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NEW BROADBAND SHOCK NOISE MODEL AND COMPUTER CODE FOR ANOPP

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Figure 1

BROADBAND SHOCK NOISE PREDICTION

The basic mechanism for broadband shock noise in the supersonic jets is the interaction between the shock waves and the turbulence in the jet exhaust. This source is in addition to jet mixing noise.

Far-field noise prediction method for this source was developed by Harper-Bourne and Fisher in 1974 by using very limited data (ref. 1). This method was extended by Tanna using hot jet data of convergent nozzles and was adopted as an SAE recommended procedure for shock associated jet noise (ref. 2). During the same time, Stone of NASA-Lewis developed an empirical procedure using the test data (ref. 3). Both of these methods were incorporated in ANOPP (ref. 4). The SAE method is applicable for single stream convergent circular nozzles. The Stone's method was applicable for single/dual stream coaxial nozzles. The flight effects are incorporated as $[1-M_\infty\cos\theta]^{-4}$ (figures 1 and 2).

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Broadband Shock Noise

- **Mechanism**
  - **Interaction Between Shock Waves and Turbulence**
  - **Addition to Turbulent Mixing Noise**
- **Prediction**
  - **ANOPP/SAE**
    - **Harper-Bourne and Fisher - 1974**
    - **SAE - 1976**
    - **Convergent Nozzles**
    - **Flight Effects -** $[1-M_\infty \cos\theta]^{-4}$
  - **ANOPP/Stone**
    - **Single/Duel Stream Coaxial Jets**
    - **Empirical Derivation**
    - **Not Sensitive to Jet Temperature**
    - **Flight Effects -** $[1-M_\infty \cos\theta]^{-4}$

Figure 2

Self Explanatory

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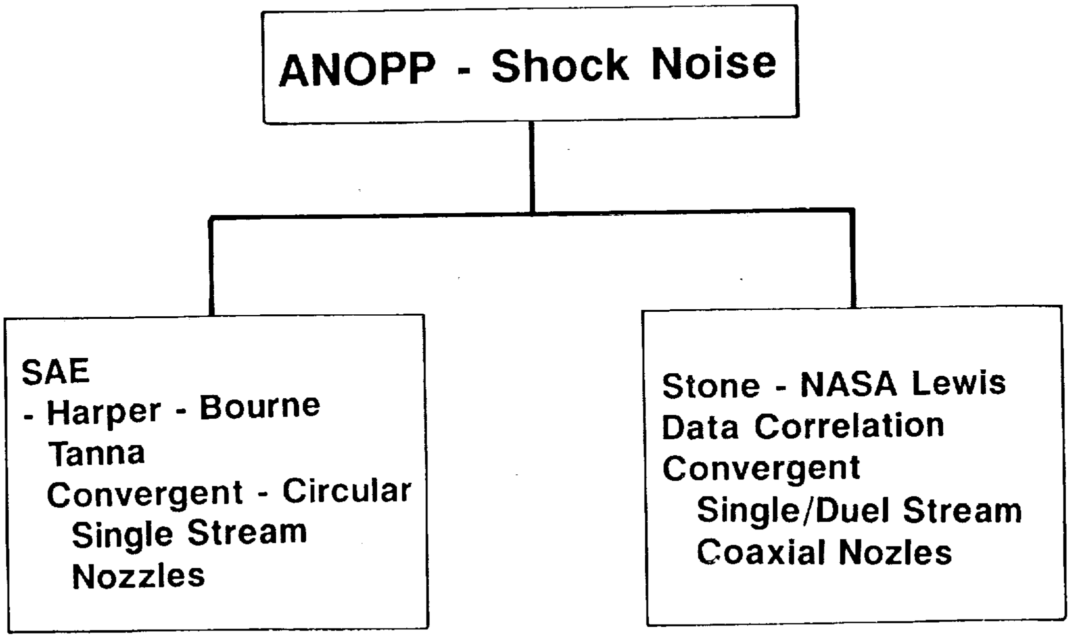
Broadband Shock Noise Prediction Code



ANOPP - Shock Noise

SAE
- Harper - Bourne
  Tanna
  Convergent - Circular
    Single Stream
    Nozzles

Stone - NASA Lewis
Data Correlation
Convergent
  Single/Duel Stream
  Coaxial Nozles

Figure 3

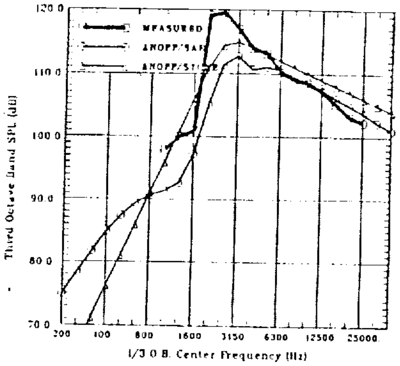
ANOPP VALIDATION FOR SHOCK NOISE

The existing ANOPP predictions for shock noise are evaluated using NASA's ambient temperature static C-D nozzle data (ref. 5). The typical results are shown in Figure 3. Both SAE method and Stone's method underpredict the peak noise levels. The spectral characteristics appears to be different. To improve the accuracy, development of new prediction code for broadband shock noise was initiated.

Lockheed **Validation of ANOPP**

NASA's Data

Nozzle Exit Diameter = 0.04989m;
M_d = 1.50; M_j = 1.80



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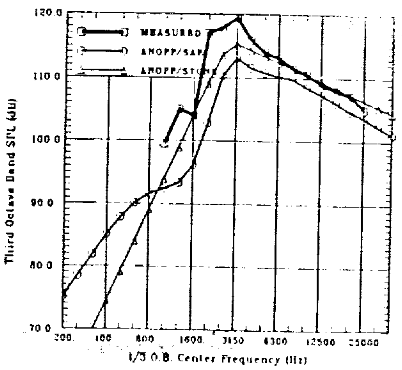
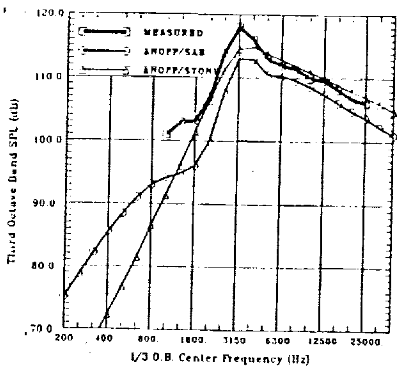


θ= 45.0



θ= 60.0

Figure 4

NEW BROADBAND SHOCK NOISE PREDICTION CODE

Recently C. K. W. Tam has developed a stochastic model theory to predict near- and far-field noise for supersonic jets (ref.6). This theoretical formulation is based on the proposition that broadband shock noise is generated by the interaction of the downstream propagating large scale turbulence structures and shockcell system. This method is applicable for moderately imperfectly expanded circular single stream jets. The jet temperature effects are included. The important input parameters to predict the shock noise levels are shown in Figure 4.

A computer code for ANOPP is being developed using this prediction method. Initially, the prediction code is applicable for circular nozzles with static (without flight effects) conditions.

