https://ntrs.nasa.gov/search.jsp?R=19930091991 2020-06-17T03:23:15+00:00Z

N62 50926

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT 926

SOUND-LEVEL MEASUREMENTS OF A LIGHT AIRPLANE MODIFIED TO REDUCE NOISE REACHING THE GROUND

By A. W. VOGELEY

CASE FILE COPY

1949

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Yearly subscription, $3; foreign, $4.50; single copy price varies according to size. - - - - - - - - - Price 10 cents

AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft (or mi)
Time	t	second	s	second (or hour)	sec (or hr)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb
Power	P	horsepower (metric)	----------	horsepower	hp
Speed	V	kilometers per hour	kph	miles per hour	mph
		meters per second	mps	feet per second	fps

2. GENERAL SYMBOLS

W Weight $=mg$

g Standard acceleration of gravity $=9.80665$ m/s² or 32.1740 ft/sec²

m Mass $=\frac{W}{g}$

I Moment of inertia $=mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ Coefficient of viscosity

ν Kinematic viscosity

ρ Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C and 760 mm; or 0.002378 lb-ft^{-4} sec^2

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb/cu ft

3. AERODYNAMIC SYMBOLS

S Area

S_w Area of wing

G Gap

b Span

c Chord

A Aspect ratio, $\frac{b^2}{S}$

V True air speed

q Dynamic pressure, $\frac{1}{2}\rho V^2$

L Lift, absolute coefficient $C_L=\frac{L}{qS}$

D Drag, absolute coefficient $C_D=\frac{D}{qS}$

D_0 Profile drag, absolute coefficient $C_{D_0}=\frac{D_0}{qS}$

D_i Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

C Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

i_w Angle of setting of wings (relative to thrust line)

i_t Angle of stabilizer setting (relative to thrust line)

Q Resultant moment

Ω Resultant angular velocity

R Reynolds number, $\rho\frac{Vl}{\mu}$ where l is a linear dimension (e.g., for an airfoil of 1.0 ft chord, 100 mph, standard pressure at 15° C, the corresponding Reynolds number is 935,400; or for an airfoil of 1.0 m chord, 100 mps, the corresponding Reynolds number is 6,865,000)

α Angle of attack

ϵ Angle of downwash

α_0 Angle of attack, infinite aspect ratio

α_i Angle of attack, induced

α_a Angle of attack, absolute (measured from zero-lift position)

γ Flight-path angle

REPORT 926

SOUND-LEVEL MEASUREMENTS OF A LIGHT AIRPLANE MODIFIED TO REDUCE NOISE REACHING THE GROUND

By A. W. VOGELEY

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

National Advisory Committee for Aeronautics

Headquarters, 1724 F Street NW., Washington 25, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 50, sec. 151). Its membership was increased from 12 to 15 by act approved March 2, 1929, and to 17 by act approved May 25, 1948. The members are appointed by the President, and serve as such without compensation.

JEROME C. HUNSAKER, Sc. D., Cambridge, Mass., *Chairman*

ALEXANDER WETMORE, Sc. D., Secretary, Smithsonian Institute, *Vice Chairman*

HON. JOHN R. ALISON, Assistant Secretary of Commerce.

DETLEV W. BRONK, PH. D., President, Johns Hopkins University.

KARL T. COMPTON, PH. D., Chairman, Research and Development Board, Department of Defense.

EDWARD U. CONDON, PH. D., Director, National Bureau of Standards.

JAMES H. DOOLITTLE, Sc. D., Vice President, Shell Union Oil Corp.

R. M. HAZEN, B. S., Director of Engineering, Allison Division, General Motors Corp.

WILLIAM LITTLEWOOD, M. E., Vice President, Engineering, American Airlines, Inc.

THEODORE C. LONNQUEST, Rear Admiral, United States Navy, Deputy and Assistant Chief of the Bureau of Aeronautics.

DONALD L. PUTT, Major General, United States Air Force, Director of Research and Development, Office of the Chief of Staff, Matériel.

JOHN D. PRICE, Vice Admiral, United States Navy, Vice Chief of Naval Operations.

ARTHUR E. RAYMOND, Sc. D., Vice President, Engineering, Douglas Aircraft Co., Inc.

FRANCIS W. REICHELDERFER, Sc. D., Chief, United States Weather Bureau.

