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Washington, D.C. 20591

Evaluation of Noise Control Technology and Alternative Noise Certification Procedures for Propeller-Driven Small Airplanes

David Brown
and
Louis C. Sutherland
Wyle Research
El Sequndo, California 90245

May 1982

Final Report

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16. Abstract

This report considers the effectiveness of current noise regulations in Appendix F of FAR Part 36, examines the potential effectiveness of future technology to achieve further noise reduction, and evaluates a number of new concepts for noise certification procedures for propeller-driven small aircraft. The latter were based, in part, on results of a flight test program carried out with Cessna Aircraft Company, to evaluate the utility of takeoff noise tests and the possible use of sound exposure level as a suitable metric for noise certification of the subject aircraft. The study indicates that existing regulations have been effective in stimulating development of quieter propellers for the existing fleet of propeller-driven small aircraft. However, it does not appear economically feasible to achieve more noise reduction in most of this fleet using existing technology with the possible exceptions of some of the two-engine aircraft. However, application of future noise reduction technology, primarily for quieter propellers, should allow a reduction in current noise limits by about 6 dB and should reduce levels of the noisiest aircraft in the current fleet by as much as 10 dB. A takeoff test is appropriate for all propeller aircraft except those equipped with cruise-optimized fixed-pitch propellers. For this test, the current level flyover test appears to represent the noisiest operating condition. Sound exposure level is applicable as a preferred noise metric to be applied to all propeller aircraft, regardless of gross weight providing, in part, the basis for removal of the discontinuity between Appendix F and Appendix C. It is estimated that current regulatory limits for small and large propeller aircraft could be translated to a single consistent takeoff sound exposure level limit of approximately 90 dB as measured under the takeoff flight path at 2.5 km from brake release.

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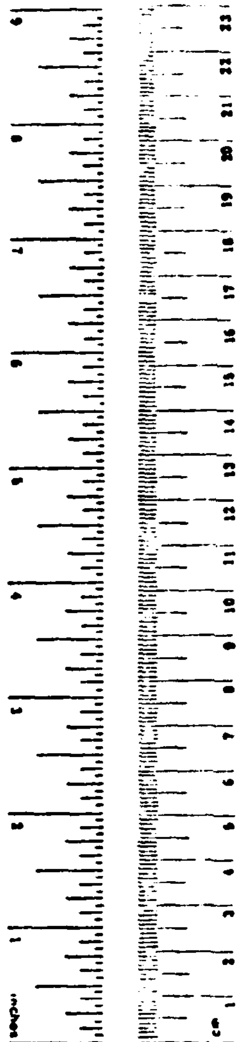
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

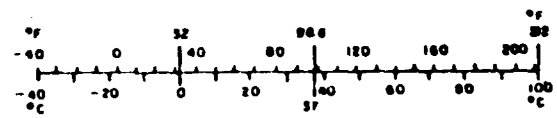
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ABSTRACT

This report considers the effectiveness of current noise regulations in Appendix F of FAR Part 36, examines the potential effectiveness of future technology to achieve further noise reduction, and evaluates a number of new concepts for noise certification procedures for propeller-driven small aircraft. The latter were based, in part, on results of a flight test program carried out with Cessna Aircraft Company, to evaluate the utility of takeoff noise tests and the possible use of sound exposure level as a suitable metric for noise certification of the subject aircraft.

The study indicates that existing regulations have been effective in stimulating development of quieter propellers for the existing fleet of propeller-driven small aircraft. However, it does not appear economically feasible to achieve more noise reduction in most of this fleet using existing technology with the possible exceptions of some of the two-engine aircraft. However, application of future noise reduction technology, primarily for quieter propellers, should allow a reduction in current noise limits by about 6 dB and should reduce levels of the noisiest aircraft in the current fleet by as much as 10 dB.

A takeoff test is appropriate for all propeller aircraft except those equipped with cruise-optimized fixed-pitch propellers. For this test, the current level flyover test appears to represent the noisiest operating condition. Sound exposure level is applicable as a preferred noise metric to be applied to all propeller aircraft, regardless of gross weight providing, in part, the basis for removal of the discontinuity between Appendix F and Appendix C. It is estimated that current regulatory limits for small and large propeller aircraft could be translated to a single consistent takeoff sound exposure level limit of approximately 90 dB as measured under the takeoff flight path at 2.5 km from brake release.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. Harvey Hubbard for his valuable contributions to this study in the evaluation of future noise reduction technology. The effort provided by Cessna Aircraft Company, Pawnee Division, in preparing much of the design tradeoff data and their support in conducting the flight test program is gratefully acknowledged.

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1.0 INTRODUCTION

1.1 History of Noise Regulations for Small Propeller Aircraft

The noise abatement regulatory program of the Federal Aviation Administration was initiated in 1969 by means of Federal Aviation Regulation, Part 36 – Noise Standards: Aircraft Type Certification, published in Federal Register 34 FR 18355, November 18, 1969. The regulation at that time prescribed noise standards for the type certification of subsonic transport category civil aircraft, and subsonic turbojet-powered civil aircraft of all categories.

Since 1969, the regulation has been amended on a continual basis to take account of, and to ensure the enforcement of, new technology which would lead to an improved noise environment around airfields. In addition, amendments have been adopted to include other categories of the civil aircraft fleet such as supersonic aircraft and propeller-driven small aircraft. Noise regulations for the latter, first adopted as Amendment 36-4 on December 31, 1976, were a result of the Federal Aviation Act of 1958 (49USC1431), amended by the Noise Control Act of 1972 (PL 92-574), which mandated FAA to consider noise regulations for each particular type of aircraft. NPRM 73-26, published by FAA on October 10, 1973, set in motion this rulemaking process which culminated in Amendment 36-4 to FAR Part 36 which prescribed:[1]

> "... noise standards for the issue of normal, utility, acrobatic, transport, and restricted category type certificate for propeller-driven small airplanes; to prescribe noise standards for the issue of standard airworthiness certificates and restricted category airworthiness certificates for newly produced propeller-driven airplanes of older type designs; and to prohibit 'acoustical changes,' in the type design of those airplanes, that increase their noise levels beyond specified limits."

This amendment applied to the above categories of aircraft with maximum takeoff weights of up to and including 12,500 lb. Simultaneously, with the issue of this new rule, FAA also issued an NPRM relating to EPA's proposed version of noise certification rules for small propeller-driven aircraft. Subsequently, following a review of the proposed EPA version, some revisions to the FAA rules were published as Amendment 36-6,[2] effective January 24, 1977. No substantive revisions have been made since.[3] However, subsequent to the Sixth meeting of the Committee on Aircraft Noise in June 1979, Working Group C of the International

Civil Aviation Organization (ICAO) has been involved in discussions of possible further refinements in these rules.[4] (Chapter 6 and Appendix 3 of Annex 16, adopted by ICAO in Amendment 12, April 1974, has very nearly the same noise rule for small propeller aircraft as adopted by FAA. Until recently (1981), the ICAO rule had a requirement for "maximum continuous power" as the test condition,[5] whereas FAA requires, according to Amendment 36-6, "not less than the highest power in the normal operating range . . ." as the test condition. Both ICAO and FAA rules now require the latter power settings.)

At present, therefore, the general concept and rulemaking basis of the existing FAR (and ICAO) regulations for noise limitation of small propeller-driven aircraft is that of the state-of-the-art (in technology and available noise certification procedures) which prevailed during the 1973 to 1975 time period, with constructive reconsideration during the formulation of Amendment 36-6 during 1976. Since that time, considerable experience has been obtained in the implementation of the regulation and in the response of the aircraft industry to meeting the noise limits imposed by the regulation. Further, the noise limiting procedure adopted in the regulation is now applicable (as of January 1, 1980) to all newly-produced aircraft within the scope of the regulation.*

With the benefit of this experience and with a view towards future needs in the amendment of regulations, FAA is currently engaged in a program of evaluation of the current regulation for small propeller aircraft and of possible changes. This report represents part of that evaluation process and is a result of studies performed by contractors under the guidance of FAA's Noise Policy and Regulatory Branch, Noise Abatement Division.

1.2 FAR Part 36, Appendix F, Procedures

The application of the regulatory procedure for noise limitations of small propeller-driven aircraft is described in Appendix F of FAR Part 36, which prescribes limiting noise levels and procedures for measuring noise and correcting noise data for the specified aircraft.

FAR Part 36, Appendix F is reproduced for reference purposes as Appendix A to this report. The following is a brief outline of those parts of the Appendix which will be further examined in later sections of this report:

*Excepting agricultural and firefighting airplanes employed in the use for which they were designed.

1. The procedures require that a minimum of six level flight flyovers be performed at a height of 1,000 ft (±30 ft) above ground level. The power setting of the aircraft during these flyovers should not be less than the maximum in the normal operating range of the aircraft. (This is now commonly referred to as "maximum normal operating power" (MNOP).)

2. Noise measurements are to be obtained, during the overflights, in terms of the Maximum A-weighted Sound Level, in decibels, using slow averaging meter response, during the overflights.

3. Sufficient flights (at least six) shall be performed to establish the arithmetic average of the measured maximum A-weighted sound levels with 90 percent confidence limits of 1.5 dB or less.

4. The measured average maximum A-weighted sound level must be corrected by a calculated performance correction factor:

$$\Delta \text{dB} = 60 - 20 \log_{10} \left((11{,}430 - D_{50}) \frac{R/C}{V_y} + 50 \right)$$

which is algebraically added to the measured level. This correction must be calculated using

D_{50} = Takeoff distance (in feet) to 50 ft obstacle height at maximum certificated takeoff weight,

R/C = Certificated best rate-of-climb, and

V_y = Speed for best rate-of-climb, in same units as the best rate- of-climb.

Where D_{50} is not listed as approved performance information, the values of 2,000 ft for single-engined aircraft and 2,700 ft for twin- or multi-engined aircraft, must be used.

5. The correction factor is limited to 5 dB.

In essence, therefore, the procedures of FAR Part 36, Appendix F for small propeller-driven aircraft are directed to measuring the maximum sound level which would be typically experienced during 1,000 ft height overflights by aircraft operated at the maximum normal operating power setting for such flights. The incorporation of a takeoff performance correction factor to this measured level is, in reality, an allowance for the fact that under best rate-of-climb takeoff procedures, many aircraft will achieve a height greater than 1,000 ft when reaching a distance of 11,430 ft (3.5 km) from its brake release point on the departure runway. The performance correction is equivalent to, and derived from, a simple inverse square law correction,

$$\Delta \text{dB} = -20 \log_{10} \left(\frac{h, \text{ft}}{1000}\right)$$

where h is the expected aircraft height at 3.5 km (11,430 ft) from brake release.

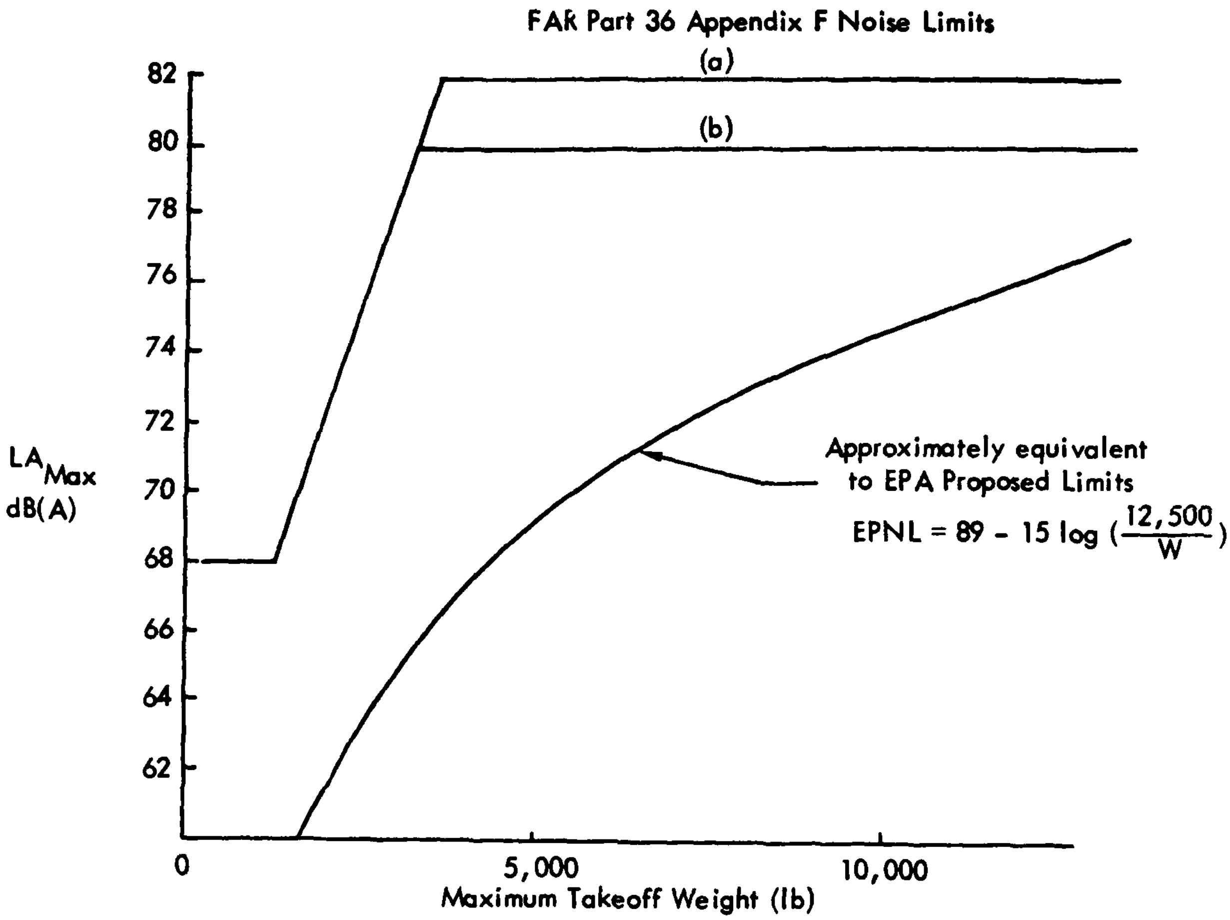
The topics to be addressed in this report are primarily concerned with the effectiveness of the above procedures as a means of regulating aircraft noise, taking account of the experience gained to date in their implementation.

1.3 FAR Part 36, Appendix F, Noise Level Limits

All aircraft which are required to comply with FAR Part 36, Appendix F, as part of their type certification must comply with noise level limits based on the maximum certificated takeoff weight of the aircraft. These limits are shown graphically in Figure 1 and apply to the measured sound levels obtained by test and corrected according to the performance correction procedure as described previously.

As shown in Figure 1, the noise limiting process has a time phased application which depends on the date of application for a type certificate. The basic limit set by the regulation applied to aircraft for which application for a type certificate was made before October 10, 1973. This limit was 68 dB(A) for aircraft with weights up to 1,320 lb, increasing at a rate of 1 dB/165 lb to a limit of 82 dB(A) at 3,630 lb, and constant at 82 dB(A) for weights from 3,630 lb up to and including 12,500 lb. The second criterion applies to aircraft for which a type certificate application was made on or after January 1, 1975. This second noise limiting criterion restricts the noise from aircraft with weights from 3,300 lb to 12,500 lb (inclusive) to a maximum of 80 dB(A). It is also applicable to all production aircraft which did not have any flight time before January 1, 1980.

The FAA noise limits were established in 1974 after considerable public discussion of technical practicability and economic reasonableness.[1] Alternative



Notes: FAR Part 36 Appendix F Noise Limits Applicable When

(a) Type certification applied for on or aft r October 10, 1973;

(b) Type certification applied for on or after January 1, 1975, and for Production aircraft with no flight time before January 1, 1980.

Figure 1. FAR Part 36 Noise Limits for Propeller-Driven Small Airplanes

proposals for regulatory noise limits were made by EPA[6] during subsequent reviews. The EPA proposed more stringent noise limits, expressed in more complex noise units of EPNdB which require spectral analysis of flyover noise histories and the application of duration corrections. An approximation to the EPA proposal for aircraft with type certification after January 2, 1980, is shown in Figure 1 for comparison purposes. This proposed limit was expressed as

$$\text{EPNL} = 89 - 15 \log(12{,}500/W), \quad \text{EPNdB}$$

where W is the aircraft maximum certificated takeoff weight, in pounds.

The approximation shown in Figure 1 is based on a relationship between EPNL, LA_{Max} and aircraft weight derived from data presented by EPA.[6]

The primary objection to the EPA proposals was that they would incur an unreasonable economic burden on the manufacturers, purchasers, and operators of future aircraft. FAA agreed with these objections and retained the current noise limits with a proviso[2] that these limits could be lowered "according to the development of technologies and to the cost-effectiveness of prescribing those (lower) noise levels."

1.4 Study Objectives and Methods

The purpose of the present report is to examine (a) the effectiveness of the current noise regulation for small propeller-driven aircraft, and (b) alternative or supplementary procedures that would ensure that new cost-effective technologies are utilized to achieve noise reduction in new aircraft designs.

As was the case during the introduction of Amendment 36-4 which first presented noise standards for the propeller-driven small airplanes, any further amendment which affects the marketability of aircraft will be subject to close scrutiny by the industry and others. It is clear, however, that experience gained by the industry in meeting Appendix F current regulations will provide a more realistic basis for the evaluation of any new regulation. Further, work on examining potential amendments to the regulation has been ongoing for some years, by FAA, ICAO, and by the industry. Another factor of high significance is that a considerable amount of research has been performed in recent years to aid the development of general aviation technology. Most of this work has been performed since the introduction of Appendix F noise regulations, and while directed more towards improving the efficiency and fuel economy of general aviation aircraft, significant advances have been made in the understanding and control of the predominant noise sources of these aircraft.

In pursuing the objectives of this study, therefore, the work reported herein relies heavily on examining the experience gained by industry over the past 5 to 10 years, the effectiveness of the FAR Part 36 Appendix F in causing this experience to be translated into the design of quieter aircraft, and the current state-of-the-art in developing new technology which has potential for further noise reduction of the small airplane fleet.

The first of these, the effectiveness of the current noise regulation, is examined in Section 2 of this report by reference to industry's response to the regulation and what this response means in terms of noise levels around airfields. Results from a demonstration flight test program are used to examine the relationship between level flyover and other flight modes. These are further used to develop a takeoff noise simulation model which is then applied to a data base of aircraft comprising 90 different aircraft types of the currently noise-certificated fleet. The need for change in regulation is examined in Section 2.3 and, as a guideline to fulfilling this need, the requirement for noise controls to be design-oriented rather than by operational restrictions is discussed in Section 2.4.

Section 3 of this report examines the ability of noise control technology to provide cost-effective noise reductions. This is first summarized in an overview of the state-of-the-art. This overview is followed by examples of the application of current technology, which requires selection from a matrix of "off-the-shelf" propeller hardware. In this evaluation, three baseline aircraft were analyzed by means of a Cessna Aircraft Company computer program for aircraft design sizing. Each analysis examined variations in propeller diameter, activity factor, blade number and rotational speed (rpm), and their resulting effects on Appendix F flyover noise levels and aircraft performance characteristics. The potential noise benefits of new (advanced) propeller technology is evaluated in Section 3.3. This evaluation is based on recent published analytical studies of propeller noise, which employ the most up-to-date noise prediction methodology. While these studies have yet to be validated by experimental proof of their findings, they have the benefit of introducing the elaborate detail of airfoil and pressure loading characteristics into the noise evaluation process. This is a significant advancement over earlier methods, which dealt only with the gross characteristics of propellers. The overall findings of this evaluation of noise control technology is summarized in Section 3.4.

Section 4 of this report examines the potential for amendment of the noise regulations for propeller-driven small airplanes. Three particular aspects of the regulation are investigated. First, the potential of adding a takeoff test procedure is considered. Second, the study considers the use of different noise metrics, such as those which include noise duration characteristics in the evaluation, those which are more amenable to measurement by direct-read instrumentation, and those which are more compatible with the environmental noise indices which are now in use. Third, the problem of continuity and compatibility between FAR Part 36 Appendix F and Appendix C is examined. This problem of continuity occurs for aircraft which may have maximum certificated takeoff weights in the region of 12,500 lb such as are currently being considered for 16-20 passenger commuter missions. Recent studies have indicated that design optimization for specific mission scenarios could affect the weight parameter sufficiently to cause a change in the applicable noise regulation. Clearly, any discontinuity in noise rules should be avoided, especially when it may detrimentally affect design optimization. The results of the above three-part examination of the noise regulation are summarized in Section 4.4 using the simulated model of takeoff test procedures. In Section 4.4, the takeoff noise levels are predicted using a conversion from the maximum A-weighted sound level, LA_{Max}, to the corresponding time-integrated metric, sound exposure level, SEL (or L_{AX}, in ISO terminology). Graphic presentations are then given of the expected trends of these modified noise levels with respect to aircraft weight and measurement location (i.e., distance from takeoff brake release).

Section 5 of this report summarizes the primary findings of the study, and the conclusions which result from these findings. Appendices B and C contain summaries of test data (Appendix B) and computer analysis data (Appendix C) acquired during the performance of this study. The former comprises noise level and aircraft performance data obtained during flight tests of Cessna 172P, 210N, and 402C aircraft in level flight, takeoff, and simulated V_y climb conditions at Sunflower Airfield, Kansas. Direct-read integrating sound level meters and Nagra IV SJ tape recorders were used in each case to obtain measurements of LA_{Max}, L_{AX}, and L_{eq} at two measurement sites and at heights above ground level of 1.2 m and 10 m. These data are used extensively throughout this report.

Appendix C is a compilation of example computer data, supplied by Cessna Aircraft Company, resulting from their use of the Cessna Aircraft Sizing Program to evaluate various changes in propeller design applied to a Cessna 210N, 414A, and a 441 aircraft. The data show the influence of propeller design changes on flyover noise level, takeoff performance, and cruise performance. These are reviewed and discussed in Section 3.2 of this report, as previously mentioned.

Finally, Appendix D provides estimates of the trends in noise impact of general aviation aircraft in support of the discussion on need for source noise control and Appendix E presents a brief example of the tradeoff involved between aircraft engine power and airframe weight to maintain a constant takeoff performance.

2.0 EFFECTIVENESS OF THE NOISE REGULATION

2.1 Industry's Response to the Regulation

Industry's awareness of the likelihood of a noise regulation applicable to propeller-driven small airplanes started in the late 1960's during the rulemaking process for FAR Part 36 noise standards for subsonic transport category and turbojet aircraft. In fact, the industry began to intensify its efforts to control noise of the general aviation fleet in 1971[7] with a significant amount of flyover noise testing of its existing aircraft and with experimentation on changes of propeller and engine installations. Many of these initial programs were to some extent based upon propeller noise control guidelines derived from noise prediction methods developed during the 1940-55 period. These methods were directed mainly to the control of lower frequency harmonic noise content and empiricized the so-called "vortex noise" which occurred at higher frequencies. It was rapidly found that these guidelines were totally inadequate for design purposes to meet future potential noise limits, especially if the limits were expressed in subjective noise metrics such as the A-weighted sound level. Very little analytical research on propeller noise was in progress during the early 1970's, most research being devoted to helicopter and turbofan noise programs.

The industry, faced with impending regulations, therefore embarked on experimental programs to determine

a. the noise signatures of its current fleet of aircraft, and

b. new guidelines for noise control.

By 1974, when the FAR Part 36 Appendix F was adopted, the industry's experience was still inadequate to resolve the major problems of system design and most aircraft noise control programs were based on trial and error. In 1976, the General Aviation Manufacturers Assocation (GAMA) produced a review document[8] on research and development work performed by the industry during the preceding 2 years. This review illustrated clearly that while very few of the design problems had been solved, some clarification of the complexity of the problems had been achieved. One of the most notable results was that blade thickness was found to play a significant role in the A-weighted sound level of flyover events. Otherwise, the basic design objective remained that of reducing the blade helical tip speed with minimum penalty in takeoff performance.

Since 1976, two separate approaches have been made to improve the design prediction aspects of propeller aircraft noise. These are reviewed in Sections 3.2 and 3.3 of this report as part of an assessment of noise control technology. Basically, the first approach was by empirical analysis of certification noise data acquired throughout the 1970's, for example, by Cessna Aircraft.[9, 10] The second approach was by use of improved analytical theory for sound radiated by propeller blade airfoils. The application of this latter approach has been oriented towards theoretical studies of propeller designs using improved airfoil sections, blade planform and thickness changes, and relatively new concepts such as blade sweep and proplets (tip plate devices). These have been primarily studies by NASA and universities, and have not, as yet, been used as design input by the industry. Industry's experimentation with some of these new concepts, such as the Q-tip (proplet), elliptical planform blade tips and supercritical airfoils has been generally unsuccessful.[7] Experimentation with blade number changes, as shown by the data compiled in Table 1, were performed to find combinations of blade number, propeller diameter and rpm which would not significantly degrade the operational characteristics of the aircraft – this being a major factor in safety and in competitive marketing. Hence, half of the three blade test versions shown in Table 1 were operated at higher blade tip speeds than the two blade versions and show no benefit in noise reduction. However, the change to a three-bladed reduced-diameter propeller allows the FAR noise limits to be met at engine rated rpm (rather than at a reduced rpm) which is a major factor in aircraft operating specifications.

Reference to Figure 2, from Reference 7, shows that between 1972 and 1980 the industry steadily increased its data base of test results and ensured that all current production aircraft met the 1980 noise limit by the due date. A similar presentation is shown in Figure 3 for aircraft produced by Cessna Aircraft Pawnee Division.

An indication of the methods employed to meet the 1980 limit is shown in Table 2, which relates only to the Cessna cases. Of these example cases, the highest nonrecurring costs have been incurred by engine changes to accommodate lower propeller rotational speeds. The Cessna 152 now has a higher compression ratio engine, the Lycoming 0-235-42C, which is the most recent of the 0-235 series and develops a rated horsepower of 115 shp at 2,700 rpm and 105 shp at

Table I

Test Cases of Two and Three Blade Propellers to Determine Flyover Noise Levels (from Ref. 9)

Aircraft	Test Case Parameters				Noise Level, dB(A)		Blade Tip Speed (fps)	FAR 36 Noise Limit
	Blade Number	Diam. (in.)	RPM	SHP	Measured	Corrected		
A-36	2 3	84 80	2550 2700	228 260	78.0 78.8	77.4 77.7	935 942	80.0
B-55	2 3	78 76	2550 2550	223 221	81.0 77.7	78.0 74.7	868 846	80.0
E-55	2 3	78 76	2550 2650	254 256	82.0 81.9	78.8 78.7	868 879	80.0
F-33	2 3	84 80	2550 2700	228 260	78.1 78.8	76.6 76.8	935 942	80.0
B-58	2 3	78 76	2550 2650	254 256	82.0 81.9	78.9 78.8	868 879	80.0
PA 28RT	2 3	76 76	2575 2575	200 200	69.1 72.5	69.3 72.8	854 854	77.5
PA-34	2 3	76 76	2575 2575	200 200	75.7 78.6	73.5 76.4	854 854	80.0
PA-44	2 3	74 74	2700 2700	180 180	77.2 78.1	75.9 76.8	871 871	80.0

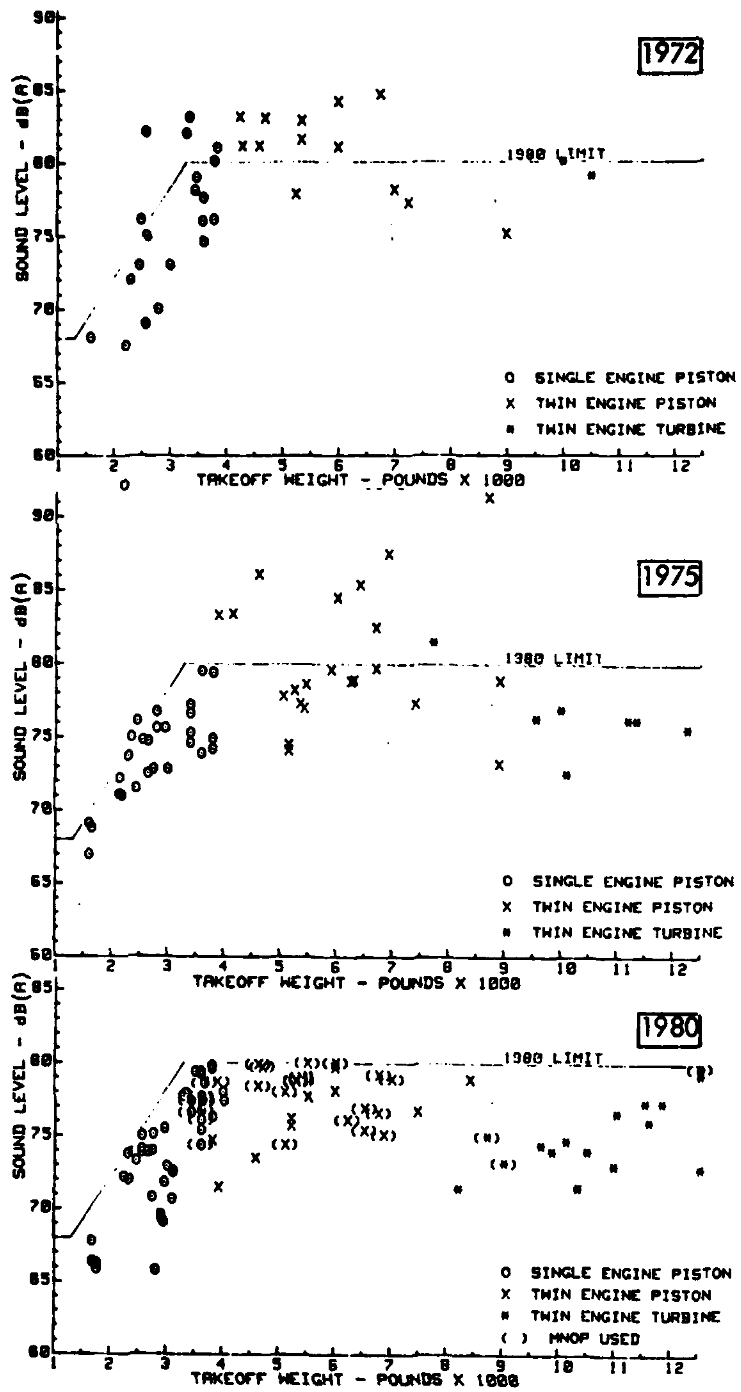


Figure 2. History of Changes in Industry Response to the Noise Certification Requirements of Appendix F. (Data From Reference 7)

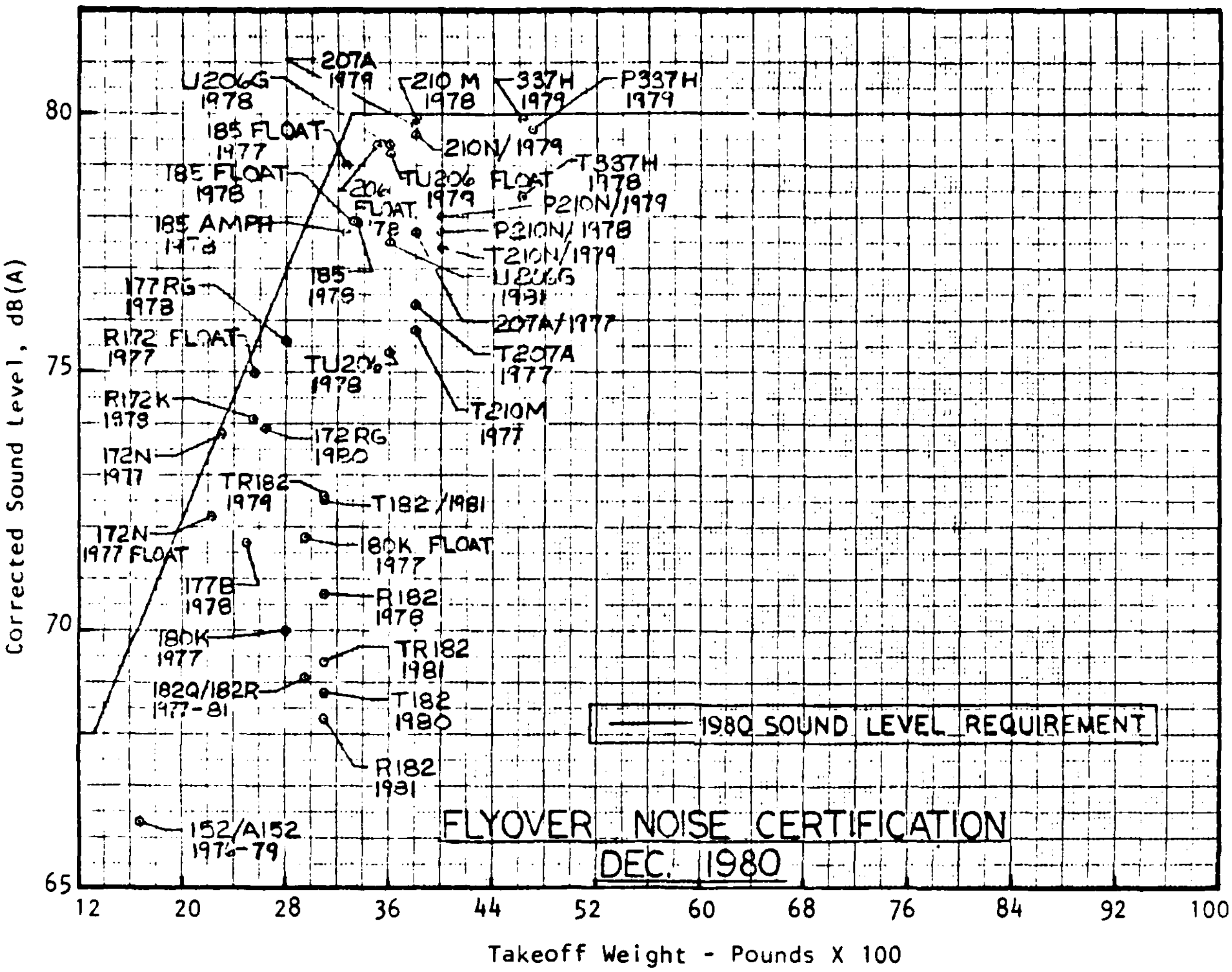


Figure 3. FAR Part 36 Type-Certification Noise Levels of Cessna Aircraft.

Table 2

Examples of Noise Control Applications to Cessna Aircraft
(costs in 1980 dollars)

Model	Description of Change	Costs		Effect on Performance	Change in Weight (lbs)	Noise Reduction dB
		Nonrecurring	Recurring			
152	RPM reduction Increase compression ratio	$488,000	$105/unit	Slight increase. 100 octane required.	+20.5	-4.9
R172	RPM reduction	136,000	244/unit	No significant change	negligible	-1.7
180	RPM reduction Increase compression ratio	125,000	277/unit	No significant change. 100 octane required.	negligible	-5.4
182	RPM reduction Increase compression ratio	38,000	259/unit	No significant change. 100 octane required.	negligible	-5.1
185	Change to 3-bladed propeller Changed blade and tip shape	5,000	724/unit	No significant change	+8.4	-3.0
T206	RPM reduction Increased manifold pressure	31,000	—	No significant change	negligible	-1.3
T207	RPM reduction Increased manifold pressure	39,000	—	No significant change	negligible	-1.3
T210	RPM reduction Increased manifold pressure	38,000	—	No significant change	negligible	-1.3
337 Series	MNOP	3,000	—	No significant change	negligible	-5.5
		$903,000	$1,609			

Models dropped: two
New quieter models: three
Models using MNOP: three

2,400 rpm. At FAR noise test conditions, it produces 110 shp at 2,550 rpm, compared with 2,650 rpm of its predecessor. The Cessna 180 and 182 models now use a Teledyne Continental O-470-U engine with 8.6:1 compression ratio requiring 100LL grade fuel. Both these aircraft were noise tested with power settings of 230 shp at 2,400 rpm, a reduction in rotational speed from 2,600 rpm of the earlier models. The turbocharged aircraft models, T206, T207, and T210, use a Teledyne TSIO-520-M/R series engine which can achieve its rated power of 285 shp at lower rpm by increasing the inlet manifold pressure. Each of these turbocharged aircraft was noise tested at 2,600 rpm (285 shp); that is, derated from 310 shp at 2,700 rpm. This trend in engine modification to allow lower rpm to be used at maximum continuous power is evident in other engine models being produced by the two main suppliers of piston engines (Lycoming and Teledyne) for propeller aircraft. Geared piston engines have been mainly limited to use in the twin-engine business aircraft range, such as the Cessna 421.

Table 3 shows (approximate) estimates of the 3-year 1979-1981 costs of these modifications for each of the aircraft identified in Table 2. These estimates are based on average monthly aircraft shipments[10] for each model during each calendar year. On a unit cost basis, the average over all of the models identified would be of the order of $300 per aircraft. This does not, however, include industry's costs of performing research and development for noise control purposes.

A new concept appears in the Figures 2 and 3 presentations which has not been discussed so far. This is the use of "MNOP" as a means of complying with the regulation. MNOP means "Maximum Normal Operating Power" which directly relates to the FAR requirement that noise tests be performed ". . . at not less than the highest power in the normal operating range provided in an Airplane Flight Manual, or in any combination of approved manual material, approved placards, or approved instrument markings; and at stabilized speed with propeller synchronized and with the airplane in cruise configuration . . .", etc.

For most of the aircraft models currently certificated under the 1980 FAR 36 noise limits, this test condition is close to or identical to the "maximum continuous power" which was the condition specified in the earlier (pre-1981) ICAO Annex 16 regulations for noise certification tests of small propeller-driven aircraft. However, for those aircraft data points shown in Figures 2 and 3 as "MNOP" cases,

Table 3

Estimate of Manufacturer's Costs of Noise Control
(Cessna Aircraft Company, Pawnee Division Aircraft)

Model	Total Cost 1980 Dollars (Thousands)				
	Nonrecurring	Recurring			3-Year Total
		1979	1980	1981	
152	488.0	127.0	90.0	61.0	766.0
R172	136.0	62.0	39.0	15.0	252.0
180	125.0	30.0	14.0	7.0	176.0
182	38.0	171.0	101.0	62.0	372.0
185	5.0	175.0	133.0	128.0	441.0
T206	31.0	-	-	-	31.0
T207	39.0	-	-	-	39.0
T210	38.0	-	-	-	38.0
337	3.0	-	-	-	3.0
Totals	903.0	565.0	377.0	273.0	2,118.0

and for a total of 31 aircraft models in the current production fleet which comply with FAR Part 36 noise limits at MNOP, the test condition was at a power setting below maximum continuous power. These cases fall into two categories:

a. where the shaft horsepower delivered to the propeller is lower than that for maximum continuous power, and at the same rpm, and

b. where both shaft horsepower and rpm are lower than for maximum continuous power.

In either case, MNOP has been implemented by introduction and specification of this limitation into manuals, placards, and instrumentation panel markings for those aircraft, as required by the FAR Part 36 test conditions. Clearly, while significant noise reductions are achievable at a reduced rpm condition, this also significantly affects the operational characteristics of the aircraft. The MNOP modification can therefore be used as a last resort for complying with the 1980 noise limits. It can also reduce operating and maintenance costs.

A major concern regarding the use of MNOP as a means of complying with the regulation is that the noise test conditions become further divorced from takeoff power conditions. This subject is discussed in Sections 2.2 and 4.0.

In summary, industry's response to the noise regulation has been successful in that the current fleet of production aircraft meets the 1980 noise limits for flyover tests at "maximum normal operating power." While industry set out at an early stage to follow, and experiment with, the then-available guidelines for noise control by design procedures, such methods were essentially abandoned in the mid-1970's because of their lack of accuracy and consistency. Since the mid-1970's through the final compliance date of January 1, 1980, significant success has been achieved in modifying some of the aircraft models which required noise reductions to comply with the regulation. For others, the concept of "MNOP" has been a final option, applied where other methods of noise limitation have not, as yet, been successful.

2.2 Effect of Noise Regulations on Noise Levels Around Airfields

While there is no doubt that the current regulation has been effective in reducing noise emissions from aircraft operating at maximum normal operating power, there has been some concern regarding its effectiveness in reducing noise levels in the immediate vicinity of airfields. This concern is evident by the current consideration of introducing a takeoff noise test to the ICAO Annex 16 regulation. In very recent years, various individual and collective tests have been performed to evaluate the takeoff noise case. In 1981, GAMA examined such cases in field tests performed by its (industry) members.

The present study has been directed towards examining takeoff noise conditions by means of two separate methods:

a. Flight tests were performed at Sunflower Airfield, Wichita, Kansas, using three different Cessna Aircraft models in flyover noise tests. These tests comprised 1,000 ft level flights (similar to those required by the existing regulation), takeoff tests commencing from a brake release runway marker position, and simulated climbout tests in which each aircraft performed climbout at its best rate of climb and at V_y (speed for best rate of climb) through a 1,000 ft height above the noise measurement station(s).

b. Noise certification data compiled by FAA on Forms 8110-23 (11-76) for some 90 aircraft models have been used as computer data input to a takeoff noise simulation model. These input data for each aircraft comprise, in part,

   - Maximum certificated takeoff weight,
   - D_{50}, rate of climb, and V_y, as used to calculate the performance correction in FAR Part 36 Appendix F,
   - Propeller rpm and flight speed during the 1,000 ft height flyover test,
   - Engine and propeller type, and
   - Measured and corrected values of maximum noise level, LA_{Max}, dB(A), averaged for the flight tests.

The use of these data in the noise simulation model is described later. First, the flight test data are reviewed for information concerning relationships between level flyover and takeoff condition noise levels.

2.2.1 Comparison of LA_{Max} Values for Different Flight Modes

A full description of the flight test program and the acquired test data is given in Appendix B of this report. In this section, reference is made to the maximum noise levels measured during each of the test flights over the primary noise measurement station located at 8,200 ft (2.5 km) from the brake release marker and on the extended runway centerline. These noise data and their associated aircraft operating parameters are shown in Table 4. For purposes of direct comparison, the maximum noise levels are also shown as corrected to a reference distance of 1,000 ft, using inverse square law to account for the difference in spreading loss and 1.1 dB/1,000 ft to account for the difference in air absorption loss (Reference 11) between the test and reference distances. Finally, an average of these corrected or reference levels for each flight mode is listed. Table 4(d) summarizes the test data in the format of average values for all flights for which height, speed, and noise level data were available. These test cases, shown for the Models 402C, T210N, and 172P in Tables 4(a), (b), and (c), respectively, indicate a very significant result in terms of the relationship between LA_{Max} and propeller tip speed in both takeoff and level flyover modes. Most reported experimental data show a direct relationship between flyover noise level and propeller helical tip speed. However, such data are typical for cases where rotational tip speed V_T and helical tip speed V_H are directly proportional, such as in a series of level flyovers at different rpm settings. The data shown in Table 4 are different in that

a. for the 402C, takeoff V_T is higher than that at level flyover, but V_H is lower,

b. for the T210N, both V_T and V_H are higher at takeoff than at level flyover, and

c. for the 172P, both V_T and V_H are lower at takeoff than at level flight conditions.

The variation in flight conditions allows a unique examination of noise level dependency on V_T and V_H separately in order to assess the viability of a takeoff test for noise certification.

First, examination of the model 402C data (Table 4(a)) suggests that the reference noise levels are not directly related to V_H. That is, the takeoff reference noise levels are higher than those for level flight, despite a reduction in V_H.

Table 4

Summary of Flyover Noise Test Data
(Noise Data Measured at 8,400 ft (2.5 km) from Brake Release

Table 4(a): Cessna Aircraft Model 402C

Flight No.	Flight Conditions				Propeller Speeds (fps)			Noise Level, LA_{Max}, dB(A)		
	Mode	rpm	KIAS	Height (ft)	Tip V_T	Horiz.* V_X	Hel. V_H	Meas.	Corr. to 1,000 ft	Ave. @ 1,000 ft
1	Level	2,600	188	-	867.9	327.9	927.8	81.5	-	
2	"	"	188	905	"	"	"	81.5	80.5	
3	"	"	188	1,049	"	"	"	79.0	79.0	
4	"	"	187	956	"	326.1	927.1	79.0	78.6	
5	"	"	188	-	"	327.9	927.8	80.5	-	79.8
6	"	"	185	1,000	"	322.6	925.9	81.0	81.0	
7	"	"	184	1,000	"	320.9	925.3	80.0	80.0	$\pm$0.9
8	"	"	186	1,012	"	324.4	926.5	79.5	79.6	
9	"	"	185	-	"	322.6	925.9	81.5	-	
10	T/O	2700	110	-	901.2	191.8	921.4	83.0	-	
11	"	"	100	-	"	174.4	917.9	84.0	-	
12	"	"	110	760	"	191.8	921.4	84.5	81.9	
13	"	"	110	875	"	"	"	82.0	80.7	82.0
14	"	"	110	935	"	"	"	83.5	82.8	$\pm$1.0
15	"	"	110	790	"	"	"	85.0	82.7	

*V_X, True Forward Velocity (fps) = 1.744 (Indicated Airspeed, KIAS) at test site.

Table 4(b): Cessna Aircraft Model T210N										
Flight No.	Flight Conditions				Propeller Speeds (fps)			Noise Level, LA_{Max}, dB(A)		
	Mode	rpm	KIAS	Height (ft)	Tip V_T	Horiz. V_X	Hel. V_H	Meas.	Corr. to 1,000 ft	Ave. @ 1,000 ft
16	T/O	2700	100	824	942.5	174.4	958.5	88.0	86.1	
17	"	"	"	540	"	"	"	87.5	81.6	82.5
18	"	"	"	618	"	"	"	86.5	81.9	
19	"	"	"	591	"	"	"	85.5	80.5	±2.5
20	Level	2600	156	1,041	907.6	272.1	947.5	79.0	79.4	
21	"	"	167	1,014	"	291.2	953.2	81.5	81.6	79.5
22	"	"	166	1,029	"	289.5	952.7	78.5	78.8	
23	"	"	166	1,014	"	289.5	952.7	78.0	78.1	±1.5
24	S/C*	2700	100	922	942.5	174.4	958.5	83.5	82.7	83.3
25	"	"	"	1,092	"	"	"	83.0	83.9	±0.8

*Simulated Climbout

Table 4(c): Cessna Aircraft Model 172P										
Flight No.	Flight Conditions				Propeller Speeds (fps)			Noise Level, LA_{Max}, dB(A)		
	Mode	rpm	KIAS	Height (ft)	Tip V_T	Horiz. V_X	Hel. V_H	Meas.	Corr. to 1,000 ft	Ave. @ 1,000 ft
26	T/O	2420	75	539	791.9	130.8	802.6	75.5	69.6	
27	"	2430	"	610	795.2	"	805.9	74.5	69.8	69.6
28	"	2420	"	552	791.9	"	802.6	75.0	69.3	
29	"	2420	"	628	"	"	"	74.0	69.5	±0.2
30	Level	2710	120	1,045	886.8	209.3	911.2	75.0	75.4	
31	"	2720	123	1,029	890.1	214.5	915.6	75.0	75.3	75.1
32	"	2650	114	1,029	867.2	198.8	889.7	74.5	74.8	
33	"	2705	121	1,000	885.2	211.0	910.0	75.0	75.0	±0.3
34	S/C	2410	75	1,000	788.7	130.8	799.5	68.0	68.0	68.9
35	"	"	"	1,077	"	"	"	69.0	69.7	±1.2

Table 4(d): Summary							
Aircraft	Flight Mode	Height (ft)	V_T (ft/sec)	V_X (ft/sec)	V_H (ft/sec)	LA_{Max}* dB(A)	No. of Tests
402C	Level	987	868	325	927	79.8 ±0.9	6
	T/O	840	901	192	921	82.0 ±1.0	4
T210	Level	1,024	908	286	952	79.5 ±1.5	4
	T/O	643	942	174	958	82.5 ±2.5	4
	S/C	1,007	942	174	958	83.3 ±0.8	2
172P	Level	1,026	882	208	906	75.1 ±0.3	4
	T/O	582	793	131	804	69.6 ±0.2	4
	S/C	1,038	789	131	800	68.9 ±1.2	2

*Average corrected sound level at 1,000 ft ±1 standard deviation

Second, Figure 4, where the average corrected levels from Table 4(d) are plotted versus tip velocity, suggests that the reference noise levels are consistently related to rotational tip speed V_T, irrespective of flight mode (takeoff, level flight or simulated climb). For example, for both the 402C and T210 data, the helical tip speeds were nearly identical for the takeoff and level flyover conditions whereas the corresponding noise levels differ significantly, and seem more closely related to differences in rotational tip speed. A predictive trend of this relationship is derived from Eq.(9) in Reference 11 for correction procedures applicable to propeller noise data, using V_T instead of V_H; that is,

$$LA_{Max} \propto K \log_{10} V_T$$

where

$K = 365 \log_{10} (D/b_{0.8}) - 268$

D = propeller diameter, and

$b_{0.8}$ = propeller blade width at 0.8 radius (in compatible units).

A blade width of 5 inches has been taken as a typical dimension for $b_{0.8}$.

Further studies of this relationship between noise level and propeller tip speeds would provide more substantial validation of the above findings.

However, the above findings would indicate that takeoff noise levels will be higher than those measured at the current FAR Part 36 conditions if higher propeller rpm is used for takeoff. This latter condition does, in fact, occur for a large portion of the propeller-driven aircraft fleet which depart from the runway at their maximum engine rated (5 minute limited) power setting and rpm. The exceptions are those aircraft with fixed pitch propellers, such as the Cessna 172P, which typically commence their takeoff run at maximum rpm, and climb at full power and at a V_y climb speed. For the Cessna 172P, this climb condition is at 2420 rpm at a pressure altitude of 2,000 ft. The rpm is then increased, for such aircraft, after leveling off to a cruise condition at maximum normal operating power.

The subject of takeoff noise levels is further examined by application of simulated takeoff conditions to each of a wide range of aircraft, as follows.

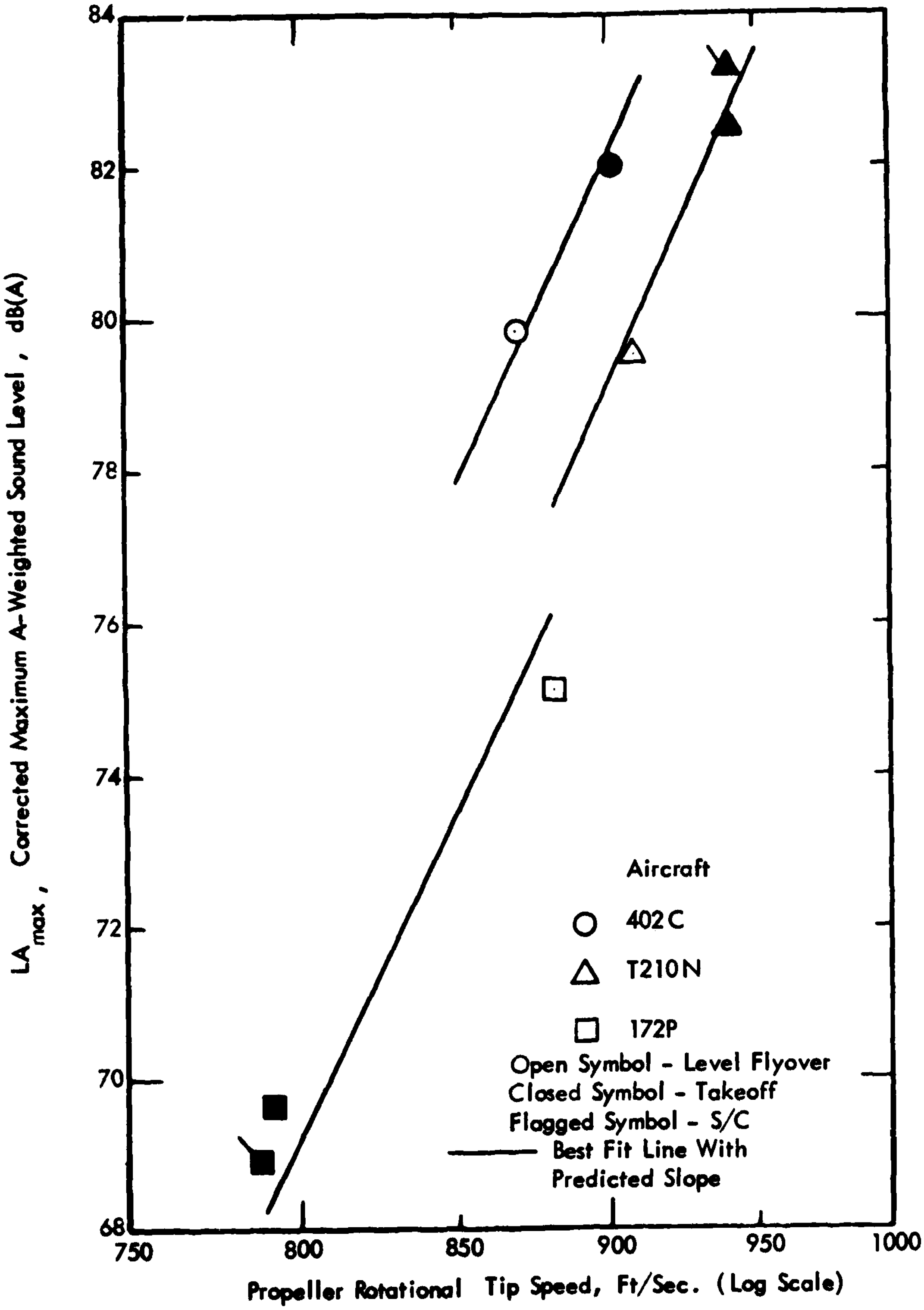


Figure 4. Correlation Between Predicted and Measured Variation in Maximum Sound Level (Corrected to 1,000 Ft) with Propeller Tip Speed, Ft/Sec.

2.2.2 Simulated Takeoff Conditions Applied to a Range of Aircraft Types

A data base of information on noise-certificated aircraft models has been compiled by FAA in Form 8110-23 (11-76) as illustrated in Table 5.[9] All of the numerical data contained in these tables have been used in this study to provide a fleetwide sample of cases for takeoff simulation evaluations. In addition, for each piston-engined aircraft with a variable pitch propeller, reference has been made to published engine data to determine the maximum rated takeoff power and rpm.

This resulting information has been compiled as an Aircraft Data file for computer analysis. Figures 5 and 6 show the corrected and measured level flyover noise levels for this fleet of aircraft in relation to their maximum certificated gross takeoff weights. Aircraft which have fixed pitch propellers or which were tested under "MNOP" conditions of reduced power are separately identified.

For takeoff simulations, the flight profile has been assumed to consist of a ground run and 50 ft obstacle clearance distance corresponding to D_{50}, followed by a maximum rate of climb departure at V_y flight speed. This climb rate is assumed to remain constant during takeoff. This procedure is identical to that used in calculating the performance correction to measured noise levels in FAR Part 36 Appendix F.

