CLIMB TO CRUISE NOISE TEST RESULTS

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S29-71

OUTLINE

OBJECTIVES

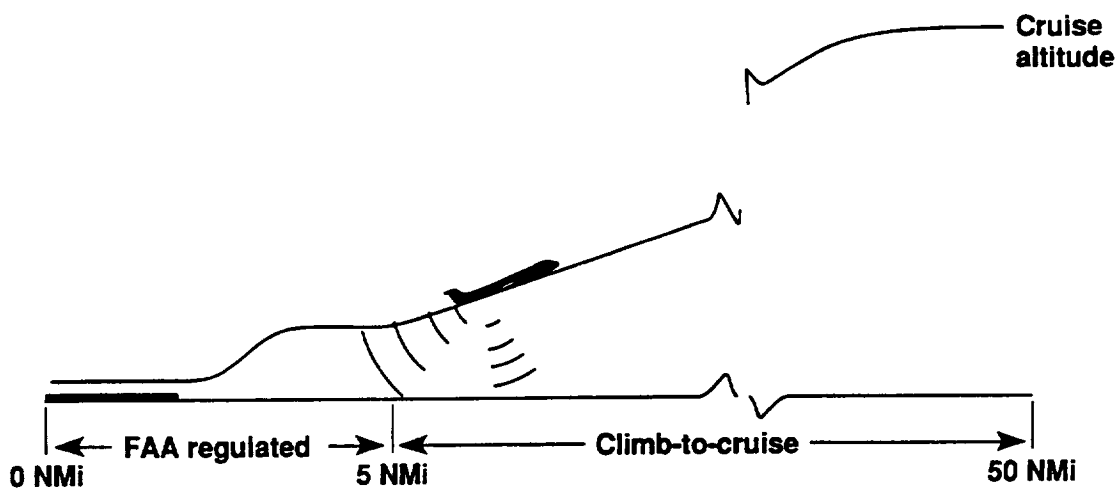
TEST PROCEDURES

DATA-PREDICTION COMPARISONS

HSCT CLIMB NOISE

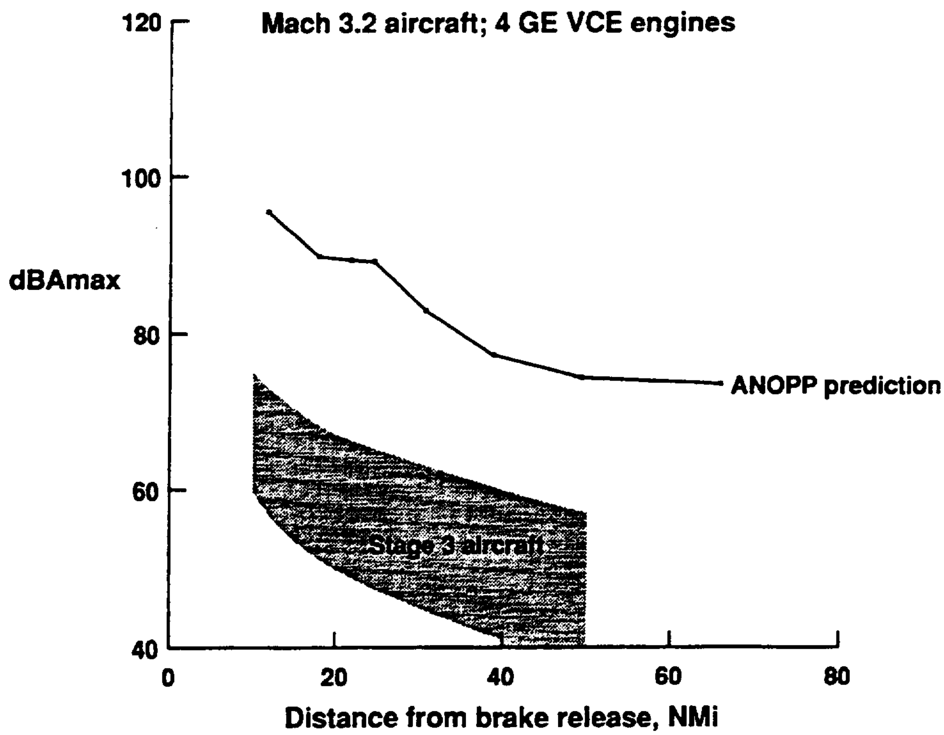
SUMMARY

CLIMB-TO-CRUISE NOISE



The initial focus of the HSCT suppressor nozzle design was to achieve a 20 dB noise reduction relative to the unsuppressed noise level of a TBE type engine. This would allow the HSCT to meet FAR 36 Stage 3 noise certification requirements at sideline. The design approach also assumed that the suppressor will be retracted soon after takeoff in order to minimize performance losses. Preliminary analyses performed at McDonnell Douglas, however, revealed that some noise suppression may be necessary even beyond 5 miles (and up to 50 plus miles) from the airport in order for the HSCT to be no more noisier than the current Stage 3 subsonic fleet at the farther out communities.

ANOPP PREDICTIONS OF HSCT CLIMB-TO-CRUISE NOISE



The climb-to-cruise noise predictions (using ANOPP) for a Mach 3.2 HSCT with four VCE engines are shown along with a band covering the corresponding noise levels of modern Stage 3 subsonic airplanes. Notice that the predicted HSCT noise (in maximum A-weighted level) is at least 20 dB higher than the subsonic airplane noise. The confidence or the accuracy of the HSCT noise predictions are unknown due to the facts that the noise methodology is based on a lower flight Mach number, nozzle pressure ratio and temperature data base and is not validated for high flight Mach numbers, nozzles pressure ratios and temperatures. High climb noise may force a suppressor nozzle design redirection or the need to leave the suppressor deployed for a longer time after takeoff (assuming it is still effective acoustically). It is, therefore, necessary that an experimental data base of noise generated by supersonic jets at high flight Mach numbers be developed that will permit a better assessment of HSCT climb noise.

