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AN IMPROVED METHOD FOR PREDICTING THE EFFECTS OF FLIGHT ON JET MIXING NOISE

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OF FLIGHT ON JET MIXING NOISE

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INTRODUCTION

In order to assess the impact of jet noise on the environment in the vicinity of the airport, it is necessary to predict the effect of flight on jet engine exhaust noise. For new or proposed aircraft, such predictions will be based at least in part on model and full-scale static and simulated flight experiments. Cost limits the number of configurations and concepts that could be flight tested. Therefore, it is essential that in-flight noise can be projected from static data.

The flight geometry is illustrated, and some of the key parameters are defined, in figure 1. (All symbols are defined in appendix A.) According to classical jet noise theory (e.g., Ffowcs Williams, ref. 1), it is expected that in-flight subsonic jet noise should vary with $10 \log\left[V_j^{8-m}(V_j - V_o)^m\right]$. For the static case ($V_o = 0$) this reduces to the well known V_j^8 expression of Lighthill (ref. 2). Thus, according to this reasoning, the difference between static and flight levels, $OASPL_F - OASPL_S$, corrected for motion effects by adding $10 \log\left[1 - M_o \cos(\theta + \beta)\right]$, should be given by $10 \log\left[(V_j - V_o)/V_j\right]^m$. Based on such considerations, several investigators (e.g., refs. 3 and 4) have expressed their results in terms of a flight velocity exponent, m, defined as follows:

$$m \equiv \left\{OASPL_F - OASPL_S + 10 \log\left[1 - M_o \cos(\theta + \beta)\right]\right\} \Big/ \left\{10 \log\left[1 - \left(\frac{V_o}{V_j}\right)\right]\right\} \quad (1)$$

Such data have typically been presented as plots of m versus θ, the angle from the inlet axis. Also, prediction methods for jet noise flight effects (e.g., Bushell (ref. 3)) have been proposed on the basis that m can be defined as a unique function of θ. However, it has been pointed out (ref. 5) that m is not a physical quantity, but an expression based on assumed relationships and that such relationships do not accurately and uniquely represent the physical processes. Furthermore, it was shown in reference 5 that the exponent m is sufficiently sensitive to the measured OASPL's that the presence of even small amounts of non-jet-mixing noise can result in negative values of m. Therefore, it was indicated that prediction methods should not be formulated on the basis of m as a function of θ, as has been proposed (e.g., refs. 3 and 4).

It has been pointed out in several studies (e.g., refs. 5 to 11) that the experimental data must be corrected for the effects of internally-generated noise, shock-cell noise and any other contaminating sources before the effects of flight on jet mixing noise can be determined. Therefore, the comparisons shown herein are limited to cases for which the jet mixing noise has been extracted from the total noise by analytically removing the noise from other sources or for which sufficient information has been provided to permit this extraction to be performed. Three typical cases have been chosen for study herein:

(1) High-bypass turbofans (JT9D-59) on a DC-10-40 airplane (ref. 9)
(2) Low-bypass turbofans (JT8D-109) on a DC-9-30 airplane (ref. 9)
(3) A turbojet (J85) on the Bertin Aerotrain (ref. 12)

These data sets cover a range of jet velocity from 280 to 680 m/sec and provide a statistically significant data base.

A composite plot of the flight velocity exponents for jet mixing noise for these cases is shown in figure 2. Also shown for comparison is the prediction curve originally proposed by Bushell (ref. 3). (Note that positive values of m indicate noise reduction in flight, while negative m values indicate noise amplification in flight.) It can be seen that the prediction of Bushell (ref. 3) does not agree well with the data, which is not surprising because that prediction was based on data not corrected for extraneous noises. Furthermore, it can be seen (as pointed out in ref. 5) that m is not a unique function of angle, but also varies with jet velocity and jet density. Thus, it is apparent that improvements over the prediction of Bushell (ref. 3) are needed, and such predictions have been proposed by NASA Lewis (ref. 8) and SNECMA.* At jet velocities below ~520 m/sec, the earlier NASA Lewis method (ref. 8) fits the data somewhat better than does the SNECMA prediction, but the earlier NASA method is inadequate at high jet velocities. Therefore, a modified method has been developed and is reported herein which shows better agreement with the data base than does reference 8 or SNECMA. Furthermore the new method is more closely related to fundamental theories (refs. 1 and 13) than the earlier methods.

FORMULATION OF PREDICTION METHOD

The prediction method formulated herein is the result of updating the method given in the NASA interim prediction method for jet noise (ref. 14). The equations presented here are for the OASPL only; the effects of flight on the spectra are not considered in this report. The equations presented are based on the primary jet conditions for turbojet and conventional-velocity-profile turbofan engines. Although the bypass stream does influence the absolute noise levels for conventional-velocity-profile turbofan engines, it has been found to have no significant effect on the static-to-flight increments (ref. 15). The application of the methods developed herein to the case of inverted-velocity-profile coaxial jets will also be described later herein (appendix B).

*Method proposed to Society of Automotive Engineers Committee on Noise Prediction by SNECMA.

In order to predict the effects of flight on jet mixing noise, three effects are considered, as follows:

(1) The kinematic effect, Δ_K, due to motion of the airplane with respect to the stationary observer.

(2) The dynamic effect, Δ_D, due to motion of the sources with respect to the propagation medium.

(3) Source strength alteration, Δ_{SO}, due to the effect of the reduced shear between the jet plume and the ambient air.

Kinematic Effect

There is general agreement in the literature on the calculation of Δ_K, that is:

$$\Delta_K = -10 \log\left[1 - M_o \cos(\theta + \beta)\right] \tag{2}$$

Dynamic Effect

The noise sources (turbulent eddies), even for the static case, are in motion with respect to the propagation medium with a convection velocity assumed to be directly proportional to the jet velocity, $V_c = kV_j$. The resulting OASPL relative to $\theta = 90^o$ is given by

$$OASPL_{J,\theta,S} - OASPL_{J,90^o,S} = -10n \log D_S$$

Where D_S is a function of $V_{c,S}$ and θ. In flight, the convection velocity relative to the propagation medium is reduced to a level that is directly proportional to the relative velocity, $V_c = k(V_j - V_o)$. The resulting effect on the OASPL relative to $\theta = 90^o$ in flight then becomes

$$OASPL_{J,\theta,F} - OASPL_{J,90^o,F} = -10n \log D_F$$

Where D_F is a function of $V_{c,F}$ and θ. The resulting dynamic effect (flight minus static) at any angle can then be calculated from

$$\Delta_D = -10n \log(D_F/D_S)$$

According to the classical theory of Ffowcs Williams (ref. 1) the directivity term is given by

$$D = \sqrt{(1 + M_c \cos\theta)^2 + \alpha^2 M_c^2} \tag{3}$$

The value obtained by Ffowcs Williams for n is 5. However, reference 14 showed that the static OASPL directivity of subsonic jets agreed more closely with the theory of Goldstein and Howes (ref. 13), which gave a value of n = 3. In reference 14 an empirical factor was incorporated to approximate the effects of supersonic convection velocity, instead of the $\alpha^2 M_c^2$ term of equation (3), and the convective factor, k, was taken as 0.62, which is consistent with reference 13. The resulting equation used in references 5, 6, 8, and 14 is given by

$$\Delta_D' = -30 \log\left[\frac{1 + M_{c,F}\left(1 + M_{c,F}^5\right)^{-1/5} \cos\theta}{1 + M_{c,S}\left(1 + M_{c,S}^5\right)^{-1/5} \cos\theta}\right] \tag{4}$$