Figures 7 and 8 show predicted takeoff noise levels (LA_{Max}) of the sample fleet at four different distances from brake release.

Figure 7 shows the predicted flyover noise levels that would occur if each aircraft generated a 1,000 ft (reference) noise level equal to that measured during the FAR Part 36 level flight test.

Figure 8 shows the predicted noise levels that would occur if each aircraft has a takeoff reference noise level equal to:

$$LA_{Max} \text{ (Takeoff at 1,000 ft)}$$

$$= \quad LA_{Max} \text{ (FAR 36 measured)} + \Delta \text{ ,} \quad \text{dB}$$

where

$$\Delta = \quad K \log_{10} (V_{TY}/V_{TT}), \quad \text{dB}$$

Table 5

Sample FAA Form 8110-23 (11-76)

NOISE DATA FOR PROPELLER DRIVEN SMALL AIRPLANES
(EXCEPT FOR AGRICULTURAL AND FIRE FIGHTING AIRPLANES)

REGION Central RIS: FS 8110-15

AIRCRAFT MANUFACTURER Cessna CERTIFICATION DATES: APPLICATION 9/6/78 ISSUED 9/25/78

MODEL DESIGNATION 402C POPULAR NAME/SUB DESIGNATION Businessliner & Utiliner

TAKEOFF GROSS WEIGHT 6850 lbs.

PROPELLER DATA: PROPELLER MANUFACTURER McCauley MODEL DESIGNATION 3AF32C93/82NC-5.5
DIAMETER 76.5 NUMBER OF BLADES 3
NUMBER OF PROPELLERS 2

ENGINE DATA: POWER PLANT MANUFACTURER TCM MODEL DESIGNATION TS10-520 VB
MAX CONTINUOUS POWER 325 HP MAXIMUM NORMAL OPERATING POWER (DURING TEST) 310 HP

TEST DATA: PROP RPM 2600 D_{50} 2195 ft. R/C 1450 FPM V_y 107.5 KTS
ENGINE RPM 2600 AIRSPEED 190 KTS DATE 7/24/78

WEATHER DATA: AMBIENT TEMP. 72°F RELATIVE HUMIDITY 77% (NO CORRECTION
"WEATHER WINDOW:" 68 ± 9°F AND 40% TO 95% R.H.

EXHAUST CONFIGURATION: CONVENTIONAL

( ) STUB PIPES
( ) SMALL COLLECTOR, SHORT EXHAUST PIPE
( ) BAFFLES IN COLLECTOR AND/OR CONES IN EXHAUST PIPE
(x) TURBINE OR TURBOCHARGED
( ) TOP EXHAUST
( ) OTHER (EXPLAIN)

MUFFLED EXHAUST

( ) MANIFOLD MUFFLER
( ) RESONATOR MUFFLER
( ) ABSORPTION MUFFLER
( ) OTHER (EXPLAIN)

NOISE LEVEL IN dBA 77.2 (MEASURED) PERFORMANCE CORRECTION: -2.1dB

FINAL CERTIFICATION NOISE LEVEL IN dBA 75.1 SOURCE OF DATA Flyover Tests

NOTES: (1) TEST CONDUCTED WITHIN "WEATHER" WINDOW X APPLICABLE PROVISION OF FAR 36 Amendments 1 through 9
(2) CORRECTIONS MADE FOR SOUND ABSORPTION ________

LOCAL REPRODUCTION AUTHORIZED FAA FORM 8110-23 (11-76)

D-402C-31

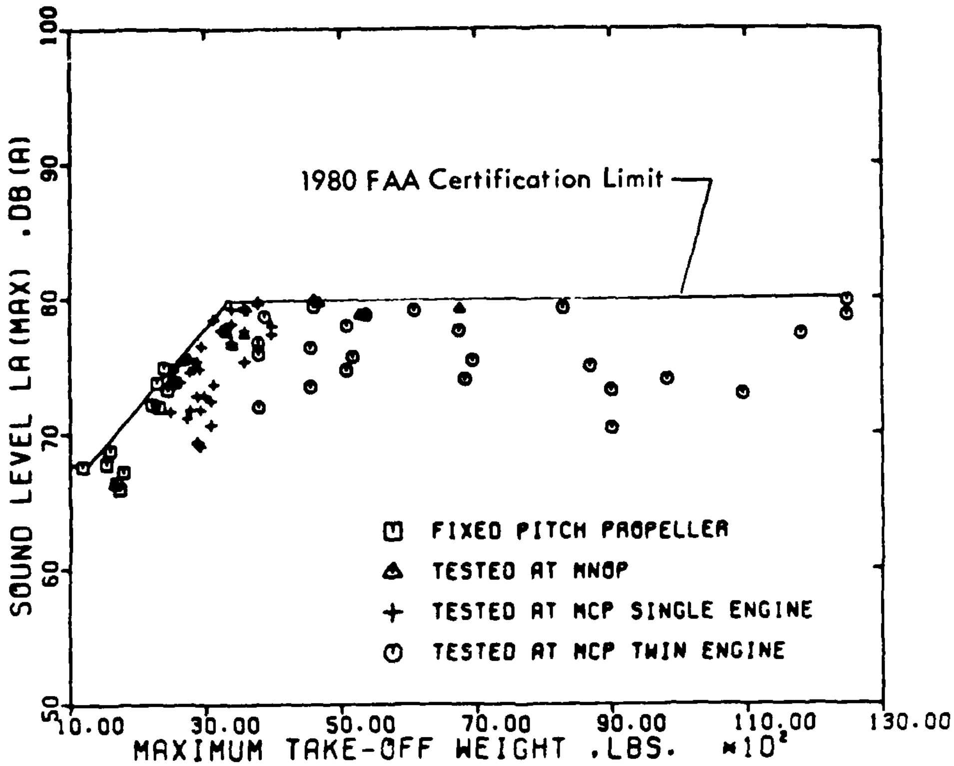


Figure 5. FAR Part 36 Appendix F Noise Levels for FAA Data Base Aircraft (measured levels corrected for distance to 1,000 ft and for takeoff performance)

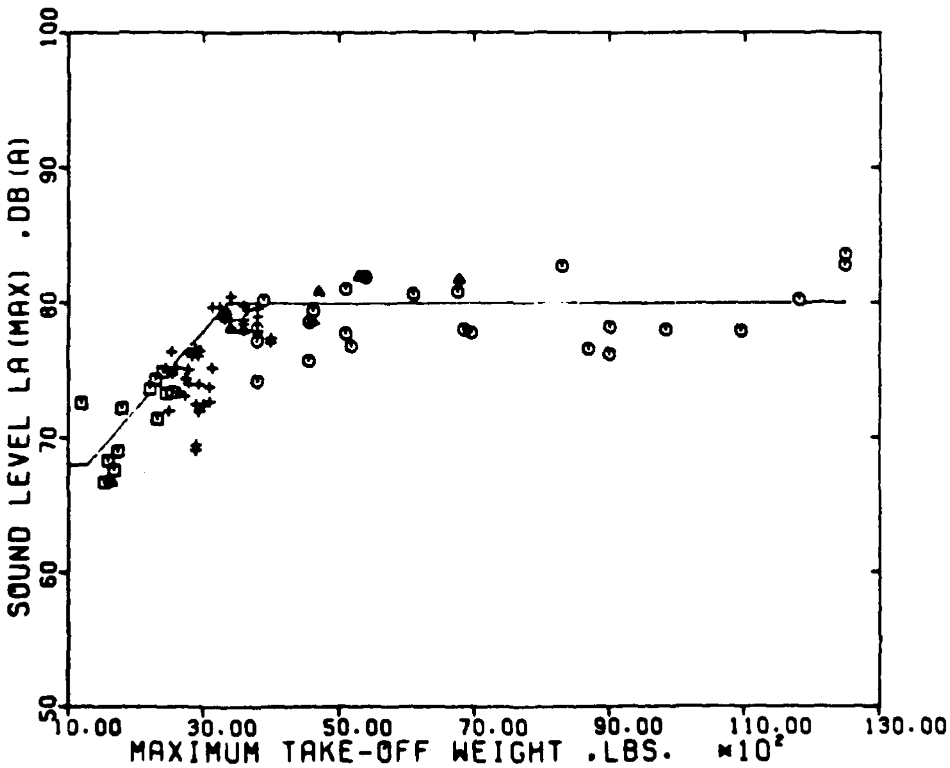


Figure 6. Measured Levels for FAA Data Base Aircraft (without performance correction)

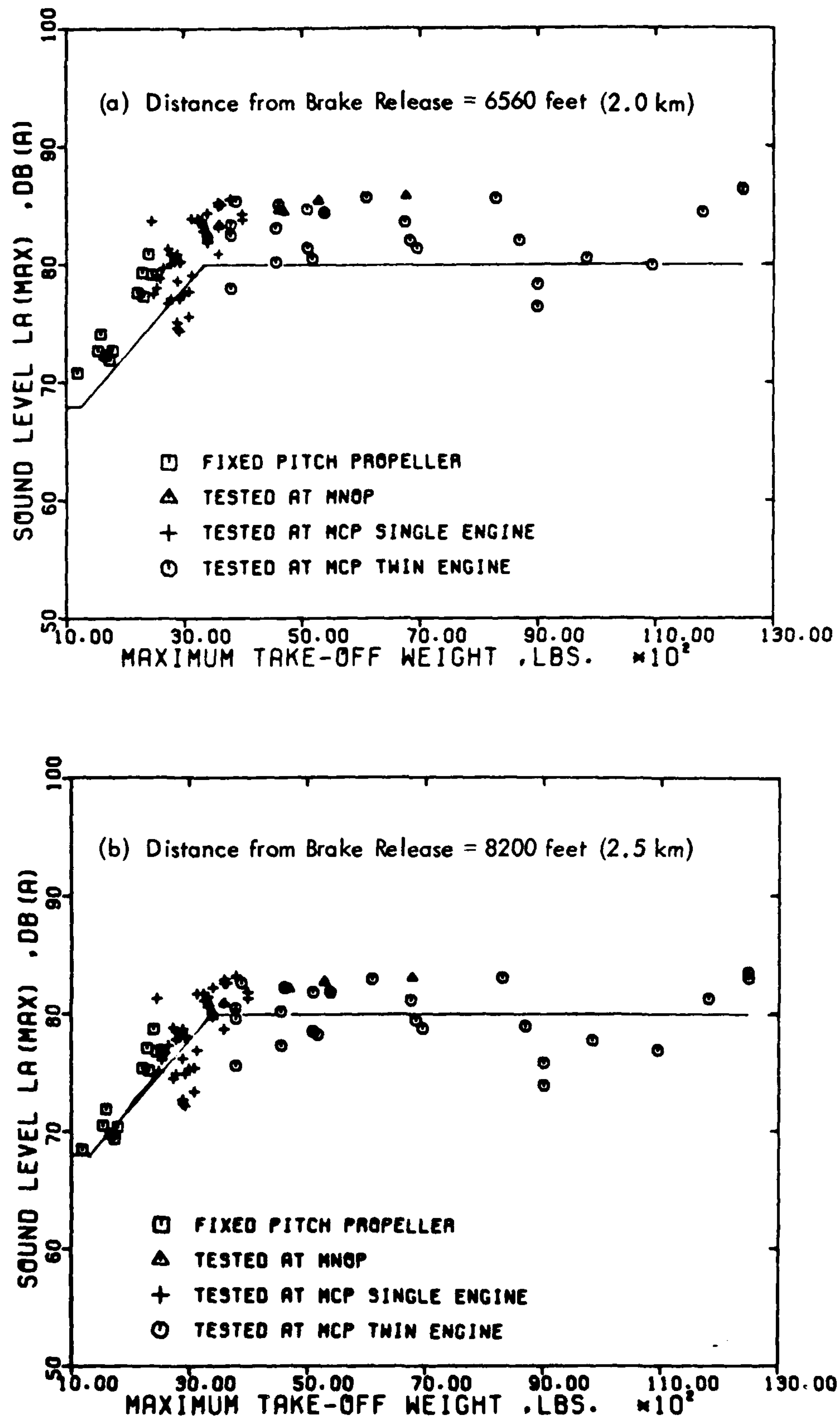


Figure 7. Predicted Flyover Noise Levels Underneath Flight Path for Takeoff Operations at Power Settings Corresponding to FAR Part 36 Test Conditions

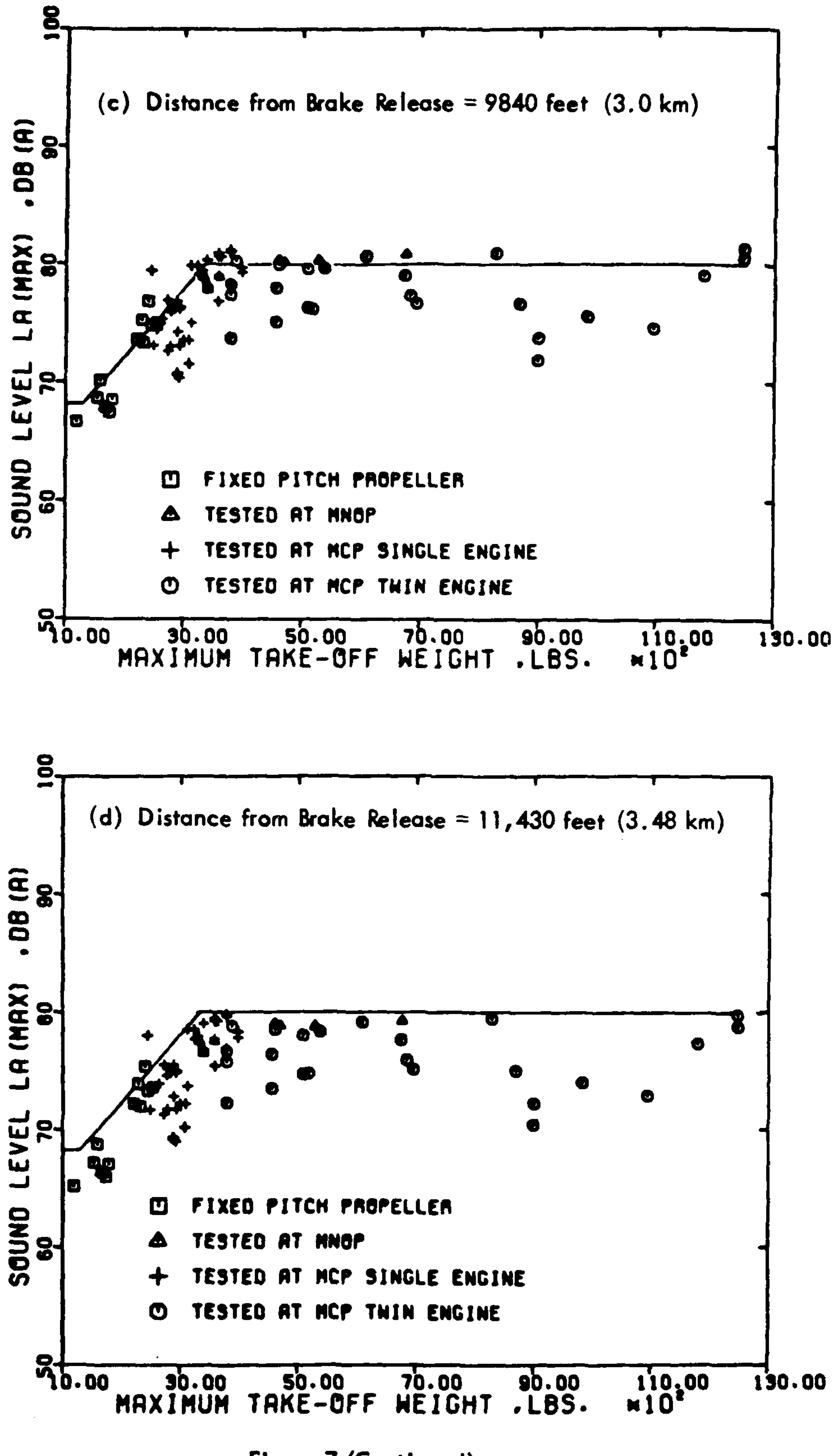
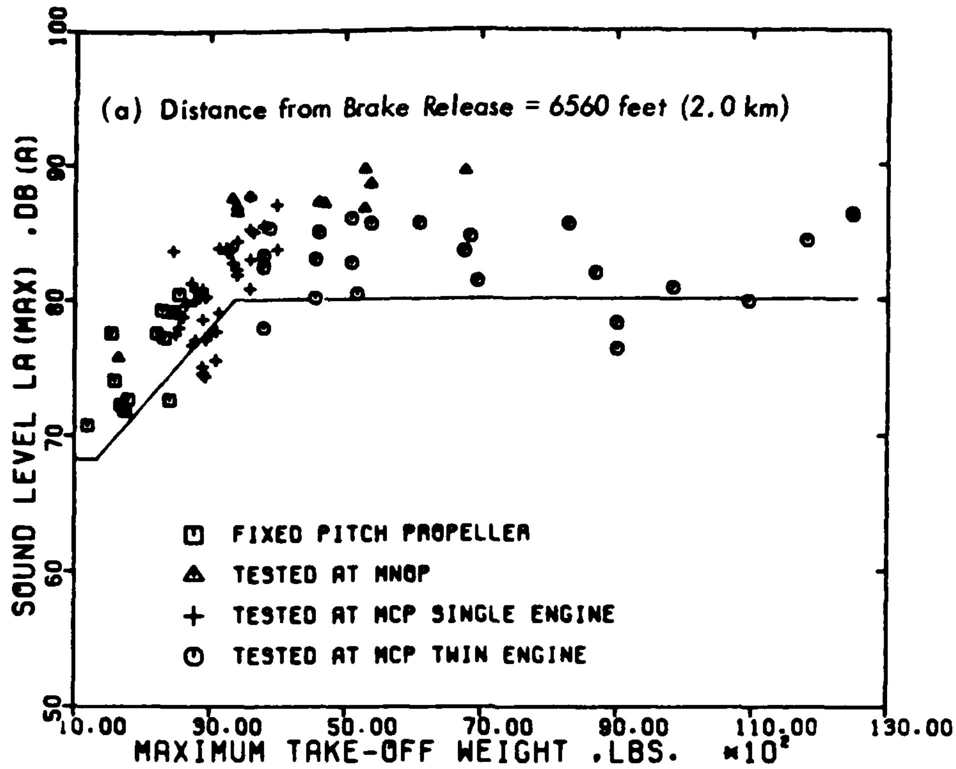


Figure 7 (Continued)



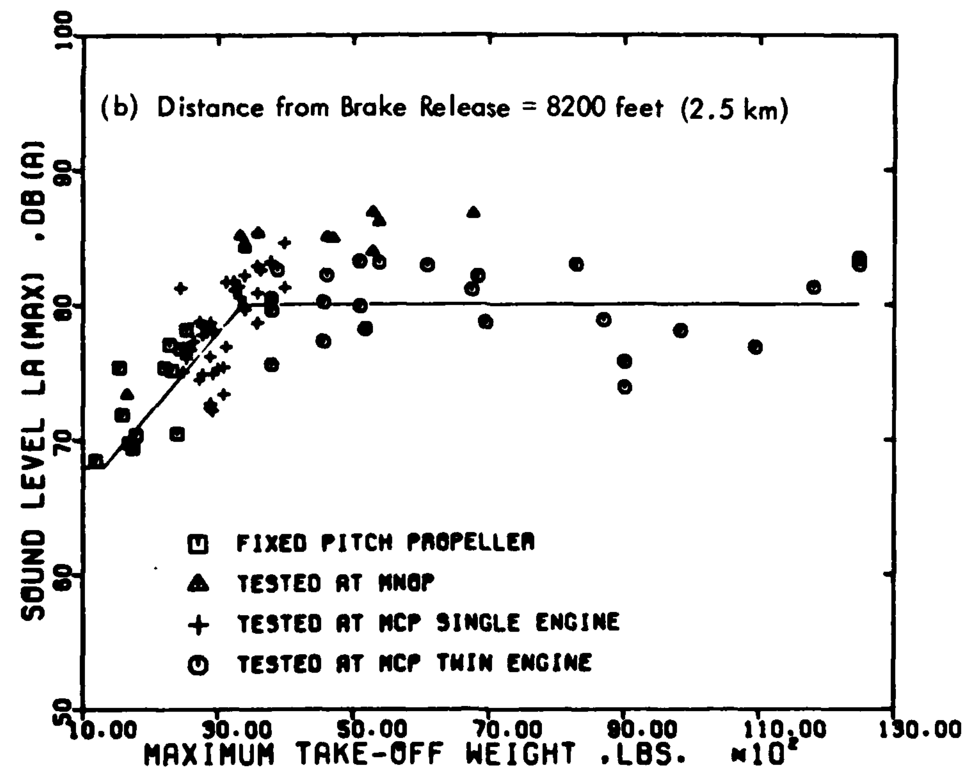
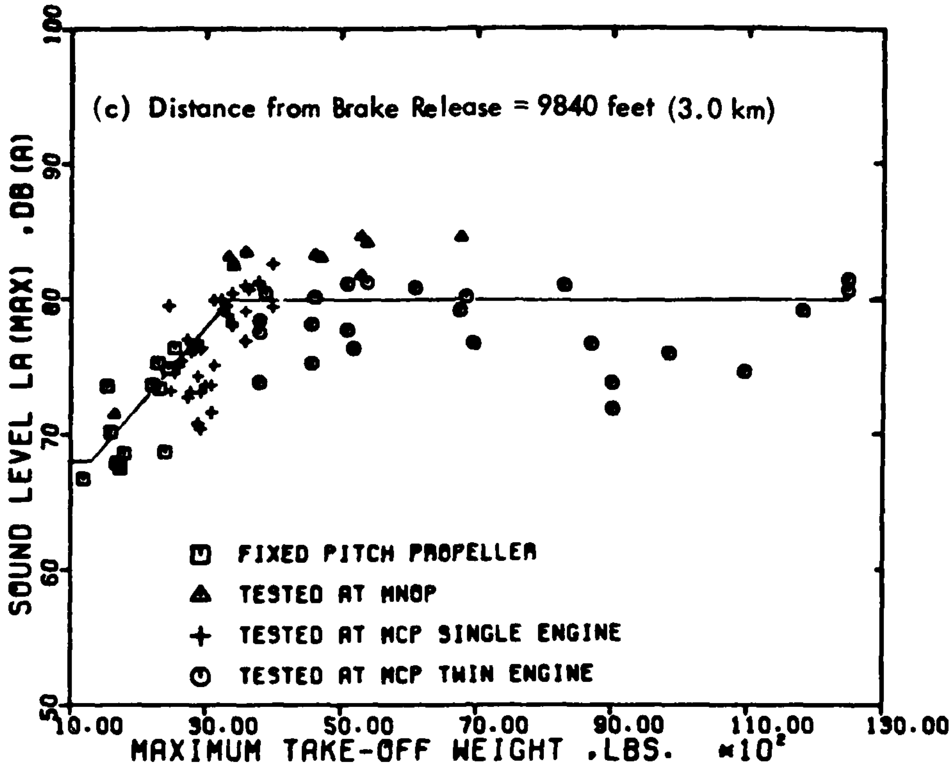


Figure 8. Predicted Flyover Noise Levels Underneath Flight Path for Takeoff Conditions at Normal (Maximum) Takeoff Power Settings



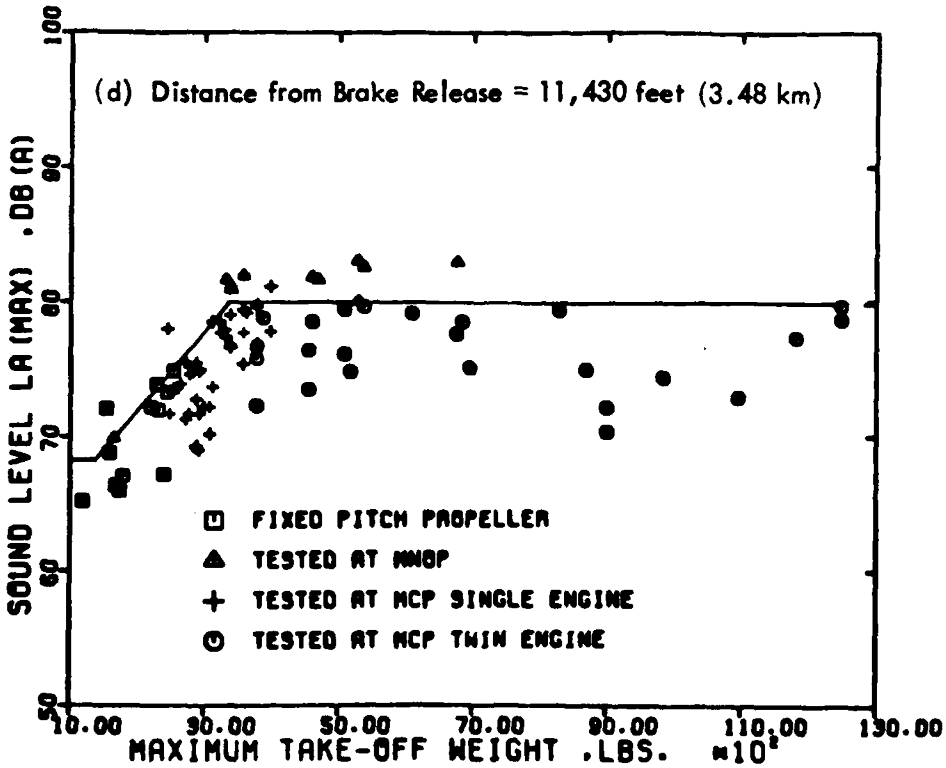


Figure 8 (Continued)

V_{TY} = Blade tip speed at maximum takeoff rated rpm,

V_{TT} = Blade tip speed at FAR Part 36 test rpm, from FAA Form 8110-23, and

K = $365 \log_{10} (D/b_{0.8}) - 268$

In each of these figures, the 1980 noise limit of FAR Part 36 Appendix F is shown for reference purposes only. This noise limit is appropriate only for the Figure 7 data at a distance of 11,430 ft from brake release, which corresponds to the performance-corrected noise levels of FAR Part 36 tests. Some of the Figure 7 noise levels differ from the corrected certification noise levels in Figure 5; these are due to the use of published D_{50} values for the aircraft in Figure 7, instead of the default D_{50} values (2,000 ft for single-engined aircraft and 2,700 ft for twin-engined aircraft) used for the noise certification of these aircraft.

The most significant feature of Figures 7 and 8 is the predicted increase in flyover noise levels caused by accounting for higher propeller speeds at takeoff. The Figure 8 data, which include this takeoff rpm effect, indicate that noise levels in excess of 85 dB(A) may be expected at a distance of up to 2.5 km (8,200 ft) from the brake release point on the takeoff runway. Further examination of this can be made by reference to measured noise data obtained at a noise monitoring station at Torrance Municipal Airport, California, during controlled takeoff tests of a range of aircraft models. These are discussed in Section 2.2.3. The FAA has also independently computed higher takeoff noise levels in its Advisory Circular 36-3b.

2.2.3 Takeoff Noise Levels Monitored at Torrance Airport

The Torrance Airport noise monitoring program continuously evaluates the maximum A-weighted sound levels of departing aircraft events at two monitoring sites located in residential areas at 8,400 ft from brake release and 400 ft sideline from Runway 29R/11L. These data are reported annually in the form of the range of measured noise levels for each type of aircraft.[12] While most of the reported data are for general aviation departures which do not conform to any predetermined noise abatement procedure, a specific separate data base has been established by means of "controlled" tests. These controlled tests have been performed for over 47 aircraft types. In each case, the aircraft was operated at or near constant gross weight and within a time span (20 minutes) which ensured relatively constant atmospheric conditions. The data base for controlled tests shows two measured noise levels for each aircraft, the higher noise level being measured with the aircraft operated using the pilot's normal takeoff procedure, and the lower noise level being measured when the same aircraft was operated using the pilot's best noise abatement technique.

Figure 9 shows a comparison of these measured controlled-test data from the Torrance monitoring system with takeoff noise levels predicted by the takeoff simulation model for the monitoring station location (i.e., 8,400 ft from brake release and 400 ft sideline distance). The measured data are designated in Figure 9 by vertical bars; the top of the bar corresponds to the level measured with the pilot's normal takeoff procedure and the lower noise level corresponds to that measured for the noise abatement takeoff. The Figure 9 test data include only those aircraft which are identified in the Torrance Airport report as having been tested in accordance with FAR Part 36 Appendix F.[12] The predicted noise levels are based on applying the propeller tip speed corrections as discussed for the Figure 8 data to the certification levels to simulate takeoff rpm conditions.

It is evident in this comparison that the highest of the predicted noise levels are typical of many of the controlled-test results obtained by normal takeoff techniques. The maximum measured and the predicted noise levels shown in Figure 8 are therefore probably representative of the actual levels experienced in areas close to general aviation airfields, for example in the range of 2 km to 3 km from the brake release point. At greater distances, such as at the 3.5 km location, it is unlikely that departing aircraft would still be operating at maximum rated takeoff power. In many cases, a height of 1,000 ft above ground level would have been reached at between 2.5 km and 3 km from brake release, and power would have been reduced to that recommended for en route climb which is at a lower manifold pressure and lower rpm than for takeoff condition. The noise levels shown in Figure 7 for the 3.5 km (11,430 ft) distance from brake release are therefore likely to be more representative of actual noise levels at this distance.

The foregoing analysis of noise levels under the takeoff flight path of propeller-driven small airplanes indicates the following:

a. In many cases these noise levels will have been reduced by virtue of noise controls implemented to meet the FAR Part 36 regulation,

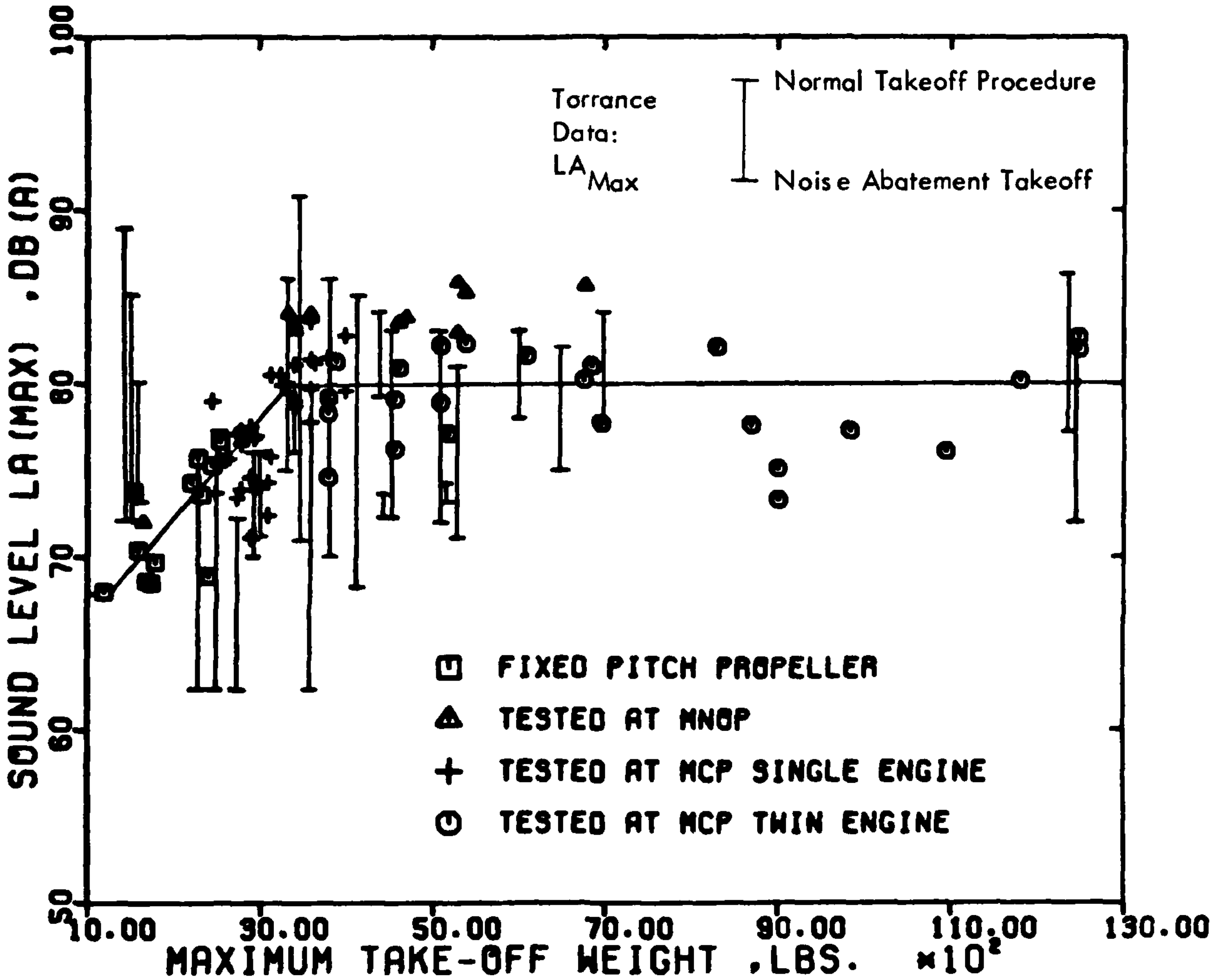


Figure 9. Comparison of Torrance Airport Controlled-Test Noise Levels with Predicted Takeoff Noise Levels (8,400 ft from brake release; 400 ft sideline)

b. Some aircraft, such as those certificated by noise tests at a power setting well below takeoff and maximum continuous power (e.g., at MNOP), will cause noise levels well in excess of the rest of the aircraft fleet, and

c. Takeoff noise levels in areas between 2 km and 3 km from brake release are likely to be in excess of 85 dB(A) and, in some cases, as high as 90 dB(A), from aircraft currently complying with FAR Part 36 noise limits.

2.3 The Need for Noise Control at Source

2.3.1 Noise Impact Near General Aviation Airports

The primary purpose of the noise abatement regulatory program of the FAA is to provide such control and abatement of aircraft noise as is necessary to protect the public health and welfare.

The preceding section has provided one perspective for the relationship between noise certification limits and the actual noise levels experienced during takeoff of small propeller aircraft. A different perspective of the overall magnitude of noise impact by such aircraft is provided by estimates of the number of people exposed near general aviation airports to significant noise levels from these aircraft. Such estimates are presented in Appendix D in support of this discussion on the need for noise control at the source. This very brief analysis, based on previous studies identified in the appendix, indicated the following trends:

1. The number of people exposed to noise from air carrier operations reached a maximum in about 1970 and has decreased subsequently as the very significant reduction in source noise for new wide body aircraft, and a corresponding flattening in the growth of operations, became effective.

2. In contrast, the number of people exposed to noise from general aviation aircraft is expected to continue to increase. While this trend does not necessarily reflect the current introduction of quieter propellers or quieter business jets, there is no expectation that a major reduction in source noise, comparable to that achieved by transition of the air carrier fleet from pure jet engines to low and then high bypass ratio turbofan engines, can be expected in the foreseeable future for the general aviation fleet.

3. The total national noise impact of general aviation aircraft, as measured by the number of people exposed to noise from their operations, is much less in magnitude than for air carrier aircraft. Nevertheless, it is expected to continue growing at the rate of the order of 7 to 8 percent per year for each of the next 10 years. This is comparable to the anticipated growth rate in total number of operations of general aviation aircraft. The influence of introducing quieter business jets and quieter propeller aircraft will be partly offset by the growth in number of operations of general aviation aircraft. (There is no basis for a lower growth in operations such as achieved by use of wide-body aircraft in the air carrier fleet.) Further, the population impacted within general aviation airport noise contours will tend to increase more rapidly than the area within such contours. This is due to the tendency for population density to increase with distance from the airport boundary, in the immediate airport vicinity.

A closer perspective for purposes of this report is provided by a rough estimate of that portion of the total number of people exposed to general aviation aircraft noise which is attributable to operations of only small propeller aircraft. Based on the same data and procedures, it was estimated that:

- o About 50 percent of the total noise impacted area (and corresponding population) exposed to noise from general aviation aircraft is due to operations by small propeller aircraft. (The total area within the L_{dn} 60 contour for all general aviation airports is estimated to be about 800 square miles in 1980 and the corresponding population exposed is estimated to be at least 130,000 people.*)
- o At least 75 percent of all general aviation airports (currently over 14,000 in number) are served exclusively by such aircraft.
- o Of the remaining general aviation airports, small propeller aircraft generate about 94 percent of the operations (i.e., single noise events) and up to 40 percent of the contour area.

*A more conservative estimate of the relationship between population and contour area around general aviation airports would indicate a total population, within the L_{dn} 60 contour, in 1980, of roughly twice this value which is in approximate agreement with preliminary results of a current, more detailed study of general aviation noise impact undertaken by EPA.

In summary, while the total magnitude of the population exposed to small propeller aircraft noise is much less than for air carrier aircraft, the noise impact from such aircraft is still significant due to its continuing growth rate, its extensiveness over a very large number of communities, and the expected higher noise sensitivity of people in relatively quiet communities adjacent to small general aviation airports.

As illustrated conceptually in Figure 10, of the three strategies available for reduction of noise impact around airports (i.e., source noise control, flight procedures and land use policies), noise source control, through application of technology, is central. To be effective, however, such source control must be supported or implemented through some sort of regulatory process – aircraft noise certification.

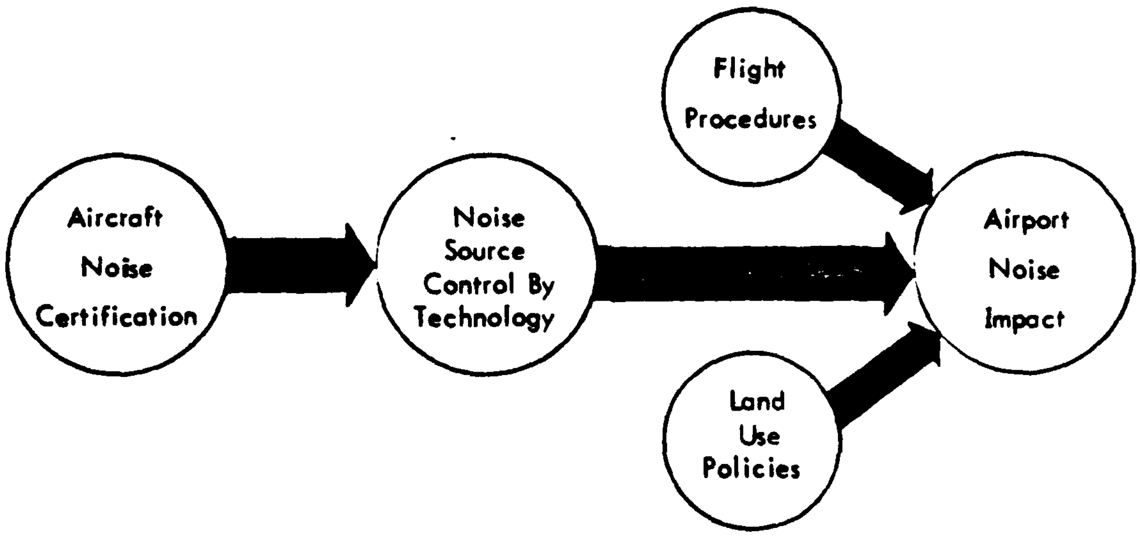


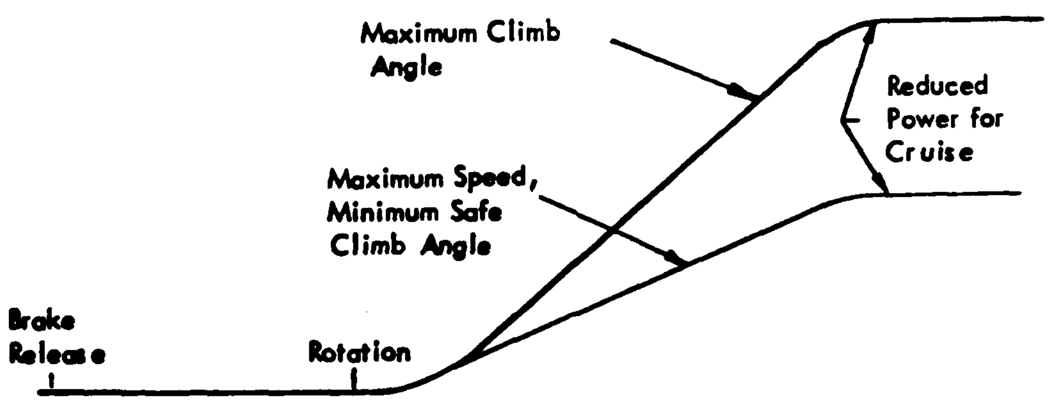
Figure 10. Conceptual Illustration of the Three Basic Strategies Available for the Reduction of Airport Noise Impact

2.3.2 Noise Control by Regulation

There are obvious practical limitations on the extent to which the regulatory process can enforce noise abatement in the relatively unconstrained real world of public usage of noisy equipment. It is, for example, true of aircraft and many other types of equipment that reductions (and increases) of emitted noise can be achieved by changes to the system design and by changes to the operating conditions of the system (such as by change of speed of operation or mechanical power loading). These potential operational methods of noise abatement cannot be directly controlled by the regulatory process. In some cases, however, regulations to enforce compliance with safety requirements which can also provide noise abatement benefits are obviously practical and economically feasible.

In the case of the propeller-driven small aircraft fleet, considerable flexibility is available to the operators of these aircraft in their method of flight operation near and around airfields and in their en route travel between airfields. Much of this availability of operational margin is essential for safety reasons, and cannot be restricted in retrospect; that is, subsequent to aircraft design and certification. It was shown in Section 2.2 that the maximum noise emission mode of small propeller aircraft is usually at maximum takeoff power (except, possibly, for fixed pitch propeller aircraft).

As suggested by the following sketch, the selection of climb rate after departure from a runway is within the broad discretion of the pilot, ranging from maximum speed, minimum safe angle of climb, to maximum angle of climb and a minimum safe power reduction at a safe altitude.



Simplified Illustration of Range of Takeoff Profiles Available for Propeller-Driven Small Aircraft.

These alternative takeoff procedures, when carried out over a populated area, produce essentially the same amount of noise output from the aircraft (because they are carried out at the same propeller rpm and same horsepower), but will produce greatly different levels of noise at ground level because of the large differences in aircraft height during overflight. Illustrative examples of these variances in noise level have been shown in the Figure 9 presentation of controlled tests at Torrance Airport. Variations in excess of 20 dB in monitored noise levels are reported in the Torrance report for general usage cases of aircraft departures on a straight-out flight path.[12] Any case for noise controls to be implemented at the source would seem to be compromised by such large noise level variations caused by user modes of aircraft operation. However, the real case for source noise control is that it should limit the maximum noise emission of the aircraft, irrespective of the user's method of operation. This would require that aircraft be tested in their noisiest mode of operation and comply with noise limits appropriate to that mode. This makes a strong case for requiring a takeoff noise test for most propeller aircraft as discussed in more detail in Section 4.

3.0 ASSESSMENT OF NOISE CONTROL TECHNOLOGY

3.1 Overview of the State-of-the-Art in Noise Control

3.1.1 General

This overview is directed toward identifying the state-of-the-art in source noise controls applicable to propeller-driven small aircraft which are required to comply with the FAR Part 36 Appendix F noise limits. Figure 11 provides an overview of the growth in number of such aircraft in the general aviation fleet. Figures 12 and 13 illustrate how the current fleet is distributed according to maximum takeoff weight and horsepower, respectively.[13]

From Section 2.2, it is clear that for most propeller-driven aircraft, the dominant source of noise is the propeller, and the maximum A-weighted noise level during takeoff is controlled primarily by the blade rotational tip Mach number. Various attempts have been made to rationalize the relationships between A-weighted noise level, propeller blade tip speed, and blade geometric factors, either for purposes of correcting noise levels obtained at off-reference flight test conditions,[11, 14, 15] or to establish basic design guidelines for the aircraft industry.[16, 17, 18] Further reference to these relationships is made in Section 3.2 of this report. In this overview, the emphasis is placed on reviewing the concepts of design technology which provide reductions of propeller blade tip speed and thereby provide substantial reduction in noise level. The basic technical problem in achieving noise reductions is that of optimizing the propeller design to achieve the required aerodynamic performance at the lowest practical tip speed, and with minimum associated penalties in weight and cost. The difficulty in achieving this optimum design is to some degree compounded by a lack of knowledge on which blade design details are the most significant in controlling the mid-frequency content (which dominates the A-weighted level) of propeller noise. These details, such as blade and blade-tip thickness, tip planform, airfoil section, activity factor, etc., influence the performance, weight, and structural integrity of the propeller to an extent that the number of variables in the optimization process can become unmanageable. This is especially the case when the real noise benefits and penalties of each detail are not yet quantifiable with confidence.

The traditional approach to this optimization has therefore been by reference to available and proven propeller/engine configurations, based on the selection of

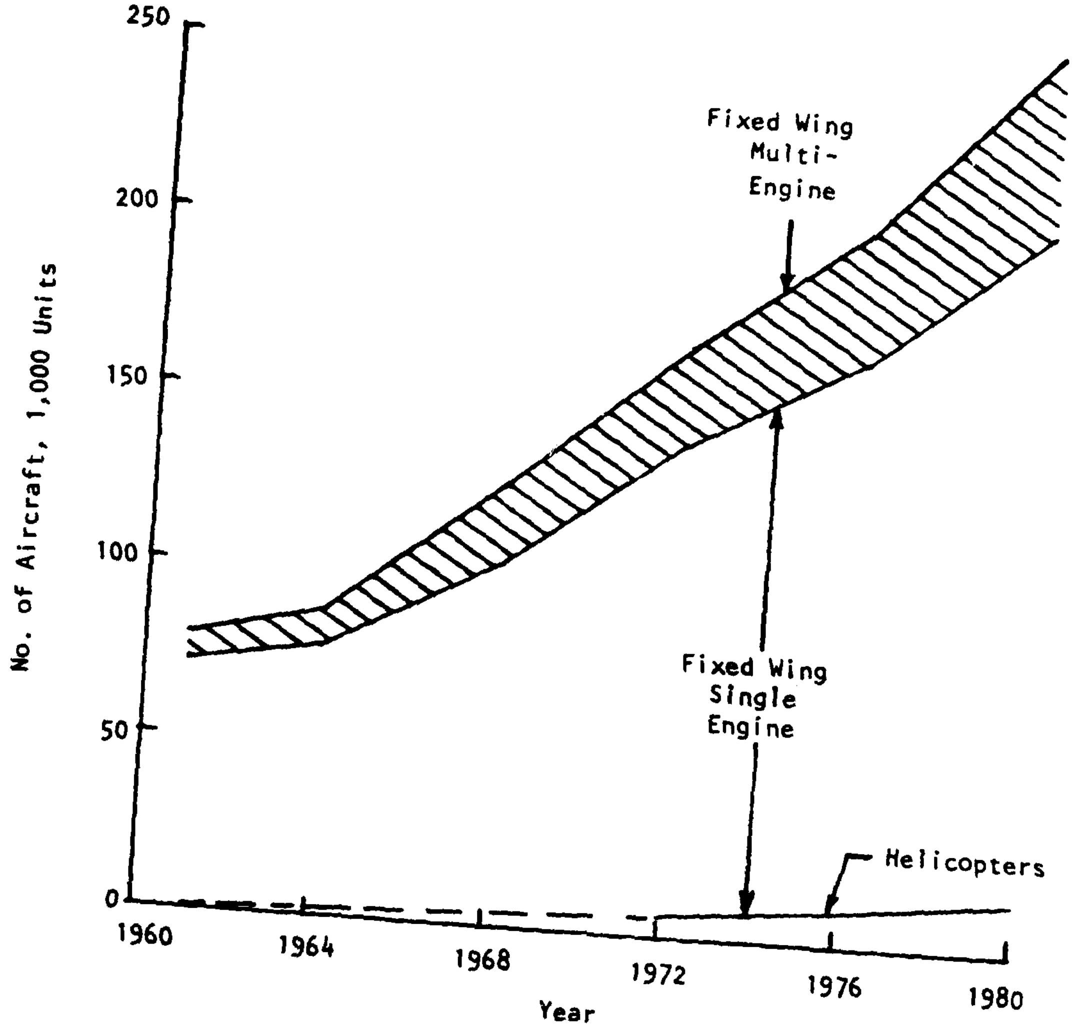


Figure 11. Growth in Number of Registered General Aviation Aircraft in United States (from 1980 FAA Statistical Data)

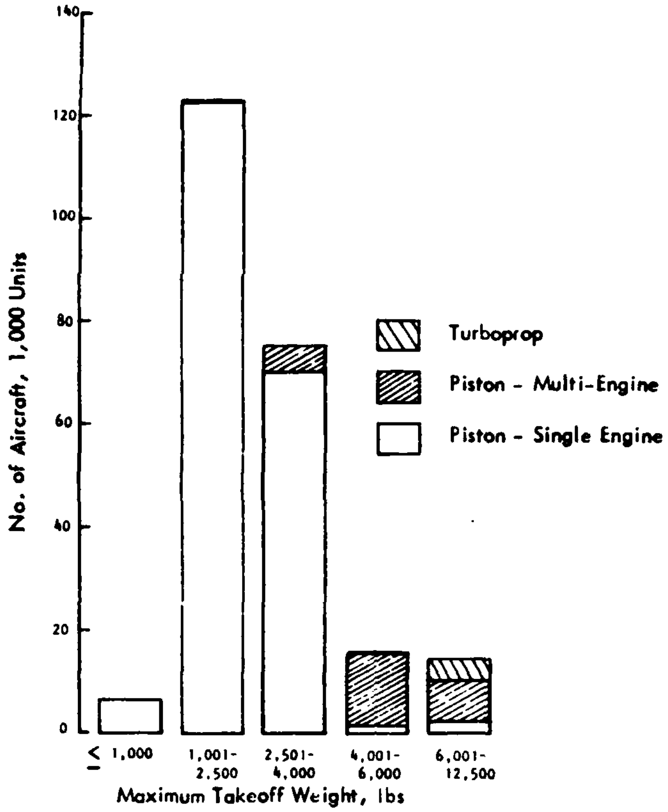


Figure 12. Distribution of U.S. General Aviation Fixed Wing Aircraft Fleet According to Maximum Takeoff Weight (from 1980 FAA Statistical Data)

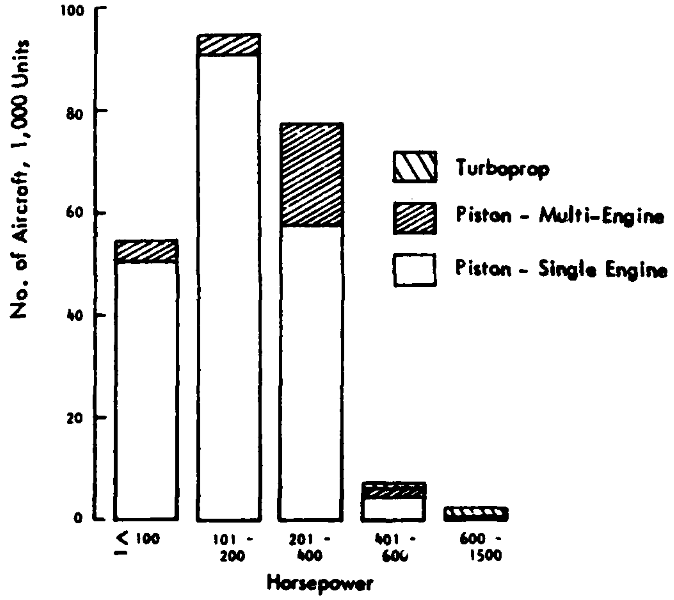


Figure 13. Distribution of U.S. General Aviation Fixed Wing Aircraft Fleet According to Horsepower (from 1980 FAA Statistical Data)

- o Propeller diameter
- o Number of blades
- o Blade activity factor
- o Propeller rpm
- o Propeller thrust and power coefficient
- o Weight limits

to give the lowest practicable tip speed which still provides the required aircraft performance. More recently, this design procedure has included the selection of blade tip planform, usually elliptical, as a potential noise reduction detail. This has a small but predictable effect on aerodynamic performance, but its real effect on an aircraft's flyover noise level is seldom known until it has been tested on the aircraft. According to industry sources, the consensus of test results shows that the elliptical tip shape is very seldom detrimental to noise levels and is sometimes beneficial.

While the above procedure may not provide the ultimate possible benefit in noise reduction, it is regarded as being close to the practical state-of-the-art.

Other options, involving changes to blade detail which differ radically from the proven hardware, are regarded currently as advanced propellers. These will require extensive testing to firmly establish their noise reduction potential, aerodynamic performance, structural integrity and endurance in operational conditions. The advanced blade studies, based on refined theoretical modes of propeller noise sources, predict considerable benefits from the use of:

- o Blade and tip thickness reductions
- o More efficient airfoil sections
- o Blade sweep
- o Blade planform and loading changes
- o Proplets to simulate duct elements.
- o New engine developments

Each of the design concepts mentioned above is further discussed with regard to its application to three classes of light propeller-driven aircraft.

3.1.2 Single Piston-Engined Aircraft

Table 6 contains a listing of several example aircraft of the small single engine class. The information in this table is presented as a means of characterizing the physical features of the power plants, propeller and gear ratio for

Table 6

Power Plant Features of Some Example Single Piston-Engined Propeller Aircraft

Aircraft		Engine			Propeller			
Mfgr.	Model	hp	No. Cyl.	rpm	Config.*	No. Blades	Diam.	Gear Ratio
Beech	Sundowner	180	4	2700	FP	2	6' 4"	1.000
	Bonanza	285	6	2700	CS	2/3		1.000
Bellanca	Aries	235	6	2575	CS	2	6' 5"	1.000
	Skyrocket	435	6	3400	CS	3	6' 10"	0.667
Cessna	Sky Hawk	160	4	2700	FP	2	6' 3"	1.000
	Hawk-XP (172)	210	6	2800	CS	2	6' 3"	1.000
	Skywagon (180)	230	6	2600	CS	2	6' 10"	1.000
	Centurion	310	6	2700	CS	3	6' 8"	1.000
Mooney	Ranger	180	4	2700	CS	2	6' 2"	1.000
Piper	Warrior	160	4	2700	FP	2	6' 2"	1.000
	Archer	180	4	2700	FP	2	6' 4"	1.000
	Arrow	200	4	2700	CS	2	6' 2"	1.000
	Dakota	235	6	2400	CS	2	6' 2"	1.000
	Cherokee	300	6	2700	CS	2	6' 8"	1.000
Rockwell	Alpine Cmdr.	210	4	2575	CS	2	6' 5"	1.000
	Turisho	260	6	2700	CS	3		1.000
Varga	Nifty	150	4	2700	FP	2	6' 2"	1.000

*FP = Fixed Pitch. CS = Constant Speed.

current examples of this class of airplane. A number of different manufacturers produce airplanes in the 150 to 300 hp range and some have several different models. No attempt is made in the preparation of Table 6 to include all current operational airplanes in that class.

