AIAA 81-2398R

Advanced Facility for Processing Aircraft Dynamic Test Data

D. J. Stouder*
Douglas Aircraft Company, Long Beach, California

An advanced facility has been developed to meet future requirements for processing aircraft dynamic test data. Although originally designed to process noise and vibration data, this facility has been steadily expanded over the past several years and is used increasingly more to process a variety of dynamic data. For example, the Data Center has been used to process test data describing wind tunnel turbulence, full and model scale aircraft flutter, and electrical systems transients. The capabilities of this facility are described using examples from a variety of flight and laboratory tests of commercial and military transport airplanes.

Introduction

THE costs of flight-testing a new commercial or military jet transport have increased dramatically during the past several years. This same period has also seen an increased need for larger quantities of data to be analyzed with improved accuracy and provided to the end user without delay. Fortunately, improvements in data processing hardware, software, and analysis techniques have helped to meet these needs while holding rising costs in line. As part of this effort, the Douglas Aircraft Company has developed an advanced dynamic data processing facility. This facility is called the Acoustics and Vibration Data Center (AVDC).

The AVDC was originally designed during the early 1970s to process noise and vibration data from flight and laboratory tests. However, during the past several years, the data center capabilities have been steadily expanded and used increasingly more for processing a variety of dynamic data from other engineering disciplines. For example, the AVDC has been used to process test data describing wind tunnel turbulence, full- and model-scale flutter, airplane electrical system transients, and other types of dynamic data. These analyses have been done in both the frequency and time domains.

This paper describes the capabilities of the facility, using examples from a variety of flight and laboratory tests related to commercial and military jet transports. Also discussed are future improvements in the data center that will increase its efficiency and capability to meet processing needs throughout the 1980s.

Facility Description

Figure 1 is a photograph of the AVDC showing its general arrangement. Because the analysis of noise, vibration, and other dynamic data generally involves some form of spectrum analysis or paired-signal Fourier analysis, the AVDC contains four independent spectral data processing systems or work stations, as shown in the photograph. Each of these systems has its own unique capabilities.

Since test signals to be processed are generally contained on multiple-channel analog magnetic tape, each system contains its own multiple-channel tape transport system. However, extensive signal patching capabilities exist which, if required, allow a given system to utilize a tape transport normally assigned to another system. Figure 2 is a block diagram of the four data processing systems, showing major individual components and the signal patching network. The input signals can also be obtained from portable instrumentation tape recorders that have various tape channel and playback configurations.

Three of the four systems are computer controlled, with the fourth system manually operated by the user. The computer-controlled systems can transfer analyzed digital data and programs back and forth using a computer bus-routing system and selected shared peripherals. In addition, each system has its own input signal conditioning components, special-purpose analyzers, data monitoring devices, and data output displays as shown in Fig. 2.

Adjacent to the main facility is the audio presentation room (APR), where high-quality audio playback of acoustical data, for listening and for analog tape duplication, takes place. The following paragraphs more fully describe the individual systems and the APR.

One-Third-Octave-Band Spectrum Analysis

Measurement of noise characteristics has become a significant part of the flight-test program for any new or modified jet transport. These noise measurements include both the interior noise levels to which the crew and passengers are exposed and the flyover noise levels heard by airport neighbors during takeoff and landing operations. The noise intensity and annoyance parameters on which customer guarantees and U.S. and international noise regulations are based are generally derived from one-third-octave-band spectrum levels.

The controlled integrating spectrum analyzer (CISA-2) was designed to process large quantities of acoustical data requiring one-third-octave-band analysis. The digital controller for CISA-2 shown in Fig. 2 is a DEC PDP-11/34 minicomputer. Data processing on CISA-2 is highly

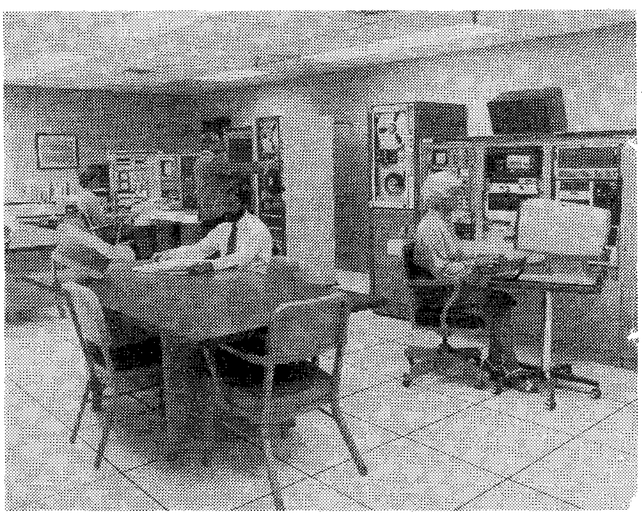

Fig. 1 Acoustics and Vibration Data Center.

Presented as Paper 81-2398 at the AIAA/SETP/SFTE/SAE/ITEA/IEEE 1st Flight Testing Conference, Las Vegas, Nev., Nov. 11-13, 1981; submitted Dec. 10, 1981; revision received March 10, 1982.

*Unit Chief, Flight Test Acoustics and Vibration Data Processing. Member AIAA.

automated, and the operator interacts with the system using a menu-driven dialog with the controller. Computer-controlled features include analog tape search (using the recorded IRIG-B time code signal on the data tape), tape channel selection, decoding of recorded transducer gain information, and optimization of the input signal level to the spectrum analyzer display.

The operator has a choice of two real-time spectrum analyzers, as shown in Fig. 3. Both analyzers provide CISA-2 with the capability of efficiently analyzing stationary or transient acoustical signals using a variety of data averaging times for one-third-octave-band center frequencies from 12.5 Hz to 80 kHz. Higher frequency analysis is possible using appropriate analog tape playback speed reduction. The system has been optimized to process airplane flyover noise data per the latest requirements of U.S. and international aircraft noise regulations. The flexibility of CISA-2 is enhanced by the high-level program language (BASIC) that controls the minicomputer. The use of BASIC allows the software to be easily modified to meet unique data requirements. Assembly language driver routines are used where processing speed is essential, such as in sampling spectrum analyzer output.

There are two operating modes available on CISA-2. In the first mode, a digital tape containing the spectral levels is the primary output. This output is used when extensive follow-on processing in a large-scale computer is required. The one-third-octave-band sound pressure levels from the spectrum analyzer are written onto a computer-compatible digital tape. This mode is primarily used for airplane flyover noise processing. The CISA-2 digital tape is input to a large-scale computer program along with other digital tapes containing airplane performance and space position data. This program applies certain additional corrections to the spectral levels contained on the CISA-2 digital tape, adjusts the flyover noise levels to reference airplane and weather conditions, and then outputs the results in tabular and graphical form. A digital tape containing the measured flyover noise levels merged with airplane performance and space position data is also generated. Figure 4 shows a flow diagram of this data cycle. As can be seen, the processing on CISA-2 is the first of several processing steps. Reference 1 describes the complete flyover noise cycle in more detail.

In the second mode, the analyzed noise levels are output in tabular or graphical format. This mode is primarily used to process data from those flight or laboratory noise tests which result in essentially stationary data. One type of data processed in this manner is airplane interior noise. Figure 5 is an example of the tabular output from an interior noise survey conducted on a current jet transport. The output includes header information, one-third-octave-band sound pressure levels (SPL), the overall SPL, the A-weighted level, the speech interference level, and optional full-octave SPL's. Figure 6 is an example of the graphical output available in this mode. Although the graph shows only a single spectrum, multiple spectra can be plotted on the same graph, each with its own line code. Both the tabulation and the plot are fully annotated, as shown.

