyover noise-prediction technique are rather severe principally because of the nature of the assumptions required and the use of empirical correction factors. The assumptions and empirical corrections have been tested in a few cases by comparing measured data (a) to predicted flyover peak instantaneous PNL's and corresponding 1/3-octave-band SPL's, and (b) to predicted composite PNL's and corresponding maximum 1/3-octave-band SPL's. Therefore, a reliable estimate of the accuracy of the prediction technique can be made only for airplanes equipped with the existing nacelles.

For existing airplanes, the accuracy of the prediction is such that the peak instantaneous PNL's are estimated to be within ±2 PNdB of the average measured values determined from a series of flyover noise tests, suitably corrected to standard conditions. For airplanes equipped with modified nacelles, the estimated accuracy is at best ±3 PNdB. However, since there is no in-flight experience with the suppression system, the jet exhaust noise may well prevent the actual PNL's from being less than the predicted values. Hence, the estimated accuracy of the PNL predictions for the modified nacelles is +3, -1 PNdB.

## Noise Predictions

Landing approach.- The conditions specified in reference 5 for the landing-approach-noise comparison were for 1 nautical mile from threshold, on a day with a temperature of 77° F, with no winds, for a runway at sea level, and with a 3° glide slope to a 50-foot height over the runway threshold. The airplane configuration was for maximum landing weight with flaps full down. The altitude of the airplane at 1 nautical mile from threshold is about 370 feet.

The predicted instantaneous PNL's for the specified landing conditions are shown in figure 1 as a function of time during the flyover. The time scale is relative to an arbitrary zero reference time representative of when the airplane would be approximately directly overhead. The 8-second-time interval shown represents the azimuth limits of 15° to 157° on the 150-foot arc used for the static tests.

The peak-to-peak change in PNL indicated by the predictions in figure 1 is about 11 PNdB between the maximum values of the data represented by the solid- and dashed-line curves. The accuracy of the estimates is shown by the shaded areas around the lines. With the accuracy estimates as shown, the peak-to-peak PNL change that will ultimately result from the flight tests of the modified nacelles could be as much as 14 PNdB or as little as 6 PNdB.

The spectra of the SPL's at the time of peak PNL for an altitude of 370 feet are shown in figure 2. The 1/3-octave bands containing the fundamental and the second harmonic of the blade-passage frequencies are marked by the dashed lines at 2500 and 5000 Hz. The SPL in the 2500-Hz band is about 20 dB less with the modified nacelle than with the existing nacelle; in the 5000-Hz band, the SPL is about 10 dB lower with the modified nacelle. The SPL in the 1250- and 1600-Hz bands containing the "Combination-tone" frequencies (see discussion in ref. 2) is 4.5 to 5 dB lower with the modified nacelle.

The 1- to 2-dB increase in the low-frequency SPL's (50 to 630 Hz) is of the same order of magnitude as noted in the ground-runup tests. As mentioned in reference 2, this increase in low-frequency noise can probably be attributed to the 24-inch lengthening of the fan-exhaust ducts in the direction of the primary-exhaust nozzle. This lengthening modifies the interaction between the turbulent exhaust flow from the fan ducts and the turbulent flow from the primary nozzle and hence modifies the noise generation process.

Take-off.- The conditions selected for comparison of the noise levels during take-off were: a location 3.5 nautical miles from the start of the take-off roll (brake release), maximum gross take-off weight, 15° flap setting, landing gear retracted, and full take-off thrust. Atmospheric and other parameters were the same as specified for the landing-approach condition. Under these conditions, a 325 000-pound DC-8 airplane will attain an altitude of about 900 feet at the 3.5-nautical-mile point. The altitude attained by the same airplane equipped with the modified nacelles will be about 835 feet if it is assumed that there is a 2.75-percent decrease in rated take-off thrust, as described in reference 2, and a 0.4-percent reduction in scrubbing drag forces.

Estimated instantaneous PNL's for the take-off condition are shown in figure 3. The reference time is again when the airplane is approximately directly overhead. The peak PNL from the modified nacelle occurs about 3 seconds after the peak PNL from the existing nacelle. Essentially no change is indicated for the value of the peak instantaneous PNL, although the duration of the top 10 PNdB of the predicted PNL history is less with the modified nacelles than with the existing nacelles. The shaded areas represent the same accuracy estimates shown in figure **1.**

The predicted SPL spectra at the times of the peak instantaneous PNL's are shown in figure 4. The large reductions at the fundamental and the second harmonic of the blade-passage frequencies (indicated by the dashed lines at 4000 and 8000 Hz) and the significant increases in low-frequency SPL's are due to (a) the effects of the selected configuration of the modified nacelle and (b) the difference in the relative times .associated with the two spectra. The 3-second difference between the two peak values probably accounts for most of the indicated increase in the law-frequency SPL's and for the indicated decrease in the high-frequency SPL's.