HON. DELOS W. RENTZEL, Administrator of Civil Aeronautics, Department of Commerce.

HOYT S. VANDENBERG, General, Chief of Staff, United States Air Force.

THEODORE P. WRIGHT, Sc. D., Vice President for Research, Cornell University.

HUGH L. DRYDEN, PH. D., *Director*

JOHN W. CROWLEY, JR., B. S., *Associate Director for Research*

JOHN F. VICTORY, LL.M., *Executive Secretary*

E. H. CHAMBERLIN, *Executive Officer*

HENRY J. E. REID, D. Eng., Director, Langley Aeronautical Laboratory, Langley Field, Va.

SMITH J. DEFRANCE, B. S., Director, Ames Aeronautical Laboratory, Moffett Field, Calif.

EDWARD R. SHARP, Sc. D., Director, Lewis Flight Propulsion Laboratory, Cleveland Airport, Cleveland, Ohio

---

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT CONSTRUCTION
OPERATING PROBLEMS
INDUSTRY CONSULTING

Coordination of Research Needs of Military and Civil Aviation
Preparation of Research Programs
Allocation of Problems
Prevention of Duplication
Consideration of Inventions

LANGLEY AERONAUTICAL LABORATORY, Langley Field, Va.

LEWIS FLIGHT PROPULSION LABORATORY, Cleveland Airport, Cleveland, Ohio

AMES AERONAUTICAL LABORATORY, Moffett Field, Calif.

Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight

---

OFFICE OF AERONAUTICAL INTELLIGENCE
Washington, D. C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics

REPORT 926

SOUND-LEVEL MEASUREMENTS OF A LIGHT AIRPLANE MODIFIED TO REDUCE NOISE REACHING THE GROUND

By A. W. Vogeley

SUMMARY

An army liaison-type airplane, representative of personal airplanes in the 150 to 200 horsepower class, has been modified to reduce propeller and engine noise according to known principles of airplane-noise reduction. Noise-level measurements demonstrate that, with reference to an observer on the ground, a noisy airplane of this class can be made quiet—perhaps more quiet than necessary. In order to avoid extreme and unnecessary modifications, acceptable noise levels must be determined.

INTRODUCTION

An important factor in the problem of increasing the utility of the personal airplane is the provision of more convenient access to airports. For this reason it is desirable that airports be close to centers of population. Strong objections to the noise of airplanes are, however, seriously hindering the proper development and location of airports. A solution to the problem of airplane-noise reduction is therefore necessary to the healthy growth of personal and commercial aviation.

The National Advisory Committee for Aeronautics first began to investigate airplane noise in about 1930. Emphasis was placed almost entirely on the study of propeller noise. Since that time a theory for predicting propeller noise has been developed and a number of papers which aid in the design of quiet propellers for personal airplanes have been issued. These, and other papers relating to the noise problem, are listed as references 1 to 10. Increased emphasis has recently been placed on this work because of the expanding personal-airplane market.

In addition to the theoretical and ground test work, a typical light airplane has been modified for flight tests to determine the applicability of the published data. This modified, or quiet, airplane was first flown and demonstrated at the Sixteenth Annual Inspection at the Langley Laboratory in May 1947. Since that time, this airplane has been tested and the test results compared with those for the unmodified airplane. The results of these tests, showing the sound-pressure levels of both airplanes as measured from the ground, are presented in this report.

DESCRIPTION OF UNMODIFIED AIRPLANE

An army liaison-type airplane was chosen as being representative of personal airplanes in the 150 to 200 horsepower class. This airplane, shown in figure 1, has a wing span of 34 feet, an over-all length of 24 feet, and a normal gross weight of 2,100 pounds.

Specifications of the components relating to the noise problem are as follows:

Engine: Horizontally opposed, six-cylinder, direct-drive, air-cooled; rated 185 horsepower at 2,550 rpm.

Exhaust system: Collector stacks for each bank of cylinders exhausting independently below the engine cowling, as shown in figure 2.

Propeller: Two-blade, 85-inch diameter, fixed-pitch; laminated wood.

Figure 1.—Unmodified test airplane.