As was shown in references 5 and 8, this formulation works reasonably well except at high jet velocities. This is thought to be a result of the formulation of the empirical supersonic convection factor. The present approach is to replace the previous formulation (eq. (4)) with a modification of the Ffowcs Williams relation, but to retain the $n = 3$ and $k = 0.62$ relations which have proven reasonable at moderate and low jet velocities. The value of α is taken to be 0.2, which is approximately the same as the 0.19 value reported by Larson, et al. (ref. 16) based on time-dependent turbulence correlations in the jet shear layer under simulated flight conditions. The resulting equation is as follows:

$$\Delta_D = -15 \log\left[\frac{(1 + M_{c,F} \cos\theta)^2 + 0.04\, M_{c,F}^2}{(1 + M_{c,S} \cos\theta)^2 + 0.04\, M_{c,S}^2}\right] \tag{5}$$

Where

$$M_{c,S} = 0.62(V_j/c_a) \tag{5a}$$

and

$$M_{c,F} = 0.62(V_j - V_o)/c_a \tag{5b}$$

This formulation is quite similar to one suggested by Cocking and Bryce (ref. 17), who used a relation of this type with $n = 3.8$ and $k = 0.65$; however, the α value suggested therein was 0.3.

Source Strength Alteration

The change in source strength in flight should be observable at $\theta = 90^\circ$, where the kinematic and dynamic effects are small. The relation obtained in reference 14 for the jet mixing noise at $\theta = 90^\circ$ (for standard atmospheric conditions) may be written:

$$\text{OASPL}_{J,90^o} = 141 + 10 \log\left[\frac{A_j}{R^2}\left(\frac{\rho_j}{\rho_a}\right)^w\right] + 10 \log \frac{(V_e/c_a)^{7.5}}{1 + 0.01(V_e/c_a)^{4.5}} \tag{6}$$

where

$$w = \left[\frac{3(V_e/c_a)^{3.5}}{0.6 + (V_e/c_a)^{3.5}} - 1\right] \tag{6a}$$

In reference 14 (and also in refs. 5, 6, and 8) the approximation, $V_e = V_j(1 - V_o/V_j)^{3/4}$ was used based on the free jet results of reference 18. In reference 18 no correction was made to the data for noise propagation through the free jet and its shear layer. More recent results (e.g., refs. 10 and 19) indicate a slightly lesser effect of flight. The current prediction based on the more recent results assumes

$$V_e = V_j(1 - V_o/V_j)^{2/3} \tag{6b}$$

In terms of the static of flight increment, the resulting relation is:

$$\begin{aligned}\Delta_{So} &= 50 \log\left(1 - \frac{V_o}{V_j}\right) + 10 \log\left[\frac{1 + 0.01\left\{(V_j/c_a)\left[1 - (V_o/V_j)\right]^{2/3}\right\}^{4.5}}{1 + 0.01(V_j/c_a)^{4.5}}\right] \\ &+ 10\left[\frac{3\left\{(V_j/c_a)\left[1 - (V_o/V_j)\right]^{2/3}\right\}^{3.5}}{0.6 + \left\{(V_j/c_a)\left[1 - (V_o/V_j)\right]^{2/3}\right\}^{3.5}} - \frac{3(V_j/c_a)^{3.5}}{0.6 + (V_j/c_a)^{3.5}}\right] \log \frac{\rho_j}{\rho_a}\end{aligned} \tag{7}$$

Summary of Method

This section summarizes the relationships recommended for the prediction of flight effects on jet mixing noise for turbojet and conventional-velocity-profile turbofan engines. The difference between flight and static OASPL's is calculated as follows:

$$\Delta_{Calc} = (\text{OASPL}_{J,\theta,F} - \text{OASPL}_{J,\theta,S})_{Calc} = \Delta_{So} + \Delta_D + \Delta_K \tag{8}$$

Where Δ_{So} is calculated from equation (7), Δ_D is calculated from equation (5), and Δ_K is calculated from equation (2). The differences between the present method and that of reference 8 are most pronounced in the rear quadrant at $\theta > 130^o$ for supersonic convection velocity; the present method predicts a peak, followed by a rapid decrease and a region of negative exponent (noise increase in flight). The peak occurs when

$M_c > 1$, and the peak moves to lower angles as M_c increases. The effects of flight in the forward quadrant are slightly less for the present method than for reference 8, but for both the noise is less in flight than statically (m positive).

COMPARISON WITH EXPERIMENTAL RESULTS

The prediction method presented herein and the SNECMA* method are compared in this section with an experimental data base obtained from recent well-documented flight and Aerotrain tests. The three engine/airframe combinations providing this data base are the following:

(1) High-bypass turbofans (JT9D-59) on a DC-10-40 airplane (ref. 9)
(2) Low-bypass turbofans (JT8D-109) on a DC-9-30 airplane (ref. 9)
(3) A turbojet (J85) on the Bertin Aerotrain (ref. 12)

For each case three data sets, at high, low and intermediate jet velocities, are examined in order to provide a statistically significant data base. A wide range of jet velocities, from 280 to 680 m/sec, is thereby covered. The angle β, between the jet axis and the axis of motion was considered neglegible in all cases compared herein.

For each engine/airframe combination, comparisons and statistical analyses are presented subsequently of predicted and experimental flight velocity exponents (eq. (1)) and static-to-flight increments, $\Delta = (OASPL_{J,\theta,F} - OASPL_{J,\theta,S})$. The experimental results are compared with the present prediction and that of SNECMA, which is based on the exponent approach. The exponent comparisons are shown only to facilitate comparisons between the methods. The m values for the SNECMA prediction are shown in figure 3. (These are the same m values shown for the proposed SNECMA method in ref. 4 except for the variation of m with V_j at large angles.)