These airplanes have horizontally opposed four- or six-cylinder engines which operate in the range of 2400 to 2800 rpm. The propellers are generally fixed pitch (FP) for the smaller models and variable pitch or constant speed (CS) for the larger models. Propeller sizes typically vary from 6.17 ft to 6.83 ft in diameter, have either two or three blades, and are direct drive. A notable exception is the high performance Bellanca Skyrocket, which has a higher flight speed, a more powerful engine, a larger propeller, and employs a geared drive with a 0.667 gear ratio.

Many airplanes of the class illustrated in Table 6 have been modified to reduce propeller tip speed for noise reduction either by changes to the propeller geometry or to the engine operating conditions. The various approaches used to reduce tip speed or in conjunction with a tip speed reduction are described below.

Reduced Diameter – A reduction in propeller diameter by clipping the propeller blades or by using a smaller diameter propeller is a convenient way to reduce tip speed while maintaining the same engine rpm and power characteristics in order to absorb the full power available from the engine. The activity factor of the propeller is increased either by the widening of the blades or by the addition of more blades.

Increased Number of Blades – The addition of more blades to the propeller is almost always useful in reducing the blade passage harmonic noise because of the beneficial destructive interference that occurs within the propeller disc. For example, a doubling of the number of blades results in a halving of the number of blade passage frequencies, and those that remain have about the same levels. Such a result is more effective at the lower tip speeds for which the lower order harmonics dominate the spectra. Hence, an increase in the number of blades is of greatest value when accompanied by a reduction in tip speed.

There is a practical limit to the number of blades which can be retrofitted to a small airplane because of the increased weight and complexity. The weight increase can cause fore and aft balance problems and a reduction in payload.

Multiblade (three, four, five, and eight blades) propellers with variable pitch mechanisms have been successfully operated on larger aircraft and thus the engineering designs are current state-of-the-art.

Reduced Engine rpm – A reduction in engine rpm with the associated decrease in propeller rpm is a very convenient approach to obtaining a propeller tip speed reduction for noise control purposes. The associated reduction of engine power available can, in some cases, be compensated for by an increase in the manifold pressure of the engine, if proper provisions have been made in the engine component designs. A more popular approach is to use a larger engine than normally required and operate it in a derated condition. A side benefit of this approach is that the reserve power is readily available for emergency use. Disadvantages are increased initial cost and weight.

Preferred Blade Geometry – Such blade geometry parameters as tip planform, surface roughness, airfoil section, and activity factor appear to have only second order effects on the noise of current propellers. Tip planform is judged not to be significant except as it influences the spanwise aerodynamic loading on the blade and the tip thickness. Less noise would probably result from a blade which carries a lower tip loading.

Surface roughness, which tends to increase with service life, is believed to have a small detrimental effect on both noise and performance. The implication is that the use of a wear-resistant material on blade surfaces, or the replacement of old blades, would give some positive results.

Improved airfoil sections, particularly those involving more camber than airfoils in common use, show promise of performance improvement.[19] Of particular significance is the possibility of improving the aerodynamic efficiencies of the thicker inboard sections which operate at the lower Reynolds numbers. Thinner tip sections are effective in reducing the thickness noise component particularly at tip speeds in the supercritical range.

Increasing the activity factor of a propeller is sometimes necessary when tip speed is reduced. Either an increased number of narrower blades or the same number of wider blades will usually result. Wider blades are likely to have thicker tip sections and thus have increased thickness noise. This is usually of secondary importance at tip Mach numbers up to about 0.75, whereas at somewhat higher Mach numbers, thickness noise can dominate. A reduction in blade chord, as in the case of more but smaller blades, implies an increase in trailing edge and wake-related noise components. The result is a peaking at higher frequencies of the broadband components.

The net effects of such blade geometry changes as those described above are to produce modest improvements in performance. An increased performance margin is then useful in the process of trading off performance losses for noise improvements.

Noise control in the future is expected to involve all of the items of current technology described above, as well as some additional design improvements that will become available in the decade of the 80's. The key to future noise control is the rapidly developing ability to more exactly predict both the performance and the generated noise so that optimized designs can be defined. Optimization is expected to include the fuselage and engine cowl, and their effects on the front end flow field, as well as the propeller and engine. Some concepts that will probably be considered are included below.

Increased Inboard Loading – The concept of moving the load distribution away from the blade tips can be shown analytically to be beneficial for noise control.[20] In order for this concept to be effective, several features of the power plant airframe combinations need to be considered. For instance, the inboard sections of the advanced propellers need to work harder than do those of the present configurations. This implies the need for improved airfoil sections that will operate effectively at these lower Reynolds numbers.[19] It also implies a minimum of fuselage blockage effects in the region of the engine, and a need for radial symmetry of the front end engine cowl geometry.

Inclusion of Blade Sweep – Sweep has been shown to be very useful in noise control for high speed propfans, helicopter rotors, and axial flow compressor blades. Similar trends are anticipated for lower speed propellers although the amount of noise reduction will be generally small at the lower blade tip speeds. For asymmetrical inflows, however, as occur on many of the current aircraft due to cowl blockage effects, the benefits could be substantial even at the lower tip speeds. Accurate analytical methods for predicting propeller noise, which are becoming available, can be applied to the modification of current configuration-critical designs as well as to new designs. In order to minimize the stress problem, it is anticipated that swept blade designs will incorporate swept forward inboard sections and swept back outboard sections as has been found beneficial for propfan and axial flow compressor blades.[21]

Inclusion of Proplets – Proplets are devices that resemble small end plates and look much the same as if the blade tip was bent backward into the plane of the propeller disc. Such devices are a fraction of a chord length in dimension and may extend to the pressure side of the blade as well as to the suction side. They can be shown analytically to be useful for improving the aerodynamic performance of a propeller operating at a given diameter and rpm. These devices permit the loading up of the outboard sections and thus do not directly produce noise reduction. They do, however, provide a performance margin which may be traded off against noise reduction.

The practicality of proplets has not been evaluated from the standpoint of durability and safety. However, the availability of new high strength-to-weight ratio structural materials such as composites is expected to enhance the potential for their effective application.

New Materials – The availability of such composite materials for propeller blades will also make possible lighter weight propellers and will also encourage the application of such concepts as blade sweep, inboard loading, increased camber and proplets in the new designs. Furthermore, these newer high strength to weight ratio composite materials can also be incorporated in the overall aircraft airframe, such as recently demonstrated for the Lear (Pusher) prop-fan. The net effect of such concepts could be improved takeoff performance resulting in lower takeoff noise levels.

Inclusion of Gear Reduction – The use of gear reduction in order to control the speed of the propeller without sacrificing engine performance is an attractive possibility. Its advantage is that it can provide a better match between the engine and a low noise propeller. Current data on engine installations suggests that gear reductions are not in use on reciprocating engines with less than a 300 hp rating. Extending their use to lower powered systems will probably be considered as an alternative to the use of oversized derated engines in future aircraft.

3.1.3 Twin Piston-Engined Aircraft

The problem of flyover noise control at the source for twin piston-engined aircraft is very similar in all respects to that for single piston-engined aircraft. In concept, twin-engine aircraft of this class, examples of which are listed in Table 7, have two power plants of the same types as are commonly installed in single-engine aircraft. Their similarities can be recognized by comparing the data of Tables 6 and 7.

Most of these aircraft have horizontally opposed four- or six-cylinder engines in the range 160 to 310 hp. The propellers are generally constant speed (variable pitch) with a full feathering (FF) capability. They vary in size from 6.33 to 6.67 ft in diameter, have either two or three blades, and are direct drive. An exception is the Beech Queen Air which has a 380 hp engine with 7.9 ft diameter geared and synchrophased propellers. As in Table 6, no attempt is made to include all manufacturers' products nor to include a complete listing of current models.

The discussions previously directed to the single piston-engine aircraft with regard to current state-of-the-art and future trends in power plant noise control are fully applicable also to twin-piston engine aircraft.

An additional factor which can affect the far field noise of twin-engine aircraft is the phasing of the propellers. Synchrophasing equipment is available for accurately controlling the relative angular blade positions of the two propellers. This type of equipment is used primarily for reducing the beat frequency variations in interior noise levels, which can be of the order of 5 to 10 dB in some aircraft. By locking phase position, the lowest level can be maintained steady with time at any particular location, the result being an elimination of these noise level variations.

Synchrophasing has limited value for far field noise control because when noise is minimized at one location it is maximized at another. It is, however, a mechanism whereby the noise levels on the ground track, or on a line parallel to the ground track, can be minimized. It therefore has serious implications in noise certification testing. One example of anomalous behavior in ground measurements attributable to phasing of twin propellers is considered later in Section 4.2.1. Note that the use of synchrophasing has no implications relative to performance, except insofar as some extra weight and complexity may be involved.

Table 7

Power Plant Features of Some Example Twin Piston-Engined Propeller Aircraft

Aircraft		Engines		Propellers						
				Configuration						
Mfgr.	Model	hp	No. of Cyl.	C.S.	F.F.	R.P.	No. of Blades	Diam. (ft)	Drive	Synch.
Beech	Baron	260	6	X	X		2/3	6.50/ 6.35	D	
	Queen Air	380	6	X	X		3	7.90	G	X
Cessna	310		6	X	X		3	6.37	D	
	340A	310	6	X	X	X	3	6.37	D	
Grumman	Cougar	160	4				2	6.09	D	
Piper	Aztec	250	6	X	X		2	6.42	D	
	Navajo	310	6	X	X		3	6.67	D	
	Seneca	200	4	X	X		2	6.33	D	
Rockwell	Commander	290	6	X	X		3	6.67	D	

C.S. = Constant Speed
F.F. = Full Feathering
R.P. = Reverse Pitch

3.1.4 Twin Turbine Engine Propeller Aircraft

Power plant features of some example twin turbine engine aircraft are shown in Table 8. In contrast to twin-piston engine aircraft, the twin turbine engine aircraft generally have more powerful engines, larger diameter propellers, geared drives, and propeller reverse pitch (RP) capabilities. They also tend to cruise at higher air speeds. The need for reduced tip speeds for noise control, and the available approaches for recovering aerodynamic performance at the lower tip speeds, are as equally valid as for piston engine powered aircraft. Turbopropeller power plants, because of their design, inherently include several known noise control features. For instance, geared drives, which are an integral feature of turbine power plants, can be used to optimize the match between the engine and the propeller. Likewise, there is usually a relatively clean nacelle configuration with a minimum of downstream nacelle blockage. This should result in more uniform blade loads as a function of blade position and thus less noise due to load fluctuations. Finally, the engine exhaust has had most of its energy removed and hence exhaust noise is not a significant component for any operating condition.

Evidence of this general trend in lower noise levels for turboprop aircraft is quite apparent from the data shown earlier in Figure 2, the lower portion of which is repeated herein as Figure 14.

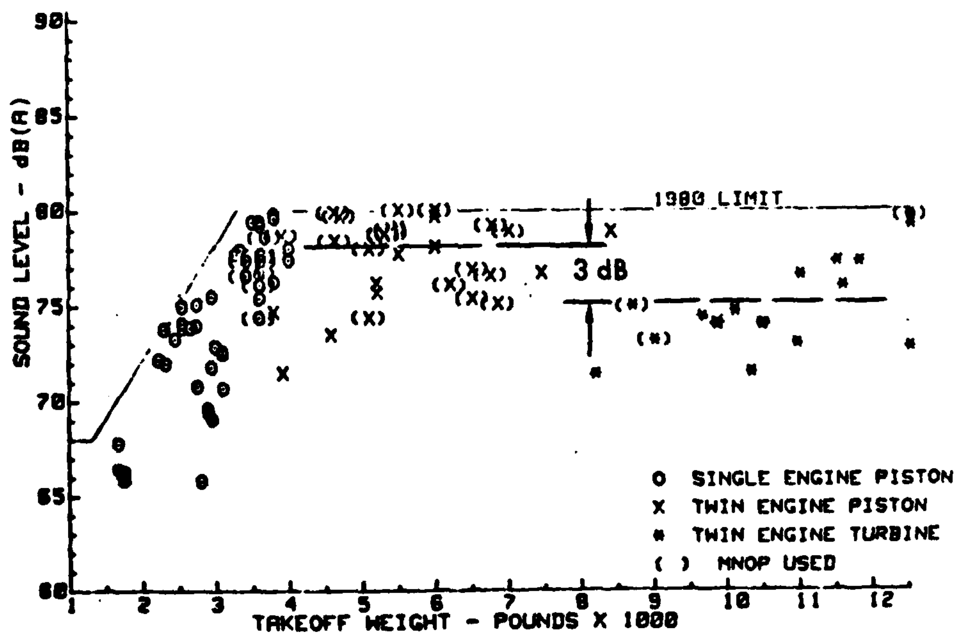


Figure 14. Illustration of the General Trend Towards Lower Noise Levels for Turboprop Aircraft vs Piston Engine Aircraft (from Figure 2).

Table 8

Power Plant Features of Some Example Twin Turbopropeller Aircraft

Aircraft		Engines	Propellers						
Mfgr.	Model	hp	C.S.	F.F.	R.P.	No. of Blades	Diam. (ft)	Drive	Synch.
Beech	King Air	550	X	X		3	7.75	G	
	Super King Air	850	X	X	X	3	8.21	G	
Cessna	Conquest	625	X	X	X	3	7.50	G	
Piper	Cheyenne	620	X	X	X	3	7.50	G	
Rockwell	Turbo Commander	700	X	X	X	3	8.83	G	
Swearingen	Merlin	840	X	X	X	3	8.18	G	
	Metro	940	X	X	X	3	8.50	G	X

C.S. = Constant Speed
F.F. = Full Feathering
R.P. = Reverse Pitch

The average certification noise levels in 1980 for two-engine turboprop aircraft is about 75 dB(A) while the corresponding level for two-engine piston propeller aircraft is about 78 dB(A) - 3 dB higher. Available data comparing sound exposure levels at 1,000 ft for these type of aircraft[22, 23] indicates a comparable trend. The actual difference was closer to about 5 dB, perhaps reflecting the somewhat smaller duration correction, and hence lower sound exposure level, due to the higher flight speed of turboprop aircraft.

Available noise and performance prediction technology is probably most valid for the relatively clean installations of turbine power plants. These prediction capabilities, plus the developing materials and fabrication technologies, will enhance the future application of advanced noise control concepts. The inclusion of blade sweep, the inclusion of synchrophasing, the use of highly cambered sections, and provisions for moving the blade loading inboard, are expected developments in the near future.

The continued trend toward higher cruise speeds at high altitude will be constrained by helical tip Mach number limits for reasons of performance and interior noise. Any helical tip Mach number constraints due to such high altitude requirements will inherently result in noise control benefits for low altitude, low forward speed operations.

3.2 Application of Existing Technology

Most applications of noise reduction methods to meet current FAR Part 36 Appendix F noise limits (in the 1000 ft flyover mode) have focused on a trade-off analysis between a range of available propellers. An example of this form of analysis, which was performed by Cessna Aircraft Company for purposes of the present study, is shown in Appendix C. In each case, the propeller was limited to a Clark Y or RAF 6 airfoil section and parametric changes involved selection of diameter, activity factor, and blade number for each of three (engine-compatible) values of rpm. The available shaft horsepower was assumed to be absorbed by each propeller at maximum takeoff rpm.

The resulting noise level estimate for each combination of parameters was obtained by means of empirically derived equations based on Cessna's data base for noise certificated aircraft.

As shown in Figure 15, a basic unique "carpet-plot" graph relating noise level with propeller diameter and activity factor* can be established for each selected combination of blade number and rpm (at maximum continuous power). Resultant operational parameters, such as takeoff distance, can be superimposed on each graph, as shown in the example case in Figure 16. The selection of a maximum takeoff distance of 2,400 ft, for example, together with a maximum noise level of 80 dB(A), limits the available envelope of propeller selection to that shown by the shaded area of the graph. Other performance parameters, such as sea level rate of climb, range, cruise speed, and time to climb (to cruise level), were similarly evaluated as illustrated in Figures 17 and 18.

The above trade-off analyses were performed for three example propeller aircraft: a single-piston engine model of 3,800 lb maximum takeoff weight, a twin-piston engine model of 6,350 lb maximum takeoff weight, and a twin turbine powered aircraft of 9,850 lb maximum takeoff weight.

Tables 9 through 11 show comparisons of operational characteristics for each of these respective models based on achieving noise certification levels below their current noise limit of 80 dB(A) at 1,000 ft flyover. The baseline (current design) case parameters are shown for reference purposes.

Examination of Table 9 for the single-engined aircraft shows that a 3 dB noise reduction is attainable by reduction of propeller diameter, increase of blade activity factor, and reduction in rpm. The primary resulting penalty is shown to be in the attainable rate of climb, due to reduction in the thrust margin available for climb at V_y. This performance penalty, combined with the increase of V_y for best rate of climb, would result in takeoff climb angles being reduced by more than 40 percent (relative to the baseline case). Noise levels under the takeoff flight path would therefore be expected to increase above the baseline levels for takeoff by more than 4 dB due to this reduction in angle of climb alone (that is, if the takeoff noise level at 1,000 ft was identical to that at FAR Part 36 Appendix F conditions). However, the takeoff noise would then be at least 5 dB higher than for level flyover due to the higher propeller speed (2,700 rpm) during takeoff. Thus, while the tradeoff for 1,000 ft level flyover noise reduction seems practical, there would be a significant offsetting penalty in takeoff noise levels under the departure flight path.

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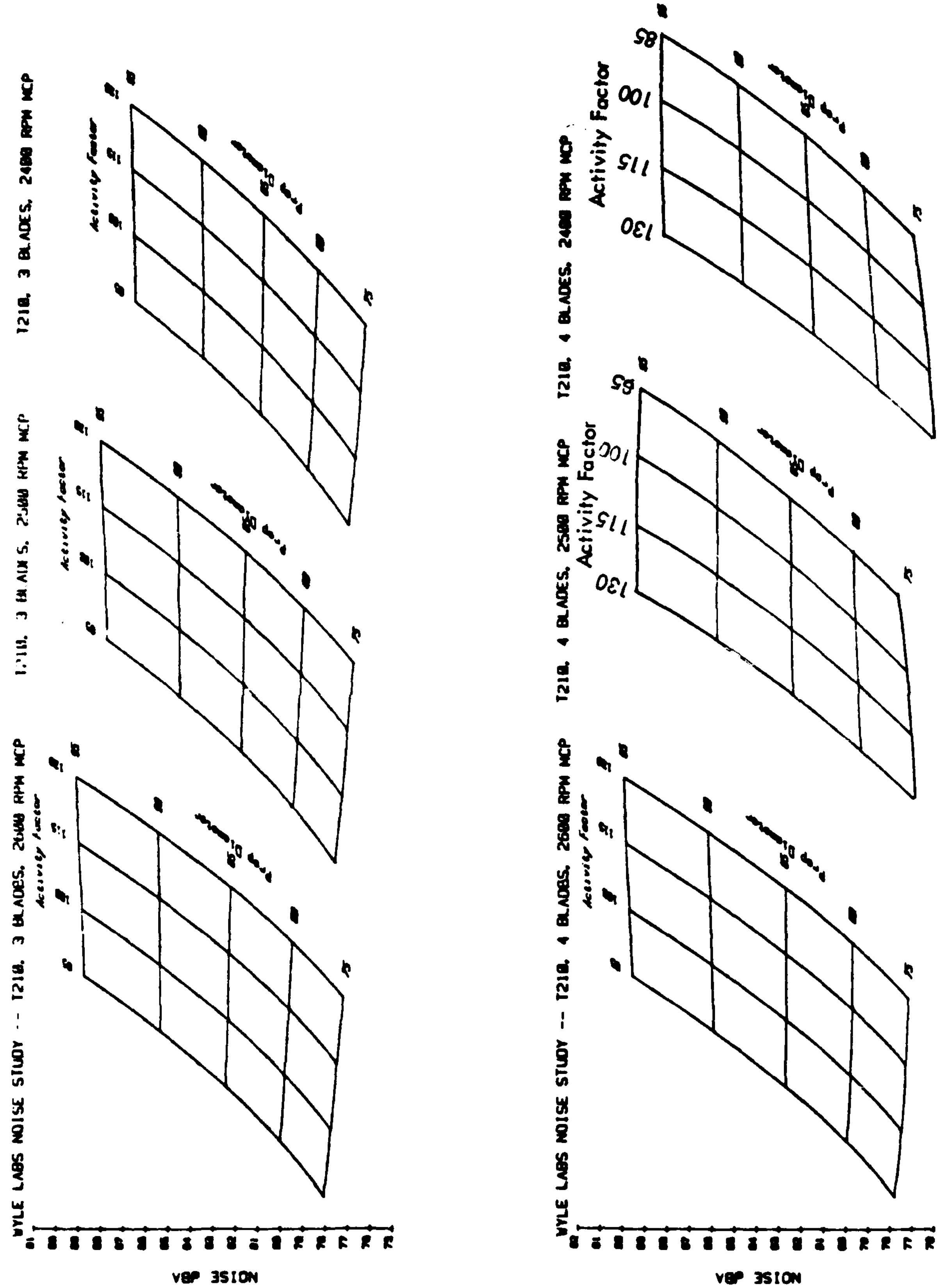
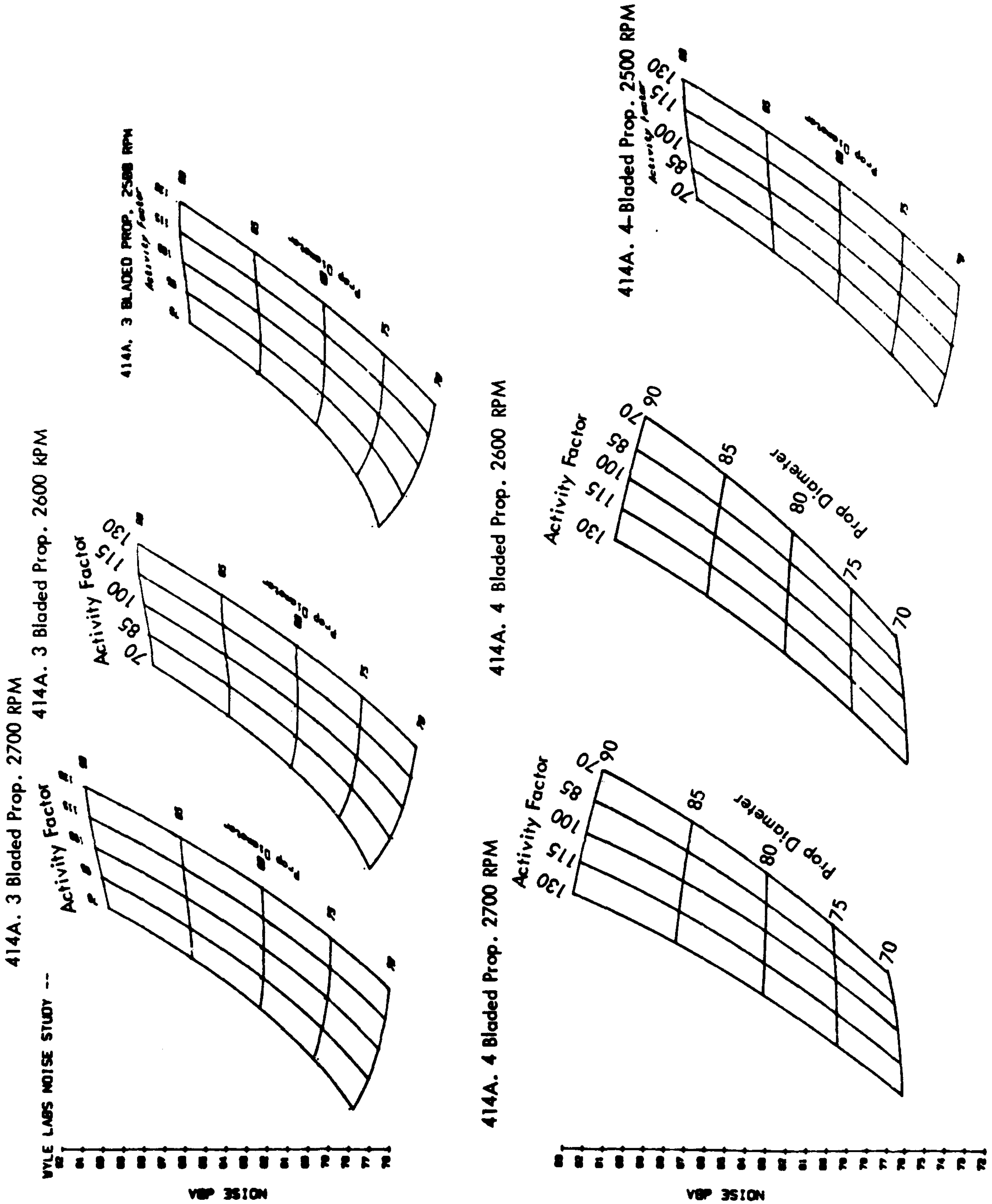
*Activity factor (AF) = $\frac{100{,}000}{16} \int_{hub}^{1.0} \frac{b}{D} \cdot x^3 \cdot dx$, where b is blade section width, D is diameter, and x is the section radius as a proportion of tip radius. AF is a measure of blade solidity and of the blade's capacity to absorb power.



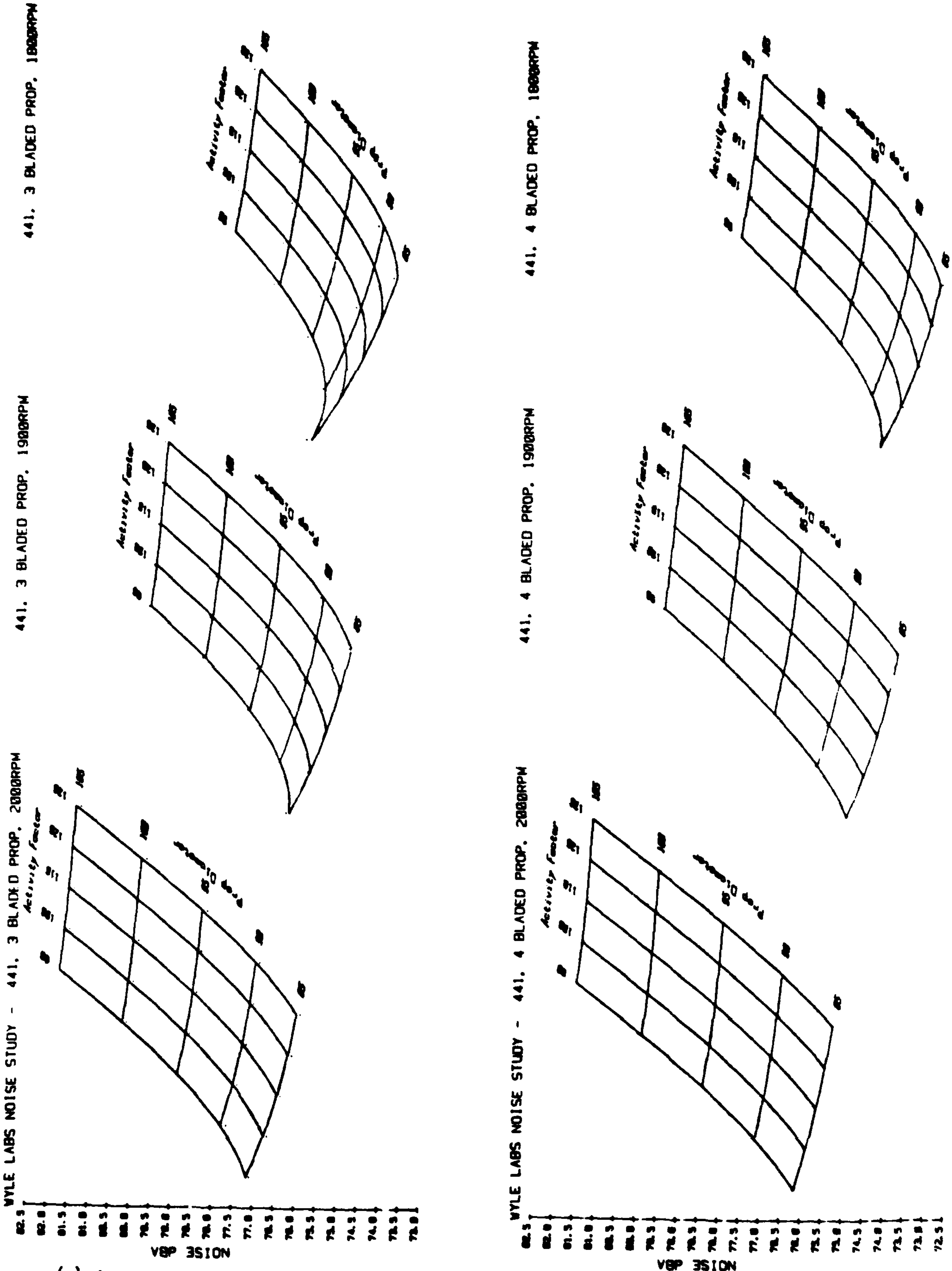
(a) T210

Figure 15. Carpet Plots kelating Noise Level, Propeller Diameter, Activity Factor, Number of Blades, and rpm at Maximum Continuous Power (data provided by Cessna Aircraft Company)



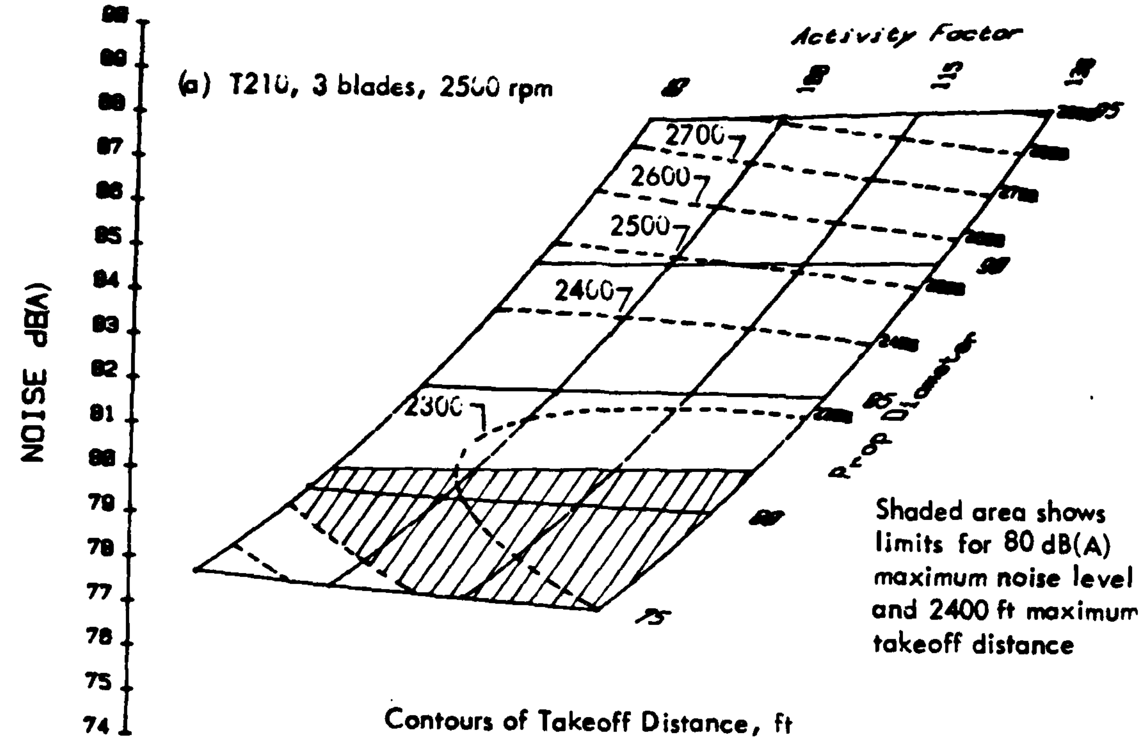
(b) 414A

Figure 15 (Continued)



(c) 441

Figure 15 (Continued)



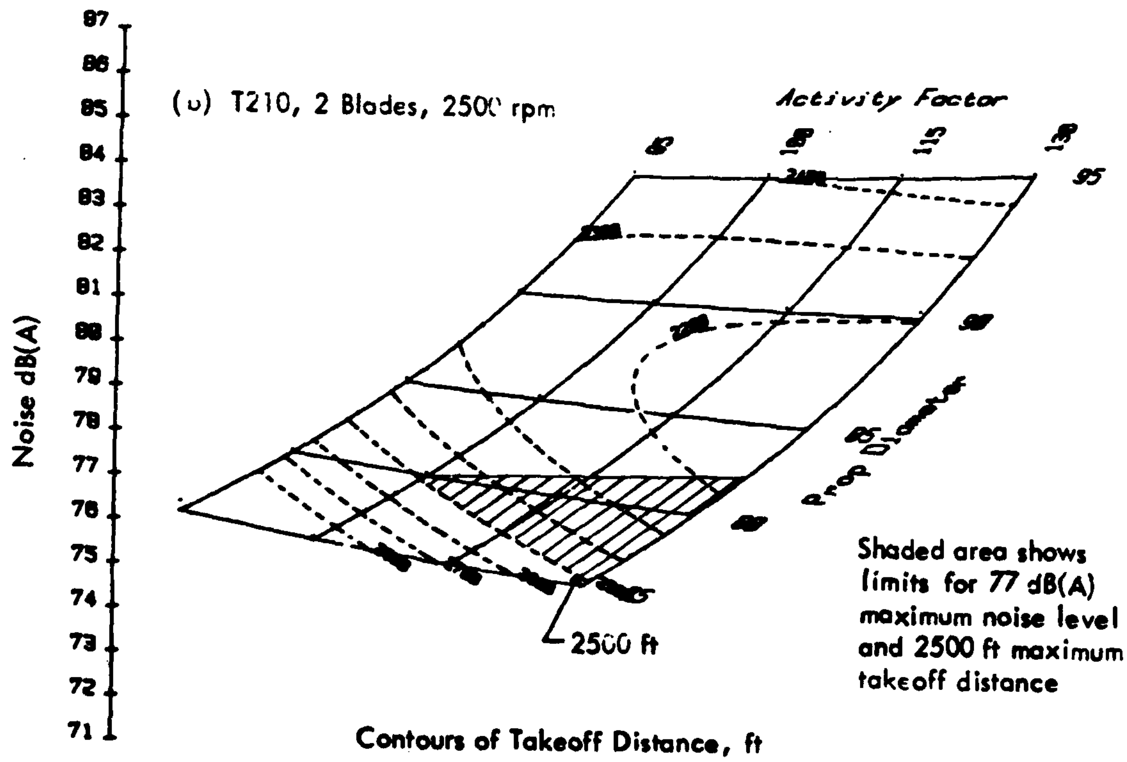
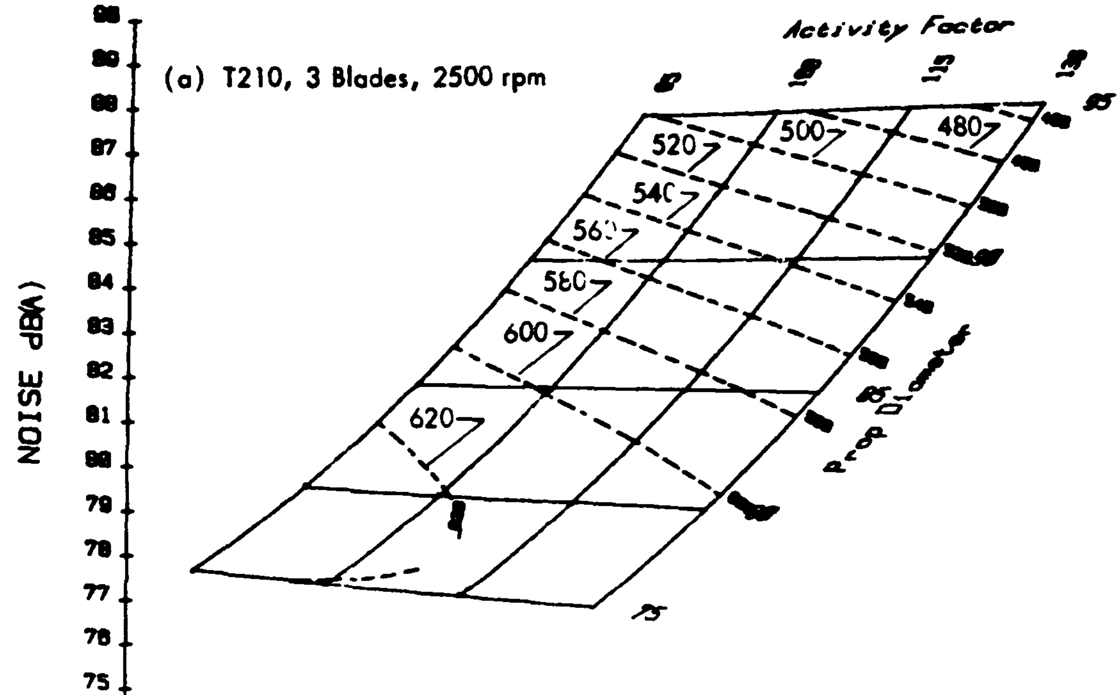


Figure 16. Illustration of Relationship Between Takeoff Distance and Noise Control Design Parameters for Single Engine Propeller Aircraft



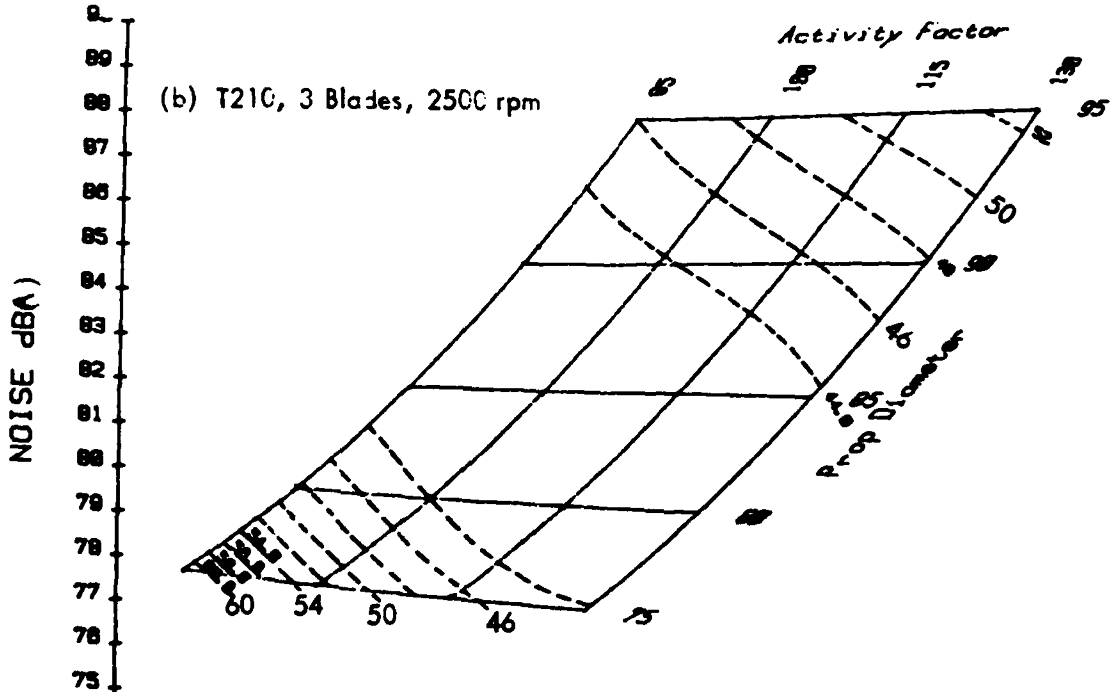


Figure 17. Illustration of Dependence of Climb Rate and Time to Climb on Noise Control Parameters

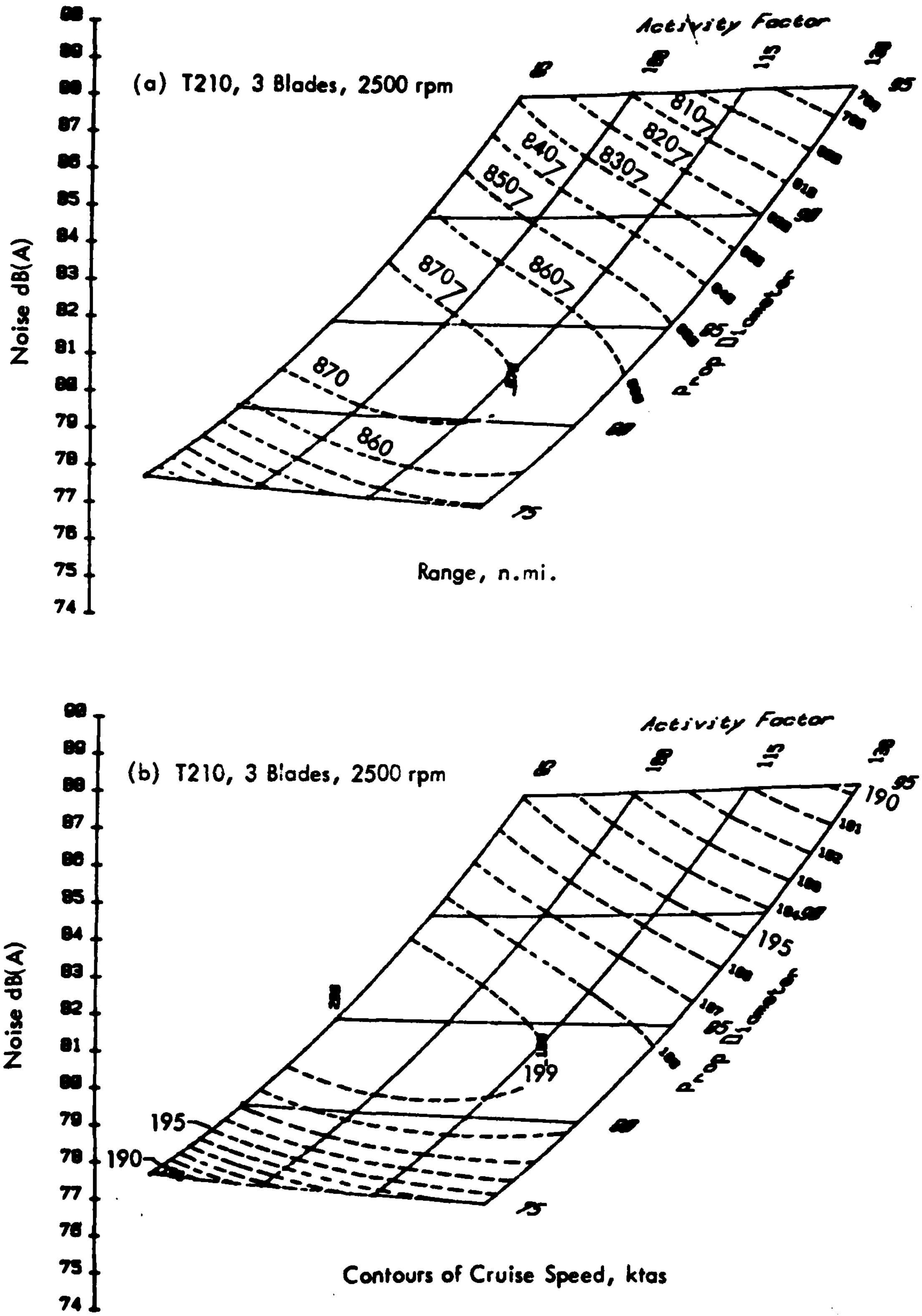


Figure 18. Illustration of Dependence of Range and Cruise Speed on Noise Control Parameters

Table 9

Noise Reduction Tradeoff Analysis for Single Piston-Engined Aircraft (from Cessna Aircraft Co.)

Maximum Takeoff Weight =	3,800 lb
Maximum Installed BHP =	300 shp
Takeoff RPM =	2700
Objectives (Input to Sizing Program for Reference Purposes):	
Takeoff Field Length =	1900 ft
Rate of Climb at Sea Level =	930 ft/min
Rate of Climb at 24,000 ft =	270 ft/min (minimum)
Range =	780 n.mi.

Parameter	Noise Level at 1,000 ft Flyover, dB(A)					
	80	77			75	
Design (Propeller) Option	B*	1	2	3	4	5
Diameter (in.)	80	75	75	75	75	75
Activity Factor	106	130	130	100	130	130
RPM at MCP	2600	2500	2400	2400	2500	2400
Blade Number	3	3	3	4	2	2
Operational						
D_{50} (ft)	2440	2303	2301	2371	2531	2530
R/C (ft/min)	850	614	513	489	653	548
V_y/V_s	0.960	1.231	1.212	1.213	1.327	1.375
24,000 ft R/C (ft/min)	420	371	363	363	240	210
Range (n.mi.)	817	848	778	788	771	661
Cruise Speed (ktas)	211	194	187	190	182	175

*B is Baseline (Current Design) Case.

Table 10

Noise Reduction Tradeoff Analysis for Twin Piston-Engined Aircraft
(from Cessna Aircraft Co.)

Maximum Takeoff Weight = 6,350 lb

Maximum Installed Bhp = 310 x 2

Takeoff rpm = 2,700

Objectives (Input to Sizing Program for Reference Purposes):

Takeoff Field Length = 2,595 ft

R/C at Sea Level = 1,580 fpm

R/C at 24,000 ft = 650 fpm

Range = 800 n.mi.

Parameter	Noise Level at 1,000 ft Flyover, dB(A)						
	80	77			75		
Design (Propeller) Option	B*	1	2	3	4	5	6
Diameter (in.)	76.5	70	75	75	70	70	70
Activity Factor	88.7	100	100	85	115	100	100
RPM at MCP	2700	2700	2500	2500	2600	2600	2500
Blade Number	3	3	3	4	3	4	4
Operational							
D_{50} (ft)	2510	2464	2630	2685	2508	2502	2597
R/C (ft/min)	1440	1552	1356	1365	1458	1436	1364
V_y/V_s @ 25,000 ft	1.200	1.363	1.234	1.179	1.332	1.255	1.298
R/C @ 25,000 ft	840	711	766	861	714	801	721
R/C @ 5,000 ft (eng. out)	270	299	227	216	268	269	234
MCP Range (n.mi.)	541	512	543	552	520	538	533
Avg. Cruise Speed (ktas)	213	205	214	216	208	212	212

*B is Baseline (Current Design) Case.

Table II

Noise Reduction Tradeoff Analysis for Twin Turbopropeller Aircraft
(from Cessna Aircraft Co.)

Maximum Takeoff Weight = 9,850 lb

Maximum Installed Bhp = 625 hp x 2

Takeoff RPM = 1900

Objectives (Input to Sizing Program for Reference Purposes):

Takeoff Field Length = 2,142 ft

R/C at Sea Level = 2,425 ft/min

R/C at 24,000 ft = 500 ft/min

Range = 700 n.mi.

Parameter	Noise Level at 1,000 ft Flyover, dB(A)							
	77	75						73
Design (Propeller) Option	B*	1	2	3	4	5	6	7
Diameter (in.)	90	85	90	90	85	95	90	85
Activity Factor	130	130	130	130	110	100	100	130
RPM at MCP	2000	1900	1800	1900	1900	1800	1800	1800
Blade Number	3	3	3	4	4	4	4	4
Operational								
D_{50} (ft)	2453	2628	2402	1951	2488	2028	2396	2383
R/C (ft/min)	2271	2137	1959	2362	2286	2570	2376	2239
V_y/V_s @ 25,000 ft	1.292	1.288	1.281	1.283	1.295	1.296	1.296	1.344
R/C @ 25,000 ft	867	563	699	954	708	961	780	661
R/C @ 5,000 ft (eng. out)	691	464	560	726	550	728	601	527
MCP Range (n.mi.)	558	520	539	563	541	567	551	536
Avg. Cruise Speed (ktas)	279	263	271	280	272	283	277	270

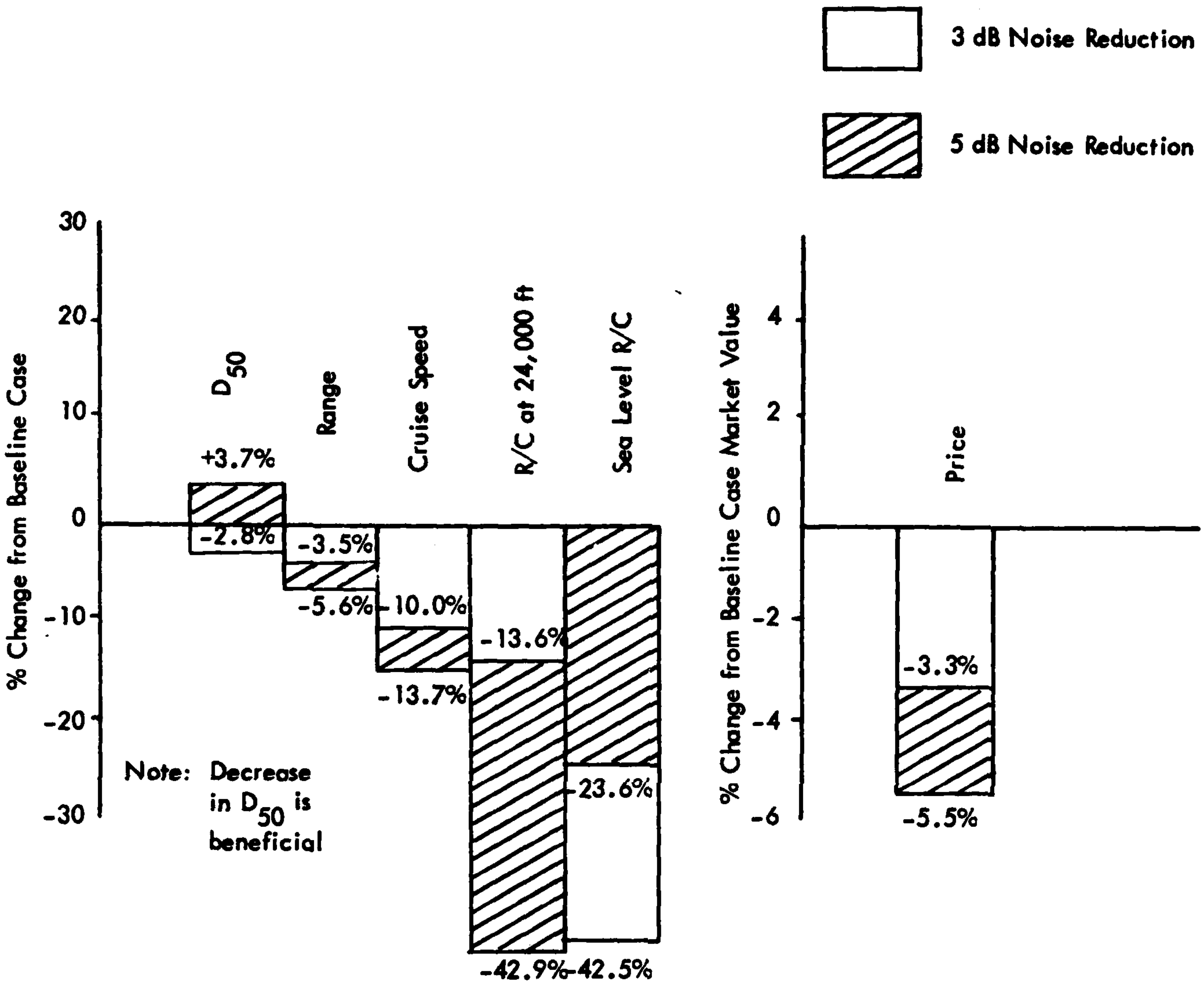
*B is Baseline (Current Design) Case.

Similar observations can be made regarding the tradeoff to achieve a 75 dB(A) "certification" noise level. However, in addition, none of the available options satisfying this 75 dB(A) noise goal is capable of meeting, or approaching, the set performance objectives for rate of climb and cruise speed. A 5 dB reduction in certification noise limit is therefore regarded as not being practical for this type of aircraft using current technology.

Table 10 shows a similar tradeoff analysis for a twin piston-engine aircraft of 6,350 lb maximum takeoff weight. In this case, the performance penalties are not as severe as for the single-engined aircraft, and one can still comply with FAR Part 23 requirements for minimum angle climb with one engine inoperative. The analysis shows that application of current technology propellers would allow reductions in "certificated" noise levels for this aircraft to meet both the 3 dB and 5 dB decrements in noise limits.

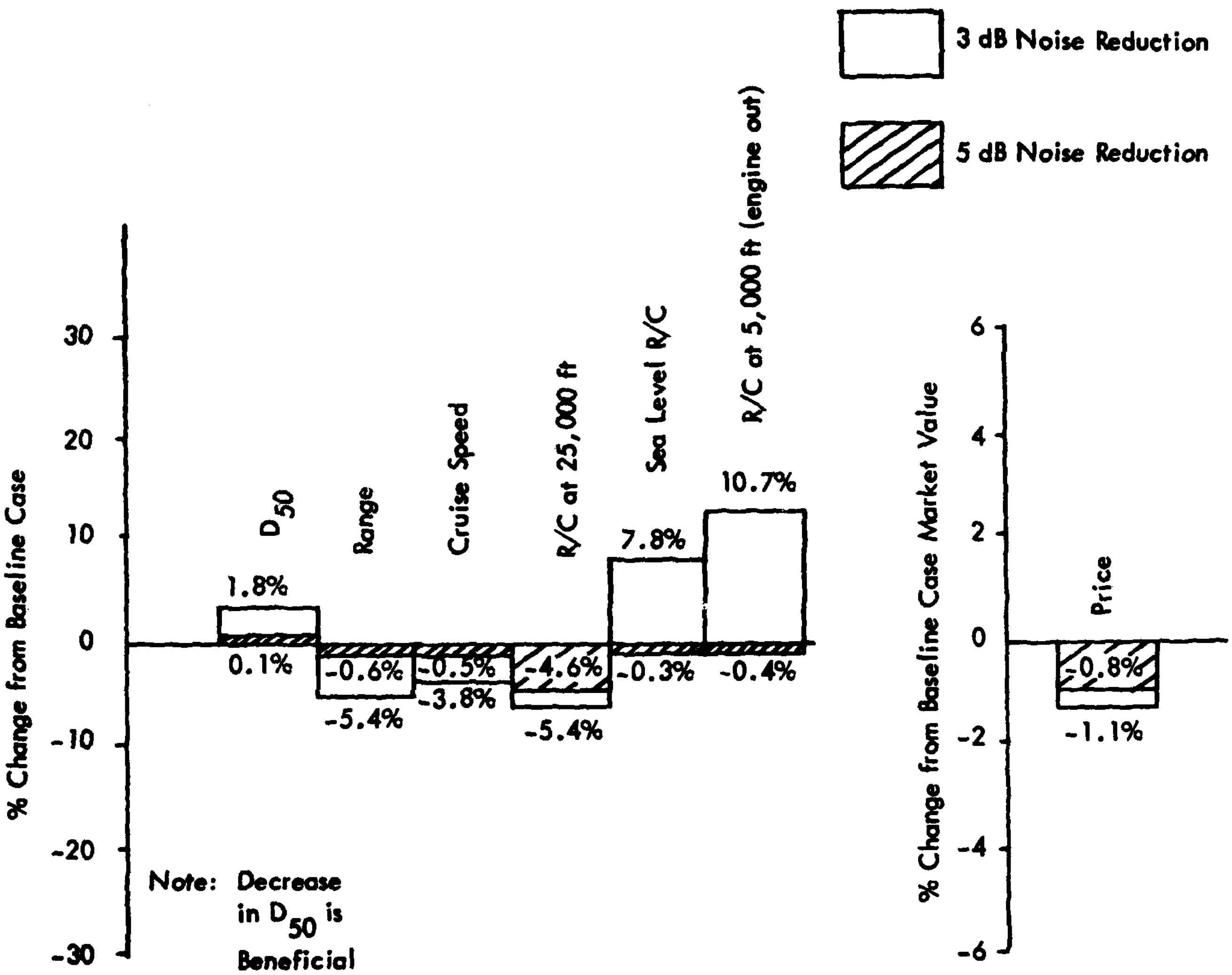
Table 11 shows the resulting analysis for a twin turboprop aircraft of 9,850 lb weight. In this case, the example aircraft has a baseline design noise level of 77 dB(A), which is already 3 dB below the FAR Part 36 requirement. (Recall the statement earlier that turboprop aircraft are generally quieter, on the average, by about 3 dB than comparable piston-powered aircraft.) The analysis is therefore focused on meeting a noise limit of 75 dB(A). The lowest noise limit attainable in the analysis was 73 dB(A), and this additional design option is shown in Table 11 for this maximum noise case. It is evident that the turboprop aircraft is more readily adaptable to lower noise emissions without major performance penalties. This is because of the more versatile power matching capability of the turbine engine with different propellers.

