Flyover Noise Testing of Commercial Jet Airplanes

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The flight development and certification programs of new commercial jet transport airplanes include flyover noise testing to define public acceptability of the airplanes. In addition, government noise standards for aircraft-type certification have influenced flight testing procedures for airplane flyover noise testing. Current flight test programs include preliminary, development, survey, certification, and demonstration phases. Flyover noise testing requires extensive and complex techniques and equipment. Specific field and flight data systems utilized include a noise recording array dispersed over a surveyed ground test range, recording stations for the surface weather (continuous) and the sound-path weather (periodic), a tracking facility for the precise continuous recording of the airplane space position, and aircraft instrumentation for recording time-synchronized airplane engine operating parameters. Data processing utilizes advanced techniques that integrate all data components of the test airplane noise system which consist of the source, path, and receivers. Existing test techniques are generally adequate; however, anticipated future aircraft noise characteristics and testing constraints indicate a need for additional development of flyover noise testing techniques.

Introduction

THE operation of commercial jet transport airplanes during takeoff and landing exposes the airport community to considerable propulsion noise. With the anticipated long-term increase in total number of takeoff and landing approach operations, and land use around airports, added emphasis has been placed on defining, regulating, and reducing the flyover noise of jet transport airplanes. Various types of organizations, including state and federal governments, have been active in regulatory efforts to control and reduce airport community noise.

Results of these regulatory efforts include several types of noise standards. The Federal Aviation Regulations (FAR) Part 36 (Ref. 1) and International Civil Aviation Organization (ICAO) Annex 16 (Ref. 2) represent specific regulatory efforts, directed at the airplane manufacturer, to be applicable during the development period of new airplanes. Maximum flyover noise level specifications are, in most cases, defined by the airplane manufacturers for the purchasing airlines. In addition, noise regulations are sometimes defined at state-licensed airports.[3]

The specific objectives of a commercial jet transport flight noise test program are to evaluate (during development) and demonstrate (prior to type certification) takeoff and landing approach noise levels, in accordance with applicable specifications. The specific noise criteria used as the measure of compliance are usually the noise limit levels of FAR Part 36 (effective perceived noise levels) and certain airline, airport, and community noise specifications (perceived noise levels, among others).

Airplane flyover noise measurement has been described in a variety of ways.[4-6] However, flyover noise testing has recently undergone significant advances, both technically and in accordance with detailed standards. These advancements include comprehensive test criteria such as: 1) detailed sound-path weather, 2) noise test site and airplane operational control, 3) improved electronic instrumentation, both in data acquisition and data processing, and 4) data normalization of sound-pressure levels for a variety of conditions (relative to airplane operations and sound-path weather) yielding noise levels in terms of complex psychoacoustic quantities.

This paper describes, in general, the current Douglas practices for airplane flyover noise testing, developed as a result of the increased efforts on defining, regulating, and reducing airport community noise. Emphasis has been placed on those practices considered unique to flyover noise testing. Field experience has resulted in highlighting certain testing techniques which need further development to efficiently achieve accurate measures of flyover noise.

Flyover Noise Testing Program

A flight test program to evaluate the flyover noise of a new commercial jet transport airplane consists of several phases including preliminary, development, and survey. These phases recognize configuration development of the test airplane, as well as the various objectives of different noise tests.

The preliminary phase begins with the initial flight of the first test airplane, traditionally an airplane which is incomplete, in comparison to the certified production airplanes, but which has a propulsion system very similar to that used on the certified production airplane. The main purpose of the preliminary phase is to obtain sufficient data during initial test flights for an early confirmation of the in-flight noise, recognizing the data limitations due to differences between the initial and planned production airplane configurations. The test results are generally used to improve confidence in the estimated in-flight noise levels predicted from static engine test stand data, and also to provide audio tapes for initial subjective evaluations.

The development phase includes a variety of program objectives emphasizing configuration changes for the engines and nacelles, and an investigation of effects of various airplane operation items such as the wing flaps and other aerodynamic systems. The test results are generally used to define the optimum airplane configuration and operation for minimum flyover noise, consistent with the over-all objectives of the airplane program.

The survey phase consists of a systematic determination of the flyover noise of the certified airplane throughout

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the operational range of the initial climb and the landing approach conditions, for noise propagation distances as applicable to airport community areas. This phase requires: 1) performance data and operational limits established for the certified airplane, and 2) an airplane equipped with all of the production systems which affect the flyover noise. The data obtained in the survey phase are used to obtain explicit noise relationships with the basic operating parameters of the airplane, and thereby define the flyover noise levels of the certified airplane.

Two other flight test phases are the certification tests (described in FAR Part 36, Subpart B) that demonstrate compliance with FAA noise standards, and special testing for certain airplane and airport operators having special requirements for flyover noise measurements or audio demonstrations.