Turbojet

Plots of flight velocity exponents versus angle for the J85 turbojet engine on the Bertin Aerotrain (ref. 12) are shown in figure 4. The results have been corrected for aerotrain background noise (ref. 12), for internal noise (ref. 8), and where appropriate for shock noise (ref. 20). These results cover a range of jet velocity from 445 to 680 m/sec. The experimental results are compared with the SNECMA prediction* in figure 4(a). Reasonably good agreement is seen although there are significant discrepancies, particularly in the forward quadrant. Furthermore the experimental data indicate that m varies with V_j at all angles; while the prediction limits such effects to $\theta > 130^o$. A comparison with the present prediction is shown in figure 4(b). The agreement is good in the rear quadrant, but the m values are consistently over-predicted for angles from 50^o to 120^o. The agreement of the present method with the experimental data at large angles is at least as good as that of the SNECMA method. The decrease in m with increasing θ at large angles and high jet velocities, which can produce negative m values (noise increase in flight), is due to supersonic convection effects (eq. (5)); this effect becomes more pronouned as jet velocity increases.

Further comparisons are made in terms of the difference in dB between the experimental and predicted flight noise increment, $OASPL_{J,\theta,F} - OASPL_{J,\theta,S}$, versus angle, as shown in figure 5 for both of the predictions. Symmetric scatter bands of ±2 standard deviations (2σ) from the predicted values are also shown. The present prediction has a 2σ band of ±3.1 dB, and the SNECMA prediction has a 2σ band of ±3.2 dB.

Low-Bypass Turbofan

Plots of flight velocity exponents versus angle for low-bypass refanned JT8D engines on a DC-9 airplane (ref. 9) are shown in figure 6. The results shown are reported to be for jet-mixing noise only; with the effects of other noise sources removed. The experimental results cover a range of jet velocity (primary) from 279 to 489 m/sec. The experimental results are compared with the SNECMA prediction in figure 6(a). The agreement is reasonable for $\theta \geq 120^{\circ}$, but for smaller angles the experimental exponents are consistently and significantly greater than the prediction. A comparison with the present prediction is shown in figure 6(b). The data appear to agree much better with the present NASA method than with the SNECMA prediction. Because the highest jet velocity corresponds to a convection velocity slightly less than sonic, no peak of the m versus θ plot is observed, such as was measured and predicted for the J85 engine on the Bertin Aerotrain.

Further comparisons are presented in terms of the difference between the experimental and predicted flight increments as a function of angle, as shown in figure 7 for each of the two predictions. Symmetric scatter bands of ±2 standard deviations (2σ) are also shown. The present method (fig. 7(b)) agrees rather well, having a 2σ band of ±2.7 dB. The SNECMA prediction (fig. 7(a)) shows significantly poorer agreement, with a 2σ band of ±6.6 dB. Furthermore, 95 percent of the actual experimental data fall within ±3.4 dB of the NASA prediction and within ±4.9 dB of the SNECMA prediction.

High-Bypass Turbofan

Plots of flight velocity exponents versus angle for high-bypass JT9D engines on a DC-10 airplane (ref. 9) are shown in figure 8. The results are corrected for differences in engine position and extraneous noises and are, therefore, reported as pure jet mixing noise. The experimental results cover a limited range of (primary) jet velocity from 427 to 503 m/sec. The experimental results are compared with the SNECMA prediction in figure 8(a). The agreement is reasonably good for $\theta \geq 100^{\circ}$, but for smaller angles the experimental exponents are consistently and significantly greater than the prediction. The present method (fig. 8(b)) shows reasonably good agreement throughout the full range of angles.

Further comparisons are presented in terms of the difference between the experimental and predicted flight increments versus angle, as shown in figure 9 for both of the predictions. Symmetric scatter bands of ±2 standard deviations (2σ) are shown. The present prediction (fig. 9(b)) shows the better agreement, having 2σ band of ±3.5 dB, while the SNECMA prediction (fig. 9(a)) has a 2σ band of ±5.1 dB. Ninety-five percent of the actual experimental data fall within ±3.3 dB of the NASA prediction and within ±4.9 dB of the SNECMA prediction.

All Cases

Although the preceding sections show that the present prediction agrees more closely with the experimental data, the discussion would be incomplete without comparisons with the combined data base. Since three conditions are included for each engine/airframe combination, the results should not be biased toward any particular case.

Comparisons are made in terms of the average difference between experimental and predicted flight increments for each case as a function of angle, as shown in figure 10. It can be seen (fig. 10(a)) that the SNECMA method consistently underpredicts the noise reduction in flight, except fairly near the jet axis (large θ). The mean bias, $\Delta_{Exp} - \Delta_{Calc}$, at each angle is shown by the solid curve. The dashed curves define a band of ±2 standard deviations from the mean bias. Over the angular range of all three data sets ($40^o < \theta < 150^o$) the present method has a smaller mean bias than the SNECMA method except at 110^o and 150^o. The standard deviation from the mean bias is also smaller for the present method except at $\theta = 120^o$.

An alternative method of comparison is shown in figure 11 where the experimental flight increment is plotted versus the flight increment predicted by each of the two methods. The bias toward underprediction of the in-flight noise reduction for the SNECMA prediction* is evident in figure 11(a); the bias appears to increase as the increments become smaller (generally corresponding to the forward quadrant.) On the average, the SNECMA method underpredicts the flight noise reduction by 1.4 dB, with a standard deviation of 2.5 dB (2σ band of ±5.1 dB). The nonbiased nature and relatively small scatter of the present prediction is apparent in figure 11(b); the average overprediction of the noise reduction in flight is less than 0.1 dB, with a standard deviation of 1.5 dB (2σ band of ±3.1 dB).

A final statistical comparison is made in figure 12, where the distribution of the number of samples is plotted versus the experimental minus calculated flight increment (in groupings of 0.5 dB width). The peak is sharper for the present method than for the SNECMA method. The SNECMA method also has a significant peak at $\Delta_{Exp} - \Delta_{Calc} = -4.0$, which indicates a significant problem with the SNECMA method. Thus, it can be seen that the present method is more symmetric about zero and has a more nearly Gaussian shape than the SNECMA method.

CONCLUSIONS

An improvement to the NASA method (1976) for predicting the effects of flight on jet mixing noise has been developed. The purely empirical supersonic convection formulation of the earlier method has now been replaced by one based on theoretical considerations. Other improvements of an empirical nature have been included based on model-jet/free-jet simulated flight tests. This report presents the new prediction method and comparisons with experimental data obtained from the Bertin Aerotrain with a J85 engine, the DC-10 airplane with JT9D engines, and the DC-9 airplane with refanned JT8D engines. It is shown that the new method agrees better with the data base than a recently proposed SAE method. Over the data base range of jet velocity (primary) from 280 to 680 m/sec, the new method has a standard deviation of 1.5 dB and the proposed SAE (SNECMA) method has a standard deviation of 2.5 dB.