Although the online processing mode of CISA-2 is normally used for stationary data, it can also be used to study time-varying data. For example, Fig. 7 is a three-dimensional (frequency-amplitude-time) display of a jet transport flyover noise recording during landing approach. This type of display is very useful for studying the time/frequency variations of a complex time-varying signal. One very useful feature of this type of display is that it can be rotated and viewed from any of the four numbered corners shown on the plot, without reprocessing the data. In addition to the analysis programs available on CISA-2, system performance validation and monitoring programs are also available and routinely used. These programs check all of the major components of CISA-2, including the spectrum analyzers.

Narrow-Band Spectrum Analysis

One-third-octave-band spectrum analysis often does not provide sufficient frequency resolution for analyzing environmental vibration or other dynamic data. This is especially true when the source of the phenomenon is being studied. For these types of analyses, narrow-band spectrum analysis with constant bandwidth filters is required. The Controlled Real-Time Analysis System (CORTAS) has been designed specifically to perform this type of analysis. Like CISA-2, CORTAS is controlled by a DEC PDP-11 minicomputer. The computer is programmed using a combination of assembly language driver routines where speed is essential, and a high-level language (FOCAL) for flexibility. The user interacts with CORTAS in a similar manner as with CISA-2, using a question and answer dialog. Figure 8 is a photograph of CORTAS.

The narrow-band spectrum analyzer used in CORTAS employs time compression techniques to output a 500-point spectrum at a maximum rate of 20 spectra per second. The analyzer is capable of handling data over various frequency ranges, from 10 to 50 kHz. The frequency resolution, and thus the effective filter bandwidth, is a function of the analysis range selected. For example, when the analyzer is set on the 10-Hz frequency range, the effective filter bandwidth is 0.03 Hz (0.02-Hz resolution). When the 50-kHz range is selected, the bandwidth is 150 Hz (100-Hz resolution).

The primary outputs of CORTAS are fully-annotated narrow-band spectrum plots. Figures 9 and 10 are examples of two types of plots that can be made by this system. Figure 9 is a narrow-band acoustic spectrum of data recorded at the Douglas Anechoic Acoustic Test Facility during a jet noise reduction test program. (This program evaluated the acoustical performance of several model-scale porous plug nozzles for potential use in a future advanced supersonic transport aircraft.) The units used are sound pressure levels in decibels (dB relative to 20 μPa). Figure 10 is a narrow-band spectrum plot of acceleration vs frequency. The data are from an evaluation of the random motion of an aerial device. Note that the plot format is quite similar to that of Fig. 9. The general layout of the header data block is used for most of the plots produced in the data center, resulting in improved software maintenance and easy readability. Standard layouts allow the user to know where to look for a particular piece of information.

Although the general plot formats are the same for all data processed on CORTAS, the dependent variable can be anything desired. Several of the most common units have been preprogrammed, but additional ones can easily be added because of the high-level programming language used by CORTAS. The plots produced by CORTAS, including those of Figs. 9 and 10, are made on an electrostatic plotter with a resolution of 200 points per inch. During CORTAS processing, the spectral levels and header data for each plot are stored on a flexible disk for later plotting. These stored data are then plotted in batches. This method not only provides for efficient, automatic plotting but also allows additional processing or error correcting without reanalyzing the data.

The flexibility of CORTAS extends beyond multiple plot forms. For example, various corrections can be applied to the data, including corrections for system frequency response, removal of background noise, and amplifier gain changes. Table 1 summarizes these and other basic capabilities of CORTAS. CORTAS can also be used to perform specialized analyses on airplane flyover noise data. One such analysis is source-band tracking; another is the merging of narrow-band spectral-level histories with airplane performance and space position data onto a computer-compatible tape for follow-on processing. Reference 2 discusses these techniques in more detail.

The Selective Analog Filter System (SAFS) is also used for narrow-band spectrum analysis of dynamic data. The

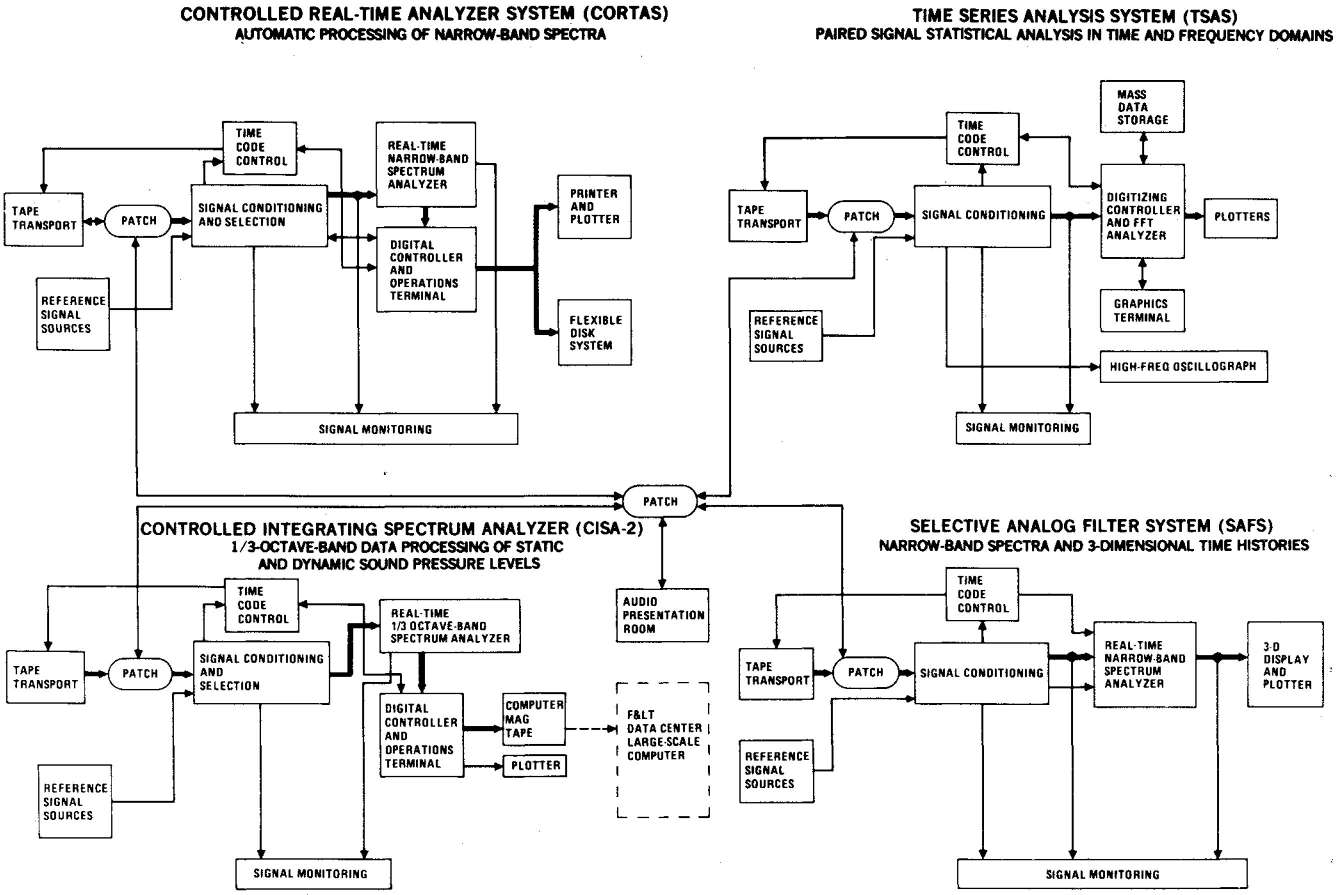

Fig. 2 Acoustics and vibration data center block diagram.