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Broadband Shock Noise

- **New Prediction Model**
  - **Background - Tam's Theory-1989-90 [JSV(1990) 140(1) 55-71]**
    - **Interaction Between Large Turbulence Structure and Shock Cells**
  - **Method - Convergent and C-D Nozzles**
    - **Moderately Imperfectly Expanded Jets (Over and Under Expanded)**
    - **Jet Temperature Effects Included**
  - **Variables - M_d, Design Jet Mach Number**
    - **M_j, Jet Mach Number**
    - **D_n, Nozzle Exit Diameter**
    - **D_j, Fully Expanded Jet Diameter**
    - **T_t, Jet Stagnation Temperature**
    - **T_∞, Ambient Temperature**

Figure 5

NEWS BROADBAND SHOCK NOISE CODE - VALIDATION

The new prediction code is validated against two sets of static test data: (1) NASA-Langley data obtained by Norum and Seiner (ref. 5), and (2) Lockheed/USAF data (ref. 7).

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Broadband Shock Noise

Validations

- NASA Data (Norum & Seiner - NASA TM84521, 1982)
  - Ambient Temperature Jets
  - Convergent Nozzle
  - C-D Nozzle ($M_d = 1.5$)
    - Overexpanded ($M_j < M_d$)
    - Underexpanded ($M_j > M_d$)
  - C-D Nozzle ($M_d = 2.0$)
    - Overexpanded
    - Underexpanded
- Lockheed Data (AFAPL-TR-76-65, 1976)
  - Ambient and Heated Jets
  - Convergent Nozzle

Figure 6

EFFECT OF TABS (SCREECH SUPPRESSIONS)

The test data in reference 5 are presented for jet, ambient temperature static conditions for three nozzles. The three nozzles used were, convergent nozzle, Mach 1.5 C-D nozzle and Mach 2.0 CD nozzle. The test data were obtained with and without using any tabs at the nozzle exit (screech suppressors). In order to compare the prediction with the measured data, the effect of tabs on the broadband shock noise was evaluated by comparing the spectra with and without spectra as shown in Figure 6. It is clear from this figure that the tabs reduce the peak broadband noise in addition to eliminating the screech tones. Therefore, the data without tabs were used in validating the prediction code. It should be noted that the data for 45° angle shows that there is about 5db difference throughout the frequency range. This difference at 45° angle appears to be consistent for most of the data points.

Effect of Tab (Screech Suppressor)