APPENDIX A

SYMBOLS

A	area, m^2
c_a	ambient sonic velocity, m/sec
D	convection factor (eq. (3)), dimensionless
k	ratio of convection velocity to jet or relative velocity, dimensionless
M	Mach number, V/c_a, dimensionless
m	flight velocity exponent (eq. (1)), dimensionless
n	convection factor exponent, dimensionless
OASPL	overall sound pressure level, dB re 20μ N/m^2
R	source-to-observer distance, m
T	total temperature, K
w	density exponent (eq. (6a)), dimensionless
V	velocity, m/sec
α	turbulent length scale ratio, dimensionless
β	angle from jet axis to flight path (fig. 1), deg
Δ	OASPL difference, flight minus static, dB
θ	angle referred to jet inlet axis, deg
ρ	density, kg/m^3
σ	standard deviation, dB

Subscripts:

1	inner stream (fully expanded)
2	outer stream (fully expanded)
90°	evaluated at $\theta = 90^\circ$
a	ambient
c	convection
Calc	calculated
D	dynamic
e	effective
Exp	experimental
F	flight
J	jet mixing

j	fully expanded isentropic jet (primary)
K	kinematic
m	merged region
o	aircraft
S	static
So	source alteration
θ	evaluated at angle θ

APPENDIX B

APPLICATION TO INVERTED-VELOCITY-PROFILE COAXIAL JETS

In order to apply the methods developed herein to coaxial jets having an inverted velocity profile, it must be recognized that two regions of jet mixing noise generation exist. Of course, shock noise and any other contaminating noises must also be handled separately. After the contributions of these two mixing regions have been separated (e.g., as in ref. 20) the flight effects for each are calculated separately using the relations developed herein with the jet properties V_j and ρ_j replaced by the appropriate properties for each region. According to reference 20, the appropriate properties for the high frequency premerged region are those of the outer stream, V_2 and ρ_2. For the low frequency merged region the appropriate properties (ref. 20) are denoted V_m and ρ_m, where

$$V_m = \frac{V_1 + V_2\left(\frac{A_2}{A_1}\sqrt{\frac{T_1}{T_2}}\right)}{1 + \left(\frac{A_2}{A_1}\sqrt{\frac{T_1}{T_2}}\right)} \tag{B-1}$$

and ρ_m must be calculated iteratively from V_m and the effective total temperature T_m:

$$T_m = \frac{T_1 + T_2\left(\frac{A_2}{A_1}\sqrt{\frac{T_1}{T_2}}\right)}{1 + \left(\frac{A_2}{A_1}\sqrt{\frac{T_1}{T_2}}\right)} \tag{B-2}$$

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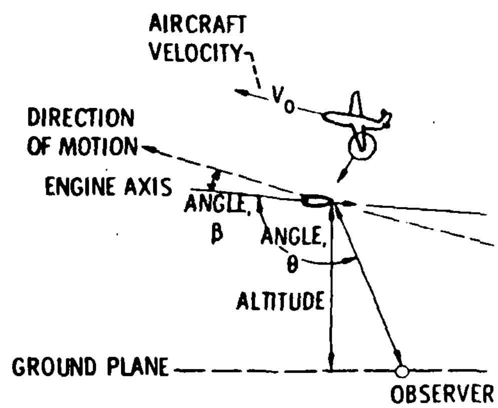
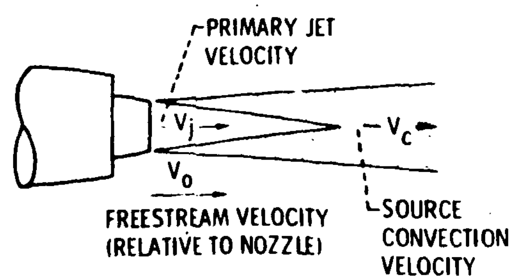


(a) GEOMETRIC PARAMETERS.



(b) JET PARAMETERS.

Figure 1. - Flight effects on jet noise: terminology for level flyover at aircraft Mach number M_0.

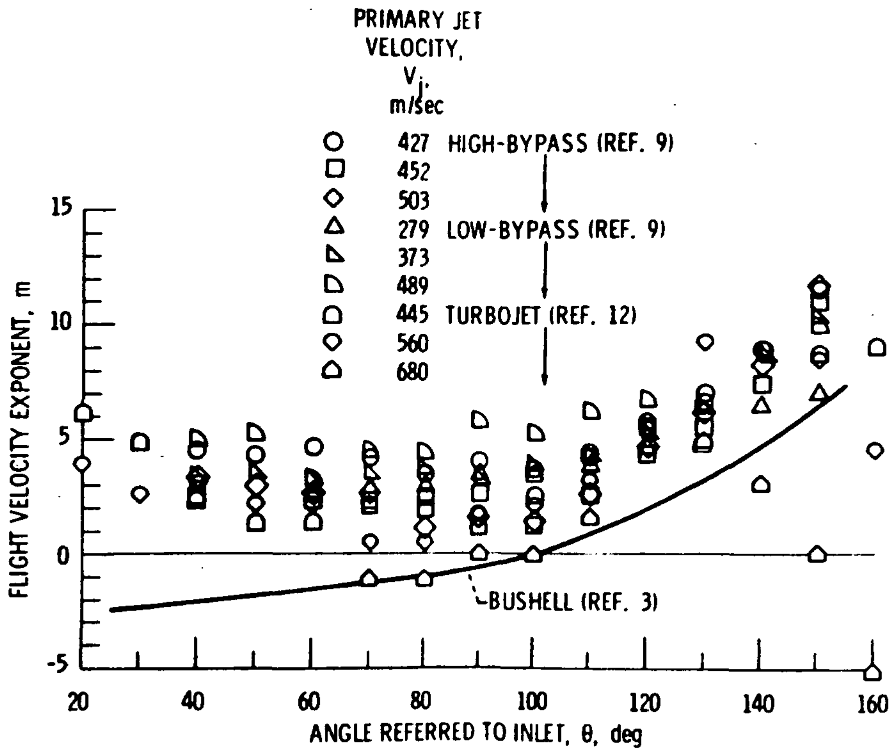


Figure 2. - Typical experimental flight velocity exponents compared with early prediction method of Bushell (ref. 3).

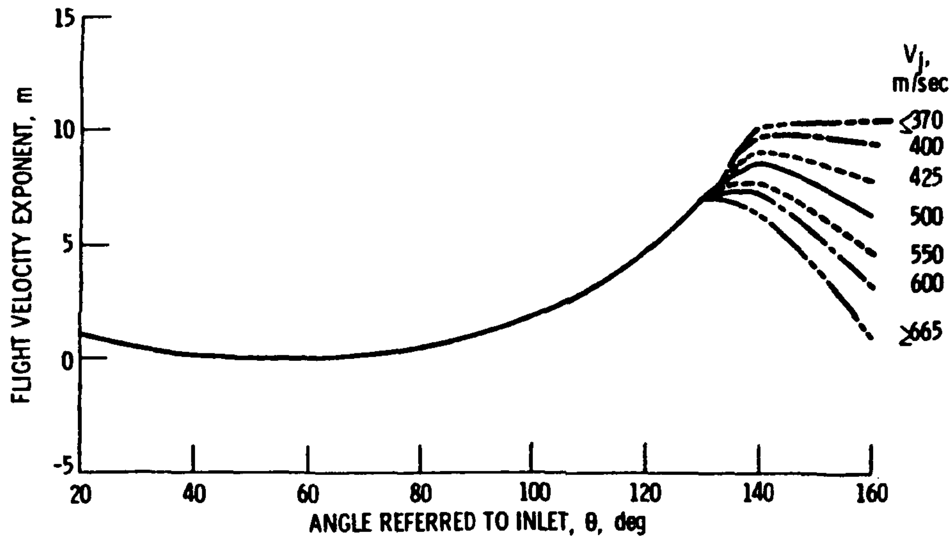


Figure 3. - SNECMA prediction for flight velocity exponent as a function of angle and jet velocity.

