NASA Contractor Report 3540

Recommendations for Field Measurements of Aircraft Noise

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APRIL 1982

NASA

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Prepared for
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NASA
National Aeronautics
and Space Administration

Scientific and Technical Information Branch

1982

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SUMMARY

Specific recommendations are provided for planning and conducting research test programs to measure aircraft noise levels, and associated aircraft, engine and atmospheric parameters, in the field under controlled conditions. Items covered include environmental test criteria, data acquisition procedures, and instrument-performance requirements. The recommendations are based on instrument and data-analysis capabilities generally available in 1981.

For most aircraft, microphones should be mounted on masts at a height of approximately 10 m above the ground to avoid spectral irregularities caused by ground-reflection effects at least for frequencies greater than approximately 100 Hz. For aircraft that produce sound having discrete low-frequency components at frequencies less than approximately 100 Hz, ground-plane microphones may be preferred instead of mast-mounted microphones. For any microphone, the preferred orientation should provide 90° or grazing incidence at all times throughout each recording.

The primary array of microphones is along the ground track below the aircraft's flight path. Microphones may be located to either side of the ground track if the test objectives include a requirement to study the propagation of sound to the side of the flight path. Aircraft configuration and engine power setting should be constant throughout the duration of the recording of the aircraft noise signal from each microphone. The recordings are to be made on magnetic tape from which sound pressure levels as functions of frequency band and time are subsequently obtained. The frequency range of interest is assumed to include 1/3-octave-band center frequencies from 25 to 10 000 Hz.

The preferred test procedure consists of flying the test aircraft several times over the microphone array at different heights and engine power settings. While aircraft noise signals are being recorded, the flight path should be along a nominally straight line and preferably level. Climbing or descending flight paths may be flown, if necessary, since detailed time-correlated aircraft-tracking data are required as well as detailed measurements of meteorological data as a function of height above ground level. Aircraft-tracking and meteorological data are needed to adjust the sound pressure levels measured by the ground-track microphones to the same distance and atmospheric-absorption loss at equal sound-directivity angles prior to ensemble averaging of the time-averaged squared sound pressures in frequency bands.

Aircraft types covered by the recommendations include fixed-wing airplanes powered by turbojet or turbofan engines or by propellers driven by piston- or turbine-powered engines. Noise produced by helicopters can also be measured by making use of the recommendations although the recommended flight procedure might need to be modified to take account of the unique aerodynamic

and acoustical characteristics of helicopters. Test procedures and test instruments other than those recommended here will be required if the test aircraft generates significant levels of sound at frequencies less than 20 Hz, e.g., some helicopters, propeller-driven airplanes, and airplanes equipped with special systems to augment the aerodynamic lift and achieve short takeoff and landing field lengths.

Although recommendations for test operations, data processing, and analysis were outside the scope of the study reported here, the recommended procedures are consistent with assumed requirements for subsequent data processing and analysis. Recommendations for test operations are not presented because specific operational requirements depend on the specific objectives of the test program. Aircraft noise data obtained according to the recommended procedures should be useful for a variety of purposes including development of generalized curves of various descriptors of aircraft noise as functions of distance and engine power setting, verification of engine- and airplane-component noise-prediction procedures, evaluation of noise-suppressor designs, and studies of sound-propagation phenomena.

INTRODUCTION

Aircraft noise levels are measured for a variety of reasons including engineering research and development, demonstration of compliance with requirements for aircraft noise certification [1,2][1], and monitoring of noise around airports [3].

Since the introduction of large jet-powered airplanes in the early 1950s, a number of organizations, including NASA, have evolved procedures for measuring aircraft noise levels in the field. The evolutionary process has been coincident with the growth of the air-transportation industry, advancements in instrument capabilities, and improvements in analytical understandings of sound-generation mechanisms and propagation phenomena. Procedures for measuring aircraft noise levels have included a wide range of techniques for data acquisition and data processing.

Aircraft noise testing for research and development purposes may be uncontrolled or controlled. Uncontrolled testing may have scientific objectives, but atmospheric conditions, engine power settings, aircraft configurations, and flight paths are usually not coordinated with, or controlled by, acoustical test personnel. Controlled tests require close coordination among the acoustical test personnel, meteorologists, aircraft tracking crew, and flight crew.

The subject of this report is acquisition of aircraft-noise data as part of a controlled research test. The report describes recommended procedures to use as the basis for planning and conducting programs for measuring aircraft noise in the field. Recommendations in this report are based in large part on a review conducted in 1976 of aircraft noise measurement procedures [4].

The report begins with a description of assumptions for the subsequent laboratory processing and engineering analysis of the data acquired in the field. The main part of the report covers three topics: environmental test criteria, data-acquisition procedures, and instrument-performance requirements. Data-

[1]Bracketed numbers refer to items cited in the list of references.

acquisition procedures are consistent with assumptions for data processing and analysis.

Recommendations for test operations, data processing, and data analysis were outside the scope of the study reported here. Certain assumptions, however, for data processing and analysis had to be made because data-acquisition procedures are significantly influenced by requirements for subsequent processing and analysis of data recorded in the field. Recommendations are not included for test operations because such details can only be determined once specific test objectives and a specific test site have been established.

SYMBOLS AND ABBREVIATIONS

c — speed of sound at the average air temperature along propagation path, m/s

d_m — minimum distance to the flight path from microphone at R, m

e' — vapor pressure of a sample of moist air at pressure p and temperature T, Pa

e'_w — saturation vapor pressure of a sample of moist air with respect to a plane surface of water, Pa

E — position of an aircraft on a flight path when it emits sound which travels at emission angle ψ to a microphone at R

f_1, f_2, f_3, f_4 — communication frequencies, MHz

h — height above ground level when an aircraft at point O on the flight path is directly over a microphone at R, m

M_a — aircraft Mach number, V_a/c

O — overhead point on the flight path

p — atmospheric pressure, Pa

p'_i — vapor pressure of moist air with respect to a surface of ice, Pa

p'_w — vapor pressure of moist air with respect to a surface of liquid water, Pa

p_0 — standard atmospheric pressure at mean sea level, 101.3250 kPa

P — position of an aircraft on a flight path when a direct sound ray, emitted at point E, reaches a microphone at R

R — position of a microphone below an aircraft flight path

t_r	time associated with a 0.5-s sample of acoustical data relative to the time when the aircraft was directly over a microphone, s
t_s	time associated with a sample of acoustical data, s
t_{s0}	time associated with the first sample of acoustical data, s
Δt	time required for an aircraft to fly from E to P along a flight path and for sound to travel from E to R, s
T	air temperature, K
T_d	temperature at the dewpoint, K
T_f	temperature at the frostpoint, K
T_{01}	standard temperature for water at the triple-point isotherm, 273.16 K
U_w	relative humidity of a sample of moist air with respect to a plane surface of liquid water, percent
V_a	aircraft speed along flight path, m/s
γ	flight-path angle relative to the horizontal, radians
η	auxiliary angle ($\eta = \phi - \psi$), radians
ϕ	aircraft position angle between the flight path and a line from P to R, radians
ϕ_0	aircraft position angle at time t_{s0} associated with the first sample of acoustical data, radians
ψ	sound emission angle between the flight path and a line from E to R, radians

ac	alternating current
ANSI	American National Standards Institute
ARP	Aerospace Recommended Practice
AWG	American Wire Gauge
BCD	binary coded decimal
dc	direct current
EST	Eastern Standard Time
FM	frequency modulation
GOES	Geostationary Operational Environmental Satellite
GMT	Greenwich Mean Time
IEC	International Electrotechnical Commission
IRIG	Inter-Range Instrumentation Group
NAB	National Association of Broadcasters
NBS	National Bureau of Standards
PST	Pacific Standard Time

rms	root mean square
SAE	Society of Automotive Engineers
UHF	ultra high frequency
UTC	Coordinated Universal Time
VFR	visual flying rules
VHF	very high frequency
WWV	NBS radio station, Fort Collins, Colorado
WWVH	NBS radio station, Kauai, Hawaii

APPLICABILITY

Aircraft types to which the recommended test procedures are applicable include those with rotating wings (e.g., helicopters) as well as fixed wings. At the time of the test, the aircraft may be operated at any gross weight within its design capabilities although operations at high gross weights may be needed in order to fly along a nominally level flight path with a given aircraft configuration (i.e., flap setting or ratio of drag to lift) at high engine power settings.

Test airplanes may be powered by turbojet or turbofan engines (of any bypass ratio) or propellers (driven by reciprocating piston engines or by turboprop engines). Afterburning in the turbine-discharge duct to augment thrust may be used with the turbojet or turbofan engines; fuel may also be burned in the fan-discharge duct of turbofan engines to increase thrust. Turbojet or turbofan engines may be equipped with variable-geometry inlet or exhaust systems which are maintained in a constant position during the noise tests. Propellers may be fixed pitch or variable-pitch.

The recommended procedures are intended to be applicable to tests conducted with a test aircraft operated under flight conditions that are approximately steady. However, all instruments and the environmental criteria recommended here are suitable for measuring aircraft noise during non-steady flight conditions as well as during a ground-runup operation.

Results of field tests conducted in accordance with the recommendations are records that can be used for subsequent processing and engineering analysis. Results of the analyses could, for example, include (1) determination of the variation of different descriptors of aircraft noise with distance and thrust, (2) verification of engine- and airplane-component noise-prediction procedures including forward-motion or flight effects as well as airplane-installation effects, (3) evaluation of the effectiveness of noise-suppressor designs, and (4) studies of sound-propagation phenomena.

GENERAL TEST OBJECTIVE

The general test objective is to determine 1/3-octave-band sound pressure levels at fixed intervals of time throughout the duration of a recording of aircraft noise. The sound pressure levels are to be equivalent to those that would have been measured in an acoustic free field and are to be reported in decibels (dB) with reference to the standard [5] pressure of 20 micropascals (20 μPa). For most tests, the nominal center frequencies [6] (geometric mean frequencies) of the 1/3-octave-band filters will range from 50 to 10 000 hertz (Hz), though lower, or possibly higher, band-center frequencies may be required for some tests although different instruments and test procedures may be required to record valid data at frequencies less than 20 Hz or above 15 000 Hz. Each set of 1/3-octave-band sound pressure levels is to be associated with corresponding values of engine or propeller operating parameters, airplane flight and configuration parameters, airplane-position data, and atmospheric data measured from near the surface of the ground to, or above, the greatest height that the test aircraft achieves during the sound recording.

ASSUMPTIONS FOR DATA PROCESSING AND ANALYSIS

Details of the data-acquisition plan depend on procedures for processing the data, techniques that will be used for analyzing the data, and data-reporting requirements.

Data Processing

Processing of flight-test data is assumed to be accomplished in a specially equipped laboratory where automatic, or semi-automatic, procedures are used for data reduction. A large-memory, high-speed digital computer performs all the calculations needed for correcting and adjusting the data and labeling the results with appropriate identifying information. No detailed, on-line data processing is accomplished in the field. A calibration laboratory is available to support the total effort of data acquisition and data processing.

To increase the level of confidence in the results, the sound pressure levels measured by the microphones under the flight path will be ensemble averaged at equal sound directivity angles after normalization, if required, to the same propagation distance and atmospheric-absorption loss.

Basic Noise Data

At each microphone, the basic noise data are the recorded variations with time of the sound-pressure signals from which 1/3-octave-band sound pressure levels are determined at discrete intervals of time throughout the duration of each recording of aircraft noise. All sound pressure levels are corrected for interference from background noise that is 5 dB, or more, below the indicated band pressure level. No background noise corrections are attempted and the indicated band pressure level is rejected if the background noise level is less than 5 dB below the indicated band pressure level. All sound pressure levels are also corrected for variations in microphone directional response at high frequencies, deviations from non-flat frequency response (including effects introduced by the windscreen), and for differences between the effective bandwidth of corresponding ideal filters for white-noise input. The accuracy of each 1/3-octave-band sound pressure level is ±1.0 dB, or better.

The total duration of a recording is generally from the first time the wideband, or flat-weighted, aircraft noise signal is 5 dB greater than the level of the flat-weighted average background noise level to the last time the signal returns to the level which is 5 dB greater than the flat-weighted average background noise level. The longest duration is associated with low-frequency aircraft noise signals, i.e., generally with 1/3-octave-band center frequencies less than 500 Hz.

Associated Parameters

Accuracy of the determinations of distance between the microphones and the aircraft reference point is assumed to be ±2 percent, or better. Accuracy of determining the net thrust or power produced by the engines is ±5 percent, or better. Accuracy of the measurements of airspeeds is ±10 percent, or better.

Accuracy of time synchronization between (1) the recording of the aircraft noise levels, (2) the recording of the corresponding aircraft and engine parameters, and (3) the recording of aircraft space-position, or tracking, data is assumed to be ±0.01 sec, or better.

Adjustments to Reference Conditions

Measured sound pressure levels, after being corrected for microphone directional response, frequency response, and background noise, are assumed to be adjusted to remove ground-reflection effects and to yield data equivalent to that which would have been measured in an acoustic free field. After the measured sound pressure levels have been adjusted to equivalent free-field conditions, it may be desirable to develop and apply additional adjustments to reference conditions so that results from various tests conducted at various times and at various places may be compared on an equal basis with confidence.

Specification of reference conditions for use in analyzing any particular set of data from a test, or series of tests, depends on the purpose of the analysis. Unlike aircraft noise certification, it is not necessary to have a constant set of reference conditions for research. On the other hand, reference conditions specified for aircraft noise certification are likely candidates to use for many analyses.

A clear specification of reference conditions is required to minimize the magnitude of the adjustments from test-to-reference conditions. Thus, the specified reference conditions should be the target, or nominal, conditions prescribed for conducting the tests. If actual test conditions are not rather close to reference conditions, the magnitude of the adjustments can be large.

Items to consider when defining reference conditions include:

- flight path
- aircraft gross weight as a percentage of maximum takeoff gross weight or maximum landing gross weight, as appropriate
- airspeed
- aircraft configuration (e.g., flap-deflection angle, speed-brake position, and the position of the landing gear)

- position of any variable-geometry devices in the engine's inlet or exhaust ducts

- number of engines that should be operating

- referred net thrust produced per engine or appropriate engine-power-setting parameter

- elevation of the ground

- direction of the steady component of the wind relative to the direction of flight and to the direction of sound propagation to the microphones

- vertical gradient of the steady wind

- gustiness of the wind and the steadiness of the wind direction at the surface and aloft

- presence or absence of a layer of cloud or fog and, if present, its height relative to the height of the aircraft's flight path

- average temperature of the air at the surface and aloft and its vertical gradient

- average relative humidity of the air at the surface and aloft and its vertical gradient

- pressure of the air at the surface and aloft and its vertical gradient

- for propellers, rate of the propeller's rotation and the amount of power supplied to the propeller by the engine

ENVIRONMENTAL CRITERIA

For aircraft noise research testing, there are three items of primary importance related to environmental criteria: (1) characteristics of the test site, (2) level of the ambient noise present during the tests, and (3) meteorological conditions of the atmosphere near the surface and aloft. Since the test objectives include studies of sound propagation as well as noise generation and suppression, it is not appropriate to establish highly restrictive conditions for environmental criteria. General environmental criteria for aircraft-noise research testing may thus be established mainly on the basis of practical considerations related to the instruments and equipment available in 1981 for field testing and to the general test plan wherein the test aircraft is flown in a stabilized configuration along nominally straight flight paths at various heights over an array of microphones.

Test Site

Most aircraft noise tests have been conducted in the vicinity of an airport, airbase, or airfield. The aircraft is flown over a runway or taxiway. Microphones are located under, and sometimes to the side of, the nominal ground track (the ground projection of the aircraft's flight path). For future aircraft-noise research tests, the test site does not have to be located in the immediate vicinity of an airport since the general test plan would not usually include a requirement to measure aircraft noise under actual takeoff or landing flight paths.

General.-To provide maximum flexibility to maneuver the test aircraft and the meteorological data airplane, to minimize the duration of each test, and ensure low levels of ambient noise, the test site (whether at an airport or not) should have as little local aircraft traffic as possible.

A test site not located at an airport should be selected so as to be relatively close to some airport where the test aircraft can be landed, serviced, and fueled. The site probably should not be more than one flying hour away from an airport where maintenance can be performed. A home airport is needed to accomplish certain aircraft-configuration changes such as modification of engine-nacelle components.

The test site could, for example, be a large, flat field or meadow adjacent to a straight section of a road in a rural area. Microphones under the flight path could be located in the field to one side of the road. The road, or even a straight section of a fence, could be used by the pilot as an aid in lining up the flight path so as to fly over the microphones. Bright-colored targets fixed to the ground could be used to provide additional visual clues and help minimize lateral deviation from the desired flight path.

Automotive traffic, if any, on the road should be temporarily halted if it is loud enough to interfere with the aircraft noise recordings. Permission to control traffic would have to be arranged with appropriate authorities. There should be no noisy farm animals or farming operations in the field. An airport could be used as a test site if there was a large grassy field next to an unused runway or taxiway with no interfering aircraft traffic and low ambient noise levels.

Because the tests should be conducted under visual-flying-rules (VFR) conditions and because the recorded sound pressure levels will be easier to interpret if the atmosphere is relatively clear and stable, test sites should be avoided that have many days per year with poor visibility because of fog, low clouds, or some form of precipitation. Test sites in a location where atmospheric conditions are not stable for more than a few days at a time, because of periodic passage of weather fronts, may be used if test-schedule delays can be accommodated at a reasonable cost.

Elevation.-The elevation of the test site above mean sea level affects the acoustic power produced by the aircraft's engines and the propagation of sound through the atmosphere. The influence of reduced atmospheric pressure should be negligible for elevations to approximately 300 meters. Test-site elevations of as much as 700 to 1000 meters require small-to-moderate adjustments to a reference elevation at sea level. Elevations above 1000 meters would entail increasingly larger adjustments to the as-measured sound pressure levels if the reference elevation is at sea level.

Terrain.-The terrain surrounding the test site should be approximately flat with no mountains or hills to interfere with aircraft operations. The general slope of the ground surface should be no more than ±30 m in 1 km (±2°) in any direction for a distance of at least 5 km from any microphone location.

A test site could be located in the general vicinity of a large body of water (e.g., a lake, reservoir, or ocean) providing the body of water is not close to any microphone location and that wave or surf action does not contribute significantly to the level of ambient noise. However, sites located near large bodies of water are not desirable because those locations experience regular daily patterns of on-shore and off-shore breezes. On-shore winds increase in strength and gustiness from the morning to the afternoon as the sun heats the land. Off-shore winds occur in the evening as the land cools.

Unless the purpose of an aircraft noise test is to study ground reflection effects from a variety of ground surfaces, at any location where sound from the test aircraft can be reflected to the microphones for any sound emission angle of interest, the terrain around the microphones should be as acoustically absorptive as possible. The ground surface should be a naturally-occurring surface such as a grassy field. The surface may be plowed if it is also further smoothed by a disc harrow or similar device to eliminate ridges left by a plow. If the ground surface is covered with grass or other plants, the plants should not be more than approximately 10 cm high. Placing sheets of man-made sound-absorbing material on the ground is not recommended because the large area to be covered imposes severe penalties because of logistics and cost. Moreover, most such sound absorbing materials are not designed for outdoor use and deteriorate relatively rapidly in regular field testing. The sheets would need to be quite thick to be absorptive to 50 Hz.

To ensure that the ground surface has a relatively high degree of sound absorption, the ground should not be frozen or covered by ice or snow. Surfaces consisting of rocky or gravel-covered ground or hard sun-baked adobe soil should be avoided.

Clear zones.-Large, tall objects in the vicinity of the microphones or along the line of sight from the microphones to the aircraft can reflect or refract the sound and modify the measured noise signal. There should be a clear zone around each microphone in which there are no objects such as large structures, trees, or hills. The clear zone should be that space defined by a cone with its vertex at a microphone, a conical half angle of 80 degrees, and a height of 3 km. The recommended clear zones also provide an adequate obstruction-free region for the aircraft-tracking system to track the aircraft as it enters and departs the test area.

Background Noise Levels

Background noise level is the sound pressure level indicated by the data-acquisition/data-processing system in the absence of a signal from the test aircraft. Background noise includes ambient sounds and the equivalent electrical noise of the acquisition/processing system.

The level of the electrical system noise is established by the choice of instruments, especially the tape recorder.

The level of the ambient sound is established by the choice of test site. Once a test is underway, there is little that can be done to reduce the level of the ambient sound. To assess the prevailing level of intermittent and steady-state background noise at different times of the day on various days of the year, sound levels should be measured, before any aircraft noise tests are conducted, in the area around candidate test sites.

Measurements of background noise level should be obtained using a precision-grade type 1 sound level meter. An integrating-averaging sound level meter is preferred because it provides simplicity of operation and more-reproducible measurements. The microphone should be placed approximately 1.5 m above ground level. A conventional sound level meter [7, 8] may also be used.

Each sample of background noise should represent the 30-sec average of the frequency-weighted squared sound pressure. Preferred frequency weightings are the FLAT (or the LINEAR or the C weighting) and the A weighting which is specified in References 7 and 8.

Candidate test sites have acceptable levels of ambient noise if, for each sample of ambient sound,

- the 30-second-average flat-weighted sound level is no greater than 70 dB, preferably no greater than 60 dB;
- the 30-second-average A-frequency-weighted sound level is no greater than 55 dB, preferably no greater than 45 dB;
- the difference between the flat-weighted and the A-weighted background noise level is at least 15 dB; and
- there are no audible discrete-frequency sounds, such as electrical transformer hum, present when the ambient sound levels are measured.

At some candidate test sites, sounds produced by birds and insects may interfere with measurements of low-level high-frequency aircraft noise, such as occur with long-propagation distances and highly absorptive atmospheric conditions. Interference caused by sounds made by birds and insects depends on the time of the day as well as the season of the year at a test site, with more interference occurring during spring and summer months than during fall and winter months. For measurements of noise produced by quiet aircraft, or even moderately quiet aircraft at long distances, it is particularly important to ensure that the level of the ambient sound when the aircraft noise signal is being recorded, does not exceed the recommended maximum values, especially the 55-dB value for the average A-weighted sound level.

Atmospheric Conditions

There are at least six physical quantities to consider when specifying limitations on atmospheric conditions for aircraft-noise research testing. They are: (1) air temperature, (2) atmospheric humidity, (3) air pressure, (4) wind, (5) atmospheric turbulence, and (6) precipitation or condensation. To obtain high-quality recordings of aircraft noise signals over the frequency range of interest with instruments available in 1981, some limits on allowable ranges for those quantities need to be established. The horizontal extent of the region of the atmosphere to which the limitations apply should be large enough that weather-aloft data are applicable to all sound propagation paths from the beginning to the end of each flyover noise recording.