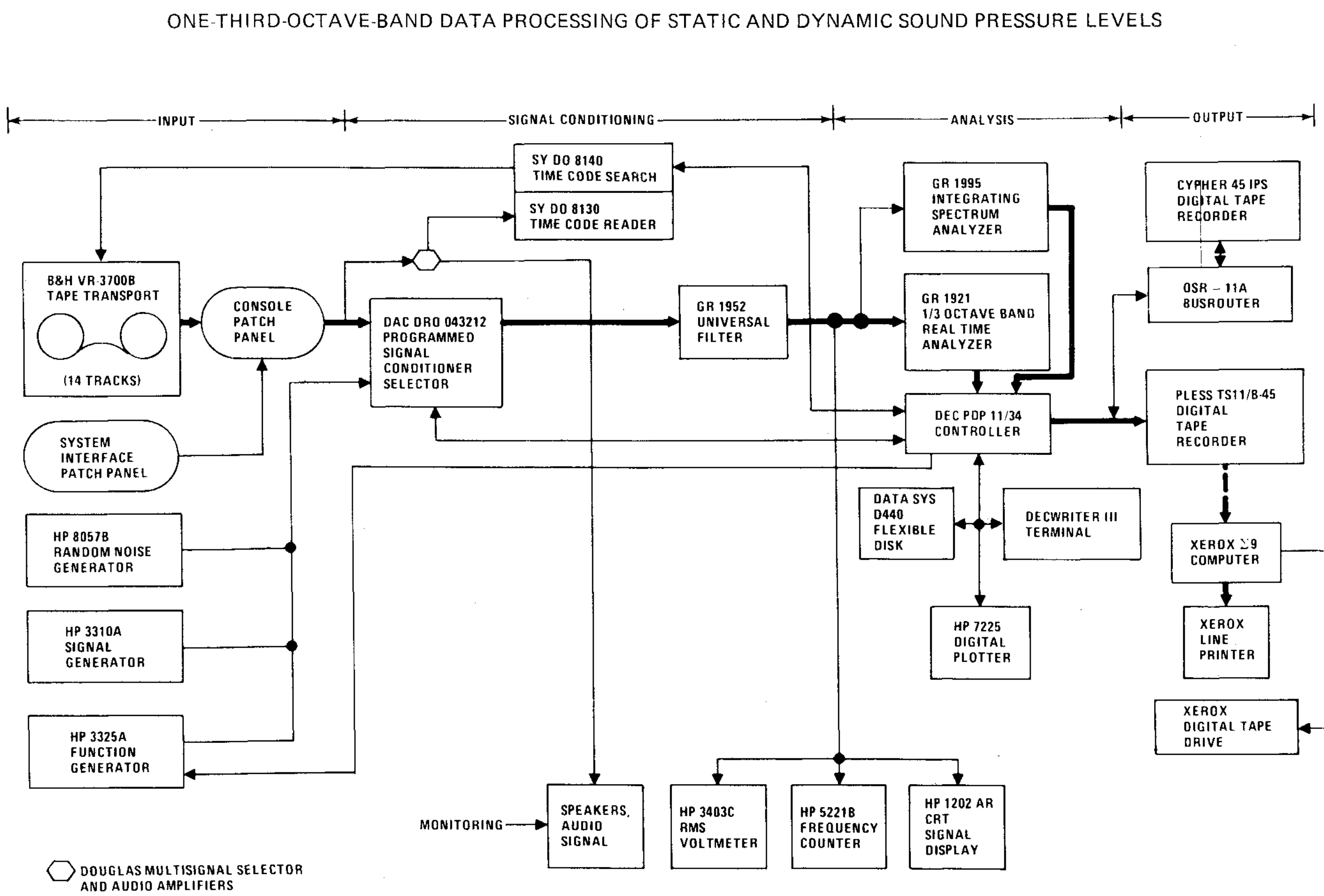

Fig. 3 Controlled integrating spectrum analyzer (CISA-2).