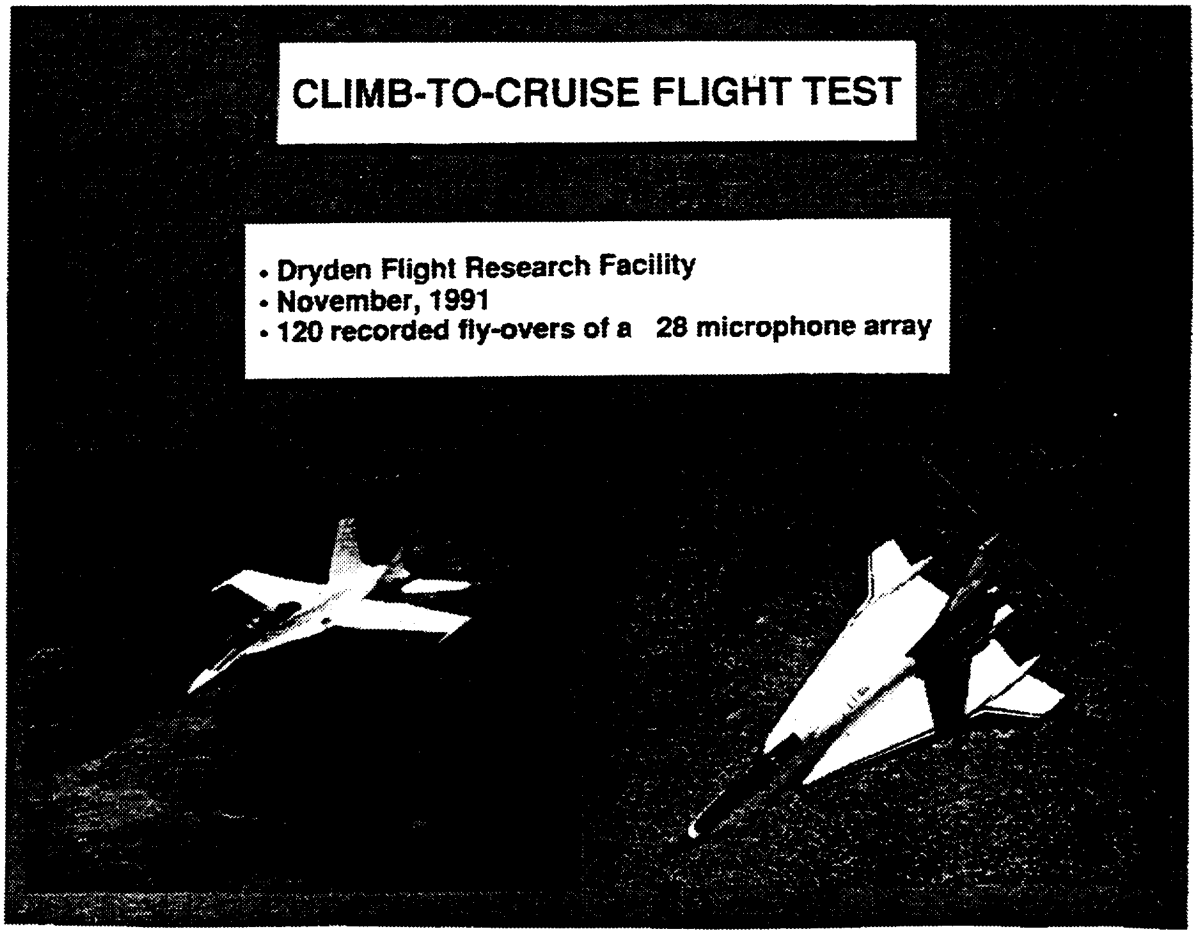
CLIMB-TO-CRUISE NOISE TEST

TEST OBJECTIVES

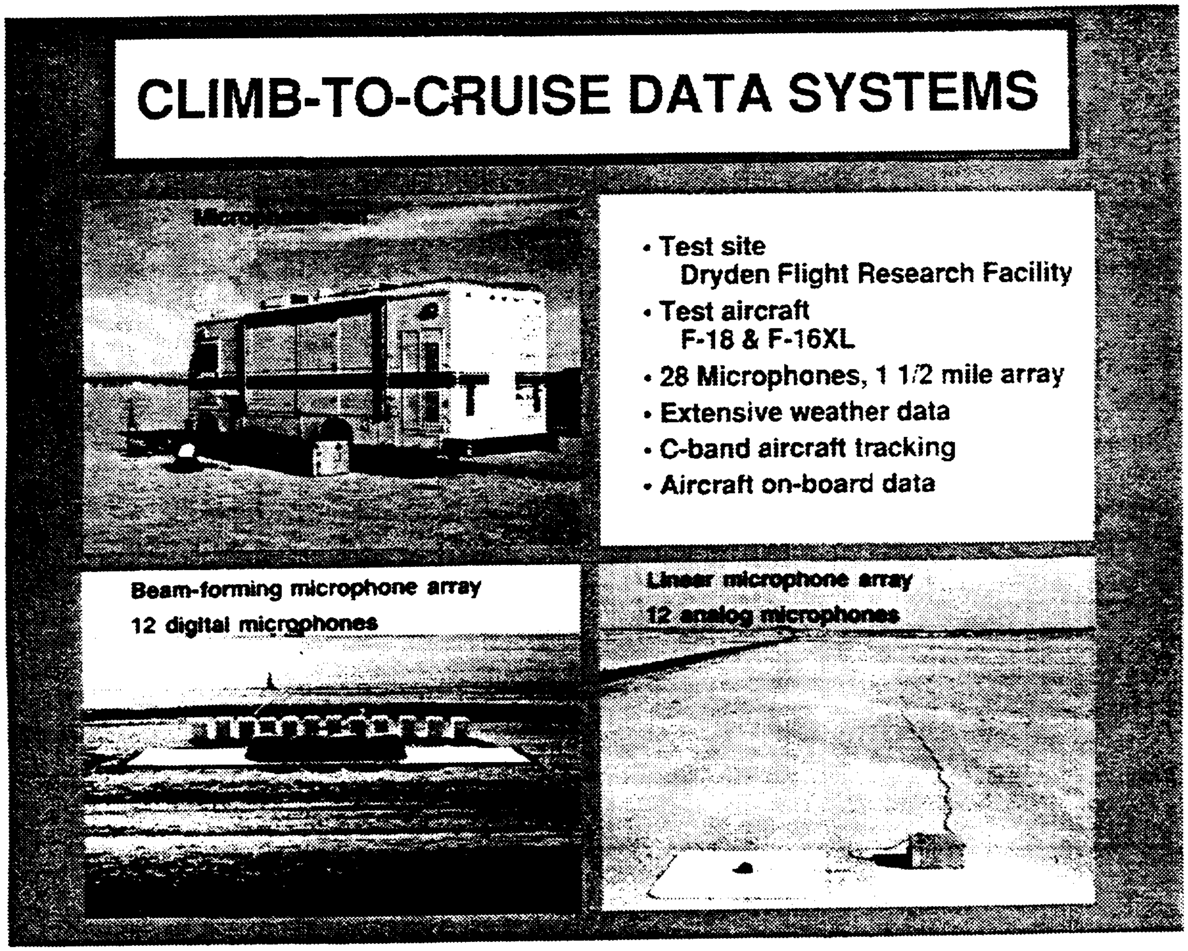
(1) Perform flight test(s) to assess HSCT subsonic climb noise using aircraft/engine with high NPR, temperature, and flight speed capabilities.

(2) Obtain a quality noise database to validate ANOPP and other system noise prediction codes at high NPR, temperature and flight speed.

Upon the recommendation of the HSR Source Noise Working Group an acoustic flight test was planned and performed by NASA Langley with two test objectives: 1) to obtain test data at conditions typical of HSCT during climb in order to assess HSCT climb noise and 2) to obtain a noise database at high NPR, NTR and flight Mach numbers in order to validate ANOPP methodology.