Temperature and humidity.-The temperature and humidity of the air along the sound propagation paths are the principal physical quantities that determine the amount of acoustical energy absorbed from a sound wave propagating through the atmosphere. Atmospheric pressure influences atmospheric absorption, but with a relatively small effect since large changes in atmospheric pressure are not encountered over most pathlengths of practical interest and because the elevation of most candidate test sites is not likely to be more than 300 to 400 m above mean sea level.

Expressions for the functional dependence of atmospheric absorption on temperature, humidity, and pressure of the air and the frequency of a sound are available in an American National Standard [9]. The amount of acoustical energy absorbed from a sound wave as it propagates through the atmosphere depends on the length of the sound propagation path as well as the three meteorological parameters and frequency. Long propagation paths result in low signal levels, especially at high frequencies. Even with the best of available instruments, the combination of long pathlengths and highly absorptive meteorological conditions easily reduces high-frequency signal strengths to levels well below the level of the high-frequency background noise. Furthermore, the high-frequency part of the spectrum of the sound from an aircraft may have such a steep slope when measured by a microphone in the acoustic far field that the power transmitted in the stopband of a filter in the data-processing system can exceed that transmitted in the nominal passband. The result can then be high-frequency band pressure levels that are greater than they should be even though the filter's transmission-response function meets all applicable requirements [10, 11].

For a given test site and a particular set of data-acquisition and data-processing instruments, two options are available for assuring valid measurements of high-frequency sound pressure levels. Either restrict the length of the sound propagation path with few limitations on meteorological conditions at the time of a test, or restrict the range of allowable meteorological conditions aloft to those which should result in minimal attenuation per unit distance and hence permit measurement of valid data over the longest pathlengths and to the highest frequency. The preferred option is to accept a restriction on the length of the propagation path at the highest frequency of interest. That choice provides the operational advantages associated with being able to conduct tests over a wide range of meteorological conditions.

But what ranges of meteorological conditions should be allowed? A recommendation for the ranges of air temperature and relative humidity was developed after examining the distribution of temperatures and corresponding relative humidities likely to be encountered at candidate test sites in the USA.

Connor, Copeland, and Fulbright [12] examined several thousand weather-sounding records to derive statistical distributions of observed values of temperature and relative humidity over a 10-year period at eleven different locations in the USA. The data in Reference 12 are presented in tabular form at height intervals of 200 m from the surface to a height of 1400 m. The distributions are arranged in four 3-month groups to show seasonal trends.

Approximate values for the most-often-observed temperatures and relative humidities were obtained by inspection of the tabulated distribution data in Reference 12. The data in Table 1 represent surface conditions for the eleven locations and four seasons. The data are further subdivided by time of day according to the two times for which data were available, namely early morning at 1200 hours Greenwich Mean Time (GMT) and late afternoon at 0000 hours GMT.

Figure 1 is a plot of all the data from Table 1 for the approximate average surface temperature and average relative humidity for the four seasons at the eleven locations. The symbols with "tails", representing temperatures and humidities in the early morning hours, tend to cluster on the right side of the graph in the range of relative humidities from 85 to 95 percent, although there were some locations where the average early-morning relative humidity was between 75 and 85 percent except for Denver which was drier because of the elevation of 1611 m.

Data for the late afternoon hours cover a wide range of temperatures and humidities with the lowest humidities being associated with Glasgow, Montana; Denver, Colorado; Columbia, Missouri; and San Antonio, Texas. Temperatures and humidities for the afternoon hours (0000 hr GMT) represent conditions likely to be encountered in the majority of aircraft noise tests conducted during daylight hours.

Dashed lines around the data points in Figure 1 indicate an approximate envelope for the range of surface conditions. The envelope extends outside the limits of the plotted data to take into account, approximately, the variations in the actual observed values of surface temperature and humidity. The variation is large at northern locations such as Caribou, Maine and Green Bay, Wisconsin and at other locations not near an ocean. The variation is relatively small at locations near an ocean, especially the more-southern locations such as Miami, Florida, and San Diego, California. The smallest variation from morning to afternoon and from season to season was that for the cool and moist weather at Tatoosh Island, Washington, in Puget Sound.

On the basis of the data in Reference 12 and other studies of long-term trends of surface meteorological conditions, it appeared that average daily temperatures greater than 30° C in conjunction with average daily relative humidities greater than 50 percent are rarely found at locations in the continental USA. Average relative humidities less than 20 percent at the surface would also be rarely found at candidate test sites, except those at high elevations. The relative humidity *aloft*, however could often be less than 20 percent though usually in association with temperatures greater than 15° C. Cold and dry conditions at the surface or aloft, in the lower left corner of Figure 1 outside the envelope line, are not likely to be encountered at a candidate test site.

Given (1) the understanding of the effect of the atmosphere on sound absorption contained in the standard ANSI S1.26-1978 [9], (2) the survey of long-term average temperatures and relative humidities at the surface from Reference 12 as summarized in Table 1 and Figure 1, and (3) a consideration of the effects of temperature and humidity on the operation of the instruments as well as the engines, it is recommended that the test-time air temperature be between 0° C and +40° C and that the test-time relative humidity not be greater than 90 percent with no condensation. The temperatures and relative humidities included within the recommended ranges are to be those existing at *any* height between ground level and the greatest height flown by the test aircraft during a recording of the noise it produces.

Because the actual recordings of aircraft noise will usually be accomplished during daylight hours after solar heating has warmed the air near the ground surface and dissipated the normal late-night and early-morning inversion of the vertical profile of the variation of temperature and relative humidity with height above ground level, the lower temperature limit of 0° C will usually apply to an air temperature measured at some height above ground level with a corresponding surface temperature greater than 0° C. The surface temperature, however, could be as low as 0° C if the vertical lapse rate was zero, or positive, for some distance near the ground.

Conducting tests when the air temperature is less than 0° C is not recommended because the accuracy of calculations of atmospheric absorption is not as good when temperatures are less than 0° C and also because of instrument problems such as thermal gradients between a calibrator and a microphone; low battery output; embrittlement of magnetic recording tape, the insulation around electrical cables, and photographic film; and an increase in the resistance between lubricated components as a result of increased viscosity of the lubricants. Furthermore, at low temperatures, special efforts are required to obtain valid humidity data because the moisture content of the air at saturation decreases as temperature decreases and because condensation freezes on the elements of the instruments and significantly increases the time needed to obtain correct humidity data.

The upper temperature limit of 40° C is consistent with the range of best accuracy of the calculation procedure for atmospheric absorption [9] as well as with the usual limit of air temperature to which jet engines can maintain take-off-rated thrust.

The upper limit of 90 percent on relative humidity was selected to allow tests to be performed under the high-relative-humidity conditions prevailing during many early-morning hours.

It was also recognized that some tests might be conducted with capacitor-type measurement microphones that use air as the dielectric between the diaphragm and the back plate. To avoid electrical noise problems associated with ionization of humid air in the strong electric field in the gap between the plates of the capacitor, the microphone may be warmed by a special heating coil in the preamplifier and a dessicant incorporated between the ambient air and the vent to the air gap. Alternatively, capacitor-type measurement microphones with an electret material to provide the polarizing voltage may be used, as recommended, instead of those having air for the dielectric and an external source for the polarizing voltage. Electret-type microphones have few problems with operation at relative humidities as high as 90 percent even at high temperatures where the moisture content of the air is high, providing there is no condensation onto the microphone [13].

A statement concerning allowable vertical lapse rates of temperature and humidity is needed to complete the specification of limitations on air temperature and relative humidity during a test. The average vertical lapse rates over the height ranges of interest may be positive, negative, or zero. No restriction is placed on the average value of positive or negative lapse rates providing meteorological parameters are measured at height intervals of 30 m, or less, and at times close to the beginning and end of the recordings for each aircraft test condition.

While no restriction on average lapse rates is considered necessary, the lapse rate for temperature or relative humidity should be relatively consistent over the height range of interest, i.e., consistently negative or consistently positive. Vertical profiles comprised of segments having positive and negative lapse rates should be avoided. The optimum temperature lapse rate to avoid refraction of the sound along the propagation paths from the aircraft to a microphone is a zero gradient over the height range. If the temperature lapse rate is nonzero, the sound will follow curved instead of straight paths from the aircraft to the microphone and thereby complicate the identification of the propagation pathlengths and sound emission angles, depending on the degree of curvature, i.e., on temperature gradients.

A zero gradient for relative humidity in conjunction with a zero gradient for temperature will also minimize subsequent problems with interpretation of the atmospheric absorption loss over the various propagation paths.

Pressure (or Elevation).-No limitations on atmospheric pressure, or test-site elevation, are considered necessary. However, the atmospheric pressure at the surface (at a height of 10 m) and aloft should be measured as part of the regular sampling of meteorological parameters.

Wind and atmospheric turbulence.-Wind and wind gradients (meaning gradients in the vertical profile of the wind) create special problems for outdoor noise measurements. If a microphone is upwind of a noise source, it may be in a wind-induced shadow zone where the measured sound pressure levels are lower than they would be in the absence of wind, and conversely for downwind. If microphones are located to the sides of the ground track and the wind direction is not in line with the flight direction, the crosswind component of the wind can introduce an asymmetry in sideline noise measurements.

Wind gradients and wind shears aloft also cause sound waves to be refracted from the path they would have followed in an atmosphere without wind gradients. Wind shear is the change in the horizontal component of the wind over some height interval, i.e., a vertical wind shear.

Friction caused by wind blowing over the ground surface produces turbulence. Solar heating of the ground during the course of a day causes temperature plumes in the air. The regions of heated air are distributed by the wind. Atmospheric turbulence is thus characterized by fluctuations in the velocity and temperature of the air. The strength of the turbulence varies greatly in time and extent, both horizontally and vertically [14]. The net effect of the propagation of sound through a turbulent atmosphere may be a reduction in the sound pressure level at a microphone relative to what would have been measured in a quiescent atmosphere because some sound energy is scattered away in another direction.

At the present time, there is no validated method for quantitatively evaluating the effect of atmospheric turbulence on sound propagation, although airborne and ground-located systems are available for measuring temperature and velocity fluctuations [15]. Until proven measurement and analysis procedures are available to account for atmospheric turbulence effects, aircraft-noise research tests should be conducted with calm-to-moderate winds with few gusts, throughout the test region and not just at the 10-m surface-measurement location.

Wind direction as well as wind speed should also be approximately constant. When the wind speed is low there are few problems with wind-induced noise at the microphones. Variations in wind direction, even at low wind speeds, cause variations in the direction of sound propagation from the source to the microphone and hence variations in the amplitude of the received sound signals.

To minimize problems with measuring and interpreting the recordings of aircraft noise, the following wind restrictions are recommended. If, during a test, the wind speed increases and remains above the limits, the test should be postponed or terminated and rescheduled.

- From a height above ground level of 10 m to a height at least equal to the maximum height of the test airplane during the duration of any flyover noise recording, the average wind speed should not exceed 5 m/s and wind gusts should not exceed 8 m/s.

- The magnitude of the average crosswind component should not exceed 3 m/s over the same ranges of height and time.

Precipitation or condensation.-Precipitation, in any form or amount, during the recordings of flyover noise is undesirable because it produces noise and has a deleterious effect on test operations and instruments, and because it is impossible in subsequent analysis to remove precipitation-related effects from the noise recordings. There should be no measurable precipitation in any form in the region of the test site during any of the flyover noise recordings.

DATA-ACQUISITION PROCEDURES

Data-Acquisition System

As indicated schematically in Figure 2, the total data-acquisition system has six component subsystems. Recordings of aircraft noise level and position along the flight path and of aircraft and engine parameters must be closely synchronized in time. Time also relates the recordings of meteorological parameters with the recordings of aircraft noise. The sampling rate for meteorological data is relatively low because meteorological parameters vary much more slowly with time than sound pressure signals or aircraft position along the flight path.

The communications block at the bottom of Figure 2 includes the various radios needed to coordinate operations among ground personnel, and the crews of the test aircraft and the meteorological data aircraft.

Information to be Recorded

Table 2 lists the acoustical, tracking, airplane, and engine data that, except for calibrations, are to be recorded for each pass of the test airplane. At least two acoustical calibrations should be recorded on each test day, once before the first recording of aircraft noise and once again when all tests are completed. Tracking calibration needs to be done at least once per test day. Special engine parameters that may need to be recorded include pressures and temperatures within the engine case, as well as the position of movable components such as blow-in doors on engine-inlet cowls, variable-pitch fans or stator vanes, and variable-area exhaust nozzles. Table 3 lists weather data that are to be recorded periodically. Table 4 lists supplemental information required for labeling and reporting.

Recording of the parameters listed in Table 2 is to be correlated by simultaneous recording of synchronized time-code signals. Each primary data system should have a time-code generator.

Acoustical Data

Central or portable tape recorders.-A key issue in the overall planning of a program to measure aircraft noise levels is whether (1) to base data acquisition on the use of a central multi-track tape recorder with several remotely located microphones connected to it by long cables or (2) to base data acquisition on the use of several portable tape recorders having two-to-four tracks on which the signals from microphones are recorded through relatively short cables. Selection of the system for recording noise levels in the field affects the system for processing the recordings as well as the procedures for conducting the field tests.

A centrally located multi-track tape recorder would probably be an instrumentation-grade machine with at least 14 tracks using one-inch-wide magnetic recording tape and the frequency-modulation (FM) recording method. The recorder would be installed in an airconditioned van or trailer. The recorder would probably require 60-Hz electrical power supplied by a motor-driven generator or, in an emergency, an inverter operating from batteries. Noise from operation of the generator would be controlled so that it does not influence the recordings of aircraft noise signals.

Portable tape recorders would use the direct (or amplitude-modulation) or the FM recording methods. Electrical power would be supplied by internal batteries or an external battery. The recorder should be kept inside a vehicle which is parked at least 50 m from the microphones. If a vehicle is not available, use of a small folding table, with a shield or umbrella to provide protection from the sun, is recommended.

Principal advantages of the central multi-track-recorder approach are the greater degree of control and the improvement in coordination of test activities that a central operation can provide. Furthermore, all data channels are synchronized automatically since microphone signals and a time-code signal are all recorded simultaneously. In addition, the use of the FM recording method allows the recording of sound pressure signals to as low a frequency as permitted by the microphone.

The principal advantage of a portable tape recorder, if it uses the direct-recording method, is that the maximum ratio of signal-plus-noise to noise is 15 to 20 dB greater than that of typical instrumentation-grade 14-track FM tape recorders. Portable tape recorders that use the FM recording method, even those that include automatic gain control to limit the amplitude of large signals, are not recommended because the mininum signal that they can record is of the order of 30 dB greater than the minimum signal that can be recorded with portable tape recorders that use the direct recording method.

The frequency response of direct-recording portable tape recorders does not extend as low as on recorders that use FM recording but does extend to 20 to 25 Hz and thus should be sufficient for recording the low-frequency sound produced by most aircraft.

The preferred instrument for recording aircraft noise signals is a portable tape recorder that uses the direct-recording method. That recommendation is based primarily on the superior electromagnetic performance capability of that type of recorder, particularly the greater ratio of signal-plus-noise to noise compared with that typically available on 14-track FM tape recorders. The total cost of acquiring, operating, and maintaining a system based on portable two-track tape recorders is considered to be less than (or at worst not exceed) the comparable cost of a central system based on a multi-track recorder.

While portable two-track tape recorders are preferred, a 14-track FM tape recorder in a central, airconditioned van could certainly be used to record the aircraft noise signals. However, valid recordings of high-frequency sound pressure levels cannot be obtained over as wide a range of meteorological conditions, or over as long a propagation path, as can be obtained with a portable two-track tape recorder. The portable tape recorder has a lower level of internal electrical noise and hence can record lower levels of wideband sound signals than can the typical 14-channel tape recorder.

Microphone locations.-As indicated by the schematic plan view in Figure 3, there should be at least four microphones at the primary locations under the flight path of the test aircraft. Optional microphone locations to the side of the ground track are also indicated in addition to the instruments for measuring meteorological data at the surface and aloft and for tracking the position of the test aircraft along its flight path.

The array of microphones shown in Figure 3 assumes that the test aircraft is flown back and forth in a series of passes over predetermined flight paths. Figure 3 also indicates the use of a central, or control, van where the test director would monitor test operations as well as measurements of meteorological data at the surface and aloft. The van also serves as a central place to store and transport the microphone systems, tape recorders, magnetic tape, spare batteries, and other supplies. A central van is desirable even if there are as few as four microphone stations where acoustical data are being recorded.

The recommended distance in Figure 3 between the four microphones along the nominal ground track is 100 m. A spacing of 100 m corresponds to a time difference of 1 to 1.5 seconds between corresponding samples of 0.5-sec-average sound pressure levels.

Ensemble averaging.-Four microphones are shown at successive locations along the ground track in Figure 3 to make use of time- and ensemble-averaging, as described in Reference 16, to improve the resolution of the determination of airplane position on the flight path. Because the level of an aircraft noise signal varies continuously as the aircraft flies over a microphone, the signal must be averaged over time to obtain statistically valid results. The averaging time periods should not be too long nor too short. If data are required to band-center frequencies as low as 50 Hz, an averaging time of 0.5 sec provides a reasonable confidence level.

In any given 0.5-second period during an aircraft-noise recording, the position of the aircraft on the flight path and the associated sound emission angle will change. The rate of change depends on the height of the flight path and the speed of the aircraft. Ensemble averaging of several independent samples of 0.5-second-average sound pressure levels reduces the uncertainty, and improves the resolution, of the determination of the average sound emission angle to associate with each sample of sound pressure level data.

The analysis in Appendix A presents an expression relating aircraft position angle to the minimum distance to the flight path, airspeed, and the time of a sample of sound pressure level data. The time-rate-of-change of aircraft position angle is greatest when the aircraft is closest to the microphone. Rapid rates of change are associated with close distances and high airspeeds.

As an example, assume a minimum distance to the flight path of 100 m, an airspeed of 80 m/s (approximately 155 knots), then Equation (A11) from Appendix A indicates that the time-rate-of-change of aircraft position angle is 0.8 radians per second or approximately 46 degrees per second around the time when the aircraft is closest to the microphone. If there was a sample of 0.5-sec-average sound-pressure-level data at the time of closest approach, the uncertainty in the value of the aircraft-position angle associated with that sample of acoustical data would be ±23 degrees.

The uncertainty in aircraft-position angle may be reduced by forming the ensemble average, on the basis of mean-squared sound pressures, of the same aircraft noise signal recorded by several microphones (i.e., for the same sound-emission angle, propagation distance, and atmospheric absorption). If four microphones are located under the flight path as in Figure 3, the uncertainty in aircraft-position angle is reduced by a factor of four or to approximately ±6 degrees for the conditions of the example.

To implement the use of ensemble averaging for each valid sample of acoustical data, the test aircraft should be stabilized in the desired nominal flight conditions (airspeed, fuselage attitude, flight path angle, and engine power setting) well before reaching the first microphone and should maintain the target conditions until well past the last microphone. Variations in minimum distance to the flight path, engine power setting, and airspeed may be evaluated by making several passes over the microphone array. Repeat runs should improve the overall level of confidence in the data.

Sound-recording system.-Figure 4 shows the preferred arrangement of the various components for recording aircraft noise signals from one microphone onto one of the direct-recording data channels of a portable, two-channel tape recorder. Signals from the time-code generator, or voice signals from the cue microphone, are recorded in the FM mode on a special channel. Considerations concerning the choice and use of certain components of a sound-recording system are discussed in the following sections.

Microphone type.-Capacitor-type (or condenser-type) measurement microphones are preferred. The preferred arrangement for establishing the electric field, and hence the nominal charge, between the two plates of the capacitor is by use of a pre-polarized or electret material in the gap between the diaphragm and backplate. An electret capacitor microphone does not require an external source of direct-current (dc) voltage to maintain the charge on the capacitor.

Capacitor-type microphones that only have air, no electret, in the gap between the plates may also be used although they require an externally-supplied dc voltage to establish and maintain the electric field. Capacitor microphones that use an external dc voltage and only have air in the gap between the diaphragm and backplate have more severe problems than electret-capacitor microphones with sudden sensitivity shifts and internal noise as a result of ionization breakdown when the moisture content of the air is high.

Microphone design.-Measurement microphones are designed primarily for use with precision sound level meters and thus are designed either to have, and be calibrated for, flattest response for random incidence if the sound level meter is to meet the ANSI requirements of Reference 7 or to have flattest response for 0° (i.e., perpendicular or normal) incidence if the sound level meter is to meet the IEC requirements of Reference 8. Measurement microphones are also designed for flattest frequency response when measuring the sound field inside a small enclosed volume such as in a coupler for calibration of hearing aids, i.e., a "pressure-response" microphone. For a 1/2-inch-diameter "pressure" microphone,the response at 10 kHz to sounds arriving with grazing or random angles of incidence is not more than 2 dB different from the response in a cavity.

The preferred design for the capacitor microphone is one that yields the flattest frequency response for sounds that impinge on the diaphragm with random angles of incidence. Use of a pressure microphone in a grazing or random-incidence sound field generally results in extending the pressure microphone's region of essentially flat response to frequencies above 10 kHz, thereby making a pressure microphone a suitable alternative for a microphone designed to have flat random-incidence response.

Measurement microphones are generally available with nominal diameters of 25 mm (one inch) and 13 mm (1/2 inch). Microphones having diameters much less than 13 mm are generally less sensitive, have higher levels of internal noise, and poorer low-frequency response though better high-frequency response. A nominal diameter of 13 mm (1/2 inch) is preferred over a nominal 25 mm (one inch) diameter because the smaller diameter yields a more uniform angular response (i.e., is more omnidirectional) to higher frequencies. The 13-mm-diameter microphones can be designed to have the same nominal sensitivity as the 25-mm-diameter microphones.

Microphone height above ground plane.-Because an objective of the tests is to produce sound pressure levels equivalent to those measured in an acoustic free field, the preferred arrangement is to mount the microphones on masts (or poles or towers) as high as practically feasible above the absorptive ground plane. A height of at least ten meters is recommended.

Microphone heights of the order of 1 to 1.5 m are not recommended for research tests because of the complications introduced by spectral irregularities caused by interference effects between the direct and reflected sound waves [17,18].

For any sound-emission angle, a 10-m height, in combination with the preferred microphone orientation, should minimize the amplitude of interference effects between sound waves that reach a microphone along a direct path from the aircraft and sound waves that are reflected from the ground surface to the microphone, at least for frequencies greater than 100 Hz. A 10-m height means that spectra at times around the time of closest approach may have some ground-reflection interference effects at frequencies less than 100 Hz.

For most jet-propelled airplanes as well as many propeller-driven airplanes and helicopters, use of mast-mounted microphones in combination with an analytical technique during data processing to remove, if necessary, low-frequency ground-reflection effects should permit equivalent free-field sound pressure levels to be determined by subtracting 3 dB from the as-measured frequency-band sound pressure levels.