Figure 19 summarizes the results of the preceding analysis cases and shows, in addition, estimated noise levels for a takeoff operation assuming a noise measurement location at 8,200 ft (2.5 km) from brake release. Also shown in Figure 19 is a "market price" factor which is used by Cessna Aircraft Company to indicate the relative depreciation of aircraft value that would result from degradation of aircraft performance. A depreciation of 1 percent may be regarded as significant, and 2 percent as unacceptable, in competitive marketing of these example aircraft.



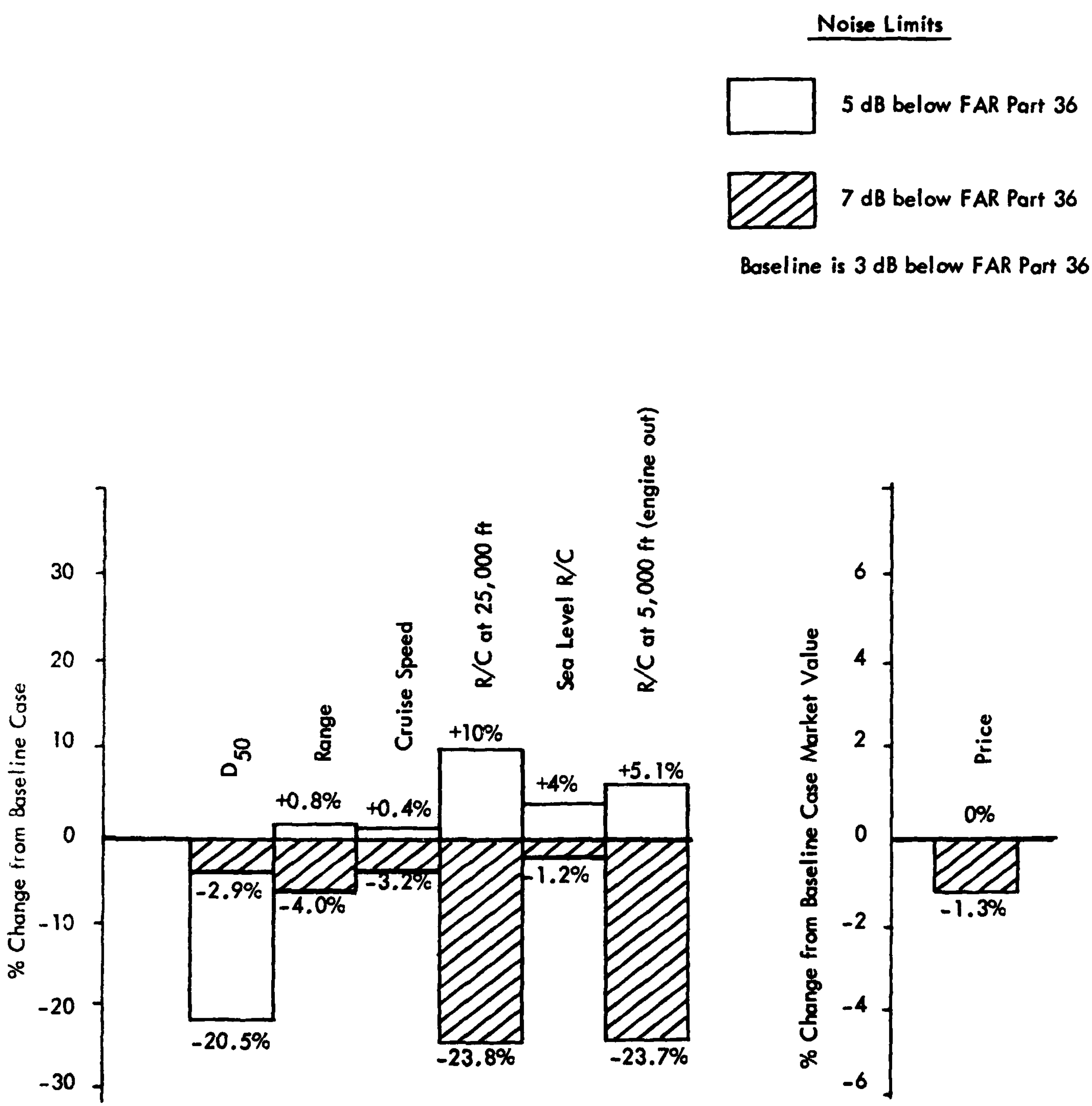
(a) Single Piston Engine Aircraft (Option 3 and Option 4)

Figure 19. Summary of Application of Existing Noise Reduction Technology (Selected options based on least change to aircraft market value for each decrement in noise level)



(b) Twin Piston Engine Aircraft (Option 1 and Option 5)

Figure 19 (Continued)



(c) Twin Turbopropeller Aircraft (Option 3 and Option 7)

Figure 19 (Continued)

In summary, application of existing technology to achieve further noise reductions of small propeller aircraft does not appear to be economically viable for most current state-of-the-art single engine small propeller aircraft. (While retrofit of older aircraft with new, quieter propellers is a desirable consideration, it is unlikely that such retroactive action could be required by a viable noise regulation.)

On the other hand, for twin-engine propeller aircraft, especially turboprop types, application of existing technology, including use of optimum propeller/engine combinations, appears to offer the potential for noise reductions, with acceptable or negligible performance losses, of 3 to 5 dB for piston-engine, and 2 to 4 dB for turboprop aircraft. Such applications could reduce the achievable maximum level flyover noise levels to about 75 dB(A) instead of the current 80 dB(A) limit for such aircraft.

3.3 Potential from Application of New Technology

3.3.1 Propeller Design Technology

A considerable resurgence of research studies of propeller designs has occurred in the period 1975-1981. This resurgence follows a long period of relative inactivity since the ending of propeller blade development work by NACA during the 1950's. Many of the concepts and airfoil section designs developed by NACA have been implemented in a limited manner such as by the use of Series 16 and Series 6 airfoils in turbopropellers, but are now considered to be of much greater utility in reducing operating costs, fuel consumption, weight, and noise levels of a wider range of small propeller-driven aircraft.

Evaluations of advanced technology propellers have been performed during the last few years by means of improved analytical procedures for noise level prediction. Pertinent background in this area is provided in References 24 to 34. Whereas earlier noise prediction methods were, to some extent, capable of evaluating the effects of gross changes in blade loading and blade thickness, these methods were insufficiently refined to provide a detailed accounting of noise level which could be confidently used in economic and performance trade-off analyses. The most significant aspect of these new analytical methods is that they employ a definition of the blade surfaces by elemental area subdivisions, and can thereby more closely represent the actual surface distributions of pressure (loading) and displacement (thickness). For general aviation propellers, where the helical tip

Mach number of propellers is subsonic, the mathematical development represents an extension of Lowson's "compact source" theory[35] which had previously been applied to helicopter rotors. The most common form of the new theory is based on Ffowcs-Williams and Hawkings' equation[36] for sound radiation from surfaces, which includes both pressure and thickness effects; that is,

$$4\pi\, p(t) = -\frac{\partial}{\partial x_i} \int_S \left[\frac{p_{ij}\, n_j}{r \left| 1 - M_r \right|} \right]_{t'} dS + \frac{\partial}{\partial t} \int_S \left[\frac{\rho_o\, v_i\, n_i}{r \left| 1 - M_r \right|} \right]_{t'} dS \qquad (1)$$

where

$p(t)$ is the sound pressure amplitude received at an instant, t, in the far-field observer time, and caused by steady force and thickness sources on the blade surface at some earlier instant of time (retarded time) $t' = t - r/c_o$,

$p_{ij}\, n_j$ is the pressure acting normal to the blade element area,

$v_i\, n_i$ is the outward (normal) component of the blade element velocity,

ρ_o and c_o are the air density and sonic velocity, respectively,

x_i and r are the Cartesian coordinates and the direct radial distance of the observer relative to the source blade element position at retarded time, and

M_r is the component of the source Mach number in the "r" direction.

This time domain equation requires evaluation at each of a number of successive observer time intervals, with the bracketed terms $[\ \ ]_{t'}$ being evaluated for each blade element at its retarded position corresponding to t'. It has been shown, by Lowson for example, that the "compact" (lumped) form of this equation for steady forces

$$4\pi\, p(t) = -\frac{\partial}{\partial x_i} \left[\frac{F_i}{r \left| 1 - M_r \right|} \right]_{t'} \qquad (2)$$

where F_i, the blade element force in Cartesian components, is exactly compatible with Gutin's[37] equation,*

---

*Also with Garrick and Watkins (Reference 38) equation which includes forward motion effects

$$p_{mB}(f) = \frac{mBM}{2\sqrt{2}\,\pi R_e r_o} \left\{ -T\cos\theta + \frac{D}{M} \right\} J_{mB}(mBM \sin\theta) \quad (3)$$

where $p_{mB}(f)$ is the rms sound pressure of the mth harmonic of the far-field sound caused by a rotating propeller with B blades. The thrust (T) and drag (D) components of blade forces are concentrated at a blade radius R_e and have a Mach number M at this radius. The observer location is at distance r_o from the hub and an azimuth θ from the forward shaft axis. Similarly, the thickness term in Eq.(1) can be likened to the closed form solutions by Deming[39] and Diprose;[40] that is,

$$p_{mB}(f) = \frac{\rho B \omega^2}{2\sqrt{2}\,\pi r_o} \int_0^{R_T} K \,.\, t \,.\, b \,.\, J_{mB}(mBM \sin\theta)\, dR \quad (4)$$

where t and b are the blade section thickness and chord at radius R, M is the section Mach number, K is an empirical constant, and $\omega = 2\pi f$ (harmonic frequency).

Thus, while the latter Eqs.(3) and (4) and their derivative forms (to include forward motion) were used for propeller noise prediction for many years, they did not have the capability of aiding detailed propeller design. The new acoustical theory allows detailed evaluation to be made of the acoustic benefits of different airfoils, cambers, spanwise and chordwise pressure distributions, and blade thickness changes at or near the blade tip. Such changes to propeller designs have recently been evaluated by Klatte and Metzger (Hamilton Standard),[41] by Korkan, Gregorek and Keiter[42] (Ohio State University and Cessna Aircraft), and by Succi[28] (Massachusetts Institute of Technology), all of whom have developed computer programs based on the Ffowcs-Williams and Hawkings theory. While these applications have concentrated on examining the versatility of propeller optimization by substituting Series 16 airfoils for Clark Y and RAF-6 sections, future work will probably be based on more advanced section designs such as refined supercritical airfoils.

In particular, work at Ohio State University on general aviation technology suggests that the new acoustical theory can be directly embodied in computational procedures for airfoil selection and propeller optimization. The technique would be similar to that used for aerodynamic evaluations, by superposition of results obtained by analysis of separated blade characteristics, such as

a. thickness distribution at zero angle of attack,

b. thickness distribution at an angle of attack corresponding to "actual minus ideal," and

c. camber line at ideal angle of attack.

Partial noise constituents, in the time domain, are evaluated from (a) for thickness noise only, from (c) for loading noise only, and from (b) which contains partial thickness and loading noise components. It has been postulated that this approach will allow predominant noise source causes to be identified and alleviated as part of the design process rather than by current procedures of retrospective analysis.

With such powerful analytical methods for acoustical analysis, combined with major advances in airfoil design and the computer coding of airfoil characteristics, significant reductions in propeller noise should become available in new aircraft of the mid to late 1980's.

At present, the available acoustic theory has been applied in each of the above mentioned studies to examine the benefits in noise reduction attainable by selective change of design parameters. The following summary is indicative of these study results:

Baseline Aircraft

Table 12 shows the aircraft baseline cases used in the studies. The Cessna 172N, 210M and 441 cases were examined by Korkan, Gregorek and Keiter,[42] while the Beech Debonair, Duchess and DeHavilland Twin Otter were examined by Klatte and Metzger.[41] The study by Succi[28] also used a Cessna 172 as a baseline case, but employed a NACA 16-506 airfoil in all of the propeller noise analyses, including the baseline case.

A significant starting point in each of these analyses was to quantify the relative significance of steady loading and thickness noise contributions to the A-weighted flyover noise level of the baseline propeller. As is shown in Table 12, blade thickness noise predominated for four of the six baseline cases. In these cases, therefore, the thickness noise must be reduced as a priority in order to achieve significant overall noise benefits. It should be noted that a reduction of tip speed will influence both steady loading noise and thickness noise, but at different rates of decay with the latter typically decreasing more rapidly with tip speed than the former. Thus, a reduction in rpm or blade diameter is again found to have a major influence in noise reduction, irrespective of the predominant source, as one might expect from the earlier analysis.

Reduced Blade Diameter

The use of reduced blade diameter as a means of reducing blade tip speed has already been examined in Section 3.2 for existing technology propellers. However, in these earlier cases, such reductions sometimes caused performance losses even when accompanied by appropriate increases in blade activity factor or blade number to absorb the available shaft horsepower.

A major advantage of the advanced technology airfoil sections (NACA 16 or better) is that the baseline aerodynamic performance can be equaled or improved with reduced diameter propellers, without increase of activity factor or blade number. Thus, significant noise reductions can be achieved without penalty in performance, weight or cost, assuming conventional materials (e.g., aluminum) are retained.

Klatte and Metzger[41] demonstrate this for the light single (Beech Debonair), light twin (Beech Duchess), and heavy twin aircraft referred to in Table 12. In each case, the substitution of a NACA 16 series airfoil with reduced radius blades led to the most cost-effective noise reductions, either with or without tip shape or tip thickness changes.

Reduced Blade Thickness

A further advantage of the change of airfoil section is that chord and thickness/chord ratio could be reduced in a selective manner without loss of aerodynamic performance. For the three Cessna aircraft studied, the 172N and 210M were predicted to benefit by the order of 4 dB by reduction of thickness/chord ratio from the nominal value of 8-1/2 percent to 5 percent. These predicted results compare well with reported experimental studies[8] where noise reductions of 4 dB were obtained with similar blade thickness reductions. Further thickness reductions provide negligible further noise reduction benefit. In the case of the Cessna 441, only 1 dB reduction was predicted to result from changing the nominal 7 percent thickness/chord ratio. This can be attributed to the predominance of loading noise rather than thickness noise in the baseline case.

Table 12

Baseline Cases Used to Evaluate Application of New Noise Reduction Technology for Small Propeller Aircraft

Aircraft Type	Maximum T/O Weight (lb)	No. of Propellers	Baseline Propeller Case		
			Airfoil	Predominant Noise Source	No. of Blades
Cessna 172N[42]	2,310	1	RAF-6	Thickness	2
Beech Debonair[41]	3,400	1	RAF-6	Thickness	2
Beech Duchess[41]	3,880	2	Clark Y	Thickness	2
Cessna 210M[42]	4,000	1	Clark Y	Loading & Thickness	3
Cessna 441[42]	9,925	2	16-64	Loading	3
Twin Otter[41]	12,500	2	Clark Y	Thickness	3

In the studies of the Beech Debonair, a change to a NACA 16 airfoil with reduced tip thickness was predicted to provide a 3 dB noise reduction. However, other changes to tip planform, such as to elliptical tips, were noted to result in significant additional noise reductions. These changes combine the effects of reduced blade tip thickness and tip loading, and provided predicted reductions of up to 7 dB in the combined effect.

In the Twin Otter study, change of tip shape and tip thickness was predicted to provide only about 1 dB benefit in noise level, except when an OV10 "low noise planform" was evaluated. The latter was expected to provide at least 3 dB benefit, relative to the baseline case.

Evaluations for the Duchess aircraft did not explicitly examine thickness effects in isolation from other (e.g., diameter) parameter changes. Noise reductions of between 2 and 3 dB due to the combined effects of reduced tip thickness and change in tip shape are indicated by the analyzed data.

Combined Changes *(without cost or weight increase)*

The first three columns of Table 13 summarize the benefits in noise reduction discussed so far for propellers with advanced airfoils which can be optimized on diameter and blade thickness reductions. Klatte and Metzger[41] indicated that these methods can be utilized with considerable propeller cost and weight reductions, as follows:

Aircraft Type	Optimum Noise Reduction Without Cost Penalty, (dB)	Propeller Cost Reduction (%)	Propeller Weight Reduction (%)
Debonair	11	22	22
Duchess	4	40	50
Twin Otter	6	5	15

Table 13

Summary of Noise Reduction Concepts Using
Advanced Airfoil Blades in Baseline Design

Aircraft Type	Noise Reduction, dB				
	Diameter Reduction	Thickness Reduction	Tip Shape	Blade Sweep	Proplets
172N	2	4	-	5 - 8	3
Debonair	5	3	3	5	-
Duchess	3	(2 to 3)		-	-
210M	3	4	-	N/A	2
441	N/A	1	-	4	1
Twin Otter	4	1	1	-	-

N/A: Not Appropriate.

The major change in technology involved in the above approach to propeller noise reduction is that of incorporating the required structural integrity and impact (wear) resistance into blades which must be capable of operating safely in unprepared or poorly maintained airstrips. Thus, if aircraft usage could be restricted according to blade sensitivity (which is an unlikely prospect) then the advanced blades discussed above could be considered as immediately available for such restricted applications. However, the noise, cost, and weight benefits predicted for these propeller designs must await an improvement in material and manufacturing technology before they can be realized for the whole fleet, rather than just for the twin engined business aircraft fleet, some of which currently use NACA 16 airfoils.

Blade Sweep

Primary interest in the use of blade sweep in propeller designs is directed towards high speed propulsors for Mach 0.8 cruise transport category aircraft.[30] In such cases the propeller blade tip speeds are subsonic in rotation but supersonic in helical motion. Thus large areas of each blade are supercritical (with local flow velocities exceeding sonic speed). Applying blade sweep reduces these local velocities and local pressure gradients, and therefore contributes greatly to improved aerodynamic performance and reduced noise output. A further advantage expected of blade sweep on noise generation is that of the geometric phase lag between the blade element sources. This effect, which should result in a change of the sound pressure time history at the observer location, is being closely investigated by Hamilton Standard in the advanced "prop-fan" designs.

The application of blade sweep to the small propeller-driven fleet of aircraft is shown by Succi[28] and Klatte and Metzger[41] to have significant potential for noise reduction. For example, Succi performed theoretical analyses of a wide range of sweep configurations applied to a Cessna 172 aircraft propeller with NACA 16 airfoil blades. His analysis suggests that up to 8 dB reduction might be achievable from moderately complex configurations, and up to 5 dB reduction for less complex sweep configurations. Klatte and Metzger[41] examined the potential of blade sweep for the Debonair aircraft example. Their theoretical work indicated that a further 5 dB noise reduction might be achieved, relative to the optimum nonswept blade discussed in the preceding note on combined changes (without cost or weight increase). The Klatte and Metzger study applied a 52 degree sweep at the radial station where critical flow first occurs. However, they also showed that while propeller weight would not be a detrimental factor, costs would be well in excess of that of current conventional propellers. The benefit of new technology in propeller materials has been examined by Keiter[43, 44] of Cessna Aircraft, McCauley Accessory Division. In these studies, aluminum blades were considered to be replaced by composite materials, such as E-glass, S-glass, Kevlar and Graphite, for a range of Cessna aircraft (172N, A188B, 210M, 414A and 441 models) while the additional cost of advanced propellers for these aircraft was predicted to be substantial, the total retail cost of the aircraft, and the operating cost, was predicted to be substantially lower (than the current baseline design) due to the more substantial savings incurred by airframe/engine resizing and more efficient economic performance.

A most significant finding of the Keiter study was that aircraft designed to meet the current FAR 36 noise limit, using advanced technology, should be able to retail at a cost savings of 8 percent to 16 percent lower than the current technology equivalents, and with between 7 percent and 17 percent reduction in trip fuel consumption. Designing these aircraft to meet a noise limit 5 dB lower than the current FAR 36 would reduce these savings by the order of 1 percent or less. Further reference is made to these results in Section 3.4 which summarizes the expected propeller noise reduction benefits of current and new technology.

Proplets

The potential aerodynamic benefit of the use of airfoil-tip winglets has been known for some time and has been used or experimented with in a wide range of aircraft wing applications. In more recent years this experimentation has extended to propeller blade tips, such as in the so-called Hartzell Q-Tip propeller. Unfortunately, these experiments have not shown a consistent benefit in noise reduction, possibly because the benefits depend on the predominant source of noise (whether it is loading or thickness), and whether the proplet is used to gain extra performance rather than reduced noise.

Two recent studies[45,46] of proplets have shown that these devices are capable of providing noise reduction by trade-off of the improved performance potential. Irwin and Muzman[45] suggest that a 1 percent increase in propeller efficiency is attainable at advance ratios corresponding to maximum efficiency, but that optimization of proplet design may be necessary to achieve the greatest benefit. Sullivan, Cheng and Miller[46] suggest that the potential increase in propeller efficiency may be as much as 1-5 percent. From a noise reduction viewpoint, this efficiency benefit can be used to reduce propeller diameter, and hence blade tip speed. This approach was included in the study by Korkan, Gregorek and Keiter[42] and indicated potential noise reductions of 3 dB for the Cessna 172, 2 dB for the Cessna 210, and 1 dB for the Cessna 441, as shown in Table 13. These results were also included in Keiter's review of advanced propeller technology.[44]

3.3.2 Noise Reduction Benefits of Applying Other New Aircraft Design Technology

The preceding discussion has emphasized noise reduction of the primary noise source – the propeller. However, as indicated earlier, noise under the takeoff path can be reduced if climb performance can be improved. The reverse is, of course, also true so that any noise reduction technique which reduces aircraft climb performance will be partially or wholly negated without a compensating change in the aircraft design to overcome or cancel out the performance degradation. Because of the high development costs associated with any basic changes to an aircraft design, such changes are unlikely to be economically feasible solely to meet noise reduction requirements. However, where they are achieved for other reasons, such as improved economy, climb performance, etc., their corresponding noise reduction benefits bear consideration.

Airframe Design and Noise

One view of the basic airframe design conditions for an aircraft is illustrated in Figure 20. The excess available power, over that required to overcome induced drag and form drag, is available for climbing. The lower the combined drag, the more excess power available and hence the better the climb performance.[47]

A simplified model for the performance of fixed wing aircraft is provided by the following expressions:

$$\text{Climb Angle, } \alpha = \sin^{-1}\left[\frac{T}{W} - \frac{C_D}{C_L}\right]$$

$$\text{Rate of Climb, R/C} = \left[\frac{2W}{AC_L\rho}\right]^{1/2}\left[\frac{T}{W} - \frac{C_D}{C_L}\right]$$

$$\text{Takeoff Distance, } D_{50}{}^{*} = \left[50\Big/\frac{T}{W} - \frac{C_D}{C_L}\right] + \frac{8}{3}\,\frac{(W/A)/(T/W)}{\rho g\, C_L}$$

where

T/W = Ratio of propeller thrust (T) to Takeoff Weight (W)

W/A = Wing Loading, ratio of weight (W) to wing area (A), lb/ft^2

C_D/C_L = Ratio of drag (C_D) to lift (C_L) coefficients

ρg = Weight density of ambient air

A representative set of values for these parameters for a single engine piston aircraft, with a maximum takeoff weight of 3,000 lb, is given by

T/W = 0.23

W/A = 18 lb/ft^2

C_D/C_L = 0.11

ρg = 0.0765 lb/ft^3 at 15°C, sea level

C_L = 2

*Distance from brake release to clear a 50 foot obstacle; assumes a linear decrease in acceleration from an initial value of T/W at brake release, to 0 at lift-off.

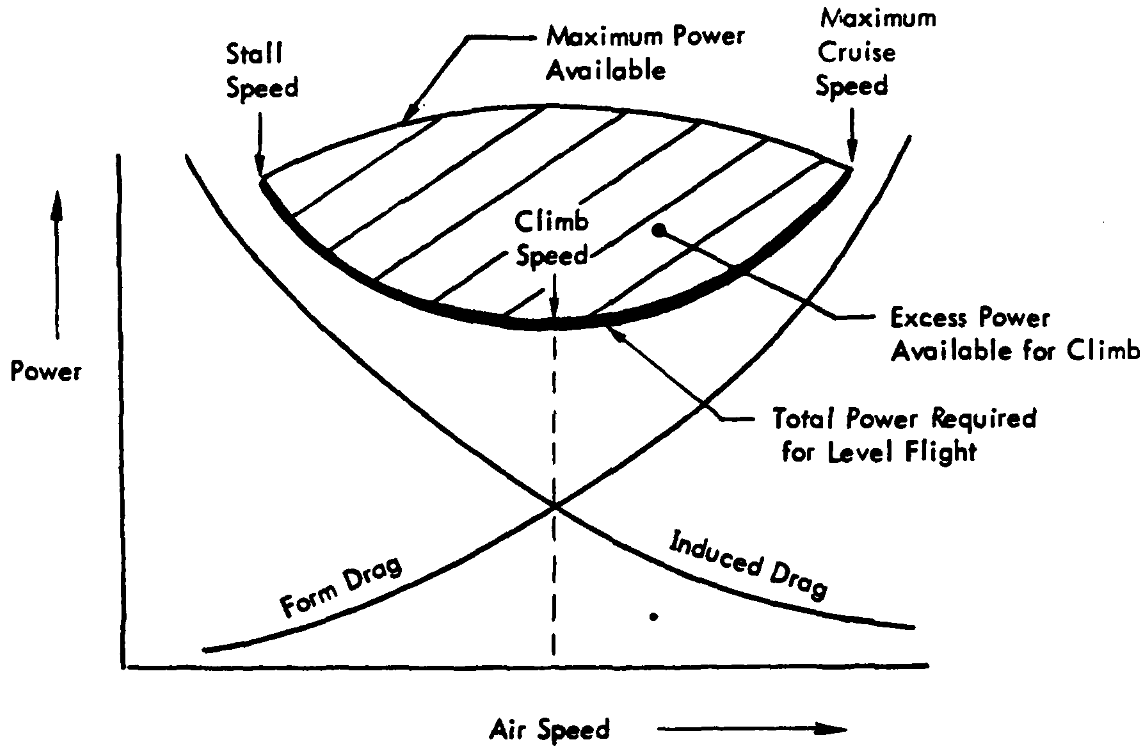


Figure 20. Illustration of Typical Aerodynamic Drag/Engine Power Tradeoff Concepts for Propeller Aircraft (from Reference 47)

The corresponding performance parameters are

α, Climb Angle	=	$\sin^{-1} 0.12 = 6.9°$
R/C, Rate of Climb	=	627 ft/min
D_{50}, Takeoff Distance	=	1,780 ft

At a distance of 2.5 km (8,200 ft) from brake release, the height, H, of the aircraft on takeoff would be

$$H = 50 + (8{,}200 - D_{50})(\tan \alpha)$$
$$= 820 \text{ ft}$$

Assuming the baseline aircraft just meets the noise certification criteria (80 dB(A)) at 1,000 ft with a maximum continuous power setting and that the higher propeller rpm during takeoff increases the source level by 3 dB, the expected level on the ground at 2.5 km from brake release would be

$$LA_{Max} = 80 + 20 \log_{10} (1000/820) + 3, \text{ dB}$$
$$= 84.7 \text{ dB(A)}$$

With this as a baseline condition, one can approximate the decrease in noise level on the ground attributable to the following type of changes in the airframe design.

- o Reduce the takeoff weight by 3 percent (assuming the same payload) - this increases the thrust to weight ratio (T/W) and wing loading (W/A) correspondingly, or
- o Reduce the drag coefficient (C_D) by 3 percent, or
- o Increase the lift coefficient (C_L) by 3 percent.

Applying each of these small, but still very significant design changes one at a time, and then in combination, one can show that the maximum noise level in the ground would be expected to decrease approximately as shown in Table 14.

Table 14

Illustration of the Potential Noise Reduction During Takeoff
Achieved by 3 Percent Improvements in Aircraft Performance Parameters

Parameter	Base Line Value	Improvement: Reduce Weight Value	Reduce Weight Δ	Reduce Drag Value	Reduce Drag Δ	Increase Lift(1) Value	Increase Lift(1) Δ	All Three Value	All Three Δ
T/W	0.23	0.237	+3%	0.23	0	0.23	0	0.237	+3%
W/A, lb/ft^2	18	17.5	-3%	18	0	18	0	17.5	-3%
C_D/C_L	0.11	0.11	0	0.107	-3%	0.107	-3%	0.103	-7%
C_L,	2.0	2	0	2	0	2.06	+3%	2.06	+3%
D_{50}, ft	1780	1681	-5.6%	1770	-0.6%	1730	-2.8%	1023	-8.8%
Climb Angle, deg.	6.9°	7.3°	+5.8%	7.1°	+2.6%	7.1°	+2.6%	7.7°	+11.6%
R/C, ft/min	627	654	+4.3%	644	+2.7%	634	+1.2%	680	+8.4%
Ht @ 8200 ft, ft	820	878	+7.1%	843	+2.8%	848	+3.4%	931	+13.6%
LA_{Max}, dB(A)	84.7	84.1	-0.6 dB	84.5	-0.2 dB	84.4	-0.3 dB	83.6	-1.1 dB

(1) Assuming change in airfoil shape only with same area.

While these hypothetical changes in performance are both significant and potentially costly to develop, the changes in noise level are small and probably not significant except for the last case. Nevertheless improvements in aircraft takeoff performance, especially that due to reduction in takeoff weight, are clearly desirable for other reasons and the corresponding noise reductions will become a very desirable side benefit that can be realized by such improvements in airframe design.

3.4 Summary of Expected Benefits

3.4.1 Current Technology

The opinion of the industry on the use of current technology for noise reduction purposes is clearly expressed by Hooper and Smith[7] who claim that it has been used to the limit, both for propellers and engines, to meet the current FAR Part 36 Appendix F noise limits. The studies by Cessna for purposes of the present work indicate that the performance margin available for further noise control is likely to be insufficient for single-engine aircraft, but may, in some cases, be economically feasible in twin-engine aircraft. However, it may not be practical to differentiate in a noise regulation between aircraft models which have and have not a potential for further noise reduction. Such differentiation is, however, already evident, but not from a regulatory viewpoint, by the usage of MNOP as a noise limiting method. It seems unlikely that this approach could be considered as having a wider application across the aircraft fleet to meet more stringent noise limits.

In summary, current (off-the-shelf) technology does not appear to have the potential of meeting more stringent noise limits for the current flyover test procedures, at least for single engine aircraft. Reference to the study of takeoff noise level predictions, presented in Section 2.2. for a sample fleet of aircraft models, would indicate that many of the currently certificated models may not be able to satisfy noise goals derived for the majority of the fleet. It is therefore concluded that more stringent noise limits will only be economically viable by the use of advanced technology propeller designs which can be integrated with current technology engines.

3.4.2 Advanced Technology

The potential for future benefits in noise reduction by development of new technology propellers has been extensively evaluated by a number of recent studies, as discussed in Section 3.3. The most recent of these by Keiter[44] in 1981, based on a study by Ohio State University and Cessna Aircraft, indicates that the use of advanced blade airfoil sections, composite materials, blade tip sweep and proplets, together with optimization of diameter (in some cases by increase of diameter), propeller rpm, and engine/airframe sizing has the potential for meeting noise limits 5 dB lower than current FAR Part 36 with substantial reduction of retail and operating costs. The cost penalty for the 5 dB lower limit was estimated to be of the order of 1 percent, this being deducted from a net cost benefit of the order of 7 percent to 16 percent resulting from the technology application.

However, many of the concepts employed in these recent studies are a result of theoretical evaluations using the most recent of acoustical and aerodynamic analytical methods. In each case, the researchers call for development programs to verify their findings. Since the one aim of the regulatory process is to ensure that the technology is fully utilized, it would appear reasonable to plan for imposition of lower noise limits of the order of 5 dB to become effective in a future time period, selected to allow sufficient time for the necessary validating development to be accomplished.

4.0 CONSIDERATIONS FOR AMENDMENT OF NOISE REGULATIONS FOR PROPELLER-DRIVEN SMALL AIRPLANES

Four areas of possible amendments to the existing noise regulations in Appendix F of FAR Part 36 (see Appendix A herein) are considered in this section based, in part, on the material presented in Sections 2 and 3.

1. Change in test procedures to require the use of a takeoff test in place of or in addition to the current level flyover test.
2. Change in the noise metric from LA_{Max} to SEL (or L_{AX}).
3. Change in Appendix C or F of FAR Part 36 to eliminate the discontinuity between the current rules at a maximum gross weight of 12,500 pounds. (The discontinuity occurs at 5,700 kg or 12,568 pounds for Appendix 3 of ICAO's Annex 16 noise regulation.)
4. Any possible change in noise limits associated with any one of the above three items.

4.1 Change in Test Procedure

In Figure 4 (Section 2), it was shown that at the same distance underneath the flight path, the noise is expected to be higher during takeoff than during cruise power settings due to the higher propeller rpm for the former condition. The exception observed was the cruise optimized fixed-pitch propeller aircraft which had a lower rpm during takeoff than during cruise at MNOP.

Thus, it could be argued that a takeoff noise certification test should be required for all propeller-driven small aircraft, with the possible exception of cruise optimized fixed-pitch propeller aircraft, to insure that worst case conditions are employed for the test. A counter to that argument is that for many airports, the population density is very low near the airport boundary underneath the climbout portion of a departure. For the majority of propeller-driven small aircraft operations (i.e., single engine, less than 3,500 pounds), the largest number of people under departure paths are likely to be exposed to reduced power conditions employed after the aircraft has leveled off at normal departure or pattern altitudes. However, the population along the airport runway sidelines may, in some situations, receive a considerable exposure to the noise during takeoff, even considering the additional ground attenuation loss of the takeoff noise during initial ground roll. Precise generalization is not possible as to which portion of the

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flight of departing propeller-driven small aircraft has the greatest noise impact on a community - the initial ground roll and takeoff at maximum takeoff power, or level flight at normal cruise power (or maximum normal operating power). This can only be resolved accurately for specific airports, case by case, or by collection and evaluation of noise exposure data and population density around a large sample of general aviation airports. No such detailed data exist at present. Therefore, in the absence of such data (see Appendix D for a global view of the noise impact near general aviation airports), the argument given at the beginning of this paragraph may be considered a necessary and sufficient reason for noise certification requirements for all but cruise optimized fixed-pitch propeller-driven small airplanes to be based on levels measured (or computed) at a position underneath the aircraft during takeoff. Note that the performance correction currently applied in Appendix F of FAR Part 36 and in Appendix 3 of ICAO's Annex 16 only accounts for the variation in altitude, due to the variation in climbout performance, at a nominal distance of 11,430 ft (approximately 3.5 km) from brake release. However, the difference in source level under the takeoff path due to variation in propeller rpm between takeoff power and maximum normal operating power is not accounted for by this correction.

To accomplish such a revised certification requirement, two options appear to be possible:

1. Conduct the noise certification tests so as to measure directly the required takeoff noise level, or
2. Modify the existing performance correction applied to level flyover test measurements to provide an effective measure of takeoff noise levels.

Based on the results obtained in this program, either approach appears feasible as outlined below.

4.1.1 Direct Measurement of Takeoff Noise Levels

The following observations are based, to a large extent, on the results obtained from the flight test program, conducted with Cessna Aircraft Company, which is reported in detail in Appendix B.

4.1.1.1 Measurement Location

Although a sideline measurement position was considered in the initial planning of the test program, it was not utilized. To maximize the simplicity and validity of the takeoff noise tests, only positions under the flight path are needed. A position of 2.5 km (8,200 ft) from brake release is considered optimum on the basis of the following rationale:

a. 2 km (approximately 6,560 ft) from brake release represents the minimum distance that is practical, based on aircraft heights and the need to represent a realistic environmental problem area.

b. 3 km (9,840 ft) and greater distances present difficulty because

   - suitable measurement locations are not available at such distances near many general aviation airfields;

   - ambient noise can become too high for quiet, high performance aircraft.

c. 2.5 km is considered to be a good compromise.

4.1.1.2 Selection of Flight Profile

In contrast to the requirement for level flyover tests that the height of the aircraft above ground level be within ±30 ft of a 1,000 ft reference distance, no such direct control on aircraft height is involved for a takeoff test. However, the aircraft performance during takeoff must be controlled - this sets the altitude indirectly. It is recommended that a "best rate of climb" takeoff profile be required for takeoff tests.

An alternative "takeoff" procedure was evaluated which showed nearly identical results, when allowance was made for minor variations from the actual takeoff tests, in altitude or propeller rpm. This consisted of a simulated climbout initiated after a low level, low power approach, followed by acceleration and then climbout along a predetermined profile, calculated by Cessna, to simulate a takeoff profile which passed through the 1,000 ft altitude over the measurement point.

4.1.1.3 Measurement of Nonacoustic Test Parameters

As discussed in Appendix B, the pertinent airplane flight parameters (i.e., propeller rpm, indicated airspeed, and temperature) were measured with standard on-board instrumentation and logged, manually, by the pilot or test observer. Airplane height was measured photographically.

Test Durations

As indicated below, only small differences were observed between the duration of each test allowing time for the aircraft to land and reposition at brake release (where appropriate), or circle around for another pass over the microphone array.

Test	Average Time Between Tests
Takeoff Tests	6 min.
Simulated Climbout	5 min.
1,000 ft Flyovers	4 min.

4.1.2 Correlation Between Takeoff, Simulated Climbout, and Level Flyover

Consider, for now, the correlation between only the maximum sound levels (LA_{Max}) on takeoff or simulated climbout and the level measured for level flyover. We will consider this correlation again in the next section in terms of the sound exposure level.

The simplest form of such a correlation can be demonstrated by applying corrections to the measured takeoff (or simulated takeoff) levels to account for differences, in propeller rpm and distance, from corresponding values for the level flyover condition. For convenience, the latter will be represented by the average measured values, corrected to a 1,000 ft distance, as summarized earlier in Table 4(d).

The results of this process are presented in Table 15. The correlation is quite good for the first two aircraft. As illustrated later, the noise during takeoff of the 172P aircraft appears to be a combination of propeller and exhaust noise so that the flyover noise levels computed from the takeoff tests do not agree as closely with the actual measured values.

Table 15

Illustration of the Correlation Between Measured Takeoff (for Simulated Takeoff) Levels Corrected to Flyover Conditions, and the Average Measured Values

Aircraft	Test Condition -	LA_{Max} [1] dB(A)	$K \log \frac{rpm}{rpm_{ref}}$ [2] dB	LA_{Max} (Flyover) Corrected dB(A)	Measured dB(A)	Δ dB
402C	T/O	82.0	-2.7	79.3	79.8	+0.5
T210	T/O	82.5	-3.2	79.3	79.5	+0.2
	S/C	83.3	-2.8	80.5	79.5	-1.0
172P	T/O	69.6	+7.5	77.1	75.1	-2.0
	S/C	68.9	+7.8	76.7	75.1	-1.6
				Average Δ		-0.8

[1] Measured test level corrected for spreading loss between Test Ht. and Reference Ht. 1,000 ft (from Table 4(d)

[2] Correction, derived from Figure 4, for difference between test rpm and rpm for level flyover.

Nevertheless, the average difference between computed and measured flyover levels is -0.8 dB, illustrating the reasonableness of computing either takeoff or flyover noise levels for propeller-driven small propeller aircraft, given the other value.

4.2 Noise Measurement Considerations

Three different noise metrics were evaluated in the tests described in Appendix B.

- Maximum Sound Level, LA_{Max}
- Sound Exposure Level, L_{AX} (using the ISO terminology)
- Average Sound Level, L_{eq}

The latter measure is reported in the detailed data in Appendix B but is not considered further in this section. It is best used to define the "average" noise level over a defined period of time instead of over a single (aircraft flyby) event whose effective duration can vary with speed or altitude of the aircraft.

The remainder of this section will consider the various aspects involved in measurement of either of the first two noise metrics, LA_{Max} or L_{AX}, the relationship observed between them, and the possible change from LA_{Max} to L_{AX} for noise certification.

4.2.1 Microphone Height

A typical time history of the A-weighted sound level, relative to its maximum value, is shown in Figure 21a) from one of the flight tests described in Appendix B. The plot shows the relative levels measured at the 2.5 km measurement location for both a 1.2 m and 10 m microphone height. The former height is currently required in Appendix F while the latter has received increasing consideration for noise certification measurements of jet-powered aircraft in order to minimize ground reflection problems. As shown in Figure 21(a), the time history of the relative A-weighted sound levels measured for the two microphone heights are in close agreement. However, Figure 21(b) shows how the time history of one-third octave band levels at 250 Hz from this same test exhibits the presence of very large fluctuations in level at the 10 m microphone. These large fluctuations are due to cancellation and reinforcement of the propeller noise harmonic at this frequency by ground reflections. Similar ground reflection anomalies also occur for the 1.2 m microphone, but are at higher frequencies and are lesser in fluctuation amplitude. It therefore appears that ground reflections for propeller noise may actually not be as significant for a 1.2 m microphone height as for a 10 m microphone height. This may be due to the fact that for the 1.2 m height, the frequency spacing between cancellation dips is much larger than for a 10 m height, thereby reducing the occurrence of coincidence with propeller harmonic frequencies. It is possible, however, that in some unique test cases, the cancellation effect may be problematic with a 1.2 m height microphone, depending on whether the aircraft propeller frequencies are "tuned" to the cancellation dip frequencies.

A more detailed comparison of the relative utility of a 10 m vs 1.2 m microphone height is not attempted here. However, it is possible to generalize as follows. Table 16 contains a summary of the average and standard deviations of all the measurements from the flight test program. From examination of this table, one can show the following:

- o The average values of maximum sound levels, LA_{Max}, measured at 1.2 m differed from those at 10 m by a mean value of +0.3 dB $\pm$1.1 dB (the values at 1.2 m were higher).

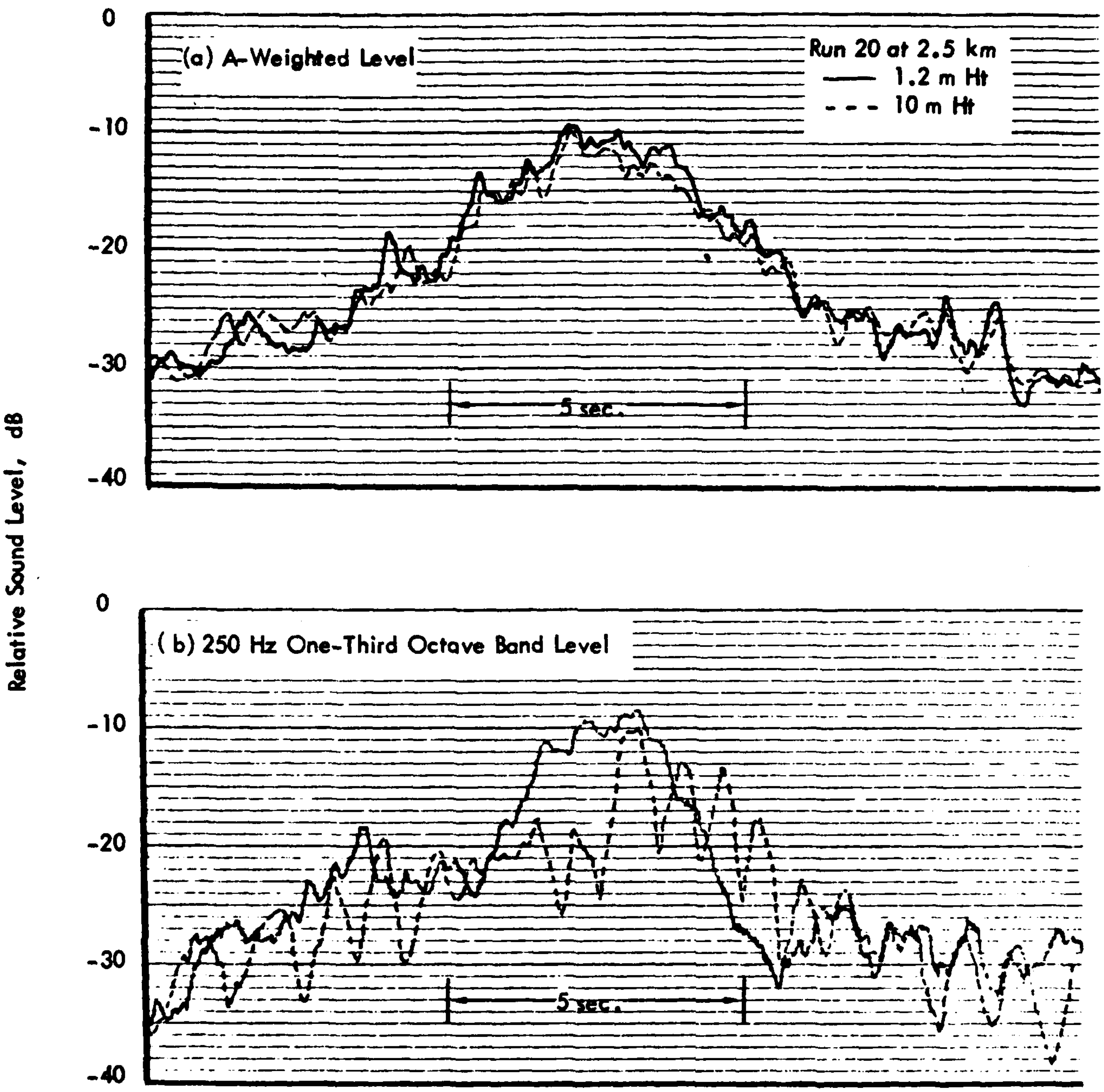


Figure 21. Time Histories of Relative A-Weighted Sound Level (a) and 250 Hz One-Third Octave Band Level (b) at 1.2 m and 10 m Microphone Positions.

Table 16

Summary of Measured Data from Flight Test Program
(see Appendix B)

Condition	Microphone Position km	Microphone Ht. m	Sound Level Parameter	172P LA_{Max} dB(A)	172P L_{AX} dB(A)	T210N LA_{Max} dB(A)	T210N L_{AX} dB(A)	402C LA_{Max} dB(A)	402C L_{AX} dB(A)
LFO	2.0	1.2	$\bar{x}$	-	-	-	-	77.8	83.5
			σ					0.56	0.36
		10	$\bar{x}$	74.4	81.8	76.8	82.3	77.9	83.7
			σ *	0.90	0.92	0.74	0.62	0.65	0.28
	2.5	1.2	$\bar{x}$	74.9	82.0	79.3	84.3	80.3	85.7
			σ	0.22	0.73	1.35	0.85	1.08	0.62
		10	$\bar{x}$	74.6	82.4	77.3	83.8	78.7	85.0
			σ	0.38	0.94	0.90	0.88	0.71	0.45
T/O	2.0	1.2	$\bar{x}$	-	-	87.0	91.8	83.3	89.5
			σ			0.	0.21	1.25	0.56
		10	$\bar{x}$	76.6	85.0	88.8	93.5	83.9	90.4
			σ	0.74	0.50	0.24	0.25	1.02	0.57
	2.5	1.2	$\bar{x}$	74.8	84.3	86.9	92.4	83.7	90.2
			σ	0.56	0.50	0.96	0.66	0.99	0.38
		10	$\bar{x}$	74.8	84.5	86.6	93.2	82.5	90.0
			σ	0.52	0.38	0.65	1.04	0.71	0.46
S/C	2.0	1.2	$\bar{x}$	-	-	-	-	-	-
			σ	-	-	-	-	-	-
		10	$\bar{x}$	69.5	81.4	83.5	89.7	-	-
			σ	0.5	0.2	-	-		
	2.5	1.2	$\bar{x}$	68.5	80.4	83.3	89.6	-	-
			σ	0.5	0.4	0.3	0.7		
		10	$\bar{x}$	67.6	80.6	83.8	90.3	-	-
			σ	0.6	0.35	0.25	0.65		

*Standard Deviation of measured values includes the effect of the variation between runs of height or propeller rpm. This variance is nominally constant with each aircraft type/flight condition block.

- o The corresponding average values of sound exposure level differed by -0.2 dB ±0.5 dB (i.e., the values at 1.2 m were lower).
- o The average standard deviations of these noise metrics were 0.71 dB and 0.60 dB for LA_{Max} at 1.2 m and 10 m, respectively (not significantly different), and 0.54 dB and 0.57 dB for L_{AX} at 1.2 m and 10 m, respectively.

Thus, the noise levels measured at 10 m appear to have approximately the same variability as those at 1.2 m and a very slightly lower maximum sound level – a result that is not inconsistent with previous observations.[48]

More detailed considerations of the effect of microphone height are also reported in References 49 and 50.

Before leaving this topic of ground reflections, attention is drawn to Figure 22 which shows an overlay of the time histories of the A-weighted sound levels from two successive flights of the 402C two-engine aircraft as measured at 2.5 km with a 1.2 m microphone height. The plot of relative levels for the second run (#7) was adjusted, vertically, so as to coincide with the first run, *during the* period of build-up and fall-off from the peak values. Note that this second record

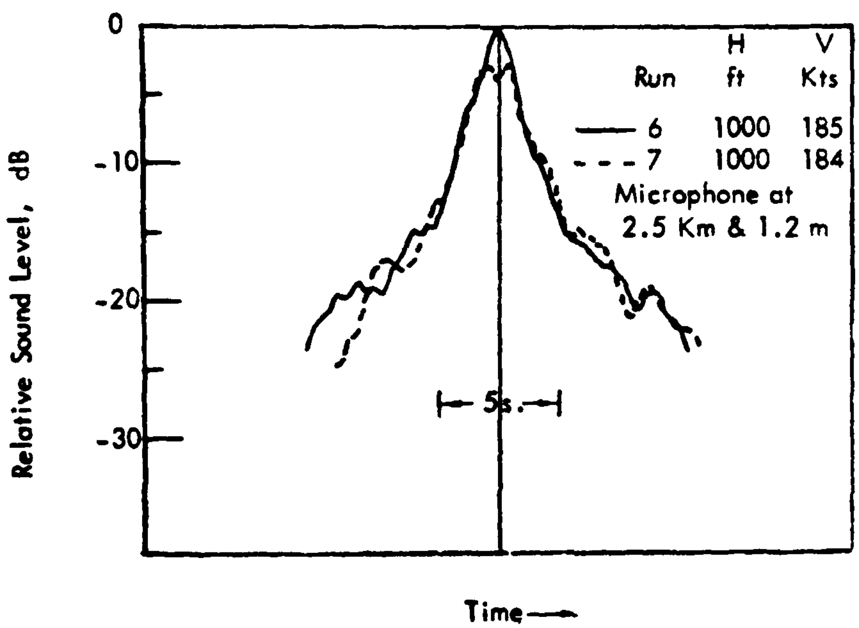


Figure 22. Illustration of Possible Phase Cancellation Effect, at a 1.2 m Microphone Height, for a Two-Engine Propeller Aircraft Level Flyover at 1,000 ft

shows a distinct dip in the peak level. The implication is that the combination of a ground reflection pattern and phasing of the two propeller signals served to cause this dip in the maximum sound level for the second test. This is confirmed by the measured data observed for this pair of tests as follows.

	LA_{Max}, dB	L_{AX}, dB
Run 6	81.0	86.0
Run 7	80.0	85.9

Thus, the time-integrated levels are nearly identical for the two runs while the maximum values differ by 1.0 dB for these tests. This dip in time history at the nominal point of maximum level was observed in four out of the nine level flyovers for this aircraft but did not appear on any of the six takeoff flights.

In summary, there is not any substantial justification for changing from a 1.2 m to a 10 m microphone height based on the results of the tests reported here.

4.2.2 Instrumentation for the Measurement of Maximum Sound Level or Sound Exposure Level

Two types of instrumentation were utilized in the flight tests for this program:

- o Direct reading integrating sound level meters with (GenRad 1988) or without (Bruel & Kjaer 2218) a "maximum level" feature to hold the value of the maximum sound level for convenient readout of LA_{Max}. Both types of meters provide a digital readout of sound exposure level and integration time. Such meters have been defined as integrating-averaging sound level meters in a current draft standard for such instruments.[51] The GenRad unit was more convenient to use for those aircraft noise flyover measurements in two respects:

  1) The holding feature allowed the maximum level to be read, easily and unambiguously, to within 0.1 dB.

  2) The GenRad meter also read integration time to the nearest second as opposed to a reading to the nearest 0.001 hour (3.6 sec) for the Bruel & Kjaer model.

- o Tape-recorded data, using high quality (Nagra Model SJ) tape recorders and subsequent tape analysis into an integrating sound level meter to read for LA_{Max} or L_{AX}, a spectrum analyzer for spectral content, or graphic level recorder to observe the time history. While this type of instrumentation was highly desirable for the type of exploratory measurements carried out for this program, it is not absolutely required for routine noise certification. However, as a reliable record of the field measurements, such a recording is invaluable and should be acquired whenever possible.

Table 17 lists additional details on many of the other sound level meters currently available on the market. Most of the other manufacturers – Metrosonics, Monarch, Quest, and Digital Acoustics – make integrating sound level meters. One potentially useful feature for such integrating sound level meters, which is available on only a few models, is an adjustable or fixed internal threshold setting. This establishes a minimum sound level, below which the integration circuit does not operate so that one measures, in effect, only that part of the sound energy on a given single event that lies above the threshold level.