Noise Testing Equipment

The equipment required to evaluate the flyover noise characteristics of current jet transport airplanes can be considered both extensive and advanced. It is extensive in the sense that several separate data acquisition and monitor systems are required to acquire the measured flyover noise data and normalize it to reference conditions. These systems include the airplane operations system, weather system, airplane space position system, and the noise recording system. Recent developments in electronics, magnetic tape recording, and data handling have produced operational flight, field test, and data equipments to acquire and process large quantities of data with degrees of accuracy, precision, and resolution levels not previously attainable.

Airplane Operations Recording

The test airplane data acquisition system must be capable of accurately recording various airplane operating parameters. The system must have a time resolution consistent with that of the noise data, which has been standardized at 0.5 sec, and a precise time base for correlating the airplane operations data with other noise test data. The categories of airplane operation parameters to be recorded are: 1) airplane flight conditions, 2) propulsion system operation, and 3) airplane systems configuration. The parameters considered necessary to define the airplane and engine flight operations, excluding space positioning, are listed in Table 1. An airborne digital data system (ADDS) has been utilized by Douglas for these measurements. The major components for the compact 125-channel version of the ADDS are shown in Fig. 1. The airborne data tape produced has a multiplexed data format which is compatible with the tape-reading facilities of the Flight Data Center.

Table 1 Airplane operation parameters recorded during flyover noise testing

Flight conditions	Engine operations	Airplane systems
Calibrated airspeed	Low-pressure-rotor speeds	External lift/drag systems including flap/slat positions
Pressure altitude	High-pressure-rotor speeds	Landing gear positions
Pitch angle	Engine pressure ratios	Noise-producing systems including auxiliary power unit
Roll angle	Exhaust gas temperatures	Gross weight
Yaw angle	Engine air bleeds	
Total air temperature		
Static air temperature		
Airplane magnetic heading		
Geometric altitude (radio altimeter)		

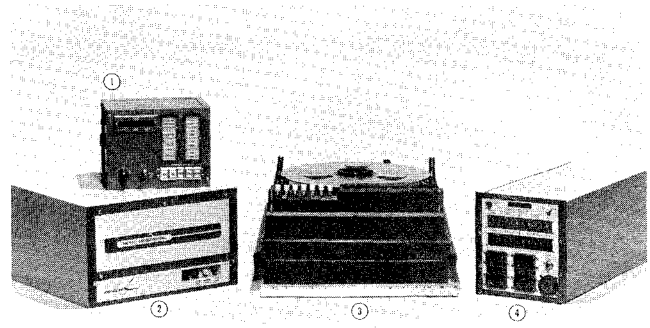

Fig. 1 Airborne Digital Data System; 1) controller, 2) signal conditioner, 3) tape recorder, 4) digitizer, time code generator.

Sound-Path Weather Recording

The measurement of the atmospheric parameters affecting the propagation of the airplane noise to the microphone stations is not well defined in terms of standard equipment or procedures. Transport airplane flyover noise attenuation through the atmosphere is controlled by the moisture content of the sound-path atmosphere. Current practice is to record the weather variables continuously near the ground ("surface"), and intermittently in the atmosphere well above the surface, up to or above the flight path height of the test airplane. The weather data of primary quantitative interest are air temperature and humidity. The values of humidity must be acquired indirectly and various techniques may be utilized. The optimum technique, considering accuracy, reliability, and practicality, consists of measuring the dry-bulb and wet-bulb (or wet-bulb depression) air temperatures and utilizing standard psychrometric relations to determine the humidity. A mobile atmospheric recording tower (MART) has been developed to accurately and efficiently acquire and record the necessary weather data near the surface. The tower extends to a height (above the ground) of 10 m (33 ft) and senses the dry-bulb temperature, wet-bulb temperature, wind speed and direction (a total of four channels), and records the data on strip-chart recorders at the base of the tower. The tower in its operational position is shown in Fig. 2. The errors in accuracy of the temperature channels are within ±0.6°F.

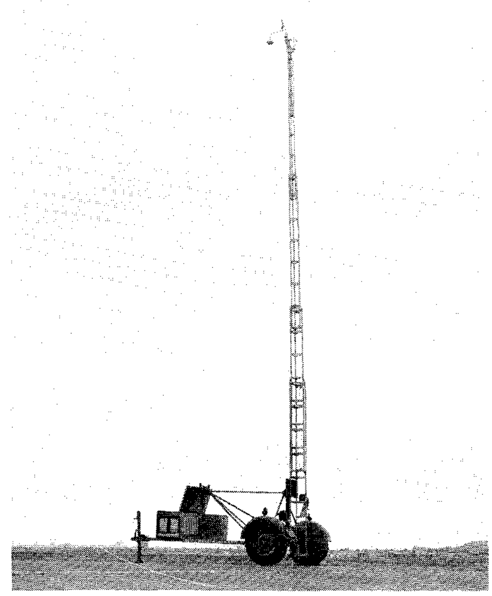

Fig. 2 Mobile Atmospheric Recording Tower (10-meter height).