The data shown in figures 3 and 4 are for the specified take-off condition. For airplanes taking off at less than maximum gross weight (probably almost all of the domestic flights and also most of the international flights), there probably will be some reduction in the peak instantaneous PNL since most of the airplanes will reach an altitude where a safe thrust reduction can be made before reaching the 3.5-nautical-mile point.

If the thrust is reduced to that required to maintain a 6-percent climb gradient (about 1000 feet/minute), then some reduction in annoyance may be obtained owing to (a) the reduction in jet-exhaust noise caused by making the thrust reduction and to (b) the reduction of the SPL's at the blade-passage frequencies caused by addition of the acoustical duct linings.

Variation of PNL with distance and thrust.- The variation of the reduction in peak PNL with distance from threshold during the landing approach is shown in figure 5. The reductions are shown to a distance of 7 nautical miles from threshold where the airplane is about 2300 feet above the ground. The reduction is approximately constant to 5 nautical miles and then begins to decrease rather rapidly. No data are presented for the take-off case because essentially no change was predicted for the peak PNL for airplanes at full take-off thrust and at distances of 800 feet or more.

The variation with distance to the airplanes of the estimated peak instantaneous PNL's is given in figure 6 for airplanes equipped with the existing and modified nacelles. This type of presentation shows directly the effect of the suppression system on the noise produced by the existing nacelle installation without consideration of the effect of the acoustical linings on airplane performance. Data are presented for full take-off thrust and for a landing thrust corresponding to maximum landing weight. The same trends noted previously are evident in figure 6; namely, larger reductions are obtained at the landing power setting than at the take-off power setting, and the reductions decrease as the distance to the airplane increases, either directly under the flight path or to the side of the runway.

The data in figure 6 also provide an indication of the changes in PNL that would be expected to the side of the airplane flight path in the vicinity of the airport. For example, at a point about 3000 feet to the side of the runway (assuming that the airplane is just high enough so that ground attenuation effects are not important), the PNL during take-off at full take-off thrust would remain unchanged at about 104 PNdB. During the landing approach, however, the PNL at 3000 feet to the side of the landing path would be reduced from about 92 to about 84.5 PNdB. It is worthwhile to note that, of those airport neighbors who are concerned only with approach noise, the people exposed to the higher values of PNL will experience the larger noise reductions.

The estimated PNL's and PNL reductions which have been presented thus far have all been those which would be experienced outdoors. Because typical house structures attenuate high-frequency noise to a greater degree than low-frequency noise, the low-frequency noise of the JT3D contributes relatively more to the PNL's indoors than to the PNL's outdoors. Thus, suppression of the high-frequency fan noise at the source will generally result in less change to the PNL indoors than outdoors.

Figure 7 presents estimates of the peak instantaneous PNL's that might be experienced inside a dwelling with windows closed. The noise reduction of the structure and insulation of the dwelling was taken from reference 12 and should be representative of modern frame houses located in temperate climates with mild winters. The PNL's inside the dwelling are 22 to 25 PNdB lower than those experienced outdoors (fig. 6) for the same thrust and distance to the airplane. For homes with more insulation (for example, in colder climates), the PNL's at corresponding points will be somewhat lower than those shown in figure 7.

The variations with distance to the airplane of the estimated reduction in peak PNL, at the same landing power setting used in figures 6 and 7, are shown in figure 8 for the noise reductions perceived outdoors and indoors. For the house construction assumed, the reduction indoors is about 2 PNdB less than the reduction outdoors. As pointed out previously, there is a considerable tolerance on the estimated reductions that may be achieved at low altitudes outdoors. The tolerances on the estimates at greater distances and indoors would necessarily be larger. More reliable data to assist in assessing the subjective merits of the suppression system must await flight tests.

## Direct Operating Cost Estimates

Direct operating costs have been estimated for JT3D-3B-powered DC-8-55 airplanes equipped with the existing production short-duct nacelles and with the nacelles modified to the retrofit configuration discussed in reference 3. The calculations were based on the method of reference 4 but modified to reflect the specific nature of a retrofit program.

The incremental direct operating cost estimates presented in reference 1 are not consistent with the DOC data presented in this paper. The estimates of reference 1 were made with the aid of change factors that relate changes in DOC to independent changes in weight, drag, and specific-fuel consumption. The change factors included allowances for all elements of DOC. Insurance, maintenance, and depreciation changes were related by simple functions of the weights of new components added to the nacelles. These functions were developed on the basis of 1966 dollar levels and assumed different values of depreciation interval and residual value compared with the more detailed DOC calculations presented in this paper. Similarly, consistency should not be expected in the weight increments quoted herein and those in reference 1, since the weight data presented in this paper are based on later and more detailed design and weight studies.