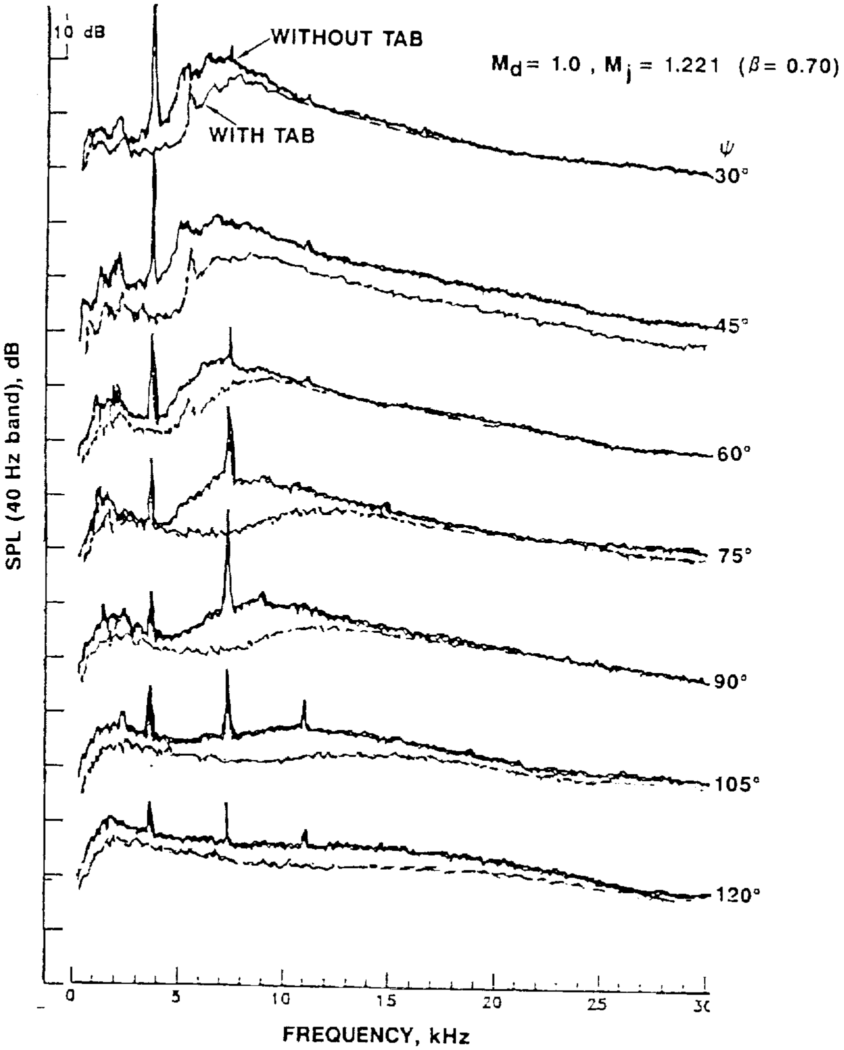

Figure 7

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Broadband Shock Noise

Validation

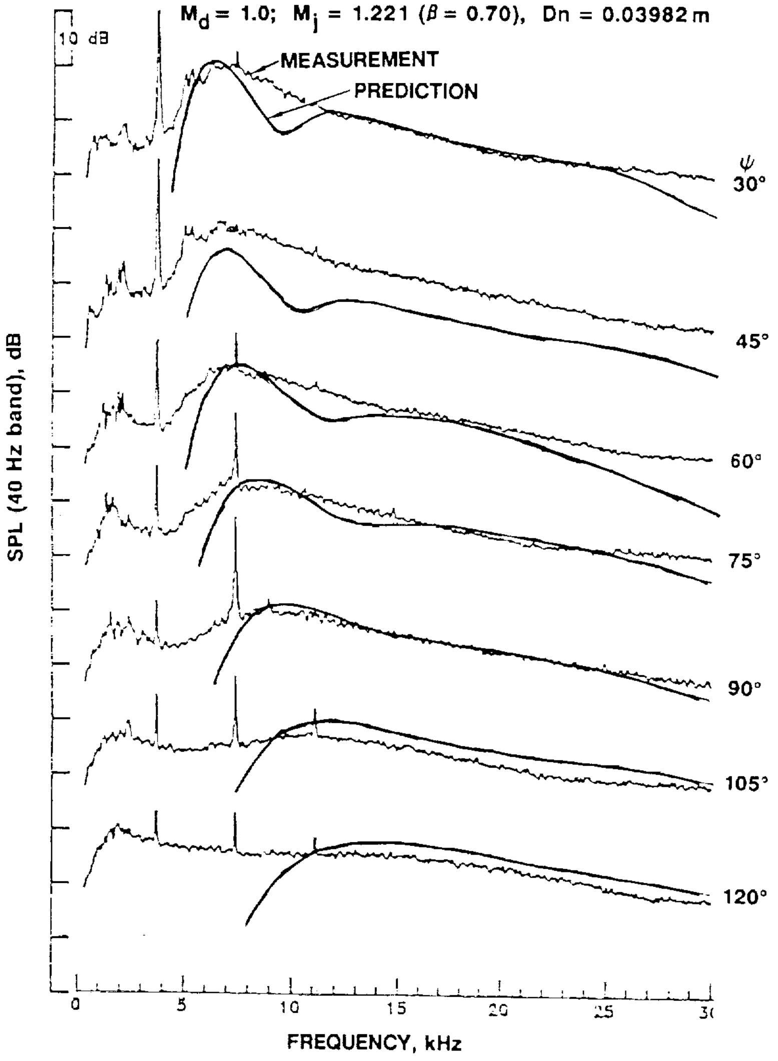
NASA Convergent Nozzle Data

Figures 8 and 9

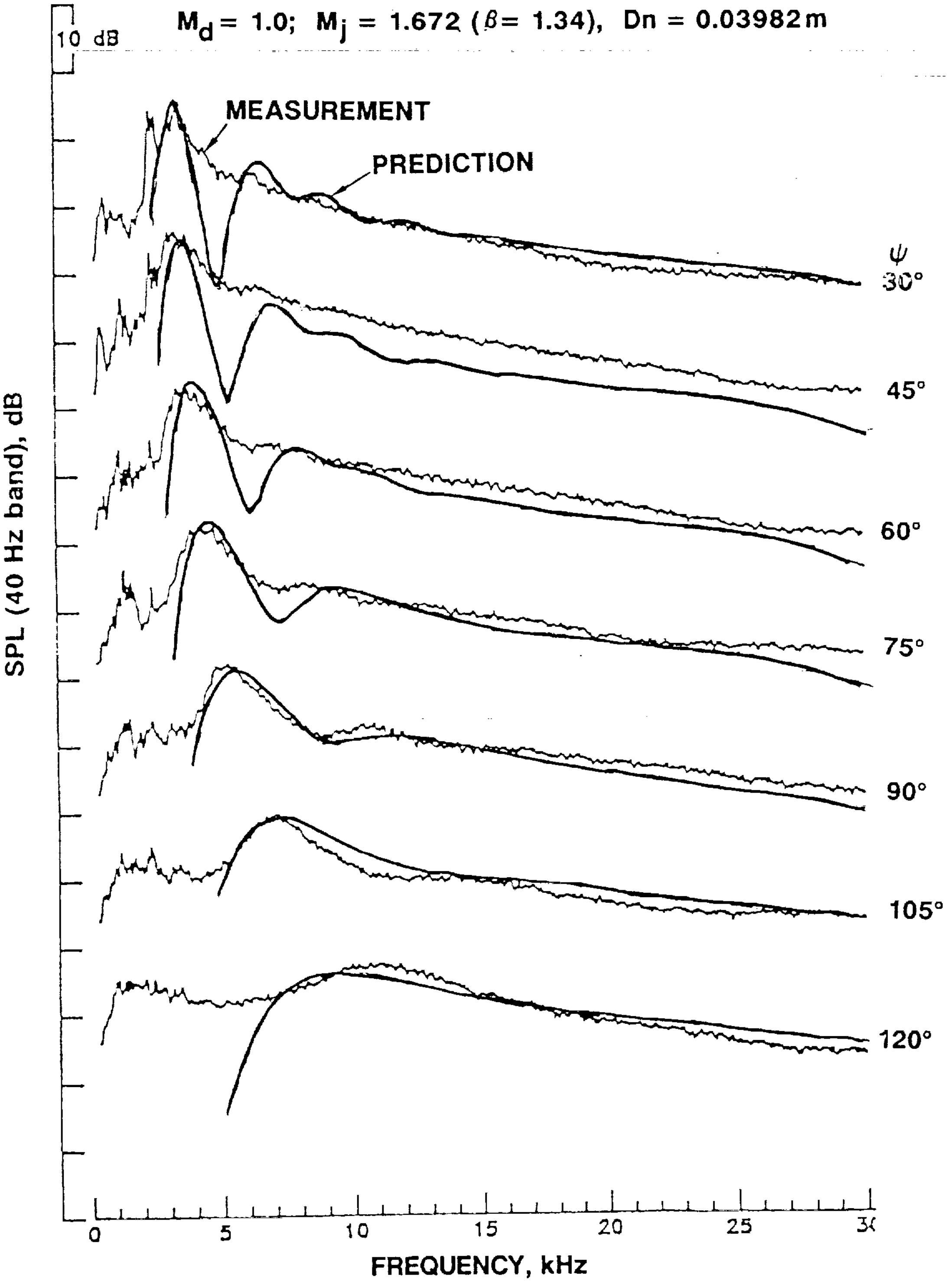
VALIDATION - NASA CONVERGENT NOZZLE DATA

The predicted results are compared with the measured data for convergent nozzles in the following two figures (8 and 9). The angles indicated in these figures are the angles from forward axis. Figure 8 is for jet Mach number of 1.221 and Figure 9 is for jet Mach number of 1.672. It is clear from these figures that there is a good agreement between prediction and measurement at all angles.