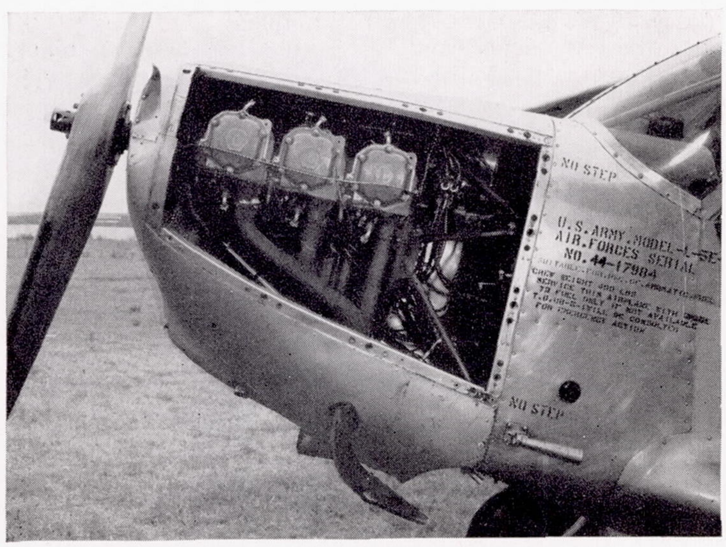


Figure 2.—Exhaust system of unmodified test airplane.

856692—50

DESIGN CONSIDERATIONS AND DESCRIPTION OF QUIET AIRPLANE

Because acceptable airplane-noise levels have not yet been determined, a level of 65 decibels at 300 feet was assumed to be a satisfactory objective. This value was therefore selected as the design goal for the propeller and muffler. Since little can be done at the present time to reduce the aerodynamic noise of the airframe, it was hoped that this noise level would be less than 65 decibels.

Propeller.—According to reference 8, a number of propellers of various diameters, numbers of blades, and operating speeds would, theoretically, meet the design value of 65 decibels. A five-blade configuration was chosen, however, because a hub suitable for this type happened to be available. The diameter was increased to 96 inches from the original 85 inches in order to take advantage of the available ground clearance and, as a result, the best take-off performance.

Figure 3, which was interpolated from the data of reference 8, shows the theoretical loudness level of the test configuration at various propeller speeds. The total loudness level as shown is the sum of the vortex-noise level (due to the shedding of vortices) and the Gutin or rotational-noise level (due to the steady aerodynamic forces on the blades). This figure indicates that the assumed 65-decibel-loudness-level requirement should easily be met by operation at a propeller rotational speed of approximately 1,000 rpm, which should produce a loudness level of about 57 decibels.

The aerodynamic design of the propeller was based on the charts of reference 7 and conventional theory to give optimum efficiency under the following conditions:

Number of blades	5
Diameter, inches	96
Rotational speed, rpm	1, 000
Airspeed, miles per hour	130
Brake horsepower	185

The available five-blade hub originally designed for model blades had very small blade sockets, and stress analysis showed that wooden shanks to fit this hub would have an insufficient margin of safety. Consequently, metal blade roots were machined to fit this hub and to flare out into the blade about 6 inches from the base. The wooden blades were glued to these stubs by the Cycleweld process. The usual metal leading edge and tip protective strip were omitted and 1/16-inch sheet rubber was substituted. Figure 4 shows a typical blade with these details.

The use of Cycleweld for blade retention and rubber sheet for protection is rather unusual. These novel methods could be used only because of the low blade stresses and low rotational speeds of the quiet propeller. They are mentioned only to illustrate to a small extent how certain of the characteristics of the quiet propeller may be used to advantage in fabrication.

The five-blade propeller, as tested, was very heavy, but only because the hub was designed for wind-tunnel work and no consideration had been given to weight. Actually the wooden blades each weigh only 6 pounds and it is estimated that, if a complete wooden propeller had been built, the total weight would have been less than 50 pounds as compared with approximately 25 pounds for the conventional two-blade propeller.