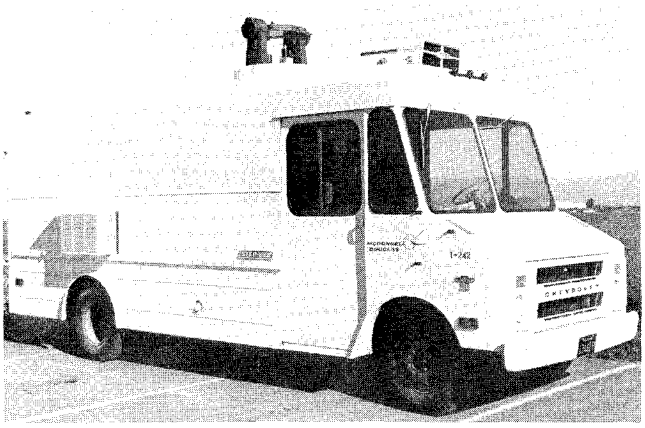

Fig. 3 Mobile Automatic Laser Tracking system.

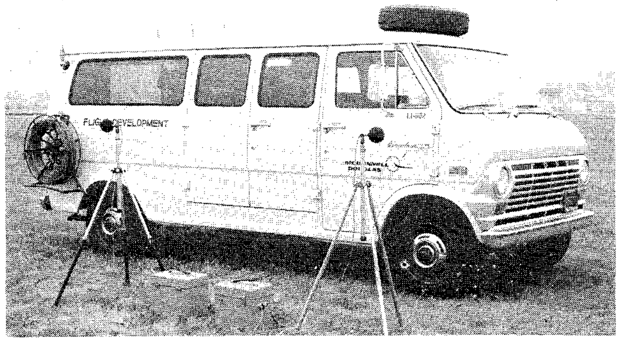

Fig. 5 Mobile noise recording systems.

To determine the primary weather variables in the atmosphere well above the surface, it is necessary to sample the atmosphere intermittently. An efficient method for doing this is to equip a light airplane with a portable sensing and recording system, and fly a predetermined pattern from the runway to the test airplane height and back down to the runway. The sound-path data recorded by the airplane consist of dry-bulb and wet-bulb depression temperature histories, together with pressure altitude and time-of-day. The temperature instruments in the airplane are of the same general type and capability as the surface system described, but require faster thermal response times. In addition, 6-ft-diam free balloons and a ground-mounted balloon theodolite, which tracks the balloons, are used to measure the horizontal wind vector up to any desired height.

Other weather sensing and recording equipment used as secondary systems include: small portable weather stations located at selected microphone stations recording the local temperatures (dry- and wet-bulb or equivalent), wind speed and direction, and existing fixed installations, such as the airport operational weather system. Hand-held motor-driven precision psychrometers (dry- and wet-bulb temperatures) are also available, primarily for field calibration purposes.

Airplane Space-Position Recording

Accurate and high-resolution space-position data must be available during the noise data processing, to define noise propagation distances for basic noise-source identification and sound-path normalization. The propagation distance data must be precisely synchronized in time with the noise data. A variety of methods and equipment such as ground-based electromagnetic radar systems and phototheodolites have been used for space-position recording, but most existing systems have been deficient in one or more important respects. A recently developed space-positioning system has been used for flyover noise testing and eliminates many of the deficiencies of the previous systems. The Mobile Automatic Laser Tracking System (MALT) uses an autotrack monopulse optical radar, with a multipower laser as the ranging beam energy source. MALT is self-contained in a small truck, uses a portable power source, and can acquire, track, and record the position of a retroreflector-equipped airplane. Tracking range is up to 60,000 ft with elevation and azimuth coverages of +45° to −5°, and ±120°, respectively. An external view of the tracker is shown in Fig. 3. The tracker is self-calibrating using ground-based retroreflector-equipped reference targets. The basic tracking data, recorded on computer-compatible digital tape, consist of standard time, a tracker-to-airplane distance (range), and beam azimuth and elevation angles, all at a data rate of 100 samples/sec. The tracker is located (typically) at a lateral distance of 3000 ft from the flight path and between the two ends of the runway when used for runway takeoff climb and landing approach noise testing. One consideration in locating the tracker unit is possible blockage of the reflected laser beam by the airplane wing or tail, depending on the combined effects of the retroreflector location and the airplane flight orientation. The reflector installation consists of a set (10) of 3-in.-diam retroreflectors in a rigid mounting fixture, to allow an incident-beam azimuth angle range of 360° and an incident-beam elevation angle range of 40°. The airplane reflector assembly is usually installed on the upper side of the fuselage, vertical stabilizer, or on the wing tip. Figure 4 is a view of the reflector assembly. Computer processing of the airplane orientation data, together with the tracking data, allows translation of the space-position reference point from the reflector installation to any other location on the airplane.