Compaison of TAM's Prediction with NASA's Measured Data



Comparison of TAM's Prediction with NASA's Measured Data

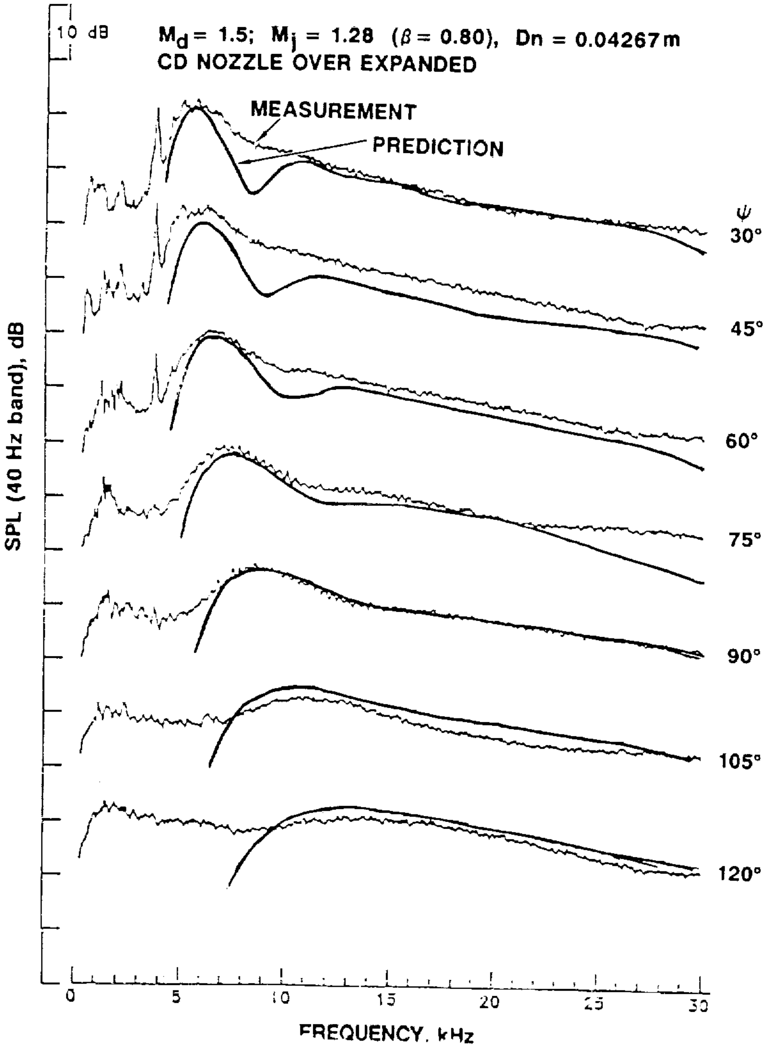


Figures 10 and 11

VALIDATION - NASA MACH 1.5 CD NOZZLE DATA

The following two figures illustrate the comparison of prediction with the measured data for convergent divergent nozzle with design Mach number of 1.5. The test data used in these comparisons is obtained from the nozzles without tabs. Figure 20 is for Mach 1.5 nozzle with overexpanded jet (M_J=1.28). Figure 11 is the comparison of prediction with measurement for Mach 1.5 nozzle with underexpanded jet (M_J=1.99).