However, some propeller-driven airplanes or helicopters may produce discrete-frequency sounds at frequencies less than 100 Hz. To measure the noise produced by those aircraft, a ground-plane-mounted microphone may be preferred over a mast-mounted microphone. The simple pressure-doubling that a ground-plane microphone should provide at any frequency should eliminate spectral irregularities caused by ground-reflection effects and thereby permit the determination of equivalent free-field sound pressure level, of any spectral component in the sound from the aircraft, by subtracting 6 dB from all measured sound pressure levels.

If a ground-plane microphone is used to avoid ground-reflection effects in the signal at the microphone, special care is needed to obtain a close approximation to a 6-dB pressure doubling at all frequencies of interest [19]. Techniques that have been employed to achieve that objective have included laying a microphone on a flat sheet of plywood, mounting a microphone through a flat plywood sheet so that the microphone diaphragm is flush with the surface, mounting a microphone flush by means of a right-angle adaptor in the curved surface of a flat-bottomed done-shaped metal structure, and mounting a microphone vertical, and a short distance above and pointing down at, a flat metal plate that is glued to a larger flat, rigid surface such as a runway.

The ground-plane surface around the microphone should be large compared with the wavelength of the lowest frequency of interest. It should be smooth, rigid, and have low acoustical absorptivity. To minimize thermal gradients and turbulence in the layer of air near the surface as a result of solar heating, the ground plane should be light in color, preferably white [20]. If a ground-board is used, sound diffracted from the edges of the board may combine with sound received directly at the microphone and produce interference patterns in the high-frequency part of the spectrum [17,21]. If the "inverted-microphone" technique is used [22,23], the distance between the ground plate and the diaphragm should be selected to minimize interference effects in the frequency range of interest for all angles of incidence encountered during the flyover noise tests.

Some type of windscreen should be installed around the ground-plane microphone to reduce the effects of velocity fluctuations in the boundary layer near the ground on the signal received by the microphone. The bottom surface of the windscreen should mate closely to the ground plane with minimal gaps.

For whatever type of ground-plane microphone installation chosen, a special laboratory calibration may be required to determine the relative response of the microphone, as installed, as a function of angle of incidence and frequency. Such data are usually not available from manufacturers of measurement microphones. The calibration should include the windscreen as a component of the total installation.

Microphone orientation.-For every microphone, the preferred orientation is that which yields grazing, or 90°, incidence for direct sound waves at all times throughout every recording of aircraft noise. Grazing-incidence response is achieved by mounting a microphone such that the diaphragm is in the plane defined by the aircraft's flight path and the center of the diaphragm. Grazing incidence, see Figure 5, requires positioning the microphone's longitudinal axis parallel to the ground surface for locations along the nominal ground track. For locations to the side of the ground track, the mounting angle should be determined from the nominal or target height of a flight path and the perpendicular distance to the ground track from the sideline position.

Incidence angles are defined between the microphone's longitudinal axis and the sound ray describing the direction a sound wave travels. An angle of 0° is for a ray that impinges on the microphone perpendicular to the plane of the diaphragm; an angle of 90° is when a ray is parallel to, or grazes, the diaphragm. Grazing incidence provides a microphone diffraction correction, as a function of frequency, which is the same for all instants of time throughout the duration of every recording of aircraft noise.

Because the test aircraft's flight path may deviate from the target flight path, the actual sound incidence may not always be at a nominal grazing incidence. However, if the variation is not more than ±10° about 90°, the variation in the diffraction correction for mast-mounted microphones should not exceed ±1 dB at 10 kHz for the preferred 13-mm-diameter microphones, with smaller variations at lower frequencies.

Microphone mast.-The design for the mast to support the microphone should permit easy access to the microphone for calibration and adjustment, as required, of the mounting angle so as to maintain the desired orientation for every test flight path. The mast could be designed as a tilt-over tower with a counterweight at the base. Another possibility is a telescoping design where the sections are raised by a hand-cranked winch and cable or pneumatically by means of a foot-operated air pump. Outriggers, or guys, may be used to provide additional stability.

The microphone, preamplifier, and windscreen should be supported from a short boom near the top of the tower. The diameter of the boom and any bracing rods should not exceed 1 cm within 1 m of the microphone to minimize interference effects caused by high-frequency reflections.

To prevent extraneous acoustical or electrical noise, the preamplifier-extension cable should not be permitted to slap against the structure of the mast.

Microphone windscreen.-A large-diameter porous windscreen should surround every microphone during every recording of aircraft noise. The purpose of the windscreen is to reduce the amplitude of low-frequency pressure fluctuations associated with airflow around a microphone, while having minimal effect on the amplitude of the sound-pressure signals from the test aircraft [19,24].

Each time a microphone mast is lowered to apply calibration signals or to adjust the sound-incidence angle, any significant amount of dirt, dust, or moisture that may have collected on the outer surface of the windscreen should be removed or the windscreen should be replaced by one that is clean and dry. Dirty windscreens may be washed and re-used after drying.

Preamplifier.-Capacitor microphones are mounted on preamplifiers. The main function of a preamplifier is not to provide voltage gain, but to convert the high electrical impedance at the output of the microphone (typically greater than 10^9 ohms) to a low impedance (typically less than 25 ohms). A low impedance is needed to drive long signal cables without introducing significant attenuation of signal amplitude.

The preamplifier-extension cable does not need to have more than three conductors if, as recommended, the microphone uses an electret material to provide the polarizing voltage. The cable should contain shields providing 100-percent coverage for the three conductors. The three conductors include one for high-potential signal voltages, one for circuit ground and dc return, and one for the positive lead from the source of dc power (i.e., the batteries in the weather-resistant enclosure). The length of the preamplifier-extension cable will probably be between 12 and 15 meters.

Preamplifier power supply.-Preamplifiers operate from a source of dc electrical power. If electret-capacitor microphones are used, the power supply should furnish approximately 20 V to the circuit elements within the preamplifier. If air-gap capacitor microphones are used, an additional source of high voltage (typically 150 V to 200 V) is needed for the polarizing voltage.

The dc electrical power is preferably supplied by batteries. The batteries should have sufficient capacity, even at low air temperature, to deliver enough current, at the high signal voltages corresponding to high sound pressure levels, that high-frequency components of the signal may be transmitted without distortion. The preamplifier's requirement for idle (no-signal) current should be minimal so as to maximize the power supply's operating time.

Signal cable.-As indicated in Figure 4, it is envisioned that a long cable will be used to transmit electrical signals from the microphone to the tape recorder. For a test setup as in Figure 3, the maximum length of signal cable is of the order of 500 meters. The preferred cable construction is a twisted pair of insulated conductors surrounded by conducting shields and covered by a protecting outer jacket.

The electrical impedance of a signal cable, as stretched out in the field, consists of distributed capacitances, inductances, and resistances. The cable's capacitive reactance is usually much larger than the inductive reactance even at the highest frequency of interest. The capacitive reactance decreases with increasing frequency and hence more current is required from the preamplifier's power supply to drive the same voltage as frequency increases, unless restrictions are placed on the maximum length of signal cable or the highest sound pressure level to be measured or unless a line-driving amplifier is used to supplement the current capacity of the preamplifier power supply.

Performance characteristics recommended for the microphone, preamplifier, dc power supply, and signal cable are compatible with transmission, over a 500-m cable with negligible distortion, of 10-kHz spectral components at a sound pressure level of 100 dB. No line-driving amplifiers should be required.

The amplitude of the signal from the preamplifier will be attenuated as a result of the loading of the capacitive reactance of the preamplifier's output-coupling capacitor by the total capacitive reactance of the cable. However, for the recommended type of preamplifier and the anticipated maximum length of the recommended type of cable, the attenuation should not exceed 0.5 dB.

The most significant effect of a long signal cable is the effect on the frequency response of the total measurement system at high frequencies as a result of resonances among the inductances, capacitances, and resistances that are distributed along the two conductors and shields. For cable lengths to 500 m, the variability in frequency response should not exceed ±1 dB for frequencies less than 20 kHz and should be accounted for by a pink-noise electrical calibration.

The signal cable should be able to withstand moderate abuse. However, when uncoiling the cable and when re-coiling it, care should be taken not to pull too hard to avoid damage to the outer jacket, shield, insulators, or conductors. Vehicles should not be allowed to drive over the cable, nor should it be walked on or stepped on by people or animals. If practical, the cable should be re-coiled at the end of each test day to avoid theft or damage from rodents chewing on the cable.

Enclosure for preamplifier power supply.-The dc power supply for the preamplifier should be kept in a rugged, weather-resistant enclosure. The enclosure should be light in color, preferably white, to minimize heating from solar radiation and should have a hinged and lockable cover. Weatherproof connectors should be provided on the sides of the enclosure for the preamplifier extension cable and the signal cable.

Spare sets of internal batteries may be stored in the enclosure. The enclosure is a convenient place to store the preamplifier extension cable, as well as the preamplifier, microphone, and windscreen. The sound level meter and its output cable could also be stored in the enclosure so that most of the components of a data channel are kept in one place. To minimize contamination of gold-plated terminals and shields on the microphone and preamplifier as well as to help prevent damage to the field-effect transistor in the preamplifier because of accidental exposure to a high-voltage charge of static electricity, the microphone may be kept mounted to the preamplifier when stored in the enclosure for transportation or between tests.

Maximization of the ratio of signal-plus-noise.-To take full advantage of the capabilities of the tape recorder and to consistently maximize the ratio of the signal to the inherent background noise, the maximum value of the aircraft noise signal should always be recorded at a standard, but relatively high, recording level. That standard recording level should be such that the amplitude of a signal at the input to the record amplifier is safely below the amplitude of a sinusoidal signal that would exceed the linear response of the magnetic tape. The maximum recording level corresponds to the amplitude of a sinusoidal signal at the input to the record amplifier which would cause the total harmonic distortion of the signal on playback to exceed a specified amount, typically 1.5 percent.

The standard recording level for a maximum flat-weighted aircraft noise signal should be at least 10 dB less than the maximum recording level for steady sinusoidal signals. A minimum 10-dB margin is needed to permit proper recording of short duration random peaks in the aircraft noise signal as well as to allow for signal levels being greater than anticipated because the test aircraft's actual flight path is not the same as the target flight path.

The recommended method of maintaining a high ratio of signal-to-noise is to amplify the maximum wideband (10 Hz to 20 kHz) signal from the preamplifier so that the rms voltage at the input to the tape recorder is always relatively high at a value between 200 and 500 mV. The tape recorder's input gain control should be adjusted so that the maximum wideband signal is always recorded as close as possible to the standard record level.

Depending on the sensitivity of the microphone, the type of aircraft, the engine power setting, and the distance of closest approach, the wideband rms signal voltage from the preamplifier might range from 0.1 mV to 1000 mV. To provide the capability of adjusting that 80-dB range of signal voltages so that the maximum voltage is always near the preferred value requires the use of an adjustable-gain, low noise, wideband, low-distortion, signal-conditioning amplifier. Sound level meters are the preferred instruments to provide that function and, as shown in Figure 4, should be located at the end of the signal cables prior to the input to each acoustic data channel on the tape recorder. Gain adjustments on the sound level meter should be in 10-dB steps and for each step the full-scale (full-range) voltage at the output should be in the desired range.

Maximizing the signal-to-noise ratio also requires attention to maintaining proper continuity of the electrical shielding from the preamplifier to the input to the sound level meter. If pickup of radio signals by the shield is noticed, it may be helpful to connect the shield, at the tape-recorder end of the signal cable, to earth ground by an insulated wire that avoids contact with the metal structure of the vehicle in which the tape recorder and sound level meters are located.

Recommendations for Recording Acoustical Data

Magnetic tape.-The equivalent electrical noise associated with the ferromagnetic coating on the tape is a factor in determining the tape recorder's signal-to-noise ratio capability. A nominal total tape thickness of 25 μm (1.0 mils) is preferred as a compromise between minimization of problems with print-through from one layer to another, minimization of problems resulting from stretching or mechanical distortion of the tape, and the desire to have as long a tape as possible on a given diameter reel (i.e., the longest recording time per reel). The backing material may be a polyester film; acetate film is not recommended.

In selecting the magnetic recording tape, the primary considerations should be (1) the sensitivity of the magnetic coating, (2) the residual noise of the magnetic coating, and (3) the amount of distortion introduced by the magnetic characteristics when recording at maximum record level. Low residual tape noise is probably the most important characteristic with high-frequency sensitivity next.

The level of the voltage of the high-frequency bias signal in the tape recorder should be adjusted to give the minimum amount of third-harmonic distortion consistent with high values of output signals at 1 kHz and 10 kHz.

Tape speed and equalization.-Tape speed when recording should be either 19 cm/s (7.5 inches/s) or 38 cm/s (15 inches/s). At either tape speed, the input signal should be recorded through an equalization or spectral pre-emphasis network in the record amplifier. The equalization network increases the amplitude of high-frequency and low-frequency components of the signal. The amount of the increase applied at any frequency is a function of tape speed, with more pre-emphasis applied at 19 cm/s than at 38 cm/s. On playback, the signal is passed through a de-emphasis network, which has a frequency response that is the converse of the pre-emphasis network, and then through an amplifier to the output terminal. The combination of the use of pre-emphasis and de-emphasis within the recorder provides a nearly-flat overall frequency response over a wide range of frequency when using the small record and playback heads suitable for a portable battery-powered tape recorder. The preferred equalization pre-emphasis/de-emphasis response curves are those standardized by the National Association of Broadcasters (NAB).

Because the sound pressure level of high-frequency signals may be very low as a result of atmospheric absorption, various techniques have been employed to recover data which would otherwise be lost. The techniques have included: (1) placing a high-frequency pre-emphasis network before the input to the tape recorder to boost the high-frequency content of the incoming signal, (2) recording the signal from a microphone on two channels but with a high-pass filter before the recorder in one channel so that high-frequency data on that channel may be recorded at a higher gain setting (the "split-spectrum" technique), and (3) recording signals from two side-by-side microphones (or from one microphone) on two channels but with the gain on one channel set at the standard recording level while the gain on the other channel is set at, or above, that for maximum recording level (the "one-overdriven-channel" technique).

Use of an external pre-emphasis network augments the high-frequency boost provided by the internal equalization circuit and could therefore mean that the signal was distorted by being recorded at too high a level. The effect of distortion cannot be removed by using a de-emphasis network during data reduction. Overload conditions in the record amplifiers are not indicated on the meter that monitors the level of the input signal or the level of the signal after it has been recorded.

The split-spectrum technique is not recommended because it requires twice as many tape recorders or permits half as many microphones and hence entails significantly greater costs for acquisition and processing of data from the same number of measurement locations. The use of the high-pass filter also causes problems with interpreting and analyzing the data.

The one-overdriven-channel technique has the same problem as the split-spectrum technique in requiring more tape recorders and hence greater costs. Furthermore, experimental evidence has not been published to establish that the nonlinear processes involved with tape saturation do not distort the waveform and hence influence the high-frequency band sound pressure levels.

None of the three special techniques for enhancing the recording of the high-frequency signals is recommended as part of the procedure for measuring aircraft noise for research purposes.

Recording of calibration signals.-Field calibrations should be recorded at the beginning of each test day before recording any aircraft noise signals. All equipment should be turned on for at least 10 minutes before applying the calibration signals.

Because the electromagnetic properties of magnetic recording tape can vary as much as ±1 dB from one roll of tape to another, acoustical calibration information should be recorded at least once on each reel of tape. Additional recordings of calibration signals should be obtained whenever an opportunity becomes available. Calibration signals should be recorded each day after all tests are completed. If a day's tests are accomplished in a group (or groups) with a substantial time break between groups (e.g., for refueling), then calibration signals should be recorded at the beginning and end of each group of aircraft noise recordings.

Acoustical sensitivity calibration consists of recording a reference sound pressure level from an acoustical calibrator that generates sinusoidal signals. If the calibrator can generate calibration signals at more than one sound pressure level, then select a calibration level close to the estimated maximum flat-weighted wideband sound levels for the next several test runs providing that level is at least 20 dB greater than the flat-weighted ambient sound level prevailing at the time. A calibration frequency of 1000 Hz is preferred, although other standard frequencies [6] may also be used.

If the acoustical calibrator can generate signals at several frequencies, then record the calibration signals, at one sound pressure level, at all available frequencies. Comparison of a data channel's relative response to acoustical signals with the relative response determined from laboratory calibrations will assist in revealing the development of problems with the microphones or other components of the measurement system. The absolute sensitivity of each data channel is, however, to be established at one calibration frequency.

To record each acoustical calibration, first adjust the gain of the sound level meter to provide the greatest on-scale indication on the instrument's analog or digital indicator. Then adjust the step attenuator on the tape recorder until the input-monitor meter indicates that the input signal is at the standard recording level. Record the acoustical calibration signals for at least ten seconds. The nominal frequency and level of each acoustical calibration should be announced on the tape, recorded by writing in a log, and written on the tape box label. Also note and record the date, approximate time of day, data channel number, microphone serial number and location, gain setting and meter reading of the sound level meter, and the attenuator setting and reading of the monitor meter on the tape recorder. Time-code signals from the time-code generator should be recorded on the special channel at the same time the acoustical calibration signals are recorded. Repeat the recording of acoustical calibration signals on the second data channel.

Because the sensitivity of a capacitor microphone is a function of temperature, the sensitivity changes when the microphone is exposed to a temperature gradient and sufficient time must be allowed for the sensitivity to stabilize after a sudden change. Sensitivity changes can occur when a cold microphone is placed inside a warm calibrator. Exposure to a temperature gradient of the order of 20° C could cause a sensitivity shift of the order of 0.5 dB. When the microphone is again exposed to the cold air, the sensitivity will return to its original value; the recovery time may be as long as 15 to 30 minutes for sudden sensitivity shifts of the order of 0.5 dB. To minimize sensitivity shifts caused by temperature gradients, the temperature of that part of the calibrator which is placed around the microphone should always be approximately equal to the temperature of the microphone.

The level of the acoustical calibration signal should be monitored on the sound level meter and, at the key or master station, also on the level recorder. For each acoustical data channel, the level of each subsequent recording of the acoustical reference signal should be within ±0.5 dB of the level of the pre-test reference signal.

If variations in the level of the acoustical calibration signal exceed ±0.5 dB at the calibration frequency during the course of a day's testing, the tests should be delayed until an investigation can be conducted to determine the cause of the unacceptably large drift. If calibrations are only performed at the beginning and end of each day's tests, the levels of the two calibration signals should be within ±0.5 dB for the tests on that day, for that channel, to be considered valid. If the variation exceeds ±0.5 dB and no explanation can be found, test data from that channel may have to be disregarded. Additional tests may have to be run to obtain valid aircraft noise data.

The system frequency-response calibration signal is to be a wideband pseudorandom electrical voltage having the spectral characteristics of so-called pink noise, i.e., a spectral slope of -10 dB/decade for the spectrum level of the mean-squared voltage per unit frequency. The pink-noise generator should be set to produce a flat-weighted wideband rms voltage of the order of 10 to 50 mV. The signal should be coupled into the preamplifier through the capacitance of a dummy microphone or through a suitable adapter with the microphone removed. System recording gain should be adjusted to record the wideband signal near the standard recording level for a duration of at least 30 seconds. Time-code should also be recorded. Gain settings and other information should be noted.

To minimize variability in calibration signals recorded on different channels on the various tape recorders, only one acoustical calibrator, one pink-noise generator, and one dummy microphone should be used. The time-code generator at each recording station should be updated by re-synchronization against a master time-code generator whenever acoustical data channels are calibrated.

Signal monitoring.-The level recorder shown on the right-hand side of Figure 4 is used to monitor the flat-weighted level of the recorded signal for the purpose of assisting in determining when to terminate a recording. A two-channel level recorder may be used if it is necessary to monitor the signals from both acoustical data channels. To provide some damping, the level recorder's pen-writing speed should approximate the 125-ms exponential time constant standardized for the fast time weighting on a sound level meter [7,8].

Each tape-recorder operator should monitor the quality of the recorded signals by listening on a headset. While a headset should be provided for each tape recorder, a level recorder is required only at one key redording station.

Recording of aircraft-noise signals.-Each recording station should be furnished with estimates of the maximum values of the flat-weighted or wideband sound pressure level expected from the test aircraft for the particular aircraft configuration, engine power setting, airspeed, and minimum distance applicable to each run. The system gain or amplification to be used when recording the aircraft noise signal is then determined by adjusting the system gain used when recording the acoustical calibration signals. The adjustment is determined from the difference between the level of the maximum wideband aircraft noise signal and the level of the acoustical calibration signal. Gain adjustments should be made first to the sound level meter (preferably in 10-dB steps) and then to the input level control on the tape recorder. The preferred 1-dB steps on the tape recorder's input level control permit the operator to attempt to always record the maximum flat-weighted level of the aircraft noise within ±2 dB of the standard recording level.

Each recording of aircraft noise should include sounds from as wide a range of sound-emission angles as possible. The recordings should start before the aircraft noise signal first begins to increase above the level of the background noise and should continue until the signal is no longer above the level of the background noise.

To provide an unambiguous determination of the background noise present at the time of a recording of aircraft noise, record a sample of background noise just prior to the start of every recording of aircraft noise. The sample of background noise should be recorded for at least 10 seconds and should be made at the same gain settings selected to record the aircraft noise signal.

Each aircraft-noise recording should be associated with a pre-assigned test run number, or other unique identification code. The run number identifies the nominal aircraft configuration parameters and engine power setting as well as the predicted values for the maximum wideband sound pressure levels at each microphone. The test aircraft should fly in either an oval racetrack pattern or an elongated figure-eight pattern. The length of the pattern should take into account other aircraft traffic that may be in the area. The length of the pattern, or the circuit time per run, should also allow for the time required by meteorological-data aircraft to sample the weather aloft, the samples being obtained at no greater than 30-minute intervals.

The crew of the test aircraft should establish stable flight conditions well before flying over the first centerline microphone. The distance back from the first microphone may be estimated by making use of Equation (A9) from Appendix A with $\psi = 5°$. For example, for a minimum microphone-to-airplane distance of 100 m, an airspeed of 100 m/s and an aircraft Mach number of 0.3, a sound-emission angle of 5° occurs 8 seconds or 800 m before the aircraft is over the microphone. If the minimum distance to the flight path (or nominal overhead height) is 1000 m, the distance back to where $\psi = 5°$ is 8 km (approximately 4.3 nautical miles).

The distances or times before reaching the first microphone can thus be substantial and the flight crew should be advised of the requirements. It may be useful to have large, readily visible landmarks to the sides of the flight path at both ends of the array of centerline microphones in Figure 3 to assist the crew in judging their position relative to the first microphone. Landmarks off each end of the centerline array may help the flight crew fly the test aircraft in both directions over the array.