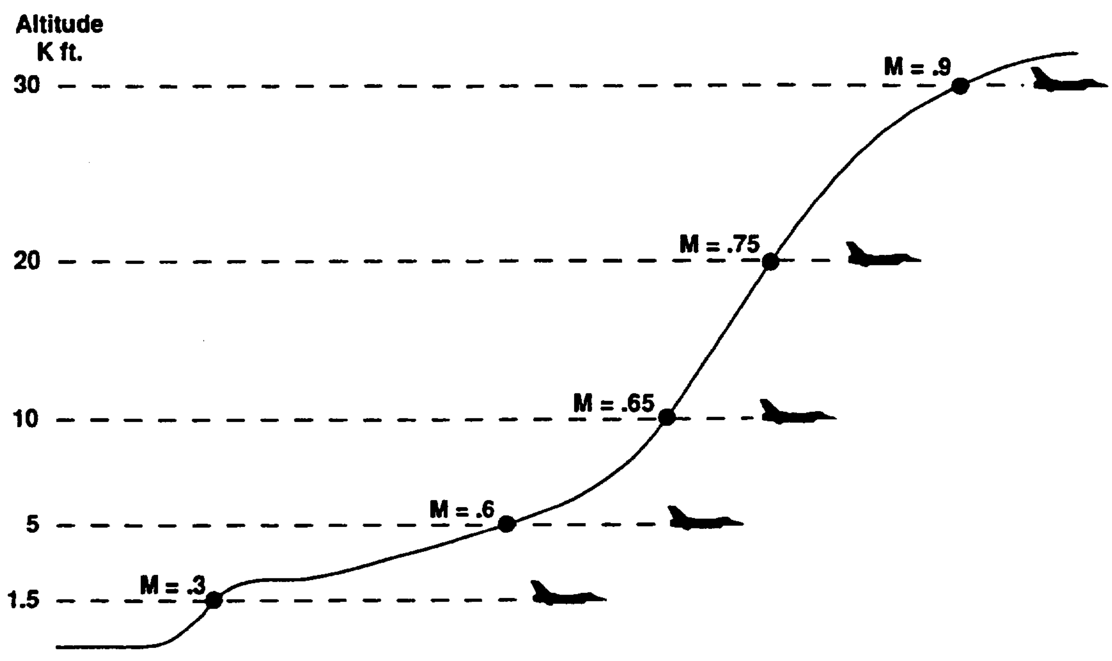


The test was performed using the F-18 and F-16XL aircraft at Dryden Flight Research Center in November 91. The F-18 is powered by two F404-400 engines which have approximately 10 percent lower Vj than VCE engines. The F-16XL is powered by a single F110-IPE engine and has a Vj approximately 10 percent higher than the Flade engine.



The data system included two microphone arrays for noise measurement under the flight path. One was a digital array for quick look analysis and another was a linear microphone array consisting of 12 microphones spaced 350 feet apart. The primary purpose of using an array is to be able to ensemble average the signals in order to improve the accuracy and statistical confidence of the measurements. The data from these microphones were recorded on analog tape for later analysis using the NASA Langley ADRAS system. At the test site extensive weather data was obtained using tethered weather balloon, rawindsonde balloon, and two 30 ft weather towers. The aircraft position during the flight was recorded using C-band beacon tracking system. The on-board data system recorded the engine and airplane operating parameters. The F-16XL had a true data system but the F-18 system was only a maintenance system and recorded data only when an event occurred.

CLIMB-TO-CRUISE FLIGHT TEST PROCEDURE



The test procedure included constant speed level flyovers at several altitudes, flight Mach numbers and engine conditions representative of an HSCT during climb-to-cruise. For evaluation of the noise prediction methodology in ANOPP, flyovers at a constant 1500 ft altitude but different flight Mach numbers were planned.

CLIMB-TO-CRUISE TEST MATRIX

- **FULL-SCALE HSCT PARAMETERS MATCHED: ALTITUDE, AIRCRAFT MACH NO., JET VELOCITY (±10%), NOZZLE PRESURE RATIO (3.1 TO 3.5)**

ALT, FT AGL	MACH	# F-18	# F-16 XL
1500	.3	8	9
5000	.6	13	2
10000	.65	15	1
20000	.75	13	
30000	.9	7	
	TOTAL RUNS	56	12

ANOPP TEST MATRIX

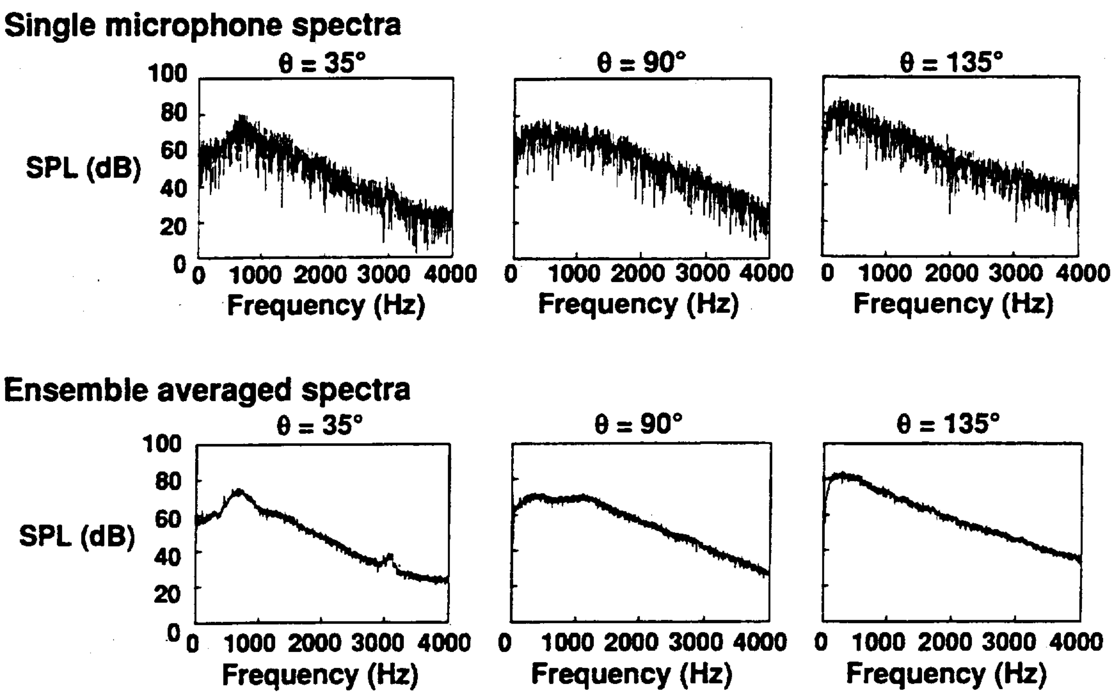
- **REQUIRED POWER FOR LEVEL FLIGHT (SECOND ENGINE AT FLIGHT IDLE).**

ALT, FT AGL	MACH	# F-18	# F-16 XL
1500	.3	5	2
1500	.6	6	2
1500	.8	6	2
1500	.95	2	2
	TOTAL RUNS	19	8

The test matrix with target conditions for the climb-to-cruise and ANOPP validation phases of the test program are shown here. Majority of the data were obtained using F-18. One engine was set at the required power for level flight while the second engine was at flight idle. The F-16XL powered by a single high thrust engine experienced significant acceleration during the low altitude climb to cruise flights. To minimize angular smearing and improve data accuracy these flights were conducted in two passes. In one pass, the aircraft got on target conditions approximately 2 to 4 miles upstream of the microphone array. In the second pass the aircraft got on target conditions just above the microphone array.