For the GenRad and Bruel and Kjaer units utilized in this program, there apparently is no such internal threshold which cuts off the integrator. Thus, if these meters were placed in a very quiet location where the acoustic ambient noise level was below the internal electrical background noise of the instrument, they would integrate this internal noise, and register an output reading corresponding *only to this internal noise. However, this is not necessarily* a handicap since this feature can be used as a means of checking on the internal noise floor to verify the integrity of any actual measured noise event.

Furthermore, an additional means of counteracting any potential errors associated with integration of the meter's internal noise floor is provided by at least one model (GenRad 1988). This model indicates when the measured sound level falls below the internal noise floor more than about 1 percent of the time while the meter is integrating the sound exposure level. Finally, a more general safeguard against any significant errors in the output of an integrating sound level meter due to its internal noise floor is expected to be included in the performance standard for such meters.[51] This is expected to require that the lowest sound level for which the meter can be used, reliably, will be defined so as to ensure accurate readings of sound exposure level within the meter's specified tolerance requirements.

With this general background on the instrumentation aspects of the noise measurement, consider now the more detailed evaluation carried out in this program concerning the measurement of sound exposure level of small propeller aircraft flyovers.

Table 17

Partial List of Available Integrating and Nonintegrating Sound Level Meters

Manufacturer and Address	Model	Type	Microphone Size and Type	Display	Weighting						Response: Impulse(I) Peak (P) Hold (H)	Display Range (dB), Type*	Output		Price	Special Features
					A	B	C	D	Lin	Octave Filter			AC	DC		
B&K Instruments, Inc. 5111 W. 164th Street Cleveland, OH 44142 (Tel: 216/267-4800)	2203	1	1/2-Inch Condenser	Analog	X	X	X		X			20, Log	X		$1,665	Model 301 set contains: 2203 SLM; 1613 octave filter set; 4220 pistonphone; 43665 accelerometer set; and Accessories. $5,304. Model 309 set contains all of the above except a 1616 one-third octave filter set is substituted for the octave filter set. $7,108.
	2206	1	1/2-Inch Condenser	Analog	X		X					20, Log	X		$1,424	
	2209	1	1/2-Inch Condenser	Analog	X	X	X	X	X		PH IH	20, Log	X	X	$2,412	Model 307 set contains: 2209 SLM; 1613 octave filter set; 4220 pistonphone; 43665 accelerometer set; and Accessories. $5,984. Model 311 set contains all of the above except a 1616 one-third octave filter set is substituted for the octave filter set. $7,788.
	2210	1	1/2-Inch Condenser	Digital	X	X	X	X	X		PH IH	90, Lin	X	X	$5,950	

* Display Range Types: Log = logarithmic scale; Lin = linear scale.

Table 17 (Continued)

Manufacturer and Address	Model	Type	Microphone Size and Type	Display	Weighting A	B	C	D	Lin	Octave Filter	Response: Impulse(I) Peak (P) Hold (H)	Display Range (dB), Type*	Output AC	DC	Price	Special Features
B&K Instruments, Inc. 5111 W. 164th Street Cleveland, OH 44142 (Tel: 216/267-4800)	2215	1	1/2-Inch Condenser	Analog	X		X			X		30, Lin	X	X	$2,217	
	2218	1	1/2-Inch Condenser	Analog/ Digital	X						PH I	50, Lin	X	X	$3,258	Digital L_{eq} Display and single-event exposure level.
	2219	2	1/2-Inch Condenser	Analog	X							20, Log			$ 505	
	2225	2	1/2-Inch Prepolarized Condenser	Analog	X						PH	40, Lin		X	$ 921	"Thermometer" Display; computes 60 sec L_{eq}.
	2226	2	1/2-Inch Prepolarized Condenser	Analog	X						IH	40, Lin		X	$ 969	"Thermometer" Display; computes 60 sec L_{eq}.
GenRad Concord, MA 01742 (Tel: 617/779-2825)	1565-D	2	1-Inch Electret Condenser	Analog	X	X	X					20, Log			$ 470	Model 1565-9910 set contains: 1565-D SLM; 1987 sound level calibrator; and Accessories. $670.
	1933	1	1/2-Inch and 1-Inch Electret Condenser	Analog	X	X	X		X	X	P I	20, Log	X	X	$3,405	Model 1933-9714 set contains: 1933 SLM; 1935 cassette data recorder; 1562 sound level calibrator; and Accessories. $4,005.
	1981	1	1/2-Inch Electret Condenser	Analog/ Digital	X						PH	50, Lin	X	X	$1,345	Model 1981-9750 set contains: 1981 SLM; 1567 sound level calibrator; and Accessories. $1,995.

* Display Range Types: Log = logarithmic scale; Lin = linear scale.

Table 17 (Continued)

Manufacturer and Address	Model	Type	Microphone Size and Type	Display	Weighting A	B	C	D	Lin	Octave Filter	Response: Impulse(I) Peak (P) Hold (H)	Display Range (dB), Type*	Output AC	DC	Price	Special Features
GenRad Concord, MA 01742 (Tel: 617/779-2825)	1982	1	1/2-Inch Electret Condenser	Analog/ Digital	X	X	X		X	X	I PH	50, Lin	X	X	$1,995	Model 1982-9720 set contains: 1982 SLM; 1562-A sound level calibrator; and Accessories $2,680
	1988	1	1/2-Inch Electret Condenser	Digital/ Analog	X	X	X		X	X	IH PH	50, Lin			$2,950	Computes L_{eq}, L_{max}, and test duration.
Metrosonics, Inc. P.O. Box 23075 Rochester, NY 14692 (Tel: 716/334-7300)	dB-306	2	1/4-Inch Ceramic	Digital Digital	X						PH	64, Lin			$1,200	Computes L_{eq}, L_{max}, and test duration. (Threshold setting for L_{eq} available.)
IVIE Electronics, Inc. 500 W. 1200 South Orem, Utah 84057 (Tel: 801/224-1800)	IE-30A	1	1/2-Inch Electret Condenser	Digital	X		X		X	X	I PH	15, Lin			$3,395	Also includes one-third octave filter.
	IE-10A	2	3/4-Inch Electret Condenser	Digital	X		X			X		15, Lin			$ 750	
Monarch Internat'l, Inc. Columbia Drive Amherst, NH 03031 (Tel: 603/883-3390)	CEL-175	1	1/2-Inch Condenser	Analog	X				X		PH	30, Lin	X	X	$1,795	Computes L_{eq}.
	CEL-187	1	1/2-Inch Condenser	Analog	X				X		PH	30, Lin			$1,255	
	CEL-283	2	1-Inch Ceramic	Analog	X							30, Lin			$ 695	Computes L_{eq}.
	CEL-193	1	1/2-Inch	Analog	X	X	X		X	X	I PH	30, Lin	X	X	$2,375	Computes L_{eq}.
	CEL-214	2	1-Inch Ceramic	Analog	X				X		I PH	40, Lin			$ 295	
	NA-14	2	1-Inch Ceramic	Analog	X						PH	40, Lin			$ 395	

* Display Range Types: Log - logarithmic scale; Lin - linear scale.

Table 17 (Continued)

Manufacturer and Address	Model	Type	Microphone Size and Type	Display	Weighting						Response: Impulse (I) Peak (P) Hold (H)	Display Range (dB), Type*	Output		Price	Special Features
					A	B	C	D	Lin	Octave Filter			AC	DC		
Quest Electronics 510 S. Worthington St. Oconomowoc, WI 53066 (Tel: 414/567-9157)	228	2	1/2-Inch Ceramic	Digital	X							40, Lin	X	X	$ 825	Computes Leq. Model 228-12 set contains: 228 SLM; CA-12 calibrator; and Accessories. $980.
	214	2	1-Inch Ceramic	Analog	X							20, Log			$ 320	Model 214-12 set contains: 214 SLM; CA-12 calibrator; and Accessories. $475.
	211 FS	2	1-Inch Ceramic	Analog	X		X					20, Log			$ 280	Model 211FS-12 set contains: 211 FS SLM; CA-12 calibrator; and Accessories. $435.
	211A	2	1-Inch Ceramic	Analog	X							20, Log			$ 240	Model 211A-12 set contains: 211A SLM; CA-12 calibrator; and Accessories. $395.
	215	2	1-Inch Ceramic	Analog	X	X	X					20, Log			$ 415	Model 215-12 set contains: 215 SLM; CA-12 calibrator; and Accessories. $570.
Columbia Research Laboratories, Inc. 1925 MacDade Blvd. Woodlyn, PA 19094 (Tel: 215/532-9464)	SPL-204	2	1-Inch Electret	Analog	X	X	X					20, Log			$ 425	Model SPL-204-14 set contains: SPL-204 SLM; SPC-14 acoustic calibrator; and Accessories. $775.

* Display Range Types: Log = logarithmic scale; Lin = linear scale.

Table 17 (Continued)

Manufacturer and Address	Model	Type	Microphone Size and Type	Display	Weighting						Response: Impulse(I) Peak(P) Hold(H)	Display Range (dB), Type*	Output		Price	Special Features
					A	B	C	D	Lin	Octave Filter			AC	DC		
Digital Acoustics, Inc. 1415 McFadden, Suite F Santa Ana, CA 92705 (Tel: 714/835/4884)	DA607-P	1	1/2-Inch Electret	Digital/ Analog	X		X		X			120, log	X	X	$8,000 (Approx.)	Computes L_{eq} and SEL, has threshold setting for SEL
	DA605	1	1/2-Inch Electret	Digital/ Analog	X		X		X			120, log	X	X	$4,000 (Approx.)	Same features (both units require mic. and calibrator extra)

* Display Range Types: Log = logarithmic scale; Lin = linear scale.

4.2.3 Measurement of L_{AX} Using Direct-Read Integrating Sound Level Meters

The definition of the single event exposure level, L_{AX}, as given by International Standard ISO 3891-1978(E), "Acoustics – Procedure for Describing Aircraft Noise Heard on the Ground," is

$$L_{AX} = LA_{Max} + \Delta A$$

where

LA_{Max} is the maximum A-weighted sound level, and

ΔA is a duration allowance which accounts for the time history of the noise event between the first and last instants at which the noise level is 10 dB below LA_{Max}.

In effect L_{AX} is the 1 second equivalent energy noise level obtained by time integration of L_A between the so-called "10 dB down points."

Direct-read integrating sound level meters provide a measurement of this 1 second equivalent energy level for either a preselected time period, or for a time period between manually activated start and stop instants. In both cases, the integration period is stored (and can be displayed) with the L_{AX} value. The problem of direct read, field evaluations of L_{AX} for aircraft flyover noise events is simply that there is no prior knowledge of the first 10 dB down point. The following information has been derived from tape-recorded histories of noise of three different aircraft in different flyover modes of operation.

Figure 23 illustrates a typical time history of L_A during an aircraft flyover event. The time history commences at some preselected marker station, e.g., brake release for a takeoff case or overflight of a runway reference point for level flight cases, and ends at the 10 dB down point after LA_{Max}.

Table 18 shows values of L_{AX} obtained by allowing the time integration process to commence at (a) a marker point well in advance of the noise event, (b) at 10 second intervals after the marker point, and (c) at the first instant at which L_A is within 10 dB of LA_{Max}. In all cases, the integration ended at the instant the sound level had diminished by 10 dB after LA_{Max}.

In addition, the table shows the time, in seconds, between the 10 dB down points (corresponding to the reference value of L_{AX}), the value of LA_{Max} during

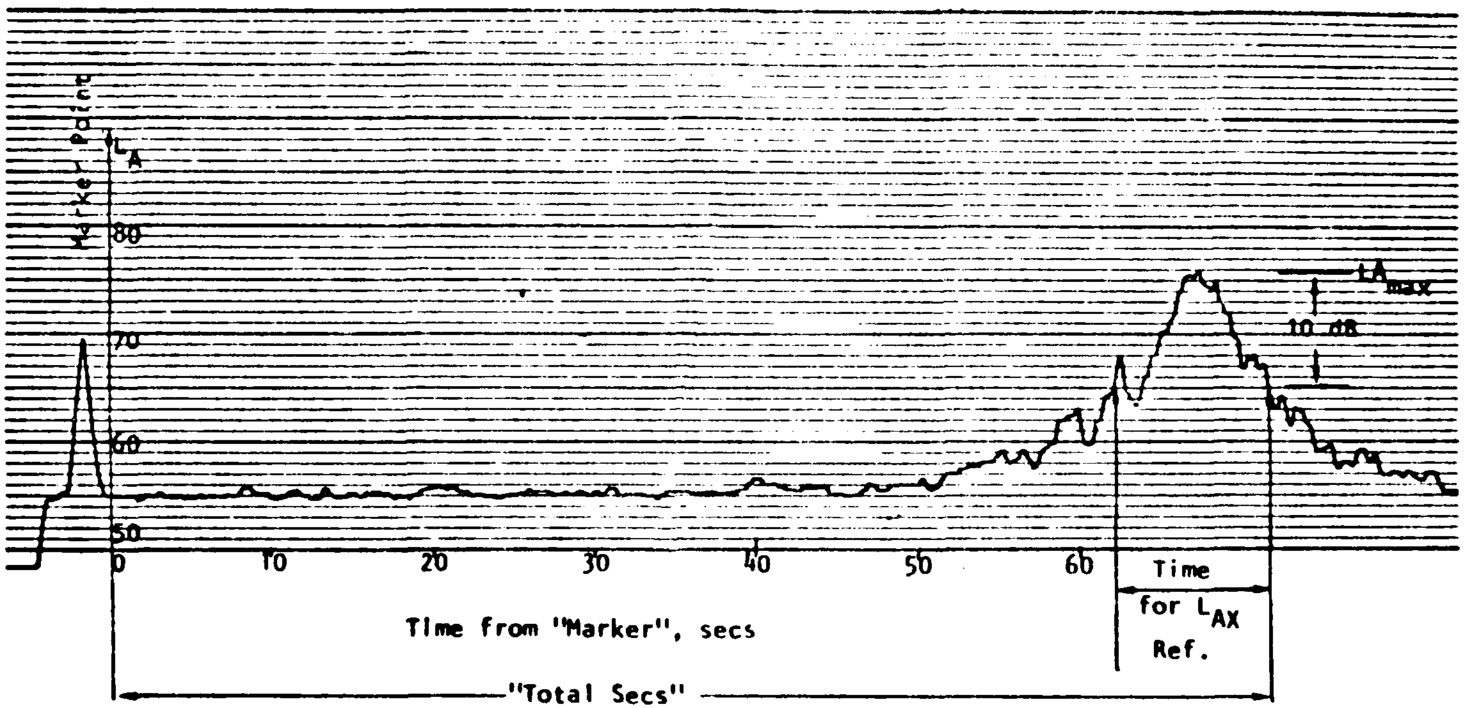


Figure 23. Illustrative Example of Time History of A-Weighted Sound Level for Aircraft Flyover

Table 18

Values of L_{AX} Obtained by Time Intregration Over Different Periods, Ending at 10 dB Down Point after LA_{Max}

(Measured at 2.5 km from brake release; microphone at 1.2 m height)

Aircraft Type	Flight Profile	L_{AX}, based on Different Integration Start Times, dB(A) — Start of Integration, secs after Marker Point[1]									Ref. Values[2]		L_A Max	Total[3] Dur.	L_A[4] Amb.
		0	10	20	30	40	50	60	70	80	L_{AX}	Secs			
172P	V_y Takeoff	84.2	84.2	84.2	84.2	84.2	84.2	84.1	84.1		83.9	20	75.0	96	48.0
	1000 ft Level Flyover	82.6	82.4	82.3	82.3	82.3	82.2	82.1			81.9	12	74.5	77	50.0
	V_y Climb through 1000'	79.5	79.5	79.5	79.4	79.3	79.2				79.1	40	68.0	92	51.0
T210N	V_y Takeoff	92.4	92.4	92.4	92.3	92.3	92.3	92.3			91.8	8	86.5	75	55.0
	1000 ft Level Flyover	85.0	85.0	84.9	84.9	84.8					84.6	7	79.0	52	52.0
	V_y Climb through 1000'	89.4	89.4	89.4	89.4	89.3					89.0	9	83.5	58	51.0
402C	V_y Takeoff	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.2	10	84.5	93	52.0
	1000 ft Level Flyover	85.6	85.6	85.6	85.5	85.5	85.3				85.2	9	80.0	60	53.0

Notes:
1 Brake release for takeoff cases; runway marker for flyover cases.
2 L_{AX} and Integrating Time for period between 10 dB down points (i.e., 10 dB re LA_{Max})
3 Total time from marker point to 10 dB down point after LA_{Max}
4 Ambient noise level before test.

the flyover event, the total duration, in seconds, of the aircraft flyover from the marker point to the last 10 dB down point, and the ambient noise level just prior to the flyover.

Table 18 was derived by analysis of tape-recorded sound histories acquired at a measurement site using the 1.2 m microphone, 2.5 km from a brake release marker point on the takeoff runway, and on the extended centerline of the takeoff runway.

Four different methods of obtaining L_{AX} values in the field, by means of direct-read integrating sound level meters, were used for comparison purposes in Table 19, based on the data shown in Table 18. The differences between the L_{AX} values obtained by these methods, relative to the L_{AX} value for the period between the 10 dB down points, are also shown in Table 19.

Additionally, an approximate evaluation of L_{AX}, as described in ISO 3839- 1978(E), is compared with the reference L_{AX} value.

The Table 19 values of L_{AX} are described as follows:

<u>Column 1: L_{AX} (Ref)</u>

These values of L_{AX} are for the period between the 10 dB down points, and can only be obtained by subsequent analysis of data records.

<u>Column 4: L_{AX} from Marker</u>

These L_{AX} values can be obtained directly in the field by commencing time integration at the instant of brake release for a takeoff event (or at the instant of flyover of the brake release marker point for other flight profiles). Time integration is (manually) stopped, after the occurrence of LA_{Max}, when the A-weighted sound level is 10 dB below LA_{Max}. It should be noted that this may not always be the "last instant" at which L_A is 10 dB below LA_{Max}.

<u>Column 5: L_{AX} from 20 seconds after Marker</u>

These values of L_{AX} can also be obtained directly in the field by commencing integration 20 seconds after the above-mentioned "marker point" instant. The objective of delaying the integration start is simply to reduce the period of ambient noise integration.

Table 19

Comparison of Methods for the Evaluation of L_{AX} for Aircraft Flyover Noise Events

		1	2	3	4	5	6*	7*	8**	Error, dB re L_{AX} (Ref.)				
Aircraft Type	Flight Profile	L_{AX} (Ref)	L_A Max	L_{eq} Amb.	L_{AX} from Marker	L_{AX} from 20 secs after Marker	L_{AX} from Col.(4) - L_{AX} Amb	L_{AX} from Col.(5) - L_{AX} Amb	L_A Max + Δ_A	From Col. (4)	From Col. (5)	From Col. (6)	From Col. (7)	From Col. (8)
172P	Takeoff	83.9	75.0	48	84.2	84.2	84.1	84.1	85.0	0.3	0.3	0.2	0.2	1.1
	Level	81.9	74.5	50	82.6	82.3	82.4	82.2	82.3	0.7	0.4	0.5	0.3	0.4
	Climb	79.1	68.0	51	79.5	79.5	79.1	79.0	81.0	0.4	0.4	0.0	-0.1	1.9
T210N	Takeoff	91.8	86.5	55	92.4	92.4	92.3	92.4	92.5	0.6	0.6	0.5	0.6	0.7
	Level	84.6	79.0	52	85.0	84.9	84.9	84.8	84.4	0.4	0.3	0.3	0.2	-0.2
	Climb	89.0	83.5	51	89.4	89.4	89.4	89.4	90.0	0.4	0.4	0.4	0.4	1.0
402C	Takeoff	90.2	84.5	52	90.5	90.5	90.4	90.5	91.5	0.3	0.3	0.2	0.3	1.3
	Level	85.2	80.0	53	85.6	85.6	85.4	85.5	86.5	0.4	0.4	0.2	0.3	1.3
						Mean Error				0.44	0.39	0.29	0.28	0.94
						Standard Deviation of Error				0.14	0.10	0.17	0.20	0.64

Notes:

*In Cols. 6 and 7, energy subtraction is used and $L_{AX}(\text{Amb}) = L_{eq}(\text{Amb}) + 10 \log_{10} T_{int}$

**Col. 8 uses ISO approximate method. $\Delta_A = 10 \log_{10} \left(\frac{t_2 - t_1}{2} \right)$

Column 6: $L_{AX} = L_{AX}$ (Col. 4) - L_{AX} (ambient)

This method of evaluating L_{AX} can be performed in the field by obtaining

a. L_{eq} (ambient)

b. L_{AX}, the direct read value over the integration period, and

c. T_{int}, the integration time, in seconds, corresponding to L_{AX}.

These values can be obtained directly from integrating sound level meters.

The corrected value of L_{AX} is given by

$$L_{AX} = 10 \log_{10} \left[10^{\frac{L_{AX}(m)}{10}} - 10^{\frac{L_{AX}(amb)}{10}} \right] \text{, dB}$$

where

$L_{AX}(m) \quad = \quad L_{AX}$ (measured), and

$L_{AX}(amb) \quad = \quad L_{eq}(\text{ambient}) + 10 \log_{10} (T_{int}/1)$, dB

The L_{AX} values in Column 6 are based on the measured L_{AX} and T_{int} values obtained by commencing integration at the marker point.

Column 7: $L_{AX} = L_{AX}$ (Col. 5) - L_{AX} (ambient)

The procedure for evaluating L_{AX} in Column 6 is repeated for Column 7 except that the values of L_{AX} and T_{int} are those obtained by commencing integration 20 seconds after the marker point.

Column 8: $L_{AX} = LA_{Max} + \Delta_A$

This method of obtaining an approximate value of L_{AX} is described in ISO 3891-1978(E) and can be employed in the field if a time history trace of L_A is acquired. In the approximate method, the value of LA_{Max} is corrected by a factor Δ_A given by:

$$\Delta_A = 10 \log_{10} \left(\frac{t_2 - t_1}{2}\right)$$

where

$t_2 - t_1$ is the time period, in seconds, between the first and last instants at which L_A is within 10 dB of LA_{Max}.

The approximate resulting value of L_{AX} is therefore based on the assumption that the time history "shape" is symmetrically triangular about the LA_{Max} instant.

Error evaluations are shown in the last five columns of Table 19. These errors are simply the differences between the L_{AX} values obtained by the above methods, relative to the reference L_{AX} values in Column 1.

To summarize, it is evident from the example cases shown in Table 19 that it is beneficial to reduce and/or account for the effect of ambient noise in evaluating L_{AX} by direct field measurement procedures. It is also evident that the ISO method for obtaining an approximate value of L_{AX} is inferior to those which employ direct read integrating sound level meters.

For future possible regulatory purposes of obtaining a valid measurement of L_{AX} for small propeller-driven aircraft, the following should be considered:

a. The minimum period of time integration should include the period between the first and last instants at which L_A is within 10 dB of LA_{Max}.

b. Measurement of L_{AX} should include a measurement of the integrating period over which the L_{AX} evaluation is obtained.

c. A measurement of ambient noise, L_{eq}, dB(A), should be obtained before and after the aircraft flyover event.

d. Corrections to the measured value of L_{AX}, to account for ambient background noise, may be made provided such corrections do not exceed some specified amount (e.g., 0.5 dB). Such corrections should be based on the measured values of L_{AX}, T_{int}, and L_{eq} (ambient) as described in this section.

4.2.4 Conversion Between LA_{Max} and L_{AX} for Level Flyover or Takeoff Noise Tests

It was shown earlier how it was possible to convert the maximum sound level measured under the takeoff path to the maximum level underneath the aircraft for a level flyover. The conversion process simply corrected for the error in source level due to differences in propeller rpm and for spreading loss, due to differences in aircraft height over the measurement point. Consider now an additional conversion – between maximum sound level and sound exposure level –

for either level flyover or takeoff and, hence, conversion from LA_{Max} for level flyover to L_{AX} for takeoff (or vice versa).

To develop the conversion algorithms, several analyses were made. First, the time histories for each of the flights, as measured at 2.0 and 2.5 km with the 1.2 m microphone height, were collected and time histories for all similar flight test conditions superimposed, as illustrated in Figure 24, relative to the level and time of the maximum level. For each of these composite time histories of relative level, a smooth line was drawn through the data and "data" points read from each of these average curves to define an average relative time history for each case.

The resulting average relative time history "data" are shown in Figure 25. Now assume, for a first approximation, that the maximum sound level is observed when the aircraft is nearly overhead. This is a reasonable assumption since published data indicate the maximum A-weighted level for flyover of small propeller aircraft actually occurs at an angle of about 5^{o} past directly overhead.[52] One can then normalize these various time histories to a single reference aircraft height and speed. Reference values of 1,000 ft and 160 kts (270 ft/sec) were employed for convenience. Neglecting the 5^{o} shift from directly overhead for LA_{Max} involves a time error of about 0.3 seconds for the reference height and altitude. The normalization process simply consists of changing the time t for each data set to a normalized time t' given by

$$t' = t(\bar{V}/270)/(\bar{H}/1{,}000), \text{ sec}$$

where $\bar{V}, \bar{H}$ = the average true airspeed, in ft/sec, and aircraft height, in ft, respectively, for the averaged time history.

In addition to the preceding assumption about the directivity of the propeller noise, this normalization of the time scale also assumes that atmospheric attenuation is negligible and need not be considered in scaling the time history.

The result of applying this scaling process to the raw averaged time histories in Figure 25 is shown by the data in Figure 26. The collapse of the relative time history data for the flyover and takeoff tests is quite satisfactory except for the 172P aircraft on takeoff. As indicated earlier, the propeller rpm for this aircraft is lower on takeoff than during level flight and it is believed that this resulted in a strong influence of engine exhaust noise which has a much broader

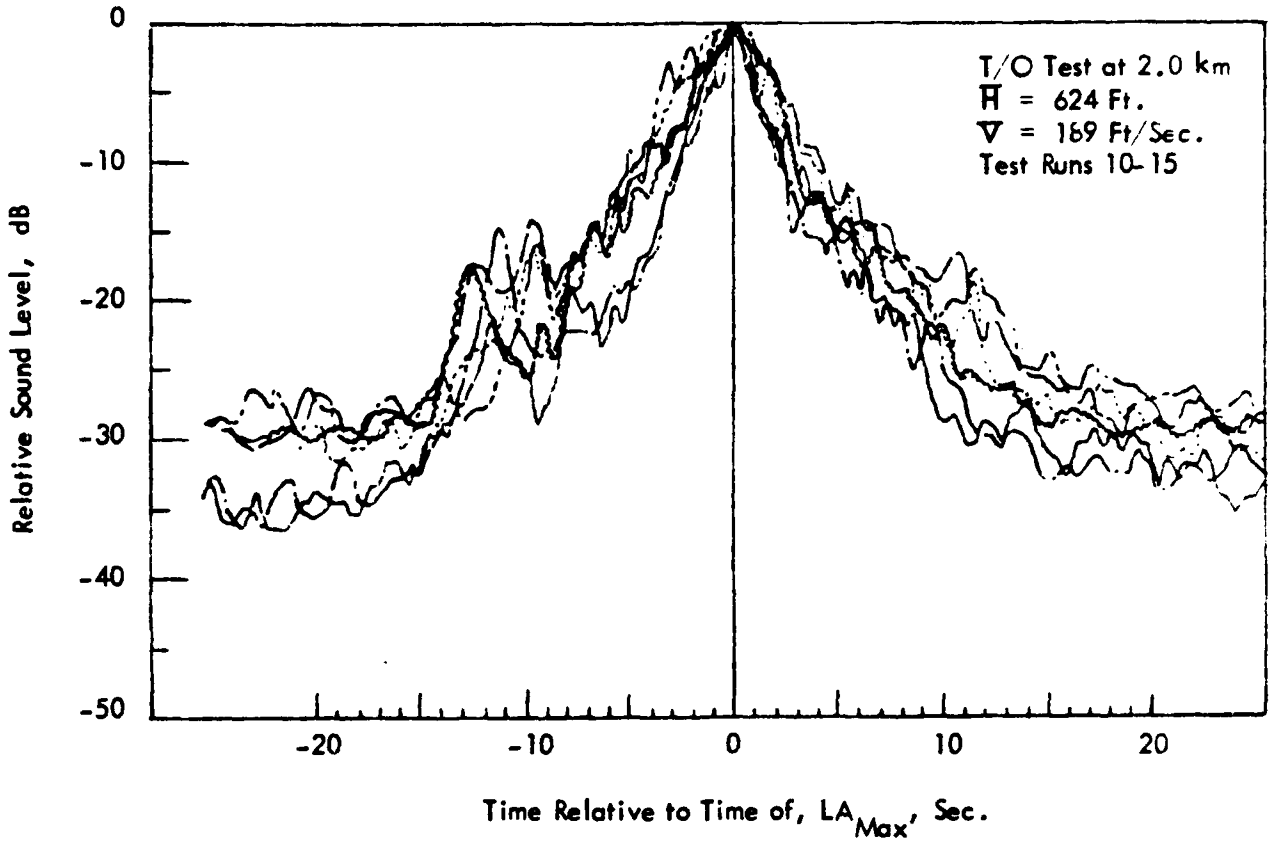


Figure 24. Overlay of Relative Time Histories of A-Weighted Sound Level Observed at 2.0 Km from Brake Release for 402C Aircraft During Takeoff Tests.

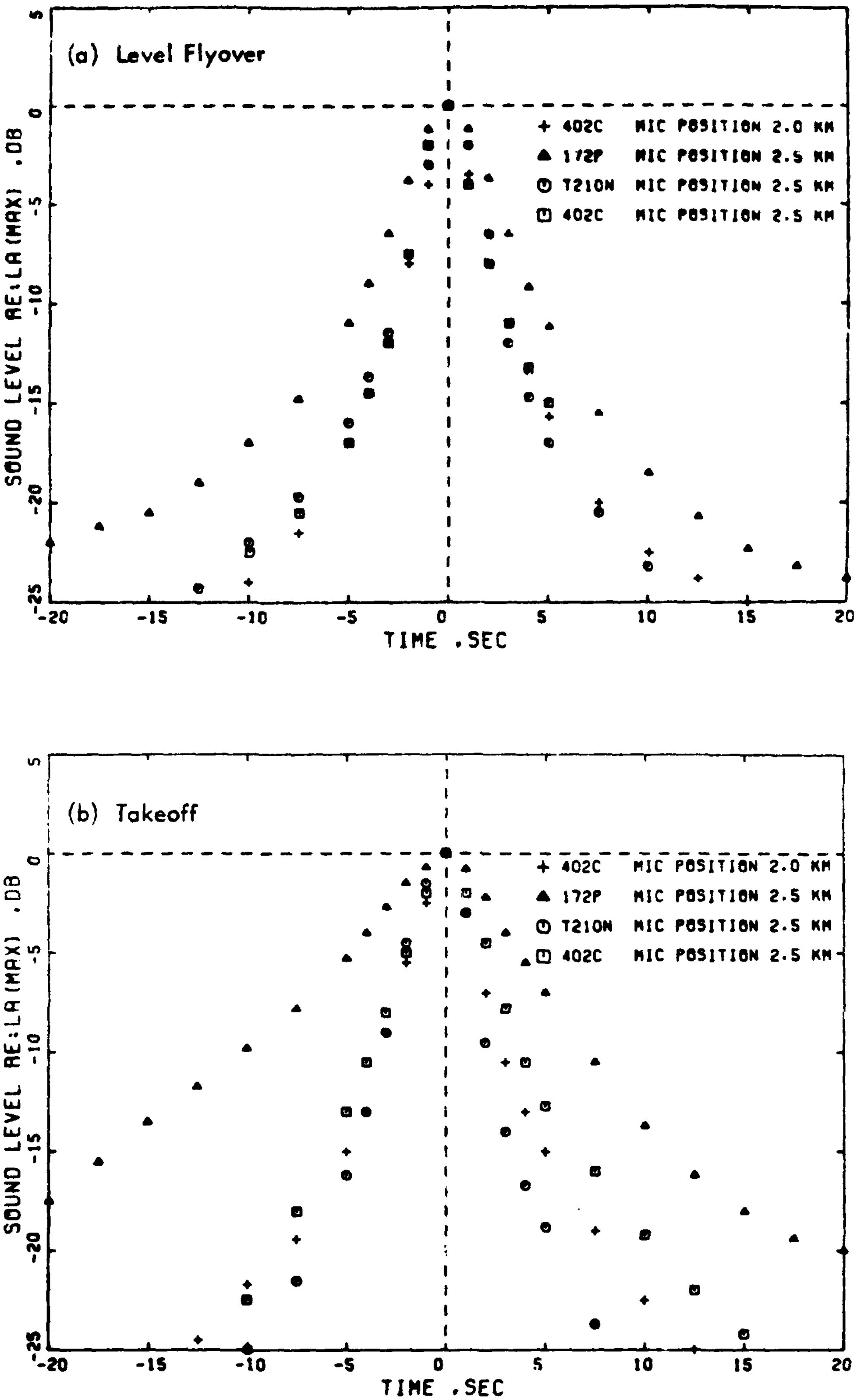


Figure 25. Average Relative Time Histories of Sound Levels Measured for a) Level Flyover and b) Takeoff Tests.

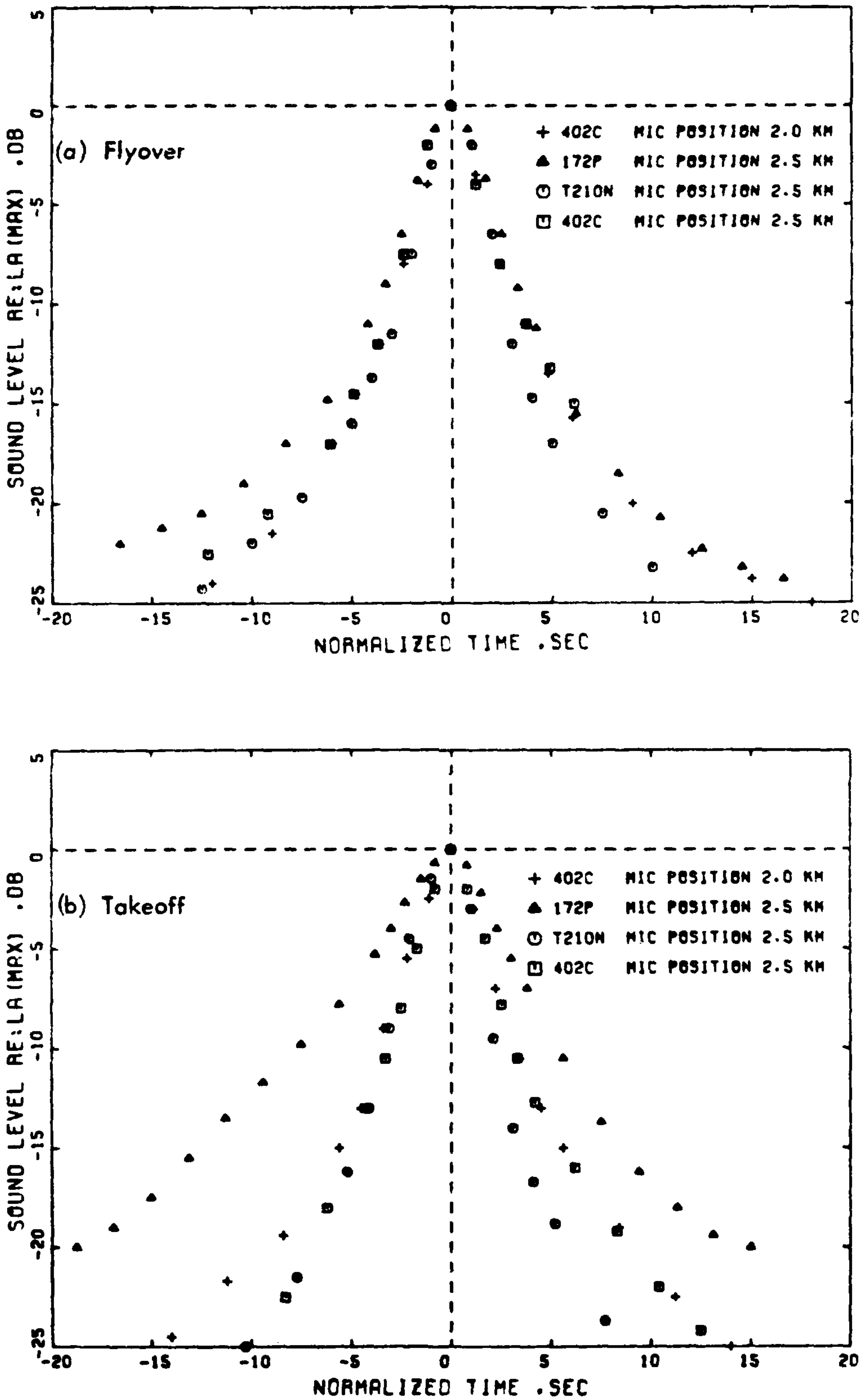


Figure 26. Normalized Time Histories Based on Scaling the Data from Figure 25 to a Reference Distance of 1,000 Ft. and Speed of 160 kts (270 Ft/sec.).

directivity pattern approaching that of a monopole. Excluding the data for the 172P takeoff time history, it was possible to construct a single curve through the remaining data in both Figure 26(a) and (b) to represent a normalized time history of the A-weighted sound level, relative to the maximum value. This empirical curve is shown in Figure 27. Also shown on this figure are the data points from Figure 26(a) and (b) for the normalized average flyover and takeoff time histories of the 402C aircraft as measured at the 2.5 km point with the 1.2 m microphone. The excellent collapse of the data, when time is normalized by the simple linear model invoked above, is quite evident.

While the curve in Figure 27 is based only on the 35 flights conducted for the three aircraft types tested in this program, it is believed to provide a good first approximation to the time history of A-weighted sound levels for takeoff or level flyover at high power for most propeller-driven small aircraft. Again, the exception is the propeller-driven small aircraft with a fixed-pitch propeller optimized for cruise. Since takeoff levels for such aircraft are also expected to be lower than flyover levels at the same distance, the takeoff condition should not be significant for regulatory purposes anyway. Thus, with this one exception, the average line on Figure 27 is proposed as a preliminary model for converting from maximum A-weighted sound level, LA_{Max} to sound exposure level, L_{AX}, for purposes of regulatory action, for propeller-driven small aircraft. Refinement in this model would be desirable based on a broader data sample.

It must be emphasized again that this proposed approach is based on an ideal inverse square spreading law for sound propagation losses inherent in the simple linear time-scaling law outlined above. However, this is considered to be a satisfactory approximation for the range of propagation distances involved in converting LA_{Max} to L_{AX} for measurements at 1,000 ft under a level flight or at 2.5 km from brake release where aircraft altitudes are expected to fall typically in the range of 500 to 1,500 ft. Based on the normalized time history in Figure 27, with a reference distance of 1,000 ft and reference speed of 160 kts (270 ft/sec), the "10 dB down" points occur at an angle approximately $\pm 45^{o}$ from vertical (ignoring the small bias of about 5^{o} in the position of maximum levels from an overhead position). As indicated by the following sketch, a correction for changes in air absorption loss when converting a time history for a 1,500 ft overhead height to a time history for a 1,000 ft distance would involve a change in levels at the "10 dB down" points due to air absorption over a distance of R_2-R_1 = 700 ft.

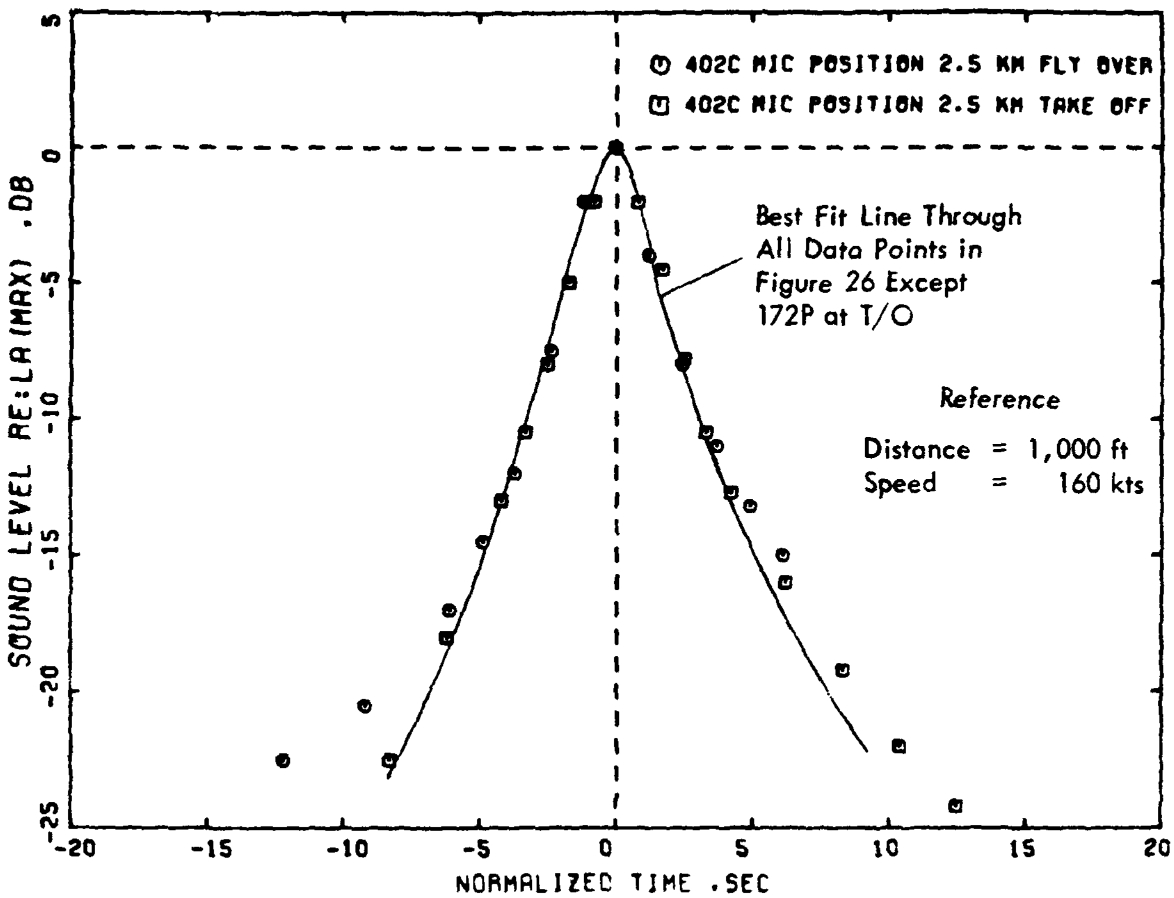


Figure 27. Average Normalized Time History of Relative A-Weighted Sound Levels for Propeller-Driven Small Aircraft During Takeoff or Level Flyover Tests at Noise Certification Power Conditions.

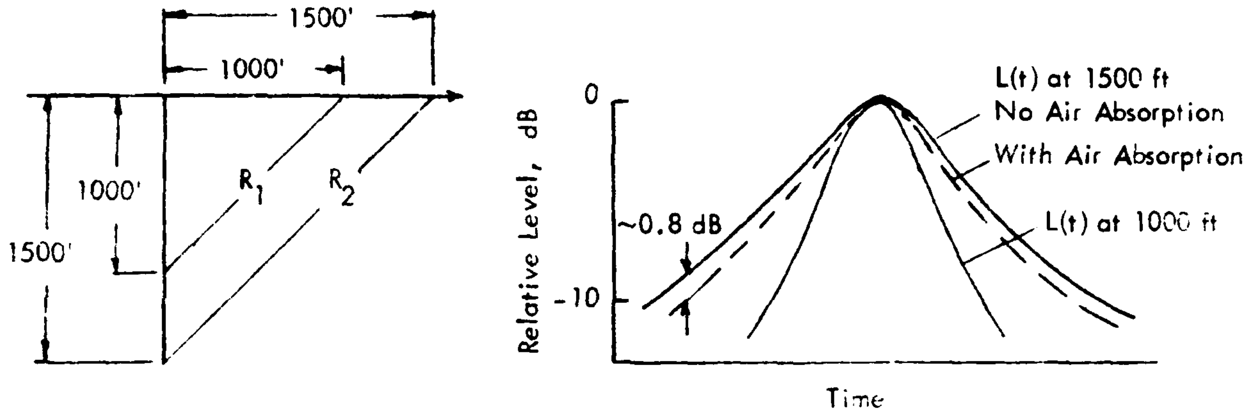


Illustration of Small Error in Time History of Level, L(t), if Air Absorption is Ignored When Converting from Level at 1,500 ft Flyby to Level at 1,000 ft Flyby.

Based on a typical effective value of about 1.1 dB per 1,000 ft for the value of air absorption loss for A-weighted propeller aircraft spectra,[11] this would represent a change in level at the 10 dB down point of about 0.8 dB. While this small change in level is not accounted for by the simple linear time-scaling model implied in Figure 27, the resulting error in sound exposure level is estimated to be no more than about 0.5 dB.

Returning now to Figure 27, integrating the relative levels, according to a simple summation applied to the smooth line, provides the basis for a duration correction D as follows:

$$D = L_{AX} - LA_{Max} = 10 \log_{10}\left[\sum_i \Delta t \cdot 10^{\Delta L_i/10} / t_o\right], \text{dB}$$

where

ΔL_i is the level L(t) relative to LA_{Max} at each i^{th} time spaced at intervals Δt apart. Δt was taken as one-half second for this summation, and

t_o the reference time of 1 second implicit in the definition of L_{AX}.

A value of D = 4.4 dB was obtained from Figure 27 by this process. The duration correction D can also be expressed in the form dictated by the linear model for the time history as

$$D = 10 \log_{10} \left[K_I \cdot H_o/V_o\right] = 4.4 \text{ dB}$$

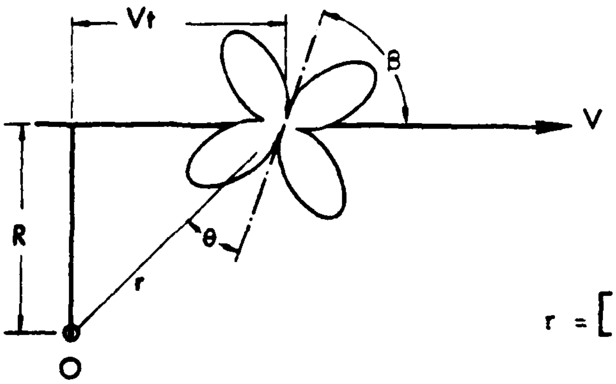
where

H_o, V_o are the reference values of distance and speed of 1,000 ft and 270 ft/sec (160 kts), respectively. On this basis, the empirical constant K_I becomes 0.74.

An independent derivation of this duration constant K_I was also carried out by a regression analysis of the experimental data relating L_{AX} and LA_{Max} assuming a linear model (i.e., energy effective duration scaling linearly with distance/velocity). In this case, K_I was 1.07. However, the value derived by integration of the curve in Figure 27 will be used for now.

The theoretical value for this constant K_I, if the source were a dipole (oriented at 90° to the line of travel), would be $\pi/2$.[53] As expected, however, the directivity of the propeller noise field is even sharper than that of a dipole. In fact, as shown below, the duration correction is closely approximated by the theoretical value for the sound exposure level in one of the lobes of a moving quadrupole oriented with one of its lobes perpendicular to the line of travel. For this ideal case, the constant K_I becomes $\pi/4$ (≈ 0.79), close to the value of 0.74 derived, empirically, from the data in Figure 27.

Noise Exposure from Passby of a Quadrupole Source at an Arbitrary Orientation (Reference 53)



The distance (r) and intensity (I) for a lateral quadrupole source passby are given by

$$r = \left[R^2 + (Vt)^2\right]^{1/2}$$

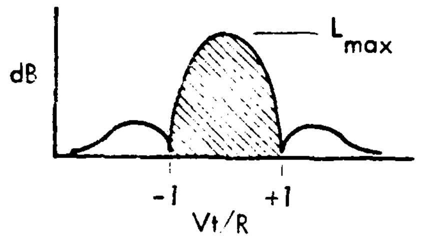
and

$$I(t) = I_{max} (\sin\theta \cos\theta)^2 \left[1 + (Vt/R)^2\right]^{-1}$$

where

$$\theta = \beta - \cos^{-1}\left[R/\sqrt{R^2 + (Vt)^2}\right]$$

If the quadrupole is turned so that one of its lobes is at 90° to the direction of travel, then $\beta = 45°$ and the resulting time history has the shape indicated by the following sketch.



Time History of Level During Passby of of a Quadrupole Source with $\beta = 45°$.

Integrating only over the time limits $t = \pm R/V$, the noise level of only the primary peak in the time history, indicated by the shaded area in the sketch, is obtained and the corresponding sound exposure level can be shown to be equal to

$$L_{AX} = L_{max} + 10 \log_{10}\left[\frac{\pi}{4} \frac{R}{V}\right], \text{dB}$$

Returning to the empirical basis for the duration correction, the conversion between LA_{Max} and LA_X can now be expressed as

$$L_{AX} = LA_{Max} + D = LA_{Max} + 10 \log_{10}\left[0.74\ H/V\right], \text{dB}$$

where H = the slant range at test conditions, ft

V = the average aircraft speed at test conditions, ft/sec.

This expression was used to convert the predicted maximum sound levels at takeoff and 2.5 km (8,200 ft) from brake release for the data base aircraft, evaluated earlier in Section 2 (see Figure 8b, page 31), to corresponding values of sound exposure level for the predicted takeoff test conditions. The results are shown in Figure 28.

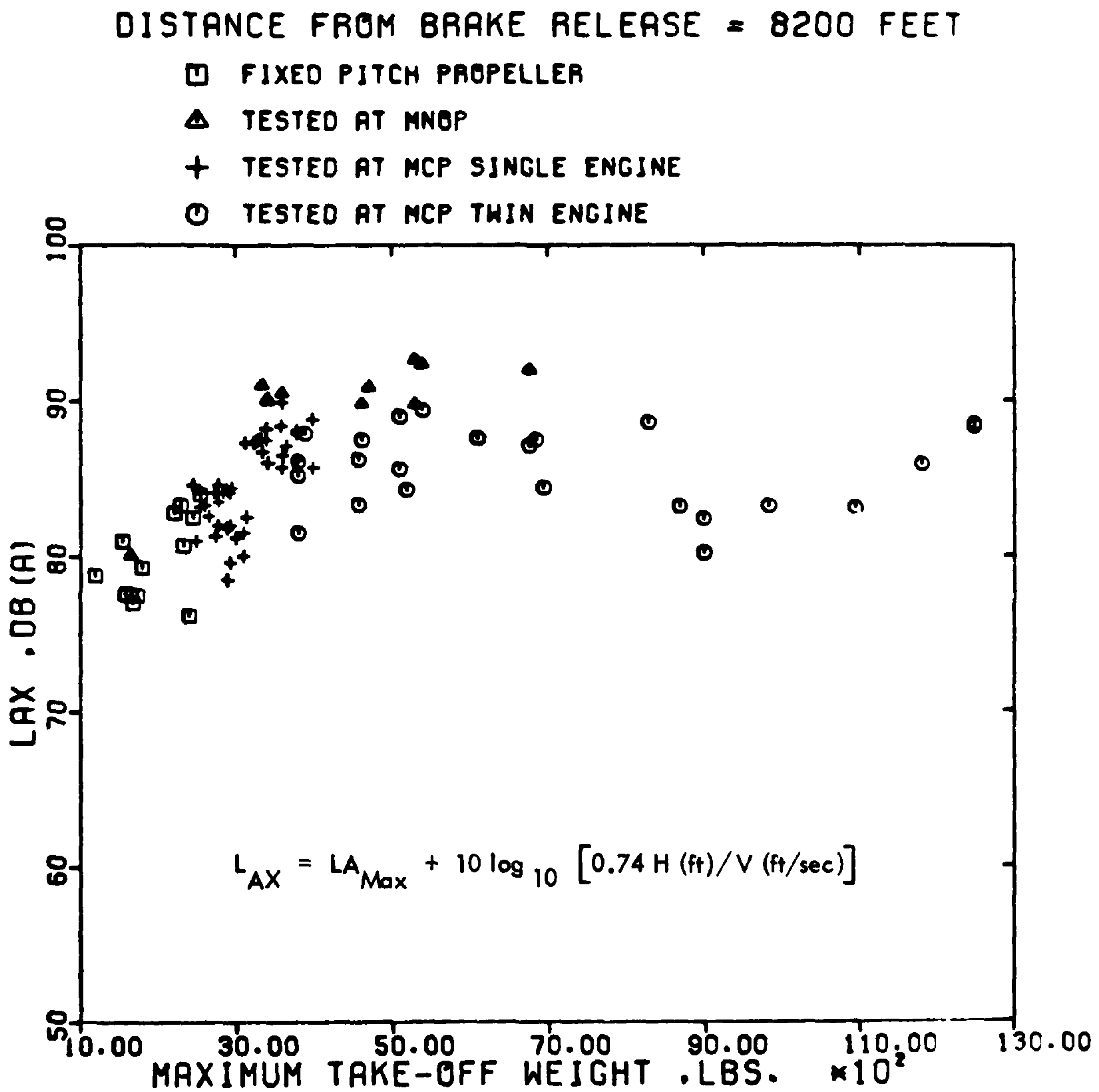


Figure 28. Predicted Values of Sound Exposure Level at 8200 ft (2.5 km) from Brake Release for Takeoff Tests of Data Base Aircraft (compare to data in Figure 8(b).

To convert values of maximum sound level from level flyover tests, $LA_{Max}(LFO)$, to sound exposure levels under takeoff conditions, $L_{AX}(T/O)$, the preceding model can be used to define the following conversion expression:

$$L_{AX}(T/O) = LA_{Max}(LFO) + 20 \log_{10}\left[\frac{H_1}{H_2}\right] + K \log_{10}\left[\frac{M_{T(2)}}{M_{T(1)}}\right] +$$

$$+ 10 \log \left[0.74\ H_2/V\right] \text{, dB}$$

where

H_1, H_2 = aircraft altitudes above the measurement points for the level flyover and takeoff tests, respectively,

K = $365 \log_{10}\left[\text{Propeller Diameter/Blade Width at 0.8 radius}\right] -268$

$M_{T(1)}, M_{T(2)}$ = the rotational tip Mach numbers for the level flyover and takeoff tests, respectively,

and V = the aircraft speed for the takeoff test.

To demonstrate the application of this conversion expression, the average values of the measured flight data, summarized earlier in Table 4(d) have been used to compute values of L_{AX} for takeoff, from the measured values of LA_{Max} during level flyover. These computed values are shown in Table 20 compared to the actual measured values of sound exposure level. As indicated in the last column by the difference, Δ, between the measured and predicted values of sound exposure level, the results are very encouraging for the 402C and T210N aircraft. The average error is only 0.9 dB for these aircraft indicating that one should be able to apply the above type of approximate conversion expression to relate maximum and sound exposure levels for flyover and takeoff. Note that if the higher value (i.e., 1.07 cited earlier) for the duration constant K_1, had been used in the above scaling equation, the predicted values of sound exposure level for the 402C and T210N aircraft would have been, on the average, approximately 1.1 dB higher than measured values. This suggests that a better approximation to the duration correction constant K_1 would be somewhere in between 0.74 and 1.07. However, in the absence of a more complete analysis of available propeller aircraft flyby noise signatures, the value of 0.74 for K_1 derived from Figure 27 will be considered a good initial approximation for now. Again, the exception to this agreement is the cruise optimized fixed-pitch propeller aircraft.