Basic assumptions used in the calculations are listed in table I. The cost of retrofit includes the cost (for four engines) of new nacelle and engine parts and the cost of installation. The retrofit cost is based on a production run of retrofit kits for 300 airplanes. No salvage allowance was assumed for replaced parts. Depreciation was computed in two parts for the retrofitted airplane. The depreciation expense for the basic unmodified airplane was assumed (1965 price depreciated over a 12-year interval) plus the additional depreciation expense resulting from amortization of the retrofit and retrofit spares costs over a 5-year interval. Utilization was treated as a variable dependent upon trip block time (fig. 4 of ref. 4). A typical mixed-class seating configuration of 135 seats was used. In an all-tourist configuration at 34-inch seat pitch, the DC-8-55 can accommodate 189 passengers. A 20-percent allowance for initial spares applies to nacelle retrofit kit parts. The initial-spares rate assumed for the new engine parts was 40 percent. It was assumed that the kits will be installed on engines at overhaul or in the spares inventory, and thus will require no airplane out-of-service time for installation.

Incremental maintenance costs were estimated on the basis of an analysis of maintenance tasks and on the assumption that further development of acoustical materials and manufacturing methods will produce linings equal in durability to present inlet- and exhaust-duct structure.

Other assumptions in the maintenance cost analysis were as follows:

(a) A frequency of unscheduled inlet- and exhaust-duct maintenance 50 percent higher than that of present ducts

(b) Eight man-hours of labor and 1 square foot of acoustical lining structure per repair

(c) Five man-hours of labor and $35 material cost for lining cleaning every 500 flight hours

The incremental nacelle-maintenance cost estimated in this manner was $1.06 per flight hour.

Effects of the nacelle modifications on basic changes affecting airplane performance are presented in table 11. The change in airplane empty weight is the net effect of the increased weights of the treated inlet and fan-exhaust ducts, the lower weight of the new fan-thrust reversers, and the change in weight owing to the other nacelle items affected by the retrofit (ref. 3).

The 0.6-percent increase in cruise specific-fuel consumption is the change in fuel flow required to produce a given installed engine thrust less the nacelle drag. The decrease in installed engine thrust is due to changes in the internal performance of the inlet and exhaust ducts and to changes in nacelle drag. For the exhaust ducts, the increased total-pressure losses due to the installation of the acoustical linings are offset to some extent by the more favorable aerodynamic lines of the 48-inch ducts. The decrease in nacelle drag is due to the longer fan-exhaust duct. The longer duct reduces the nacelle surface area wetted by the fan-exhaust stream and thus reduces the scrubbing drag. However, the longer duct increases the nacelle area wetted by the external flow upstream from the fan nozzle and thus increases the free-stream drag. The contributors to the net change of 0.6 percent in specific-fuel consumption include:

(a) Inlet and exhaust-duct losses, 1.0 percent

(b) Scrubbing drag, -0.7 percent

(c) Free-stream drag, 0.3 percent

The change in maximum cruise thrust indicated in table II applies to the maximum-cruise-thrust rating. Most cruise conditions require a thrust sufficiently below the cruise-thrust rating as not to be affected by this change. The 2.1-percent decrease in the maximum-cruise-thrust rating will affect high take-off weight operations if high initial-cruise altitude is required. None of the cruise performance calculated for the data in this paper was affected by the change in maximum-cruise-thrust rating. The change shown in table II differs from that presented in reference 2 because the installed thrust changes presented herein include the effects of the nacelle modifications on the external drag as well as the internal thrust.

It is predicted that the drag-rise Mach number will be unaffected by the modifications. Cruise-speed changes will therefore be required only through the effects of the change in the maximum-cruise-thrust rating discussed previously.

The contributors to the 2.35-percent take-off thrust loss indicated in table II include:

(a) Inlet- and exhaust-duct loss effects, 2.75 percent

(b) Scrubbing drag, -0.4 percent

Payload-range characteristics for the DC-8-55 airplane with the existing and modified nacelles are presented in figure 9. The maximum range for all payloads is reduced approximately 50 nautical miles by the modified nacelles.

The change in weight-limited payload due to the change in nacelle weight is negligible. The reference payload of 30 175 pounds was calculated on the basis of 205 pounds for each of the 135 passengers and his baggage, plus an additional 2500 pounds for the cargo load typically carried in passenger service. For the passenger airplane considered, the full space-limited payload is 36 175 pounds, assuming 165 pounds for each passenger with the cargo compartment filled with cargo and baggage with a density of 10 pounds/cubic foot. The assumed domestic fuel reserves provided for a 1-hour hold at 99-percent maximum specific range at the final cruise weight, 2 minutes at take-off power for a missed approach, and climb, cruise, and descent to an alternate airport 200 nautical miles from the original destination. The use of international fuel reserves would reduce the maximum range approximately 150 nautical miles, but would not appreciably affect the relative performance of airplanes equipped with the existing and the modified nacelles.