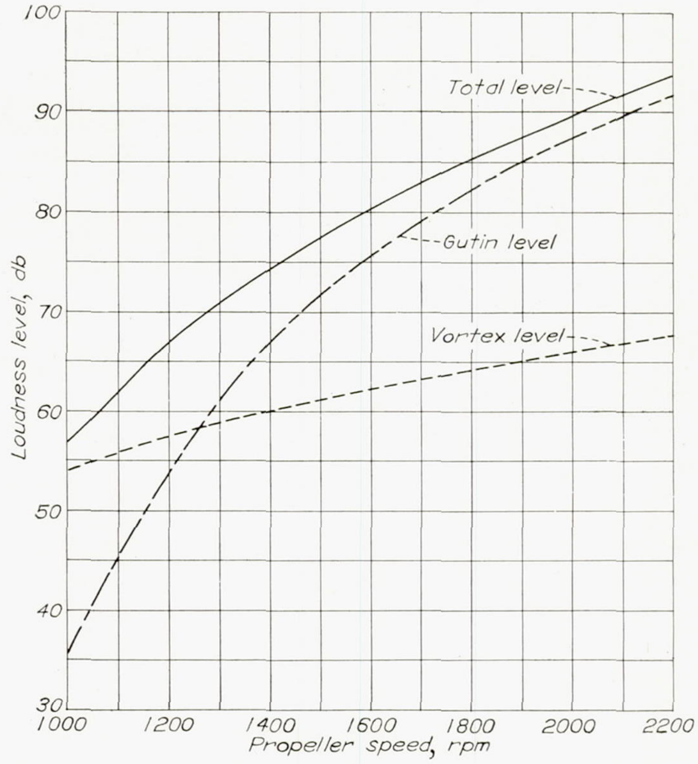


FIGURE 3.—Theoretical loudness level, five-blade propeller. Diameter, 8 feet; speed, 130 miles per hour; horsepower, 185; distance, 300 feet. Interpolated from data of reference 8.

Engine.—For a valid comparison of loudness levels an engine developing as much brake horsepower as the standard engine and geared to turn the propeller at 1,000 rpm was required. It was found that an available engine, with a rating of 210 horsepower at 3,000 rpm and geared 1.56 to 1.0 could be modified to provide a gear ratio of 2.79 to 1.0. Operation of this engine at 2,790 rpm in order to obtain the desired propeller speed was originally expected to produce approximately 185 horsepower. Later information indicated, however, that actually about 200 horsepower was developed.

It is interesting to note that no weight penalty need result from the use of gearing since, based on maximum ratings, the geared engine develops 0.515 horsepower per pound as compared with 0.505 horsepower per pound for the direct-drive engine.

The installation of this engine required only slight alterations to the airplane. The original provisions for cooling the standard engine were marginal; and because of the experimental nature of the geared engine, the cooling was improved by installation of a small oil-radiator scoop and small cowl flaps. Figure 5, a photograph of the final modified airplane, shows these details.

Exhaust system.—The available literature on muffler design was studied and found to be rather inadequate. The final design was evolved from application of the principles given in reference 9 and by application of the trial-and-error method to the test setup shown in figure 6. Engine power was absorbed by the electric motor run as a generator and cooling air was provided by the blower.

Before the special high-gear-ratio engine became available, it was the intention to use a standard geared engine at low engine speed. For this reason, the muffler was actually developed to provide attenuation of the first-order firing

