A Computer System for Aircraft Flyover Acoustic Data Acquisition and Analysis

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A minicomputer-based system housed in a mobile trailer was designed for field measurements of aircraft flyover noise. The system was used to accomplish recent Federal Aviation Regulation Part 36 noise certification testing for the new Boeing Models 757 and 767 aircraft. The multiuser system performed acoustic and telemetered data acquisition, analysis, and data base storage. All data were available to on-line color monitors and on hardcopy. One-third octave band acoustic data were acquired and analyzed via microcomputer-controlled digital frequency analyzers. Ground weather data and telemetered data, including upper air weather and airplane position and performance information, were received, stored, and displayed automatically. By integrating all of the data, fully corrected acoustic time histories, spectra, effective perceived noise level values were calculated within minutes of an airplane flyover. On-line data output was used to make test operational decisions and evaluate aircraft noise level predictions. This computer system increased test efficiency by providing high-quality data to personnel for real-time decisionmaking.

Introduction

ALL new and derivative large transport aircraft must comply with standards established by the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO).[1,2] The standards require that aircraft meet certain noise limits for takeoff and landing conditions. This proof of "noiseworthiness" usually requires testing the aircraft under prescribed conditions—the aircraft must be flown on a planned flight path over an array of microphones, and aircraft position and engine performance must be controlled and measured (Fig. 1) Once the atmospheric conditions and noise received on the ground are measured, these parameters are used to normalize the noise measurements to reference conditions. Effective perceived noise levels (EPNL) are then established at takeoff, sideline, and approach reference locations.

A computer-based system, known as Acoustic Data Processor 4 (ADP-4), that integrates these data and presents on-line information for evaluation is described herein. However, before describing the computer system, some background information and explanation of the test procedures and requirements are necessary.

Background

A typical certification test of a large transport aircraft is usually conducted at a remote site selected for optimum test conditions and involves key personnel on site to support the aircraft and conduct the tests. The expense of operating the aircraft makes it important that the test be conducted efficiently. A timely indication that the aircraft will certify as planned is extremely valuable. If the test site were to be vacated and later data analysis were to show incomplete or unexpected data, retesting would be very expensive in dollars and in schedule impact. Such a delay late in an airplane's flight testing program could cause delivery delays and customer inconvenience. Therefore, an on-line data system capable of monitoring test progress and predicting probable "pass or fail" of the aircraft is highly useful in keeping the airplane within budget and on schedule.

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On-line data have been acquired in some form during all flyover testing conducted by Boeing in the past 30 yr. Initially, hand-held sound-level meters were used for on-line visibility, then strip chart recordings of dBA or maximum-hold digital meters were used. Eventually, a system was built around a Digital Equipment Corporation Model PDP-8 computer and a General Radio Model 1921 frequency analyzer to provide calculated noise numbers. In 1978 that system was replaced with an improved configuration using a PRIME Model 300 minicomputer and four analyzers. Incorporation of a minicomputer allowed noise number calculation and correction of the data for system response, test day conditions, and airplane performance. However, two major problems still existed with the PRIME 300-based system: it was slow and the corrections applied to the data were not as complete as those applied to the final data on a large mainframe computer. Data processing could not keep up with data acquisition. Weather parameters were being measured, but the data were not available to the computer, except in limited summary form. Assumptions made from this summary introduced the potential for large errors. Target values were used for airplane performance and location information, and slight variations from the actual values added to the errors.

To overcome these limitations, ADP-4 was designed, with the major objectives being to provide the finest possible information with which to normalize the test data and to speed up the processing tasks. The software used to accomplish the objectives are discussed subsequently.

Software Description

Input/output (I/O) requirements were for four user operations: 1) acoustic data acquisition; 2) acoustic data analysis; 3) display and printing of noise, weather, and performance data; and 4) nonacoustic data acquisition. Operations 1-3 are manned tasks, while 4 is not. The software programs for these operations are, respectively, ACQU, ANALYSIS, VUEDAT, and TELEM plus a utility for manual entry of data, if required, called PREFLY (Fig. 2).