Because the test aircraft is not likely to always be visible to the tape-recorder operators, radio communications should be used to announce when a test run is about to occur. Someone in the flight crew should broadcast a warning when the aircraft is 60 seconds, or more, before starting to be set up for the next test run. At that time, all instruments in the measurement system that had been shut down to conserve battery power should be turned on. A period of 10 to 20 seconds may be required to build up the charge on capacitors in the various electronic circuits and to reach stable operating conditions.

After checking the setting for the gain to be used for recording the aircraft noise signal, the operator at every station should record a brief announcement which states that the signal being recorded represents the recording of background noise before test run number XX. Also announce the gain setting on the sound level meter and tape recorder for each data channel.

Upon completion of the announcement, the tape should continue to record the background noise signals and the selector switch should be set to permit the modulated 1-kHz time-code signal to be recorded on the third track. The peak-to-peak voltage of the time-code signal at the tape recorder should be between 2 and 3 V to yield a signal-to-noise ratio of approximately 40 dB.

At the key tape-recorder station where the level-recorder is located, note the test run number and gain settings on the chart paper. Select a paper speed which will permit a display of the complete aircraft noise signal in a convenient length of paper. Engage the paper drive making sure that the pen is writing above the bottom edge of the paper.

While announcements and background noise levels are being recorded, the flight crew should be setting the conditions for the upcoming test run (e.g., nominal height, engine power setting, airspeed, flap deflection, landing gear position, and aircraft pitch angle). As soon as the aircraft's conditions have reached essentially stable values, a member of the flight crew should broadcast a short countdown to a mark by saying something like "Mark reference for test run XX. Five, four, three, two, one, mark!". The "Mark" signal may be determined from an event counter or a time-of-day time-code generator.

A member of the flight crew should note the time of day at the time of the mark and record it on an aircraft-parameter log sheet along with the run number. Each tape-recorder operator should monitor the countdown and note the time of day displayed on the time-code generator when the mark signal is received. Time at the mark should be noted on the level-recorder chart paper and entered in the log sheet. The operator of the aircraft-positioning equipment should also monitor the countdown for correlation with the tracking and recording of the position of the aircraft.

After the mark signal is broadcast, the flight crew should maintain aircraft and engine conditions as constant as possible throughout the duration of the recordings of acoustical and aircraft-position data.

The time for terminating the recordings of acoustical and aircraft-position data should be determined by the operator at the key microphone station such as either of the end positions in the array of centerline microphones in Figure 3.

After the aircraft noise signal has reached its maximum value, the signal will decay back to the level of the background noise. As the aircraft flies away from the microphones, the signal will eventually fluctuate around the level of the background noise recorded before the start of the aircraft noise recording. When the aircraft noise signal is consistently between 0 and 2 dB greater than the average background noise level as displayed on the level recorder at the key station, it is time to stop the recordings except that a few additional seconds should be allowed for the time that the aircraft noise signal needs to reach the microphones at the ends of the sideline array, or at the other end of the centerline array.

Once the time for terminating the recordings has been determined, the operator at the key station broadcasts a "data off" announcement. The recordings of acoustical, aircraft-position, aircraft-parameter, and engine-parameter data should cease. The aircraft should be maneuvered to set it up for the conditions specified for the next test run.

Background noise.-From time to time as opportunities arise, the 30-second-average flat-weighted and A-weighted levels of background noise should be read directly on the sound level meter. The flat-weighted sound level of the background noise should remain below the test-site criterion level of 70 dB. The A-weighted sound level should remain below the criterion level of 55 dB.

The ambient sound level may be acceptable at the beginning of a test series, but may increase for some reason during the 3-to 5-hour period that may be needed to conduct the tests. To maximize the signal-to-noise ratios for each test in a series of tests, it is often advantageous to begin the tests with those test runs at the greatest heights and lowest engine power settings. Subsequent tests will be at lower heights or higher engine power settings and the greater signal strengths may be sufficient to overcome interference from increased levels of ambient noise.

Nevertheless, if the average flat-weighted ambient sound level exceeds 70 dB or the average A-weighted ambient sound level consistently exceeds 55 dB during the course of a test series, it is likely that a large amount of data will be irretrievably lost. Thus, if the average ambient sound level does increase to an unacceptable value during a series of tests, the test director must decide whether (1) to proceed with the test and take a chance of recording a relatively small amount of valid data or (2) to terminate the test and reschedule it for another day. If it is a feasible consideration, the test should be cancelled and re-scheduled rather than record data which are likely to be rejected later because of background noise contamination.

Laboratory Calibrations

Laboratory calibrations required to support data acquisition should be performed at least once per year and within the 90-day period prior to the first day of scheduled aircraft noise measurement.

Sound pressure level, frequency, and waveshape of the signal produced by the acoustical calibrator should be measured over a range of air temperatures, using fully-charged and partially-discharged batteries, for every combination of frequency and level available from the calibrator.

For the pink-noise generator, measure the 60-second-average band level of the output voltage in 1/3-octave frequency bands at center frequencies from 20 to 25,000 Hz for wideband, flat-weighted rms output voltages from, at least, 5 to 100 mV. [The fluctuating voltages need only be averaged for 10 seconds for band center frequencies at and above 1000 Hz.]

For microphones and their associated preamplifiers, laboratory calibrations should determine the frequency response from 10 to 20,000 Hz, relative to the response at 1000 Hz, in an anechoic chamber for 0° and 90° sound-incidence angles. Sensitivity and capacitance of the microphone should be measured at a frequency of 1000 Hz. Microphone calibrations should be performed at an air temperature between 15° and 25° C and a relative humidity between 50 and 70 percent.

Laboratory calibrations for sound level meters and tape recorders should determine relative frequency response, amplitude linearity, response to short-duration transient signals, and electrical background noise. Tests of the performance characteristics of sound level meters should be conducted by making use of a dummy microphone mounted on one of the preamplifiers normally associated with that sound level meter for field tests. For tape recorders, performance tests should also include a determination of the signal-to-noise ratio at the standard recording level and 10 dB below the standard recording level. Other electrical performance parameters of the sound level meters and tape recorders should also be measured for comparison with results of previous tests and the manufacturer's advertised claims.

Performance characteristics of the foam windscreens should be measured, but may be done on a type basis and do not need to be repeated unless the windscreen type is changed. Insertion loss should be measured as a function of frequency, sound-incidence angle, windspeed, and wind-incidence angle. Sound-incidence angles should include 0° and 90°. At each sound incidence angle, the wind-incidence angle should include 0° and 90°. Steady windspeeds should include 0, 5, and 10 m/s. The sound source should produce sinusoidal signals at the nominal 24 center frequencies of the 1/3-octave bands from 50 to 10,000 Hz. The reduction of wind-generated noise (no sound source present) should also be measured. The average linear density of the pores of the open-cell foam should be determined.

Aircraft and Engine Data

The aircraft and engine parameters noted in Table 2 should either be constant throughout the duration of a noise recording or should change rather slowly. Ambient air pressure, ambient air temperature, aircraft gross weight, aircraft configuration, and engine power parameters should all be rather constant. Airspeed and height, however, may increase during the course of a run.

The data-sampling rate should be fast enough to track changes in the most-rapidly-varying parameter. For many test aircraft and most tests (except those involving flight paths with rapid rates of climb or descent or those involving changes to the engine power setting) use of a pre-printed tabular form on a clipboard is adequate for recording the desired information. Data should be recorded from the time at the "Mark" (or from slightly before the "Mark" time) to the time at "data off". Time-of-day or event-marker code should be noted along with the aircraft and engine data.

If a cockpit clipboard is not suitable, then some other system is required. Other systems include an on-board digital data system, a movie camera in the cockpit to photograph the instruments, or a movie camera mounted on a special panel containing instruments that duplicate the cockpit instruments. The digital data system is preferred because its output is amenable to processing by a digital computer at a significant savings in cost and time compared with costs and processing time associated with film-based systems.

Aircraft-Position Data

A laser-tracking system is recommended for determining the position of an aircraft reference point as a function of time because a computer-controlled laser system can provide highly accurate aircraft-position data over the complete range of distances and angles of practical interest and because the total cost of acquiring comparable aircraft-position data of the same accuracy and depth of detail was considered to be lower for a laser-based system than for other systems. Other systems include: a downward-looking movie camera installed in the test aircraft, photo-theodolites or cinetheodolites at several ground stations, radio-frequency radar systems, or microwave systems.

Film-based tracking systems entail significant expenditures for film and labor, where labor costs include the costs associated with field operations as well as the costs associated with transcribing and processing the time-correlated aircraft-position data from hundreds, or thousands, of exposure frames. The time required to process data from film-based systems can introduce a significant delay in the analysis of the aircraft's noise levels.

Data from the laser-tracking system should be digitized at a high sampling rate and recorded along with time-code data on magnetic tape for subsequent processing by a digital computer. Analog data should be recorded in real time on X-Y plotters that are part of the laser-tracker system. The approximate tracking data from the X-Y plotters should be examined to decide whether the flight path for a particular run was, or was not, close enough to the target flight path to be acceptable. Repeat runs may be required if the actual flight path was too far from the target flight path.

The laser-tracking system may be installed in a permanent facility or in a van or a transportable shelter. The optical system for the laser transmitter and receiver and for the tracking system should be mounted on a pedestal that can be supported by leveling jacks on a concrete pad or similar flat, hard surface. Independent support is needed to isolate the optical and tracking systems from the influence of winds or movements by test personnel within the associated van or equipment shelter.

The 3-phase electric power (30 kW) that is required may be supplied from a transformer on a nearby power line, or comparable source. A motor-driven ac generator could also be used to furnish the electric power although it might require the addition of special noise control features to ensure that noise from the motor-generator does not increase the ambient noise levels at the microphones. Portable laser-tracker systems are commercially available for lease or rent.

The laser-tracker system should be located to the side of the nominal ground track of the test aircraft as shown in Figure 3. The location should provide an unimpeded view of the test aircraft for all azimuth angles, elevation angles, and ranges of interest. A distance of approximately 500 m to the side is suggested. At that distance, the maximum angular velocity of the test aircraft should not exceed the maximum slew rate of the tracker pedestal.

An array of retroreflectors should be mounted on the test aircraft in some convenient location such as in a replacement for an access panel. A retroreflector may consist of an array of mirrors in the shape of equilateral triangles that are joined at a common vertex so as to form one corner of a cube. The function of a retroreflector is to reflect the laser signal back to the receiver with high efficiency, even in bright sunlight.

If the test aircraft is flown in both directions along the nominal flight paths to minimize test time and to take advantage of favorable meteorological conditions, then the retroreflectors must be visible from both sides of the aircraft. To accomplish that objective may mean mounting a retroreflector package near each wingtip or on each side of the vertical fin. A location on the bottom of the fuselage may not be feasible because it is likely that several runs will be flown with landing gear (and some portion of the landing-gear doors) extended and also with wing flaps extended. In Reference 25, Willshire describes a problem with loss of some aircraft tracking data as a result of shielding when a laser retroreflector was mounted on the bottom of the fuselage of a T-38A airplane.

The laser-tracking system may be calibrated by measuring the range, elevation, and azimuth to a target whose position relative to the laser had been determined by surveying. The locations of the microphones can also be determined by the laser tracker by making use of reflecting tape on the masts.

The laser tracker does not provide airplane-attitude data (i.e., angles of pitch, roll, and yaw). As with other external tracking methods, attitude data must be supplied from an onboard aircraft system such as a gyro or inertial navigation system.

The digitized stream of aircraft-tracking data (range, azimuth, elevation) should be processed to yield the variation with time of the coordinates of a suitable acoustic reference point relative to an appropriate coordinate-system origin. Appendix A provides guidance for using the aircraft-position data to determine sound-emission angles, aircraft-position angles, and sound-propagation distances.

Meteorological Data

Because high-quality meteorological data are needed to interpret and analyze the measured aircraft noise levels, the recommended test procedure includes a combination of primary and secondary (or backup) systems for measuring meteorological data. Figure 3 indicates four systems for measuring meteorological data, one for surface data at a height of 10 m (the weather tower) and three for sampling data at various heights above ground level (instrumented airplane, tethered radiosonde, and pilot balloons or pibals). The quantities that each of the four systems should measure are those listed in Table 3. Measurements of meteorological quantities should be time synchronized with the measurements of aircraft noise though at a lower sampling rate.

Air temperature and humidity.-The primary systems for measuring air temperature and humidity are those on the 10-m tower and in the meteorological airplane. For both systems, the preferred technique for determining relative humidity is from a measurement of air temperature and dewpoint, or frostpoint for dewpoints less than 0° C.

Dewpoint should be measured by a method that requires no field calibration. An optical device to control the temperature of a flat metal mirror so as to maintain a constant surface reflectance is recommended. The surface reflectance should be chosen to be a fraction of that from the mirror when the surface is clean and dry.

The recommended instrument for measuring humidity uses a chilled flat, metal mirror to detect the temperature of samples of moist air at saturation conditions. The instrument measures dewpoint with respect to a plane surface of liquid water for dewpoints above 0° C. When the dewpoint (or air temperature) is less than 0° C, a layer of ice (frost) builds up on the surface of the mirror, and when equilibrium is reached between the rate of evaporation and the rate of condensation, the temperature of the mirror is the frostpoint with respect to a plane surface of ice.

For the instrument mounted on the 10-m tower, aspiration airflow is provided by a motor-driven fan that draws a continuous flow of air over the temperature and dewpoint sensors.

For the instruments in the meteorological airplane, the dewpoint sensor may be mounted in a fresh-air duct that supplies outside air to the cockpit, or through a hole in a window panel. The temperature sensor should be installed under a wing in a tube to shield the sensing element from solar radiation and moisture droplets; it should be relatively far outboard to avoid heat radiated from the engine and fuselage.

Electrical power is required to operate the thermoelectric device that cools the surface of the metal mirror and to operate the signal-conditioning equipment that provides the analog dc voltages which correspond to the temperature of the air or the temperature of the metal mirror (i.e., the dewpoint or frostpoint). For the instrument mounted on the 10-m tower, additional electrical power is needed to operate the motor that drives the fan.

In 1981, instruments possessing the capability to conform to the desired requirements were not generally available as battery-powered devices, only as instruments requiring ac electrical power, although it might be possible to obtain a specially modified instrument that could operate on ac or dc power.

For the instrument on the 10-m tower, the best choice for supplying the required power was considered to be a solid-state dc-to-ac inverter with standard wet-cell batteries as the source of dc power. An ac generator driven by a small gasoline engine might be used as the source of ac electrical power if the noise it produced was adequately suppressed.

Electrical power needed to operate the surface-tower instrument may be of the order of 130 VA in terms of the product of rms voltage and rms current. Assuming that battery power is obtained from automotive batteries having an average voltage of 11 V and assuming the inverter has a typical conversion efficiency of approximately 60 percent with a typical idle (no-load) current of 9 A, the battery supply will need to furnish approximately 21 A when the temperature-humidity instrument is operating.

For 10 hours of continuous operation at an air temperature of 20° C, three 90 A-h batteries would be needed to furnish enough dc power for an inverter of the assumed efficiency. At lower temperatures, more batteries would be needed, probably connected in a series-parallel arrangement to provide a nominal 24 V instead of 12 V in order to reduce current drain.

An inverter meeting the requirements described here may produce the ac voltage by electronically chopping the dc signal to obtain a square wave which is then applied to a step-up transformer to increase the voltage. Magneto-strictive forces may cause the laminates of the transformer to vibrate and generate sound at the fundamental and the even harmonics of the nominal 60-Hz power frequency. The inverter may also incorporate a fan that blows cooling air over fins to dissipate heat, increase operating life, but produce measurable sound. To provide some noise reduction as well as weather protection, the inverter should be installed in a vented enclosure mounted near the base of the 10-m tower. The batteries should also be enclosed in a vented enclosure (or containers) and fastened to the structure used to transport the tower.

Electrical ac power for the airborne instrument should be somewhat easier to furnish since less than half as many volt-amperes should be required because the airborne instrument uses ram air for aspiration and hence has no fan or fan-drive motor. Power may be obtained from a 115-V, 60-Hz source on the airplane (if available) or from a dc power source in the airplane (or an extra battery) and an inverter. Supplemental battery capacity at low temperatures should not be needed in the airplane.

Relative humidity should be determined from the ratio of the vapor pressure at the dewpoint (or frostpoint) to the saturation vapor pressure at the static air temperature. Tabulated vapor pressures are available in the International Meteorological Tables published by the World Meteorological Organization [26] though they differ somewhat from the tabulated data in the earlier publication of the Smithsonian Institution [27]. However, for consistent determinations of vapor pressure and relative humidity, Goff [28] has published definitive relationships between vapor pressure and temperature, see Appendix B.

Temperatures determined by the airborne and surface instruments should be recorded, preferably by use of a programmable calculator with a printer. Given air temperature and dewpoint (or frostpoint), the calculator determines vapor pressures and hence relative humidities by making use of Equations (B2) or (B3) and (B1) from Appendix B. Other measures of humidity, such as molar concentration, may also be calculated. The print-out should include time of day. In the airplane, the print-out should also include height above ground level as calculated from measurements of static pressure. Use of a calculator with printer is preferred over the use of a strip-chart or magnetic tape recorder because the resulting accuracy of the relative humidity is better and because the data are available in real time since the need to transcribe information is eliminated.

Operation of the chilled-mirror dewpoint-measuring instruments on the weather tower and in the meteorological airplane should be checked occasionally throughout each test day. The check should verify that dust has not collected on the mirror to the extent that the reflectance has changed beyond the ability of the instrument to compensate. Minute salt crystals that may have collected on the mirror (e.g., from operations near an ocean) should be removed because the indicated dewpoints will be too low. On the other hand, the mirror should not be cleaned too often because some dust particles are needed as nuclei around which water molecules can condense onto the surface. Dewpoints may be too high if the mirror surface is too clean.

The tethered radiosonde also provides temperature and humidity data aloft, but not to the same accuracy as the dewpoint instrument in the meteorological airplane because of the limited mass which a balloon of practical size can lift. Preferred instruments for the radiosonde are those which can measure dry-bulb and wet-bulb temperatures. Temperatures may be sensed by thermistors, a device which changes its electrical resistance in proportion to changes in the temperature of the air to which it is exposed. The variation of resistance with temperature is not linear and individual calibration curves are required. The two thermistors should be installed in an enclosure for protection from solar radiation. A small battery-powered fan may be used to provide aspiration.

Wet-bulb temperature may be measured by placing a wick around one of the thermistors. One end of the wick is maintained in a reservoir having enough distilled water for 60 to 90 minutes of operation, i.e., enough to permit the balloon to ascend to, and be retrieved from, a height of 1000 m.

Data output from the radiosonde should be transmitted continuously by a UHF transmitter to a receiver in a ground station. A programmable digital calculator with associated printer is the preferred means of recording the data transmitted from the radiosonde. The printer should display time of day, static air pressure (or the difference between the pressure at ground level and aloft), height above ground level, dry and wet-bulb temperature, and relative humidity determined from empirical calibration data. The speed and direction of the horizontal component of the wind should also be printed out.

Use of dry-bulb and wet-bulb thermistors is not recommended when the air temperature is less than 0° because of the difficulty in maintaining a coating of ice on the wick and because of the long time needed to obtain a valid frost-point measurement with a frozen wick.

Air pressure.-Air pressure needs to be measured and recorded at ground level and aloft. Measurements of static atmospheric pressure will be used during data processing since the level of the output of an acoustical calibrator is a function of atmospheric pressure. Measured values of atmospheric pressure will also be useful during data analysis since atmospheric pressure is needed to calculate the molar concentration of water vapor. Pressure is also a parameter in the calculation of atmospheric absorption as well as being a factor in determining the thrust produced by the aircraft's engines. Moreover, tests probably should not be conducted when a low-pressure region is approaching the test site and the atmospheric pressure is steadily decreasing indicating the likelihood of unstable air and relatively strong atmospheric turbulence as well as precipitation.

A spring-wound barograph using a calibrated aneroid capsule to measure pressure changes should provide acceptably accurate measurements of air pressure at the surface. For convenience, the recording chart paper may be marked with a scale in millibars with a range of 100 millibars. The linkage between the recording pen and the aneroid capsule should contain a device to compensate for the effect of the temperature of the air on expansion of the material from which the aneroid capsule is made. The barograph may be mounted in the control van.

In the meteorological airplane, the recommended instrument is an electrical pressure transducer. To avoid time-lag caused by the use of long lengths of tubing, the transducer should be mounted near the static port of the pitot-static system for measuring airspeed. Heights calculated from an aircraft static-pressure measurement should be accurate within ±3 to ±5 m for heights greater than approximately 30 m. Below a height of 30 m, ground effects degrade the accuracy of a pitot-static system. If heights of less than 30 m must be measured, a radio altimeter is recommended.

For the tethered radiosonde, the variation of pressure with height may be determined as the difference between the pressure at the surface and the pressure aloft using a variety of instruments. An aneroid capacitance is a suitable choice. Actual pressure at any height may be determined from the pressure at the surface and the differential pressure calculated from the capacitance-pressure calibration curve.

Wind speed and wind direction.-For surface winds, measurements of average wind speed and wind direction should be obtained from instruments on the 10-m tower. Winds aloft are also to be measured.

The preferred wind sensor for surface winds is a combination of a propeller anemometer and a large-area vane. The unit should be mounted on a vertical shaft with the propeller's axis horizontal.

For good linearity at low wind speeds, the preferred method for generating an output signal is to use a dc tachometer generator that produces a dc output voltage which is directly proportional to the rotational speed of the propeller. At a given propeller shaft speed, the magnitude of the voltage produced at a given wind speed depends on the mass of the propeller. A molded thermoplastic propeller should be able to produce 2 V at approximately 13 m/s; a lighter plastic-foam propeller should be able to produce 2 V at approximately 8 m/s.

An electrical signal to represent the position of the wind vane may be conveniently obtained by applying a dc voltage across a linear potentiometer. The dc voltage should be supplied by an external battery located near the base of the tower in the vented enclosure with the batteries and signal-conditioning equipment for the temperature-dewpoint sensors. A potentiometer made from a continuous strip of conductive plastic is preferred over a wire-wound potentiometer. A total resistance of 1000 ohms is a convenient value.

The dc analog signals for wind speed and wind direction may be transmitted by a standard multi-conductor cable to a battery-powered strip-chart recorder in the control van. Alignment of the recordings of wind direction on the chart paper with azimuth angles relative to true north requires adjusting the orientation of a mark on the potentiometer with the northerly direction indicated by a compass with appropriate correction.

For minimum mass, wind-aloft data from the tethered radiosonde may use a cup anemometer for wind speed and a combination of magnetic compass and potentiometer for wind direction. The cup anemometer should provide reasonably accurate measurements of horizontal wind speeds if the air is not turbulent. If the air is turbulent, the tethered balloon may oscillate laterally and produce apparent fluctuations in average wind speed. The axis of the rotating cups may be tilted away from the vertical so that wind components other than horizontal are included. The vertical motion of the anemometer as the balloon ascends or descends may introduce another error. (The error caused by the vertical motion of the anemometer should be assessed by periodically halting the balloon during its ascent or descent.)