Table 20

Illustration of the Correlation Between Predicted and Measured Values of Sound Exposure Level in Takeoff. Predicted Values Based on Measured Values of Maximum Sound Level and Duration Correction Model

Aircraft	Level Flyover(1)		Takeoff Parameters									L_{AX} (T/O)		
	LA_{Max} dB(A)	$V_{T(1)}$ ft/sec	Condit.	H_2(2) ft	$V_{T(2)}$(2) ft/sec	V(2) ft/sec	$20 \log \frac{H_1}{H_2}$ dB	K(3)	$K \log \frac{V_{T(2)}}{V_{T(1)}}$ dB	D(4) dB	Calc(5) dB(A)	Meas.(6) dB(A)	Δ(7) dB
	A	B		C	D	E	F	G	H	I	J	K	L
402C	79.8	868	T/O	840	901	192	1.5	167	+2.7	+5.2	89.2	90.2	+1.0
T210N	79.5	908	T/O	643	942	174	3.8	175	+2.8	+4.4	90.5	91.8	+1.3
			S/C	1,007	942	174	-0.1	175	+2.8	+6.4	88.6	89.0	+0.4
172P	75.1	882	T/O	582	793	131	4.7	162	-7.5	+5.2	77.5	83.9	+6.4
			S/C	1,038	789	131	-0.3	162	-7.8	+7.7	74.7	79.1	+4.4

(1) Average level flyover noise levels, at 2.5 km position, corrected to 1,000 ft (height) and average tip speed $V_{T(1)}$

(2) Measured height, H_2, tip speed, $V_{T(2)}$, and airplane speed, V, during takeoff test

(3) $K = 365 \log_{10}$ [Propeller Diameter/Blade Width at 0.8 radius] - 268

(4) Duration Correction = $10 \log_{10} [0.74\ H_2/V]$, dB

(5) L_{AX} computed from Col. A + Col. F + Col. H + Col. I

(6) L_{AX} measured - reference values measured between 10 dB down points (from Table 18)

(7) Δ = Difference between Measured and Calculated values of L_{AX}

In summary, a reasonable method is provided for converting from maximum sound level to sound exposure level for measurement of propeller-driven small aircraft flyby noise signatures. The desirability of adopting the latter metric is considered in the next section.

4.3 Transition of Noise Certification Levels for Propeller Aircraft

Propeller aircraft weighing more than 12,500 lb are considered large transport aircraft for which noise certification requirements in Appendices A, B, and C of FAR Part 36 apply. The latter requirements differ from those in Appendix F for small propeller aircraft in terms of the following major factors:

- Measurement Positions
- Flight Procedures
- Correction Procedures
- Noise Metric

As a result of these differences, there is a discontinuity in the noise limits for propeller aircraft relative to their gross weight maximum. While it is evident that this discontinuity in ruling at the 12,500 lb gross weight value can be circumvented by judicious selection of design parameters by the manufacturing industry, there is clearly a case for eliminating such a discontinuity. This is especially true in advanced commuter aircraft concepts which fall close to a 12,500 lb weight and which may have significant beneficial design and efficiency features at risk depending on whether noise limits are to be based on Appendix F or Appendix C.

For example, in a recent study of the applicability of advanced technology to general aviation aircraft,[54] consideration was given to over 50 technologies which could be applied to a six-passenger private/business aircraft and a 19-passenger commuter aircraft. In the latter case, the optimum efficiency of advanced commuter aircraft designs incurred gross weight changes from 12,500 lb to 12,580 lb, and from 14,000 lb to 11,660 lb, depending on design mission specifications. Each of these changes involves a jump from one noise rule to the other. Since such design optimization requires an extremely sensitive analysis of the tradeoff between aerodynamic, structural, power system and market features, discontinuities in noise rules at the 12,500 lb maximum gross weight limit must be considered as incompatible with the goals of advancing aviation technology. Consider, therefore, how this discontinuity in noise certification requirements might be removed.

4.3.1 Differences in Measurement Positions and Flight Procedures

The primary bases for differences in measurement positions and flight procedures between Appendix F and Appendix C have already been discussed. It is desirable, however, to elaborate on why approach and sideline positions required for Appendix C are not considered necessary for propeller-driven small aircraft.

The noise levels during approach of such aircraft are ordinarily well below those on takeoff, with the possible exception of larger turboprop aircraft. Thus, with this exception, there does not appear to be sufficient need to require an approach noise certification measurement for propeller-driven small aircraft. While sideline positions near general aviation airports may, indeed, receive significant noise exposure during takeoff of propeller aircraft, there is a substantial effort by the industry to develop prediction models to estimate such levels.[55] Since takeoff tests are shown in this report to be applicable for most propeller-driven aircraft, then it is not considered necessary to measure sideline levels separately for propeller-driven small aircraft since such levels will simply be a reduced reflection of the takeoff noise level. As the weight of the propeller aircraft increases beyond the current 12,500 lb limit, the following rationale appears reasonable in considering alternative measurement positions:

- For propeller aircraft above 12,500 lb, require an approach measurement, as specified in Appendix C, but at a position closer to landing threshold. A distance of 1 km (3,281 ft) from landing threshold would seem reasonable, as compared with 2 km as used in Appendix C.

- For propeller aircraft above 12,500 lb, eliminate the sideline measurement, providing a takeoff noise measurement is made underneath the flight path at a position well before any power reduction can be employed. The 2.5 km position defined for propeller-driven small aircraft should satisfy this latter requirement.

4.3.2 Correction Procedures

Procedures to correct measured noise certification levels for nonstandard flight profiles should be similar to those employed now or as proposed herein.

- For propeller aircraft below 12,500 lb, correct for:
  - changes in spreading loss due to significant deviations in takeoff path resulting from nonstandard takeoff performance
  - changes in source level due to deviations from rated propeller rpm.

- o For propeller aircraft above 12,500 lb, in addition to the above, correct for
  - changes in air absorption loss due to significant deviations in the takeoff or approach flight path from reference values.

4.3.3 Noise Metrics

Perhaps the most difficult aspect of the noise certification interface between small and large propeller-driven aircraft is the change in the noise metric (and corresponding limits) from maximum A-weighted noise levels in Appendix F to effective perceived noise levels in Appendix C.

Based, in part, on the results obtained in this program, it has been determined that just one noise metric – sound exposure level (i.e., time-integrated A-weighted sound levels) – could be used for noise certification of all propeller aircraft, regardless of weight. This is based on the following rationale:

- o Current state-of-the-art in sound level measurements is well-advanced and makes this measurement very straightforward and readily accomplished without excessive instrumentation costs. Airframe manufacturers not presently equipped with such instruments can rent them or hire qualified consultants without incurring instrument purchase costs. Data analysis would certainly be much simpler and less costly than with the use of the EPNL metric.
- o The sound exposure level of single aircraft flyby events is a necessary part of computing the composite noise index, day-night average level, L_{dn}, now widely used for defining community noise impact. For general use in constructing curves of sound exposure level versus distance, a different algorithm would be required to define duration corrections at large distances where air absorption losses will make the linear time-scaling model employed here for noise certification measurements no longer valid. However, the

latter would still be useful to provide baseline values for sound exposure level which could then be extrapolated to larger distances with a suitable nonlinear time-scaling model (e.g., $\propto$ 6 log (Distance)) such as currently being considered for noise vs slant distance data for jet aircraft.

- The vast majority of aircraft in the propeller aircraft fleet have gross weights below 12,500 lb and, as considered in Appendix D of this report, are believed to generate approximately 50 percent of the total noise impact created by all general aviation aircraft. Of the remaining 50 percent, the vast majority of noise impact will be generated by business jet aircraft leaving only a small portion attributable to propeller-driven large aircraft. Thus, any possible lack of precision in the certification noise metric applied to large propeller aircraft is considered an acceptable trade for measurement simplicity.

- Available data, such as summarized in Table 21, does not indicate an overwhelming basis for rejecting sound exposure level as a reasonable measure of human response to propeller aircraft noise. The data in Table 21 are based on the results of Ollerhead on subjective noise rating scales for piston and turboprop aircraft.[56] He examined the relative accuracy of various noise metrics for evaluating human response to recorded flyby test sounds from 34 piston aircraft and 31 turboprop aircraft. The relative accuracy is measured by the standard deviation of the difference between the objective (e.g., sound exposure level) and subjective (judged noisiness) measures of the test sounds. Although sound exposure level is shown, by these results, to be the least accurate of the metrics evaluated, the difference between the least and most accurate is not large.

Table 21

Relative Accuracy of Various Noise Metrics in Judging the Noisiness of Propeller Aircraft Sounds

(Data from Ollerhead, Ref. 56)

	σ, Standard Deviation in Predicted Noisiness, dB					
Noise Metric ——>	LA_{Max}	L_{AX}	PNL	IPNL[1]	PNLT	EPNL
34 Piston A/C	2.3	2.7	2.0	1.8	2.6	2.1
31 Turboprop A/C	3.5	3.4	2.8	2.4	3.2	2.7
All Combined	2.9	3.0	2.4	2.1	2.9	2.4

[1] Time-Integrated PNL

- o Finally, as illustrated in Figure 29, data on estimated or measured values of sound exposure level at 1,000 ft for propeller aircraft, plotted as a function of total shaft horsepower, suggest a continuous and reasonably smooth transition from small to large aircraft. This type of plot can also be considered as roughly representing the relationship between sound exposure level and maximum gross weight since the latter is closely correlated with engine horsepower.[6]

4.3.4 Conversion of Effective Perceived Noise Level to Sound Exposure Level

As a final part of treating the transition problem between small and large aircraft, it is desirable to consider what would be the net change in present certification levels for large propeller aircraft upon being converted to sound exposure level. One example of such a conversion is illustrated as follows.

According to Appendix C of FAR Part 36, for Stage III aircraft, the minimum noise limit on takeoff is 89 EPNdB, effective at a gross weight below 44,673 lb for aircraft with more than three engines (or below 106,250 lb for aircraft with fewer than three engines). This level is measured at a distance of 6.5 km (21,325 ft).

Assuming a typical large propeller aircraft with a maximum takeoff weight of 45,000 lb, a takeoff distance, D_{50}, of 4,000 ft, and a nominal climb angle of 6 degrees, the aircraft's height at 2.5 km and 6.5 km from brake release would

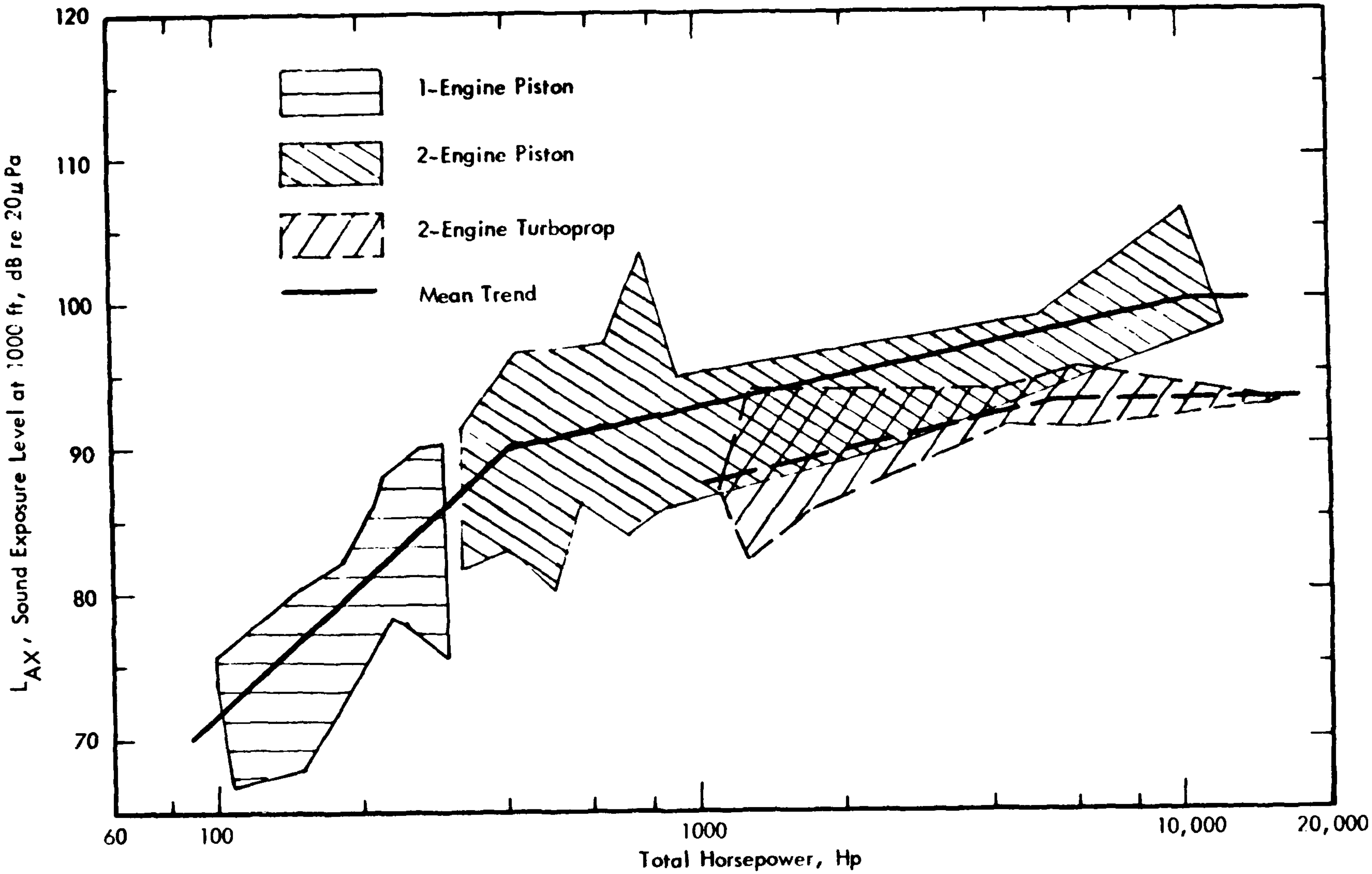


Figure 29. Relationship Between Measured Sound Exposure Level, Normalized to 1000 ft, and Total Horsepower for Piston and Turbine-Powered Propeller Aircraft (data from References 6, 22, 52).

be about 490 ft and 1,870 ft, respectively. The difference in EPNL at these two positions would be expected to be about 7 dB so that the EPNL at 2.5 km would be about 89 + 7 = 96 EPNdB. Correcting for the difference in reference time (1 second vs 10 seconds) between L_{AX} and EPNL, assuming a 2 dB tone correction in EPNL and applying a typical correction of -13 dB between A-weighted levels and perceived noise levels, the approximate sound exposure level at 2.5 km can be estimated as follows:

Baseline EPNL @ 6.5 km	=	89 EPNdB
Correction for Difference in Height	=	+7
Correction for Difference in Time Ref.	=	+10
Eliminate Tone Correction		-2
Correction for Weighting Function		-13
Estimated L_{AX} @ 2.5 km	=	91 dB

The data shown earlier in Figure 28 for the estimated values of sound exposure level at 2.5 km under the takeoff path for representative propeller-driven small aircraft indicates that this value of 91 dB, projected downward from the EPNL for large propeller aircraft, would be quite consistent.

Thus, as suggested by this very simplified example, it should be possible to remove the existing discontinuity between Appendix C and Appendix F limits for propeller aircraft by adopting a single noise metric, L_{AX}, measured under the takeoff flight path at 2.5 km without changing the effective constraint placed on the allowable source noise levels by either of the current regulations.

Airplane manufacturers would, of course, be able to make reasonable estimates of their anticipated compliance with any such new regulation by employing the type of analysis outlined above but using the much greater precision possible with their own more detailed data bases.

This section should not be ended without acknowledging the many other studies on revising current propeller aircraft noise certification procedures.[4] These include considerations of takeoff tests, such as discussed here, use of sound exposure level, use of level flyover and takeoff tests (with allowed trades), and more complex schemes for defining weight and aircraft type categories for noise certification.

4.4 Changes in Noise Level Limits

The preceding analyses have considered the use of a takeoff test procedure for propeller-driven small aircraft (except cruise-optimized fixed-pitch propeller aircraft) and the measurement of the sound exposure level at a position 2.5 km from brake release using the 1.2 m microphone height.

4.4.1 Noise Limits Excluding Cruise-Optimized Fixed-Pitch Aircraft

Based on the predicted values for this noise level shown earlier in Figure 28, and the discussion on the potential for noise reduction through application of future technology, the following rationale was used to select possible noise certification levels based on these concepts. These levels, illustrated in Figure 30, are intended to be applicable only to other than cruise-optimized fixed-pitch propeller aircraft.

1. Stage 0 certification levels allowing all current aircraft to pass, under this new procedure, would consist, as shown, of an upper bound to the data in Figure 30.
2. Stage 1 certification levels, corresponding to noise levels attainable with currently available technology without the use of the MNOP power reduction approach, would consist of an upper bound for the latter type of aircraft. As indicated in Figure 30, this corresponds to a line about 4 dB below the Stage 0 levels.
3. Stage 2 certification levels would represent an anticipated further reduction of 6 dB in Stage 1 levels – attainable now by a very few models but expected to be achievable by all new models of the propeller-driven small aircraft fleet upon application of the future technology outlined in Section 3. Timing for the imposition of such levels would necessarily have to reflect the need for the further research and development called for.

4.4.2 Noise Limits for Cruise-Optimized Fixed-Pitch Aircraft

For cruise-optimized fixed-pitch propeller aircraft, the takeoff test is not necessary. The current level flyover test appears to be the only practical test

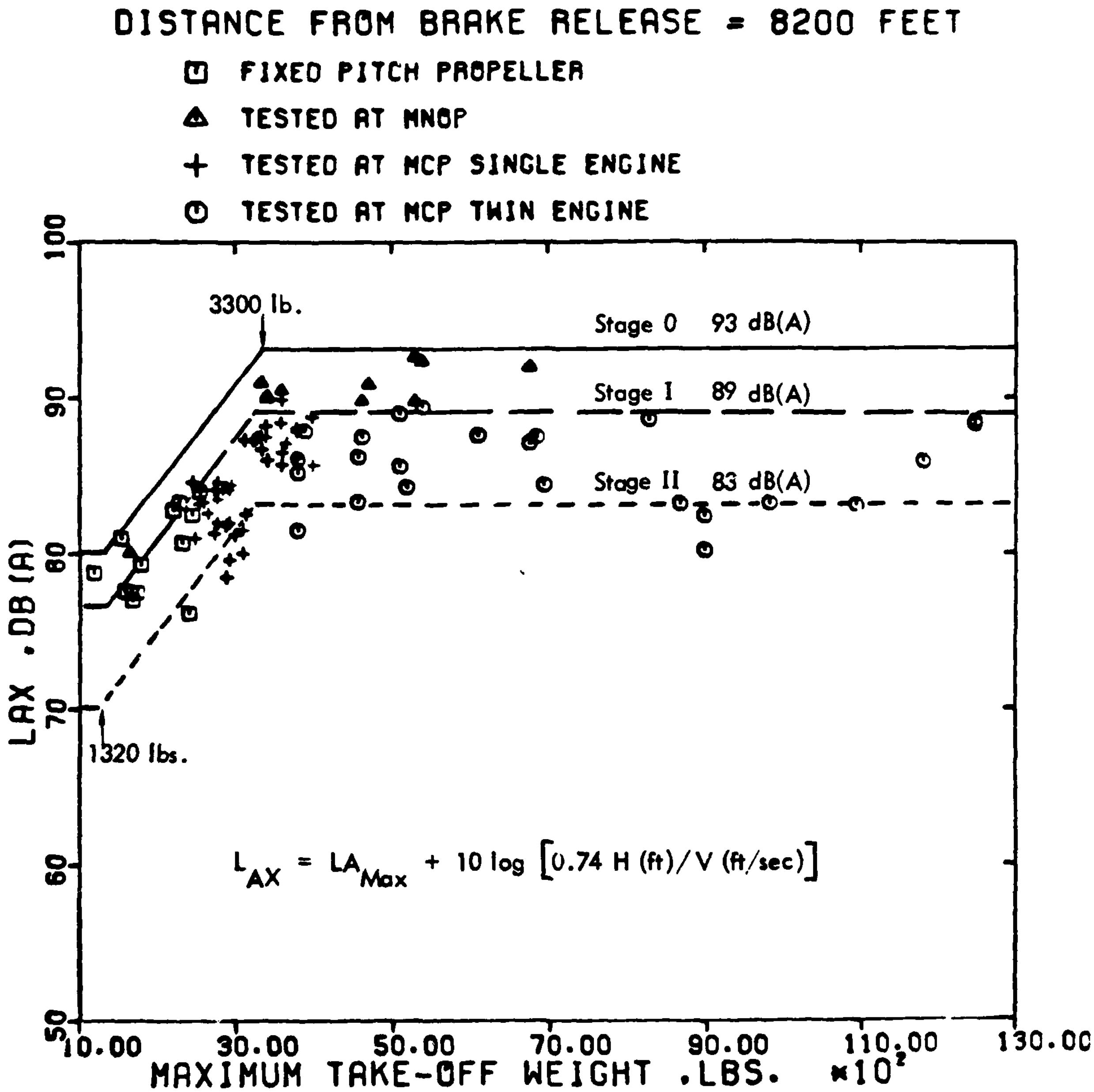


Figure 30. Possible Values of Sound Exposure Level at 8200 ft (2.5 km) from Brake Release for Noise Certification Takeoff Tests of Propeller-Driven Small Aircraft Except Cruise-Optimized Fixed Pitch Propeller Aircraft.

procedure suitable for such aircraft. However, sound exposure level could be adopted in the future as the preferred, but possibly optional, noise measurement metric to provide consistency throughout the propeller aircraft fleet. Thus, reasonable Stage I noise certification levels for such aircraft, in terms of sound exposure level, could be defined by simply applying the type of duration correction outlined earlier to existing noise certification measurements specified in terms of maximum noise level.

For example, based on this program, the Cessna 172P aircraft has a maximum gross weight of 2,400 lbs and a corresponding noise certification limit for the maximum noise level at 1,000 ft of 68 + (2400-1320)/168 = 74.4 dB(A).[1] Based on the flight performance observed for this aircraft in level flyover at 1,000 ft (i.e., average flight speed of about 200 ft/sec), the corresponding sound exposure level limit would be about

$$
\begin{aligned}
L_{AX}(\text{limit}) &\simeq 74.4 + 10 \log_{10}\left[0.74 \cdot 1000/200\right] \\
&\simeq 80.1 \text{ dB(A)}
\end{aligned}
$$

or roughly 6 dB above the present noise certification limit expressed in terms of maximum sound level. A Stage 2 noise limit could follow the same logic as for variable pitch propeller aircraft – namely, a 6 dB reduction below Stage I limits.

4.4.3 Summary

The net effect of such an evolution in noise certification limits would tend to reduce takeoff levels of the noisiest aircraft currently in the fleet by 10 dB and reduce by about 6 dB the maximum levels generated by the quieter aircraft in the fleet which now do not require any use of power limitations to pass current noise certification rules. The net change on the noise impact around general aviation airports dominated by propeller aircraft would be very substantial. The total area enclosed by the noise contours around such airports would be expected to reduce by 5 to 7 times.

5.0 CONCLUSIONS AND SUMMARY

An analysis of noise reduction technology that can be applied to propeller-driven small aircraft has indicated the following:

- The existing FAR Part 36 Appendix F regulation has been effective in ensuring that available noise control technology has been applied to the noise-certificated portion of the current fleet of propeller-driven small airplanes.

- The level flight flyover test procedure, as required by the existing regulation, has been adopted by the industry as the sole means of optimizing design parameters to meet noise reduction requirements. The concept of MNOP (Maximum Normal Operating Power) has evolved as a means of meeting noise limits in cases where available noise reduction technology is otherwise inadequate for the level flyover tests.

- Assessment of current technology indicates that while further noise reductions may be achievable for some aircraft models, it is not sufficiently versatile to accommodate a change in noise limits (for all new aircraft) at this time.

- Propeller design technology has received significant research effort during the past 5 years. This research indicates that a change from the current designs to advanced airfoil and optimized planform propeller blades will lead to improved aerodynamic performance, reduced fuel consumption, and reduced retail costs of propeller-driven aircraft. The potential for noise reduction of future aircraft can be achieved by utilizing this improved aerodynamic performance in an optimization process which includes noise limitation as a primary constraint. A 5 dB reduction in current noise limits has been projected to be a practical future objective, based on current flyover test procedures.

Flight tests were conducted to evaluate new possible noise certification test procedures. The following summarizes the results of this evaluation:

- Propeller aircraft not equipped with cruise-optimized fixed-pitch propellers tend to generate higher noise levels during takeoff than during level flyover at power settings currently specified for noise certification. (Results from the unique series of tests indicate that this difference is predictably related to changes in the rotational, and not helical, tip speed of the propeller.) Therefore, takeoff noise tests may provide a more stringent measure of aircraft noise.

- o The models reported herein to account for source level changes due to rotational tip speed of the propeller, and to predict duration corrections at distances typical of certification measurements, provide the foundation for allowing measured sound levels on takeoff or level flyover to be correlated and converted from maximum sound level to sound exposure level or vice versa.

- o The use of the time-integrated A-weighted noise level (i.e., sound exposure level) is applicable as a universal metric for noise certification of all propeller aircraft, regardless of gross weight. This change would provide the principal basis for eliminating the current cumbersome discontinuity in noise certification requirements at the 12,500 lb gross weight limit between small and large propeller aircraft.

- o Practical takeoff noise limits for future technology propeller-driven small aircraft can be set at least 6 dB below current state-of-the-art noise limits and 10 dB below levels generated by the noisiest small propeller aircraft in the fleet today.

Consideration of the sound exposure level metric should be based on its ease of measurement with existing instrumentation, its consistency with the currently applied composite noise metric, day-night average noise level, L_{dn}, and its suitability as a reasonable predictor of human response to noise, not unlike the EPNL noise metric currently used for all large jet and propeller aircraft.

Further effort would be required in order to refine the concepts outlined herein before they can be incorporated into noise regulations. However, the overall impact of their application should simplify noise certification procedures and assist in motivating the development of economically reasonable and technically feasible advances in further noise reduction of propeller-driven small aircraft. Adoption of a single noise metric for all propeller aircraft, such as discussed herein, can also be expected to provide a positive influence for stimulating environmentally-compatible growth in that part of the aviation market near the current interface of 12,500 lb gross weight between small and large propeller aircraft.

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APPENDIX A

Federal Aviation Regulations, Volume III, Part 36

(Noise Standards: Aircraft Type and Airworthiness Certification)

"Noise Requirements for Propeller-Driven Small Airplanes"

The following copy of FAR Part 36 Appendix F is presented for reference purposes in relation to the contents of this report. This copy should not be used for any other purposes nor should it be considered to contain all relevant amendments.

Appendix F

Noise Requirements for Propeller-Driven-Small Airplanes

PART A—GENERAL

§ F36.1 Scope. This appendix prescribes limiting noise levels, and procedures for measuring noise and correcting noise data, for the propeller driven small airplanes specified in § 36.1.

PART B—NOISE MEASUREMENT

§ F36.101 General test conditions.

(a) The test area must be relatively flat terrain having no excessive sound absorption characteristics such as those caused by thick, matted, or tall grass, by shrubs, or by wooded areas. No obstructions which significantly influence the sound field from the airplane may exist within a conical space above the measurement position, the cone being defined by an axis normal to the ground and by a half-angle 75 degrees from this axis.

(b) The tests must be carried out under the following conditions:

(1) There may be no precipitation.

(2) Relative humidity may not be higher than 90 percent or lower than 30 percent.

(3) Ambient temperature may not be above 86 degrees F. or below 41 degrees F. at 33′ above ground. If the measurement site is within 1 n.m. of an airport thermometer the airport reported temperature may be used.

(4) Reported wind may not be above 10 knots at 33′ above ground. If wind velocities of more than 4 knots are reported, the flight direction must be aligned to within ±15 degrees of wind direction and flights with tail wind and head wind must be made in equal numbers. If the measurement site is within 1 n.m. of an airport anemometer, the airport reported wind may be used.

(5) There may be no temperature inversion or anomalous wind condition that would significantly alter the noise level of the airplane when the noise is recorded at the required measuring point.

(6) The flight test procedures, measuring equipment, and noise measurement procedures must be approved by the FAA.

(7) Sound pressure level data for noise evaluation purposes must be obtained with acoustical equipment that complies with §F36.103 of this appendix.

§ F36.103 Acoustical measurement system.

The acoustical measurement system must consist of approved equipment equivalent to the following:

(a) A microphone system with frequency response compatible with measurement and analysis system accuracy as prescribed in § F36.105 of this appendix.

(b) Tripods or similar microphone mountings that minimize interference with the sound being measured.

(c) Recording and reproducing equipment characteristics, frequency response, and dynamic range compatible with the response and accuracy requirements of § F36.105 of this appendix.

(d) Acoustic calibrators using sine wave or broadband noise of known sound pressure level. If broadband noise is used, the signal must be described in terms of its average and maximum root-mean-square (rms) value for nonoverload signal level.

§ F36.105 Sensing, recording, and reproducing equipment.

(a) The noise produced by the airplane must be recorded. A magnetic tape recorder is acceptable.

[(b) The characteristics of the system must comply with the recommendations in International Electrotechnical Commission (IEC) Publication No. 179, entitled "Precision Sound Level Meters" as incorporated by reference in Part 36 under §36.6 of this Part.]

(c) The response of the complete system to a sensibly plane progressive sinusoidal wave of constant amplitude must lie within the tolerance limits specified in IEC Publication No. 179, dated 1973, over the frequency range 45 to 11,200 Hz.

(d) If limitations of the dynamic range of the equipment make it necessary, high frequency pre-emphasis must be added to the recording channel with the converse de-emphasis on playback. The pre-emphasis must be applied such that the instantaneous recorded sound pressure level of the noise signal between 800 and 11,200 Hz does not vary more than 20 dB between the maximum and minimum one-third octave bands.

(e) If requested by the Administrator, the recorded noise signal must be read through an "A" filter with dynamic characteristics designated "slow," as defined in IEC Publication No. 179, dated 1973. The output signal from the filter must be fed to a rectifying circuit with square law rectification, integrated with time constants for charge and discharge of about 1 second or 800 milliseconds.

(f) The equipment must be acoustically calibrated using facilities for acoustic free-field calibration and if analysis of the tape recording is requested by the Administrator, the analysis equipment shall be electronically calibrated by a method approved by the FAA.

(g) A windscreen must be employed with the microphone during all measurements of aircraft noise when the wind speed is in excess of 6 knots.

§ F36.107 Noise measurement procedures.

(a) The microphones must be oriented in a known direction so that the maximum sound received arrives as nearly as possible in the direction for which the microphones are calibrated. The microphone sensing elements must be approximately 4' above ground.

(b) Immediately prior to and after each test, a recorded acoustic calibration of the system must be made in the field with an acoustic calibrator for the two purposes of checking system sensitivity and providing an acoustic reference level for the analysis of the sound level data.

(c) The ambient noise, including both acoustical background and electrical noise of the measurement systems, must be recorded and determined in the test area with the system gain set at levels that will be used for aircraft noise measurements. If aircraft sound pressure levels do not exceed the background sound pressure levels by at least 10 dB(A), approved corrections for the contribution of background sound pressure level to the observed sound pressure level must be applied.

§ F36.109 Data recording, reporting, and approval.

(a) Data representing physical measurements or corrections to measured data must be recorded in permanent form and appended to the record except that corrections to measurements for normal equipment response deviations need not be reported. All other corrections must be approved. Estimates must be made of the individual errors inherent in each of the operations employed in obtaining the final data.

(b) Measured and corrected sound pressure levels obtained with equipment conforming to the specifications described in § F36.105 of this appendix must be reported.

(c) The type of equipment used for measurement and analysis of all acoustical, airplane performance, and meteorological data must be reported.

(d) The following atmospheric data, measured immediately before, after, or during each test at the observation points prescribed in § F36.101 of this appendix must be reported:

(1) Air temperature and relative humidity.

(2) Maximum, minimum, and average wind velocities.

(e) Comments on local topography, ground cover, and events that might interfere with sound recordings must be reported.

(f) The following airplane information must be reported:

(1) Type, model and serial numbers (if any) of airplanes, engines, and propellers.

(2) Any modifications or nonstandard equipment likely to affect the noise characteristics of the airplane.

(3) Maximum certificated takeoff weights.

(4) Airspeed in knots for each overflight of the measuring point.

(5) Engine performance in terms of revolutions per minute and other relevant parameters for each overflight.

(6) Aircraft height in feet determined by a calibrated altimeter in the aircraft, approved photographic techniques, or approved tracking facilities.

(g) Aircraft speed and position and engine performance parameters must be recorded at an approved sampling rate sufficient to ensure compliance with the test procedures and conditions of this appendix.

§ F36.111 Flight procedures.

(a) Tests to demonstrate compliance with the noise level requirements of this appendix must include at least six level flights over the measuring station at a height of 1,000 ±30 and ±10 degrees from the zenith when passing overhead.

(b) Each test over flight must be conducted—

(1) At not less than the highest power in the normal operating range provided in an Airplane Flight Manual, or in any combination of approved manual material, approved placard, or approved instrument markings; and

(2) At stabilized speed with propellers synchronized and with the airplane in cruise configuration, except that if the speed at the power setting prescribed in this paragraph would exceed the maximum speed authorized in level flight, accelerated flight is acceptable.

PART C—DATA CORRECTION

§ F36.201 Correction of data.

(a) Noise data obtained when the temperature is outside the range of 68 degrees F. ±9 degrees F., or the relative humidity is below 40 percent, must be corrected to 77 degrees F. and 70 percent relative humidity by a method approved by the FAA.

(b) The performance correction prescribed in paragraph (c) of this section must be used. It must be determined by the method described in this appendix, and must be added algebraically to the measured value. It is limited to 5 dB(A).

(c) The performance correction must be computed by using the following formula:

$$\Delta dB = 60 - 20 \log_{10} \left[\frac{(11{,}430 - D_{50}) R/C}{V_y} + 50 \right]$$

Where:

D_{50} = Takeoff distance to 50 feet at maximum certificated takeoff weight.

R/C = Certificated best rate of climb (fpm).

V_y = Speed for best rate of climb in the same units as rate of climb.

(d) When takeoff distance of 50′ is not listed as approved performance information, the figures of 2000′ for single-engine airplanes and 2700′ for multi-engine airplanes must be used.

§ F36.203 Validity of results.

(a) The test results must produce an average dB(A) and its 90 percent confidence limits, the noise level being the arithmetic average of the corrected acoustical measurements for all valid test runs over the measuring point.

(b) The samples must be large enough to establish statistically a 90 percent confidence limit not to exceed ±1.5 dB(A). No test result may be omitted from the averaging process, unless omission is approved by the FAA.

PART D—NOISE LIMITS

§ F36.301 Aircraft noise limits.

(a) Compliance with this section must be shown with noise data measured and corrected as prescribed in Parts B and C of this appendix.

(b) For airplanes for which application for a type certificate is made on or after October 10, 1973, the noise level must not exceed 68 dB(A) up to and including aircraft weights of 1,320 pounds (600 kg.). For weights greater than 1,320 pounds up to and including 3,630 pounds (1,650 kg.) the limit increases at the rate of 1 dB/165 pounds (1 dB/75 kg.) to 82 dB(A) at 3,630 pounds, after which it is constant at 82 dB(A) up to and including 12,500 pounds. However, airplanes produced under type certificates covered by this paragraph must also meet paragraph (d) of this section for the original issuance of standard airworthiness certificates or restricted category airworthiness certificates if those airplanes have not had flight time before the date specified in that paragraph.

(c) For airplanes for which application for a type certificate is made on or after January 1, 1975, the noise levels may not exceed the noise limit curve prescribed in paragraph (b) of this section, except that 80 dB(A) may not be exceeded at weights from and including 3,300 pounds to and including 12,500 pounds.

(d) For airplanes for which application is made for a standard airworthiness certificate or for a restricted category airworthiness certificate, and that have not had any flight time before January 1, 1980, the requirements of paragraph (c) of this section apply, regardless of date of application, to the original issuance of the certificate for that airplane.

APPENDIX B

Description of Procedures and Results of A Demonstration Flight Test Program Performed to Evaluate Noise Level Measurement Methods

B.1 Introduction

A demonstration flight test program was performed by Cessna Aircraft Company and Wyle Laboratories on September 14, 1981, at Sunflower Airfield, Hutchinson, Wichita, Kansas. This program was designed to investigate the viability of a takeoff test method for noise certification of propeller-driven small airplanes and to evaluate methods of measuring noise levels in terms of various noise metrics.

Three aircraft were utilized in the test program. These aircraft were supplied and operated by Cessna Aircraft Company and comprised:

- o A Cessna Model 402C, twin reciprocating-engined aircraft.
- o A Cessna Model T210N, single turbocharged reciprocating-engined aircraft.
- o A Cessna Model 172P, single reciprocating-engined aircraft.

Design and performance information for these aircraft is contained in Table B-1 of this appendix.

The tests were performed as closely as possible in accordance with the test plan described in Section B.2 of this appendix. Variations from the test plan were caused by delays in commencing the 1-day program due to heavy ground fog at the airfield, intermittent failure of radio transceivers at the test site, and failure of one microphone preamplifier (which could not be replaced without further delay of the compressed flight schedule).

A total of 35 flight tests were performed during the program. Sixteen of these flights were level flyover tests at conditions which simulated the current FAR Part 36 Appendix F test requirements, 14 flight tests were takeoff operations from a brake release marker on the main runway, and five tests were simulated V_y (best rate of climb) climbout operations with an objective of attaining a height of 1,000 ft above a primary noise measurement station.

Table B-1

Flight Test Aircraft Data

Aircraft Type: Registration No.:	172P N6786R	T210N N7416N	402C N402CW
Max. Takeoff Wt.: (lbs)	2,400	4,000	6,850
Max. Takeoff Power: (BHP)	160	310	325 ea.
RPM for Max. Takeoff Power:	2,700	2,700	2,700
MNOP: (MCP for 172P and T210N) (BHP)	160	285	310
RPM for MNOP:	2,700	2,600	2,600
Cruise Speed @ 65% Power @ 2,500 ft MSL:	104 KTAS	149 KTAS	171 KTAS
Cruise Speed RPM:	2,300	2,500	2,300
D_{50}: (ft)	1,625	2,160	2,195
Best Rate of Climb (R/C) (sea level): (fpm)	700	930	1,450
V_y for R/C (sea level): KIAS	76	100	109
V_{so} (sea level) (flaps up/down)	(51/46) KIAS	(67/58) KCAS	(80/71) KCAS
Flaps (degrees)	30°	30°	45°
Propellers			
Blade No.:	2	3	3
Model No.:	DTM 7557	90DFA-10	82NC-5.5
Diameter: (inches)	75	80	76.5
Tip Shape:	Elliptical	Square	Round
Blade Thickness @ 95% Rad.: (inches)	0.24	0.30	0.23
Blade Chord @ 95% Rad.: (inches)	3.18	4.57	3.46
Engines			
Model No.:	LYC: 0-320-D2J	TCM: TS10-520-R	TCM: TS10-520-VB
Exhaust Type:	Muffler	Turbocharger	Turbocharger

As described in the test plan, flyover noise data were recorded on a two-channel Nagra IV SJ at each of two primary noise measurement stations, located at 2 km (6,560 ft) and 2.5 km (8,200 ft), respectively, from the brake release marker and on the extended centerline of the runway. These recordings were of noise histories measured at two microphone heights (1.2 m and 10 m) at each primary station. In addition, direct-read instrumentation was used to obtain field measurements of LA_{Max}, L_{AX}, L_{eq}, and Integration Time from the 10 m height microphone data at each noise measurement station (corresponding to channel 1 records on each recorder, as identified in the Data Logs shown in Section B.2 of this appendix).

Subsequent laboratory analysis of the records obtained from the 1.2 m height microphone was performed using the same evaluation method (that is, by means of direct-read instrumentation) but with the added benefit of having time history traces of each record prior to the evaluation. All data acquired during the field test and subsequent analysis programs are shown in Section B.2 of this appendix.

A review and discussion of the procedures and results of the flight test program is presented in Section 4.2.1 of this report.

B.2 Test Plan

Pages B-4 through B-13 contain the Test Plan developed specifically for the flight test demonstration and noise measurement program. The contents of the test plan are as follows:

1.0 PURPOSE

The purpose of this test plan is to define procedural requirements for the performance of a series of flight and acoustic measurement tests which are to investigate the viability of a "takeoff test" method for noise certification of propeller-driven small airplanes. This test plan is not intended to represent a draft of a regulatory procedure. Rather, it is oriented towards obtaining background information which will be useful to the Federal Aviation Administration in future consideration of possible changes to regulatory processes.

Responsibility for the content of this test plan lies solely with Wyle Laboratories as a contractor to the Federal Aviation Administration. This plan has not been approved by any Government agency.

2.0 GENERAL DESCRIPTION

The test program will consist of a number of flights of representative propeller-driven aircraft over a system of noise measuring equipment located at the airfield. Each flight will be performed with the aircraft gross weight within a margin of 10 percent of its certificated maximum takeoff weight. A prerequisite *for the test program is that meteorological conditions fall within an extended "weather window"* as specified later in this test plan.

The primary noise measurement system will comprise two sets of microphones located on the extended centerline of the runway and at distances of 2.0 km and 2.5 km (6,560 ft and 8,200 ft), respectively, from a marked brake release point on the runway.

The aircraft shall perform three sets of flights over the primary noise measurement system, as follows:

1. Takeoff test flights, commencing from an approved brake release marker on the runway and comprising takeoff at maximum rated takeoff power, and continuing at best rate-of-climb and V_y airspeed over the noise measurement stations.
2. Straight and level flyovers conforming with FAR Part 36, Appendix F procedures; that is, with the aircraft in a clean configuration, at a height of 305 m (1,000 ft) $\pm$10 m, and at a power setting equivalent to the "maximum in the normal operating range" for the aircraft.
3. Simulated takeoff "climbout" tests with the aircraft at a "best rate-of-climb at V_y" condition in a segment which (a) overflies the primary noise measurement stations, and (b) achieves a height of 305 m (1,000 ft) at some point while overflying the measurement stations.

It is anticipated that a minimum of six test flights will be performed for the takeoff and level flight conditions, and a minimum of three test flights will be performed for the simulated takeoff test.

The noise measuring equipment will comprise direct read and magnetic tape recording instrumentation at each primary measuring site. The direct read instrumentation at the primary sites will be capable of providing a measure of the maximum A-weighted sound level (with "Slow" meter response) and a time-integrated measure of the sound exposure level (L_{AX}, SEL) and the energy average sound level (L_{eq}) over measured time periods. Measurements of the maximum A-weighted sound level will also be obtained at one secondary site. Meteorological, photographic, and aircraft instrument records will be obtained for each flight, as defined in this test plan.

3.0 FIELD TEST REQUIREMENTS

3.1 General Test Conditions

For purposes of this flight test program the following general test conditions will be adhered to as closely as is practical within economic and logistical constraints:

(i) Locations for measuring noise from the aircraft in flight should be surrounded by relatively flat terrain having no excessive sound absorption or obstructive characteristics (such as tall buildings or trees) between the aircraft and sound sensing equipment within the measurement flight path range. Significant sound reflection from equipment accessories or nearby buildings must be avoided at the microphone locations.

(ii) The tests should be carried out under the following weather conditions:

(a) No rain or other precipitation

(b) Ambient temperature and relative humidity within the Ambient Weather Test Window shown in Figure 1

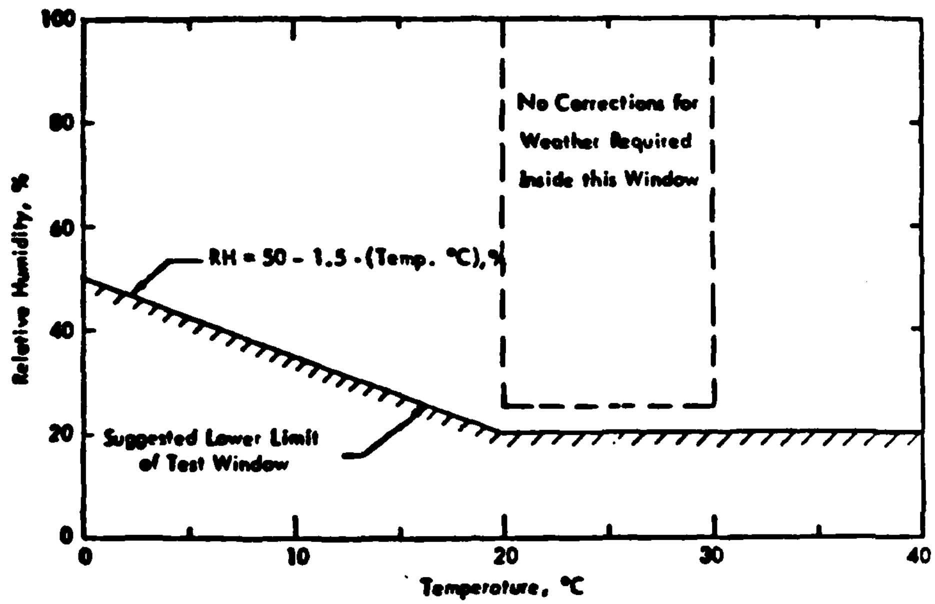

Figure 1. Suggested Ambient Weather Test Window (no tests allowed outside limit between 0 to 40°C, lower humidity limit indicated by hatched line and 100%; no weather correction required for tests conducted inside window bounded by dashed line).

(c) Wind velocity not above 10 knots at each microphone unit, and cross wind component not above 5 knots at 10 m above ground level

(d) No temperature inversion or anomalous wind conditions that would significantly affect the noise level of the aircraft as measured at each microphone location

(e) No excessive wind conditions at flight altitude that would significantly affect the performance of the aircraft in takeoff and flyover operations.

3.2 Noise Measurement Locations

The equipment to be used for noise data acquisition at each measurement location is specified in Section 4.0, "Acoustic Measurement Equipment."

The locations for installation of this equipment are as illustrated in Figure 2 and specified as follows:

3.2.1 Primary Noise Measurement Sites

The primary noise measurement sites shall be on the extended centerline of the takeoff runway and at distances of 2.0 km (6,562 ft) and 2.5 km (8,202 ft) from the approved brake release marker on the runway.

3.2.2 Secondary Noise Measurement Site

One secondary noise measurement site shall be used to acquire supplementary noise data. This shall be at a distance of 450 m (476 ft) to the side of the runway centerline, and at a distance parallel to the runway which is equivalent to the sum of D_{50} (the takeoff distance to 50 ft height at maximum certificated takeoff weight) from the brake release marker plus 300 m.

3.3 Meteorological Data Measurements

The following meteorological data will be obtained during each test flight:

(i) Maximum and minimum wind vector and average wind speed,
(ii) Barometric pressure,
(iii) Temperature, and
(iv) Relative humidity.

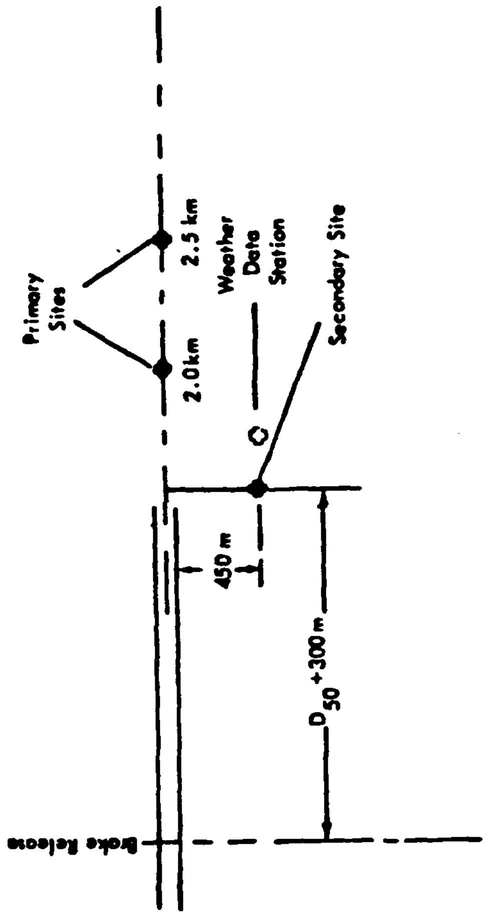

Figure 2. Illustration of Data Acquisition Site Layout

Wind, temperature, and relative humidity will be measured at 10 m above ground level, at a location adjacent to the takeoff runway. In addition, outside air temperature will be measured at flight level intervals by means of aircraft instruments.

3.4 Photographic Measurements of Aircraft Height

A calibrated photographic method shall be used at each of the two primary noise measurement locations underneath the flight path to determine the actual heights of the aircraft during actual and simulated takeoff flyovers and during level flights over each microphone.

4.0 ACOUSTIC MEASUREMENT EQUIPMENT

4.1 General Requirements

4.1.1 Primary Noise Measurement Site Equipment

The noise measuring equipment at each of the two primary measuring sites shall consist of the following instrumentation:

(i) Two measurement microphones* shall be used at each site. One microphone shall be at 1.2 m (4 ft) above ground level and the other shall be at 10 m (32.8 ft) above ground level.

(ii) Each microphone shall be cable-connected to a microphone input of a 2-channel instrumentation tape recorder* (e.g., Nagra IV SJ or equivalent). The higher microphone (at 10 m height) shall be connected to Channel 1, and the lower microphone connected to Channel 2.

(iii) The recording equipment shall be set to record the sound pressure analog signal in the linear (unweighted) mode.

(iv) A direct ("line") output from Channel 1 of the recording equipment shall be input to an integrating sound level meter* (e.g., B&K 2218, GR 1988, or equivalent) which will provide a visual (direct) meter display of maximum A-weighted sound level and time-integrated A-weighted sound level during each test flight.

*These items will comply with specifications as contained in Section 4.2.

(v) An acoustic calibrator with a 1000 Hz signal (e.g., B&K 4230 or equivalent) shall be used at each site to provide a means of calibrating each measurement system, including the recording media and direct read integrating sound level meters.

(vi) Each microphone shall be firmly mounted on a suitable mounting pole or tripod with the microphone diaphragm in a vertical plane (the axis at the microphone preamplifier will be horizontal).

(vii) A suitable windscreen shall be installed on each microphone.

4.1.2 Secondary Noise Measurement Site Equipment

The noise measuring equipment at the secondary measuring site shall consist of the following:

Either

(i) A direct reading sound level meter* capable of providing a direct measurement of the maximum A-weighted sound level using "Slow" meter response characteristics,

or

(ii) An instrumentation tape recorder* with appropriate microphone.

(iii) Each microphone* shall be mounted at a height of 1.2 m (4 ft) above ground level with the microphone diaphragm in the vertical plane.

(iv) A suitable windscreen shall be installed on each microphone.

(v) Calibration shall be by means of an acoustic calibrator with a 1000 Hz signal.

4.2 Equipment Specifications

4.2.1 Microphone Characteristics

The microphones to be used at the primary noise measurement sites shall be "pressure response" microphones to be installed such that the flight path of the aircraft will be in the grazing incidence plane of the microphone diaphragm.

*These items will comply with specifications as contained in Section 4.2.

The variation of sensitivity of the complete pressure response microphone systems with an angle of $\pm 20^\circ$ of grazing incidence (i.e., 70° to 110° from the normal through the diaphragm) shall not exceed ± 2 dB for any frequency over the range 40 Hz to 12,500 Hz (B&K type 4166 microphones meet these specifications).

The microphone to be used at the secondary noise measurement sites shall be a pressure response microphone to be installed such that the line of closest approach to the flight path of the aircraft will be in the grazing incidence plane of the microphone diaphragm.

In all other aspects, each measurement system will comply with ANSI S1.4-1971 specifications for Type I Sound Level Meters.

4.2.2 Integrating Sound Level Meters

The integrating characteristics of sound level meters to be used at the primary noise measurement sites shall be capable of providing:

(a) The maximum A-weighted sound level with "Slow" meter response characteristics,

(b) The Sound Exposure Level, L_{AX} (or SEL), as defined by ISO 3891, "Procedure for Describing Aircraft Noise Heard On the Ground," and

(c) The Average Energy Sound Level (L_{eq}) and the time period of integration.

4.2.3 Magnetic Tape Recorders

The time history of sound pressure as measured by the sensing equipment shall be recorded with broadband linear characteristics using a tape recorder meeting the requirements of SAE J184 (ANSI S6.1-1973), "Qualifying a Sound Data Acquisition System" (Nagra IV SJ tape recorders suggested in Section 4.1.1 comply with this requirement).

5.0 FLIGHT PROCEDURES

5.1 General

Test flights will comprise a series of takeoff operations from an approved brake release marker, a series of level flyovers, and a series of simulated climbout flights over the noise measuring stations. These flights may be performed as separate sets of tests or as a series of alternating tests (i.e., takeoff, level flight; takeoff, etc.), whichever is more convenient to expedite the test program.

The aircraft will be at its certificated maximum takeoff weight at the start of testing and will be within 10 percent of this gross weight during tests.

The following procedures apply to the respective tests.

5.2 Takeoff Tests

Each takeoff will commence from a still position with the aircraft at a marked brake release point.

Flaps will be at takeoff position per Pilot's Operating Handbook (POH). This setting will be maintained until the gear are retracted, or (for fixed geared aircraft) until the aircraft has attained adequate altitude and airspeed to establish a clean configuration V_y climb.

Landing gear retraction should be initiated at an altitude of 50 ft above ground level.

Takeoff power per POH will be maintained throughout the takeoff and climb. As soon as practical after liftoff, one of the following airspeeds should be obtained as specified:

(a) V_y for single-engine aircraft
(b) V_{yme} for twin-engine aircraft.

The aircraft will be flown on a straight out pattern over the extended centerline of the runway, and over the noise measurement sites, at its performance rating, configuration and attitude for best rate of climb (R/C) consistent with its rated airspeed (V_y or V_{yme}).

The duration of the takeoff test will be limited by engine operating parameters (e.g., 5 minutes at rated takeoff power) or a lesser time period which will ensure adequate data acquisition at ground level and in the aircraft cabin.

5.3 1000 Foot Level Flight Flyover Tests

As far as is practical, the level flight flyover tests will be performed in accordance with procedures described in FAR Part 36, Appendix F, Section F36.111, "Flight Procedures." These are reproduced, in part, as follows:

(a) Tests should include at least six level flights over the measuring station at a height of 1,000 ft ± 30 ft and ± 10 degrees from the zenith when passing overhead.