ACQU

Acoustic data acquisition is perhaps the simplest operator task because all that is involved is starting frequency analyzer integration. However, because the function is time related (i.e., knowing airplane location, knowing when to start taking data, and discerning this information from radio transmissions), and because on-line data cannot be repeated, it also

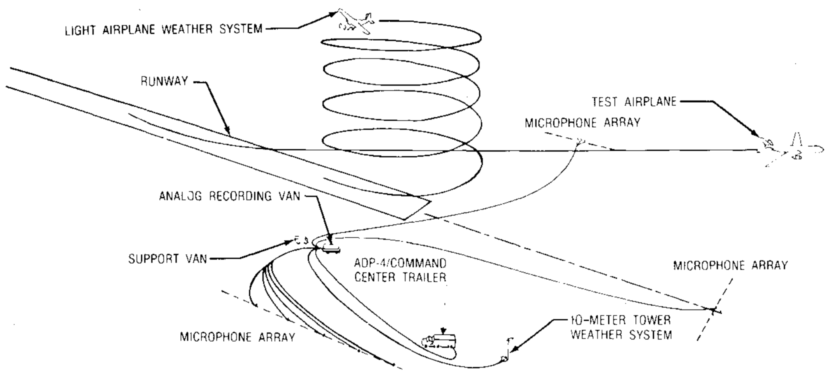

Fig. 1 Certification test setup.

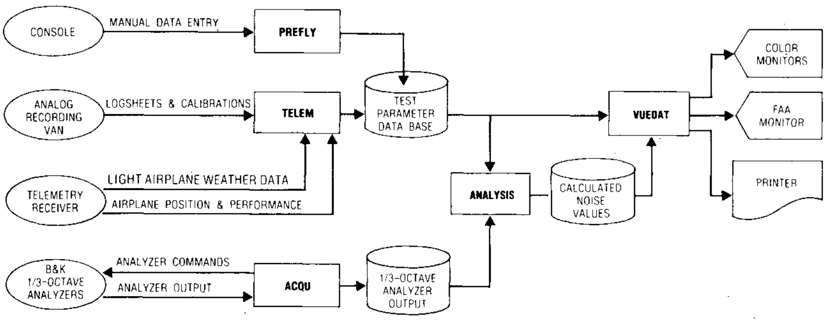

Fig. 2 ADP-4 software block diagram.

can be the most harried job. To lighten the task, the program allows the user to input all data acquisition setup information described above before test and save that information in a table. No input other than condition number is required from flyover to flyover. Since the program does not require information from any other software, it is not dependent on a chain of operations. If the operator needs to change a setup parameter, the structure of the program allows this by a single command. The philosophy carried through from specification to implementation and operation was that the program always had to be ready to take data when required. Output from this program is automatically placed in raw data files.

Analysis

The method of acoustic data analysis was determined by a requirement to use an existing program developed by The Boeing Company for calculating final data on large mainframe computers. The only change made for use on the ADP-4 system was in the I/O handling. All calculations (which include SPL, PNL, PNLT, EPNL, tone correction, and maximum noy bands) were copied exactly from the existing program and are in accordance with FAR Part 36. The operator task is similar to data acquisition in that all inputs required for data analysis are stored in a table before analysis and the only operator input from flyover to flyover is the condition number. The program is in a waiting mode until the test data are available. This allows on-line data analysis to be completed within 4 min of a flyover. Changing any input is accomplished quickly by the specific command for that parameter in the setup task. Previous Boeing minicomputer-based flyover noise systems wrote the analyzed data to a graphics terminal where it was hardcopied; however, no analyzed data were stored. If the copy was lost or the extrapolation parameters were changed, complete reanalysis of the raw data was required. The new system has complete data storage in a data base. Calculated acoustic data as well as input data are stored to provide complete traceability. If the hardcopied data are lost, a new copy is simply spooled on a line printer. If new extrapolations are required, only a portion of the calculations is repeated using stored numbers as the baseline.

The improved operator input methods and data base storage allow data to be post-test analyzed and output in great quantities very rapidly. Normally, fully corrected extrapolated data for four microphones (sometimes extrapolated two or three different ways) are available within 2-4 h after completion of the day's flyovers. This additional analysis augments the on-line data and allows engineers to assess trends and make projections.

The data analysis program also performs weather analysis. This combines ground weather measured during the condition, upper air weather measured by the test aircraft, and upper air weather from light aircraft surveys surrounding a condition to provide a unique layered weather profile (in 100-ft increments) for each condition. This profile is then used in the acoustic data extrapolation for that condition.