To sense wind direction, the instrument package should be supported below the balloon by a harness or sling such that the package does not rotate with respect to the axis of the balloon. The balloon has a streamline shape with fins and is assumed to rotate about the tether line such that the nose always points into the wind. When wind direction is to be sensed and transmitted to the ground station, the compass should be magnetically locked to the potentiometer to give a voltage proportional to the heading.

The alternative or backup system for measuring winds aloft uses free-rising meteorological balloons (pilot balloons). A pilot balloon is a small latex rubber balloon which is filled with just enough helium to lift a small weight. The balloon rises until it bursts.

Tracking the ascent of the pibal may be accomplished by special balloon theodolite in conjunction with a balloon timer which emits a signal at fixed intervals, for example every 60 seconds. The timer is started when the balloon is released. The theodolite operator tracks the balloon by keeping the cross hairs of a graticule centered on the balloon as it rises. Crank handles permit separate adjustment of azimuth and elevation angles which are read from graduated scales when the 60-second timer sounds. The angle scales should provide a resolution of 0.1°.

The position of the balloon as it rises should be graphed on special plotting paper. Horizontal wind speeds may be determined from the changes in azimuth and elevation coordinates at 60-second intervals by making use of the assumption that, in the absence of turbulence, the balloon rises at a constant rate.

Pilot balloons are available in a variety of sizes. The four most appropriate sizes are denoted 10, 20, 30, and 100 grams according to their mass. The preferred 10-g size has an initial diameter (at sea level elevation) of about 8 cm. It bursts at an altitude (above sea level) of approximately 7 km where the diameter has increased to about 60 cm.

If the 10-g size is large enough to be seen and tracked by the operator of the theodolite, its use is preferred because it has the slowest ascension rate of about 150 m/min and hence provides the most data points in the important region between the ground surface and a height of interest, e.g., 1000 m.

Surface-weather tower.-For portability and ease of setup, the tower for surface weather measurements should be mounted on a trailer. A tilt-over, crank-up, two-section, telescoping design is recommended. A four-section design provides a shorter nested length but has less rigidity than a two-section design. Booms at the top of the tower for supporting the temperature, humidity, wind-speed, and wind-direction instruments should be at least one meter long. Each boom should be capable of supporting a mass of 6 kg.

The tower may be one designed to be raised and lowered by a hand-cranked cable on a winch. A worm-gear drive may be included to provide mechanical advantage. No guy wires should be needed. Outriggers may be incorporated for additional stability. An accessory box, with vent holes, may be located on the trailer. The batteries, inverter, signal-conditioning equipment, and reels of signal cable may all be kept in the box.

The weather tower should be located relatively close to the array of microphones so that the measurements are representative of 10-m surface conditions near the microphones. The ground surface around the weather tower should be similar to that around the microphones. The weather tower should not be so close to any microphone that the sound produced from operation of the instruments makes a measurable contribution to the background noise level. The distance between the weather tower and the control van where the measurements are recorded and monitored should be at least 100 m, though as much as 500 m would be practical in terms of signal losses.

Operations.-Temperature, dewpoint, wind speed, and wind direction data measured by the instruments on the 10-m weather tower should be recorded continuously from at least one hour before the scheduled test start time until the end of that day's testing. Measurements of temperature, humidity, pressure, and wind aloft should also begin at least one hour before the scheduled test start time and continue at the recommended intervals throughout the day.

Each of the four channels of data from the weather tower should be calibrated before the start of the tests by transmitting dc voltages corresponding approximately to the minimum and maximum signal amplitudes, e.g., 1 V and 5 V. Data-recording devices in the control van should be adjusted to on-scale readings by use of manufacturer's calibration data that have been verified as part of the laboratory-calibration effort.

To obtain information on the horizontal as well as the vertical distribution of temperature, humidity, and pressure, and to ensure that the data are representative of average meteorological conditions along the sound propagation paths, the meteorological airplane should fly along ascending and descending paths parallel to the microphone arrays as indicated in Figure 3. A spiral path over the centroid of the array could be flown as an alternative to the flight paths shown in Figure 3. Meteorological data should be sampled at altitude increments no greater than 30 m.

The meteorological airplane should fly at least twice per hour during the day's test period. Temperature, dewpoint, and pressure (height) data should be recorded continuously in the airplane during each ascent and descent. Time of day at the beginning and end of the recording should be noted. Airspeed and rate of climb (or rate of descent) should be low enough to accommodate the response time of the instruments and gradients in temperature and humidity.

Although measurements of aircraft noise are not recommended when the air temperature along the sound propagation path is less than 0° C, measurements of meteorological data need to be initiated before the scheduled time for beginning to record the sound produced by the test aircraft. Thus, some meteorological data may be measured when the air temperature is less than 0° C before the air has been warmed by the sun to a temperature greater than 0° C.

At any height where the dewpoint is less than 0° C, more dwell time is needed to obtain an accurate measurement of the frostpoint than is needed for a measurement of the dewpoint at temperatures greater than 0° C.

An adequate dwell time is particularly important when passing from a region where the dewpoint is above 0° C to a region where the dewpoint is less than 0° C because the condensate on the surface of the mirror can exist for a period of time in a liquid state as supercooled water at a temperature less than 0° C. The temperature of the mirror's surface under those conditions will be a dewpoint and not a frostpoint. Since the dewpoint is lower than the frostpoint (for moist air at a given temperature and pressure), vapor pressure calculated assuming the dewpoint was actually a frostpoint will be less than at the true frostpoint and the indicated relative humidity will be less than the actual relative humidity. Given an adequate dwell time when the dewpoint or air temperature is less than 0° C, any layer of supercooled liquid water will eventually become a layer of ice and a frostpoint can be determined. However, in order to reach equilibrium after the layer of ice is formed, additional time is needed for water molecules to condense out of the stream of moist air onto the ice layer on the mirror. The amount of time needed to reach equilibrium depends on the temperature of the air and increases as the temperature decreases because of the increasing scarcity of water molecules in the stream of moist air flowing over the surface of the mirror. For the usual case when air temperatures and dewpoints aloft are above 0° C, the time needed to determine the dewpoint should only be a few seconds.

The total time needed to complete each ascent-descent maneuver should, in general, not be more than 10 to 15 minutes including time to take off and land. That time estimate assumes that the meteorological airplane is based relatively close to the test site. If the test site is not near a paved runway, a smooth grass or dirt surface is needed for a runway. The surface of a field should be adequate if the path is suitably marked and the ground is not too soft. A nearby road might also serve as a temporary runway for the meteorological airplane.

For each ascent-descent maneuver, the airplane should climb to a height that exceeds by at least 100 m the maximum height that the test aircraft is expected to reach during any noise recording in the next one-hour period. Unusual wind or atmospheric-turbulence conditions encountered during the ascent-descent flights should be reported to the test director.

To avoid interference with the noise recordings, the ascent-descent flight of the meteorological airplane should not begin until the test aircraft has departed the test area and a data-off signal has been broadcast from a key microphone station. The test aircraft may have to hold somewhere while the meteorological airplane is sampling the data aloft.

The tethered radiosonde should be put up and hauled down, if feasible, at least once per hour when noise tests are being conducted. For calm-to-low wind conditions, an ascent rate of 30 to 60 m/min should be achievable for the response time and mass of the recommended instruments and the mass of the lightweight tether line which probably should not be more than 1000 m long. If the elevation of the test site is near sea level, an aerodynamic balloon with a volume of approximately 3 m^3 should provide sufficient lift to achieve that ascent rate. Larger balloons may be required for test sites at higher elevations or to provide more lift under windy conditions. The descent rate should be of the order of 30 to 60 m/min depending on the torque available from the motor that turns the winch. Ascent and descent rates should be slow enough to track temperature and humidity gradients.

If permitted by the prevailing wind conditions and the length of the available tether line, the tethered radiosonde should be allowed to rise to a height greater than the maximum height which the test aircraft is expected to reach during the next test hour. Because the operation of putting up and hauling down the tethered radiosonde is relatively quiet and because the location for the operation should be relatively far to the side of any flight path flown by the test aircraft (as shown in Figure 3) as well as downwind if there is a cross-wind, it should be feasible to operate the tethered radiosonde while the test aircraft is in the test area and noise recordings are being made. For safety reasons, the tethered radiosonde should not be allowed to ascend into a cloud. If the tests are conducted in a controlled air space, the operation of the tethered radiosonde should be coordinated with air traffic control. Prior approval to fly the balloon, however, should not be required for balloons less than 3.3 m^3 in volume and less than 1.8 m in diameter.

A pibal should be released approximately once per test hour and should be tracked (if visible) to a height greater than the maximum expected height of the test aircraft in the next test hour. Wind-profile data (i.e., the vertical profile of the horizontal component of the wind) should be calculated and given to the test director for comparison with the criteria for wind aloft.

The test director should also collect the record of the data measured by the meteorological aircraft after each ascent-descent flight as well as the data from the tethered radiosonde. The data should be examined to determine if the measured conditions are within acceptable limits and to keep the test crew informed about developing trends.

Time Synchronization

Time is the key parameter for correlating the acoustical data recorded from the various microphones, the aircraft tracking data, the aircraft and engine data recorded in the airplane, and the meteorological data at the surface and aloft. The preferred system for timekeeping is the 24-hour system based on coordinated Universal Time or UTC that begins at midnight at the zero-longitude meridian at Greenwich, England. Coordinated Universal Time is synonymous with Greenwich Mean Time (GMT) or with Zulu Time. Local time of day differs from nominal coordinated Universal Time by an integral number of hours depending on the longitude at the site.

In the United States, coordinated Universal Time is maintained by the United States Naval Observatory in cooperation with the US National Bureau of Standards (NBS). UTC time signals are broadcast continuously by NBS at 2.5, 5, 10, 15, or 20 MHz from radio stations WWV in Fort Collins, Colorado, and WWVH in Kauai, Hawaii.

Because the transmission of high-frequency radio signals is influenced by the electromagnetic characteristics of the upper atmosphere, which vary from time-to-time and day-to-day, the clarity of the high-frequency time-of-day radio signals is quite variable. Signals are often contaminated by noise and may be lost entirely for periods as long as a few hours at a particular frequency or be affected by reflections from nearby objects.

To improve the signal-to-noise ratio and reliability of the time information available from the WWV radio signals, an alternative system is available for use at sites in North and South America. The alternative system uses time signals relayed from satellites over the equator in stationary (or geosynchronous) orbits. The satellites are known as Geostationary Operational Environmental Satellites (GOES) and are operated by the National Oceanic and Atmospheric Administration.

Continuous time signals synchronized with the NBS time standard are transmitted to the satellites. Problems with electromagnetic interference and reflections are practically eliminated because the propagation path is essentially along straight lines from a satellite to a ground station. Synchronization to UTC time signals from an orbiting satellite is preferred over synchronization to radio signals from stations WWV or WWVH.

The UTC time information (in hours, minutes, and seconds) must be encoded in some format in order to be recorded for use in subsequent data processing. A large number of time-code formats have been developed since 1960. Those in widest use have been standardized by the Inter-Range Instrumentation Group (or

IRIG). The IRIG B format [29] is preferred for use in synchronizing aircraft noise test data because it uses a 1-kHz carrier frequency with a one-second time frame and can provide time resolution of 1 ms. The IRIG B format is readily available from commercial time-code generators.

Modulation of the 1-kHz carrier is achieved by a series of shifts in the amplitude of a superimposed dc voltage. The duration of the dc voltage shift controls the number of cycles in tone bursts at the 1000-Hz carrier frequency. The IRIG B format has 100 tone bursts every second.

Modulation ratio is the ratio of the amplitude of the 1-kHz wave, when modulated by a high-amplitude dc voltage to generate a "mark" signal, to the amplitude of the 1-kHz wave when modulated by a low-amplitude dc voltage to generate a "space" signal.

The time-synchronization system in the control van includes a receiver-generator to receive time code relayed from the GOES satellite, translate the code to UTC time code, and generate BCD serial time code in the IRIG-B format as an amplitude-modulated 1-kHz carrier. A master time-code translator-generator is connected to the receiver-generator, automatically synchronizes its internal timing circuits with the signal from the receiver-generator, and generates serial time code in the IRIG-B format.

As indicated in Figure 4, a time-code translator-generator is to be located at each tape recorder. An additional time-code translator-generator should be located with the laser tracker. Meteorological data from the tethered radiosonde and pibals may be correlated with sufficient accuracy using time-of-day as read from a clock and noted at appropriate intervals. The meteorological airplane should have a clock on the instrument panel to provide time-of-day information.

The "mark" signal, which is broadcast from the test aircraft to the ground stations before beginning a run, may use a counter that is pulsed at one-second intervals. The time-of-day clock in the test aircraft should be synchronized to the minute, or better, with time-of-day from the ground-located master time-code generator.

At least four, and preferably 24, hours before the scheduled start of the tests, the master time-code receiver-generator and translator-generator in the control van should be initially synchronized to the UTC satellite time signal. If the latitude and longitude of the receiver are known, the accuracy of the correlation with the UTC time signal at the transmitter may be improved by accounting for the propagation time from the transmitter to the satellite and then from the satellite to the receiver at the test site. Propagation time corrections may be automatic if the receiver incorporates a programmable microprocessor. Continuous synchronization to the satellite signal may be achieved by leaving the receiver connected to the master time-code generator.

To minimize drift in the timing signal (i.e., drift in the frequency of the crystal-controlled oscillator), the master time-code generator and the receiver should not be shut down until all tests (or series of tests on successive days) are completed. Time-code generators at the tape recorders and at the laser tracker should operate continuously throughout each test day. Unlike the master time-code generator, they may be shut down overnight between successive test days providing they are energized a few hours before the scheduled start of a new test series. Since the receiver and all time-code generators will be powered by batteries during a test, battery capacity consistent with the lowest air temperature should be provided at each location.

Synchronization between the master time-code generator and the other time-code generators should be accomplished using a separate portable time-code translator-generator. The portable generator is taken to the other time-code generators to synchronize each of them, in turn, with the IRIG B time-code signal. Accuracy of initial synchronization among the various time-code generators should be within ±5 ms. Re-synchronization should be performed whenever acoustical calibration signals are recorded.

The time-code generators should be set to produce a modulation ratio between 3 and 4 for the amplitude-modulated 1-kHz wave that carries the BCD time code which is recorded on the FM center track.

Since the UTC time-code signal recorded on the tape recorders is used to locate and identify the acoustical data signals as well as to correlate the acoustical data with the aircraft-tracking data, the limited high-frequency response of the FM center track on the tape recorder should be kept in mind when planning the procedures for processing the recorded data. For the recommended portable two-channel tape recorders, the FM center track may have a nominally flat frequency response from 0 to approximately 3500 Hz. Above 3500 Hz, the response may decrease at a relatively rapid rate.

If the data-processing system includes a mechanism for automatically controlling the playback tape recorder, then it likely will also contain a tape-search feature based on reading the BCD time code from the FM center track. To operate the tape-search system, the time-code reader must be provided a readable signal. To provide a readable signal at the uncontrolled fast-forward and fast-reverse tape speeds, it may be necessary to record the acoustical data and time-code data in the field at a controlled tape speed greater than 19 cm/s, for example at 38 cm/s.

Communications

Thorough pretest planning, daily pre-flight and post-flight meetings, and an adequate communication system are prerequisite for the success of an aircraft noise test program. The communication system is used to coordinate the field activities and to assist in implementing the data-acquisition efforts.

Table 5 summarizes the communication systems that need to be provided. All systems should use frequencies in the Very High Frequency (VHF) range (30 to 300 MHz). Since the distance between transmitter and receiver is only a few kilometers, at most, and involves transmission paths which are primarily line of sight, the broadcasting mode should be FM for clarity of the audio signal with minimal interference from electromagnetic radiation.

At least two test frequencies, called f_1 and f_4 in Table 5 are required. Frequency f_1 should be one that is specially licensed for flight testing. Frequency f_4 should be another specially licensed test frequency for business operations on the ground; no ground-to-air or air-to-ground communications occur at frequency f_4.

If the test site is at an airport or air base such that the airspace, in which the test flying will be conducted, is under the control of an air traffic controller, then the control van will need a receiver that can be tuned to the appropriate frequency. There may also be a requirement for communications with airport ground control. The air traffic control and ground control frequencies, called f_2 and f_3 in Table 5, are also VHF frequencies and are likely to be in the range from 110 to 130 MHz.

The test director in the control van should be responsible for overall test coordination, especially with the crew in the test aircraft. Transmission from the key microphone stations to the test aircraft only should be to indicate the end of data recording for each flight.

INSTRUMENT PERFORMANCE REQUIREMENTS

Specific recommendations were developed for various performance capabilities required by the different instruments needed to measure aircraft noise levels in accordance with the procedures described in the previous section. The recommendations were considered to represent the best technology commercially available in 1981. Detailed recommendations are given in the accompanying tables with supplementary recommendations noted in the following sections.

Instruments for Acoustical Data

Performance requirements for most of the acoustical test instruments and equipments in Figure 4 are given in Table 6.

Headphones used to monitor the signals being recorded on tape, or to monitor the playback of data that has been recorded, should provide good isolation from exterior sounds (e.g., the test aircraft or the meteorological airplane). The headphones should have an impedance between 50 and 200 ohms, approximately, and should be connected for monophonic, not stereophonic, listening.

The cue microphone may be a dynamic (or electromagnetic) type, or equivalent. It should have a push-to-talk switch that is normally short-circuited. For normal voice level, the rms voltage at the input to the tape recorder should be of the order of 0.5 to 1 V. To provide a signal at that voltage, it may be necessary for the microphone to incorporate a battery-powered preamplifier.

Instruments for Aircraft and Engine Data

The accuracy and resolution of instruments normally installed in the test aircraft should be adequate for measuring all the aircraft and engine parameters listed in Table 2, including time of day or elapsed time. For measurements of engine pressures, engine temperatures, and shaft rotational speeds, accuracies that should be achievable are ±0.2 percent of the full-scale reading, ±2° C, and ±0.2 percentage points, respectively.

If the test objectives require measurement of airplane or engine parameters other than those listed in Table 2, special transducers and other instruments may have to be installed to record the data. Examples of other parameters include engine-inlet total temperature, fan-discharge temperature or pressure, combustor-exit temperature or pressure, and temperature and pressure differences across turbine stages.

Instruments for Aircraft-Position Data

The recommended laser-tracker system should be able to provide the following measurement capabilities and accuracies. The requirements apply for an atmosphere that is clear without significant haze, mist, fog, or dust.

- target range: ±0.3 m for ranges from 100 to 10 000 m and ±1 m for ranges to 30 000 m
- azimuth: ±2 m rad (±0.1 degree) for azimuth angles from -2π to $+2\pi$ rad (-360 to +360 degrees) relative to the normal to the aircraft's ground track for any range to 30 000 m
- elevation: ±2 m rad (±0.1 degree) for elevation angles from -0.09 to +1.6 rad (-5 to +90 degrees) relative to the local horizontal for any range to 30 000 m
- automatic tracking: angular velocity (azimuth and elevation) as great as 1.5 rad/s (85 deg/s), and angular acceleration as great as 0.3 rad/s^2 (15 deg/s^2)

Note that the time-correlated stream of aircraft position data may be used to provide an independent determination of the test aircraft's ground speed.

Instruments for Meteorological Data

Performance requirements are given in Table 7 for the instruments to be installed on the 10-m surface-weather tower and in the meteorological airplane for measurement of air temperature and dewpoint (or frostpoint). For those instruments, the resulting accuracy of a determination of relative humidity should be within ±1 to ±3 percentage points, depending on the temperature, for relative humidities less than 90 percent. For relative humidities greater than 90 percent, the accuracy should be within ±3 to ±5 percentage points.

The dry-bulb and wet-bulb thermistors on the tethered radiosonde should yield relative humidities with an accuracy of ±3 to ±4 percentage points for relative humidities between 20 and 90 percent when the air temperature is greater than 0° C. The uncertainty will be larger for relative humidities less than 20 percent or greater than 90 percent.

For measurements of wind speed on the 10-m surface-weather tower, the propeller-vane anemometer should have a starting threshold no greater than 0.5 m/s. The working range of wind speeds should include speeds as great as 20 m/s (40 knots).

Accuracy of the wind-speed and wind-direction data from the tethered radiosonde should be within ±0.3 m/s for wind speeds between 0.5 and 20 m/s, and within ±5° for wind directions from 0° to 360°.

Instruments for Time Code

Table 8(a) lists performance requirements for the satellite receiver/generator. The external antenna should be designed for the ultra-high-frequency (UHF) signal from the satellite at the nominal 469 MHz carrier frequency.

Performance requirements for stationary and portable time-code translator (reader)/generators are given in Table 8(b). The footnote describes differences applicable to requirements for the portable time-code generator.

Communication Systems

Several types of portable battery-powered VHF transceivers and receivers capable of satisfying the requirements for a good ground-based communication system are available from various manufacturers. All transceivers and receivers should be able to operate in the FM mode.

Transceivers for ground-to-air and air-to-ground transmissions should be equipped with selectable frequencies separated by at least 25 kHz. At least 500 channels should be available between 110 and 150 MHz. The transmitter should be capable of radiating at least one watt of power at any frequency selected. The frequency response of the transmitter and receiver should be approximately flat from at least 400 Hz to at least 2000 Hz. Operation should be possible in air temperatures between -10° to +40° C.

The transceiver should be equipped with a switch-selectable loudspeaker for monitoring transmissions from the test aircraft, meteorological aircraft, air traffic control, and ground control. A telephone-like handset is convenient for the operator to use when transmitting; it should include a push-to-talk switch.

Receivers of air-to-ground transmissions should be similar to the corresponding transceivers in terms of sensitivity, stability, frequency selectivity, and operational temperature range.

Transceivers for ground-to-ground transmissions may be significantly less complex than the transceivers or receivers needed for air-to-ground and ground-to-air transmissions. They need to radiate much less power because the greatest range for line-of-sight signals should be approximately 15 km compared with 40 to 50 km for the ground-to-air transceivers. They only need to operate at one pre-set frequency which may be of the order of 40 to 60 MHz.

CONCLUDING REMARKS

Techniques have been described for conducting field tests to obtain measurements of aircraft noise for research purposes. Specific recommendations were given for environmental criteria, data-acquisition procedures, and instrument-performance requirements. Topics covered included acoustical data, aircraft and engine data, aircraft-position data, meteorological data, time-synchronization requirements, and voice-communication-system requirements.

Aircraft noise data acquired in accordance with the recommendations should be useful for validation of aircraft noise prediction methods, for studies of sound-propagation phenomena, and for evaluation of noise-suppressor designs.