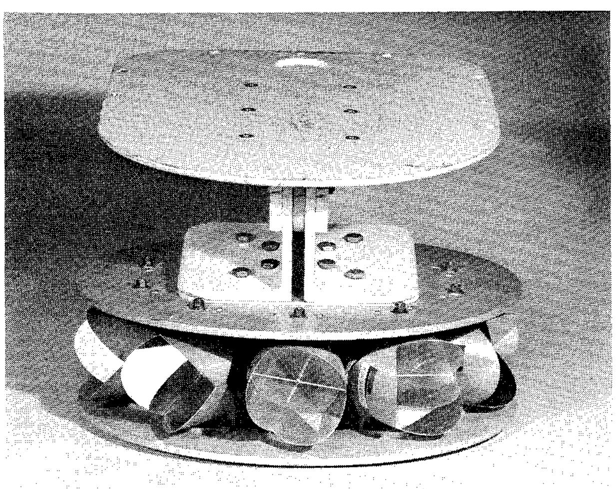

Fig. 4 Laser tracker beam retroreflector.

Noise Recording

Current noise recording systems for flyover noise testing are complex and extensive due to the many considerations involved in the data acquisition. These considerations include microphone station arrays with high over-all system accuracy, wide dynamic range for the system, precise time correlation, data monitoring, large separation distances, reliability, and transportability. A mobile noise recording system satisfying these requirements has been developed and used for a number of flyover noise programs. This system uses a number of instrumentation subsystems which result in data magnetic tapes that can be rapidly processed using compatible automated data-processing

Fig. 6 Mobile noise recording console.

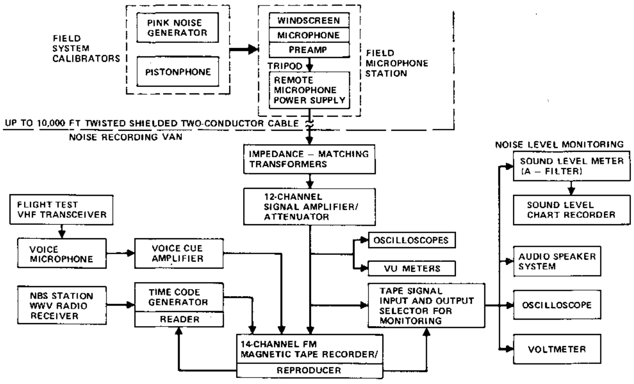

Fig. 7 Noise data acquisition system.

equipment located in the Acoustics and Vibration Data Center. The principal field equipment consists of: 1) a set of field microphone systems and calibration units, 2) microphone signal transmission cables, 3) a central system for microphone signal conditioning, monitoring, tape recording and playback, and 4) a frequency-weighted sound-level monitoring chart display. All of this equipment is installed in a small van-type truck. Two views of the noise recording truck are shown in Figs. 5 and 6 and the interconnection of the principal units is indicated in Fig. 7 (the microphone stations shown in Fig. 5 are normally located well away from the truck). As currently configured, up to 12 microphone stations are deployed at distances up to 10,000 ft from the truck. Each field microphone station weighs 22 lb, including the dry-cell batteries with a built-in recharging system, and is easily transported in a small case. The ½-in.-diam. condenser microphone (with wind screen) systems have a sensitivity range of 32 to 160 dB(A) and a frequency range of 20 Hz to above 12 kHz. Pre-emphasized tape recording (+20 dB at 10 kHz relative to 1 kHz) allows a system dynamic range of 80 dB in the ⅓-octave-band centered at 10 kHz, relative to the maximum flyover noise level. This dynamic range with preemphasis is only necessary with flyover noise spectra that have very steep roll-off in the high frequencies. Field calibrators at the microphone stations include precision pistonphones for sound pressure level (SPL) reference recording and electrical pseudo-random pink noise generators for system frequency response calibration recording. The signal transmission cables are of the low-impedance twisted-pair type, allowing the use of a variety of relatively low-cost and low-weight wires. Additional equipment installed in the truck includes time-correlation units, field and aircraft voice communications, electrical power and air-conditioning systems, and storage provisions. The complete self-contained electrical power system in the truck allows continuous operation of the noise recording system from the truck engine alternator. Short-term operation with a constant-voltage source is also possible with the large Ni-Cad batteries, which can be subsequently recharged from the engine alternator or from external power.

Communications

Sufficient and reliable communications equipment in use during flyover noise testing is vital due to the many separate testing units involved and the real-time coordination required. A typical arrangement of the separate testing units on a ground test range is shown in Fig. 8, indicating the ground distances involved in the communications network. Two different test communication networks are required. One is a ground-to-ground (field) system and the other is an air-to-ground (flight test) system. The field test communications system (operating in the FM-VHF business frequency band) links the space-position recording tracker, surface weather unit, and microphone station personnel with the field central unit. The flight test communications system links the test airplane and the weather airplane (on separate frequencies) with the field central unit. These test systems are in addition to normal airport ground-control and air traffic control radio systems required for aircraft and vehicle operations,