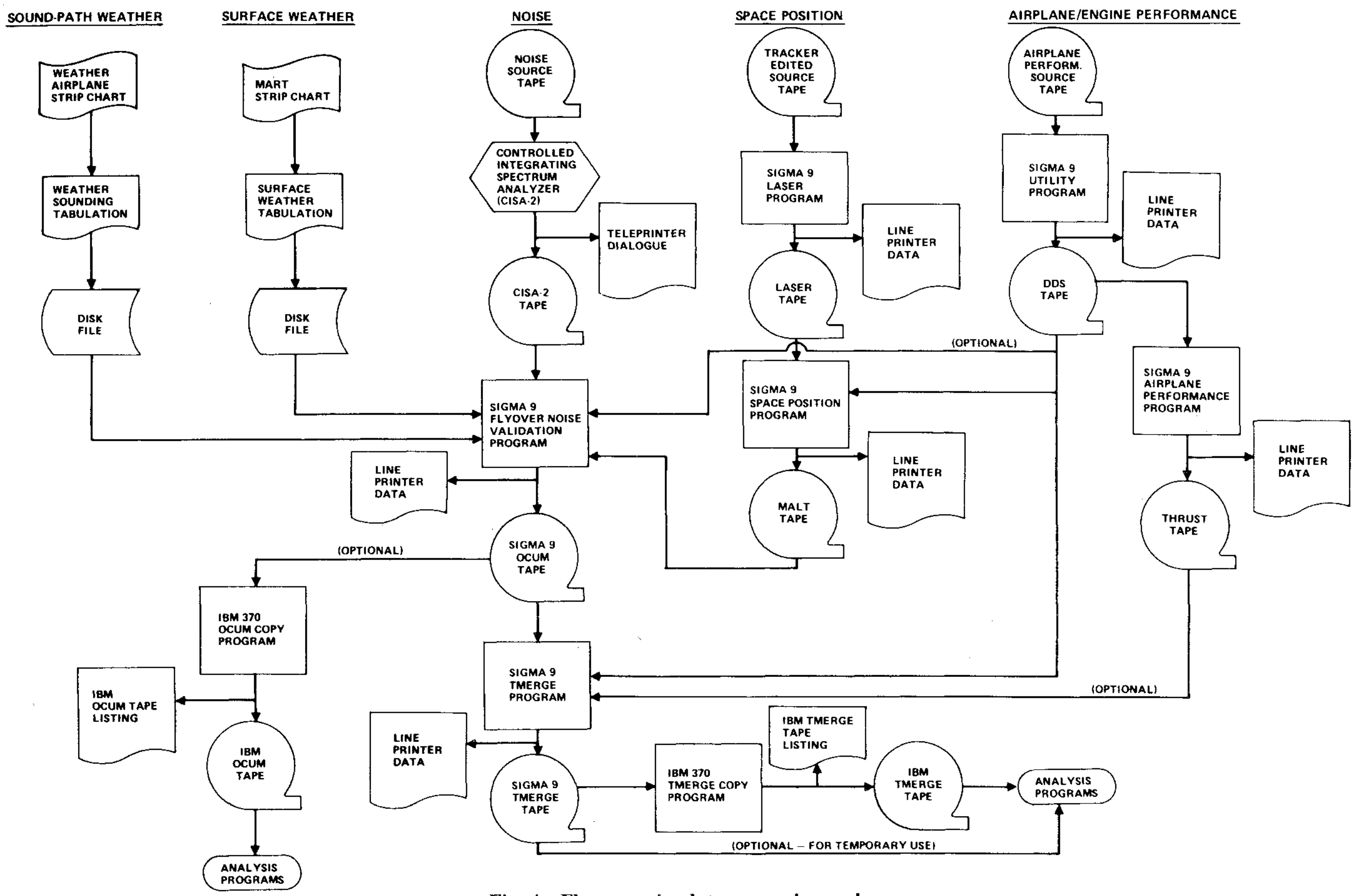

Fig. 4 Flyover noise data processing cycle.

TEST DESCRIPTION: SPECIFICATION INTERIOR NOISE

MODEL: SHIP NO.: CONFIG: PROD. JOB NO.: 887

DATA SET: FLT 6 TEST POINT: 4.1 TEST DATE: 10-SEP-80

PACS: 2 AUTO AIRSPEED: 293 KIAS ALTITUDE: 29980 FT.

1/1 & 1/3 OCTAVE BAND SOUND PRESSURE LEVEL, RE 20 MICROPASCALS

1/3 OB GMF (HZ)	MIC NO. 8 L 20 SE 14A		MIC NO. 8 L 21 SE 14C		MIC NO. 8 L 22 SE 14E	
**********	********	********	********	********	********	********
50	84.2		70.9		83.3	
63	82.9	87.0	70.9	74.7	81.3	85.8
80	76.8		67.1		74.6	
100	75.8		70.5		73.9	
125	74.9	79.5	68.2	74.2	75.6	79.4
160	73.0		69.2		74.2	
200	71.2		68.2		71.9	
250	74.7	78.4	70.3	76.6	72.9	77.9
315	74.3		74.5		74.2	
400	71.1		72.3		70.4	
500	70.5	76.0	69.0	75.9	68.5	74.8
630	72.0		71.4		70.8	
800	71.6		70.3		70.3	
1000	67.2	73.5	67.5	72.8	65.9	72.1
1250	64.6		64.6		62.5	
1600	61.2		59.5		59.1	
2000	55.6	62.6	54.5	61.0	54.9	61.1
2500	51.9		50.0		52.5	
3150	46.3		44.6		46.3	
4000	43.3	49.1	41.4	47.2	42.6	48.6
5000	42.2		40.0		40.5	
6300	41.1		38.7		38.7	
8000	41.4	46.1	38.4	43.3	38.4	43.6
10000	41.5		38.6		39.3	
OASPL	88.6		82.1		87.6	
A-WTD	77.6		76.7		76.5	
SIL	61.7		60.4		60.6	

COLNP AVG TIME: 16.1 SEC. 11-SEP-80

Fig. 5 CISA-2 tabular output.

spectrum analyzer used in SAFS is essentially the same as the one used in CORTAS. However, in SAFS, the analyzer is connected directly to graphics display and hard-copy units for displaying spectral histories. The graphics display control unit provides the user with options for the following: the time spacing between the individual spectra (vertical sweep rate) on a cathode ray tube (CRT), the setting of the amplitude threshold, and the operating mode (amplitude or intensity). After the various options have been selected, the recording of the data to be processed is played back, with the analysis started at the appropriate time so that the significant portion of the history is encompassed within the CRT display. Figure 11 is an example of this type of analysis for a takeoff flyover noise recording. This history was made by using the spectrum analyzer on its 5000-Hz range and by obtaining a new spectrum every 0.1 s. The display makes it quite easy to distinguish between the ground reflection effects (the series of semicircular patterns) and the Doppler-shifted engine tone. The three-dimensional spectral history technique is an excellent method for displaying the narrow-band spectra for the significant flyover noise history. However, it is evident in the figure that no quantitative amplitude information is possible with this equipment.

Paired Signal Analysis

Paired-signal analysis, often called time series analysis or Fourier analysis, is very useful for studying input-output or stimulus-response problems. This type of analysis is accomplished in either the time, frequency, or amplitude domains. For example, in the time domain, cross-correlation can be used to measure time delays and to find the location of disturbing sources. In the frequency domain, the coherence function can be used to determine the contribution (as a function of frequency) that a particular input (e.g., a vibrating fuselage panel) has on a given measured response (e.g., the measured noise levels in an airplane cabin).

Probably the most versatile data processing system developed for the data center is the Time Series Analysis System (TSAS). Figure 12 is a block diagram of TSAS. This system is capable of performing dual-channel analysis in either the time, frequency, or amplitude domains. As shown in the diagram, two of the major components of the system are a minicomputer, which does the fast Fourier transformation (FFT) calculation, and an FFT preprocessor. The

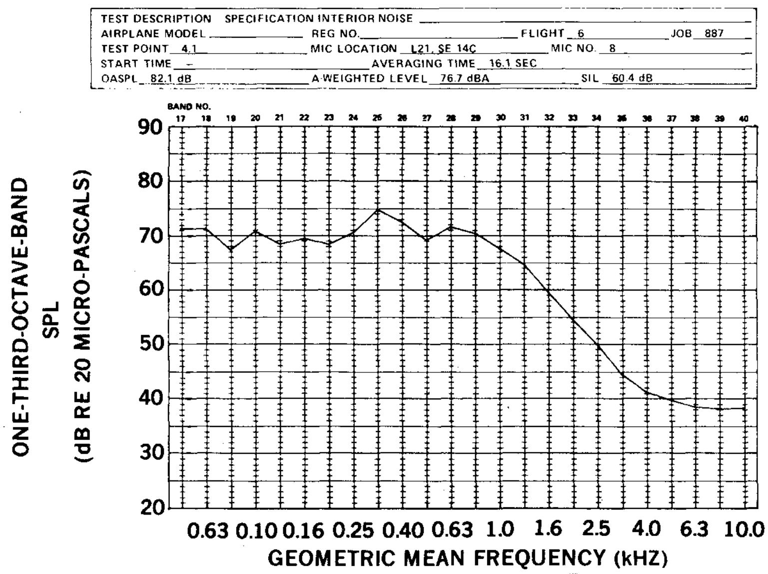

Fig. 6 One-third-octave-band noise spectrum.

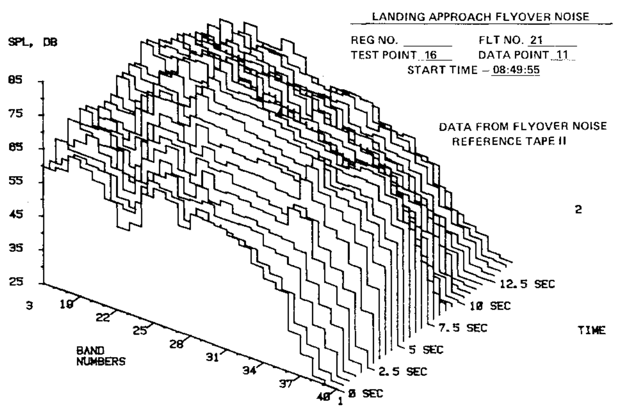

Fig. 7 One-third-octave-band spectral history.