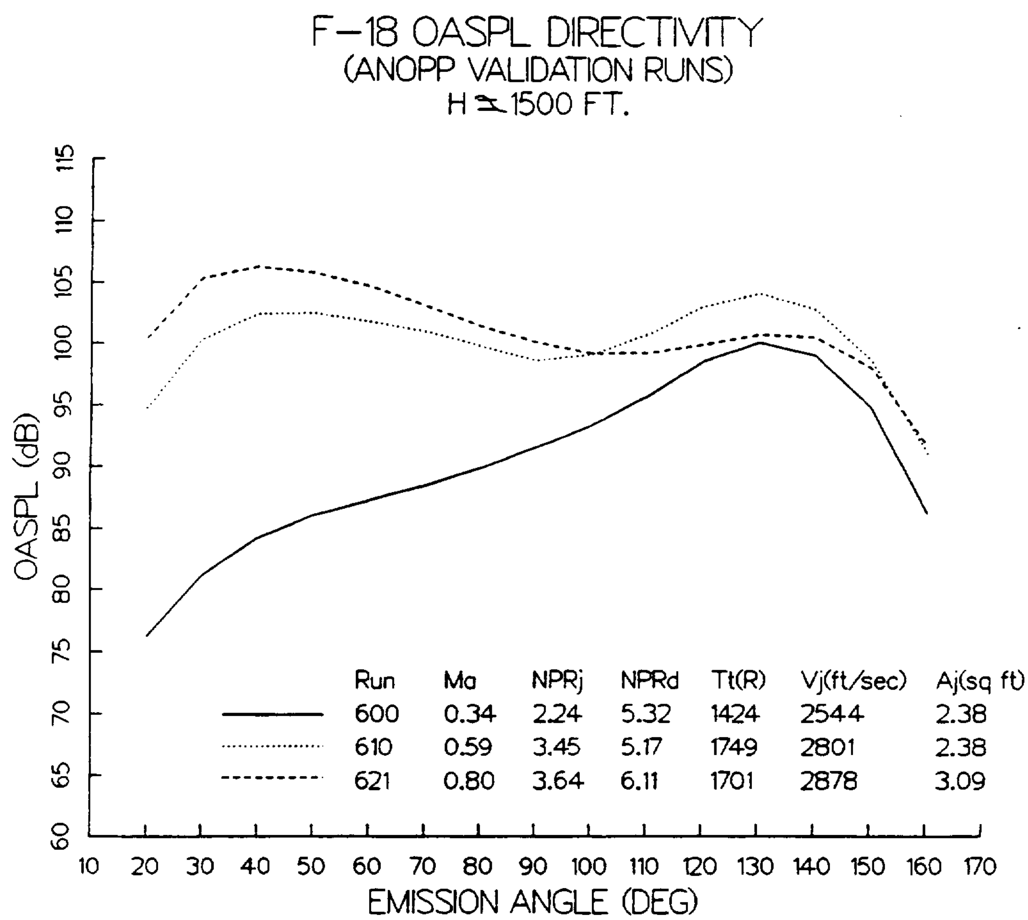
ENSEMBLE AVERAGING OF MICROPHONE DATA

CLIMB TO CRUISE FLIGHT TEST F-18 SPECTRA
Mach 0.3 at 1500 Feet



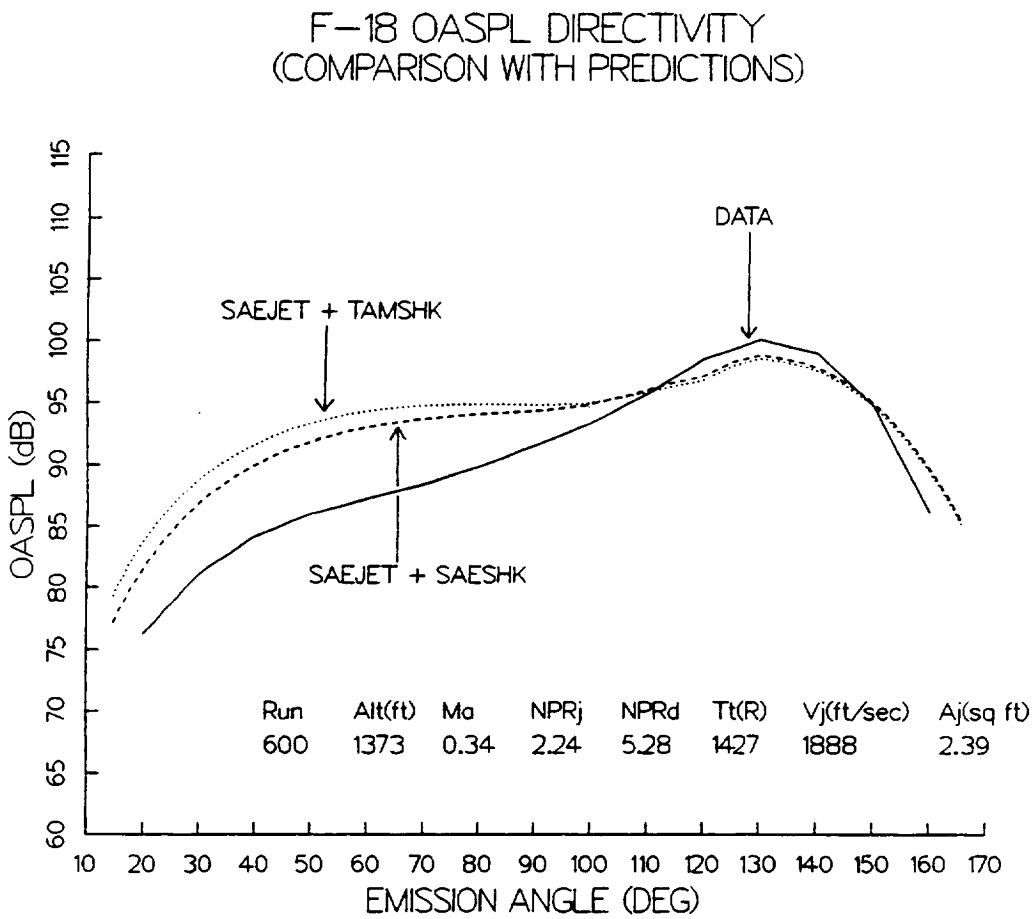
These data show the advantage of using the linear microphone array. The single microphone data have lot of variation in SPLs in adjacent frequencies indicating low statistical confidence. Ensemble averaging significantly improves the accuracy of the measurements.