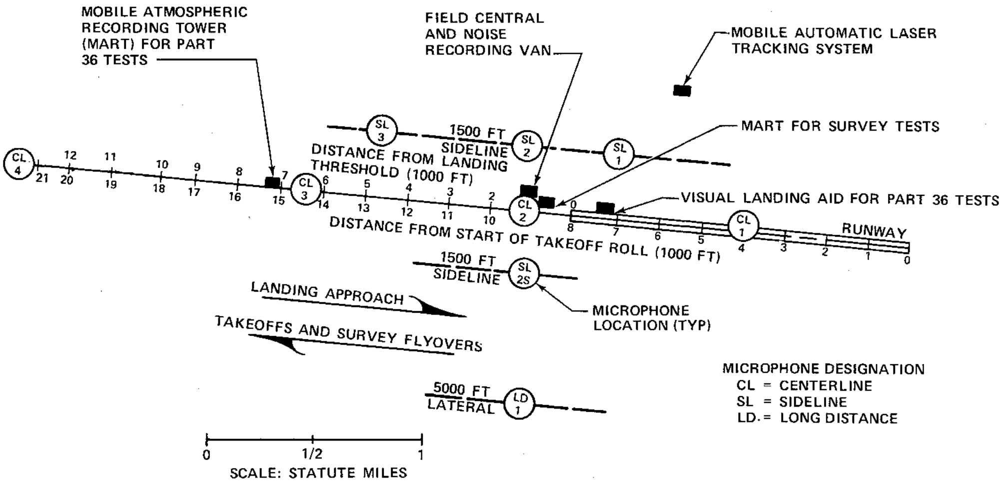

Fig. 8 Noise testing units—typical test range locations.

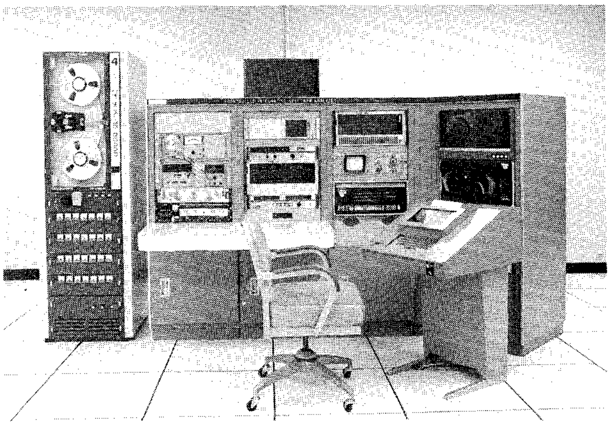

Fig. 9 Controlled Integrating Spectrum Analyzer.

and National Bureau of Standards (NBS) standard-time receivers required for data-time synchronization.

Data Processing

The facilities recently developed for flight test general data processing and for noise data processing were dictated by the accuracy and precision desired, the large quantities of data required, and the need for rapid processing. These data facilities are almost completely automated and consist of the Controlled Integrated Spectrum Analyzer system located in the Acoustics and Vibration Data Center, and the Flight Data Center together with an extensive library of computer programs. The flyover noise tape recordings (from the field) are converted using the analyzer system, to a time series of ⅓-octave-band levels which are recorded on digital computer tape. The analyzer system, Fig. 9, includes an analog tape reproducer, a time-code reader, tape search and control, signal conditioning and monitoring, a ⅓-octave-band parallel-filter spectrum analyzer (using integrating detection techniques), and an incremental digital tape recorder. All of the analyzer system units are controlled by a small programmed digital computer. The interconnection of the principal units is shown in Fig. 10.

The Flight Data Center contains a large-scale digital computer and a variety of output devices including tape drivers, line printers, and Cathode Ray Tube visual and hard-copy displays. A portion of the Flight Data Center computing facilities is shown in Fig. 11. The airborne data tape, the space-positioning data tape from the tracker unit, and the spectrum analyzer system output data tape are all processed and integrated using the large-scale digital computer and the input/output devices. The library of computer programs includes a comprehensive program for noise-data-processing containing a number of subprograms necessary to convert the spectral levels on the

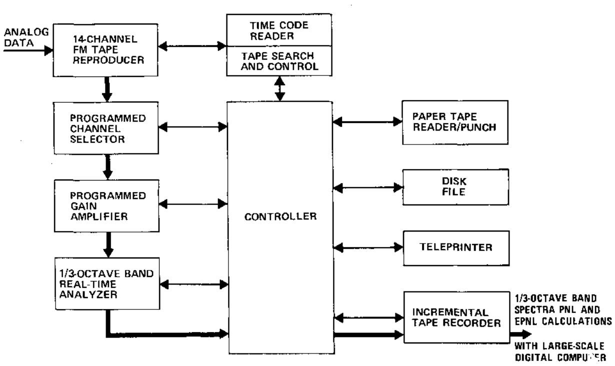

Fig. 10 Controlled Integrating Spectrum Analyzer (principal units).

Fig. 11 Flight Data Center computing facilities.

analyzer output tape into calibrated and edited sound pressure levels (SPLs), and to combine the tracker and air-borne data tapes and SPLs into different types of reference flyover noise levels. The program, written in Fortran IV, contains approximately 4000 statements and requires approximately 1¼ min of computer time for each field microphone tape recording.