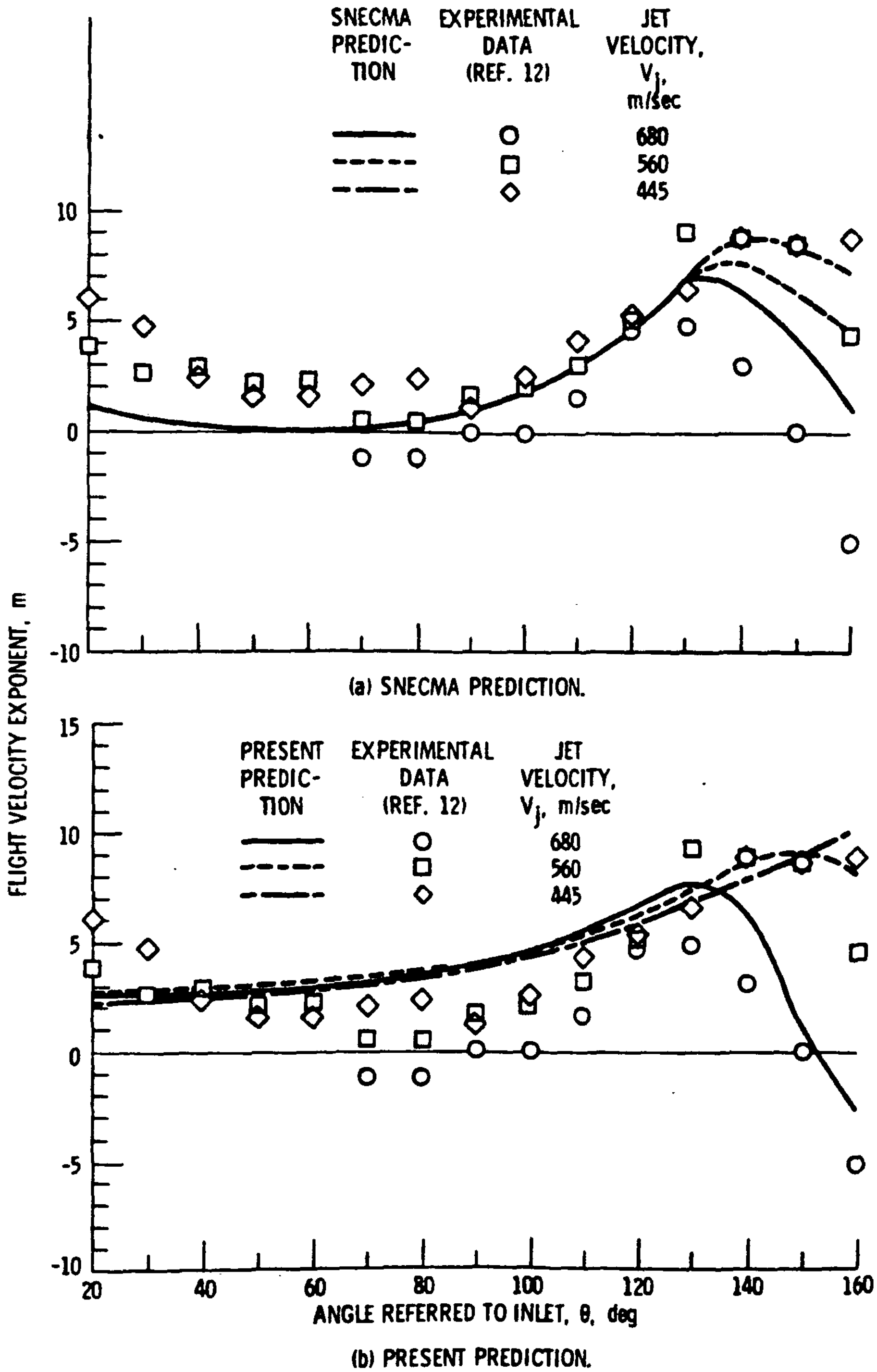


Figure 4. - Comparison of experimental and predicted flight velocity exponents for jet mixing noise of a J85 turbojet engine on the Bertin aerotrain; flight Mach number, 0.24.

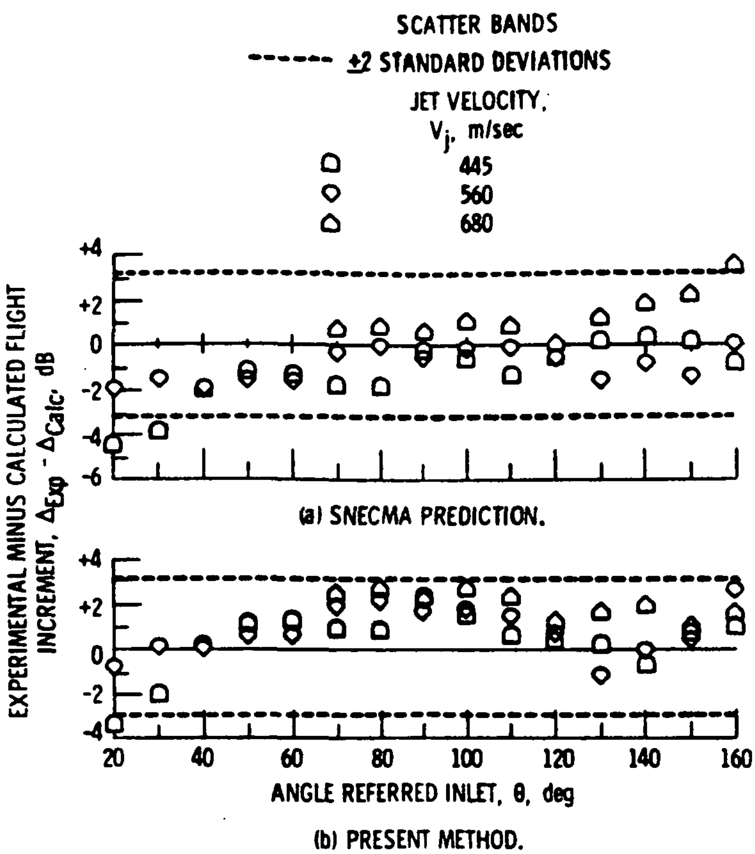


Figure 5. - Comparison of prediction methods with experimental data for J85 turbojet engine on Bertin Aerotrain (ref. 12).