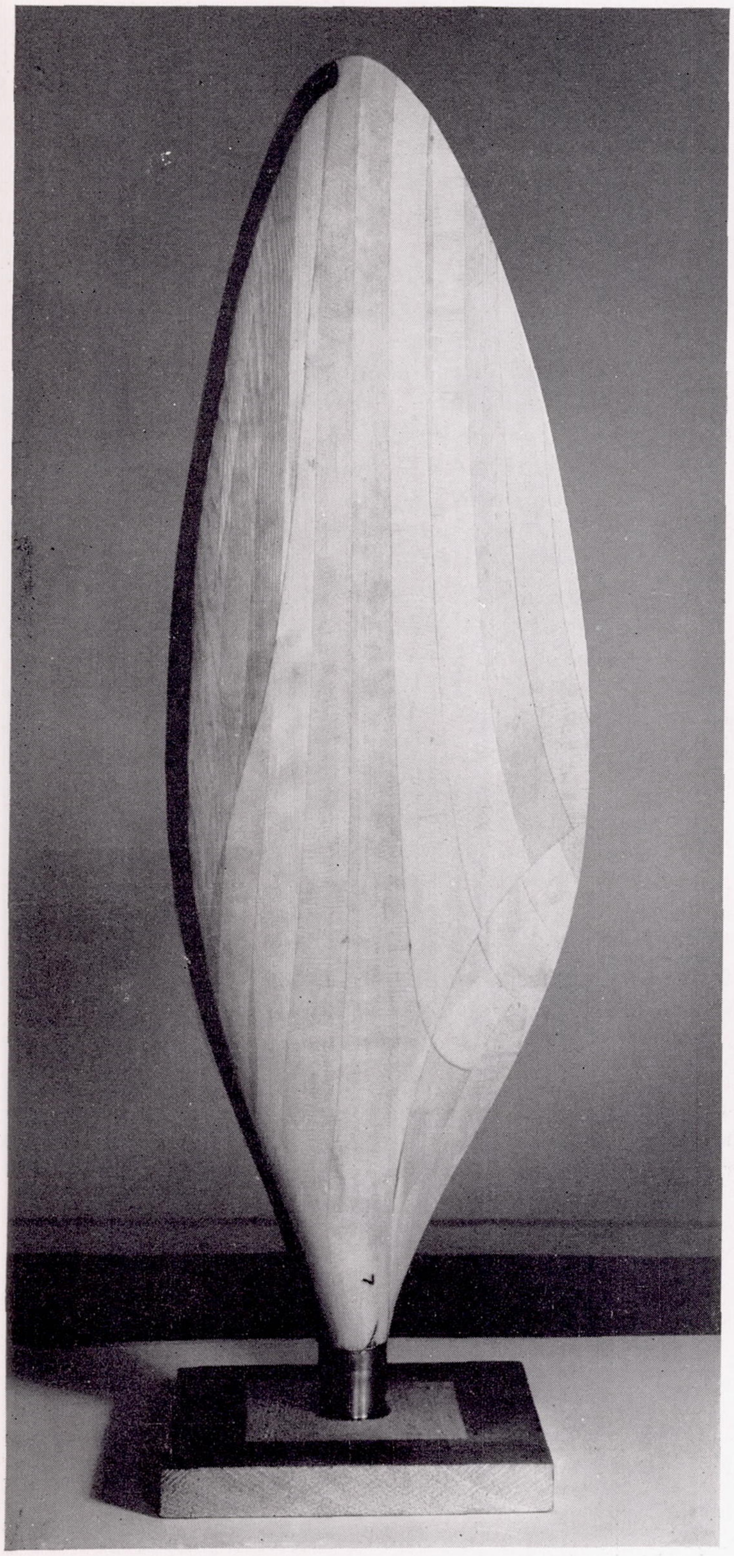


FIGURE 4.—Typical propeller blade with metal root and rubber leading-edge strip.

frequency of an engine running at about 1,600 rpm. Since, with the acoustical-filter-type muffler, the chamber size is an inverse function of the design frequency, the muffler is larger than necessary for the high-speed engine, and the same amount of noise reduction might have been obtained with a smaller muffler designed for the higher frequency. Details of the exhaust system are shown in figures 7 and 8.

This muffler work was done by the staff of the Langley Full-Scale-Tunnel Section.

FIGURE 5.—Modified test airplane.

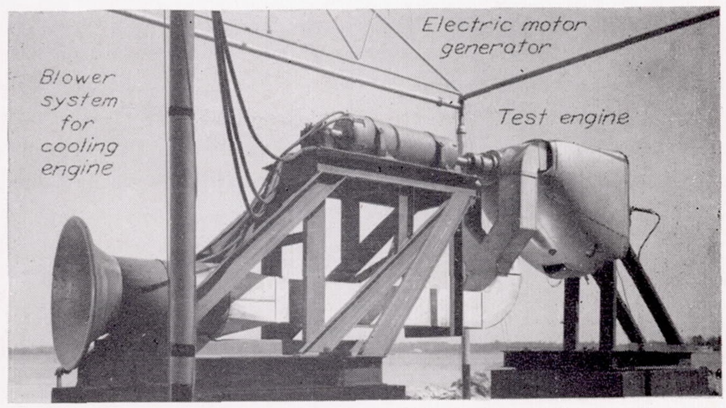


FIGURE 6.—Test stand for engine and mufflers. (Setup is shown without muffler in place behind engine.)