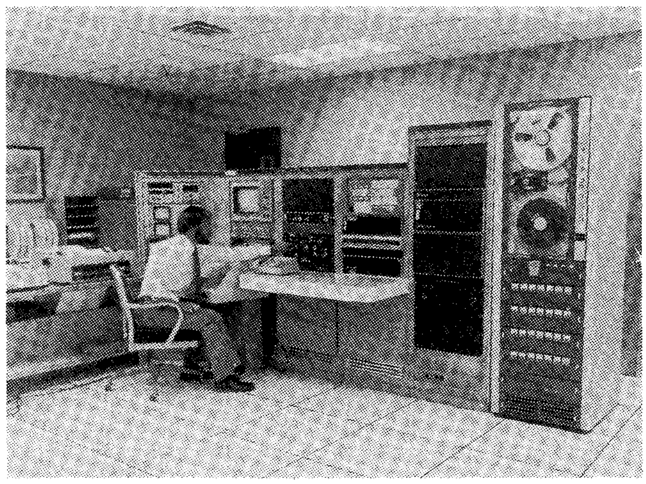

Fig. 8 The controlled real-time analysis system (CORTAS).

software that performs the FFT calculation and related analyses was developed by the manufacturer of the FFT preprocessor. It consists of a high-level language called Time Series Language (TSL) for application programs, and a large library of application and driver routines written in both TSL and assembly language. As with the other automated systems in the data center, the user interacts with TSAS by using a question and answer dialog on a graphics terminal. The processed data are generally output in either graphical or tabular form.

TSAS has two operating modes. Since the FFT calculation is implemented in the minicomputer, it is relatively slow when compared to hardware-implemented approaches. The higher the frequency that one wishes to analyze, the faster the data must be digitized and the FFT calculated. In the first operating mode of TSAS, a given block of data is digitized, and then the FFT for this block is calculated and saved while the next block is being digitized. Because the FFT is calculated using software, the real-time bandwidth of TSAS in this mode is approximately 300 Hz. When analyzing higher frequencies, some data will be lost while the preceding block's FFT is being calculated. Thus this mode is used when analyzing data below 300 Hz, or when time gaps in the data are not important (e.g., when analyzing stationary data).

The FFT preprocessor in TSAS is capable of digitizing the data fast enough to handle frequencies up to 25 kHz without any loss of continuous data. Therefore, the second mode of TSAS involves digitizing the incoming analog data at the required rate for the frequency range being analyzed, and storing the results on a mass storage device (DEC RL01 cartridge disk). Once the data have been digitized, the FFT and other analysis functions within the application programs are then calculated.

Since all of the analysis is done with software once the data have been digitized and stored, a great deal of flexibility exists. For example, the frequency range analyzed can be broken up into as many as 1600 frequency points for single-channel analysis, depending upon the application program being used. This second mode is used for high-frequency analysis when no data loss can be tolerated. However, because of the added flexibility, it is also often used for analyzing data within the real-time limits of the first mode. Although the first mode provides the same choice of analyses, the analog tape must be replayed for each new analysis since the data acquisition routines are a part of the analysis programs. In the second, or high-frequency analysis mode, this is not required since the stored data are the input to the analysis programs. Table 2 lists the basic capabilities of TSAS. These capabilities generally apply to both operating modes.

Figures 13 and 14 show some examples of data which were processed with TSAS. The output data of TSAS can be in tabular form, on annotated plots, on digital tape, or on other computer media.

Figure 13 is an example of TSAS being used in the single-channel amplitude domain mode. The data are from the same test program as the example in Fig. 10. The plot shows the number of times that the lateral displacement of the aerial

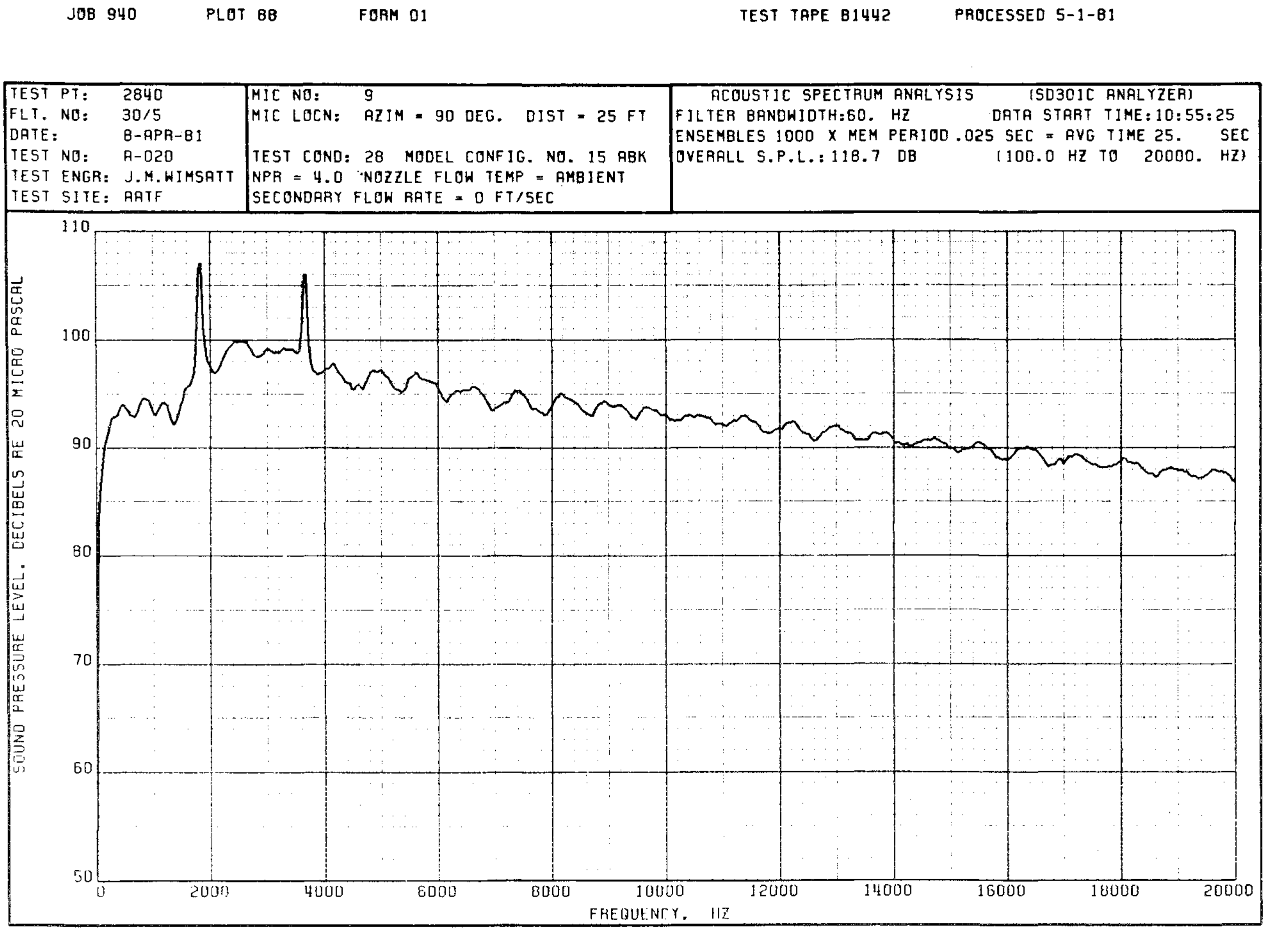

Fig. 9 Acoustic narrow-band spectrum.