REFERENCES

1. Noise Standards — Aircraft Type and Airworthiness Certification. Part 36 of the Federal Aviation Regulations. (Part 36 was first published 1 December 1969; Part 36 includes Changes 1 to 15 with Change 15 effective 1 August 1981.)

2. International Standards and Recommended Practices — Aircraft Noise. Annex 16 to the Convention on International Civil Aviation. International Civil Aviation Organization, Montreal, Canada. (The first edition of Annex 16 was published in August 1971 and became applicable on 6 January 1972; the fourth edition was adopted in May 1981 and became applicable on 26 November 1981.)

3. Acoustics — Procedure for Describing Aircraft Noise Heard on the Ground. ISO 3891-1978, International Organization for Standardization, Geneva, Switzerland.

4. Marsh, Alan H.: Recommended Procedures for Measuring Aircraft Noise and Associated Parameters. NASA Contractor Report CR-145187 (April 1977).

5. American National Standard Preferred Reference Quantities for Acoustical Levels. American National Standards Institute, ANSI S1.8-1969 (R1974), Acoustical Society of America, New York, NY.

6. American National Standard Preferred Frequencies and Band Numbers for Acoustical Measurements. American National Standards Institute, ANSI S1.6-1967 (R1976), Acoustical Society of America, New York, NY.

7. American National Standard Specification for Sound Level Meters. American National Standards Institute, ANSI S1.4-1971 (R1976), Acoustical Society of America, New York, NY.

8. Sound Level Meters. IEC Standard, Publication 651, International Electrotechnical Commission, Geneva, Switzerland (First Edition 1979).

9. American National Standard Method for the Calculation of the Absorption of Sound by the Atmosphere. American National Standards Institute, ANSI S1.26-1978, Acoustical Society of America, New York, NY.

10. American National Standard Specifications for Octave, Half-Octave, and Third-Octave-Band Filter Sets. American National Standards Institute, ANSI S1.11-1966 (R1971), Acoustical Society of America, New York, NY.

11. Marsh, Alan H.: Evaluation of Alternative Procedures for Atmospheric Absorption Adjustments during Noise Certification; Volume I: Analyses and Results. Federal Aviation Administration Contractor Report FAA-EE-80-46-I (January 1982).

12. Connor, Andrew B.; Copeland, W. Latham; and Fulbright, Danny C.: Low Altitude Temperature and Humidity Profile Data for Application to Aircraft Noise Propagation. NASA Technical Note TN D-7975 (September 1975).

13. Frederiksen, E.; Eirby, N.; and Mathiasen, H.: Prepolarized Condenser Microphones for Measurement Purposes. Brüel and Kjaer Technical Review No. 4 (1979).

14. Valley, Shea L., ed.: Handbook of Geophysics and Space Environments. Air Force Cambridge Research Laboratories, Office of Aerospace Research, United States Air Force (1965).

15. Chapkis, R. L.: Atmospheric Turbulence Effects on Aircraft Noise Propagation. NASA Contractor Report CR-159325 (June 1979).

16. Chun, K. S.; Berman, C. H.; and Cowan, S. J.: Effects of Motion on Jet Exhaust Noise From Aircraft. NASA Contractor Report CR-2701 (June 1976).

17. Smith, M. J. T.: International Aircraft Noise Measurement Procedures — Expensive Acquisition of Poor Quality Data. American Institute of Astronautics and Aeronautics Paper No. 77-1371, AIAA Fourth Aeroacoustics Conference (3-5 October 1977).

18. Taniguchi, H. H.; and Rasmussen, G.: Selection and Use of Microphones for Engine and Aircraft Noise Measurements. *Sound and Vibration*, 13, No. 2, 12-20 (February 1979).

19. Mueller, Arnold W.: A Comparison of the Three Methods Used To Obtain Acoustic Measurements for the NASA Flight Effects Program. NASA Technical Memorandum 81906 (October 1980).

20. SAE Committee A-21: Practical Methods To Obtain Free-Field Sound Pressure Levels From Acoustical Measurements Over Ground Surfaces. Appendix A: Procedure Developed by SNECMA To Remove Ground Reflection Effects From Sound Pressure Levels Measured by Microphones Located Above a Hard Surface (March 1979). SAE Aerospace Information Report AIR 1672 (March 1981).

21. SAE Committee A-21: Practical Methods To Obtain Free-Field Sound Pressure Levels From Acoustical Measurements Over Ground Surfaces. Appendix D: Approximation of Freefield Sound Pressure Levels in Jet-Powered Aircraft Flyover Noise Testing — Methods Evaluated by Rolls Royce (third draft, April 1981). SAE Aerospace Information Report AIR 1672 (to be issued with Appendix D).

22. SAE Committee A-21: Practical Methods To Obtain Free-Field Sound Pressure Levels From Acoustical Measurements Over Ground Surfaces. Appendix B: Procedure Developed by The Boeing Company To Determine Equivalent Free-Field Sound Pressure Levels Around an Engine Test Stand (January 1979). SAE Aerospace Information Report AIR 1672 (March 1981).

23. SAE Committee A-21: Practical Methods To Obtain Free-Field Sound Pressure Levels From Acoustical Measurements Over Ground Surfaces. Appendix C: Procedure Developed by Pratt & Whitney Aircraft (P&WA) To Determine Equivalent Free-Field Sound Pressure Levels at a Static Jet-Engine Test Stand (August 1980). SAE Aerospace Information Report AIR 1672 (March 1981).

24. Hosier, Robert N.; and Donavan, Paul R.: Microphone Windscreen Performance. National Bureau of Standards Instrumentation Report NBSIR 79-1599 (January 1979).

25. Willshire, William L., Jr.: Assessment of Ground Effects on the Propagation of Aircraft Noise: The T-38A Flight Experiment. NASA Technical Paper 1747 (December 1980).

26. Letestu, S., ed.: International Meteorological Tables. World Meteorological Organization, Geneva, Switzerland (1966).

27. List, Robert J.: Smithsonian Meteorological Tables. Smithsonian Miscellaneous Collections, Vol. 114, First reprint of sixth revised edition, Smithsonian Institution, Washington, DC (February 1958).

28. Goff, John A.: Saturation Pressure of Water on the New Kelvin Scale. Humidity and Moisture, Arnold Wexler, Ed.-in-Chief, Vol. 3, Fundamentals and Standards, pp.289-292, Reinhold Publishing Corporation, New York (1965).

29. Inter-Range Instrumentation Group: IRIG Standard Time Formats. Document 104-70, Secretariat, Range Commander's Council, White Sands, New Mexico (August 1970).

APPENDIX A

ESTIMATION OF SOUND-RECORDING TIMES, SOUND-EMISSION AND AIRCRAFT-POSITION ANGLES FROM TIME-CORRELATED ACOUSTIC AND AIRCRAFT-POSITION DATA

Consider the geometrical relationships shown in Figure A1 for a microphone location under the flight path. The aircraft, denoted by point P, flies along a straight flight path at constant speed V_a and Mach number $M_a = V_a/c$ where c is the speed of sound corresponding to an average temperature of the air along the propagation paths. The flight path is inclined at an angle γ relative to the horizontal; angle γ is positive when climbing and negative when descending. The inclination, if any, of the thrust axis relative to the direction of flight should be considered when calculating angle γ since the sound emission angle should be determined relative to the thrust axis, for single-engine aircraft, or to the equivalent thrust axis that acts through the aircraft's approximate center of gravity for multi-engine aircraft.

Angle ψ is the sound-emission angle (or sound directivity angle) between the flight path and a line from point E to point R where point E denotes where the aircraft was on the flight path when it emitted the sound pressure signal which arrives at the microphone at receiver position R when the aircraft is at point P. The aircraft moves from point E to point P over a distance $V_a(\Delta t)$ in the time Δt that it takes a sound wave to travel distance $c(\Delta t)$ from point E to point R. When the aircraft is at point P, the flight path is at angle ϕ with respect to a line from point P to the microphone at R. Angles ψ and ϕ are measured from the direction of flight and are positive downwards.

Auxiliary angle η is useful for determining angle ψ knowing angle ϕ and can be found from the law of sines for plane triangles, namely

$$[c(\Delta t)]/\sin(\pi - \phi) = [V_a(\Delta t)]/\sin \eta \qquad \text{(A1)}$$

from which

$$\eta = \arcsin(M_a \sin \phi) \qquad \text{(A2)}$$

The three angles are related by

$$\phi = \psi + \eta \qquad \text{or} \qquad \psi = \phi - \eta \qquad \text{(A3a)} \quad \text{(A3b)}$$

When the aircraft is overhead, Figure A1(b), $\phi = (\pi/2) + \gamma$. If the flight path is horizontal ($\gamma = 0$), $\psi = (\pi/2) - \arcsin(M_a) = \arccos(M_a)$ when the aircraft is over the microphone.

Because it is convenient to distinguish between events occurring before or after the overhead position, relative data-sample times t_r are shown in the three parts of Figure A1 with respect to the time of day at overhead and as well as relative to the time of day associated with the first 0.5-second data sample. However, even though time-of-day time code is recorded along with the sound pressure signals for the purpose of correlating different test events, the time of day at the instant of closest approach may not be available unless a specific procedure is included to add a time mark on the data-recording tape when the aircraft is overhead or directly opposite for microphones to the side of the flight track.

If the data tapes do not contain a mark at the time of the aircraft's closest approach to each microphone (as they likely may not if two, or more, data channels are being recorded simultaneously), then time-code signals can only be used to identify the time of each data sample relative to one another and not relative to the time at overhead. In this case, the relative data-sample time should be computed with respect to the time associated with the first sample of data.

Whether the relative data-sample time is determined with respect to the time of day at the instant of closest approach or to the time of day associated with the first sample of data or to some other reference time, the preferred time for identifying a data sample is the midpoint of the integration period used to determine the average band pressure levels. If the time at the start of the integration period for the first data sample is some particular value of clock time from the time-code generator (which should be the same start time for all frequency bands), then the test time to associate with the first data sample is half the averaging period later. The test time for all successive data samples should then be in increments of the constant-duration averaging periods, e.g., 500 ms.

A standard definition for the relative time to associate with each sample of sound pressure level data is required because relative time is used with the aircraft position data (which is recorded as a function of time-code clock time) to determine angles ψ and ϕ and hence sound propagation distances.

If the time associated with a sample of acoustical data is determined with respect to the time t_{s0} of the first data sample, then, from the distance travelled along the flight path, the time t_s for any subsequent data sample is related to the corresponding aircraft-position angles by

$$(t_s - t_{s0}) = (d_m/V_a)(\cot \phi_0 - \cot \phi) \qquad \text{(A4)}$$

where angle ϕ_0 is associated with sound pressure levels at time t_{s0} and angle ϕ is associated with sound pressure levels at time t_s. Time t_{s0} may be taken as a reference time of zero seconds.

The procedure for determining aircraft-position-angle ϕ will depend on the details of the system selected to track the position of the aircraft along the flight path. The coordinates of an aircraft reference point as a function of time-of-day time code should be available from the aircraft tracking system. Given the coordinates of the aircraft reference point and the coordinates of the microphone (relative to a reference coordinate system), the airspeed, the average temperature of the air through which the aircraft is flying and hence the speed of sound at the height of the aircraft (and thus the aircraft's Mach number), an angle ϕ and a distance PR can be determined for the relative time of each sample of sound pressure level data.

Once angle ϕ is known, angle η can be calculated by use of Equation (A2) since Mach number M_a is also known at any data-sample time. Angle ψ is then found from Equation (A3b). Knowing angles ϕ and ψ plus flight-path angle γ and either distance PR or height h from the tracking data, the minimum distance d_m between the microphone and the flight path and the sound propagation distance ER can be readily calculated for each instant of relative data-sample time.

From the geometrical relationships in Figure A2, where distance x along the flight path is introduced for convenience, a relation between ϕ and ψ is found from

$$\tan \phi = d_m/x = [c(\Delta t)\sin \psi]/x \tag{A5}$$

or, with $x = c(\Delta t)\cos \psi - V_a(\Delta t)$,

$$\tan \phi = [c(\Delta t)\sin \psi]/[c(\Delta t)\cos \psi - V_a(\Delta t)]$$

$$= (\cot \psi - M_a \csc \psi)^{-1} \tag{A6}$$

A relation between relative data-sample time and sound-emission angle can be found, for the case shown in Figure A1(c) when the aircraft has passed the overhead point and t_r is positive, from

$$V_a t_r = V_a(\Delta t) + c(\Delta t)\cos(\pi - \psi)$$

or

$$t_r = \Delta t - (c/V_a)(\Delta t)\cos \psi \tag{A7}$$

Sound-propagation time Δt can be eliminated from Equation (A6) through

$$\sin(\pi - \psi) = d_m/c(\Delta t) = \sin \psi \tag{A8}$$

to yield, for any value of ψ,

$$t_r = (d_m/V_a)[M_a \csc \psi - \cot \psi] \tag{A9}$$

where $t_r > 0$ for $\psi > \arccos(M_a)$ and $t_r < 0$ for $\psi < \arccos(M_a)$.

The longest duration, between two sound-propagation angles, occurs for flights at the greatest height (largest value of d_m) and lowest airspeed (smallest value of V_a), and vice versa.

As an example, assume an airspeed of 100 m/s and an average air temperature of approximately 20° C so that the speed of sound is 343 m/s giving an aircraft Mach number of 0.2915. If acoustic data can be recorded over a range of sound-emission angles from 20° to 160°, the durations between relative data-sample times for three minimum distances are calculated from Equation (A9) and tabulated below.

d_m, m	t_{r1} for $\psi = 20°$, sec	t_{r2} for $\psi = 160°$, sec	$\Delta t = t_{r2} - t_{r1}$, sec
100	-1.9	3.6	5.5
1000	-18.95	36.0	54.95
3000	-56.85	108.0	164.85

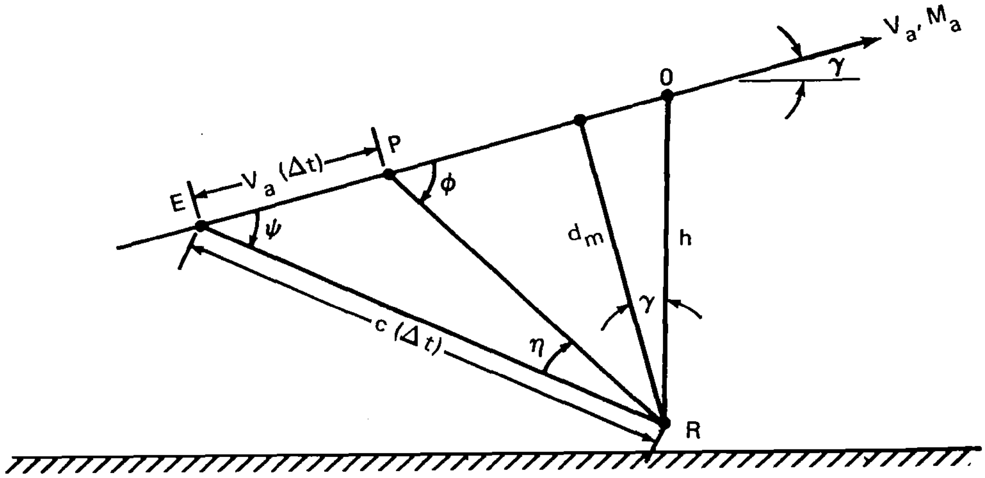
The time rate of change of aircraft-position angle can be estimated from Equation (A9) with distance x replaced by $V_a t_r$ where t_r is in the time frame relative to the time when the aircraft is overhead. For aircraft locations prior to overhead where t_r is negative as in Figure A1(a), aircraft-position angle is given by

$$\phi = \arctan(-d_m/V_a t_r) \tag{A10}$$

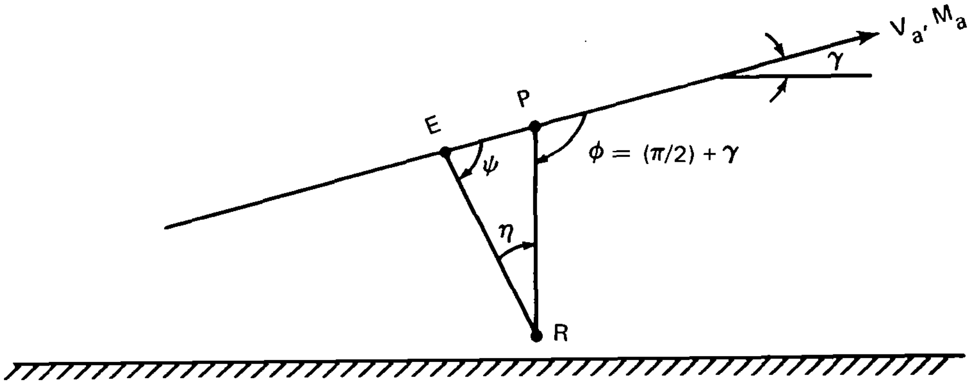
from which the time rate of change is

$$d\phi/dt_r = (d_m/V_a)/[(d_m/V_a)^2 + t_r^2] \tag{A11}$$

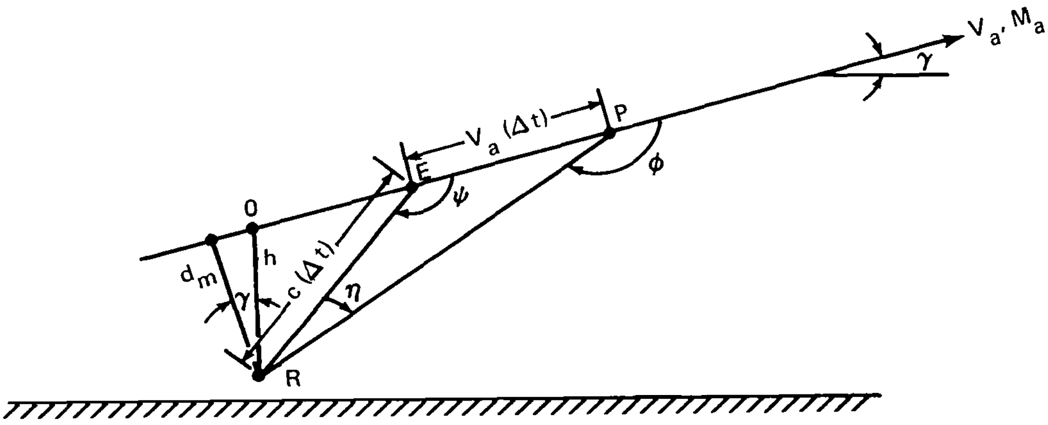
in radians/second. The rate of change is greatest when $t_r = 0$, or around the time at the point of closest approach. Rapid rates of change are also associated with close distances and high airspeeds.



(a) BEFORE AIRPLANE IS OVERHEAD, $t_r < 0$.



(b) AIRPLANE OVERHEAD, $t_r = 0$.



(c) AFTER AIRPLANE IS OVERHEAD, $t_r > 0$.

Figure A1.-Geometrical relationships between aircraft and microphone at different relative times during a flyover.

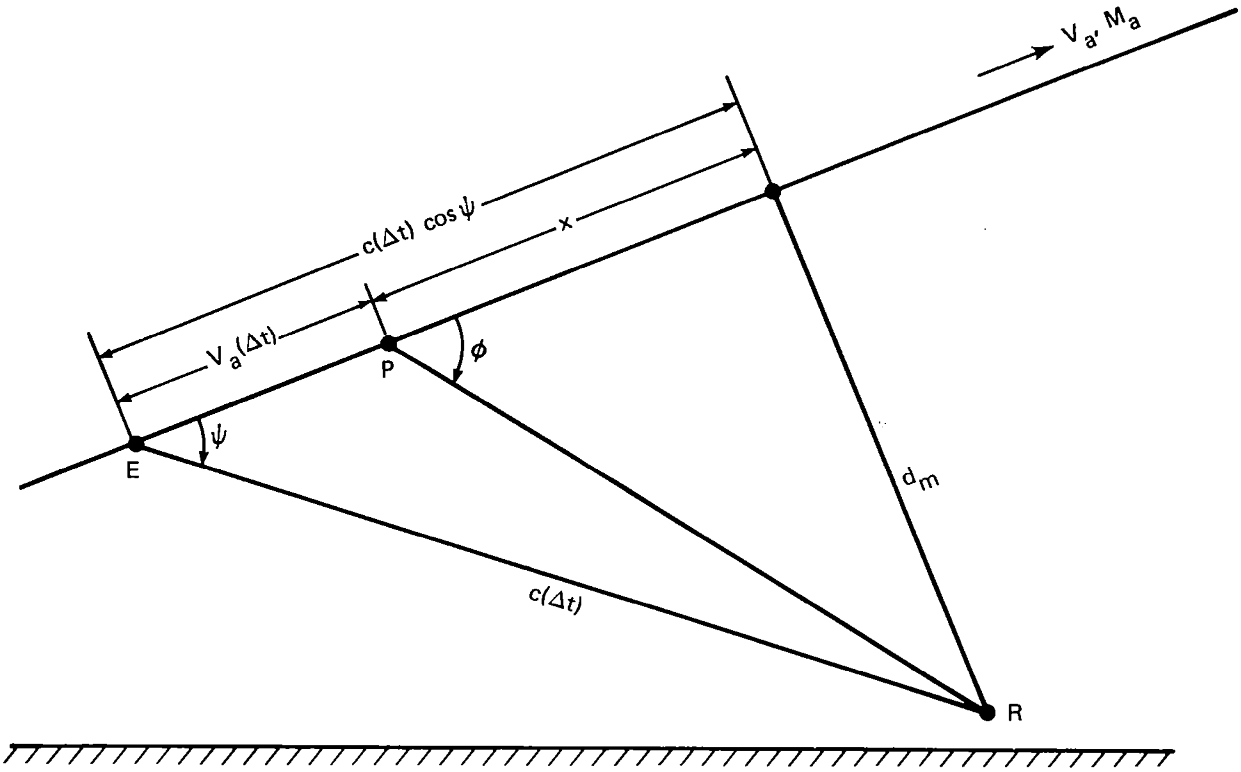


Figure A2.-Flight path geometry for determining relationship between angles ϕ and ψ.

APPENDIX B

CALCULATION OF RELATIVE HUMIDITY FROM MEASUREMENTS OF DEWPOINT (OR FROSTPOINT) AND AIR TEMPERATURE

For a sample of moist air at pressure p and temperature T, relative humidity, U_w, with respect to water is defined as 100 times the ratio of the mole fraction of the water vapor of the sample of moist air to the mole fraction of water vapor which the sample of moist air would have if it were saturated with respect to a plane surface of water at the same pressure p and temperature T. Even for air temperatures below 0° C, relative humidity is to be determined with respect to liquid water, not ice.