Noise Testing Procedures

Flyover noise testing requires special test procedures to obtain noise data that include all data elements with equal emphasis. These procedures primarily involve the operation of the test airplane, monitoring of the sound-path weather, qualifications of the on-site noise levels, obtaining adequate dynamic range and time correlation for the noise recordings, and the integrated data processing for both sound pressure levels and perceived noise levels.

Airplane Operations

To acquire repeatable and accurate airplane flyover noise data, transport airplane flight procedures must differ in several respects from normal takeoff, climb, and landing approach operations. This is due primarily to requirements for noise-source control (engine power management) and flight path (and ground track) control over the discrete locations of the microphone ground stations. Current noise data processing and analysis techniques cannot account for engine power variations, with time or between engine positions, during flight over a microphone ground station. Therefore, the test engine powers must be precisely set and kept constant for that segment of the flight path which results in the significant noise time history at one or more microphone station locations. Special flight procedures become more important for climbs at heights of 1000 ft or greater above the runway (in airline operation, power normally is reduced from a takeoff rating to a climb rating), and special procedures are required during landing approaches where the normal operating parameter of engine power must be kept constant. Therefore, variations must be closely monitored for the normally constant approach conditions of airspeed and glide-slope.

Several factors make it advisable to provide ground track guidance. With discrete microphone ground stations and the uncertainties associated with the noise field axial symmetry around the airplane, it is desirable to control the flight path so that the airplane flies directly over the microphone stations (or to the side for special lateral testing) to minimize data uncertainties introduced by flight path lateral deviations. With the high airplane body angles associated with climbs during noise testing, it is difficult (in the cockpit) to maintain adequate visual contact with the projected ground track of the climbout, including reference to microphone locations. During landing approach noise testing, with the high pilot workload, it is also difficult for the flight crew to monitor and assess the ground track relative to the microphone station locations.

Therefore, to obtain the desired controlled operation of the test airplane over the discrete microphone stations, for both climb and approach testing, the optimum procedure is to broadcast directional advisories from a ground tracking station for specific portions of the test.

Weather Monitoring

The sound-path weather monitoring procedures consist of two parts: 1) forecasting and assessing the acceptable test weather conditions prior to and during the flyover noise testing, and 2) obtaining adequate records of the sound path weather during the flyover noise testing with sufficient detail and accuracy to normalize the measured noise levels to the reference weather conditions for the sound path. The criteria for acceptable test weather conditions depend on the particular phase of flyover noise testing scheduled. For the majority of flyover noise testing, adequate moisture content, absence of thermal inversions, low wind speeds, and adequate visibility are all general weather constraints for acceptable flyover noise test conditions. The weather conditions developed for noise testing, to ensure adequate data accuracy and repeatability, are listed in Table 2. The geographical location for continuous recording of the surface weather (10 m above the ground) must be carefully chosen, as the surface weather recording can be subject to local influences not representative of the conditions at the surface and the sound paths. The monitoring of the weather conditions above the surface (soundings) is dictated by the type and stability of the weather conditions and the time intervals of the noise test flybys. Once initial soundings are made for forecasting, the forecast can be updated by monitoring the surface weather. Test weather conditions may change rapidly (for example, at the beginning of the day); therefore, frequent weather soundings, with adequate coverage in the first few hundred feet, are necessary to provide the data to be used in the subsequent data analysis. Generally, weather soundings as infrequent as one every hour may be adequate to provide the necessary data.

Table 2 Weather conditions for flyover noise testing

Surface temperature and humidity

Temperature range:	Normal	Limit
	45–85°F	40–90°F

Minimum relative humidity:	Temperature (°F)	Normal min RH (%)	Limit min RH (%)
	40	...	75
	45	90	65
	55	70	50
	65	55	40
	75	45	30
	85	35	25
	90	...	20

Temperature and moisture conditions aloft

	Normal	Limit
Temperature vertical gradient (TVG) range, °F/1000 ft	STD ±3	STD ±7
Moisture vertical gradient range, wet-bulb temp, °F/1000 ft	TVG[a] ±3	TVG[a] ±6

Wind speeds

	Normal	Limit
Maximum surface wind speeds:	8 knots[b]	14 knots[c]
Maximum wind speed vertical gradients:	6 knots/1000 ft[b]	12 knots/1000 ft[c]

[a] Refers to actual temperature vertical gradient.
[b] The normal values are based on observations of chart records of flyover SPL's exhibiting small fluctuations.
[c] The limit values are based on observations of chart records of flyover SPL's which exhibit severe fluctuations, and represent a wind shear theoretical limit for atmospheric mechanical stability.