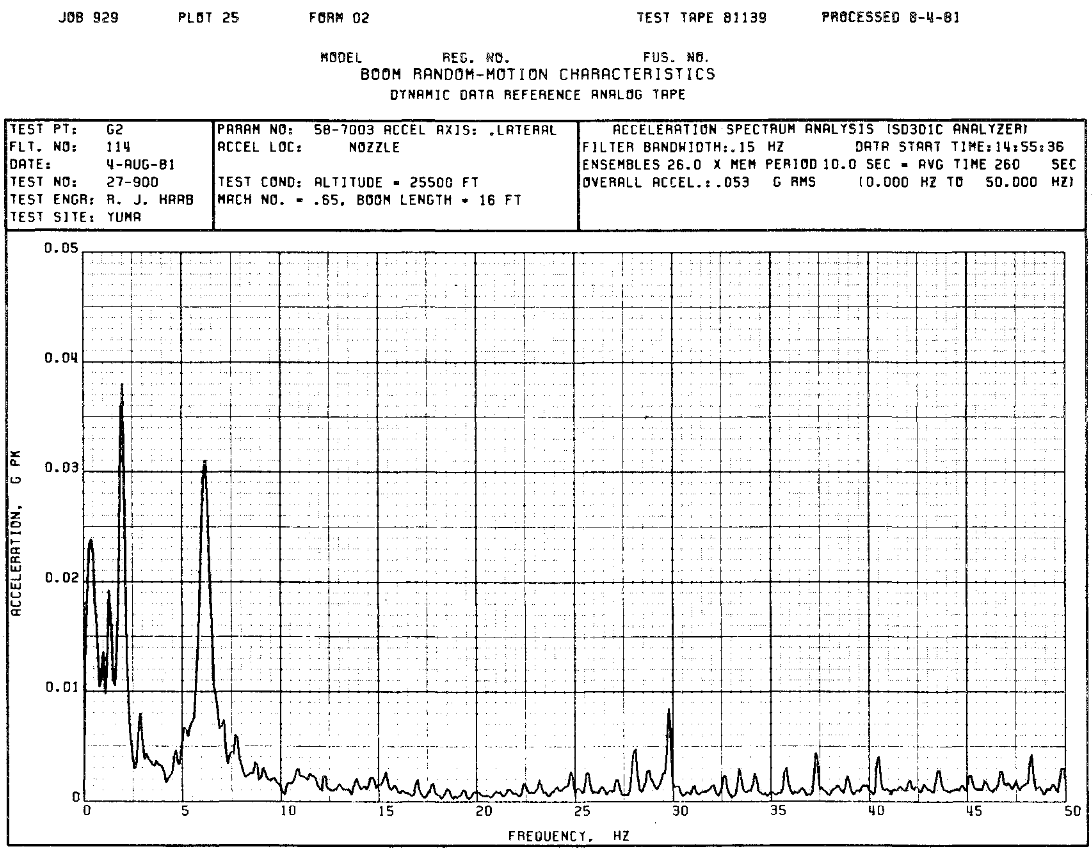

Fig. 10 Acceleration narrow-band spectrum.

Table 1 CORTAS analysis capabilities

General	
Frequency range: 10 Hz – 50 kHz	Frequency resolution: range/500
Selectable averaging time	Lin/log amplitude scale
Calibrated in engineering units	Analysis autostart
Overall rms calculated	Cursor control with amplitude and frequency tab
Background noise removal	Transient trigger
Electrostatic or analog plotter output	Fully annotated plots with electrostatic plotter/computer
Partial frequency range plot	

Flyover noise analysis	
Peak level tracking:	Tracks peak level and calculates corresponding source frequency with graphical or tabular output
Source-band tracking:	Tracks received band level corresponding to input source frequency with graphical or tabular output
Spectral history:	In conjunction with follow-on processing within a large-scale computer, provides fully corrected narrow-band spectral levels merged with airplane performance and space position data on a computer-compatible digital tape

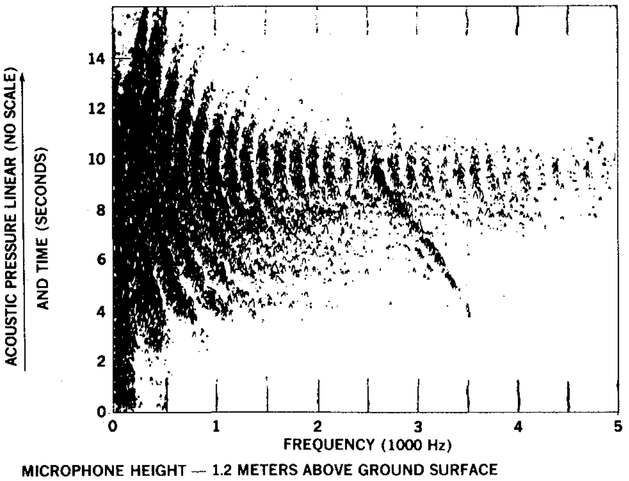

Fig. 11 Flyover noise spectral history showing ground reflections and engine tones.

device exceeded a given deviation from the centerline. The interest here was concentrated on the very few times during the 4 min averaging period that the boom drifted significantly from the centerline. To enhance this information, the number of counts shown on the vertical axis were plotted on a log scale. Also, the zero counts were suppressed. The display and the software used to generate it were developed essentially on-line and evolved during the data processing for the test program. It is a good example of how the flexibility of TSAS can be used to provide output optimized for given test objectives.

Figure 14 is an example of cross-correlation analysis function between two microphones. The data are from the jet noise reduction test program described earlier. In addition to the standard annotation, the maximum value of the cross-correlation function and its delay time are also noted. The independent variable in Fig. 14 is pressure squared, in units of Pascals. Performing cross-correlation analyses similar to those shown in Fig. 14 (between several pairs of microphones in an array) was a technique found to be useful in locating the distributed jet noise sources.

Audio Presentations

Adjacent to the main facility is the audio presentation room (APR), which is pictured in Fig. 15. The APR includes a well-equipped control console, wall drapes to improve the room acoustics, comfortable seating, and elevated speakers. The control console contains tape recording systems, signal conditioning, monitoring devices, and a variety of signal-filtering components. In addition, remote control and signal patching are provided to the multiple-channel tape systems in the AVDC.

A variety of tasks are performed in the APR, including playing back analog noise recordings for critical listening, providing low-noise duplicate tapes in various formats, and analyzing the sounds on cockpit voice recorder (CVR) tape recordings. The noise reduction effects of an airplane modification can be demonstrated in the APR with realistic audio—a very useful capability. Also, duplicates of selected portions of noise data tapes are made; these form the basis for sales demonstration tapes. The APR provides an excellent facility to make these tapes and to verify their audio quality.