MEASURED OASPL DIRECTIVITIES



Only selected F-18 data have been analyzed to date. Results of the ANOPP validation runs (600 series) are presented first. At the lowest flight Mach number (M = 0.34) and slightly supercritical nozzle pressure ratio NPR = 2.24 the OASPL directivity is observed (Run 600) to be dominated by the jet mixing noise with the rear arc noise level exceeding the forward arc noise levels by 15 dB. (Unfortunately, noise data at the same NPR but higher flight Mach numbers could not be obtained.) As the flight Mach no. is increased to 0.59 and the nozzle operation is made significantly more supercritical (NPR = 3.45; Run 610), shock noise increases significantly. In the corresponding OASPL directivity, the sound levels in the forward arc (shock noise) and in the rear arc (jet mixing noise) are nearly equal. As the flight Mach no. is further increased to M = 0.8 (Run 621) the shock noise in the forward arc increases. The noise level in the forward arc is now higher than the level in the rear arc.

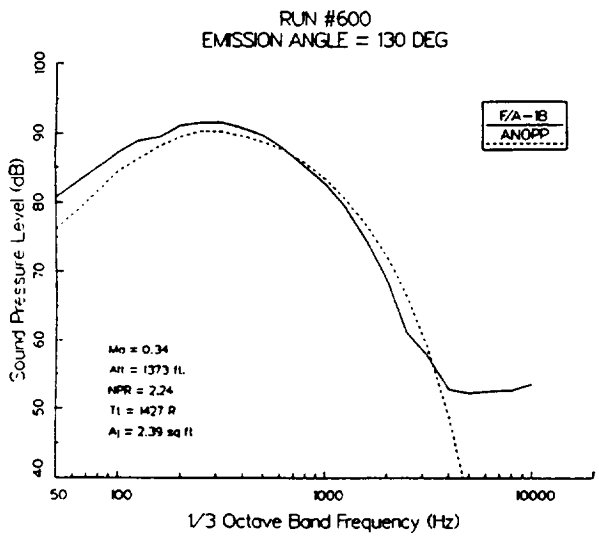
MEASURED OASPL DIRECTIVITIES COMPARED WITH ANOPP-PREDICTIONS

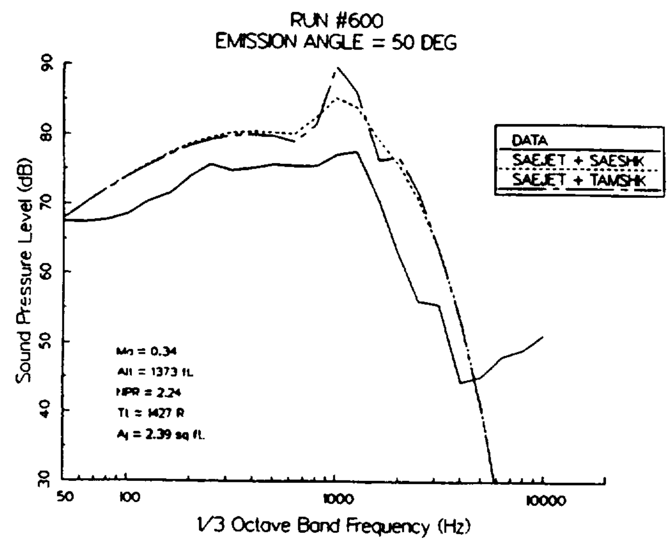


The next several charts show a comparison of the measured flyover noise data (both directivity and one-third octave band spectra) with predictions based on ANOPP. The jet mixing noise was predicted using the SGLJET module based on the SAE ARP 876 methodology. The shock noise was predicted using two different modules - SAESHK based on SAE method and TAMSHK based on Tam's recent theory for a supersonic jet in forward flight. The spectral comparisons are shown at 130 degrees and 50 degrees from inlet to evaluate both mixing and shock noise comparisons. For the low flight Mach no. and slightly supercritical nozzle pressure ratio case (Run 600) the mixing noise prediction (rear arc) is in good agreement with data. But the shock noise is over predicted by 5 dB using SAESHK and by 7 dB by using TAMSHK. The C-D nozzle was operating overexpanded for most flyovers in this test; the predictions therefore used the nozzle throat area and NPR. The significant over prediction of shock noise for this slightly overexpanded nozzle condition is surprising.

MEASURED AND PREDICTED SPL SPECTRA

F–18 SPL SPECTRUM
(COMPARISON WITH PREDICTIONS)



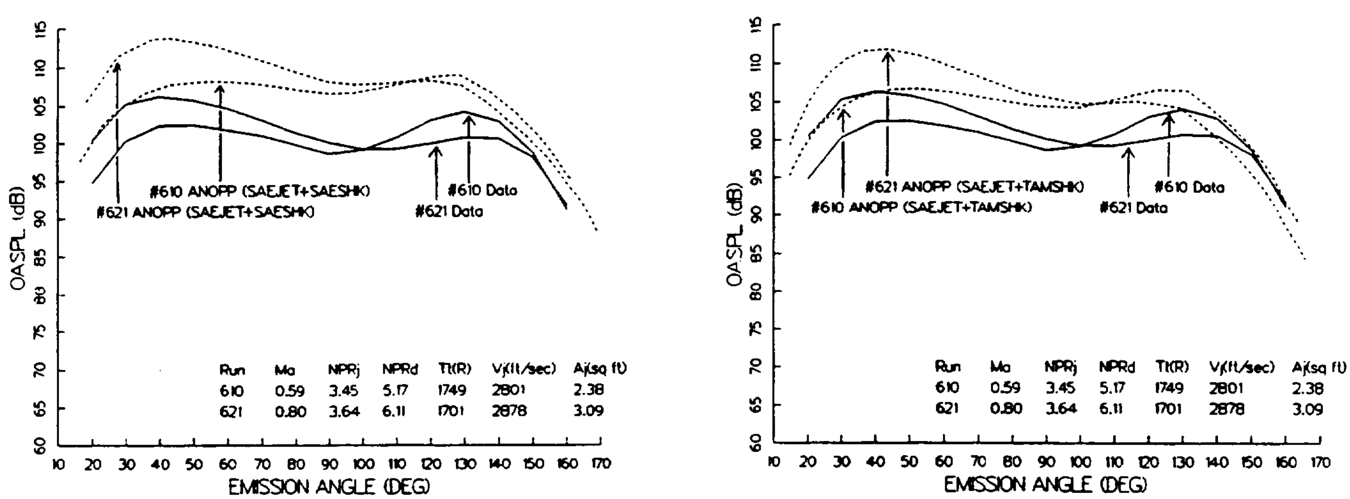


As would be expected from the OASPL comparison the predicted spectrum in the rear arc (O = 130 degrees) compares well with measurements. This validates the mixing noise prediction methodology at this low flight Mach number.