The effect of the modified nacelles on direct operating cost is shown in figure 10 for cruise at standard-day conditions. For ranges up to the value corresponding to maximum take-off weight (approximately 5350 nautical miles), the operating costs will be increased approximately 5.7 percent. At greater ranges, where passengers must be off-loaded in favor of fuel, the operating costs will be increased approximately 12 percent.

A breakdown of the total increase in direct operating cost for a range of 850 nautical miles is shown in table III. The selected range corresponds to the present average stage length of DC-8 service. The slight increase in crew expense is the result of the small effect of the modifications on time to climb and therefore block speed. Small changes are predicted in insurance, fuel, and maintenance expenses. The largest element of increased operating cost is the increased depreciation resulting from the added capital investment required by the retrofit.

The data presented in figures 9 and 10 were based on the assumption that sufficient FAA runway length was available to permit take-offs at maximum gross weight with the existing and the modified nacelles. The modified nacelles will have more effect on direct operating cost for operations from short runways than from long runways as shown in figure 11. The data presented in figure 11 were calculated for sea-level take-offs at $77^{\circ}$ F, and standard-day cruise with the reference payload of figure 9. The points at which the direct operating cost increments rise sharply correspond to the take-off weight limit for the particular runway length available. At ranges beyond those points, payload off-loading is required.

Since much work is necessary to identify the acoustical lining materials and manufacturing and inspection methods required for satisfactory service in routine airline operations, the retrofit cost estimate presented in this paper is somewhat uncertain. Figure 12 is presented to permit assessment of the impact on direct operating cost of possible variations in retrofit cost.

Similarly, figure 13 is presented to permit assessment of the effects of depreciation intervals other than the 5-year interval used in the preparation of figures 10 to 12.

The direct operating cost data presented in this paper apply only to the two specific nacelle configurations analyzed. The degree to which nacelle structure and equipment items must be changed to accommodate the new treated ducts is peculiar to the two particular nacelle configurations studied. The scope of the changes needed to install nacelle modifications with acoustically treated inlet and fan-exhaust ducts may be substantially different for other engine installations. Similarly, the development of satisfactory internal duct lines in other designs may significantly change the external aerodynamic lines and the cruise drag. A detailed design study and operating cost analysis is needed to assess the impact of applying duct-lining technology to each specific installation of each specific engine model.

## CONCLUDING REMARKS

Flyover noise reductions and direct operating cost changes have been predicted for modifications to the nacelles of DC-8 airplanes. These modifications consist of new inlet and fan-exhaust ducts containing acoustically absorptive duct linings. The predictions were based on data obtained on a static outdoor JT3D-engine test stand equipped with the existing nacelles and with simulations of the modified nacelles.

It was predicted that the peak flyover instantaneous perceived-noise level (PNL) would be reduced approximately 11 PNdB directly beneath the landing-approach path of a DC-8 at maximum landing weight, on a $3^{\circ}$ glide slope, and 1 nautical mile from the runway threshold. The peak PNL would not be appreciably changed at a point beneath the take-off flight path, 3.5 nautical miles from brake release for an airplane at maximum take-off gross weight and full take-off thrust.

The magnitude of the noise reduction achieved by DC-8 airplanes equipped with the modified nacelles will vary over a considerable range depending on the thrust level of the airplane, the distance to the airplane (either under or to the side of the flight paths), and the construction of the dwelling if the listener is indoors. Those listeners exposed to the highest noise levels from the existing airplanes during the landing approach will experience the largest noise reductions. Although no change is indicated in the peak PNL for those listeners exposed to noise at full take-off thrust, some noise reduction during take-off may be obtained for those airplanes that can make safe thrust reductions during initial climb. Reliable data to assess the subjective effects of the proposed noise-suppression system must await the results of the flyover-noise tests of the modified nacelles.

The methods used in preparing the flyover-noise predictions were recently formulated and have yet to be validated. The accuracy of the present predictions is therefore uncertain, and caution must be exercised in their use. For example, the accuracy of the flyover-noise predictions requires a tolerance on the 11-PNdB predicted reduction in landing PNL such that the predicted change in peak PNL is in the range from 6 to 14 PNdB.

It was estimated that the direct operating costs of the DC-8-55 airplane would be increased approximately 5.7 percent by the retrofit of the nacelle modifications chiefly because of increased depreciation. This increase applies for operations that are not limited by take-off field length or maximum gross weight.

The predicted effects on flyover noise and operating costs apply only to the specific engine and nacelle designs considered. Substantial differences in the design of the modifications and in their effects on noise and operating costs may be expected in the application of duct-lining technology to other JT3D installations and to other installations of other engines.