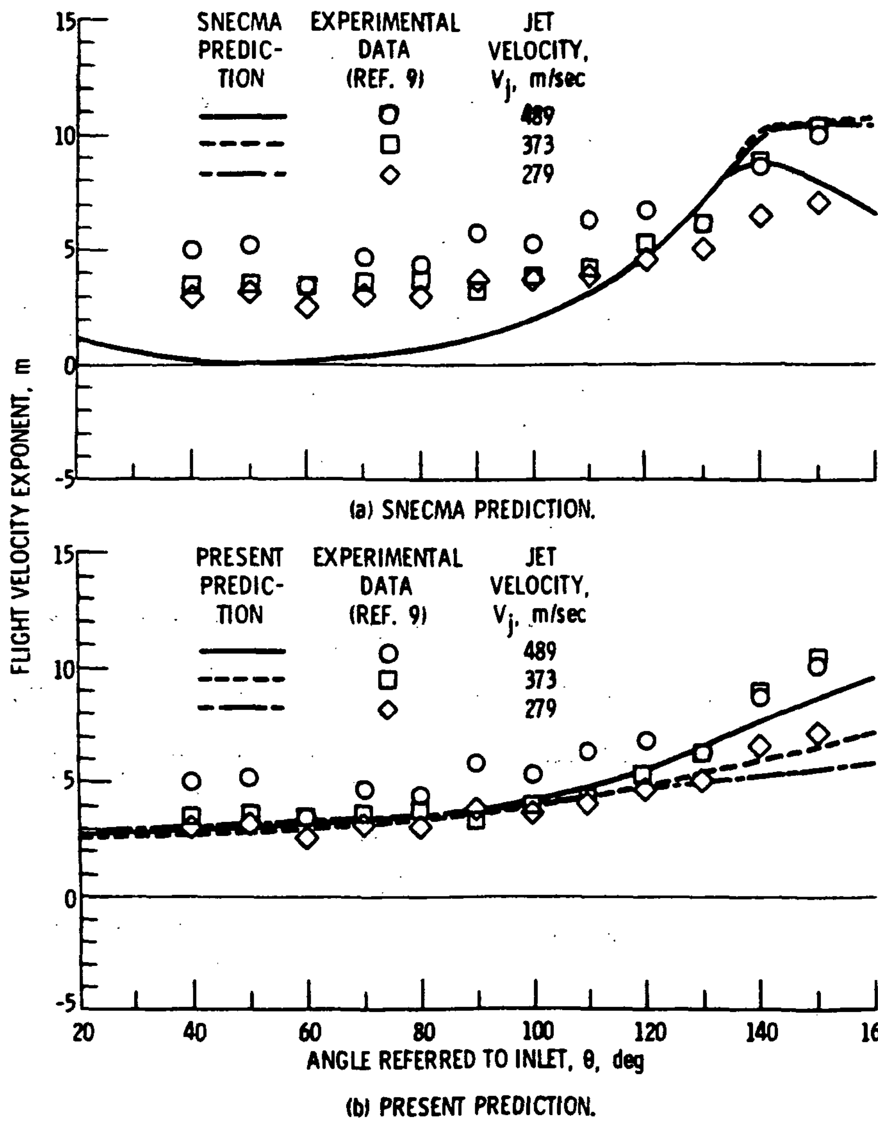


Figure 6. - Comparison of experimental and predicted flight velocity exponents for jet mixing noise of a DC-9-30 airplane with JT8D-109 engines; flight Mach number ~ 0.25.

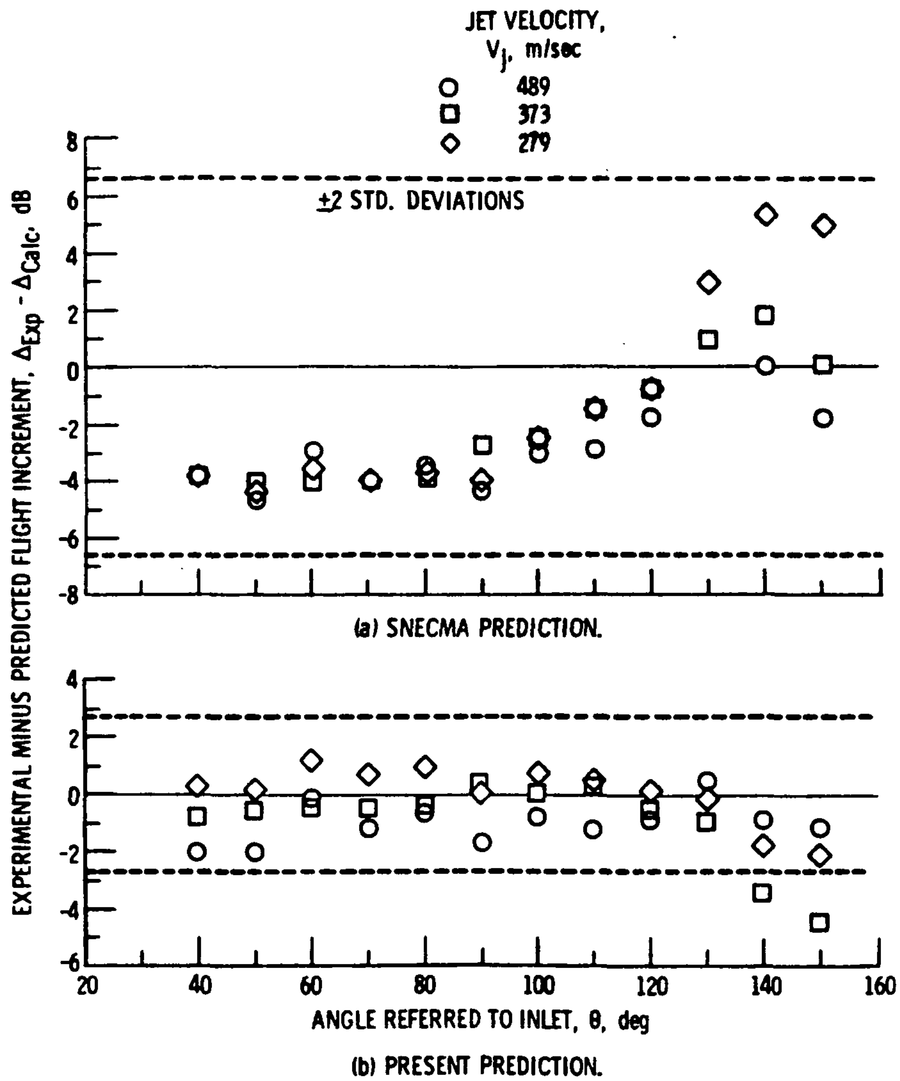


Figure 7. - Comparison of prediction methods with experimental data for DC-9-30 airplane with JT8D-109 engines (ref. 9).