(b) Each test overflight should be conducted -

(1) At not less than the highest power in the normal operating range provided in an Airplane Flight Manual, or in any combination of approved instrument markings; and

(?) At stabilized speed with propeller synchronized and with the airplane in cruise configuration, except that if the speed at the power setting prescribed in this paragraph would exceed the maximum speed authorized in level flight, accelerated flight is acceptable.

Each flyover condition shall be maintained during the overflight of both primary noise measurement sites.

5.4 Simulated Takeoff Climbout Tests

The tests will simulate, as closely as possible within safe limits of aircraft operation, the takeoff segment that would occur on a best rate-of-climb at V_y airspeed through a 1,000 ft height point above a microphone station suitably located under the takeoff flight path.

The simulation flight segment shall overfly the primary noise data recording stations in a V_y climb which shall achieve a 1,000 ft height at some point above the measurement stations. These tests need not be performed if the 1,000 ft height point will be achieved at less than 2.6 km from brake release in a takeoff test (previously described).

The feasibility and performance of these simulation tests will be at the discretion of Cessna Aircraft Company.

6.0 TEST PROCEDURES

6.1 Test Site and Equipment Preparation

Ground markers will be placed at an approved brake release point on the runway and at each of the data acquisition locations, including:

(i) the primary noise measurement sites on the extended runway centerline,

(ii) the secondary noise measurement sites, as determined for each aircraft, and

(iii) the meteorological data acquisition site.

These marker locations will be selected such that each site is readily accessible and conforms with the requirements of Section 3.0, "Field Test Requirements."

Data acquisition systems will be installed at each location in accordance with Sections 3.0 and 4.0. Acoustic data acquisition systems will have been calibrated, prior to installation, to ensure compliance with equipment specifications. Photographic equipment will have been calibrated, prior to field installation, for the test aircraft.

6.2 Field Calibrations

All acoustic data acquisition systems will be calibrated prior to and during the test program. This requires the input of a 1000 Hz acoustic calibration signal to each microphone. Sound level meters shall be calibrated after adjustment of meter gain to the calibration signal level. Any deviation in sound level meter reading from the preceding calibration level shall be recorded in the test log book. For tape recorder systems, a 30-second recording of the calibration signal shall be made on each magnetic tape. Amplifier/attenuator settings of all equipment will be recorded in a test log book and annotated on magnetic tape for each data recorder system. The schedule of calibration shall be based on the requirement for a calibration signal to be recorded at the beginning and end of each magnetic recording tape.

6.3 Test Performance

The test supervisor shall ensure that all systems are operative and calibrated prior to test commencement.

Acoustic data acquisition systems will be adjusted to amplifier/attenuator settings which will allow direct read capability of the expected test noise levels on each sound level meter, and which will allow tape recordings of the noise history to be obtained within the recording limits of the equipment. Care shall be taken to set the recording level so as to utilize as much of the dynamic range of the recorder as practical. These settings will be recorded for each test in a test log book.

A 60-second sample of the ambient noise at each of the primary sites will be recorded on magnetic tape prior to the commencement of, and immediately following, the flight operations. For the later post-test recording, gain settings of the data acquisition equipment will be identical to those to be used in the prior flight tests.

The commencement of a test will be the time of aircraft brake release and start of takeoff run, or an otherwise suitable time marker for level overflights, and notification of this time will be provided to all test personnel. The following procedures will be followed for each test:

(a) Flight Crew

The test flights will be performed in accordance with Section 5.0 of this test plan.

A flight test engineer, aboard the aircraft, will record the following flight data:

1. Date, test number, aircraft type, and test type (takeoff or flyover)
2. Time at brake release (or at start of a level flyover)
3. Flight path direction
4. Propeller rpm, manifold pressure and airspeed at the segment of the test flight which occurs during flyover of the two primary noise measurement positions
5. Outside air temperature
6. Altitude during 1000 ft flyover test segment
7. Description of flight profile.

(b) Acoustic Test Engineers (Ground Personnel)

Sound level meters and microphone/amplifier systems will be activated at least 1 minute before each test commencement. (This excludes activation of L_{AX} integration on integrating sound level meters.)

Each tape recorder will be activated before the time of aircraft brake release or before the start of a 1000 ft flyover segment or simulated climbout.

Time integration, for evaluation of L_{AX} and L_{eq} at each of the primary noise measurement sites, will commence at the time of aircraft brake release and will continue until the A-weighted sound level at the site has diminished by more than 10 dB from the maximum observed sound level during the aircraft overflight.

The tape recording of data shall be stopped at 30 seconds after the completion of the L_{AX} time integration period.

The engineer at each primary test site shall record the following information for each test flight:

1. Site identification and date
2. Test number, aircraft type and test type (takeoff or flyover)
3. Time at aircraft brake relase (or at start of a level flyover)
4. Amplifier/attenuator settings on each item of acoustic measurement equipment used in the test
5. Maximum A-weighted sound level, measured with "Slow response" meter characteristics, during the aircraft flyover
6. L_{AX}, L_{eq}, and integration time as given by the integrating sound level meter at each primary noise measurement site
7. Comments on the flight and data acquisition procedures, and on the measured noise data, which would qualify, or otherwise, the validity of the test data.

The engineer at each secondary test site shall record all of the preceding information, as measured at the secondary site, except with regard to L_{AX}, L_{eq}, and integration time data.

(c) Photographers

A photographer at each primary noise measurement site shall be responsible for ensuring that a photograph is obtained of the aircraft in its overhead position during each test flight. Each photograph shall be identified as follows:

1. Site identity and date
2. Test number, aircraft type and test type
3. Time (approximate)
4. Camera serial number or other identification.

A calibration photograph of each aircraft shall be obtained at a known distance for purposes of aircraft range scaling.

(d) Meteorological Station Attendant

Meteorological data will be obtained at the weather station for each test flight. The following information shall be recorded for each test:

1. Test number, date and time
2. Wind magnitude and direction at 10 m height
3. Temperature
4. Barometric pressure
5. Relative humidity

7.0 DOCUMENTATION

Each test series on each aircraft will be documented with the following information:

(i) Aircraft type and model designation

(ii) Propeller and engine designations

(iii) Propeller blade number, diameter, and tip thickness and chord at 95% radius.

(iv) Propeller tip shape (standard, cut, etc.)

(v) Exhaust type

(vi) Maximum takeoff weight

(vii) D_{50}, certificated best rate of climb (R/C), speed for best rate of climb (V_y or V_{yme}), and V_{so}.

(viii) Maximum takeoff power (hp) and propeller rpm

(ix) Maximum normal operating power (hp) and propeller rpm

(x) Cruise speed at 65% power at 1,000 ft above sea level.

Each test will be documented with all of the test data and observations recorded at each site.

8.0 MEASUREMENT EQUIPMENT AND STAFF ALLOCATIONS

8.1 Site Provisions

8.1.1 Primary Noise Recording Sites

Site 1 will be a sound measuring station located 2 km from a brake release marker, and on the extended centerline of the takeoff runway.

The site will be attended by

- a noise data recording engineer, and
- a photographer.

Equipment will comprise:

- One Nagra IV SJ Magnetic Tape Recorder with QSKA SK 2-channel amplifier
- One 10 m cable with QSPB microphone preamplifier
- One 2 m cable with QSPB microphone preamplifier
- Two B&K 4166 Microphones
- One 10 m microphone support stand
- One 1.2 m microphone support stand
- Two microphone windscreens
- One B&K 4230 Calibrator
- One B&K 2218 Integrating Sound Level Meter
- Connecting cable from Nagra IV SJ Channel I line output to B&K 2218 amplifier input
- One camera
- Batteries and Magnetic Tape
- Data and Record Log Sheets
- Communication Transceiver

Site 2 will be a sound measuring station located 2.5 km from a brake release marker, and on the extended centerline of the extended runway.

The site will be attended by:

- a noise data recording engineer, and
- a photographer.

Equipment will comprise

- One Nagra IV SJ Magnetic Tape Recorder with QSJA SK 2-channel amplifier
- One 10 m cable with QSPB microphone preamplifier
- One 2 m cable with QSPB microphone preamplifier
- Two B&K 4166 Microphones
- One 10 m microphone support stand
- One 1.2 m microphone support stand
- Two microphone windscreens
- One B&K 4230 Calibrator
- One B&K 2218 Integrating Sound Level Meter
- One GR 1988 Integrating Sound Level Meter
- Connecting cables from Nagra IV SJ Channel I line output to B&K 2218 and GR 1988 preamplifier inputs
- One camera
- Batteries and Magnetic Tape
- Data and Record Log Sheets
- Communication Transceiver

8.1.2 Secondary Noise Recording Site

Site 3 will be a sound measuring station located at a sideline distance of 450 m from the takeoff runway centerline and at a distance equal to (D_{50} + 300 m) along this sideline from a point adjacent to the brake release marker. The distance (D_{50} + 300 m) will be predetermined for each aircraft.

The site will be attended on an intermittent basis (for tape changes and calibration) by:

- a noise data recording engineer

Equipment at this site will comprise:

- One B&K 2203 Sound Level Meter
- One B&K 4134 (1/2-inch) Microphone and Adaptor
- One Nagra IV SJ Tape Recorder
- One 1.2 m microphone support stand
- One microphone windscreen
- One B&K 4230 Calibrator
- Batteries and Magnetic Tape
- Data and Record Log Sheets
- Cable connection from B&K 2203 output to Nagra IV SJ input

B.1.3 Meteorological Data Station

This site will be located near the airfield runway.

Equipment will comprise:

- One suitable 10 m height meteorological station capable of providing data in accordance with Sections 3.3 and 6.3(d) of the test plan

- Data Log Sheets

B.3 Test Data

The following test data were obtained during the flight test demonstration program:

Table B-2 summarizes the meteorological data measured at Sunflower Airfield during the flight test program.

Table B-3 (4 sheets) comprises facsimile copies of Aircraft Data Sheets as used by the flight crew of each aircraft during the tests.

Table B-4 (10 sheets) comprises the Test Data Logs used at each primary noise measuring station. That is:

> Sheets 1-4: Data obtained at Measurement Station ("Alpha") at 2.0 km from the runway brake release marker.
>
> Sheets 5-10: Data obtained at Measurement Station ("Baker") at 2.5 km from the runway brake release marker.

Each of these Test Data Log Sheets shows the time of day, run number, aircraft type, and flight profile for each flyover test. Photographic records are identified in the Test Log by the flight number and the estimated aircraft height over the measurement station, as scaled from each Polaroid photograph. Recording data, shown in the test logs, refers to Nagra IV SJ Attenuator Settings as described in the footnotes to each log sheet. A column in each log sheet shows the input calibration sound pressure level (where appropriate) and/or the type of Integrating Sound Level Meter used to obtain the direct-read noise data from Channel 1 (10 m height microphone). One B&K 2218 sound level meter was used at the 2.0 km (Alpha) station, whereas at the 2.5 km (Baker) station, B&K 2218 and GR 1988 sound level meters were connected in parallel to provide separate noise level readings from the 10 m height microphone input to Channel 1 of the Nagra.

The noise data shown in each of these Test Log sheets represent the levels read directly in the field from the sound level meters after accounting for system attenuator settings. These direct read values are subsequently verified by laboratory analysis of the data simultaneously recorded in the field through the same microphone. A Bruel & Kjaer 2218 Integrating Sound Level Meter was used for this laboratory analysis. These data were measured in accordance with the procedures specified in Section 6.2 of the Test Plan (Section B.2 of this appendix).

Table B-5 (10 sheets) comprises the same Test Data Log format as was used in the field measurement program. However, the data shown in Table B-5 was obtained by subsequent laboratory analysis of the tape-recorded Channel 1 (1.2 m height microphone) time histories. A Bruel & Kjaer 2218 Integrating Sound Level Meter was used for data evaluations in all of these cases.

Sheets 1-4 of Table B-5 apply to recordings obtained at 2 km from the brake release marker ("Alpha"), and

Sheets 5-10 apply to recordings obtained at the 2.5 km station ("Baker").

Table B-2

Meteorological Data

Date: 9/14/81 Test Site: Sunflower Airfield

Station Barometric Pressure: 28.30 in. Hg Station Hp: 1500 ft

		Wind @ 30 ft		Wind @ 1.2 m		Temp. (°F)		
Flight No.	Time	Vel. (mph)	Dir. (deg)	Vel. (mph)	Dir. (deg)	30 ft	1.2 m	Rel. Hum. (%)
1	1126	7	030	5	030	71	77	64
2	1135	8	030	7	030	73	78	61
3	1140	9	030	5	030	74	79.5	59
4	1145	6	030	6	030	74	80	58
5	1148	6	030	6	030	73	80	58
6	1152	5	030	6	030	75	81.5	55
7	1156	11	030	8	030	74	81	56
8	1159	6	030	6	030	76	81	56
9	1203	8	030	8	030	74	81	56
10	1401	11	030	7	030	77	81	56
11	1408	7	030	2	030	76	83	48
12	1415	6	030	6	030	77	83	48
13	1421	4	000	0	000	77	84	48
14	1428	2	000	0	000	79	84	48
15	1434	8	000	4	000	79	85	48
16								
17	1525	5	045	5	045	79	84	48
18	1532	6	045	3	045	79	84	48
19	1538	5	045	7	045	79	83	48
20	1613	11	030	9	030	78	83	44
21	1616	11	045	9	045	78	83	44
22	1619	6	045	6	045	78	83	44
23	1628	11	045	9	045	78	83	44

Table B-2 (Continued)

Flight No.	Time	Wind @ 30 ft Vel. (mph)	Wind @ 30 ft Dir. (deg)	Wind @ 1.2 m Vel. (mph)	Wind @ 1.2 m Dir. (deg)	Temp. (°F) 30 ft	Temp. (°F) 1.2 m	Rel. Hum. (%)
24	1637	11	030	9	030	78	83	44
25	1641	9	045	6	045	79	83	44
26	1711	8	030	8	030	79	83	44
27	1716	10	045	10	045	79	83	41
28	1721	9	045	6	045	79	83	41
29	1725	8	045	6	045	79	83	41
30	1739	11	045	10	045	79	83	41
31	1743	11	045	7	045	79	83	43
32	1745	11	045	6	045	79	83	43
33	1749	15	045	10	045	79	83	43
34	1801	7	030	5	030	79	83	42
35	1807	10	045	8	045	79	83	42

Table B-3

PREPARED BY	DATE	PAGE 1 of 4
CHECKED BY	DATE	REVISION	REPORT NO.
		MODEL

Cessna.

CESSNA AIRCRAFT CO. PAWNEE DIVISION WICHITA, KANSAS

MODEL 402 FLYOVER NOISE TEST- AIRCRAFT DATA SHEET

DATE 14 Sept '81 REGISTRATION NUMBER 402 CW TEST NO.

PILOT B.F. OBSERVERS DRE

GROSS WEIGHT: BEFORE 6900 AFTER Elapsed Time 0.9

ENGINE
- MANUFACTURER ____ TYPE ____
- MODEL NUMBER ____ SERIAL NUMBER ____
- MAXIMUM CONTINUOUS POWER: RPM ____ HP ____

PROPELLER
- MANUFACTURER ____ SERIAL NUMBER ____
- HUB NUMBER ____ BLADE NUMBER ____

MUFFLER
- MANUFACTURER ____ PART NUMBER ____

OVERFLIGHT INFORMATION ← [PHOTO SCALE]

FLIGHT NO	HDG	TIME START	RPM	MP IN HG	ALTITUDE FT IND/	IAS KTS	OAT °F	TIME STOP	REMARKS Type of Test
1	N	1126	2600	39.0	2500/ 1100 Ft	183	68		Level F.O
2	S	1135	2600	39.0	2500/ [—]	188	68		L. F.O
3	N	1140	2600	39.0	2610/ [1000]	188	69		L. F.O
4	S	1145	2600	39.0	2560/ [956]	187	69		L. F.O
5	N	1152	2600	39.0	2590 [—]	188	69		L. F.O No photo
6	S	1152	2600	39.0	2550 [1000]	185	69		L. F.O.
7	N	1156	2600	39.0	2530 [1000]	184	69		L. F.O
8	S	1159	2600	39.0	2570 [1012]	186	70		L. F.O
9	N	1203	2600	39.0	2590 [—]	185	70		L. F.O No Photo
~~10~~									
~~11~~									
~~12~~									

COMMENTS

Table B-3 (Continued)

TITLE ______ PAGE 2 of 4

Cessna.

PREPARED BY ______ DATE ______ REPORT NO. ______

CHECKED BY ______ DATE ______ REVISION ______ MODEL ______

CESSNA AIRCRAFT CO. PAWNEE DIVISION WICHITA, KANSAS

MODEL 402 FLYOVER NOISE TEST- AIRCRAFT DATA SHEET

DATE 14 Sept REGISTRATION NUMBER 402CW TEST NO. ______

PILOT BB OBSERVERS DRE

GROSS WEIGHT: BEFORE Fuel 400 [illegible] Landing AFTER Off 1400 On 1453 [illegible]

ENGINE: MANUFACTURER ______ TYPE ______ MODEL NUMBER ______ SERIAL NUMBER ______ MAXIMUM CONTINUOUS POWER: RPM ______ HP ______

PROPELLER: MANUFACTURER ______ SERIAL NUMBER ______ HUB NUMBER ______ BLADE NUMBER ______

MUFFLER: MANUFACTURER ______ PART NUMBER ______

OVERFLIGHT INFORMATION

FLIGHT NO	HDG	TIME START	RPM	MP IN HG	ALTITUDE FT	IAS KTS	OAT °F	TIME STOP	REMARKS Type of Test
10	N	1401	2700	39	~800	95/110	67		Takeoff
11	N	1408	2700	39	[illegible]	95/110	68		Takeoff No [illegible]
12	N	1415	2700	39	~800	95/110	69		Takeoff OK
13	N	1421	2700	39	~800	95/110	70		Takeoff OK
14	N	1428	2700	39	800	95/110	72		Takeoff OK
15	N	1434	2700	39		95/110	72		Takeoff
7									
8									
9									
10									
11									
12									

COMMENTS ______

Table B-3 (Continued)

TITLE ____	Cessna.	PAGE 3 of 4
PREPARED BY ____ DATE ____		REPORT NO. ____
CHECKED BY ____ DATE ____	REVISION ____	MODEL ____
CESSNA AIRCRAFT CO.	PAWNEE DIVISION	WICHITA, KANSAS

MODEL T210N FLYOVER NOISE TEST - OBSERVER DATA SHEET

DATE 9/14/81 REGISTRATION NUMBER N7416N ~~TEST~~ FLT NO. 201

PILOT L R Ikard OBSERVERS R. K. Rice

GROSS WEIGHT: BEFORE 4048 ( ) AFTER ____ ( )

OVERFLIGHT INFORMATION DIAL

~~RUN~~ NO.	HDG (°)	RPM	M.P. (in. Hg)	IAS (KTS)	OAT (~~°F~~)	ALTITUDE ( ) AGL	REMARKS	TOD
16	N	2700	36.4	100	79/75	T.O.		3:20
17	N	2700	✓	✓	7/75	✓		3:25
18	N	✓	36.2	✓	83/76	✓		3:32
19	N	✓	✓	✓	82/76	✓		3:38
20	N	2600	35.	156	78	2640	1050 RDR ALT FLYOVER 41' TO 2H1	4:13
21	S	✓	✓	167	79	2620	1000 RDR ALT	4:16
22	N	✓	✓	166	80	2630	1050 RDR ALT	4:19
23	S	✓	✓	166	79	2610	1000 RDR ALT	4:22
24	N	2700	36.3	100	78	Sim/TO.	≈ 1000 FT AGL	4:37
25	N	✓	✓	✓	78	✓		4:41

COMMENTS TO END 201

LOG ON 4:47 1846

Table B-3 (Continued)

TITLE			PAGE 4 of 4
PREPARED BY	DATE	Cessna.	REPORT NO.
CHECKED BY	DATE	REVISION	MODEL
CESSNA AIRCRAFT CO.		PAWNEE DIVISION	WICHITA, KANSAS

MODEL 172P FLYOVER NOISE TEST - OBSERVER DATA SHEET

DATE 9/11/81 REGISTRATION NUMBER N6786R ~~TEST~~ FLT NO. 306

PILOT L P Ekerd OBSERVERS R K Rice

GROSS WEIGHT: BEFORE ? (LBS) AFTER ( )

OVERFLIGHT INFORMATION

~~RUN~~ NO.	HDG (°)	RPM @V4	M.P. (in. Hg)	IAS (KTS)	OAT (°F)	ALTITUDE (FT) AGL	REMARKS TOD
26	N	2420	27.5	SHIELD 75	81 GRD / 76 100'	T.O.	PWR SETTING ... FLFIIA FLAPS UP 5:11
27	N	2430	27.5	✓	81/76	✓	5:16
28	N	2420	27.5	✓	82/76	✓	5:21
29	N	✓	✓	✓	82/76	✓	5:25
30	N	2710	26.7	120	76	2625	FLYOVER 1045' 5:31
31	S	2720	✓	123	✓	2600	1029' 5:43
32	N	2650	26.7	114	✓	2605	1029' 5:45
33	S	2705	26.7	121	✓	2600	1000' 5:52
34	N	2410	26.8	75	74	SIM. T.O.	PWR & TEMP @ 1000 AGL 1000' 6:01
35	N	✓	✓	✓	74	✓	6:07

COMMENTS T.O. SUN 5:11 ALT SET 410'

LOG CLEAR 6:32 770' OUT RUNWAY 35L

1:21 (1.4)

Table B-4

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones)

Sheet 1 of 10

Date: 9/14/81

Measurement Station: Alpha @ 2.0 km

Tape No.: A-1

SLM Type: B&K 2218

Mic. Types: (1) 4134 (2) 4134

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1012	Cal.	-	-	-	-	60	30	0	94 dB	(104)			B&K 2218
1126	1	402 C	L/No.	1	936	60	20	0	B&K	-	-	-	.010 h
1135	2	402 C	L/So.	2	933	60	20	0	2218	78.0	83.8	68.7	.008 h
1140	3	402 C	L/No.	3	1068	60	20	0	2218	77.0	83.7	66.1	.015 h
1145	4	402 C	L/So.	4	988	60	20	0	2218	78.0	83.4	67.1	.007 h
1148	5	402 C	L/No.	5	1024	60	20	0	2218	78.5	84.2	67.0	.014 h
1152	6	402 C	L/So.	6	1008	60	20	0	2218	77.5	83.6	67.0	.012 h
1156	7	402 C	L/No.	7	996	60	20	0	2218	79.0	84.0	66.7	.015 h
1159	8	402 C	L/So.	8	1012	60	20	0	2218	78.0	83.3	68.3	.008 h
1203	9	402 C	L/No.	9	1041	60	20	0	2218	77.0	83.6	66.8	.013 h
1401	10	402 C	T/No.	10	-	60	20	0	2218	85.0	90.4	71.7	.020 h
1408	11	402 C	T/No.	11	619	60	20	0	2218	84.0	90.5	71.8	.021 h

Note:

Flight Profiles: T - Takeoff, L - Level Flight, S - Simulated Climbout/Direction; No. - North, So. - South

Attenuator Settings: G - Gain Selector (40, 60, or 80 dB)
M - Main Attenuator (10 dB increments)
V - Vernier Attenuator (1 dB increments)

Nagra - Channels 1 and 2

Calibration: Input Calibration Level (dB) or SLM type, as appropriate.

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones)

Sheet 2 of 10

Date: 9/14/81

Measurement Station: Alpha @ 2.0 km

Tape No.: A-1

SLM Type: B&K 2218

Mic. Types: (1) 4134 (2) 4134

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1415	12	402 C	T/No.	12	536	60	20	0	2218	85.0	90.8	72.5	.018 h
-	Cal.	-	-	-	-	60	30	0	94 dB	(104)	-	-	Cal.
1421	13	402 C	T/No.	13	676	60	20	0	B&K	83.0	89.8	71.2	.020 h
1428	14	402 C	T/No.	14	678	60	20	0	2218	82.5	89.6	70.7	.021 h
1434	15	402 C	T/No.	15	609	60	20	0	2218	85.0	91.1	72.1	.021 h
1520	16	T210N	T/No.	-	-	-	-	-	-	-	-	-	-
1525	17	T210N	T/No.	17	415	60	20	0	2218	89.0	93.8	79.8	.006 h
1532	18	T210N	T/No.	18	456	60	20	0	2218	88.5	93.2	77.0	.011 h
1538	19	T210N	T/No.	19	389	60	20	0	2218	89.0	93.4	77.3	.011 h
1613	20	T210N	L/No.	20	1080	60	20	0	2218	77.0	83.0	67.0	.011 h
1616	21	T210N	L/So.	21	1037	60	20	0	2218	76.5	81.5	66.5	.008 h
1619	22	T210N	L/No.	22	1097	60	20	0	2218	77.0	82.8	65.4	.015 h

Table B-4 (Continued)

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones) Sheet 3 of 10

Date: 9/14/81

Measurement Station: Alpha @ 2.0 km Tape No.: A-2 SLM Type: B&K 2218

Mic. Types: (1) 4134 (2) 4134

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integ. Time h = hours
1622	23	T210N	L/So.	23	1047	60	20	0	2218	-	-	-	-
1637	24	T210N	S/No.	24	783	-	-	-	2218	-	-	-	-

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones) Sheet 4 of 10

Date: 9/14/81

Measurement Station: Alpha @ 2.0 km Tape No.: A-2 SLM Type: B&K 2218

Mic. Types: (1) 4134 (2) Faulty

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integ. Time h = hours
1641	25	T210N	S/No.	25	906	60	20	0	B&K	83.5	89.7	73.3	.011 h
1711	26	172 P	T/No.	26	401	60	20	0	2218	77.5	85.6	69.3	.011 h
1716	27	172 P	T/No.	27	457	60	20	0	2218	76.5	84.9	67.9	.013 h
1721	28	172 P	T/No.	28	427	60	20	0	2218	77.0	85.1	66.5	.020 h
1725	29	172 P	T/No.	29	503	60	20	0	2218	75.5	84.2	66.6	.015 h
1739	30	172 P	L/No.	30	1045	60	20	0	2218	75.5	82.9	64.2	.020 h
1743	31	172 P	L/So.	31	1010	60	20	0	2218	74.5	81.3	65.3	.010 h
1745	32	172 P	L/No.	32	1052	60	20	0	2218	74.5	82.3	63.7	.020 h
1749	33	172 P	L/So.	33	1046	60	20	0	2218	73.0	80.5	63.8	.013 h
1801	34	172 P	S/No.	34	990	60	20	0	2218	69.0	81.5	61.6	.027 h
1807	35	172 P	S/No.	35	1010	60	20	0	2218	70.0	81.2	61.8	.023 h
1825	Cal.	-	-	-	-				94 dB				

Table B-4 (Continued)

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones)

Sheet 5 of 10

Date: 9/14/81

Measurement Station: Baker @ 2.5 km

Tape No.: B-1

SLM Type: B&K 2218 & GR 1988

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours s = secs
0857	-	-	-	-	-	60	40	0	94 dB	(104)			B&K 2218
									94 dB	(114)			GR 1988
1126	1	402C	L/No.	-	-	60	40	0	B&K	80	85.8	68.0	.016 h
									GR	82	85.2	66.4	75 s
1135	2	402 C	L/So.	2	905	60	40	0	B&K	80	85.7	70.7	.008 h
									GR	81.9	85.0	68.3	47 s
1140	3	402 C	L/No.	3	1049	60	40	0	B&K	78.2	85.1	67.3	.016 h
									GR	79.0	84.4	65.4	78 s
1145	4	402 C	L/So.	4	956	60	40	0	B&K	78.0	84.5	70.7	.006 h
									GR	80.1	83.9	66.9	49 s
1148	5	402 C	L/No.	-	-	60	40	0	B&K	78.0	84.7	67.2	.015 h
									GR	79.5	84.0	65.9	64 s

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones)

Sheet 6 of 10

Date: 9/14/81

Measurement Station: Baker @ 2.5 km

Tape No.: B-1

SLM Type: B&K 2218 & GR 1988

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours s = secs
1152	6	402 C	L/So.	6	1000	60	40	0	B&K	78.0	-	-	-
									GR	81.3	84.5	69.1	34 s
1156	7	402 C	L/No.	7	1000	60	40	0	B&K	79.0	85.0	68.0	.016 h
									GR	80.8	84.1	66.3	60 s
1159	8	402 C	L/So.	8	1012	60	40	0	B&K	78.9	84.5	70.1	.007
									GR	80.1	83.8	68.6	32 s
1203	9	402 C	L/No.	-	-	60	40	0	B&K	79.0	85.4	68.7	.012 h
									GR	80.2	84.5	67.6	48 s
1401	10	402 C	T/No.	-	-	60	30	0	B&K	83*	90.8	70.5	.029 h
									GR	84.0	89.9	69.7	104 s
1408	11	402 C	T/No.	-	-	60	40	0	B&K	83.0	90.4	70.6	.026 h
									GR	84.6	89.6	69.5	101 s

Table B-4 (Continued)

Flight Test Program . unflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones)

Sheet 7 of 10

Date: 9/14/81

Measurement Station: Baker @ 2.5 km

Tape No.: B-1

SLM Type: B&K 2218 & GR 1988

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours s = secs
1415	12	402 C	T/No.	12	760	60	40	0	B&K	83.5	90.5	70.8	.025 h
									GR	85.7	89.6	69.9	93 s
1421	13	402 C	T/No.	13	875	60	40	0	B&K	82.5	89.9	70.2	.025 h
									GR	83.8	89.1	69.4	94 s
1428	14	402 C	T/No.	14	935	60	40	0	B&K	81.5	89.3	69.8	.024 h
									GR	82.5	88.5	68.9	90 s
1434	15	402 C	T/No.	15	790	60	40	0	B&K	[illegible]2.4	90.3	70.6	.025 h
									GR	84.8	89.5	69.8	92 s
1520	16	T210N	T/No.	16	824	60	40	0	B&K	87*	94.7	74.5	.029 h
									GR	90.4	94.1	74.0	102 s
1525	17	T210N	T/No.	17	540	60	40	0	B&K	87*	93.6	75.0	.020 h
									GR	89.1	92.9	74.2	73 s
1532	18	T210N	T/No.	18	618	60	40	0	B&K	87.0	92.5	73.7	.020 h
									GR	87.9	91.8	73.1	72 s

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones)

Sheet 8 of 10

Date: 9/14/81

Measurement Station: Baker @ 2.5 km

Tape No.: B-1

SLM Type: B&K 2218 & GR 1988

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours s = secs
1538	19	T210N	T/No.	19	591	60	40	0	B&K	85.5	92.0	73.4	.020 h
									GR	87.5	91.2	72.6	72 s
1613	20	T210N	L/No.	20	1041	60	40	0	B&K	77.5	84.5	67.2	.014 h
									GR	80.2	83.7	66.4	52 s
1616	21	T210N	L/So.	21	1014	60	40	0	B&K	78.5	83.9	70.8	.005 h
									GR	81.2	83.1	70.1	19 s
1619	22	T210N	L/No.	22	1029	60	30	0	B&K	77*	84.4	67.0	.015 h
									GR	79.4	83.0	66.3	54 s
1622	23	T210N	L/So.	23	1014	60	30	0	B&K	76.0	82.3	69.5	.005 h
									GR	78.4	81.5	69.0	17 s
1637	24	T210N	S/No.	24	922	60	30	0	B&K	84*	90.9	74.0	.013 h
									GR	86.7	90.3	73.1	51 s

Table B-4 (Continued)

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones)

Sheet 9 of 10

Date: 9/14/81

Measurement Station: Baker @ 2.5 km

Tape No.: B-1

SLM Type: B&K 2218 & GR 1988

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours s = secs
1641	25	T210N	S/No.	25	1092	60	40	0	B&K	83.5	89.6	73.6	.011 h
									GR	85.2	88.8	71.6	52 s
1711	26	172 P	T/No.	26	539	60	40	0	B&K	75.0	84.6	64.8	.026 h
									GR	75.4	83.9	64.9	79 s
1716	27	172 P	T/No.	27	610	60	30	0	B&K	74.6	84.9	64.9	.027 h
									GR	75.5	84.2	64.1	99 s
1721	28	172 P	T/No.	28	552	60	30	0	B&K	75.4	84.7	64.8	.026 h
									GR	75.6	83.9	64.0	96 s
1725	29	172 P	T/No.	29	628	60	30	0	B&K	74.0	83.9	64.0	.027 h
									GR	75.9	83.1	63.1	98 s
1739	30	172 P	L/No.	30	1045	60	30	0	B&K	74.5	83.4	65.4	.017 h
									GR	75.1	82.6	64.0	71 s

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 10 m ht microphones)

Sheet 10 of 10

Date: 9/14/81

Measurement Station: Baker @ 2.5 km

Tape No.: B-1

SLM Type: B&K 2218 & GR 1988

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Direct-Read Data (Channel 1)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Tape SLM	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours s = secs
1743	31	172 P	L/So.	31	1029	60	30	0	B&K	74.0	81.2	66.6	.008 h
									GR	75.4	80.4	65.3	32 s
1745	32	172 P	L/No.	32	1029	60	30	0	B&K	75.0	83.2	64.4	.021 h
									GR	76.0	82.4	63.5	77 s
1749	33	172 P	L/So.	33	1000	60	30	0	B&K	74.8	81.7	65.8	.010 h
									GR	76.5	80.9	64.9	38 s
1801	34	172 P	S/No.	34	1000	60	30	0	B&K	67.0	80.2	59.7	.030 h
									GR	68.6	78.9	59.1	95 s
1807	35	172 P	S/No.	35	1077	60	30	0	B&K	68.2	80.9	61.6	.023 h
									GR	69.3	80.3	60.1	101 s
1836	Cal.	-	-	-	-	60	40	0	94.0	(104)			B&K 2218
									94.0	(114)			GR 1988

Table B-5

Flight Test Program at Sunflower Airfield, Kansas — Sheet 1 of 10

Data Analysis Log (data recorded from 1.2 m ht microphones)

Date: 9/14/81

Measurement Station: Alpha @ 2.0 km — Tape No.: A-1 — SLM Type: B&K 2218

Mic. Types: (1) 4134 (2) 4134

Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1012	Cal.	-	-	-	-	60	30	0	94 dB	(104)			B&K 2218
1126	1	402 C	L/No.	1	936	60	20	0	B&K	-	-	-	
1135	2	402 C	L/So.	2	933	60	20	0	2218	78.0	83.5	68.6	.008 h
1140	3	402 C	L/No.	3	1068	60	20	0	2218	77.0	83.2	66.1	.014 h
1145	4	402 C	L/So.	4	988	60	20	0	2218	77.5	83.0	68.7	.007 h
1148	5	402 C	L/No.	5	1024	60	20	0	2218	78.5	84.2	67.2	.013 h
1152	6	402 C	L/So.	6	1008	60	20	0	2218	78.0	83.6	67.1	.012 h
1156	7	402 C	L/No.	7	996	60	20	0	2218	78.5	83.7	66.3	.015 h
1159	8	402 C	L/So.	8	1012	60	20	0	2218	78.0	83.6	68.8	.008 h
1203	9	402 C	L/No.	9	1041	60	20	0	2218	77.0	83.1	66.5	.013 h
1401	10	402 C	T/No.	10	-	60	20	0	2218	85.0	90.0	71.3	.020 h
1408	11	402 C	T/No.	11	619	60	20	0	2218	83.0	89.6	70.7	.021 h

Note: Flight Profiles: T - Takeoff, L - Level Flight, S - Simulated Climbout/Direction; No. - North, So. - South

Attenuator Settings: G - Gain Selector (40, 60, or 80 dB)
M - Main Attenuator (10 dB increments) — Nagra - Channels 1 and 2
V - Vernier Attenuator (1 dB increments)

Calibration: Input Calibration Level (dB) or SLM type, as appropriate.

Flight Test Program at Sunflower Airfield, Kansas — Sheet 2 of 10

Data Analysis Log (data recorded from 1.2 m ht microphones)

Date: 9/14/81

Measurement Station: Alpha @ 2.0 km — Tape No.: A-1 — SLM Type: B&K 2218

Mic. Types: (1) 4134 (2) 4134

Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1415	12	402 C	T/No.	12	536	60	20	0	2218	84.5	90.0	71.7	.018 h
-	Cal.	-	-			60	30	0	94 dB	(104)	-	-	Cal.
1421	13	402 C	T/No.	13	676	60	20	0	B&K	81.5	88.6	70.0	.020 h
1428	14	402 C	T/No.	14	678	60	20	0	2218	82.0	88.8	70.0	.021 h
1434	15	402 C	T/No.	15	609	60	20	0	2218	83.5	89.8	71.1	.021 h
1520	16	T210N	T/No.	-	-	-	-	-	-	-	-	-	-
1525	17	T210N	T/No.	17	415	60	20	0	2218	87.0	91.8	77.9	.006 h
1532	18	T210N	T/No.	18	456	60	20	0	2218	87.0	92.0	75.8	.011 h
1538	19	T210N	T/No.	19	389	60	20	0	2218	87.0	91.5	75.1	.011 h
1613	20	T210N	L/No.	20	1080	60	20	0	2218				
1616	21	T210N	L/So.	21	1037	60	20	0	2218				
1619	22	T210N	L/No.	22	1097	60	20	0	2218				

Table B-5 (Continued)

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 1.2 m ht microphones)

Sheet 3 of 10

Date: 9/14/81

Measurement Station: Alpha @ 2.0 km

Tape No.: A-2

SLM Type: B&K 2218

Mic. Types: (1) 4134 (2) 4134

Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1622	23	T210N	L/So.	23	1047	60	20	0	2218	-	-	-	-
1637	24	T210N	S/No.	24	783	-	-	-	2218	-	-	-	-

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 1.2 m ht microphones)

Sheet 4 of 10

Date: 9/14/81

Measurement Station: Alpha @ 2.0 km

Tape No.: A-2

SLM Type: B&K 2218

Mic. Types: (1) 4134 (2) Faulty

Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1641	25	T210N	S/No.	25	906	60	20	0	B&K	-	-	-	-
1711	26	172P	T/No.	26	401	60	20	0	2218	-	-	-	-
1716	27	172P	T/No.	27	457	60	20	0	2218	-	-	-	-
1721	28	172P	T.No.	28	427	60	20	0	2218	-	-	-	-
1725	29	172P	T/No.	29	503	60	20	0	2218	-	-	-	-
1739	30	172 P	L/No.	30	1045	60	20	0	2218	-	-	-	-
1743	31	172 P	L/So.	31	1010	60	20	0	2218	-	-	-	-
1745	32	172 P	L/No.	32	1052	60	20	0	2218	-	-	-	-
1749	33	172 P	L/So.	33	1046	60	20	0	2218	-	-	-	-
1801	34	172 P	S/No.	34	990	60	20	0	2218	-	-	-	-
1807	35	172 P	S/No.	35	1010	60	20	0	2218	-	-	-	-
1825	Cal.	-	-	-	-				94 dB				

Table B-5 (Continued)

Flight Test Program at Sunflower Airfield, Kansas — Sheet 5 of 10

Data Analysis Log (data recorded from 1.2 m ht microphones)

Date: 9/14/81

Measurement Station: Baker @ 2.5 km — Tape No.: B-1 — SLM Type: B&K 2218

Mic. Types: (1) 4166 (2) 4166

Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
0857	-	-	-	-	-	60	40	0	94 dB	(104)			B&K 2218
1126	1	402C	L/No.		-	60	40	0	B&K	81.5	86.5	68.7	.016 h
1135	2	402 C	L/So.	2	905	60	40	0	B&K	81.5	86.3	71.7	.008 h
1140	3	402 C	L/No.	3	1049	60	40	0	B&K	78.5	85.1	67.3	.016 h
1145	4	402 C	L/So.	4	956	60	40	0	B&K	79.0	84.7	70.7	.006 h
1148	5	402 C	L/No.	-	-	60	40	0	B&K	80.5	85.9	68.5	.015 h

Flight Test Program at Sunflower Airfield, Kansas — Sheet 6 of 10

Data Analysis Log (data recorded from 1.2 m ht microphones)

Date: 9/14/81

Measurement Station: Baker @ 2.5 km — Tape No.: B-1 — SLM Type: B&K 2218

Mic. Types: (1) 4166 (2) 4166

Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
1152	6	402 C	L/So.	6	1000	60	40	0	B&K	81.0	86.0	70.2	.010 h
1156	7	402 C	L/No.	7	1000	60	40	0	B&K	80.0	85.9	68.1	.016 h
1159	8	402 C	L/So.	8	1012	60	40	0	B&K	79.5	84.9	70.7	.007 h
1203	9	402 C	L/No.	-	-	60	40	0	B&K	81.5	86.2	69.5	.013 h
1401	10	402 C	T/No.	-	-	60	30	0	B&K	83.0	90.0	71.4	.020 h
1408	11	402 C	T/No.	-	-	60	40	0	B&K	84.0	90.5	70.6	.026 h

Table B-5 (Continued)

Flight Test Program at Sunflower Airfield, Kansas — Sheet 7 of 10

Data Analysis Log (data recorded from 1.2 m ht microphones)

Date: 9/14/81

Measurement Station: Baker @ 2.5 km — Tape No.: B-1 — SLM Type: B&K 2218

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1415	12	402 C	T/No.	12	760	60	40	0	B&K	84.5	90.4	70.7	.025 h
1421	13	402 C	T/No.	13	875	60	40	0	B&K	82.0	89.9	70.1	.025 h
1428	14	402 C	T/No.	14	935	60	40	0	B&K	83.5	89.7	70.3	.024 h
1434	15	402 C	T/No.	15	790	60	40	0	B&K	85.0	90.8	71.2	.025 h
1520	16	T210N	T/No.	16	824	60	40	0	B&K	88.0	93.3	73.3	.027 h
1525	17	T210N	T/No.	17	540	60	40	0	B&K	87.5	92.7	74.1	.020 h
1532	18	T210N	T/No.	18	618	60	40	0	B&K	86.5	92.2	73.5	.020 h

Flight Test Program at Sunflower Airfield, Kansas — Sheet 8 of 10

Data Analysis Log (data recorded from 1.2 m ht microphones)

Date: 9/14/81

Measurement Station: Baker @ 2.5 km — Tape No.: B-1 — SLM Type: B&K 2218

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1538	19	T210N	T/No.	19	591	60	40	0	B&K	85.5	91.5	72.9	.020 h
1613	20	T210N	L/No.	20	1041	60	40	0	B&K	79.0	84.8	67.6	.014 h
1616	21	T210N	L/So.	21	1014	60	40	0	B&K	81.5	85.1	72.6	.005 h
1619	22	T210N	L/No.	22	1029	60	30	0	B&K	78.5	84.4	67.0	.015 h
1622	23	T210N	L/So.	23	1014	60	30	0	B&K	78.0	82.9	70.1	.005 h
1637	24	T210N	S/No.	24	922	60	30	0	B&K	83.5	90.3	73.0	.015 h

Table B-5 (Continued)

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 1.2 m ht microphones)

Sheet 9 of 10

Date: 9/14/81

Measurement Station: Baker @ 2.5 km

Tape No.: B-1

SLM Type: B&K 2218

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1641	25	T210N	S/No.	25	1092	60	40	0	B&K	83.0	88.9	71.4	.015 h
1711	26	172 P	T/No.	26	539	60	40	0	B&K	75.5	84.9	65.7	.023 h
1716	27	172 P	T/No.	27	610	60	30	0	B&K	74.5	84.4	64.4	.028 h
1721	28	172 P	T/No.	28	552	60	30	0	B&K	75.0	84.3	64.5	.026 h
1725	29	172 P	T/No.	29	628	60	30	0	B&K	74.0	83.5	63.6	.027 h
1739	30	172 P	L/No.	30	1045	60	30	0	B&K	75.0	83.0	65.5	.019 h

Flight Test Program at Sunflower Airfield, Kansas

Data Analysis Log (data recorded from 1.2 m ht microphones)

Sheet 10 of 10

Date: 9/14/81

Measurement Station: Baker @ 2.5 m

Tape No.: B-1

SLM Type: B&K 2218

Mic. Types: (1) 4166 (2) 4166

Test Description				Photographic		Recording			Cal.	Tape Analyzed Data (Channel 2)			
Time	Run No.	Aircraft Type	Flight Profile T/L/S	Photo I.D. No.	Est. ht. (ft)	Attenuator Settings G	M	V	Input Cal. or SLM Type	L_{max} dB(A)	L_{ax} dB(A)	L_{eq} dB(A)	Integr. Time h = hours
1743	31	172 P	L/So.	31	1029	60	30	0	B&K	75.0	81.1	66.0	.008 h
1745	32	172 P	L/No.	32	1029	60	30	0	B&K	74.5	82.4	63.9	.019 h
1749	33	172 P	L/So.	33	1000	60	30	0	B&K	75.0	81.6	65.5	.011 h
1801	34	172 P	S/No.	34	1000	60	30	0	B&K	68.0	80.0	59.7	.029 h
1807	35	172 P	S/No.	35	1077	60	30	0	B&K	69.0	80.8	61.2	.025 h
1836	Cal.	-	-	-	-	60	40	0	94.0	(104)			B&K 2218

APPENDIX C

Example Cases of Aircraft Design Noise Analysis Based on Cessna Aircraft Sizing Program

Cessna Aircraft Company participated in the noise control technology assessment part of this program and performed a design evaluation of three different aircraft models by means of their Aircraft Sizing Program.

The noise abatement methods studied were constrained to changes in propeller size and rpm, using the same blade airfoil (Clark Y or RAF 6) in each aircraft model study.

Four design parameters were investigated:

1. Change of blade number
2. Change of propeller rpm
3. Change of propeller diameter
4. Change of propeller activity factor

These design parameters were varied for a single-engined (T210), twin-engined (414A), and twin turbopropeller (441) aircraft size. In each analysis, the range of parameters was limited to that considered to be technically feasible for the aircraft size. The primary output parameter evaluated by the program was flyover noise level. Secondary parameters (denoted as "constraints") evaluated by the program were

- o Takeoff distance,
- o Rate of climb at sea level,
- o Rate of climb at altitude,
- o Payload range, and
- o Cruise speed.

Two cost factors were evaluated: "DOC" and "Price." However, these do not reflect the actual cost of implementing the changes for noise control. They are indications of market value, based on the hypothetical evaluation of the influence of performance degradation on the competitive pricing of the aircraft. Thus a lower "price" value indicated that the aircraft would need to be sold at a lower price in a competitive market.

The above evaluations were performed for a total of 555 cases, comprising 2, 3, and 4 blade propeller designs for the T210 and 414A aircraft, and 3 and 4 blade propellers for the 441 aircraft. Three different rpm cases were evaluated for each aircraft; namely:

2,400, 2,500 and 2,600 rpm for the T210,

2,500, 2,600, and 2,700 rpm for the 414A, and

1,800, 1,900, and 2,000 rpm for the 441 aircraft size.

The following example cases of these analyses are shown in this appendix for the T210 single engine aircraft only.

Table C-1 2 Blades, 2500 rpm

Table C-2 2 Blades, 2400 rpm

Table C-3 3 Blades, 2600 rpm

Table C-4 3 Blades, 2500 rpm

Table C-5 3 Blades, 2400 rpm

Table C-6 4 Blades, 2500 rpm

Table C-7 4 Blades, 2400 rpm

Each table consists of a matrix of one of the following parameters according to the propeller diameter (row) and blade activity factor (column).

Part (a)

- o Maximum Noise Level, dB(A)
- o Drag Polar, C_{do}
- o Drag Polar, $1/\pi Ae$
- o Takeoff Dist. (D_{50}), ft
- o Rate of Climb @ Sea Level, ft/min.

Part (b)

- o Rate of Climb @ 24,000 ft, ft/min.
- o Range, n.mi.
- o Cruise Speed, ktas
- o Basic Empty Weight, lb
- o Required Fuel Capacity, lb

Part (c)

- Cruise Efficiency (Payload Range)
- Time to Climb (to cruise level), min.
- V_y/V_s at 24,000 ft
- Average Cruise Speed, ktas (Payload Range)
- V/V* (Payload Range)

Part (d)

- Fuel Volume Ratio
- Maximum Speed at 17,000 ft, ktas
- Estimated Price, $
- Estimated Direct Operating Cost, $

Table C-1

WYLE LABS NOISE STUDY -- T210, 2 BLADES, 2500 RPM MCP

NOISE dBA

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	76.4	75.7	75.1	74.7
80.0000	77.6	77.1	76.8	76.3
85.0000	79.3	78.9	78.5	78.3
90.0000	81.2	81.1	81.0	81.0
95.0000	84.0	84.0	84.0	84.1

Drag Polar Cdo

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0190	0.0190	0.0190	0.0190
80.0000	0.0190	0.0190	0.0190	0.0190
85.0000	0.0190	0.0190	0.0190	0.0190
90.0000	0.0190	0.0190	0.0190	0.0190
95.0000	0.0190	0.0190	0.0190	0.0190

Drag Polar 1/πAe

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0490	0.0490	0.0490	0.0490
80.0000	0.0490	0.0490	0.0490	0.0490
85.0000	0.0490	0.0490	0.0490	0.0490
90.0000	0.0490	0.0490	0.0490	0.0490
95.0000	0.0490	0.0490	0.0490	0.0490

TAKEOFF DIST. ft.

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	3232.0	2890.3	2684.0	2531.1
80.0000	2672.8	2492.7	2356.0	2239.4
85.0000	2375.1	2254.3	2172.7	2127.3
90.0000	2264.3	2233.5	2219.8	2216.0
95.0000	2390.3	2398.4	2425.7	2458.2

ROC @ SEA LEVEL ft/min

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	571.2	600.2	624.9	652.6
80.0000	641.0	658.3	670.7	686.5
85.0000	678.2	695.1	704.6	699.3
90.0000	692.7	684.8	674.5	661.6
95.0000	644.7	627.4	609.4	591.1

Part(a)

Table C-1 (Continued)

WYLE LABS NOISE STUDY -- T210, 2 BLADES, 2500 RPM MCP

ROC @ 24000 ft ft/min

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	134.0	155.4	188.8	239.6
80.0000	204.4	288.1	351.6	378.6
85.0000	362.3	376.2	381.3	401.5
90.0000	386.9	411.2	402.7	395.6
95.0000	395.7	393.4	393.2	388.4

Range - NM

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	0.0	674.5	727.1	771.3
80.0000	755.1	810.1	840.7	852.1
85.0000	847.8	860.5	867.0	869.7
90.0000	866.4	869.6	865.7	861.5
95.0000	859.4	855.0	849.9	841.6

CRUISE SPEED KTAS

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	156.0	170.8	177.7	181.8
80.0000	181.9	187.2	190.3	192.1
85.0000	191.5	194.4	195.7	196.3
90.0000	195.9	196.7	196.6	196.1
95.0000	195.9	195.1	194.2	193.0

Basic Empty Weight - lbs

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	2289.0	2289.0	2289.0	2289.0
80.0000	2289.0	2289.0	2289.0	2289.0
85.0000	2289.0	2289.0	2289.0	2289.0
90.0000	2289.0	2289.0	2289.0	2289.0
95.0000	2289.0	2289.0	2289.0	2289.0

Required Fuel Capacity - lbs

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	556.0	556.0	556.0	556.0
80.0000	556.0	556.0	556.0	556.0
85.0000	556.0	556.0	556.0	556.0
90.0000	556.0	556.0	556.0	556.0
95.0000	556.0	556.0	556.0	556.0

Part(b)

Table C-1 (Continued)

WYLE LABS NOISE STUDY -- T210, 2 BLADES, 2500 RPM MCP

Cruise efficiency PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.00000	100.00000	115.00000	130.00000
75.0000	0.00000	0.03052	0.03215	0.03308
80.0000	0.03334	0.03474	0.03555	0.03594
85.0000	0.03593	0.03663	0.03686	0.03680
90.0000	0.03672	0.03666	0.03632	0.03591
95.0000	0.03587	0.03534	0.03477	0.03415

Time to Climb - min

	Activity Factor			
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	122.32	97.46	79.97	65.10
80.0000	73.16	56.67	47.80	44.60
85.0000	46.98	44.17	42.38	40.83
90.0000	42.46	40.59	40.15	39.65
95.0000	40.91	40.09	39.54	39.45

Vy/Vs @ 24000 ft

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	1.518	1.437	1.380	1.327
80.0000	1.347	1.305	1.257	1.261
85.0000	1.292	1.247	1.205	1.195
90.0000	1.224	1.212	1.172	1.133
95.0000	1.187	1.154	1.132	1.106

Average Cruise Speed KTASPAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	160.5	167.0	170.8	172.7
80.0000	173.5	176.6	178.4	179.2
85.0000	179.3	180.8	181.3	181.2
90.0000	181.0	180.8	180.0	179.0
95.0000	178.9	177.6	176.3	174.8

V/V* PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	0.000	0.766	0.799	0.817
80.0000	0.819	0.842	0.854	0.862
85.0000	0.859	0.870	0.874	0.874
90.0000	0.872	0.872	0.869	0.864
95.0000	0.862	0.856	0.849	0.841

Part(c)

Table C-1 (Continued)

WYLE LABS NOISE STUDY -- T210, 2 BLADES, 2500 RPM MCP

Fuel Volume Ratio

			Activity	Factor
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	2.641	2.641	2.641	2.641
80.0000	2.641	2.641	2.641	2.641
85.0000	2.641	2.641	2.641	2.641
90.0000	2.641	2.641	2.641	2.641
95.0000	2.641	2.641	2.641	2.641

MAX SPEED KTAS AT 17000 FT.

			Activity	Factor
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	174.897	179.424	181.709	182.768
80.0000	185.121	187.094	187.988	188.320
85.0000	189.717	190.706	190.566	190.003
90.0000	190.797	190.178	189.270	188.288
95.0000	188.879	187.594	186.204	184.889

PRICE EST.

			Activity	Factor
Prop Diameter	85	100	115	130
75.0000	175132	177680	178967	179564
80.0000	180891	182004	182509	182696
85.0000	183485	184044	183965	183647
90.0000	184095	183745	183233	182678
95.0000	183012	182286	181502	180760

DOC EST.

			Activity	Factor
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	116.04	116.80	117.19	117.37
80.0000	117.76	118.10	118.25	118.30
85.0000	118.54	118.71	118.68	118.59
90.0000	118.72	118.62	118.46	118.30
95.0000	118.40	118.18	117.95	117.72

Part(d)

Table C-2

WYLE LABS NOISE STUDY -- T210, 2 BLADES, 2400 RPM MCP

NOISE dBA

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	75.9	75.2	74.6	74.2
80.0000	77.0	76.5	76.2	75.7
85.0000	78.5	78.1	77.8	77.5
90.0000	80.3	80.1	80.0	80.0
95.0000	82.8	82.8	82.8	82.9

Drag Polar Cdo

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0190	0.0190	0.0190	0.0190
80.0000	0.0190	0.0190	0.0190	0.0190
85.0000	0.0190	0.0190	0.0190	0.0190
90.0000	0.0190	0.0190	0.0190	0.0190
95.0000	0.0190	0.0190	0.0190	0.0190

Drag Polar $1/\pi Ae$

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0490	0.0490	0.0490	0.0490
80.0000	0.0490	0.0490	0.0490	0.0490
85.0000	0.0490	0.0490	0.0490	0.0490
90.0000	0.0490	0.0490	0.0490	0.0490
95.0000	0.0490	0.0490	0.0490	0.0490

TAKEOFF DIST. ft.