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11. Kryter, Karl D.; Johnson, P. J.; and Young, J. R.: Judgment Tests of Aircraft Noise. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 37 herein,)

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## TABLE I.- BASIC ASSUMPTIONS USED IN DOC CALCULATIONS

| | |
|---|---|
| Cost of retrofit **(1972** dollars), dollars | **545 500** |
| Depreciation period, yr – | |
| For airframe | **12** |
| For nacelles | **5** |
| Utilization | Variable |
| Seats | **135** |
| Initial spares, percent | 20 |
| Down time, hr | 0 |
| Maintenance of nacelles | Functional analysis |

## TABLE II.- BASIC CHANGES AFFECTING AIRPLANE PERFORMANCE

| | |
|---|---|
| Operating empty weight, lb | **332** |
| Cruise specific-fuel consumption, percent | 0.6 |
| Maximum cruise thrust, percent | **2.1** |
| Cruise speed, knots | 0 |
| Take-off thrust, percent | **-2.35** |

## TABLE III.- DIRECT OPERATING COST INCREASES

[Model **DC-8-55;** range, **850** n. mi.]

| Element | $\Delta$DOC, percent |
|---|---|
| Crew | **0.02** |
| Insurance | **.38** |
| Fuel | **.40** |
| Maintenance | **.56** |
| Depreciation | **4.38** |
| Net change | **5.74** |