Comparison of TAM's Prediction with NASA's Measured Data



Comparison of TAM's Prediction with NASA's Measured Data

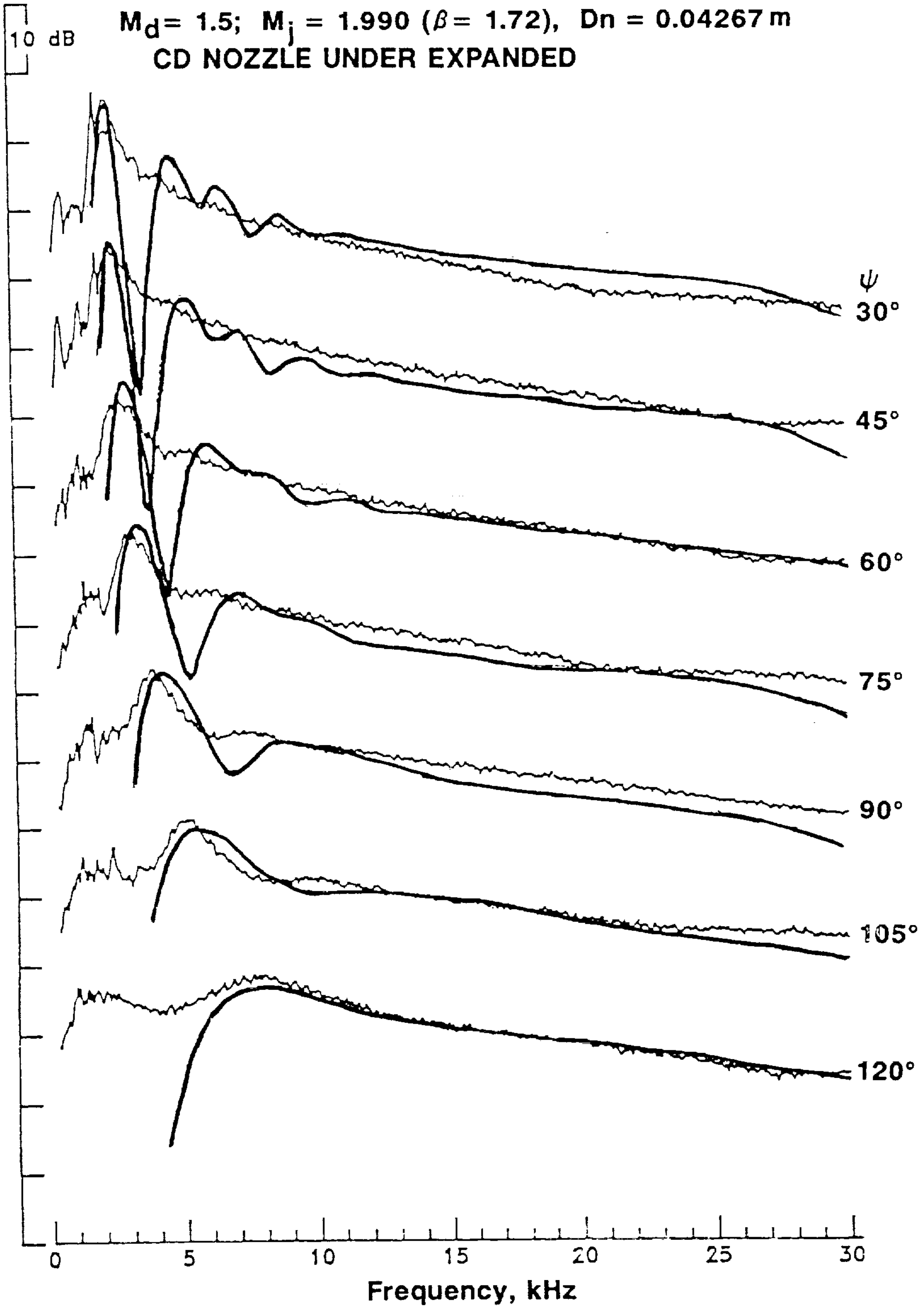


Figure 12

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Broadband Shock Noise

Validation

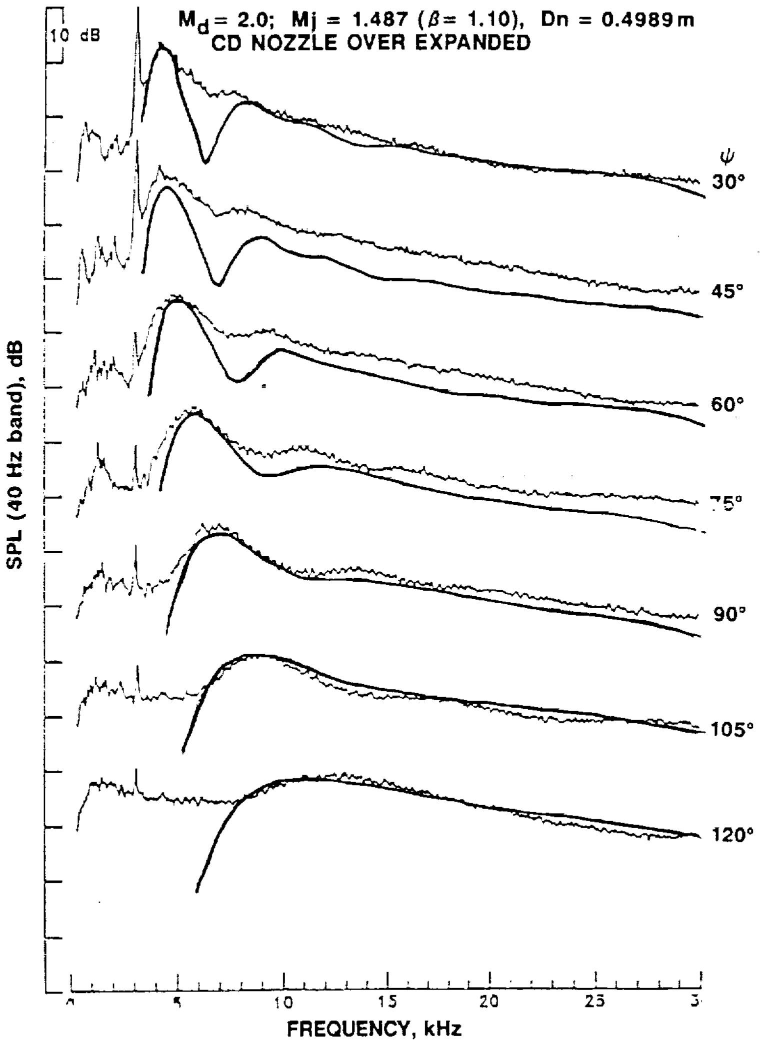
NASA CD Nozzle Data

Figures 13 and 14

VALIDATION - NASA MACH 2.0 CD NOZZLE

The following two figures (13 and 14) illustrate the comparison of prediction with the measured data for convergent divergent nozzle with design Mach number of 2.0. There is a good agreement between the prediction and data.