Noise Recording

The measuring of airplane flyover noise requires specific procedures to ensure that the acoustic pressures recorded in the field can be processed to obtain valid flyover noise levels free from the effects of both the microphone station location and the instrumentation system. Because these effects are always present to some time-varying degree, noise recording procedures include the periodic acquisition of ambient noise levels and system calibration levels to provide adequate information for subsequent automatic adjustment of the test SPL's. Three types of associated data recordings are necessary (in addition to the airplane flyover noise recordings) for these purposes: 1) total ambient noise (acoustic ambient noise and instrumentation system electrical noise), 2) reference sound pressure level (generally a low-frequency tone with an SPL error of less than 0.2 dB produced by a pistonphone) for amplitude calibration, and 3) the reference frequency-response signal (either a calibrated broad-band random [or pseudo-random] signal, or a series of pure tones). The multi-channel recording system is sometimes used to obtain over-all maximum dynamic range by the use of two recording channels, set at different ranges, for the same microphone station signal.

The time synchronization of the flyover noise data recordings and the airplane space positioning in the field must be considered of primary importance in the subsequent data processing. After individual units have synchronized the time code generators to a single time source, such as the NBS time standard, any residual time differences can be detected by all field units with the recording of a radio-transmitted audio tone-burst from the airplane time code generator, with subsequent time-differential adjustments during the data processing.

Data Processing

The individual types of data processing and the integration of the data into normalized noise data require procedures generated, in part, by the noise data dynamic ranges, data accuracies, and the multiple and changing formulations of psychoacoustic noise terms. The normalized noise data are the result of data processing using procedures to remove or minimize the variations due to particular test techniques or conditions within prescribed tolerance limits. The four individual types of basic data processed and integrated are: 1) airplane operational parameters describing the noise source, 2) airplane (noise source) space position, 3) atmospheric parameters describing the sound-path propagation conditions, and 4) airplane-emitted SPLs recorded near the ground.

The initial step in data processing is an identification or editing of the noise recordings to determine the "significant flyover noise" time, as defined for the test objectives. For example, the significant time for data in accordance with FAR Part 36 is that during which the noise levels are within 10 PNdB of the maximum perceived noise level (tone-corrected). This time period then determines the significant time period for all four types of basic data to be processed.

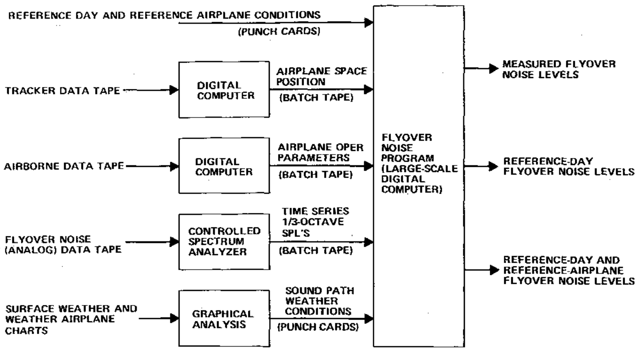

Fig. 12 General data flow.

The airplane operational parameters are processed to define the engine operation and the conditions of the airplane relative to engine noise emitted. No standard techniques have been developed to handle variations in airplane operation during an individual time period of significant flyover noise. Therefore, mean values of airplane operational parameters are derived for the "significant noise" time, always with the limitation of only small variations within the time period. The primary noise-related airplane parameters are the engine power settings, airplane pitch angle, airplane true airspeed, static air temperature, and the freestream air pressure. Other related airplane parameters include the airplane gross weight and external configuration.

With modern tracking systems such as the MALT, airplane position data, with respect to ground reference locations, can be obtained automatically at very high sample rates, and with the required accuracies as a function of standard time. Computer smoothing of the position data is utilized to increase the statistical accuracy of the 0.5-sec-increment position data. For a typical landing approach case, a simulated Monte Carlo error computation resulted in MALT errors of approximately 3 ft for the airplane space position coordinates, with a statistical confidence of one standard deviation, at a tracking range of 10,000 ft. The position data are transformed to an arbitrary noise source reference point on the test airplane, such as midway along a line joining the centers of the two inboard engine exhaust nozzle exits. Finally, using the acoustic velocity (currently based on surface weather), the airplane position is determined for the received noise at incremental time points, accounting for the acoustic propagation time. Therefore, the actual acoustic propagation path length is determined for each spectrum of the airplane-emitted noise time series received near the ground, and these propagation paths are used for the subsequent normalizing (for reference weather) computations. The uncertainty in the airplane-microphone path distance must be less than 6 percent to contribute less than 0.5 dB in noise level uncertainty on just the basis of spherical dispersion of acoustic energy. The precision of the space-position data procedures is also dictated by: 1) the need to determine noise source angular directivity for certain testing, 2) the significant noise propagation times, and 3) the uncertainties regarding a single noise source point on multi-engine airplanes.

Determination of the sound-path propagation medium is accomplished using the field data obtained from the discrete surface weather locations (continuous recordings) and upper-air weather surveys (intermittent recordings). Procedures include an engineering analysis of the weather data, interpolating in time between soundings, to determine the sound-path moisture content, the primary propagation parameter, for each flyover noise test. In addition, the thermal gradient and the surface wind speed and vertical gradient all determine the qualitative acceptability of the sound propagation path, and these data are appraised and documented. Using existing standard values for unit-path-length atmospheric absorption of sound of specific frequency bands as a function of the moisture content,[7] together with the propagation path lengths, the absolute (or differential) atmospheric absorption of the received flyover noise spectra is calculated on an incremental time series basis, using digital computer methods.