The predicted spectra in the forward arc (O = 50 degrees) have the general shape of the measured data but the peak SPL is overpredicted by 7 dB (SAESHK) and by 10 dB (TAMSHK). The peak frequency in the predicted spectra seems to be one one-third octave band lower. Near the spectrum peak TAMSHK predictions also include additional peaks and valleys.

MEASURED OASPL DIRECTIVITIES COMPARED WITH PREDICTIONS

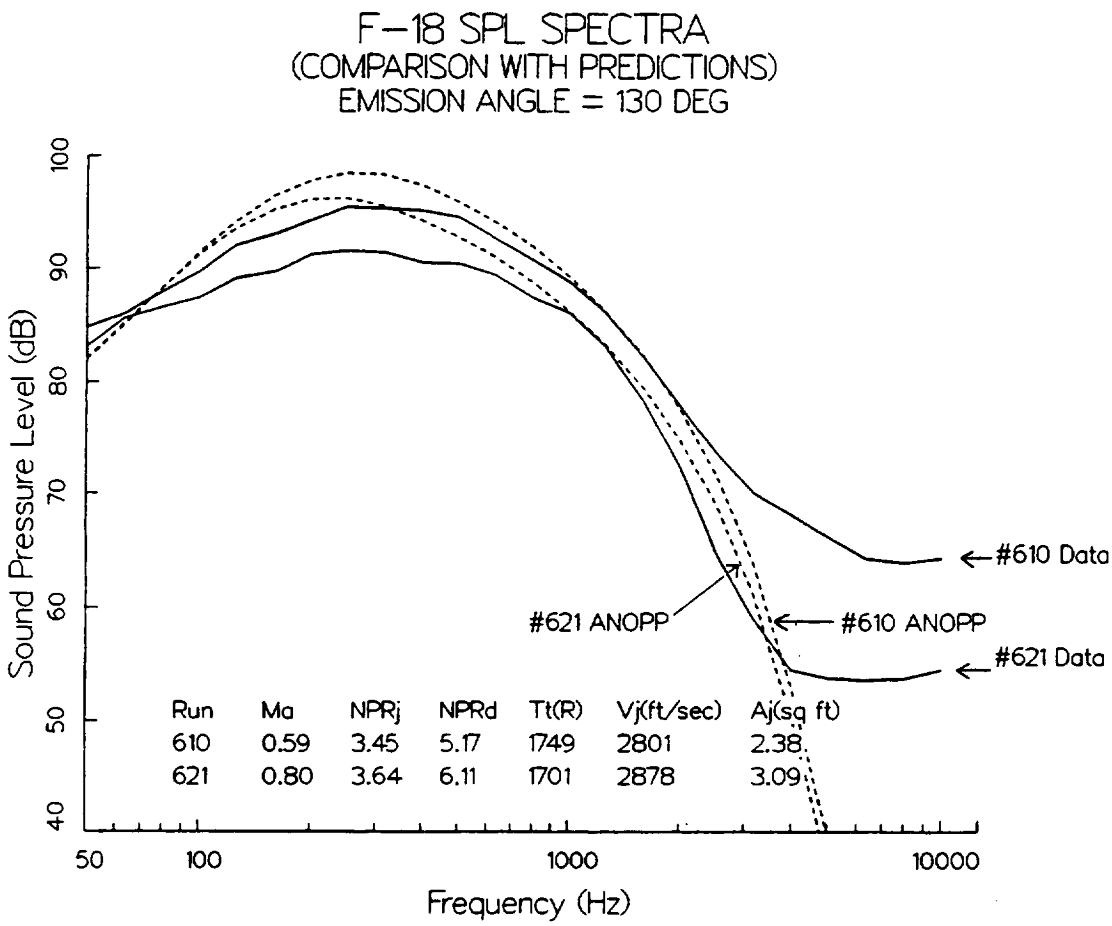
F–18 OASPL DIRECTIVITY
(COMPARISON WITH PREDICTIONS)



Runs 610 and 621 have very similar engine conditions but the flight Mach numbers are different (0.59 and 0.80). Data show that when the flight Mach no. is increased, the peak OASPL in forward are increases by 4 dB (more shock noise amplification) and the peak OASPL in the rear arc decreases by 3 dB. The changes predicted by the SAE procedures are 6 dB increase in forward arc and 1 dB decrease in rear arc. The absolute levels from predictions are up to 7 dB higher than data.

Similar trends are also seen in the predictions using TAMSHK. The maximum OASPL level is overpredicted by 5 dB.

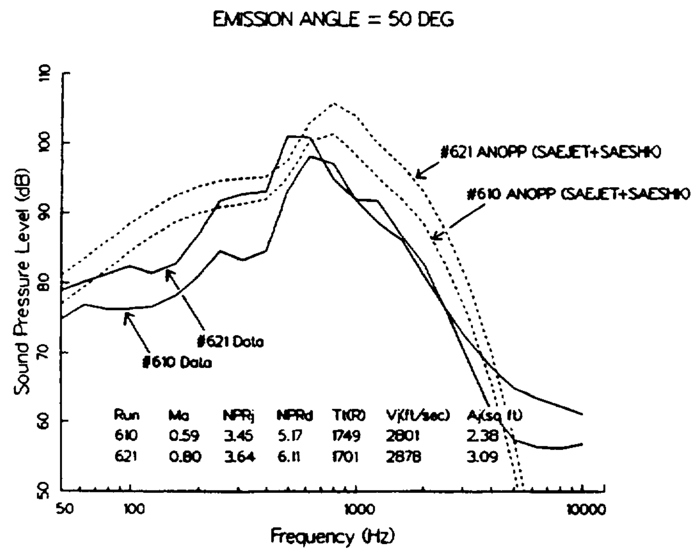
MEASURED AND PREDICTED SPL SPECTRA AT 130 DEG

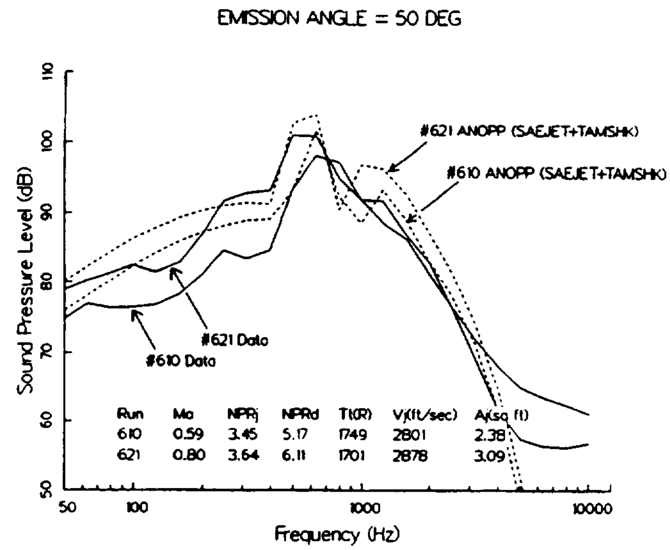


The spectral comparisons also show the SPLs at 130 degrees decreasing with increasing flight Mach number. The predicted absolute levels are again higher than data, and the predicted changes due to changes in flight Mach no. are lower. The general shapes of the predicted and measured spectra are in fair agreement.