## ESTIMATED PERCEIVED-NOISE LEVEL DURING FLYOVER

ALTITUDE = 370 FT; LANDING POWER

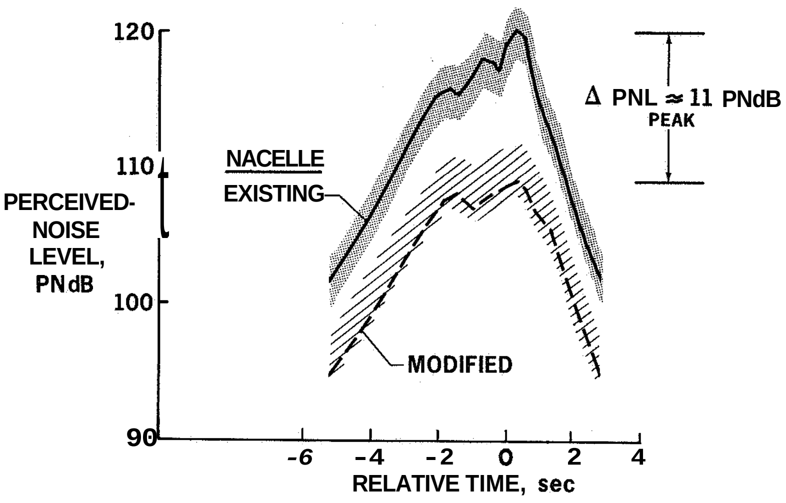


Figure 1

## ESTIMATED SPECTRA AT TIME OF PEAK INSTANTANEOUS PNCS

ALTITUDE = 370 FT; LANDING POWER

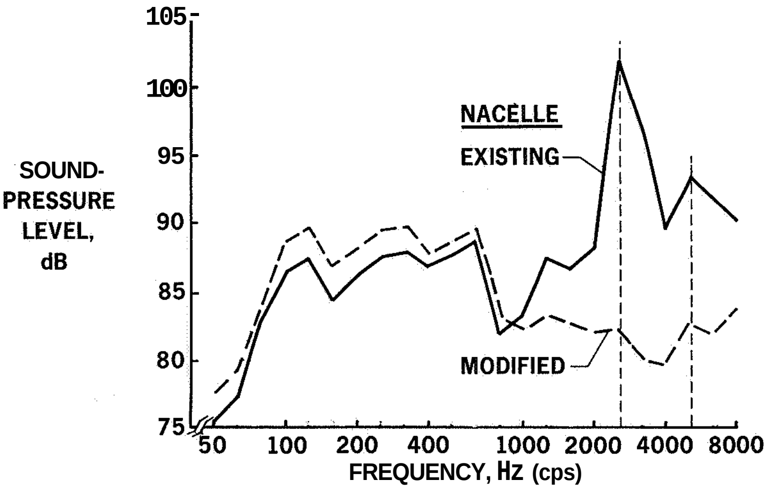


Figure 2

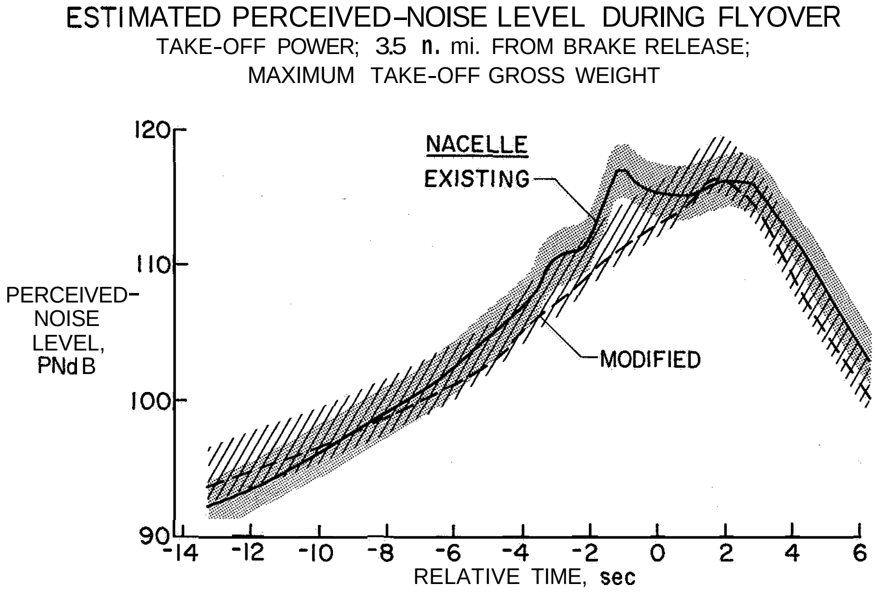

ESTIMATED PERCEIVED-NOISE LEVEL DURING FLYOVER
TAKE-OFF POWER; 3.5 n. mi. FROM BRAKE RELEASE;
MAXIMUM TAKE-OFF GROSS WEIGHT

Figure 3

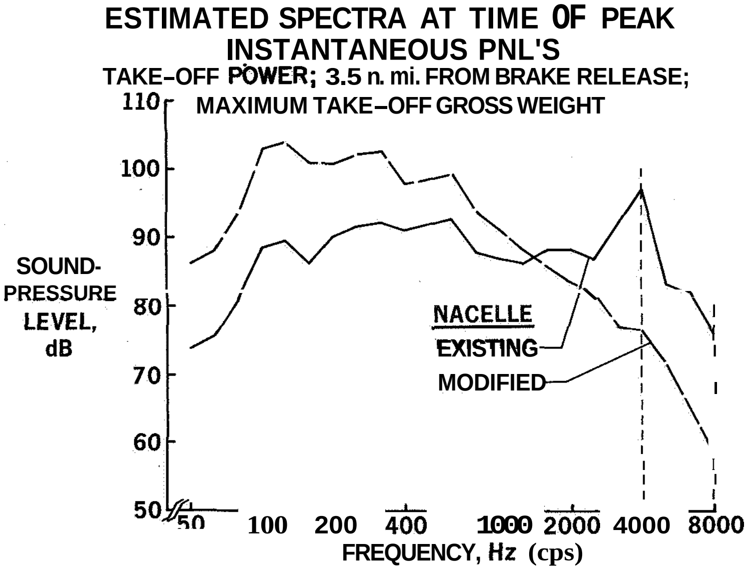
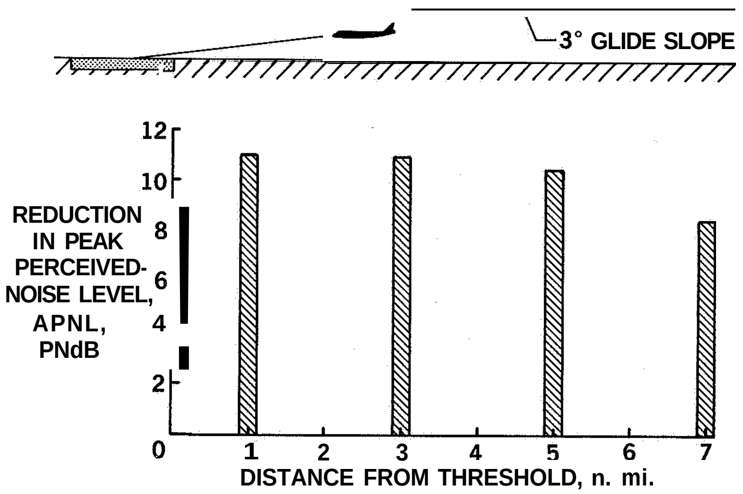

ESTIMATED SPECTRA AT TIME OF PEAK INSTANTANEOUS PNL'S
TAKE-OFF POWER; 3.5 n. mi. FROM BRAKE RELEASE;
MAXIMUM TAKE-OFF GROSS WEIGHT