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	3231.5	2889.5	2683.0	2530.2
80.0000	2671.8	2491.8	2355.1	2238.6
85.0000	2374.2	2253.4	2171.7	2126.3
90.0000	2263.1	2232.3	2218.6	2214.7
95.0000	2388.9	2396.8	2424.1	2456.6

ROC @ SEA LEVEL ft/min

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	478.0	504.0	524.9	548.2
80.0000	539.6	558.1	566.6	578.8
85.0000	576.3	592.4	601.2	598.5
90.0000	599.2	594.1	586.1	575.3
95.0000	569.3	555.6	541.4	526.3

Part(a)

Table C-2 (Continued)

WYLE LABS NOISE STUDY -- T210, 2 BLADES, 2400 RPM MCP

RUC @ 24000 ft ft/min

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	182.5	176.5	184.7	209.7
80.0000	169.3	228.4	296.6	354.7
85.0000	321.8	371.3	378.6	379.0
90.0000	376.0	392.4	413.9	401.6
95.0000	406.0	398.6	396.8	396.9

Range - NM

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	0.0	542.3	607.0	660.9
80.0000	627.6	701.7	747.1	775.5
85.0000	764.0	789.9	801.3	806.9
90.0000	805.2	812.2	815.9	813.0
95.0000	814.1	811.9	809.4	805.8

CRUISE SPEED KTAS

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	0.0	161.3	170.0	175.1
80.0000	175.4	181.7	185.3	187.0
85.0000	187.1	190.1	191.6	192.4
90.0000	192.3	193.4	193.7	193.1
95.0000	193.3	192.8	191.8	190.6

Basic Empty Weight - lbs

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	2289.0	2289.0	2289.0	2289.0
80.0000	2289.0	2289.0	2289.0	2289.0
85.0000	2289.0	2289.0	2289.0	2289.0
90.0000	2289.0	2289.0	2289.0	2289.0
95.0000	2289.0	2289.0	2289.0	2289.0

Required Fuel Capacity - lbs

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	556.0	556.0	556.0	556.0
80.0000	556.0	556.0	556.0	556.0
85.0000	556.0	556.0	556.0	556.0
90.0000	556.0	556.0	556.0	556.0
95.0000	556.0	556.0	556.0	556.0

Part(b)

Table C-2 (Continued

WYLE LABS NOISE STUDY -- T210, 2 BLADES, 2400 RPM MCP

Cruise efficiency PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.00000	100.00000	115.00000	130.00000
75.0000	0.00000	0.02850	0.03050	0.03175
80.0000	0.03214	0.03393	0.03496	0.03557
85.0000	0.03572	0.03670	0.03726	0.03752
90.0000	0.03752	0.03790	0.03788	0.03766
95.0000	0.03779	0.03753	0.03714	0.03672

Time to Climb - min

	Activity Factor			
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	217.88	163.27	128.91	102.27
80.0000	122.31	89.57	70.51	58.46
85.0000	65.75	56.70	53.36	51.20
90.0000	53.27	50.66	48.50	47.99
95.0000	49.38	48.38	47.35	46.57

Vy/Vs @ 24000 ft

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	1.575	1.525	1.446	1.375
80.0000	1.389	1.334	1.294	1.240
85.0000	1.278	1.262	1.232	1.186
90.0000	1.232	1.204	1.193	1.152
95.0000	1.205	1.159	1.135	1.109

Average Cruise Speed KTASPAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	166.0	174.3	179.2	182.1
80.0000	183.5	187.6	190.0	191.4
85.0000	191.9	194.2	195.5	196.1
90.0000	196.2	197.0	197.0	196.4
95.0000	196.8	196.1	195.1	194.0

V/V* PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	0.000	0.801	0.844	0.869
80.0000	0.871	0.902	0.919	0.928
85.0000	0.928	0.943	0.951	0.955
90.0000	0.954	0.960	0.961	0.958
95.0000	0.959	0.957	0.951	0.946

Part(c)

AD-A116 495 WYLE LABS EL SEGUNDO CA F/G 20/1
EVALUATION OF NOISE CONTROL TECHNOLOGY AND ALTERNATIVE NOISE CE--ETC(U)
MAY 82 D BROWN, L.C SUTHERLAND DTFA01-80-C-10133
UNCLASSIFIED WR-82-4 FAA/EE-82-14 NL

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Table C-2 (Continued)

WYLE LABS NOISE STUDY -- T210, 2 BLADES, 2400 RPM MCP

Fuel Volume Ratio

Prop Diameter	Activity Factor 85.000	100.000	115.000	130.000
75.0000	2.641	2.641	2.641	2.641
80.0000	2.641	2.641	2.641	2.641
85.0000	2.641	2.641	2.641	2.641
90.0000	2.641	2.641	2.641	2.641
95.0000	2.641	2.641	2.641	2.641

MAX SPEED KTAS AT 24000 FT.

Prop Diameter	Activity Factor 85.000	100.000	115.000	130.000
75.0000	0.000	161.035	169.739	174.803
80.0000	175.133	181.393	184.934	186.661
85.0000	186.714	189.706	191.270	192.047
90.0000	191.909	193.055	193.294	192.721
95.0000	192.841	192.401	191.352	190.208

PRICE EST.

Prop Diameter	Activity Factor 85	100	115	130
75.0000	0	167355	172234	175080
80.0000	175265	178789	180785	181760
85.0000	181789	183479	184363	184802
90.0000	184724	185372	185507	185183
95.0000	185251	185002	184409	183763

DOC EST.

Prop Diameter	Activity Factor 85.00	100.00	115.00	130.00
75.0000	0.00	113.72	115.18	116.03
80.0000	116.08	117.14	117.73	118.02
85.0000	118.03	118.54	118.80	118.93
90.0000	118.91	119.10	119.14	119.05
95.0000	119.07	118.99	118.81	118.62

Part(d)

Table C-3

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2600 RPM MCP

NOISE dBA

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	78.0	77.7	77.5	77.2
80.0000	80.0	79.8	79.6	79.4
85.0000	82.4	82.3	82.3	82.2
90.0000	85.3	85.4	85.4	85.5
95.0000	88.7	88.9	89.0	89.1

Drag Polar Cdo

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0190	0.0190	0.0190	0.0190
80.0000	0.0190	0.0190	0.0190	0.0190
85.0000	0.0190	0.0190	0.0190	0.0190
90.0000	0.0190	0.0190	0.0190	0.0190
95.0000	0.0190	0.0190	0.0190	0.0190

Drag Polar $1/\pi Ae$

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0490	0.0490	0.0490	0.0490
80.0000	0.0490	0.0490	0.0490	0.0490
85.0000	0.0490	0.0490	0.0490	0.0490
90.0000	0.0490	0.0490	0.0490	0.0490
95.0000	0.0490	0.0490	0.0490	0.0490

TAKEOFF DIST. ft.

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	2736.7	2610.5	2521.0	2448.4
80.0000	2532.2	2455.4	2421.7	2407.3
85.0000	2508.4	2501.6	2504.7	2518.9
90.0000	2675.0	2710.4	2745.7	2785.5
95.0000	3033.2	3096.2	3153.2	3213.0

ROC @ SEA LEVEL ft/min

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	838.2	846.5	841.2	841.2
80.0000	847.1	850.6	850.1	836.4
85.0000	835.7	819.9	804.5	787.6
90.0000	772.8	750.7	730.4	710.2
95.0000	676.8	651.8	631.4	611.8

Part(a)

Table C-3 (Continued)

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2600 RPM MCP

ROC @ 24000 ft ft/min

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	322.4	395.2	415.5	406.4
80.0000	410.8	412.2	426.4	417.8
85.0000	429.7	404.9	387.4	376.5
90.0000	383.0	369.9	351.3	316.7
95.0000	326.3	288.4	257.7	229.3

Range - NM

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	762.5	791.1	797.9	798.6
80.0000	811.3	816.9	818.6	813.3
85.0000	822.9	816.1	809.3	803.5
90.0000	808.2	800.7	791.5	779.3
95.0000	781.9	766.4	752.6	738.2

CRUISE SPEED KTAS

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	198.0	202.6	205.4	206.9
80.0000	208.8	211.0	212.1	212.5
85.0000	213.4	213.6	212.8	212.1
90.0000	213.0	212.0	210.8	209.6
95.0000	210.4	208.7	207.1	205.6

Basic Empty Weight - lbs

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	2289.0	2289.0	2289.0	2289.0
80.0000	2289.0	2289.0	2289.0	2289.0
85.0000	2289.0	2289.0	2289.0	2289.0
90.0000	2289.0	2289.0	2289.0	2289.0
95.0000	2289.0	2289.0	2289.0	2289.0

Required•Fuel Capacity - lbs

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	556.0	556.0	556.0	556.0
80.0000	556.0	556.0	556.0	556.0
85.0000	556.0	556.0	556.0	556.0
90.0000	556.0	556.0	556.0	556.0
95.0000	556.0	556.0	556.0	556.0

Part(b)

Table C-3 (Continued)

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2600 RPM MCP

Cruise efficiency PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.00000	100.00000	115.00000	130.00000
75.0000	0.03461	0.03553	0.03597	0.03617
80.0000	0.03742	0.03778	0.03773	0.03747
85.0000	0.03821	0.03792	0.03752	0.03711
90.0000	0.03747	0.03692	0.03633	0.03578
95.0000	0.03603	0.03528	0.03457	0.03392

Time to Climb - min

	Activity Factor			
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	45.85	38.42	36.87	36.52
80.0000	36.85	35.74	34.82	34.97
85.0000	34.97	35.56	36.00	36.25
90.0000	36.56	36.90	37.71	39.60
95.0000	39.88	42.22	44.57	47.40

Vy/Vs @ 24000 ft

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	1.314	1.256	1.256	1.212
80.0000	1.246	1.196	1.186	1.156
85.0000	1.201	1.155	1.121	1.100
90.0000	1.142	1.116	1.091	1.057
95.0000	1.106	1.074	1.034	1.011

Average Cruise Speed KTASPAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	189.3	191.5	192.5	193.0
80.0000	196.2	197.0	196.9	196.2
85.0000	198.1	197.3	196.2	195.2
90.0000	196.2	194.8	193.4	192.1
95.0000	192.6	190.7	189.0	187.4

V/V* PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	0.915	0.930	0.936	0.939
80.0000	0.955	0.960	0.961	0.958
85.0000	0.967	0.963	0.958	0.952
90.0000	0.958	0.950	0.942	0.936
95.0000	0.938	0.928	0.918	0.910

Part(c)

Table C-3 (Continued)

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2600 RPM MCP

Fuel Volume Ratio

Prop Diameter	Activity Factor 85.000	100.000	115.000	130.000
75.0000	2.641	2.641	2.641	2.641
80.0000	2.641	2.641	2.641	2.641
85.0000	2.641	2.641	2.641	2.641
90.0000	2.641	2.641	2.641	2.641
95.0000	2.641	2.641	2.641	2.641

MAX SPEED KTAS AT 17000 FT.

Prop Diameter	Activity Factor 85.000	100.000	115.000	130.000
75.0000	197.280	198.486	198.915	198.717
80.0000	201.884	201.738	200.900	199.980
85.0000	201.760	200.621	199.648	198.510
90.0000	199.219	197.749	196.286	194.888
95.0000	195.417	193.467	191.685	190.029

PRICE EST.

Prop Diameter	Activity Factor 85	100	115	130
75.0000	187762	188445	188688	188576
80.0000	190370	190288	189812	189291
85.0000	190300	189655	189103	188458
90.0000	188860	188027	187199	186408
95.0000	186708	185605	184597	183661

DOC EST.

Prop Diameter	Activity Factor 85.00	100.00	115.00	130.00
75.0000	119.82	120.02	120.09	120.06
80.0000	120.59	120.57	120.43	120.27
85.0000	120.57	120.38	120.22	120.02
90.0000	120.14	119.90	119.65	119.41
95.0000	119.50	119.17	118.87	118.59

Part(d)

Table C-4

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2500 RPM MCP

NOISE dBA

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	77.7	77.4	77.2	76.9
80.0000	79.6	79.5	79.2	79.1
85.0000	81.9	81.8	81.8	81.8
90.0000	84.7	84.7	84.8	84.9
95.0000	88.0	88.1	88.2	88.3

Drag Polar Cdo

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0190	0.0190	0.0190	0.0190
80.0000	0.0190	0.0190	0.0190	0.0190
85.0000	0.0190	0.0190	0.0190	0.0190
90.0000	0.0190	0.0190	0.0190	0.0190
95.0000	0.0190	0.0190	0.0190	0.0190

Drag Polar $1/\pi Ae$

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0490	0.0490	0.0490	0.0490
80.0000	0.0490	0.0490	0.0490	0.0490
85.0000	0.0490	0.0490	0.0490	0.0490
90.0000	0.0490	0.0490	0.0490	0.0490
95.0000	0.0490	0.0490	0.0490	0.0490

TAKEOFF DIST. ft.

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	2592.8	2467.0	2376.8	2302.6
80.0000	2385.1	2306.7	2258.4	2239.6
85.0000	2332.7	2320.8	2319.2	2325.9
90.0000	2466.0	2490.3	2518.9	2551.7
95.0000	2766.5	2819.0	2866.7	2916.9

ROC @ SEA LEVEL ft/min

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	624.0	618.1	613.6	614.0
80.0000	623.1	622.9	615.3	601.5
85.0000	612.5	599.1	586.0	571.7
90.0000	569.0	551.5	536.4	521.2
95.0000	501.2	482.4	467.0	452.1

Part(a)

Table C-4 (Continued)

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2500 RPM MCP

ROC @ 24000 ft ft/min

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	245.9	315.5	362.7	371.0
80.0000	368.9	359.7	365.4	378.0
85.0000	379.3	368.9	345.8	331.2
90.0000	343.2	332.1	319.9	293.7
95.0000	312.1	275.5	244.7	214.7

Range - NM

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	792.8	829.4	847.2	848.0
80.0000	865.6	867.8	867.8	864.1
85.0000	875.6	868.7	859.5	851.2
90.0000	858.0	847.9	837.6	825.5
95.0000	829.6	811.4	794.6	777.2

CRUISE SPEED KTAS

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	188.4	191.8	193.3	194.1
80.0000	197.0	198.4	198.6	198.3
85.0000	200.0	199.4	198.4	197.5
90.0000	198.4	197.0	195.7	194.3
95.0000	194.9	192.9	191.2	189.5

Basic Empty Weight - lbs

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	2289.0	2289.0	2289.0	2289.0
80.0000	2289.0	2289.0	2289.0	2289.0
85.0000	2289.0	2289.0	2289.0	2289.0
90.0000	2289.0	2289.0	2289.0	2289.0
95.0000	2289.0	2289.0	2289.0	2289.0

Required Fuel Capacity - lbs

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	556.0	556.0	556.0	556.0
80.0000	556.0	556.0	556.0	556.0
85.0000	556.0	556.0	556.0	556.0
90.0000	556.0	556.0	556.0	556.0
95.0000	556.0	556.0	556.0	556.0

Part(b)

Table C-4 (Continued)

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2500 RPM MCP

Cruise efficiency PAYLOAD RANGE

Prop Diameter	Activity Factor 85.00000	100.00000	115.00000	130.00000
75.0000	0.03509	0.03570	0.03586	0.03581
80.0000	0.03761	0.03765	0.03737	0.03696
85.0000	0.03798	0.03751	0.03698	0.03646
90.0000	0.03682	0.03608	0.03537	0.03471
95.0000	0.03488	0.03395	0.03309	0.03229

Time to Climb - min

Prop Diameter	Activity Factor 85.00	100.00	115.00	130.00
75.0000	63.77	51.84	45.73	44.60
80.0000	45.41	44.24	43.03	42.16
85.0000	42.59	42.60	43.30	43.71
90.0000	43.75	43.95	44.43	46.02
95.0000	45.74	48.23	50.83	54.06

Vy/Vs @ 24000 ft

Prop Diameter	Activity Factor 85.000	100.000	115.000	130.000
75.0000	1.322	1.268	1.232	1.231
80.0000	1.260	1.193	1.172	1.160
85.0000	1.193	1.159	1.118	1.091
90.0000	1.130	1.108	1.084	1.060
95.0000	1.105	1.070	1.042	1.018

Average Cruise Speed KTASPAYLOAD RANGE

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	177.6	178.8	179.0	178.9
80.0000	183.1	183.2	182.5	181.6
85.0000	183.9	182.8	181.6	180.3
90.0000	181.3	179.5	177.7	176.2
95.0000	176.7	174.5	172.4	170.5

V/V* PAYLOAD RANGE

Prop Diameter	Activity Factor 85.000	100.000	115.000	130.000
75.0000	0.847	0.858	0.861	0.861
80.0000	0.883	0.885	0.882	0.878
85.0000	0.891	0.885	0.878	0.872
90.0000	0.876	0.867	0.858	0.849
95.0000	0.850	0.838	0.826	0.815

Part(c)

Table C-4 (Continued)

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2500 RPM MCP

Fuel Volume Ratio

Prop Diameter	Activity Factor 85.000	100.000	115.000	130.000
75.0000	2.641	2.641	2.641	2.641
80.0000	2.641	2.641	2.641	2.641
85.0000	2.641	2.641	2.641	2.641
90.0000	2.641	2.641	2.641	2.641
95.0000	2.641	2.641	2.641	2.641

MAX SPEED KTAS AT 17000 FT.

Prop Diameter	Activity Factor 85.000	100.000	115.000	130.000
75.0000	186.358	186.902	186.998	186.772
80.0000	191.369	190.858	189.835	188.828
85.0000	192.041	190.827	189.617	188.530
90.0000	190.010	188.340	186.992	185.576
95.0000	186.271	184.433	182.620	180.936

PRICE EST.

Prop Diameter	Activity Factor 85	100	115	130
75.0000	181588	181896	181950	181822
80.0000	184419	184130	183552	182983
85.0000	184799	184112	183428	182815
70.0000	183651	182707	181946	181147
95.0000	181540	180502	179480	178531

DOC EST.

Prop Diameter	Activity Factor 85.00	100.00	115.00	130.00
75.0000	117.97	118.06	118.08	118.04
80.0000	118.82	118.73	118.56	118.39
85.0000	118.93	118.73	118.52	118.34
90.0000	118.59	118.31	118.08	117.84
95.0000	117.96	117.65	117.34	117.06

Part(d)

Table C-5

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2400 RPM MCP

NOISE dBA

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	77.2	76.9	76.7	76.5
80.0000	79.1	78.9	78.8	78.6
85.0000	81.2	81.1	81.1	81.2
90.0000	83.8	83.8	83.9	84.0
95.0000	86.8	87.0	87.1	87.2

Drag Polar Cdo

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0190	0.0190	0.0190	0.0190
80.0000	0.0190	0.0190	0.0190	0.0190
85.0000	0.0190	0.0190	0.0190	0.0190
90.0000	0.0190	0.0190	0.0190	0.0190
95.0000	0.0190	0.0190	0.0190	0.0190

Drag Polar 1/πAe

Prop Diameter	Activity Factor 85.0000	100.0000	115.0000	130.0000
75.0000	0.0490	0.0490	0.0490	0.0490
80.0000	0.0490	0.0490	0.0490	0.0490
85.0000	0.0490	0.0490	0.0490	0.0490
90.0000	0.0490	0.0490	0.0490	0.0490
95.0000	0.0490	0.0490	0.0490	0.0490

TAKEOFF DIST. ft.

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	2591.7	2465.9	2375.7	2301.5
80.0000	2384.0	2305.6	2257.2	2238.4
85.0000	2331.4	2319.4	2317.9	2324.5
90.0000	2464.5	2488.7	2517.3	2550.0
95.0000	2764.6	2817.0	2864.6	2914.7

ROC @ SEA LEVEL ft/min

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	525.9	522.4	514.5	513.2
80.0000	523.6	522.9	516.5	501.8
85.0000	519.9	507.1	495.2	481.7
90.0000	490.0	475.4	462.3	449.0
95.0000	442.0	426.1	412.8	399.9

Part(a)

Table C-5 (Continued)

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2400 RPM MCP

ROC @ 24000 ft ft/min

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	213.4	265.4	319.4	362.7
80.0000	361.7	373.3	356.3	358.8
85.0000	362.7	377.9	364.0	337.0
90.0000	359.5	337.8	327.3	313.7
95.0000	328.7	312.6	279.6	247.4

Range - NM

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	679.9	728.5	763.2	778.3
80.0000	792.7	801.0	802.5	801.2
85.0000	814.3	812.7	807.5	798.9
90.0000	810.4	802.1	795.6	789.0
95.0000	794.6	784.7	772.1	758.2

CRUISE SPEED KTAS

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	181.9	185.3	186.7	187.2
80.0000	191.8	193.1	193.4	193.3
85.0000	196.3	195.8	194.8	193.7
90.0000	195.6	194.2	193.1	191.7
95.0000	192.7	190.7	189.2	187.5

Basic Empty Weight - lbs

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	2289.0	2289.0	2289.0	2289.0
80.0000	2289.0	2289.0	2289.0	2289.0
85.0000	2289.0	2289.0	2289.0	2289.0
90.0000	2289.0	2289.0	2289.0	2289.0
95.0000	2289.0	2289.0	2289.0	2289.0

Required Fuel Capacity - lbs

Prop Diameter	Activity Factor 85.0	100.0	115.0	130.0
75.0000	556.0	556.0	556.0	556.0
80.0000	556.0	556.0	556.0	556.0
85.0000	556.0	556.0	556.0	556.0
90.0000	556.0	556.0	556.0	556.0
95.0000	556.0	556.0	556.0	556.0

Part(b)

Table C-5 (Continued)

WYLE LABS NOISE STUDY -- 1210, 3 BLADES, 2400 RPM MCP

Cruise efficiency PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.00000	100.00000	115.00000	130.00000
75.0000	0.03394	0.03497	0.03544	0.03560
80.0000	0.03734	0.03778	0.03786	0.03769
85.0000	0.03891	0.03868	0.03829	0.03788
90.0000	0.03860	0.03809	0.03757	0.03704
95.0000	0.03749	0.03678	0.03612	0.03549

Time to Climb - min

	Activity Factor			
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	99.97	78.17	63.70	55.95
80.0000	57.53	54.86	53.85	52.68
85.0000	53.07	51.67	51.68	52.77
90.0000	52.16	52.82	53.11	53.67
95.0000	53.58	54.53	57.19	60.65

Vy/Vs @ 24000 ft

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	1.369	1.305	1.256	1.212
80.0000	1.238	1.244	1.183	1.151
85.0000	1.184	1.169	1.138	1.096
90.0000	1.146	1.107	1.086	1.062
95.0000	1.106	1.079	1.054	1.019

Average Cruise Speed KTASPAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	187.9	190.2	191.1	191.4
80.0000	195.8	196.8	197.1	196.6
85.0000	199.6	199.0	198.0	196.9
90.0000	198.8	197.4	196.3	195.0
95.0000	195.9	194.3	192.7	191.2

V/V* PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	0.903	0.919	0.926	0.929
80.0000	0.952	0.958	0.960	0.959
85.0000	0.974	0.971	0.966	0.961
90.0000	0.970	0.964	0.958	0.951
95.0000	0.956	0.946	0.938	0.930

Part(c)

Table C-5 (Continued)

WYLE LABS NOISE STUDY -- T210, 3 BLADES, 2400 RPM MCP

Fuel Volume Ratio

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	2.641	2.641	2.641	2.641
80.0000	2.641	2.641	2.641	2.641
85.0000	2.641	2.641	2.641	2.641
90.0000	2.641	2.641	2.641	2.641
95.0000	2.641	2.641	2.641	2.641

MAX SPEED KTAS AT 24000 FT.

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	181.593	184.938	186.345	186.843
80.0000	191.464	192.703	193.004	192.829
85.0000	195.882	195.380	194.370	193.264
90.0000	195.187	193.827	192.626	191.268
95.0000	192.239	190.280	188.711	187.040

PRICE EST.

	Activity Factor			
Prop Diameter	85	100	115	130
75.0000	178902	180787	181581	181862
80.0000	184472	185173	185343	185244
85.0000	186971	186687	186115	185490
90.0000	186578	185808	185129	184361
95.0000	184910	183803	182917	181974

DOC EST.

	Activity Factor			
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	117.17	117.73	117.97	118.05
80.0000	118.83	119.04	119.09	119.06
85.0000	119.58	119.49	119.32	119.14
90.0000	119.46	119.23	119.03	118.80
95.0000	118.96	118.63	118.37	118.09

Part(d)

Table C-6

WYLE LABS NOISE STUDY -- T210, 4 BLADES, 2500 RPM MCP

NOISE dBA

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	77.5	77.3	77.1	77.1
80.0000	79.6	79.5	79.5	79.5
85.0000	82.3	82.3	82.4	82.4
90.0000	85.3	85.5	85.6	85.7
95.0000	88.8	89.0	89.2	89.3

Drag Polar Cdo

	Activity Factor			
Prop Diameter	85.0000	100.0000	115.0000	130.0000
75.0000	0.0190	0.0190	0.0190	0.0190
80.0000	0.0190	0.0190	0.0190	0.0190
85.0000	0.0190	0.0190	0.0190	0.0190
90.0000	0.0190	0.0190	0.0190	0.0190
95.0000	0.0190	0.0190	0.0190	0.0190

Drag Polar 1/πAe

	Activity Factor			
Prop Diameter	85.0000	100.0000	115.0000	130.0000
75.0000	0.0490	0.0490	0.0490	0.0490
80.0000	0.0490	0.0490	0.0490	0.0490
85.0000	0.0490	0.0490	0.0490	0.0490
90.0000	0.0490	0.0490	0.0490	0.0490
95.0000	0.0490	0.0490	0.0490	0.0490

TAKEOFF DIST. ft.

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	2450.7	2371.7	2319.0	2285.1
80.0000	2341.0	2325.1	2321.9	2327.5
85.0000	2418.8	2433.7	2456.6	2484.9
90.0000	2646.5	2694.5	2739.3	2787.5
95.0000	3042.1	3114.5	3178.6	3244.7

ROC @ SEA LEVEL ft/min

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	589.5	587.4	582.1	566.5
80.0000	586.3	569.2	554.2	538.2
85.0000	552.7	535.2	519.5	503.6
90.0000	500.2	481.8	466.4	451.3
95.0000	429.2	411.4	397.0	383.3

Part(a)

Table C-6 (Continued)

WYLE LABS NOISE STUDY -- T210, 4 BLADES, 2500 RPM MCP

RUC @ 24000 ft   ft/min

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	362.0	366.7	341.5	340.1
80.0000	352.0	361.1	330.9	279.8
85.0000	325.8	306.2	292.0	274.0
90.0000	293.7	263.7	230.1	197.8
95.0000	217.4	182.6	154.1	125.7

Range - NM

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	856.9	856.3	851.5	847.6
80.0000	872.0	865.8	852.8	842.3
85.0000	860.0	849.1	838.9	828.6
90.0000	836.8	819.6	802.2	783.2
95.0000	790.4	766.1	741.4	712.1

CRUISE SPEED KTAS

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	196.0	197.0	196.9	196.5
80.0000	200.9	199.9	198.7	197.7
85.0000	200.2	198.9	197.5	196.1
90.0000	197.3	195.4	193.6	191.9
95.0000	192.8	190.4	188.2	186.2

Basic Empty Weight - lbs

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	2289.0	2289.0	2289.0	2289.0
80.0000	2289.0	2289.0	2289.0	2289.0
85.0000	2289.0	2289.0	2289.0	2289.0
90.0000	2289.0	2289.0	2289.0	2289.0
95.0000	2289.0	2289.0	2289.0	2289.0

Required Fuel Capacity - lbs

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	556.0	556.0	556.0	556.0
80.0000	556.0	556.0	556.0	556.0
85.0000	556.0	556.0	556.0	556.0
90.0000	556.0	556.0	556.0	556.0
95.0000	556.0	556.0	556.0	556.0

Part(b)

Table C-6 (Continued)

WYLE LABS NOISE STUDY -- T210, 4 BLADES, 2500 RPM MCP

Cruise efficiency PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.00000	100.00000	115.00000	130.00000
75.0000	0.03686	0.03677	0.03645	0.03602
80.0000	0.03818	0.03762	0.03705	0.03651
85.0000	0.03775	0.03699	0.03628	0.03562
90.0000	0.03606	0.03512	0.03428	0.03349
95.0000	0.03375	0.03262	0.03160	0.03066

Time to Climb - min

	Activity Factor			
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	45.85	44.94	44.97	44.44
80.0000	44.19	43.56	45.07	46.41
85.0000	45.21	46.02	46.71	47.87
90.0000	47.02	49.20	52.24	56.18
95.0000	54.56	59.15	64.58	72.50

Vy/Vs @ 24000 ft

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	1.233	1.229	1.166	1.140
80.0000	1.172	1.158	1.117	1.075
85.0000	1.121	1.090	1.071	1.044
90.0000	1.088	1.060	1.025	0.998
95.0000	1.045	1.018	0.982	0.963

Average Cruise Speed KTASPAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	181.4	181.1	180.4	179.4
80.0000	184.4	183.0	18 .7	180.5
85.0000	183.3	181.6	179.9	178.5
90.0000	179.5	177.2	175.4	173.5
95.0000	174.2	171.5	169.0	166.8

V/V* PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	0.874	0.874	0.870	0.865
80.0000	0.893	0.886	0.879	0.872
85.0000	0.888	0.878	0.869	0.861
90.0000	0.867	0.854	0.842	0.833
95.0000	0.835	0.819	0.804	0.790

Part (c)

Table C-6 (Continued)

DATA FILE WLSE4B
WYLE LABS NOISE STUDY -- T210, 4 BLADES, 2500 RPM MCP

Fuel Volume Ratio

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	2.641	2.641	2.641	2.641
80.0000	2.641	2.641	2.641	2.641
85.0000	2.641	2.641	2.641	2.641
90.0000	2.641	2.641	2.641	2.641
95.0000	2.641	2.641	2.641	2.641

MAX SPEED KTAS AT 17000 FT.

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	188.941	188.570	187.576	186.546
80.0000	191.360	189.968	188.630	187.542
85.0000	191.051	189.487	187.957	186.490
90.0000	188.303	186.327	184.533	182.873
95.0000	183.867	181.484	179.318	177.312

PRICE EST.

	Activity Factor			
Prop Diameter	85	100	115	130
75.0000	183047	182837	182276	181695
80.0000	184413	183627	182871	182257
85.0000	184239	183355	182491	181663
90.0000	182687	181571	180559	179623
95.0000	180184	178840	177620	176491

DOC EST.

	Activity Factor			
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	118.41	118.34	118.18	118.00
80.0000	118.82	118.58	118.36	118.17
85.0000	118.76	118.50	118.24	117.99
90.0000	118.30	117.97	117.66	117.39
95.0000	117.55	117.15	116.79	116.45

Part(d)

Table C-7

WYLE LABS NOISE STUDY -- T210, 4 BLADES, 2400 RPM MCP

NOISE dBA

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	77.1	76.9	76.8	76.7
80.0000	79.2	79.1	79.1	79.1
85.0000	81.6	81.7	81.8	81.9
90.0000	84.5	84.6	84.7	84.8
95.0000	87.7	87.9	88.0	88.2

Drag Polar Cdo

	Activity Factor			
Prop Diameter	85.0000	100.0000	115.0000	130.0000
75.0000	0.0190	0.0190	0.0190	0.0190
80.0000	0.0190	0.0190	0.0190	0.0190
85.0000	0.0190	0.0190	0.0190	0.0190
90.0000	0.0190	0.0190	0.0190	0.0190
95.0000	0.0190	0.0190	0.0190	0.0190

Drag Polar $1/\pi Ae$

	Activity Factor			
Prop Diameter	85.0000	100.0000	115.0000	130.0000
75.0000	0.0490	0.0490	0.0490	0.0490
80.0000	0.0490	0.0490	0.0490	0.0490
85.0000	0.0490	0.0490	0.0490	0.0490
90.0000	0.0490	0.0490	0.0490	0.0490
95.0000	0.0490	0.0490	0.0490	0.0490

TAKEOFF DIST. ft.

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	2449.6	2370.6	2317.8	2283.8
80.0000	2339.8	2323.7	2320.6	2326.1
85.0000	2417.4	2432.2	2455.0	2483.3
90.0000	2644.7	2692.6	2737.4	2785.5
95.0000	3039.8	3112.1	3176.1	3242.1

ROC @ SEA LEVEL ft/min

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	494.1	489.4	484.1	471.8
80.0000	490.7	472.7	457.2	441.5
85.0000	465.0	448.5	433.8	418.7
90.0000	429.0	412.7	399.0	385.4
95.0000	377.4	361.8	349.0	336.7

Part(a)

Table C-7 (Continued)

WYLE LABS NOISE STUDY -- T210, 4 BLADES, 2400 RPM MCP

ROC @ 24000 ft ft/min

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	315.5	363.2	367.6	334.6
80.0000	350.4	346.5	353.2	319.2
85.0000	347.3	314.0	295.9	280.1
90.0000	302.9	285.6	258.1	223.4
95.0000	253.5	216.0	185.4	155.2

Range - NM

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	769.3	787.9	789.5	785.7
80.0000	807.5	802.5	796.5	786.5
85.0000	808.2	796.1	788.4	781.5
90.0000	792.9	783.1	770.7	754.7
95.0000	766.7	747.3	727.5	703.2

CRUISE SPEED KTAS

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	189.4	190.2	190.4	190.1
80.0000	195.8	194.9	193.6	192.3
85.0000	196.6	195.0	193.7	192.3
90.0000	194.7	192.8	191.1	189.4
95.0000	190.8	188.4	186.3	184.4

Basic Empty Weight - lbs

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	2289.0	2289.0	2289.0	2289.0
80.0000	2289.0	2289.0	2289.0	2289.0
85.0000	2289.0	2289.0	2289.0	2289.0
90.0000	2289.0	2289.0	2289.0	2289.0
95.0000	2289.0	2289.0	2289.0	2289.0

Required Fuel Capacity - lbs

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	556.0	556.0	556.0	556.0
80.0000	556.0	556.0	556.0	556.0
85.0000	556.0	556.0	556.0	556.0
90.0000	556.0	556.0	556.0	556.0
95.0000	556.0	556.0	556.0	556.0

Part(b)

Table C-7 (Continued)

WYLE LABS NOISE STUDY -- T210, 4 BLADES, 2400 RPM MCP

Cruise efficiency PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.00000	100.00000	115.00000	130.00000
75.0000	0.03641	0.03671	0.03674	0.03659
80.0000	0.03872	0.03833	0.03784	0.03737
85.0000	0.03897	0.03838	0.03781	0.03726
90.0000	0.03818	0.03743	0.03672	0.03607
95.0000	0.03669	0.03579	0.03498	0.03424

Time to Climb - min

	Activity Factor			
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	64.76	55.93	54.71	54.99
80.0000	54.84	54.14	53.71	55.45
85.0000	53.80	55.54	56.47	57.34
90.0000	56.28	57.31	59.87	64.23
95.0000	61.30	66.17	71.79	79.71

Vy/Vs @ 24000 ft

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	1.262	1.213	1.214	1.147
80.0000	1.188	1.149	1.137	1.095
85.0000	1.141	1.095	1.068	1.048
90.0000	1.088	1.061	1.036	1.013
95.0000	1.058	1.019	0.996	0.974

Average Cruise Speed KTASPAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.0	100.0	115.0	130.0
75.0000	193.6	194.2	194.2	193.8
80.0000	199.1	198.1	196.8	195.7
85.0000	199.7	198.2	196.9	195.6
90.0000	197.8	196.0	194.3	192.8
95.0000	194.2	192.0	190.1	188.3

V/V* PAYLOAD RANGE

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	0.940	0.943	0.945	0.943
80.0000	0.972	0.967	0.960	0.954
85.0000	0.975	0.968	0.961	0.954
90.0000	0.966	0.957	0.948	0.939
95.0000	0.946	0.935	0.924	0.914

Part (c)

Table C-7 (Continued)

WYLE LABS NOISE STUDY -- T210, 4 BLADES, 2400 RPM MCP

Fuel Volume Ratio

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	2.641	2.641	2.641	2.641
80.0000	2.641	2.641	2.641	2.641
85.0000	2.641	2.641	2.641	2.641
90.0000	2.641	2.641	2.641	2.641
95.0000	2.641	2.641	2.641	2.641

MAX SPEED KTAS AT 24000 FT.

	Activity Factor			
Prop Diameter	85.000	100.000	115.000	130.000
75.0000	189.000	189.758	189.970	189.675
80.0000	195.406	194.456	193.161	191.894
85.0000	196.185	194.621	193.318	191.907
90.0000	194.278	192.388	190.620	188.924
95.0000	190.309	187.973	185.852	183.884

PRICE EST.

	Activity Factor			
Prop Diameter	85	100	115	130
75.0000	183080	183508	183628	183461
80.0000	186702	186164	185432	184715
85.0000	187142	186257	185520	184723
90.0000	186063	184994	183995	183037
95.0000	183819	182500	181303	180193

DOC EST.

	Activity Factor			
Prop Diameter	85.00	100.00	115.00	130.00
75.0000	118.42	118.55	118.58	118.53
80.0000	119.50	119.34	119.12	118.91
85.0000	119.63	119.37	119.15	118.91
90.0000	119.31	118.99	118.69	118.40
95.0000	118.64	118.24	117.89	117.56

Part(d)

APPENDIX D

Projected Trends in Noise Impact Around General Aviation Airports

Evaluation of the impact of noise from general aviation aircraft provides a useful perspective for considering the need for applying source noise control to the dominant portion of the aircraft (i.e., small propeller aircraft) which make up this fleet. One previous study[D-1] provided a quantitative estimate of the total land area and population within the L_{dn} 65 contour around 6,610 general aviation airports for which traffic data were available as of 1972. Noise impact was assumed negligible for an additional 5,800 general aviation airports of record, as of 1972,[D-2] which were assumed to be private with unlighted, unpaved runways. These estimates have been revised using more recent FAA traffic data at 1,507 of the nation's busiest general aviation airports.[D-3, D-4] This resulting profile of numbers of such airports, broken down by the number of annual operations, the availability of jet fuel, and runway length is shown in Table D-1. The remainder of the 6,610 airports not included in this update were assumed to fall into the same range of operations and airport type (i.e., no jets, runway less than 3,500 ft) as before.

The same airport modeling techniques applied in Reference D-1 were reapplied with the updated traffic data in Table D-1 to provide a new estimate of the impacted area and population around general aviation airports. The techniques involved in the original study included the following major elements:[D-1]

- An average airport was defined for each of the four airport categories listed in Table D-1.
- A mix of operations by type of general aviation aircraft was estimated for each airport type. The types of general aviation aircraft consisted of large or small jets (thrust greater or less than 8,000 lbs), large and small turboprop and piston propeller aircraft (with engine greater or less than 1,450 horsepower). The resulting distribution of operations by airport and aircraft type is shown in Table D-2.
- From References D-2 and D-5 and Table D-2, an estimate was made of the absolute number of operations of each aircraft type. In the original study,[D-1] approximately 88 percent of these operations were estimated to consist of flights by small propeller aircraft. Although

Table D-1

Estimated Distribution of Annual Operations of General Aviation Aircraft by Number and Airport Type*

Number of Annual Operations	Number of Airports			
	Jet Fuel Available Runway Length >4,750'	Jet Fuel Available Runway Length ≤ 4,750'	No Jets Runway Length > 3,500'	No Jets Runway Length ≤ 3,500'
>400,000	6		1	
200,000 - 399,999	14	2	15	2
100,000 - 199,999	63	2	43	6
50,000 - 99,999	102	6	82	24
25,000 - 49,999	156	10	182	96
10,000 - 24,999	126	12	175	1,509
1,000 - 9,999	43	4		2,847
< 1,000	4			1,078
Total	514	36	498	5,562

*Data from current FAA statistical records

Table D-2

Percent Distribution of Operations for Each General Aviation Airport Category in Table D-1 and for Each Aircraft Type

Airport Category	Large Piston[2]	Small Piston		Turboprop		Large Jets[1]	Small Jets	Total
		Single Engine	Multi-Engine	Large[2]	Small			
Large Airport with Jets 5% Night Operations	0.3	85.7	8.6	0.7	1.8	2.0	0.9	100
Medium Airport 1% Night Operations	0.3	87.5	8.8	0.7	1.8	0	0.9	100
Large Airport without Jets 1% Night Operations	0.3	88.3	8.9	0.7	1.8	0	0	100
Small Airport 0.5% Night Operations	0	89.2	9.0	0	1.8	0	0	100

[1] Thrust 8,000 lb

[2] Horsepower 1,450 hp

the current general aviation fleet now has a slightly greater proportion of business jets, they still constitute only about 1.3 percent of the fixed-wing general aviation fleet and operations of small propeller aircraft still dominate the operations of general aviation aircraft.

- o Standard contour calculation methods, using INM,[D-6] were then applied to estimate noise contours for a conservative model for the operational pattern at each airport.
- o Finally, data on populations exposed to airport noise[D-1, D-7, D-8] were used to estimate the population within these contours for each of the airport types.
- o Scaling factors based on the distribution of numbers of operations by airport type[D-1, D-8] were then used to scale the values for each average airport to the nation.

To provide a very rough estimate of the previous and future trends in the population impacted by general aviation operations, the following scaling models were used, based on results for the 1975-1980 time period and on other airport noise impact studies.[D-1, D-7, D-8]

- o Average total number of operations per year per general aviation aircraft was assumed to be 640. (If only general aviation operations at FAA-operated control towers had been used, this figure would have been only about 250 per year.)
- o Noise impacted area was assumed to scale as the number of operations to the 0.9 power (Reference D-8).
- o The same (nonlinear) relationship between population and contour area employed for the 1975-1980 baseline period was used to estimate trends in population impacted by general aviation aircraft operations.

The result of this evaluation, which is only intended to provide approximate trends, is shown in Figure D-1 in terms of the estimated number of operations of general aviation aircraft and the population impacted by these operations. Note that the ordinate value for some of the curves has been multiplied by a constant for convenience in plotting. An estimate of the number of people impacted for the nation is shown in Figure D-1 for both L_{dn} 65 and 60 contours. The latter value

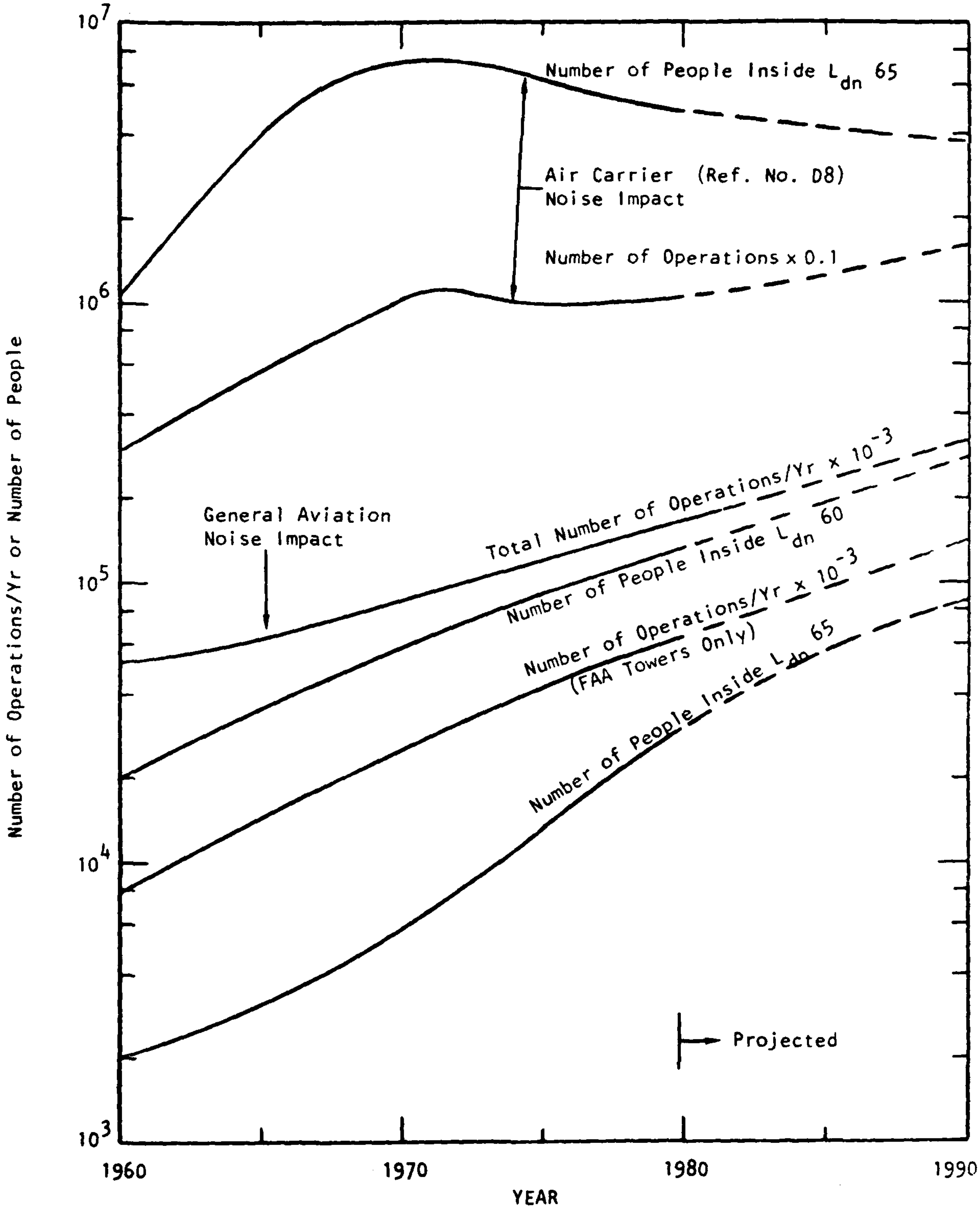

Figure D1. Estimates of the Historical and Projected Trends in Total Number of Operations and People Exposed to Noise Around Air Carrier and General Aviation Airports.

was obtained from the same consistent trend in total national contour area vs L_{dn} value that has been found in previous studies.[D-1, D-7, D-8] For the sake of comparison, comparable trends in the number of air carrier aircraft operations and the total number of people within the L_{dn} 65 contour for these operations is also shown.

Several general observations can be made about the trends indicated in Figure D-1.

1. The number of people exposed to noise from air carrier operations reached a maximum in about 1970 and has decreased subsequently as the very significant reduction in source noise for new wide body aircraft, and a corresponding flattening in the growth of operations, became effective.

2. No such pattern is indicated for the number of people exposed to noise from general aviation aircraft. While the trend lines shown do not reflect the current introduction of quieter propellers or quieter business jets, there is no expectation that a major reduction in source noise, comparable to that achieved by transition of the air carrier fleet from pure jet engines to low and then high bypass ratio turbofan engines, can be expected for the general aviation fleet, in the absence of further reductions in the noise of propeller aircraft.

3. Thus, while the total national noise impact of general aviation aircraft, as measured by number of people exposed to noise of their operations, is much less in magnitude than for air carrier aircraft, it is expected to continue growing at the rate of the order of 7 to 8 percent per year for the next 10 years. This is comparable to the anticipated growth rate in total number of operations of general aviation aircraft. The influence of introducing quieter business jets and quieter propeller aircraft based on current technology, will be partly offset by the growth in number of operations of general aviation aircraft. (There is no basis for a lower growth in operations such as achieved by use of wide-body aircraft in the air carrier fleet.) Further, the population impacted within an airport noise contour grows more rapidly than the growth in the area of the contour as the latter extends farther and farther into the community beyond the airport boundary.

To place this rough analysis in even closer perspective for purposes of this report, it was desirable to estimate that portion of the total number of people exposed to general aviation aircraft noise which is attributable to operations of small propeller aircraft (i.e., propeller aircraft with a maximum takeoff weight less than 12,500 lb). Based on the same data and procedures outlined above, it was estimated that:

- o About 50 percent of the total noise impacted area (and corresponding population) exposed to noise from general aviation aircraft is due to operations by small propeller aircraft. (The total area within the L_{dn} 60 contour for all general aviation airports is estimated to be about 800 square miles in 1980.)
- o At least 75 percent of all general aviation airports (currently over 14,000 in number) are served exclusively by such aircraft.
- o Of the remaining general aviation airports, small propeller aircraft generate about 94 percent of the operations (i.e., single noise events) and about 40 percent of the contour area.

In summary, while the total magnitude of the population exposed to small propeller aircraft noise (i.e., currently estimated to be at least 130,000 people inside the L_{dn} 60 contour)* is much less than for air carrier aircraft, the noise impact from such aircraft is still significant due to its continuing growth rate, its extensiveness over many communities, and the expected higher sensitivity of people in relatively quiet communities adjacent to small general aviation airports.

These conclusions are consistent with the increased concern about general aviation aircraft noise reflected, for example, in recent conferences on the topic held in the U. S.[D-10] and the extensive research and investigation on the problem in France,[D-11] Germany,[D-12] Switzerland,[D-13] and the Netherlands.[D-14]

One aspect of the noise impact from general aviation aircraft not brought out by this simplified analysis is associated with the most critical locations around general aviation airports from the standpoint of noise impact. The main body of this report has pointed out that noise levels generated during takeoff by most propeller-driven small airplanes (except, perhaps, fixed pitch propeller aircraft) are

*A more conservative estimate of the relationship between population and contour area around general aviation airports would indicate a total population, within the L_{dn} 60 contour, in 1980, of roughly twice this value which is in approximate agreement with preliminary results of a current, more detailed study of general aviation noise impact undertaken by EPA (Reference D-9).

generally higher than during cruise. Depending on the size and mission of the aircraft, the distance from brake release where the takeoff power (i.e., propeller rpm) is cut back to cruise conditions, will vary substantially.

However, it is possible to generalize to this extent concerning noise impact under the takeoff path. An extensive statistical survey of population density around a large number of airports was reported in Reference D-1. These data showed that for the smaller airports, with (commercial) operations in the range of 10 to 39 per day, a peak population density in the range of 500 to 800 people per square mile is not reached until one is about 2 miles (approximately 10,000 ft) from the center of the runway. Assuming an average runway length for such small airports of 4,000 ft, this places the peak population density at about 12,000 feet (3.7 km) from brake release. At this distance, one can expect that the smaller propeller-driven general aviation aircraft will have normally reached their cruise altitude (and hence cruise power setting). Thus, noise impact underneath the flight path of these smaller aircraft, which often spend a substantial portion of time in pattern flying near the airport, is most likely to be associated with cruise power settings. This is, of course, even more likely for the case of fixed pitch propeller-driven aircraft based on the pattern reported herein from the flight test program (i.e., higher propeller rpm during cruise for the Cessna 172P at MNOP than during takeoff).

This rough generalization could be used as an argument to retain the level flight noise certification test procedures for the smaller propeller-driven aircraft. However, this neglects the true situation around many small airports where sideline distances to substantially populated residential areas are often quite short. Thus, noise exposure along these sideline areas due to the higher noise levels generated during takeoff by most propeller-driven small aircraft, again possibly excepting fixed pitch propeller aircraft, may very well be a dominant part of community noise impact of general aviation aircraft.

Clearly, more definitive information on the actual location, relative to the takeoff flight path, of residential areas most exposed to general aviation noise is needed.

REFERENCES FOR APPENDIX D

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APPENDIX E

Illustrative Example of Tradeoff Between Engine Power and Aircraft Weight to Maintain Performance

Perhaps one of the more severe penalties that might occur as a result of imposing source noise control technology is associated with a loss in engine power. For an aircraft designed close to its limiting minimum climb rate of 300 ft/min required by FAR Part 23, any such power loss can require a related reduction in gross takeoff weight in order to maintain the minimum climb rate. However, seemingly small reductions in horsepower can result in very substantial losses in cabin payload or fuel load – either factor presenting a serious loss in aircraft productivity. This loss could be overcome, however, by corresponding reductions in empty weight. This is best illustrated by an example.

The typical tradeoff relationship between a reduction in horsepower and the necessary percent reduction in gross weight in order to maintain the same climb rate for a typical single engine, four-place, retractable landing gear propeller aircraft is about 7 percent weight reduction for a 10 percent horsepower reduction.* This relationship was applied to the case of an aircraft with an original gross weight of 3,300 lb, empty weight of 2,000 lb, fuel load of 500 lb, and cabin payload of 800 lb. The results, summarized in Table E-1, show the decrease in either of these latter two weight parameters for just a 3 percent reduction in horsepower and with or without 3 percent decrease in empty weight. The results are that, for the Case (I) for a constant fuel load (or nearly constant range), the reduction in cabin payload is either about 8 or only 0.7 percent, depending on whether the 3 percent weight reduction is included.

If the cabin payload is maintained constant (Case II), the necessary decrease in fuel load (proportional to range) would be about 13 percent without any weight reduction or 1.2 percent with a weight reduction. While vastly simplified, this example serves to point out the fact that small decrements in aircraft performance can have a large relative impact on aircraft productivity, but that this penalty can be nearly offset if weight reductions, equal or greater than the engine power reduction on a percentage basis, can be utilized. The potential benefit of applying new high strength to weight materials for major structural portions of an aircraft is clear.

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*Marinelli, J. and Benefiel, R. L., "Designing for Noise and Emission Control in General Aviation," Beech Aircraft Co., AIAA Paper 73-1158, 1973.

Table E-1

Illustration of How a Decrease in Empty Weight of 3 Percent Can Nearly Offset a Decrease in Engine Horsepower of 3 Percent When Same Takeoff Climb Rate is Maintained for a Typical Small Propeller-Driven Aircraft

Weight Element (in pounds)	Original Weight	After 3% Reduction in Horsepower	
		Same Empty Weight	3% Decrease
Gross Weight	3,300	3,234*	3,234
Empty Weight	2,000	2,000	1,940 (-3.0%)
Useful Load	1,300	1,234 (-5.0%)	1,294 (-0.5%)
Case I - Maintain			
Same Fuel Load	500	500	500
Cabin Payload	800	734 (-8.2%)	794 (-0.7%)
Case II - Maintain			
Same Cabin Payload	800	800	800
Fuel Load (Range)	500	434 (-13.2%)	494 (-1.2%)

*Based on typical tradeoff between gross takeoff weight and engine horsepower of about 7 percent weight reduction to maintain the same takeoff climb angle for a 10 percent reduction in horsepower.

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