VUEDAT

The large amount of data to be displayed and printed during a noise certification test requires the task of outputting data to be a separate operator function. Operator inputs again are structured so that all program requirements are set up in three tables, one for the display monitors, one for hardcopy listings, and one for hardcopy graphs. The operator then enters only the output selection and condition number. The program also allows setting each output type in an automatic mode: output data are automatically displayed or presented when the program senses that the data base has been updated with pertinent data. This allows on-line data to be displayed as soon as they are available, which is particularly useful for upper air weather surveys where the display screens are updated seconds after each weather sample is received from the light airplane.

Document quality output formats are similar for each type of data (noise, weather, and performance), but easily distinguishable through careful color selection and format. The types of output formats are listed below.

Noise‡

1) PNLT summary listing: spectrum number, time, acoustic emission angle, sound propagation distance, PNL,

‡Available for as-measured, normalized, and extrapolated data.

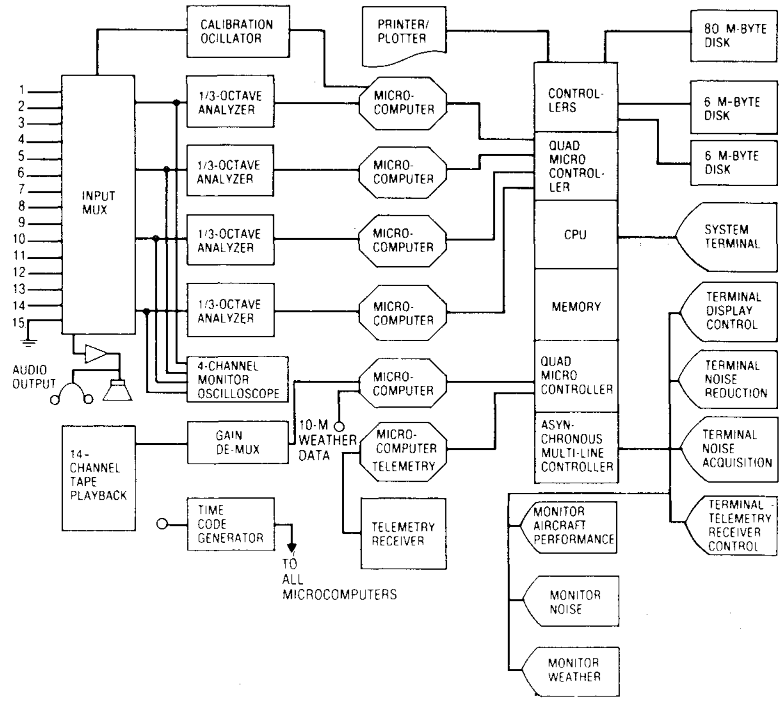

Fig. 3 Hardware block diagram.

PNLT, maximum noy band, tone correction band, EPNL, extrapolation parameters, and ⅓ octave band spectrum at PNLT max.

2) SPL summary listing: spectrum number, all ⅓ octave band SPLs, EPNL, extrapolation parameter, and ⅓ octave band spectrum at PNLT max.

3) PNLT time history graph (PNLT vs time).

4) One-third octave spectra graph (SPL vs frequency band): any spectra.

Weather (Metric or English Units)

1) Upper air summary listing: time, altitude, temperature, dewpoint, relative humidity, 8-kHz atmospheric absorption, 3.15-kHz atmospheric absorption, and refractivity plus ground weather.

2) Upper air summary listing: time, altitude, static pressure, dynamic pressure, saturation vapor pressure, absolute vapor pressure, absolute humidity, and relative humidity (plus ground weather summary, below).

3) Ground weather summary listing: date, time, temperature, dewpoint, relative humidity, wind speed, (maximum and average), and crosswind speed (maximum and average).

4) FAR 36 weather window graph: relative humidity vs temperature.

5) Temperature, dewpoint, relative humidity, turbulence, 8-kHz absorption, and 3.15-kHz absorption vs altitude graphs.

Performance (Metric or English Units)

Summary listing of airplane position, engine performance, and weather for each of four microphone positions.

The color capability of the displays serves to draw attention to data that are outside a predetermined tolerance. Certain parameters that are used to determine if a condition is acceptable (such as ground weather, wind speed, or airplane altitude) may be displayed in red characters with a yellow background if the values are outside a preset tolerance. Otherwise, data are normally displayed in green characters. Users find this helpful in the fast pace of activity and decisionmaking present during a flyover test.