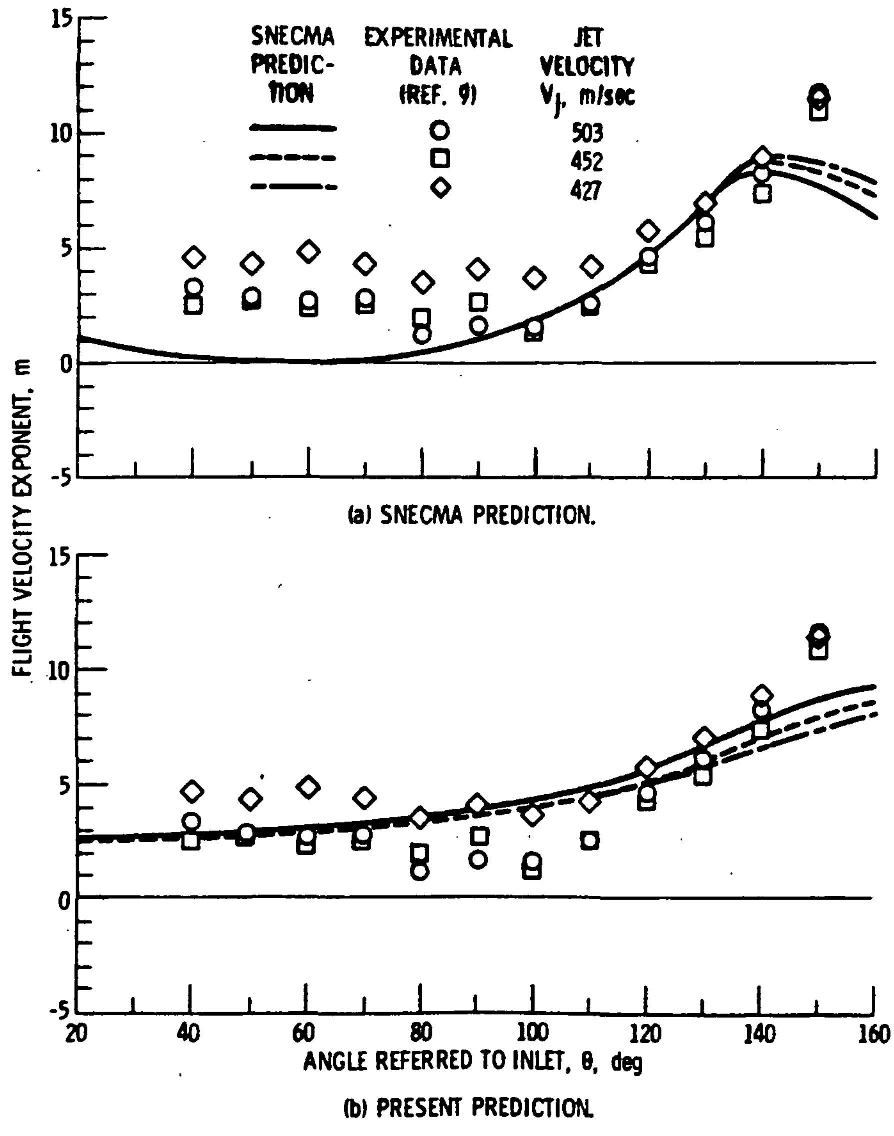


Figure 8. - Comparison of experimental and predicted flight velocity exponents for jet mixing noise of a DC-10-40 airplane with JT9D-59A engines; flight Mach number ~ 0.29.

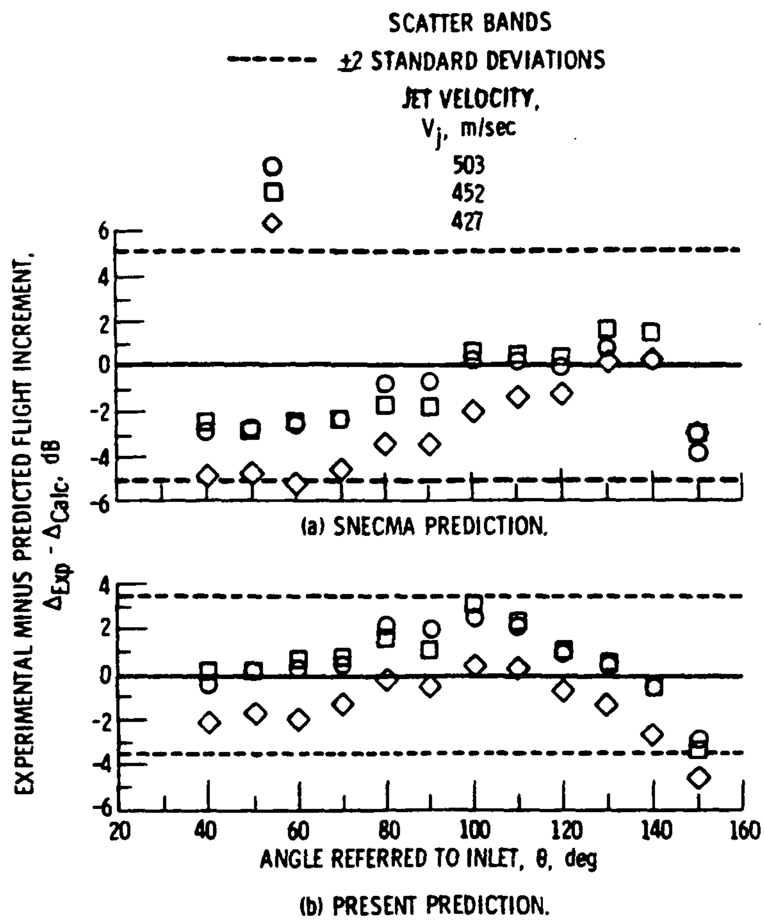


Figure 9. - Comparison of prediction methods with experimental data for DC-10-40 airplane with JT9D-59A engines (ref. 9).