Comparison of TAM's Prediction with NASA's Measured Data



Comparison of TAM's Prediction with NASA's Measured Data

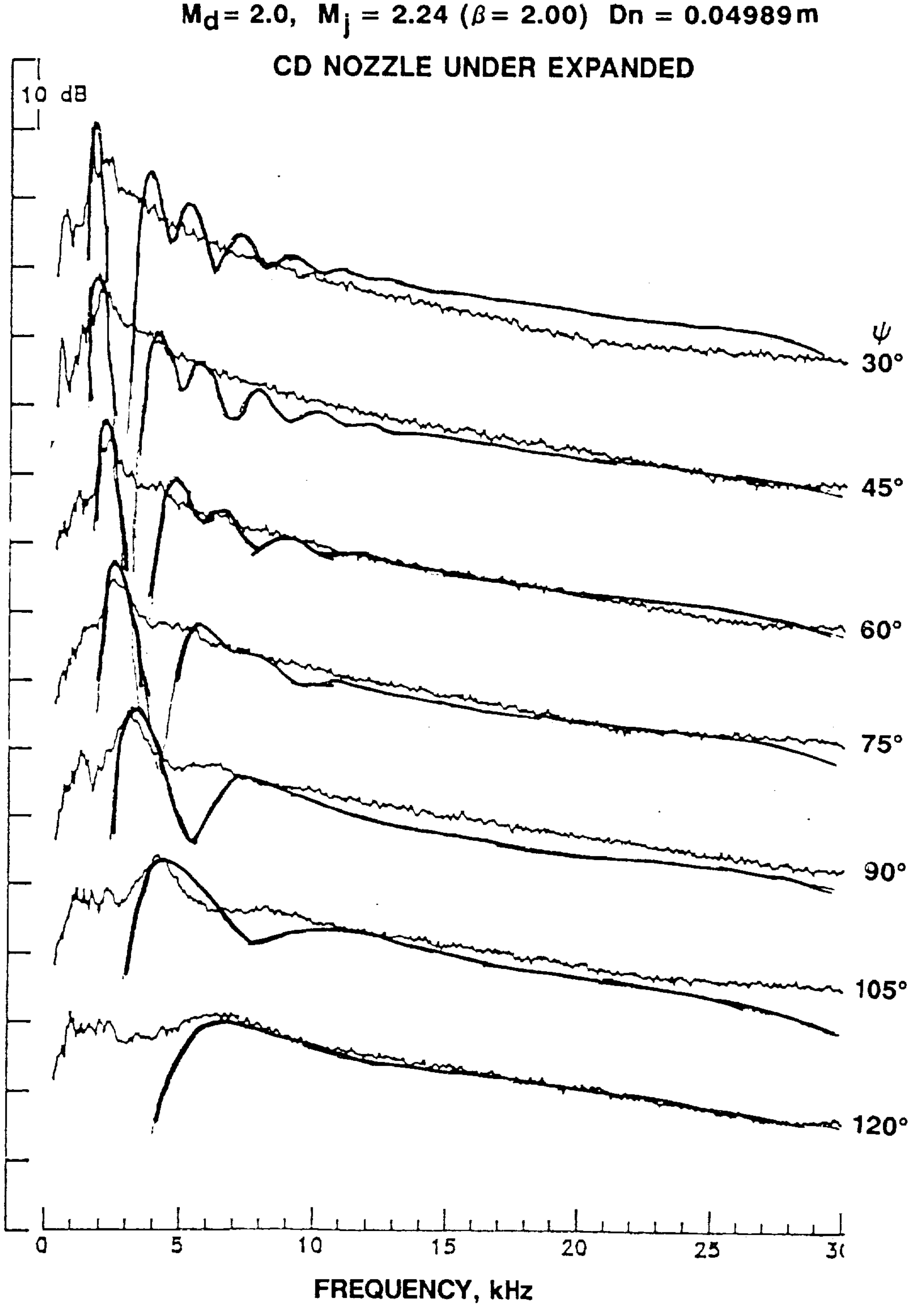


Figure 15

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Broadband Shock Noise

Validation

Lockheed Data

Figure 16

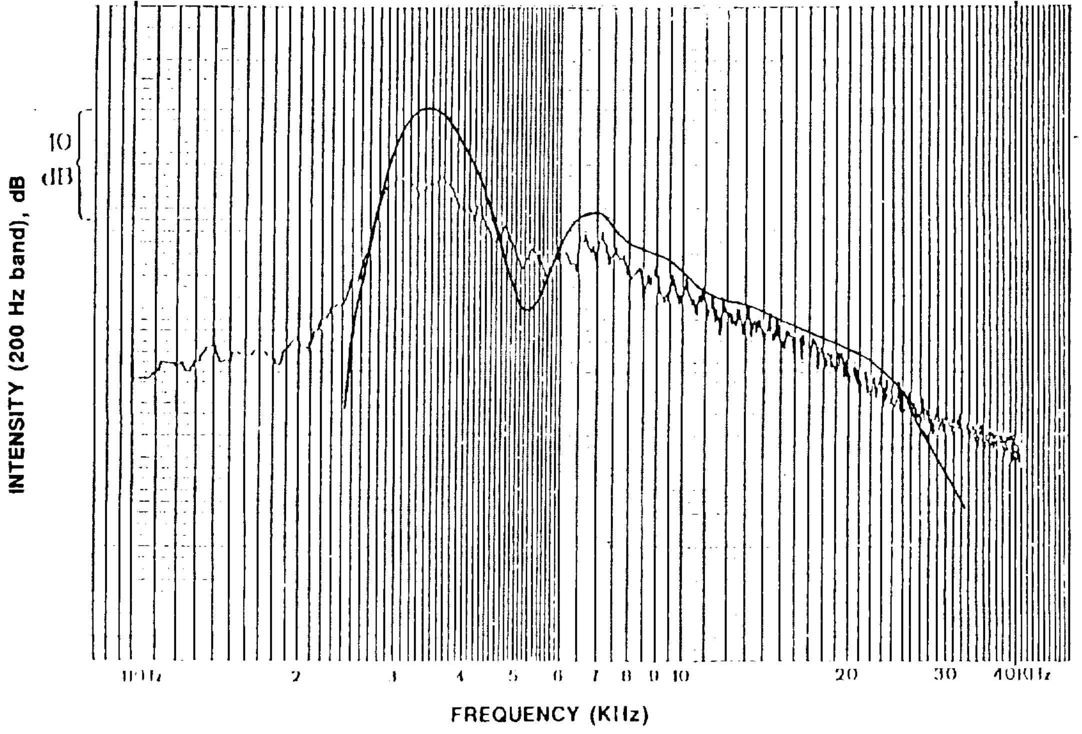
VALIDATION - LOCKHEED DATA

The following figures (16a-16f) compare the predictions with Lockheed's test data. These data were obtained for convergent nozzles with ambient temperature jet and heated jet. Figures 16a and 16b are for ambient temperature jets (jet stagnation temperature = ambient temperature). Figures 16c and 16d are for isothermal jets (jet temperature=ambient temperature). Figures 16e and 16f are for hot jets (jet temperature is higher than ambient temperature). The tests were conducted with tabs (screech suppressors) at the nozzle exit. The general spectral characteristics of prediction agrees with the measured data. The peak levels of the measured data, however, are less than the prediction. These differences in the peak levels are attributed to the presence of the tabs as illustrated in figure 6.

Lockheed

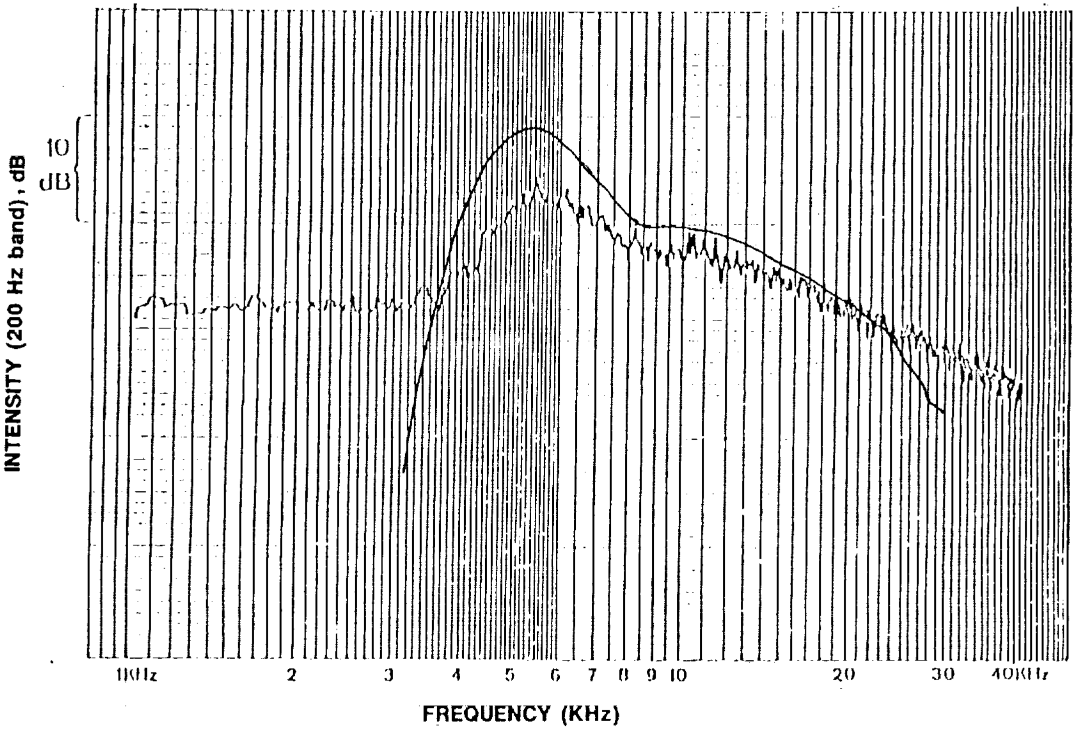
Comparison of TAM's Prediction with Lockheed's Data

$M_d = 1.0$ $M_j = 1.49$; $Dn = 0.0508$ m $\psi = 45°$ $\frac{T_t}{T_\infty} = 1.0$



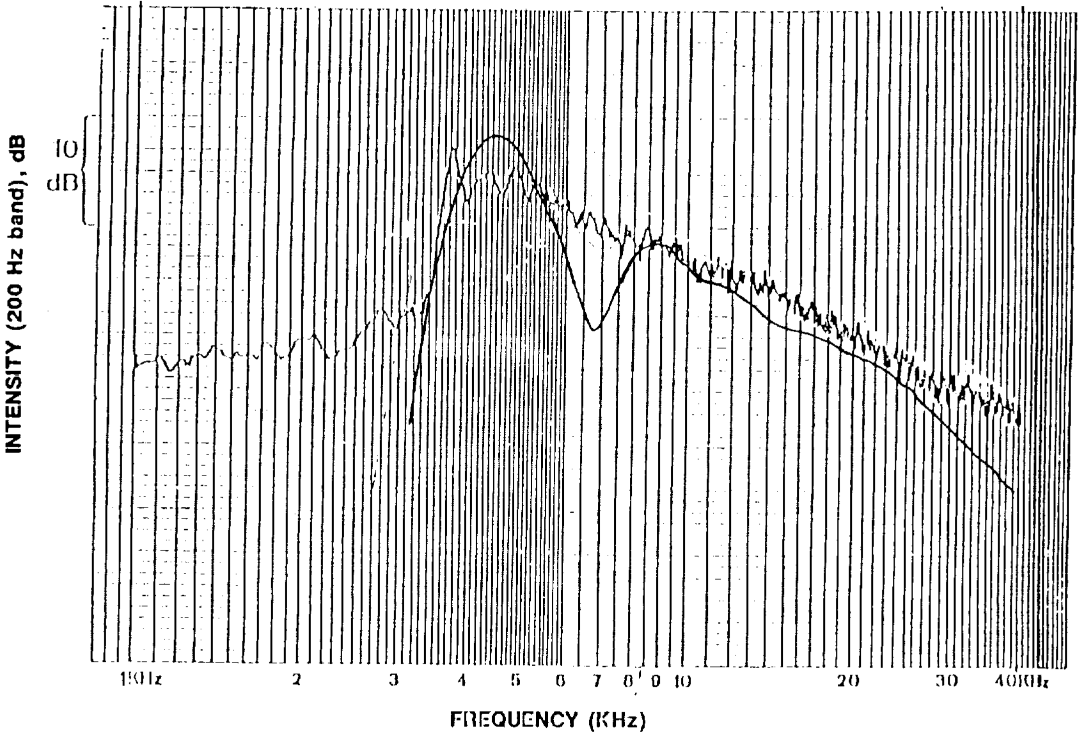
Comparison of TAM's Prediction with Lockheed's Data