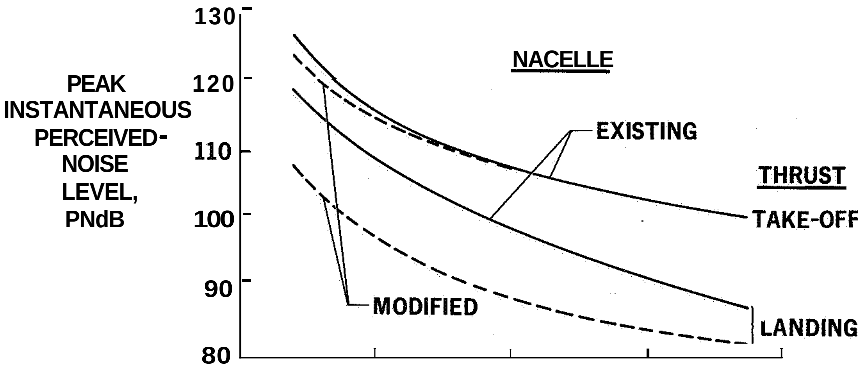
Figure 4



**ESTIMATED PERCEIVED-NOISE LEVEL REDUCTIONS UNDER LANDING APPROACH PATH**

MAXIMUM LANDING WEIGHT

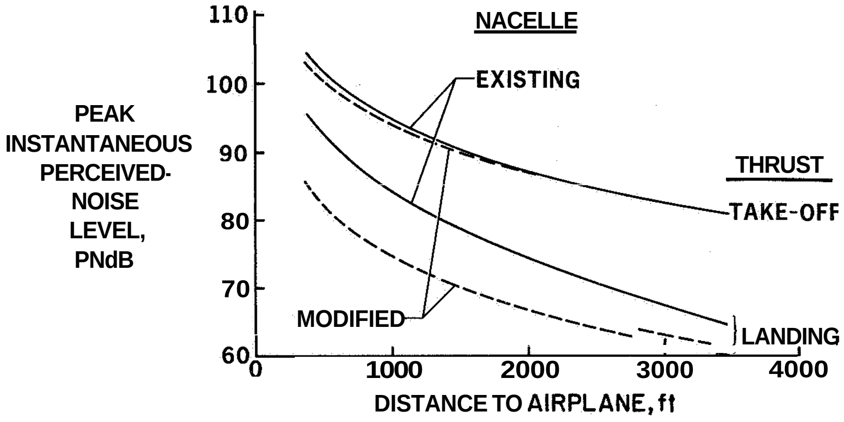
Figure 5



**ESTIMATED PERCEIVED-NOISE LEVELS OUTDOORS**

DC-8 WITH JT3D ENGINES

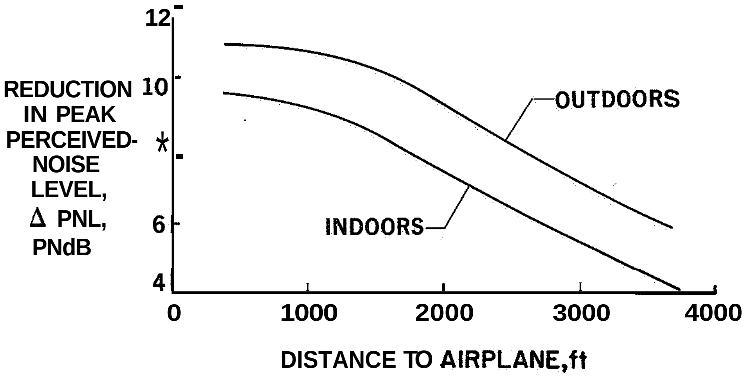
Figure 6



ESTIMATED PERCEIVED–NOISE LEVELS INDOORS

DC-8 WITH JT3D ENGINES

Figure 7



ESTIMATED NOISE REDUCTIONS

JT3D WITH MODIFIED NACELLES; LANDING POWER

Figure 8

## PAYLOAD-RANGE CHARACTERISTICS

DOMESTIC OPERATION; STANDARD DAY;
MODEL DC-8-55