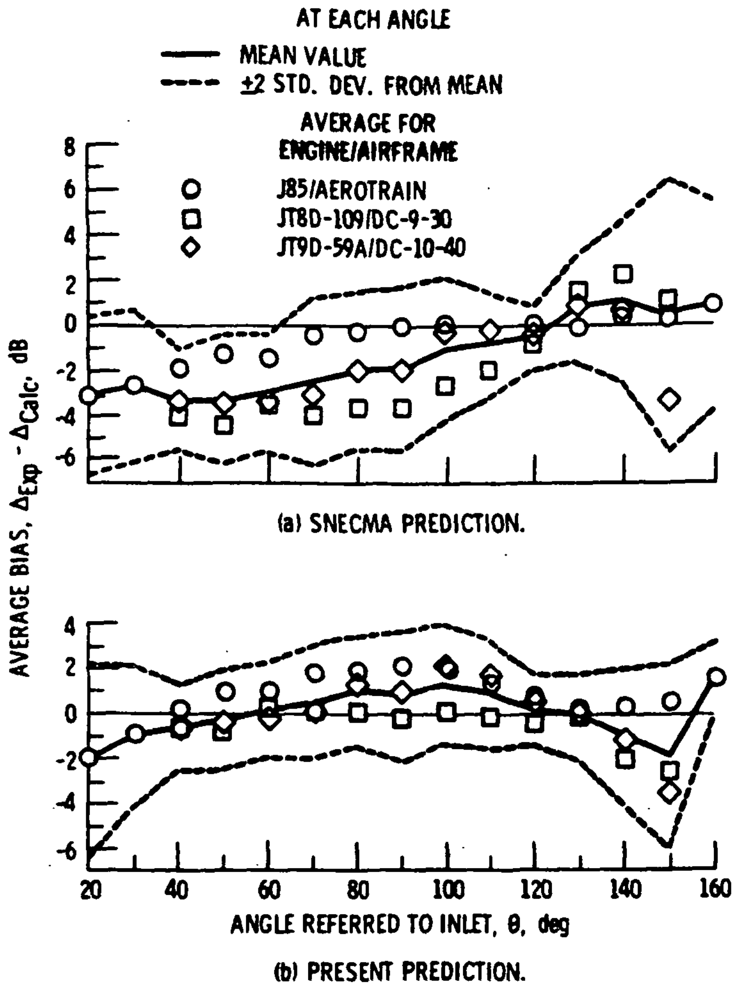


Figure 10. - Agreement of experimental with predicted flight increments as a function of angle.

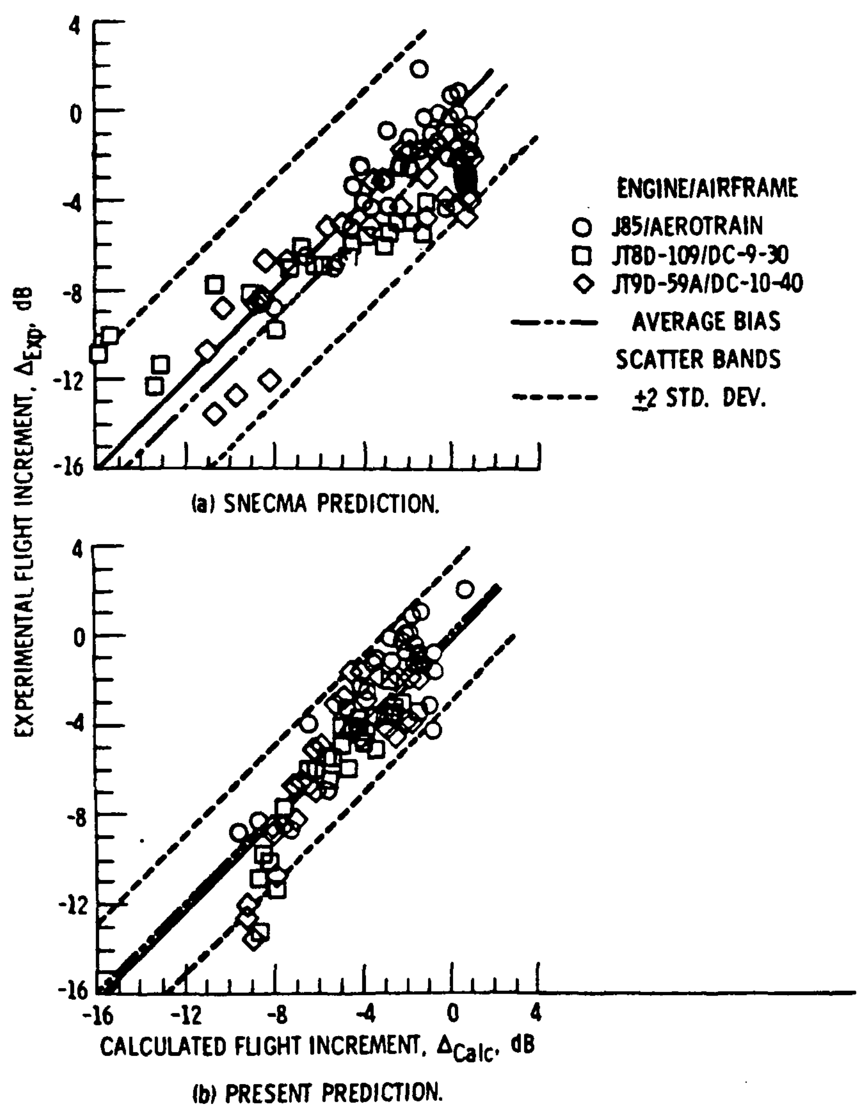
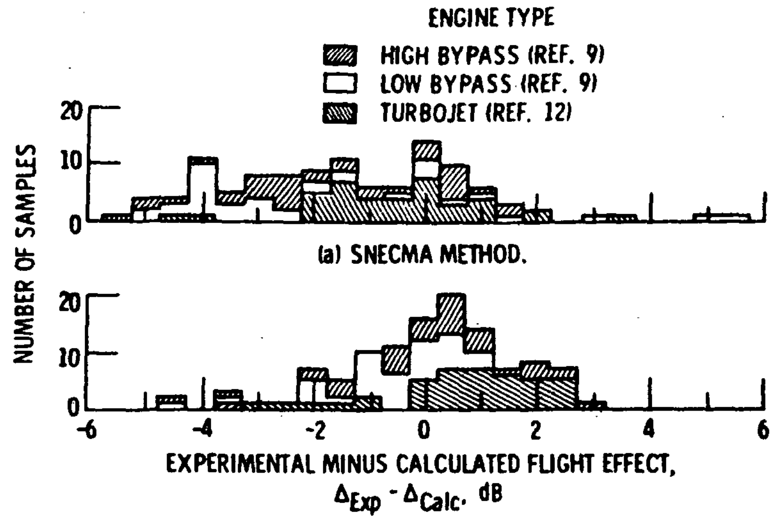


Figure 11. - Experimental versus calculated flight increments; comparison of prediction methods.



(b) PRESENT METHOD.

Figure 12. - Statistical comparison of prediction methods.

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16. Abstract

An improvement to the NASA method (1976) for predicting the effects of flight on jet mixing noise has been developed. The earlier method has been shown to agree reasonably well with experimental flight data for jet velocities up to about 520 m/sec (~1700 ft/sec). The poorer agreement at high jet velocities appeared to be due primarily to the manner in which supersonic convection effects were formulated. The purely empirical supersonic convection formulation of the earlier method has now been replaced by one based on theoretical considerations. Other improvements of an empirical nature have been included based on model-jet/free-jet simulated flight tests. This report presents the new prediction method and comparisons with experimental data obtained from the Bertin Aerotrain with a J85 engine, the DC-10 airplane with JT9D engines, and the DC-9 airplane with refanned JT8D engines. It is shown that the new method agrees better with the data base than a recently proposed SAE method.

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