$M_d = 1.0$ $M_j = 1.49$; $Dn = 0.0508m$ $\psi = 90°$ $\frac{T_t}{T_\infty} = 1.0$



Comparison of TAM's Prediction with Lockheed's Data

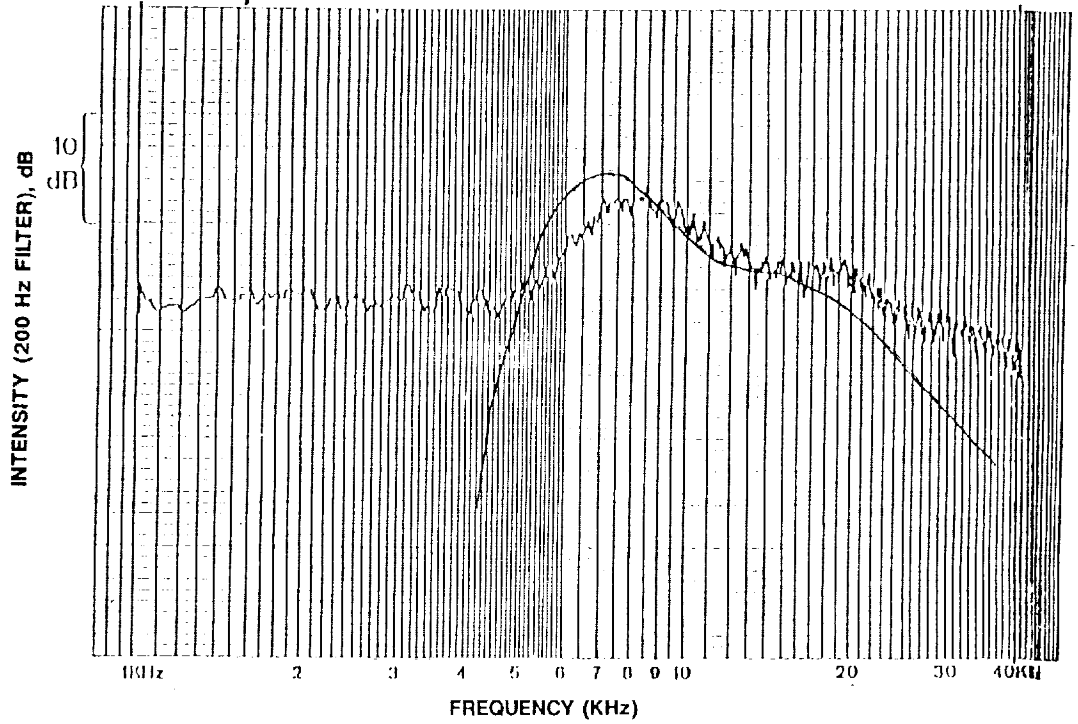
$M_d = 1.0;\ M_j = 1.372;\ Dn = 0.0508m\ \ \psi = 45^\circ\ \ \frac{T_t}{T_\infty} = 1.367,\ \ \frac{T_j}{T_\infty} = 1.0$



Lockheed

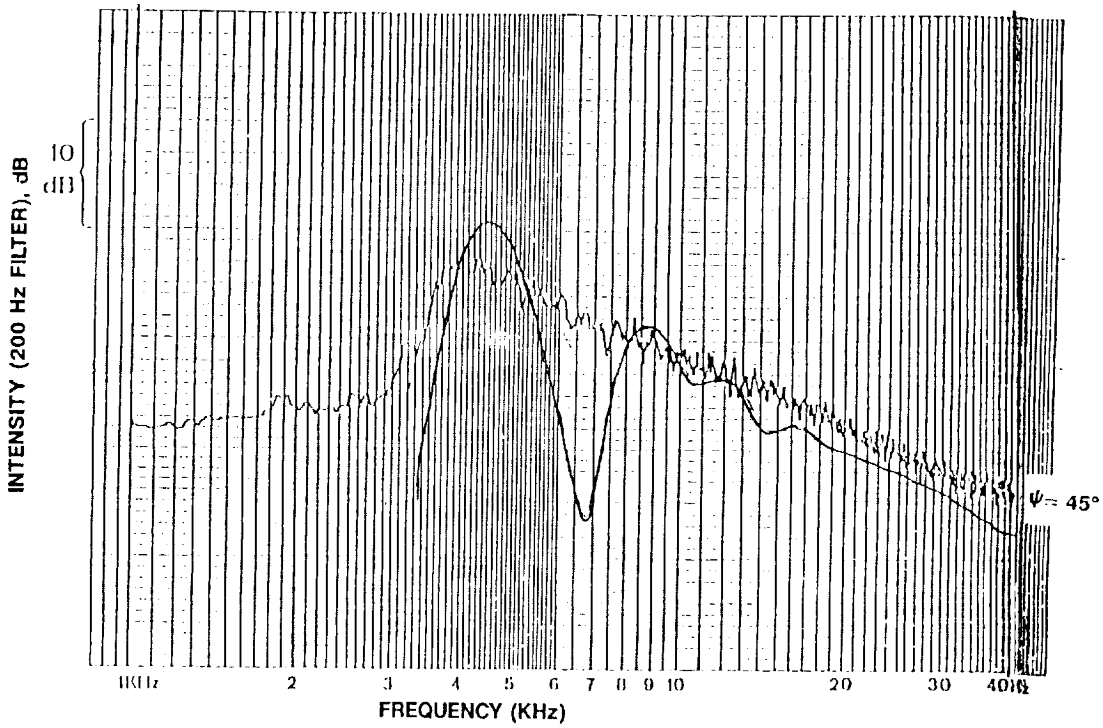
Comparison of TAM's Prediction with Lockheed's Data

$M_d = 1.0$; $M_j = 1.49$; $\psi = 90°$ $Dn = 0.0508\,m$ $\frac{T_t}{T_\infty} = 1.367$, $\frac{T_j}{T_\infty} = 1.0$



Comparison of TAM's Prediction with Lockheed's Data

$M_d = 1.0$; $M_j = 1.49$; $\psi = 45°$ Dn = 0.0508m $\frac{T_t}{T_\infty} = 2.524$



Comparison of TAM's Prediction with Lockheed's Data

$M_d = 1.0$; $M_j = 1.48$; $\psi = 90°$ Dn = 0.0508 m $\frac{T_t}{T_\infty} = 2.524$