All commercial jet transports are equipped with a cockpit voice recorder (CVR). These recorders generally consist of four channels of recorded information contained on a continuous or autoreversing tape cartridge with about 30 min of recording capacity. The tape channels monitor radio transmissions, interphone conversations, and a cockpit area microphone that picks up crew conversation and other sounds in the cockpit. The APR is equipped to play back all of the several formats of CVR tapes installed on the Douglas jet transport family. The CVR tapes are played back in the APR to evaluate audio improvements during the development of CVR installation. The facility is also used to play back test recordings for demonstrating CVR compliance with FAA requirements.

Many of the capabilities of the APR have been developed specifically to enhance CVR signals in order to aid accident investigations. It is extremely important to an investigation that the maximum amount of information be extracted from a CVR tape involved in an airline incident or accident. This information includes accurate voice transcription regarding what was said, by whom, and when, relative to the events leading up to the incident. In addition to the voice signals, the CVR tape often contains other information that can be useful in the investigation. The tape can include unique sounds which indicate the activation of various control systems and the engine tones, from which engine rotation speed can be determined. Extracting information such as this is quite challenging because of the generally high background noise level on CVR tape and the adverse recording conditions of an accident-related tape.

During previous accident investigations, several methods have been used to enhance the signals, including analog band-pass and band-reject filters, and multiple re-recording in conjunction with analog filtering. The enhanced tapes can then be analyzed more effectively using data processing systems of the AVDC to identify various flight events—narrow-band spectral time histories have proven quite effective in this regard. In addition, adaptive digital filtering and other techniques used in related disciplines are being explored for potential application.

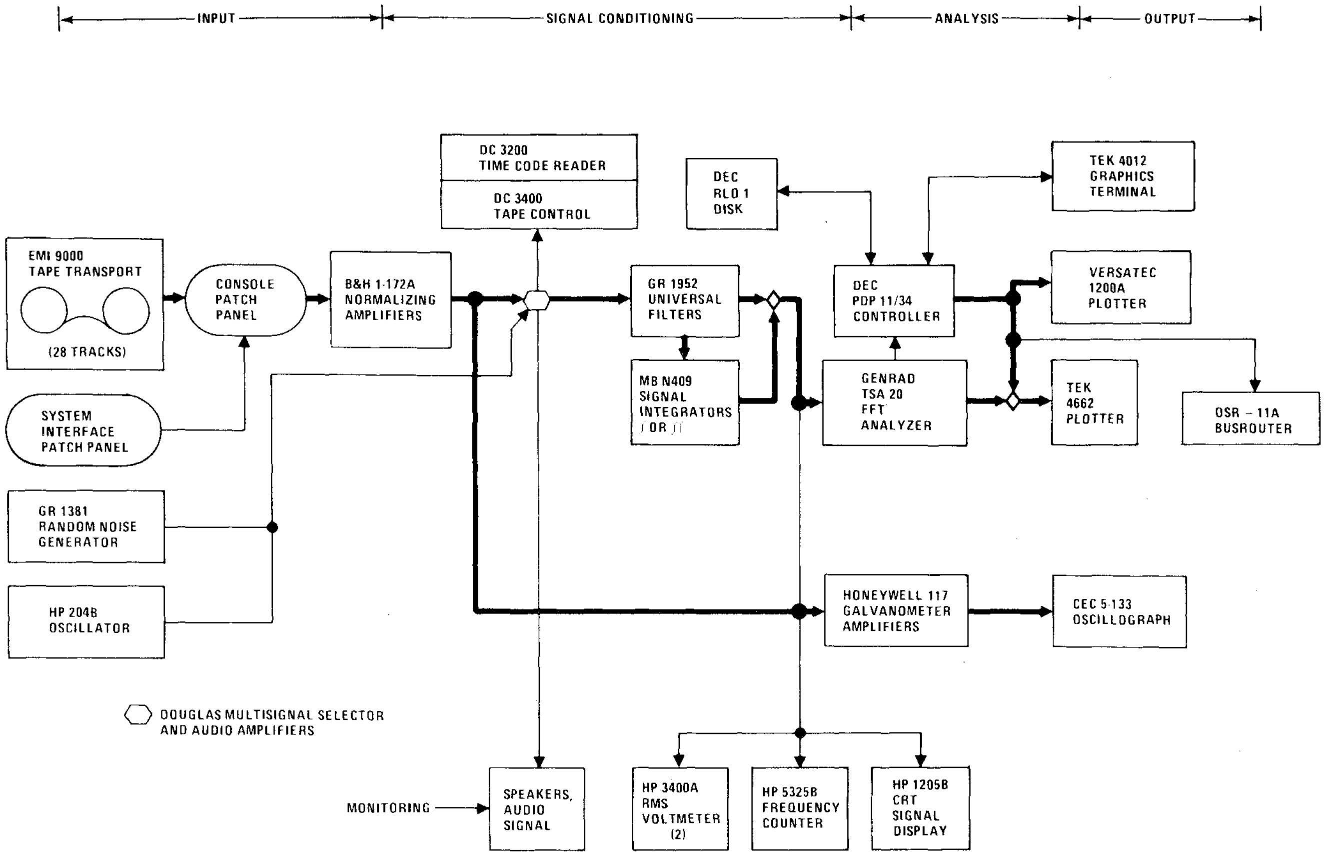

Fig. 12 Acoustics and vibration data center—time series analysis system (TSAS).