TELEM

Telemetry data require no operator input other than to start the program. The program automatically puts the received data into the data base available for access by other programs. A message is displayed at a terminal when data are received. If no one is monitoring the terminal and a radio reception or format error occurs, the terminal beeps to get operator attention. Silencing the beep requires merely pushing any key. Meanwhile, the program continues to receive. Cyclic redundancy check (CRC) is used as the error-checking procedure because of its proven capability and simple implementation. Telemetry data are also safeguarded to be uneditable. However, if the telemetry link fails, manual entry and full edit capability of manually entered data are available. Although layering of weather is accomplished automatically, a relayering task is available in case ground weather data are altered. An option for viewing the message log of the program (which is stored) is also available.

Hardware Description

A PRIME 400 computer is used to accommodate the system described above. This virtual memory timesharing computer has 0.5 megabyte of error-correcting metal oxide semiconductor (MOS) memory and 2 kilobytes of cache memory to speed execution. An 80-megabyte disk is partitioned to provide a paging program, and data storage disks. Additional disk cartridge drives provide raw data storage and an interchangeable medium with other systems for software data support. Backup storage and data transmittal are provided by an industry standard 9-track digital magnetic tape drive. An asynchronous multiline controller (AMLC) provides 16 RS232 communication lines for user terminals. A parallel interface drives the electrostatic printer-plotter via a copy controller that is also able to produce prints from a Tektronix graphics terminal. Two custom interfaces provide for direct memory access (DMA) to and from up to four Intel microcomputers are used. Each is erasable programmable read-only memory (EPROM) programmed to use the same program control protocol and data return buffer, and each has access to current test time code signals for synchronization of data. See Fig. 3 for further details.

The entire system is housed in a 40-ft trailer that can be trucked conveniently. In addition to the minimum environmental considerations required for equipment functioning, certain operator environmental conditions are included for more efficient operation. A well-lighted comfortable work area is provided for test programs, where the work atmosphere may vary from tedious to frenzied. In that regard, the trailer is divided into two areas: equipment and data evaluation areas. The equipment area features a computer-room-type floor that allows convenient access to all cabling. An area behind the computer rack allows easy access for troubleshooting and maintenance. The data evaluation area is carpeted and has an office-type appearance. Paneling, fluorescent lights, storage cabinets, windows, and air conditioning are provided in both areas. This arrangement has proved well suited to keeping equipment functioning and personnel productive.

Conclusion

Overall performance of the system on the Boeing Models 757 and 767 noise certification tests was excellent. Minor software bugs and telemetry transmission errors were the only problems encountered, and they were corrected on site with little or no test delay. Statistics showing some of the performance and timing aspects of the system are listed below:

1) Acoustic data acquisition
   Total conditions: 152
   Missed conditions (hardware failure or operator error): 2
   Efficiency: 98.7%
2) Acoustic data analysis
   On-site EPNL vs "final" EPNL values: normally less than 0.25 EPNdB difference; average difference = 0.1 EPNdB.
3) Nonacoustic data acquisition
   a) Airplane performance
      Total conditions: 152
      Total received: 128§
      Efficiency: 84.2%
   b) Weather
      Total data points: Over 10,000
      Missing points (transmission errors): less than 1%
4) On-line data timing
   a) Weather: displayed almost immediately every 5 s
   b) Performance: displayed within 15 s of receiving telemetry (usually within 2 min of "data off")
   c) Noise:
      As-measured: displayed within 3 min after "data off"
      Extrapolated: displayed within 5 min after "data off"
5) Printing (time after request)
   Weather: six graphs and two listings—3min
   Performance: one listing—15 s
   Noise: two listings and two graphs (for four microphones each)—6-8 min

The availability of such complete data during testing proved invaluable in the Models 757 and 767 tests. On occasion, the on-line data showed certain unexpected noise characteristics and, as a result, minor changes in test plans were made in order to more fully investigate these phenomena. Also, the extrapolated on-site data were very useful in showing whether or not certain flight criteria had any measurable effect on noise heard on the ground.

Future plans for use of ADP-4 include noise research and noise certification of various Boeing airplanes as well as use of the system by other aircraft manufacturers on a contract basis.

§Remainder were transmitted by voice over radio and manually entered.

References

[1]"Part 36 Noise Standards: Aircraft Type and Airworthiness Certification," Federal Aviation Regulations, Federal Aviation Administration, Department of Transportation, Washington, D.C., March 2, 1978.

[2]"Environmental Protection, Volume 1, Aircraft Noise," International Standards and Recommended Practices, Annex 16 to the Convention on International Civil Aviation, International Civil Aviation Organization, Montreal, Canada, Nov. 26, 1981.