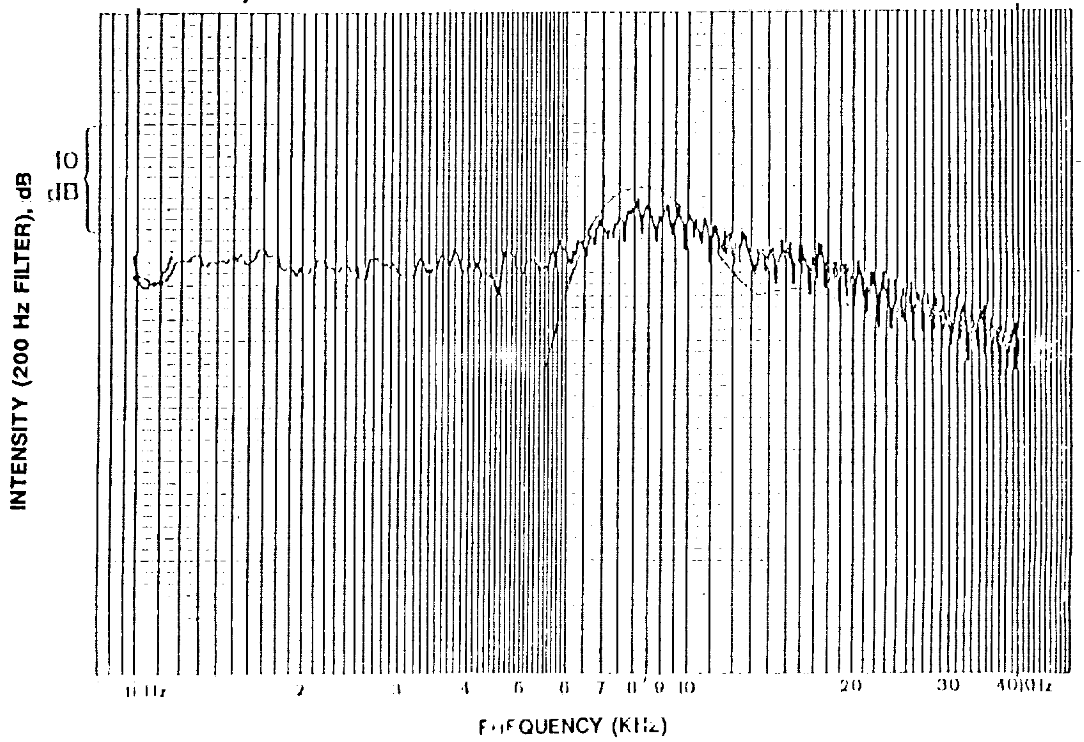


Figure 17

Self Explanatory

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Comparison of New Model With Existing Models

- ANOPP/SAE
- ANOPP/Stone

Figure 18

COMPARISON OF NEW MODEL WITH EXISTING ANOPP

The new spectral results from the new shock noise prediction code are compared with the results from the existing ANOPP codes (SAE and Stone) in the following figures 18a and 18b. These comparisons are for circular nozzles ambient temperature jet and static condition. Figure 18a is for convergent nozzle and figure 18b is for Mach 1.5 CD nozzle.

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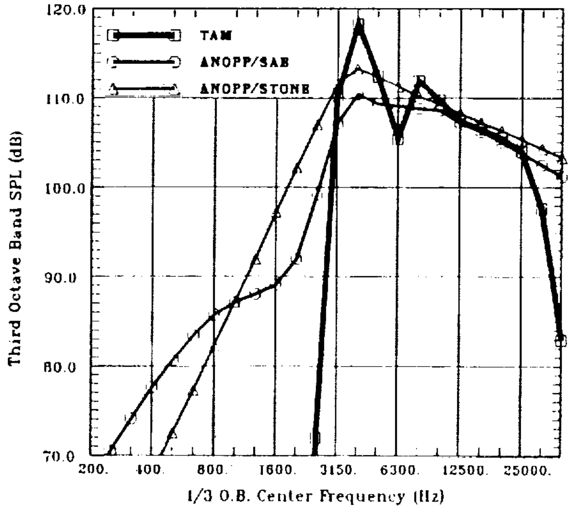
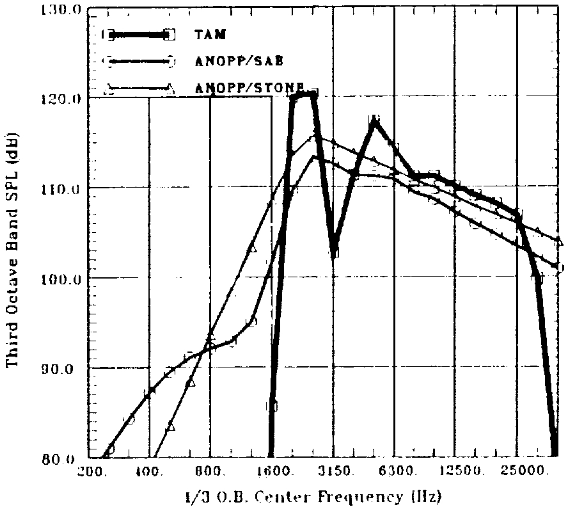
Comparison of TAM's Prediction with ANOPP



Nozzle Exit Diameter=0.03982 m; Md= 1.00; Mj= 1.49
θ= 30.0

Comparison of TAM's Prediction with ANOPP



Nozzle Exit Diameter=0.04267 m; Md= 1.50; Mj= 1.99
Θ= 30.0

Figure 19

CONCLUDING REMARKS - FURTHER DEVELOPMENTS

The new prediction code is based on theoretical background using small scale experimental data. This procedure is applicable for convergent, convergent divergent circular nozzles for moderately imperfectly expanded jets. The temperature effects are included, however, the flight effects are not included. This prediction code is validated against two independent sets of model data. The correlation between prediction and measurement are excellent.

This prediction method must be extended to account for flight effects and to noncircular nozzles. The code must be validated against a larger data base including flight test data. The flight effects on shock noise appears to be an important issue to be resolved. This required a good data base.

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Broadband Shock Noise

Further Developments

- Flight Effects
- Noncircular Nozzles
- Validations
  - Hot Jet Data
  - Flight Test Data
- Require More Data

REFERENCES

1. Harper-Bourne, M. and Fisher, M. J.: The Noise from Shock Waves in Supersonic Jets. AGARD-CP-131, March 1974.

2. Gas Turbine Jet Exhaust Noise Prediction. ARP 876, Appendix C, Soc. Automot. Eng., March 1978.

3. Stone, James R. and Montegani, Francis J.: An Improved Prediction Method for the Noise Generated in Flight by Circular Jets. NASA TM-81470, 1980.

4. Zorumski, William E.: Aircraft Noise Prediction Program - Theoretical Manual, NASA Technical Memorandum 83199, Part 2, February 1982.

5. Norum, T. D. and Seiner, J. M.: Measurements of Mean Static Pressure and Far-Field Acoustics of Shock-Containing Supersonic Jets.

6. Tam, C. K. W.: Broadband Shock-Associated Noise of Moderately Imperfectly Expanded Supersonic Jets, Journal of Sound and Vibration

7. The Generation and Radiation of Supersonic Jet Noise, Volume IV Shock Associated Noise Data. Technical Report AFAPL-TR-76-65, June 1976.

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