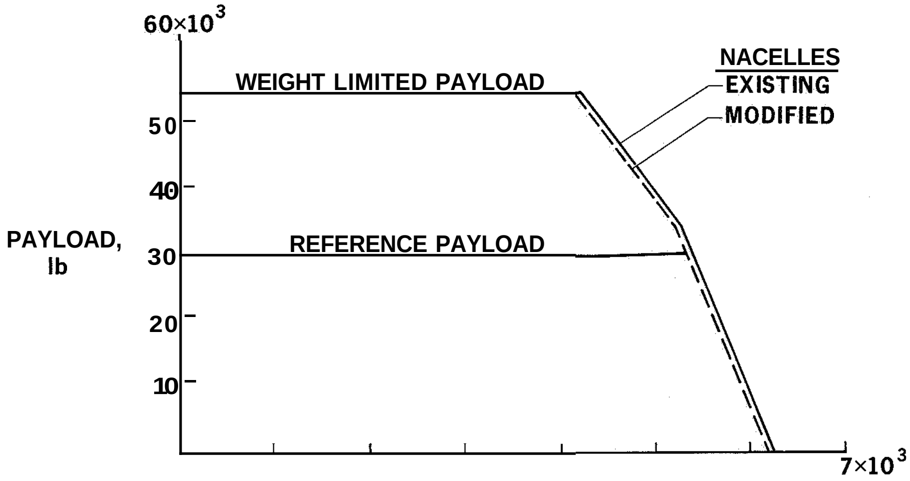


Figure 9

## DIRECT OPERATING COST

MODEL DC-8-55

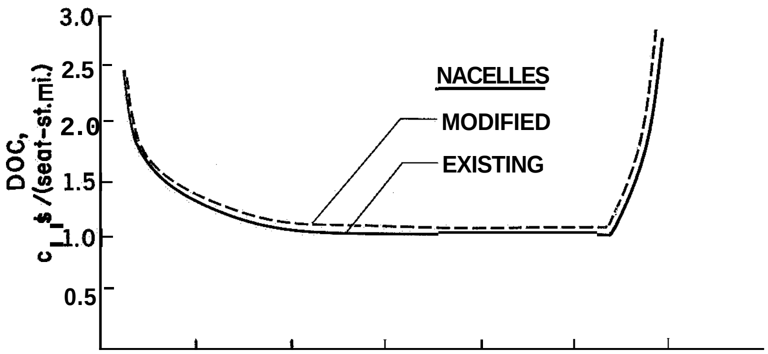


Figure 10

## EFFECT OF TAKE-OFF RUNWAY LENGTH ON DIRECT OPERATING COST INCREMENT

MODEL DC-8-55; SEA LEVEL; 77°F

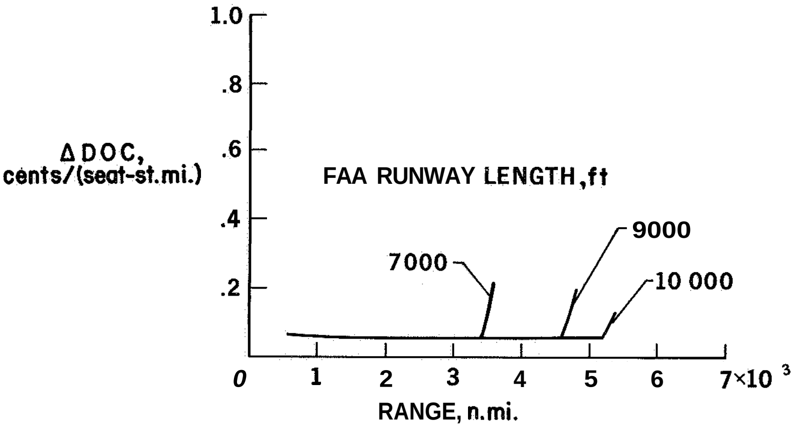


Figure 11

## EFFECT OF RETROFIT COST ON DIRECT OPERATING COST

RANGE = 850 n. mi.

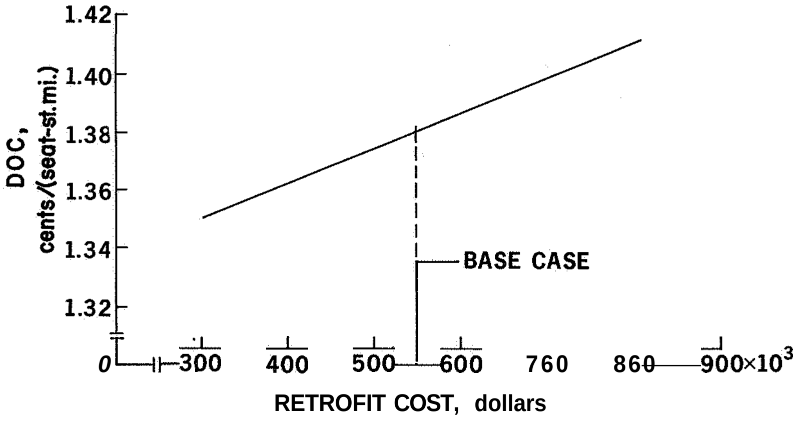
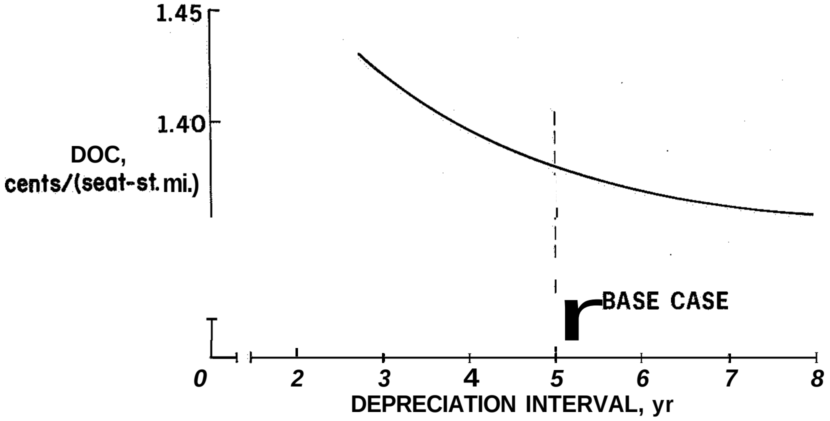


Figure 12



EFFECT OF DEPRECIATION INTERVAL ON
DIRECT OPERATING COST
RANGE = 850 n. mi.

Figure 13