The ratio of mole fractions in the definition of relative humidity can be shown [26] to be equal to the corresponding ratio of vapor pressures for moist air. Thus

$$U_w = 100\ (e'/e'_w)_{p,T} \tag{B1}$$

where e' is the vapor pressure of the sample of moist air at pressure p and e'_w is the saturation vapor pressure with respect to a plane surface of water for moist air at pressure p and temperature T.

For saturation over liquid water, Goff [28] gives the following expression to calculate vapor pressure at the dewpoint, or the saturation vapor pressure over liquid water at the static or ambient air temperature:

$$\begin{aligned}\log_{10}(p'_w/p_0) = {} & 10.79586[1 - (T_{01}/T)] \\ & - 5.02808 \log_{10}(T/T_{01}) \\ & + 1.50474\times10^{-4}\left\{1 - 10^{-8.29692[(T/T_{01}) - 1]}\right\} \\ & + 4.2873\times10^{-4}\left\{-1 + 10^{4.76955[1 - (T_{01}/T)]}\right\} \\ & - 2.2195983\end{aligned} \tag{B2}$$

where p'_w has units of kPa if p_0 (the standard atmospheric pressure) has units of kPa with the standard value of 101.3250 kPa (1013.250 millibars) at mean sea level at a temperature of 288.15 K (15° C), and T_{01} is the standard value for the triple-point isotherm temperature of 273.16 K. Absolute zero on the kelvin scale is at -273.15 K, the steam-point isotherm is at 373.15 K (100° C). Temperature T in Equation (B2) is in kelvins.

The general symbol p'_w in Equation (B2) represents the vapor pressure e' of the sample of moist air if the temperature is the dewpoint T_d. Saturation vapor pressure over liquid water, e'_w, will be calculated if the static air temperature is used in Equation (B2). Equation (B2) is considered to be applicable for temperatures between -50° C and +100° C.

For air temperatures or dewpoints less than 0° when saturation is over ice and frostpoints are measured, Goff gives

$$\begin{aligned}\log_{10}(p_i'/p_0) = & -9.096936[(T_{01}/T) - 1] \\ & - 3.56654 \log_{10}(T_{01}/T) \\ & + 0.876817[1 - (T/T_{01})] \\ & - 2.2195983\end{aligned} \tag{B3}$$

where p_i' is the vapor pressure, in kPa, of moist air over a layer if ice when the frostpoint T_f is used for temperature T. Equation (B3) also yields the saturation vapor pressure over ice if the static air temperature is used for the calculation, but that pressure is not needed for standard relative humidity calculations. Equation (B3) is considered to be applicable for temperatures between -100° C and 0° C.

Equations (B2 and (B3), along with Equation (B1), could be stored in a hand-held programmable calculator to simplify calculations of vapor pressure and relative humidity in the field. It would only be necessary to enter two temperatures, dewpoint or frostpoint and air temperature, and the calculator would display (print out) the corresponding relative humidity. Note that because the preferred system in the meteorological airplane is based on a measurement of dewpoint (or frostpoint), humidity calculations are independent of the value of the air pressure at the time of the measurement.

In summary, use Equation (B2) for vapor pressure at dewpoints, Equation (B3) for vapor pressure at frostpoints, and Equation (B2) for saturation vapor pressure over water at any temperature. (At a dewpoint or frostpoint of 0° C (or more precisely at the isotherm temperature of 0.01° C), Equations (B2) and (B3) give the same result, namely a vapor pressure of 611.11 Pa.) Given the two vapor pressures, use Equation (B1) to calculate relative humidity.

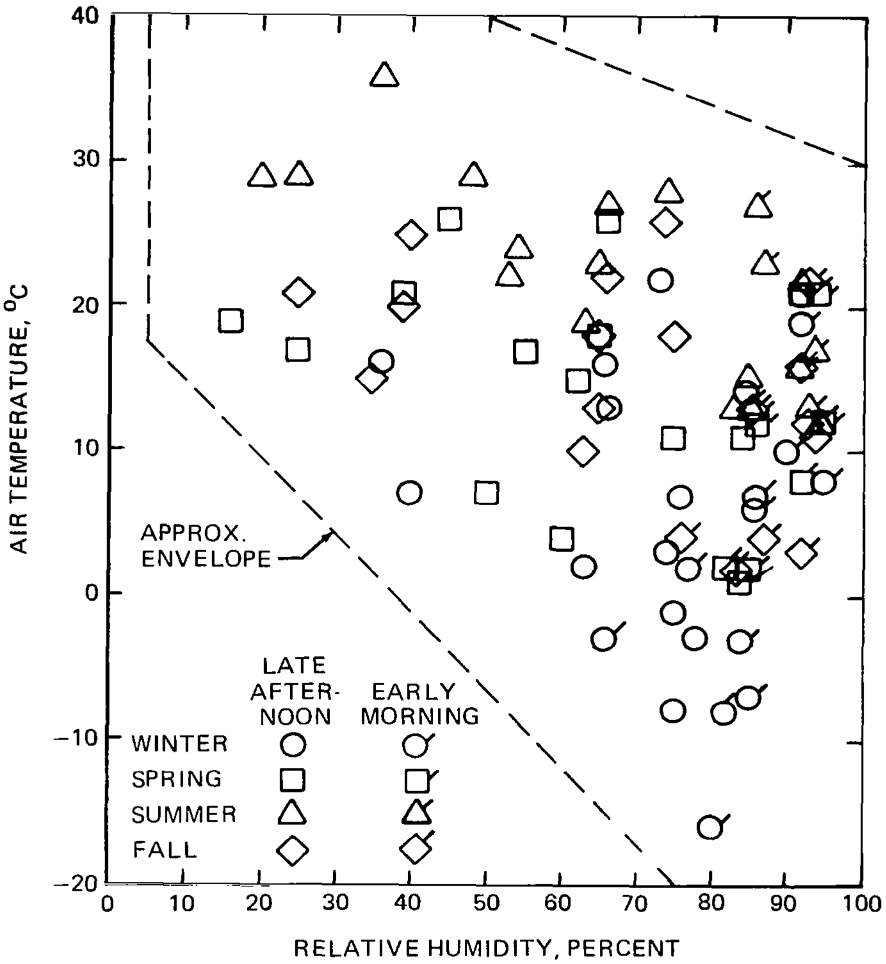


Figure 1.-Approximate range of average surface temperatures and relative humidities encountered in the late afternoon and early morning hours at eleven sites in the USA.

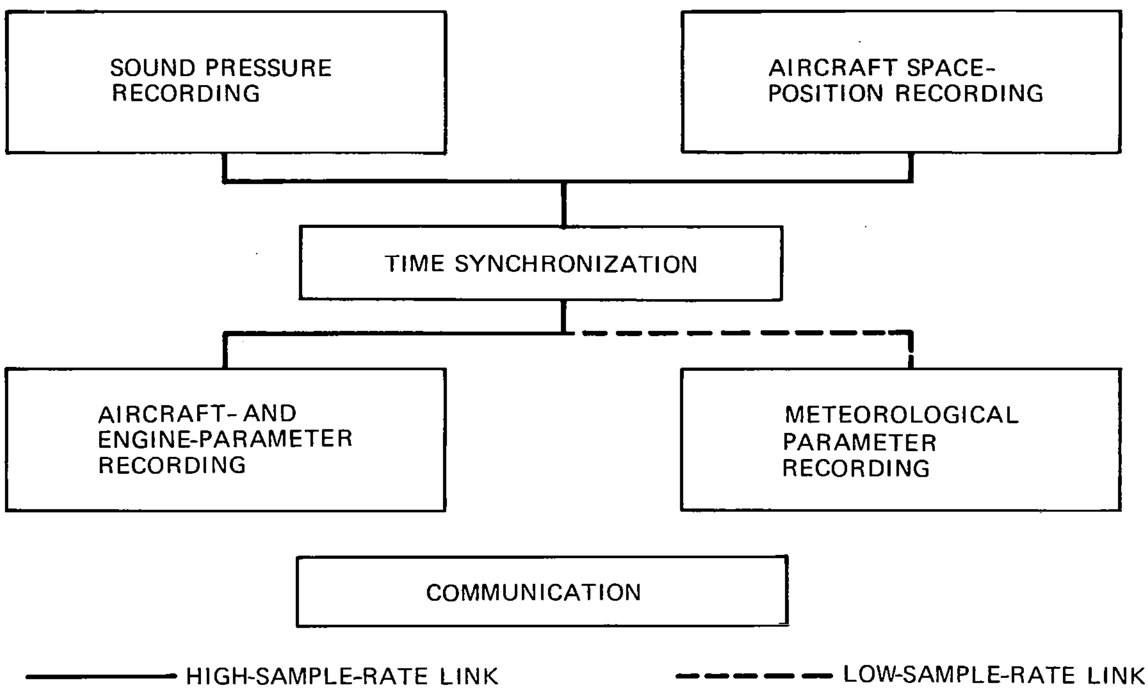


Figure 2.-System components for acquisition of aircraft noise data.

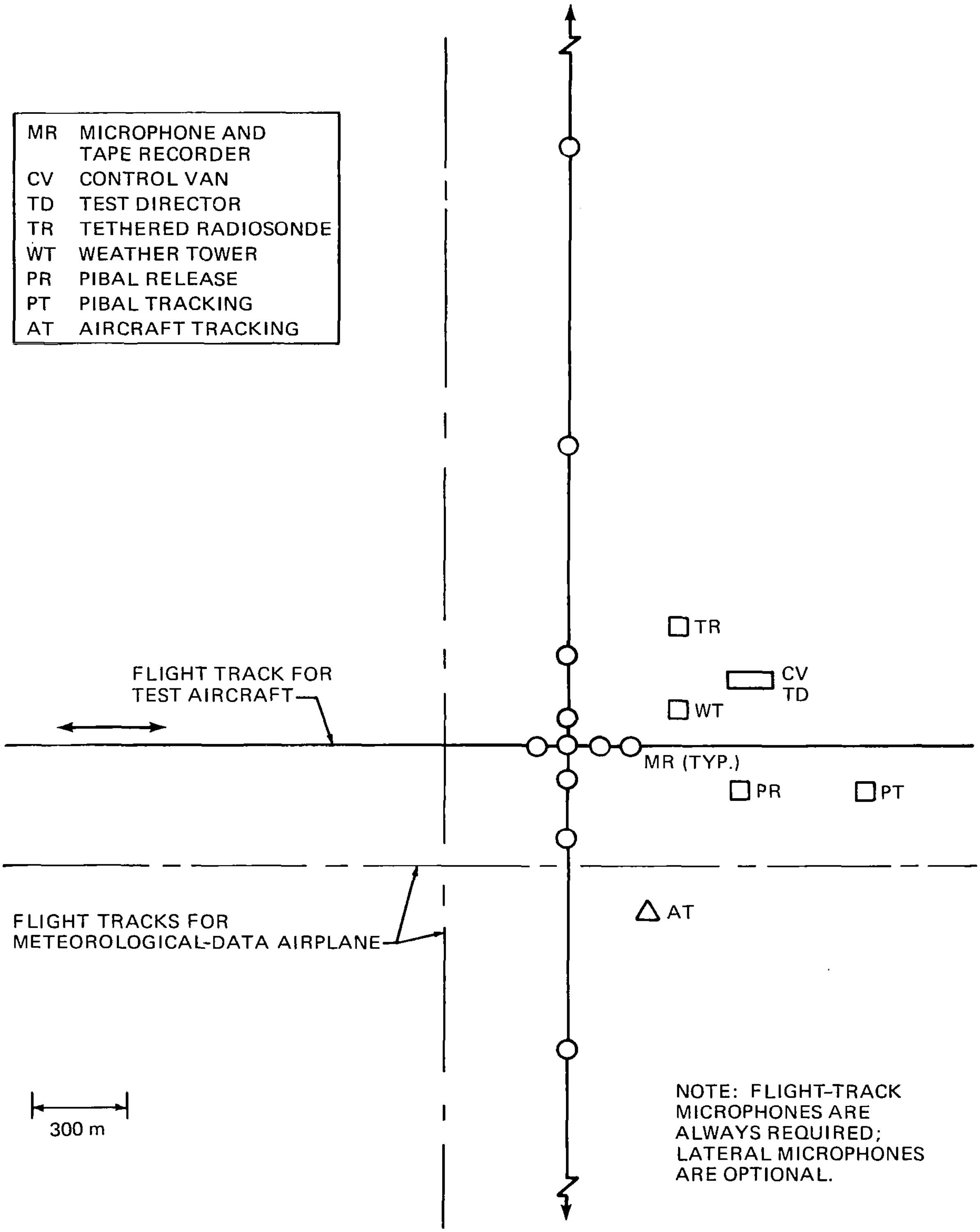


Figure 3.-Schematic plan view of test site showing major elements for recording of acoustic, tracking, and meteorological data.

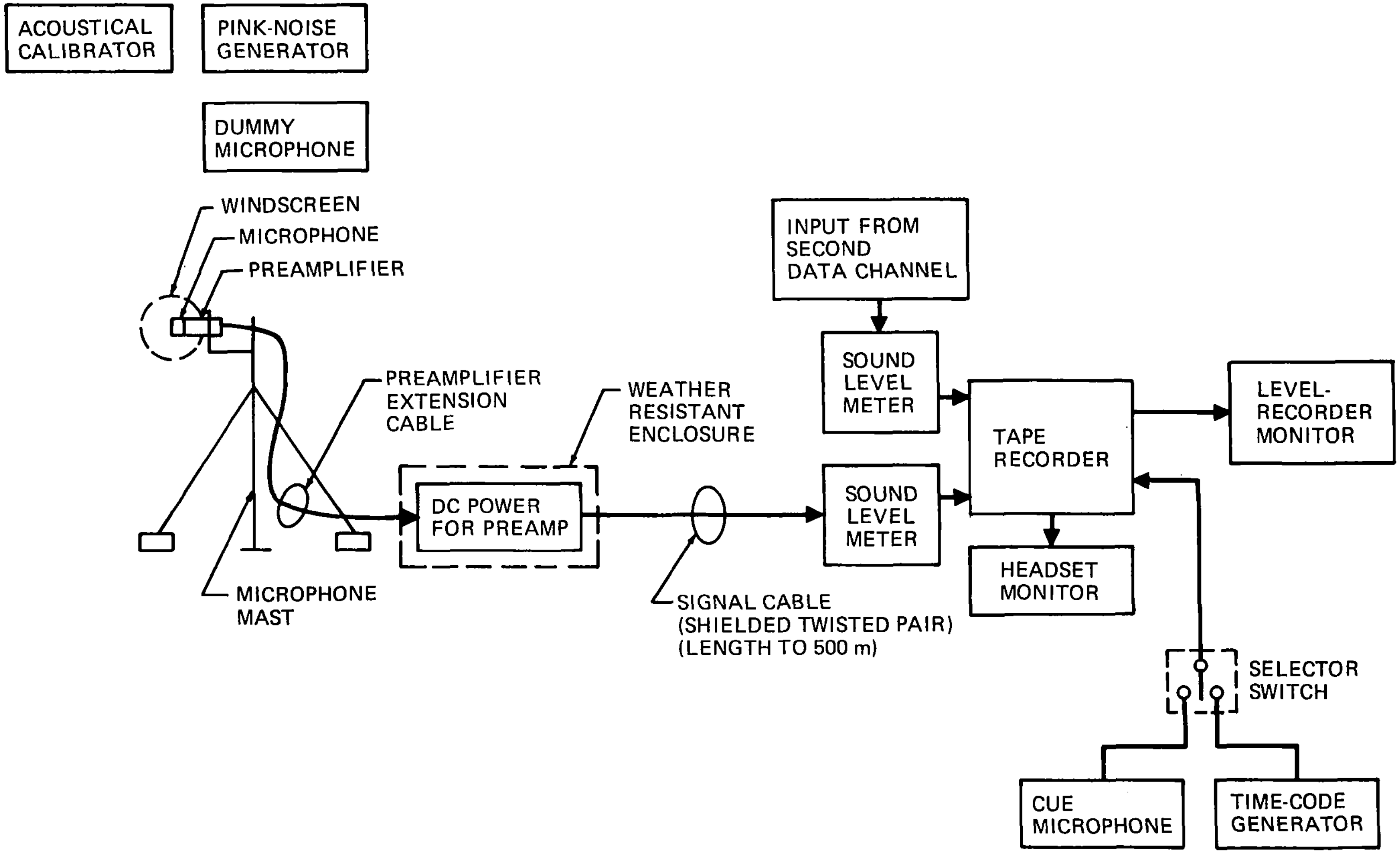


Figure 4.-Sound-recording system for one data-acquisition station.

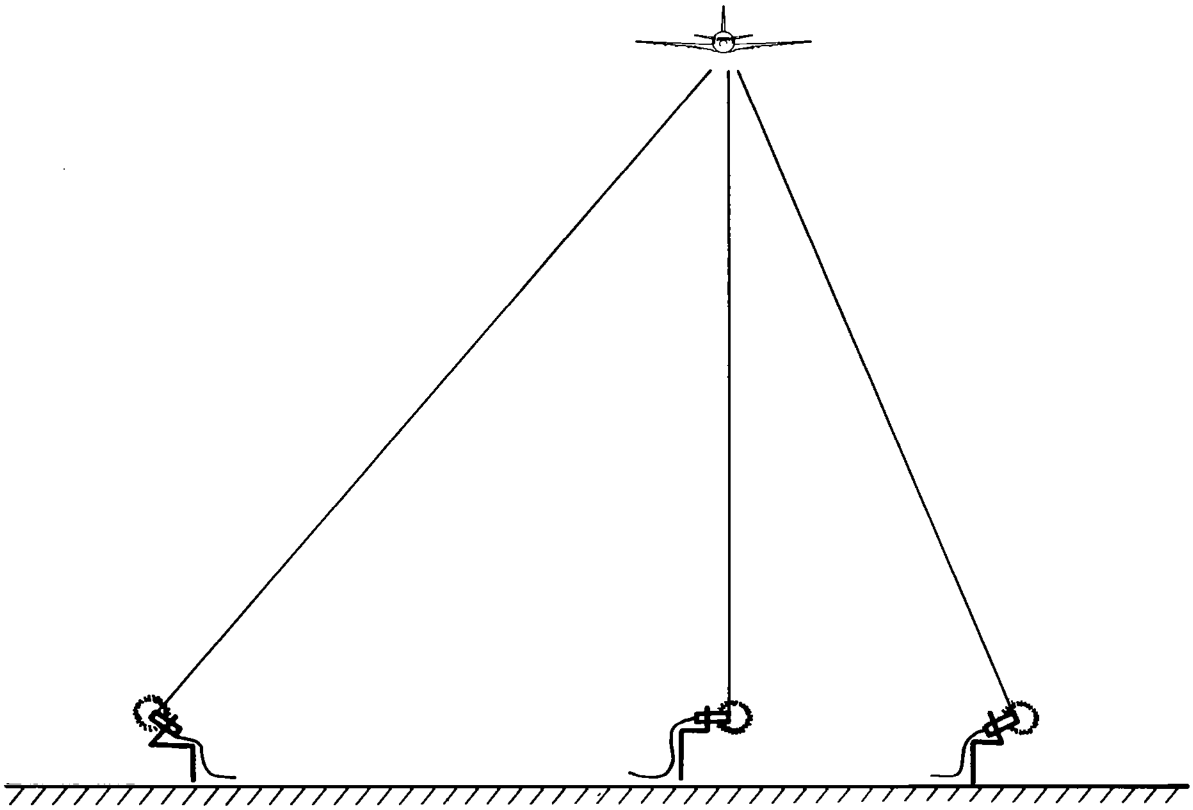


Figure 5.-Illustration of orientation of microphones for grazing incidence at locations on and to the side of the flight track.

TABLE 1.-Approximate values of long-term most-often-observed surface temperatures and relative humidities at eleven locations in the USA.