The basic acoustic data produced, for the variety of engineering and regulatory purposes, are the airplane-emitted SPLs resolved in ⅓-octave frequency bands (bandwidths of approximately 23% of the center frequency) over the audio frequency range of 45 to 11,200 Hz. The frequency analysis results in a time series of spectra, each spectrum containing 24 SPLs. Instrumentation effects and ambient noise effects are accounted for automatically with the computer routines programmed for data correction and adjustment. Some unique procedures have been developed to account for the presence of documented interfering SPLs and the consequence of having incomplete data spectra as a result of the dominance of interfering SPLs. Although the spectra time series are normally obtained from the analyzer system at increments of ½ sec, digital methods are used to time-average the incremental data from the analyzer system, to result in SPLs corresponding to those on an indicating meter with the dynamic response characteristics of a precision sound level meter set for "slow" damping, as defined in Ref. 8. With the resulting time series of ⅓-octave-band SPLs, corresponding sound-path attenuation values, and the space position of the airplane, a variety of computations can be performed to describe the flyover noise levels of the test airplane. The general data flow into and out of the large-scale digital computer is shown in Fig. 12.

The statistical validity of flyover noise measurements using current practices has been demonstrated to be adequate for regulatory purposes. For example, takeoff flyover noise measurements for heights of approximately 1500 ft, using six flyovers, result in 90% confidence limits for the mean value, of less than 0.8 EPNdB, with data normalized as indicated in Reference 1. Comparable confidence limits for landing approach noise measurements (for a height of 370 ft) are less than 0.4 EPNdB.

Additional Development of Test Techniques

The complex testing as described herein represents substantial costs and efforts; both in testing equipment and technical capability, and in airplane operating expense and schedules. Therefore, additional efforts are justified to improve certain aspects of the current testing techniques and provide adequate techniques for future airplane noise testing. The improvements would result in additional flexibility in airplane testing and increased confidence in the final data.

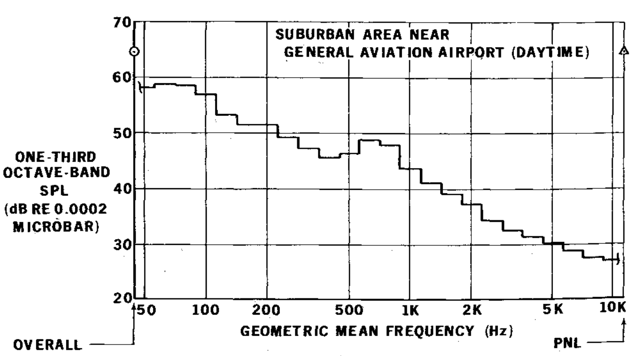

Fig. 13 Typical ambient noise level spectrum.

It is desirable to make improvements in airplane test operations, and appropriate data analysis techniques, to account for testing deviations from defined operational conditions. Currently, in order to obtain acceptable data for given operational conditions, it is necessary to utilize the exact airplane configuration and flight conditions. Techniques or criteria need to be developed for specific airplane operational flexibilities such as using takeoff climbs in place of complete takeoffs to demonstrate flyover noise (FAR Part 36), use of variable lift/drag devices to control flight parameters without affecting airplane noise in the far-field, and data compensation for time-varying flight parameters (such as engine power).

The weather conditions required for acceptable noise testing, and techniques for including the effects of the sound-path weather, are topics that indicate further development and standardization. Current criteria for weather conditions for noise testing do not adequately describe acceptable sound-path (upper air) conditions, nor do they treat the subject of surface or upper-air winds sufficiently. With more complete descriptions of the sound-path weather conditions, standard data processing procedures may be developed to account for the effects of non-reference weather conditions throughout the sound propagation path.

Finally, as airplane noise levels are reduced at the source, and as ambient acoustic levels at airport test sites increase, additional problems will be encountered in discriminating between the existing ambient acoustic levels and the measured noise levels of test airplanes. A typical ambient noise spectrum is shown in Fig. 13 to illustrate the current situation. These problems are compounded with test sound-path noise attenuations higher than reference-weather sound-path attenuations, which at very long distances result in very low levels of received noise. Solutions could include: 1) adoption of standard ambient acoustic spectra on a ⅓-octave-band basis which would determine the lower limits of significance of flyover noise, emphasizing the very-low and very-high frequency bands; and/or 2) field acoustic techniques to minimize existing ambient noise at test microphone stations.

Concluding Remarks

Flyover noise testing of commercial jet transport airplanes has been developed to accommodate the immediate needs of product development and regulatory procedures. The resulting techniques require complex equipment and procedures which produce the necessary data with a minimum of data uncertainty. The type of future development of these testing techniques is indicated to provide measurements with increased validity under conditions of increased testing flexibility.

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