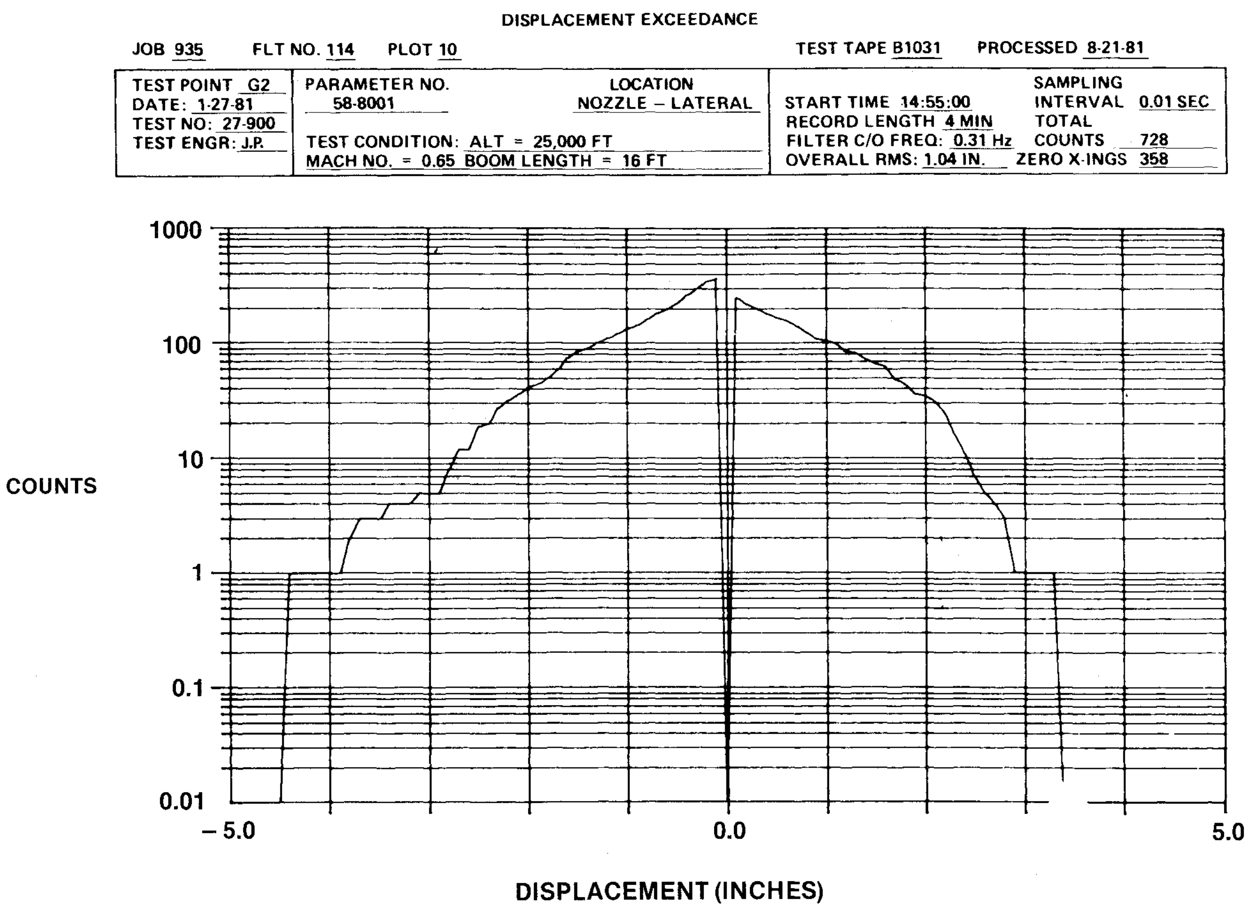

Fig. 13 Amplitude exceedance plot.

Table 2 TSAS analysis capabilities

General	
Two-channel analysis	Interactive display
Flexible data output format	Calibrated in engineering units
Overall rms calculated	Selectable analysis parameters
Time domain analysis	
Auto- and cross-correlation waveform averaging	Broadband time histories
Frequency domain analysis	
Auto- and cross-power spectra	Power spectral density
Spectral histories	Transfer function
Coherence function phase relationships	Coherent output power
Amplitude domain analysis	
Histogram	Probability density function
Probability distribution function	Amplitude exceedance

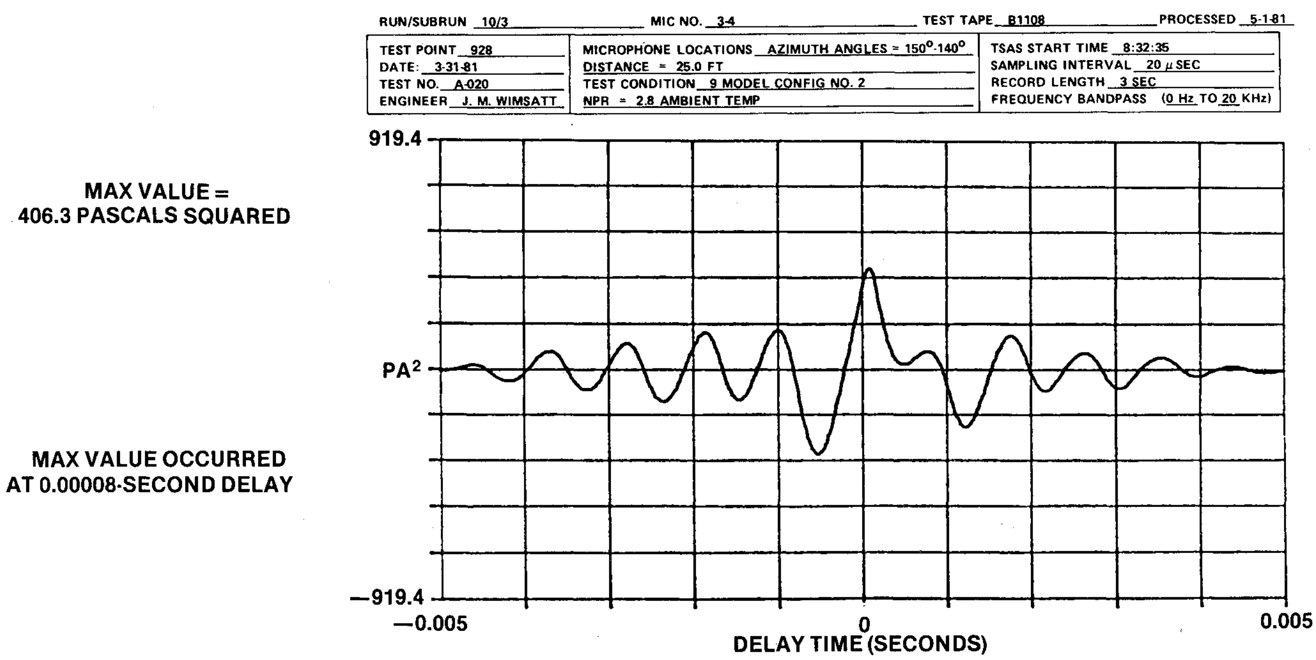

Fig. 14 Cross-correlation analysis.

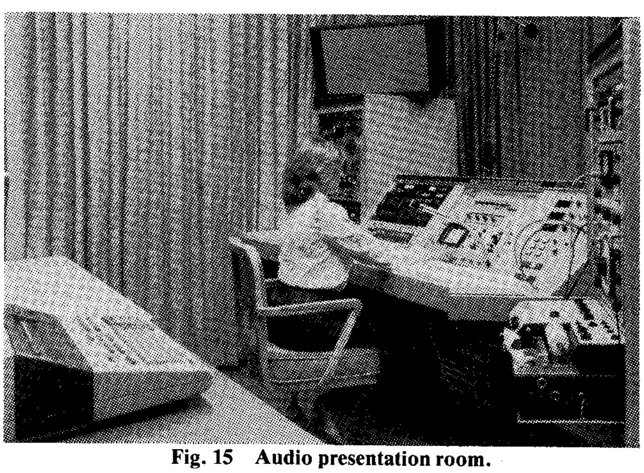

Fig. 15 Audio presentation room.

Future Development

The capabilities of the AVDC will continue to be improved and refined to meet the flight-test challenges of the 1980s. The flight-testing and associated data processing of the next generation of commercial jet transports will certainly be more extensive and complex in many respects. Changes in how tests are conducted and how data are acquired will affect the AVDC in several ways: the quantity of digitally recorded dynamic data (including noise and vibration data) will increase, there will be increased reliance on computer processing, and use of data base management techniques will continue to expand.

The main flight-test data processing facility is scheduled to be completely replaced in the mid-80s. Regardless of what form the system ultimately takes, it will significantly affect all areas of flight-test operations; AVDC operation will be no exception. Future development of the AVDC will be coordinated with development of the main facility. The capabilities of the main facility can thus enhance those of the AVDC, ensuring that the AVDC will continue to efficiently process dynamic data from jet transport test programs.

References

[1] Stouder, D.J., "Current Practices and Future Trends in the Processing of Airplane Flyover Noise Data," McDonnell Douglas Corporation, Douglas Paper 6648, Dec. 1977.

[2] Stouder, D.J., "Narrow-Band Spectrum Analysis Techniques for Processing Airplane Flyover Noise Data," McDonnell Douglas Corporation, Douglas Paper 6904, June 1980.