(a) Early morning (1200 hr GMT)

Location	Winter[a]		Spring[b]		Summer[c]		Fall[d]	
	T, °C	U_w, %	T, °C	U_w, %	T, °C	U_w, %	T, °C	U_w, %
Caribou, ME	-16	80	2	82	13	93	3	92
Norfolk, VA	2	77	14	85	22	92	16	92
Miami, FL	19	92	21	92	27	86	22	93
Green Bay, WI	-7	85	2	85	16	92	4	87
Columbia, MO	-3	84	12	86	21	92	12	93
Glasgow, MT	-8	82	1	84	13	83	2	84
Denver, CO	-3	66	2	82	13	83	4	76
San Antonio, TX	10	90	21	94	23	87	21	92
Tatoosh Island, WA	6	86	8	92	12	95	11	94
Oakland, CA	7	86	11	84	13	86	13	86
San Diego, CA	8	95	12	95	17	94	16	92

(b) Late afternoon (0000 hr GMT)

Location	Winter		Spring		Summer		Fall	
	T, °C	U_w, %	T, °C	U_w, %	T, °C	U_w, %	T, °C	U_w, %
Caribou, ME	-8	75	7	50	22	53	10	63
Norfolk, VA	3	74	15	62	27	66	18	75
Miami, FL	22	73	26	66	28	74	26	74
Green Bay, WI	-3	78	4	60	24	54	13	65
Columbia, MO	2	63	21	39	29	48	20	39
Glasgow, MT	-1	75	17	25	29	25	15	35
Denver, CO	7	40	19	16	29	20	21	25
San Antonio, TX	16	36	26	45	36	36	25	40
Tatoosh Island, WA	7	76	11	75	15	85	13	84
Oakland, CA	13	66	17	55	19	63	18	65
San Diego, CA	16	66	18	65	23	65	22	66

[a]Winter = average of records in December, January, and February

[b]Spring = average of records in March, April, and May

[c]Summer = average of records in June, July, and August

[d]Fall = average of records in September, October, and November

TABLE 2.-Acoustical, Tracking, and Aircraft and Engine Data

Acoustical data	Tracking data
Time code	Time code
Sound pressure	Coordinates of aircraft reference point
Background noise	
Remarks (gain settings)	
Calibration	Calibration
Reference level	
Frequency response	

Aircraft and engine data	
Time code	
Aircraft	Each Engine
Indicated airspeed	Inlet total pressure
Ambient air pressure	Primary nozzle total pressure
Ambient air temperature	Engine pressure ratio (if applicable)
Altitude above mean sea level	Shaft rotation speed (each shaft)
Operating gross weight	Primary nozzle total temperature
Attitude: pitch, roll, yaw	Fuel flow rate
Flap deflection angle	Special parameters as required
Leading-edge device: extended or retracted	
Landing gear: extended or retracted	
Air conditioning: off or on (no. of units operating)	
Angle of attack (if available)	
Climb or descent rate or gradient	

TABLE 3.-Weather Data

Surface tower	Weather airplane
Time of day Air temperature Dewpoint Wind speed Wind direction (Continuous)	Time of day Air temperature Dewpoint Air pressure Height (Each ascent and each descent)
Tethered radiosonde	**Meteorological balloons**
Time of day Air temperature Relative humidity Wind speed Wind direction Height (Each ascent and each descent)	Time of day Wind speed Wind direction Height (Each ascent)

TABLE 4.-Supplemental Information

- Coordinates of each microphone location
- Plan view of test site, showing locations of microphones, central acoustic test van, aircraft tracking system, surface weather tower, tethered radiosonde, meteorological balloons
- Elevation and slope of ground surface
- Description of terrain around each microphone location and surface weather tower
- Block diagrams showing the instruments used for acoustical, tracking, and weather data, with instrument model and serial numbers
- Test aircraft registry number, model number, and name-plate information
- Model and thrust rating of test aircraft's engines
- Description of acoustical features of the test aircraft's engines: nacelle duct linings, jet noise suppressor nozzle, etc.
- Dimensioned 3-view drawing of the test aircraft
- Description of the weather airplane showing installation of test instruments
- Black and white photographs
    - Test aircraft on the ground (several views)
    - Test aircraft's engines and nacelles (several views)
    - Microphone installations
    - Central acoustic test van: interior and exterior
    - Surface weather tower installation
    - Tracking system: interior and exterior, as applicable
    - Weather airplane on ground (several views, including instruments)
    - Tethered radiosonde (several views, including instruments)
    - Meteorological balloons (several views, including instruments)

TABLE 5.-Summary of ground-located communication equipment and functions

Item	Freq.	Type[a]	Functions[b]	Locations
1	f_1	R/T	air-to-ground and ground to-air communications	control van key microphone stations meteorological airplane
2	f_1	R	monitor communications from test aircraft to ground stations	other microphone stations laser tracker tethered radiosonde
3	f_2	R	monitor communications with air traffic control	control van
4	f_3	R/T	communicate with ground traffic control	control van test vehicles
5	f_4	R/T	communications among ground personnel	control van all microphone stations laser tracker meteorological airplane tethered radiosonde pibal release pibal tracker

[a]R/T: receive and transmit
R : receive only

[b]all transmissions use VHF frequencies and the FM mode

TABLE 6.-Acoustical Instruments

(a) Acoustical calibrator

Item	Quantity	Requirement
1	design-center sound pressure level[a] in cavity of coupler at design reference conditions of 101.3 kPa, 20° C, and 65% relative humidity	124, 114, or 94 dB re 20 μPa
2	tolerance limits on accuracy of design-center sound pressure level at design-center frequencies over working range of battery voltage and air temperature	±0.3 dB
3	nominal design-center frequency of sinusoidal signal[b]	250, 500, or 1000 Hz
4	tolerance limits on accuracy of design-center frequency	±2 percent
5	maximum total harmonic distortion of sinusoidal signal at any operational sound pressure level, frequency, or environmental condition	1 percent
6	minimum range of air temperature, when operating	-10° to +50° C
7	maximum coefficient of temperature sensitivity for reference sound pressure level over operational temperature range	±0.02 dB/°C
8	minimum range of relative humidity, when operating, at any temperature in the operating range, without condensation	0 to 90 percent
9	electrical power	internal battery
10	battery-condition indicator	must be provided
11	influence, on sound pressure level produced by the calibrator, of the atmospheric pressure being different than the 101.3 kPa reference atmospheric pressure at altitudes above or below sea level	manufacturer must provide information to correct the output for differences between reference and actual atmospheric pressure

[a]At a minimum the calibrator must provide a signal at one of the indicated sound pressure levels. It is desirable for the calibrator to be able to generate sound pressure levels at 10-dB intervals from 124 dB (or 114 dB) to 74 dB.

[b]The calibrator must provide a signal for at least one of the indicated frequencies. If only one frequency is provided, 1000 Hz is preferred. It is desirable for the calibrator to be able to produce signals at the six nominal preferred octave frequencies from 125 to 4000 Hz.

TABLE 6.-Continued

(b) Pink-noise generator

Item	Quantity	Requirement
1	minimum frequency range over which the average slope of the 1/3-octave-band spectrum of the pink-noise voltage is within ±1 dB of a zero slope	40 to 20,000 Hz
2	minimum wideband (2 to 50,000 Hz), open-circuit, full scale, root-mean-square voltage of pink-noise signal	500 mV
3	amplitude-probability-density distribution of wideband pink-noise signal	Gaussian, symmetrical about rms value to $\pm 4\sigma$
4	minimum range of air temperature, when operating	-10° to +40° C
5	maximum variability of level of wideband, pink-noise signal at any temperature in operational range	±0.3 dB
6	minimum range of relative humidity, when operating, without condensation and at any temperature in operational range	0 to 90 percent
7	electrical power	internal battery
8	battery-condition indicator	must be provided
	(c) Dummy microphone	
1	nominal capacitance of shielded capacitor in dummy microphone relative to the nominal capacitance of the measurement microphone	±30 percent

TABLE 6.-Continued

(d) Windscreen

Item	Quantity	Requirement
1	type	general purpose
2	nominal shape	sphere
3	minimum nominal diameter	90 mm
4	material	polyester (polyurethane)
5	construction	reticulated, open-cell foam
6	range of nominal pore spacing	1000 to 2000 pores/meter

TABLE 6.-Continued

(e) Microphone and preamplifier

Item	Quantity	Requirement
1	microphone type	capacitor (condenser)
2	microphone polarizing voltage preferably supplied by	bound electric charges in electret material
3	preferred nominal outside diameter of microphone	13 mm
4	minimum open-circuit sensitivity of microphone at 1000 Hz and 101.3 kPa, 20° C, and 65% relative humidity	-40 dB re 1 V/Pa
5	preferred direction for incidence of sound waves onto microphone to achieve widest range of nominally flat frequency response	random
6	minimum range of frequency response of microphone and preamplifier, for sound in the calibration direction, within ±2 dB of the response at 1 kHz	10 to 12,000 Hz
7	minimum capacitance of microphone at 1 kHz and 20° C	15 pF
8	minimum operational range of air temperature for microphone and preamplifier at 95% relative humidity	-10° to +50° C
9	for air temperatures between -10° and +50° C, maximum coefficient of microphone temperature sensitivity at 500 Hz . . .	±0.01 dB/°C
10	minimum high-amplitude sound pressure level for 3% total harmonic distortion of sinusoidal signal at frequencies in the range of nominally flat response	145 dB re 20 μPa
11	with a dummy microphone having the measurement microphone's nominal capacitance on the preamplifier, maximum flat-weighted (10 to 20,000 Hz) rms value of electrical background noise at output terminals	10 μV
12	same as 11, but maximum A-weighted rms value of electrical background noise	3 μV

TABLE 6.-Continued

(e) Microphone and preamplifier (Concluded)

Item	Quantity	Requirement
13	minimum input resistance of preamplifier	2 GΩ
14	nominal gain through preamplifier at 1 kHz and tolerance limits . .	0 dB ± 0.2 dB
15	maximum output resistance of preamplifier	25 Ω
16	minimum value of maximum rms signal current available at output of preamplifier	1 mA

TABLE 6.-Continued

(f) Preamplifier dc-power supply

Item	Quantity	Requirement
1	range of nominal output voltage	to suit selected microphone and preamplifier
2	current capacity	to suit impedance of longest signal cable at highest frequency of interest for greatest signal voltage (i.e., for maximum high-frequency SPL incident on microphone of given sensitivity)
3	minimum range of air temperature, when operating	-10° to +50° C
4	electrical power	battery
5	battery-condition indicator	must be provided

TABLE 6.-Continued

(g) Signal cable

Item	Quantity	Requirement
1	conductor	stranded wires
2	strand wires	tinned copper
3	conductor configuration	twisted pair or cabled with fillers, tight lay
4	minimum number of strand wires per conductor	7
5	minimum diameter of conductor (minimum AWG)	0.7 mm (22 AWG)
6	maximum nominal resistivity of one conductor	60 Ω/km
7	preferred conductor-insulation material	polyethylene
8	preferred shield coverage	100 percent
9	preferred shield configuration	conductors wrapped with aluminized polyester film with tinned-copper drain wire for terminations
10	preferred material for outer jacket	vinyl (polyvinylchloride)
11	maximum nominal overall outside diameter	5 mm
12	maximum nominal capacitivity between conductors	100 pF/m

Note: Stranded construction for the conductors permits moderate flexing. Polyethylene insulation material provides low capacitivity and high resistance to moisture penetration. The polyethylene dielectric and the vinyl outer jacket retain reasonable flexibility for ease of un-coiling and re-coiling the cable in the field when the air temperature is below freezing.

TABLE 6.-Continued

(h) Sound level meter

Item	Quantity	Requirement
1	minimum input resistance	1 GΩ
2	minimum value of largest rms signal voltage at input	10 V
3	minimum value of rms signal voltage, at output jack for ac signals, corresponding to full-scale deflection of indicator meter for each measurement range	400 mV
4	maximum output impedance	1 kΩ with any load permissible
5	minimum range of linear output on each measurement range	20 dB
6	decibel-step attenuators for level range control	must be provided
7	maximum step size for attenuators	10 dB
8	tolerance limits on accuracy of step attenuators for any attenuation setting in measurement range and any frequency from 10 Hz to 20 kHz	±0.2 dB
9	minimum measurement range for flat-weighted sound levels	30 to 130 dB re 20 μPa
10	minimum frequency range over which the flat-weighted response to electrical signals is within ±0.5 dB of the response at 1 kHz	10 to 20,000 Hz
11	minimum range of air temperature, when operating	-10° to + 50° C
12	minimum range of relative humidity, when operating, at any temperature in operating range, without condensation	0 to 90 percent
13	electrical power	internal battery
14	battery-condition indicator	must be provided

TABLE 6.-Continued

(i) Tape recorder

Item	Quantity	Requirement
1	minimum number of channels for recording acoustical data	2
2	minimum number of channels for recording spoken annotation or identification data and time-code data	1
3	minimum tape width	6.35 mm (1/4 in.)
4	erase, record, and playback heads	separate
5	meter to monitor level of undamped rms value of signal voltage at input jacks	must be provided and have a scale in decibels
6	minimum range of signal voltage levels that can be monitored on monitor meter	20 dB
7	minimum frequency range over which the signal-monitor meter responds within ±0.5 dB	10 to 20,000 Hz
8	decibel-step attenuators to control the recording level of the acoustical data signals	must be provided for each acoustic data channel
9	preferred step sizes for data-signal input-level control by attenuators	1 dB and 10 dB
10	maximum difference, at any frequency from 10 Hz to 40 kHz, between the nominal and actual value of a step change in input-level attenuator setting	±0.2 dB
11	minimum total range of input-signal levels that can be controlled by input-level attenuators	80 dB
12	nominal values of controlled tape speeds that must be provided . . .	at least 38 and 19 cm/s
13	for any temperature in operating range, any supply voltage in working range of internal batteries, any distribution of tape between the supply and takeup reels, and any position of the recorder, maximum difference between actual and nominal controlled tape speed	±0.2 percent

TABLE 6.-Continued

(i) Tape recorder (Continued)

Item	Quantity	Requirement
14	jack for headphones to monitor input signals or signals from playback of recordings for acoustical data or announcements through cue microphone	must be provided
15	for a tape speed of 38 cm/s and any temperature in the operating range, maximum time between when the electronic circuits are energized and a recording may be started	15 seconds
16	minimum range of air temperature, when operating with internal alkaline batteries	-10° to +60° C
17	minimum range of relative humidity, when operating, at any temperature in operating range, without condensation	0 to 90 percent
18	electrical power	internal battery
19	battery-condition indicator	must be provided
20	minimum input resistance for line inputs	100 kΩ
21	minimum range of rms values of wideband random signal voltage for acoustical data that can be recorded without distortion	1 mV to 10 V
22	for acoustical-data channels, minimum frequency range for overall response, within ±1 dB of the response at 1 kHz, for constant-amplitude sinusoidal signals recorded and played back on the same recorder when the signals are recorded 20 dB below the level of the rms voltage that produces the maximum magnetic flux gradient (for direct-mode recordings) for recordings without distortion (i.e., for recordings 20 dB below the maximum recording level)	25 to 35,000 Hz at 38 cm/s tape speed 25 to 20,000 Hz at 19 cm/s tape speed

TABLE 6.-Continued

(i) Tape recorder (Concluded)

Item	Quantity	Requirement
23	for acoustical-data channels, minimum ratio of signal plus noise to noise, for recording and playback on the same tape recorder, between the level of the rms voltage for a sinusoidal signal, in the operating frequency range and recorded at maximum sensitivity at maximum recording level, and the level of the rms voltage of the flat-weighted wideband (20 Hz to 40 kHz) signal with the input shorted to circuit ground and recorded with maximum sensitivity	54 dB at 38 cm/s 58 dB at 19 cm/s
24	for acoustical-data channels, maximum third-harmonic distortion of a 1-kHz sinusoidal signal recorded at maximum recording level, at a tape speed of 38 cm/s, and played back on the same recorder	1.5 percent
25	for acoustical-data channels, minimum attenuation of crosstalk between recording channels for a 1-kHz signal recorded at maximum recording level, at tape speeds of 38 and 19 cm/s, and played back on the same recorder	60 dB
26	for acoustical-data channels, maximum difference between the phase angle of a 10-kHz sinusoidal signal recorded simultaneously on two channels at a tape speed of 19 cm/s	±15 degrees (±4.2 μs)
27	for acoustical-data channels, maximum wow and flutter, at any point on a 178-mm (7-in.) tape reel, when measured as a peak-to-peak value that is frequency weighted according to NAB standard	±0.1 percent
28	for acoustical-data channels, minimum level of erased sinusoidal signal, recorded at maximum recording level, relative to level of signal before being erased, for recordings at 38 cm/s	80 dB
29	for voice and time-code channel, minimum frequency range for overall response, within ±1 dB of the response at 1 kHz, for recordings at normal recording level	200 to 3000 Hz

TABLE 6.-Continued

(j) Level recorder

Item	Quantity	Requirement
1	minimum number of data-recording channels	1
2	basic capability to be provided	record on paper, as a continuous function of time, 10 times the logarithm, base ten, of the time-weighted time-average of the square of an instantaneous time-varying voltage signal; that is, record as a running time average $10\,\lg\{(1/\tau)\int_{-\infty}^{t}[v^2(t)]e^{-(t-\xi)/\tau}\,d\xi\}$ relative to 1 volt where τ is the exponential averaging time
3	minimum input resistance	15 kΩ
4	minimum range of rms voltage for signals to be recorded	10 mV to 5 V
5	minimum range of input-level control (sensitivity control for adjusting zero level on recording paper)	50 dB
6	minimum frequency range over which the response to a constant-amplitude sinusoidal electrical signal is flat within ±0.2 dB of the response at 1 kHz	30 to 20,000 Hz
7	pen-writing speed or system averaging time	adjustable over a wide range with various fixed values one of which approximates the standard fast weighting of a sound level meter for which the exponential time constant is defined by τ = 125 ms

TABLE 6.-Concluded

(j) Level recorder (Concluded)

Item	Quantity	Requirement
8	recording paper	paper roll with continuous black lines on white paper
9	minimum length of roll of recording paper	40 m
10	minimum range of logarithmic potentiometer	25 dB
11	width of recording paper for range of logarithmic potentiometer	to give an ordinate scale that is linear in decibels with no greater than 2 dB/division
12	linearity of pen movement over width of ordinate scale	$\leq \pm 0.3$ dB
13	resolution for reading levels from paper record	$\leq \pm 0.5$ dB
14	preferred system for driving paper	stepper motor controlled by temperature-compensated crystal
15	minimum range of paper speeds to be provided	0.3 to 10 mm/s, adjustable to fixed values
16	preferred writing system	disposable pen using liquid ink and having a fiber-plastic point
17	preferred ink color	black
18	pushbutton event marker	highly desirable
19	minimum range of air temperature, when operating	-10° to +40° C
20	minimum range of relative humidity, when operating, at any temperature in the operating range, without condensation	0 to 90 percent
21	electrical power	internal battery
22	battery-condition indicator	must be provided
23	minimum continuous operating time with new alkaline batteries at a temperature of 20° C	10 hr

TABLE 7.-Instruments for measuring air temperature and dewpoint (or frostpoint) on a 10-m tower and in meteorological airplane

Item	Quantity	Requirement
1	operating principle for measuring dewpoint (frostpoint)	Cool a plane surface until condensation (or ice) forms and equilibrium is established between the rate of condensation and the rate of evaporation. Dewpoint (or frostpoint) is the temperature of the surface at equilibrium.
2	minimum range of air temperatures, dewpoints, or frostpoints that can be measured	-50° to +50° C
3	minimum rate for cooling the plane surface for temperatures greater than 0° C	2° C/sec
4	minimum range of relative humidity that can be determined at any air temperature between -30° and +40° C	surface: 2 to 100 percent airborne: 10 to 100 percent
5	tolerance limits on accuracy of temperature measurements	±0.3° C above 0° C ±0.5° C from -30° to 0° C

TABLE 7.-Continued

Item	Quantity	Requirement
6	aspiration of temperature-sensing elements	surface: small, quiet fan w/ minimum flow rate of 0.03 m^3/s airborne: by ram air over sensors
7	location of temperature-sensing elements relative to the fan in the unit for surface measurements	upstream of fan with the fan above the temperature sensors
8	temperature preferably measured by	individually calibrated resistance thermometers with approximately linear variation of resistance with temperature over operating range
9	material used for construction	inert, nonhygroscopic, resistant to corrosion by common atmospheric pollutants

TABLE 7.-Concluded

Item	Quantity	Requirement
10	design of enclosure around sensing elements in unit used to obtain surface measurements	light-colored shelter to minimize heating by solar radiation, designed for all-weather operation
11	format for data output to paper-chart recorder	signal-conditioning equipment that uses solid-state electronics to provide a linear variation of dc voltage from -5 to +5 V to correspond to temperatures in operating range
12	requirement for 60-Hz, single-phase, ac electrical power	surface: 1.2 A at 115 V or 0.6 A at 230 V airborne: 0.5 A at 115 V
13	preferred system for providing electrical power	surface: batteries and solid-state dc to ac inverter airborne: same or aircraft power

TABLE 8.-Time-code instruments

(a) Receiver/time-code generator

Item	Quantity	Requirement
1	basic capability to be provided	receive UTC time information relayed from the eastern or western GOES satellite on a nominal carrier frequency of 469 MHz, translate the information, and generate serial time code in IRIG B format
2	source for input signal	a moderate UHF antenna
3	tuning to, and synchronization with, a satellite time signal	automatically accomplished
4	correction for time delay along propagation path from transmitter to satellite to receiver	automatically accomplished after setting latitude and longitude coordinates for receiver location
5	output signal	BCD-modulated 1-kHz carrier in IRIG B format
6	visible display of UTC time of day	9 digits with day of year, hour, minute, second
7	display activation	to conserve battery power, the time display should be normally off with a push-button to activate the display when required
8	minimum range of air temperature, when operating	10° C to 30° C
9	electrical power	external or rechargeable internal battery and 115-V, 60-Hz ac
10	battery-condition indicator	must be provided

TABLE 8.-Continued

(b) Time-code translator (reader)/generator[a]

Item	Quantity	Requirement
1	input signal to translator (reader)	IRIG B serial time code on BCD-modulated 1-kHz carrier
2	synchronization of internal time with input signal	automatic synchronization and verification to an accuracy within ±50 μs
3	minimum range of frequency for essentially flat response to electrical signals	100 to 10,000 Hz
4	minimum range of peak-to-peak input-signal voltages that can be accommodated, without adjustment	0.5 to 5 V
5	minimum range of input-signal modulation ratios that can be accepted, without adjustment	2:1 to 6:1
6	minimum input resistance	100 kΩ
7	time base	temperature-compensated oscillator controlled by a quartz crystal
8	time-base stability or maximum change in resonance frequency of crystal oscillator over temperature range	$\pm 1 \times 10^{-5}$ Hz from 0° to +50° C
9	maximum drift rate, or aging rate, of change in period at the resonance frequency of the quartz crystal per 86,400 s (or per day)	1×10^{-7} second/day
10	maximum time-base drift error per day, without re-synchronization	4.3 ms
11	shift from translate (read) mode to generate mode	by switch on front panel without loss in synchronization of time signal
12	output signal from generator	BCD-modulated 1-kHz carrier in IRIG B format
13	minimum range of peak-to-peak output-signal voltages	0 to 5 V, adjustable

TABLE 8.-Concluded

(b) Time-code translator (reader)/generator[a] (Concluded)

Item	Quantity	Requirement
14	minimum range of modulation ratio of output signal	2:1 to 4:1, adjustable
15	minimum range of air temperature, when operating	0° to +50° C
16	minimum range of relative humidity, when operating, at any air temperature in operating range, without condensation	0 to 90 percent
17	visible display of UTC time of day	9 digits with day of year, hour, minute, second
18	display activation	display normally off, activated by pushbutton
19	electrical power	external or rechargeable internal battery and 115-V 60-Hz ac
20	battery-condition indicator	must be provided

[a] The portable time-code generator has the same performance requirements as the stationary time-code generators except:

(1) the range of flat frequency response may be smaller, (2) the range of input-signal modulation ratios may be smaller, and (3) there is no switch needed to shift from the read mode to the generate mode since the generator only reads the IRIG B time code of the input signal from the master time-code generator for the purpose of automatically synchronizing the internal time base with the time base in the master generator.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-3540		

4. Title and Subtitle	5. Report Date
RECOMMENDATIONS FOR FIELD MEASUREMENTS OF AIRCRAFT NOISE	April 1982
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Alan H. Marsh	8005
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
DyTec Engineering, Inc. 2750 East Spring Street Long Beach, CA 90806	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Contractor Report
National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code 505-32-03-01 (L-77401A)

15. Supplementary Notes

David A. Hilton and William L. Willshire, Jr., were the NASA Langley Technical Officers. This report supplements more-detailed recommendations given in NASA Contractor Report CR-145187, April 1977. FINAL REPORT

16. Abstract

This report provides specific recommendations for environmental test criteria, data acquisition procedures, and instrument performance requirements for measurement of noise levels produced by aircraft in flight. Recommendations are also given for measurement of associated airplane and engine parameters and atmospheric conditions. Recommendations are based on capabilities which were available commercially in 1981; they are applicable to field tests of aircraft flying subsonically past microphones located near the surface of the ground either directly under or to the side of a flight path. Aircraft types covered by the recommendations include fixed-wing airplanes powered by turbojet or turbofan engines or by propellers. Although recommendations for test operations, data processing, and analysis were outside the scope of the study described in this report, the recommended field-measurement procedures are consistent with assumed requirements for data processing and analysis. Recommendations for test operations are not included in this report because specific operational requirements depend on test objectives.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Aircraft noise Flyover noise ANOPP	Unclassified - Unlimited Subject Category 71

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	92	A05

For sale by the National Technical Information Service, Springfield, Virginia 22161