MEASURED AND PREDICTED SPL SPECTRA AT 50 DEG

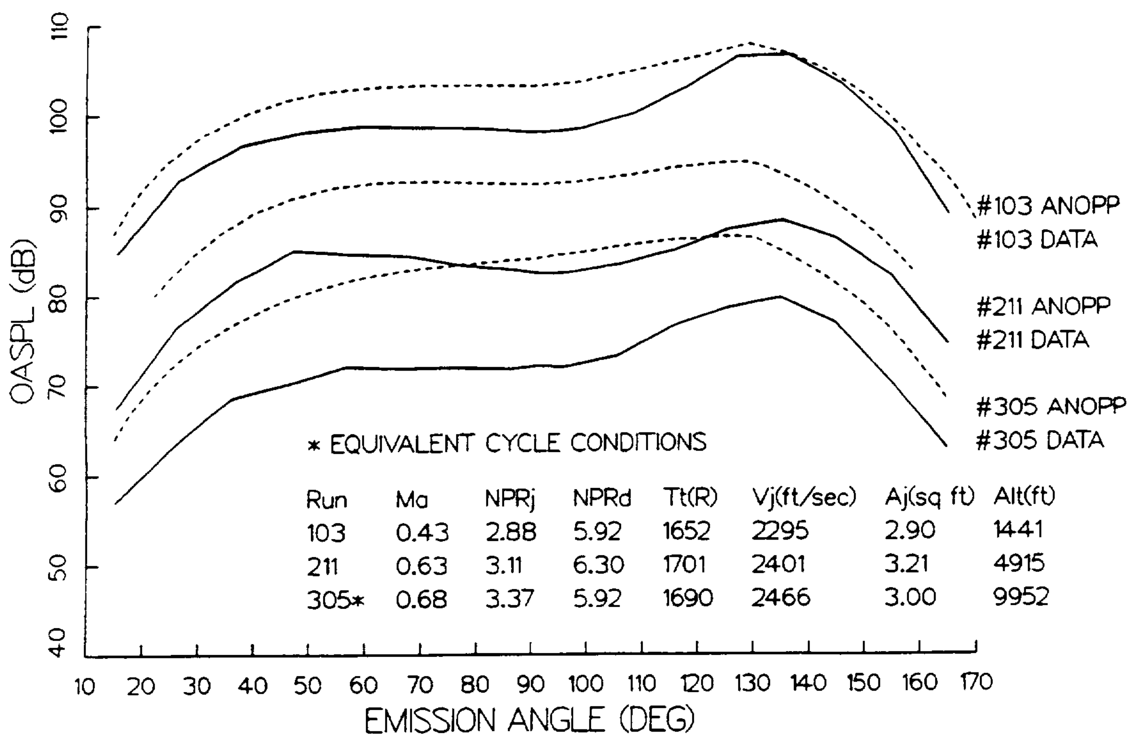
F–18 SPL SPECTRA
(COMPARISON WITH PREDICTIONS)





In the forward arc (O = 50 deg) the comparison between the SAESHK based predictions and data reveal both the overprediction as well a higher predicted peak frequency. Using TAMSHK the predictions are in better agreement with data both in amplitude (less than 5dB overprediction in peak SPL) and peak frequency.

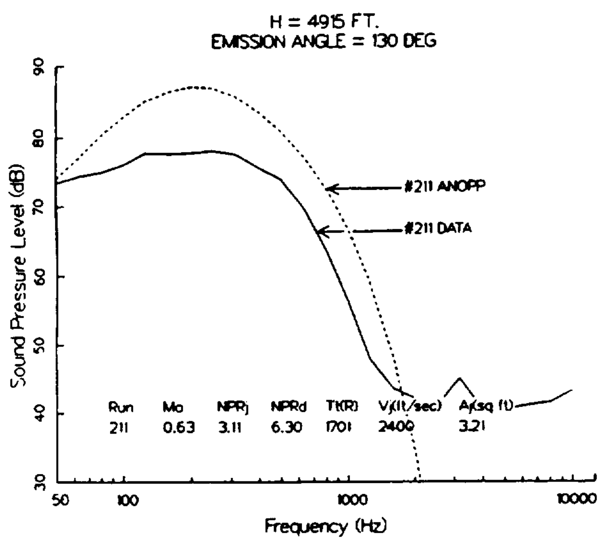
CLIMB TO CRUISE NOISE DIRECTIVITIES
DATA VS. ANOPP PREDICTIONS

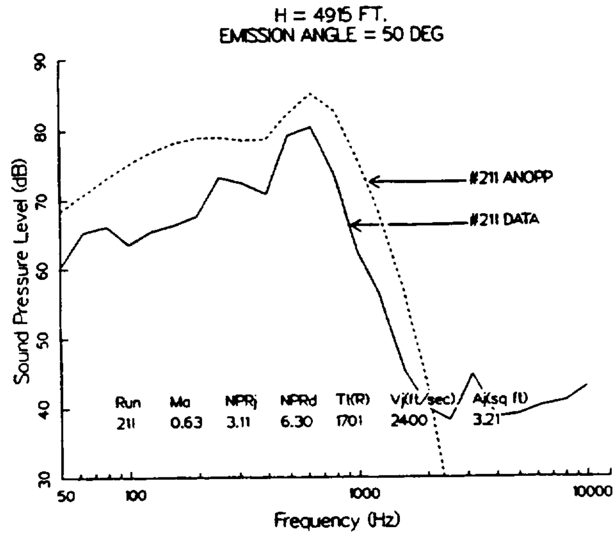


The climb to cruise runs analyses is now presented. The measured OASPL directivity for three flyovers at approximately 1500, 5000 and 10000 ft (and at conditions representative of HSCT climb) show the large effect of spherical divergence with increasing altitude. But the peak level measured for the high flight Mach number (M = 0.68) run is still in the rear arc indicating dominance of jet mixing noise and either lower than expected shock noise or greater than expected absorption of high frequency broadband shock noise during propagation thru the atmosphere.

The ANOPP predictions for these runs show fair agreement with data for the low NPR, low altitude and low flight Mach no. run but increasingly greater overprediction of shock noise for the higher NPR, higher flight Mach no, higher altitude runs. Additional data need to be analyzed to determine if the differences are primarily due to the flight Mach number, NPR or atmospheric absorption.

F–18 CLIMB NOISE SPECTRUM
(COMPARISON WITH PREDICTIONS)





SPL spectral comparisons for the 5000 ft run show an overprediction in levels but generally agreeable spectrum shape. If atmospheric absorption was not accounted for properly, we would expect increasingly larger differences (between data prediction) with increasing frequencies and increasing altitude.

F-18 TO HSCT SCALING PROCEDURE

1. F-18 SPL NARROW BAND SPECTRA
2. SHIFT SPECTRA TO HSCT FREQUENCIES

$$F_{HSCT} = F_{F\text{-}18} \frac{D_{F\text{-}18}}{D_{HSCT}} \frac{V_{jHSCT}}{V_{jF\text{-}18}}$$

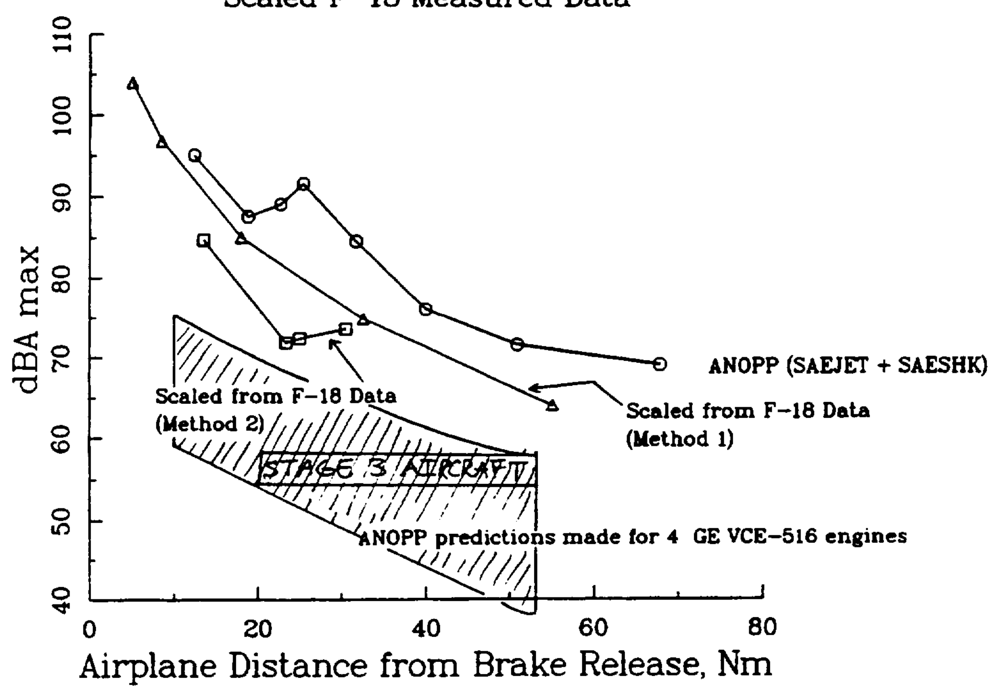
3. CONVERT TO ONE-THIRD OCTAVE SPECTRA
4. CORRECT SPL FOR ABSORPTION DIFFERENCE DUE TO FREQUENCY SHIFT AND DIFFERENT ALTITUDE
5. CORRECT SPL FOR DIFFERENCES IN
   - NO. OF ENGINES
   - JET EXIT VELOCITY AND DENSITY
   - NOZZLE AREA
   - AIRCRAFT ALTITUDE
   - AMBIENT RHO * C
6. APPLY A-WEIGHTING
7. FIND MAXIMUM dBA

One of the main objective of this test program was to obtain a data base that includes noise measurements at high flight Mach no., NPR and altitude and to scale these measurements to HSCT conditions in order to obtain a better assessment of the HSCT climb noise. The scaling procedure is outlined here. It includes scaling to HSCT frequencies and adjusting the amplitude for absorption differences as well as differences in F-18 operating conditions and HSCT operating conditions.

Two slightly different scaling approaches were used. In method 1 (intended for a quick assessment based on initial data), the F-18 data at a given altitude was used as the starting point and corrections were made for Vj and altitude differences but not for flight Mach no,. differences. In method 2, F-18 data at a specified flight Mach no. was used as the starting point (in order to properly capture the flight effects in the baseline) and corrected for altitude and Vj differences.

CLIMB–TO–CRUISE NOISE PREDICTIONS

Comparison of ANOPP Predicted Maximum
A–Weighted Noise Levels with
Scaled F–18 Measured Data



The HSCT climb noise levels as scaled from the F-18 database are shown here. The levels are lower than originally predicted but still higher than the corresponding levels for the current Stage 3 fleet. Furthermore the scaling is based on a very limited database with the F-18 C-D nozzle operating at overexpanded conditions and if the corresponding HSCT is operating underexpanded, the validity of the scaling needs to be examined. Clearly further analysis is required using the other F-18 data to establish the validity. Another concern is the F-16XL database (because of a high thrust single engine configuration) has several flyovers in which the airplane accelerates significantly during the run.

SUMMARY

- ANALYZED LIMITED DATA FROM F-18 CLIMB-TO-CRUISE AND ANOPP VALIDATION FLIGHT TEST
- MAX OASPL PREDICTIONS IN THE FORWARD ARC HIGHER THAN DATA BY UP TO 8dB
- FLIGHT AMPLIFICATION OF SHOCK NOISE IN MEASURED DATA IS LESS THAN PREDICTED BY ANOPP METHODS
- F-18 CLIMB NOISE DATA SHOW MAX LEVELS TO BE DUE TO MIXING NOISE
- HSCT CLIMB NOISE (SCALED FROM F-18 DATA) STILL HIGHER THAN STAGE 3 FLEET NOISE BUT LOWER THAN PREDICTED BEFORE
- ADDITIONAL ANALYSIS REQUIRED USING OTHER F-18 RUNS AND F-16XL RUNS

Flight tests were conducted using F-18 and F-16XL aircraft to acquire supersonic jet noise data at (i) conditions representative of an HSCT in climb to subsonic cruise in order to improve assessment of HSCT climb noise and (ii) 1500 ft altitude but different flight Mach numbers in order to validate ANOPP jet and shock noise prediction methodology. Analyses of limited data and comparison with ANOPP predictions (using SAE mixing noise, SAE shock noise and TAM shock noise methodologies) indicate that the ANOPP methods overpredict the maximum shock noise as well as the amplification of shock noise by increased flight speeds. F-18 climb noise data when scaled up to full scale HSCT indicated the HSCT in subsonic climb to be nosier than current Stage 3 aircraft but lower than ANOPP predictions. In most flights the F-18 was found to be operating with an overexpanded C-D nozzle. Analyses using data from other F-18 and F-16XL flights is required to properly quantify the flight effects, the accuracy of the predictions, and HSCT climb noise.