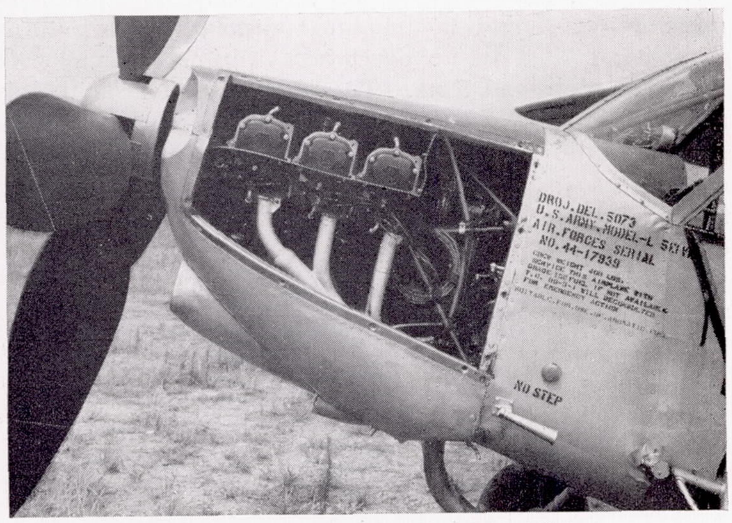


FIGURE 7.—Exhaust-collector system, modified test airplane.

SOUND MEASUREMENTS

All sound measurements were made with the General Radio Company sound level meter, model 759–A. This instrument has three different scales to be used for measuring sounds at three general intensity levels. The frequency response of each scale approximates the response of the ear when subjected to sounds of the proper sound-pressure level. In this manner, the sound-pressure levels measured by the instrument are made roughly equivalent to the loudness levels as experienced by the ear.

For these tests, however, it was convenient to make all measurements on the "C," or flat-response, scale. Although the use of this scale may lead to differences of a few decibels between the sound-pressure level and the loudness level under certain conditions, it appears justified for these tests. Most

FIGURE 8.—Muffler installation, modified test airplane.

of the measurements of the standard airplane were made at a level high enough to require the use of the "C" scale. The noise from the modified airplane was relatively free of low frequencies, and because it is the low-frequency response of the ear that is the primary reason for differences between sound-pressure and loudness levels, measurements of the sound from the modified airplane are not materially affected by changes in the instrument low-frequency response.

As a consequence, the terms noise level, sound-pressure level, and loudness level (although used properly in each instance) may all be interpreted as loudness levels.

RESULTS AND DISCUSSION

Sound-pressure-level measurements were taken of both the unmodified and the modified airplanes while on the ground and while passing overhead at various altitudes.

Results of ground tests.—The results of the ground tests are given in figure 9. These measurements were made at a distance of 50 feet from the center of the propeller. The engine speeds covered range from essentially idling speed to full-throttle speed. Except for a variation of about 5 decibels, with a minimum apparently between 60° and 90°, the sound-level pattern about both airplanes may be considered uniform.

At the highest engine speeds tested, the sound-pressure level of the unmodified airplane is about 22 decibels higher than that of the modified airplane. In terms of distance, according to reference 5, if an acceptable level of 65 decibels is assumed, the unmodified airplane must be located at least 2,000 feet from the nearest residence during warm up and start of take-off. The modified airplane, however, needs to be less than 200 feet away.

Results of flight tests.—Sound-level measurements of the airplanes in flight at an altitude of 300 feet are presented in figure 10. The maximum sound-level meter readings were taken as the airplanes passed directly overhead. All the runs of figure 10 were made with power for level flight over the speed range from near the stall to maximum. This figure shows clearly the amount of noise reduction that has been accomplished and that the assumed desirable level of 65 decibels has, for practical purposes, been realized.

The variation of sound-pressure level with altitude for the two airplanes operating at maximum speed is shown in figure 11. This figure indicates the large increase in altitude required before the sound-pressure level of the unmodified airplane becomes as low as that of the modified airplane (for example, 1,600 ft compared with 200 ft).

Tests were made of the modified airplane in flight with throttle closed (power off) to evaluate the amount of noise generated by the airframe alone. Propeller speeds in this condition were sufficiently low so that propeller noise did not affect the sound-pressure-level measurements. The measured values, corrected to 300 feet altitude, are given in figure 10. From these data it is estimated that the sound-pressure level would be approximately 62.5 decibels at the maximum speed of about 130 miles per hour. According to figure 3, therefore, the noise of the airplane itself is about 5 decibels higher than the theoretical value of the noise produced by the propeller. While the values given in reference 8 are given with a probable accuracy of ±10 decibels (due to uncertainty as to the vortex-noise level), indications are that the propeller configuration chosen was more effective than necessary for the test airplane because of the relatively high aerodynamic-noise level.

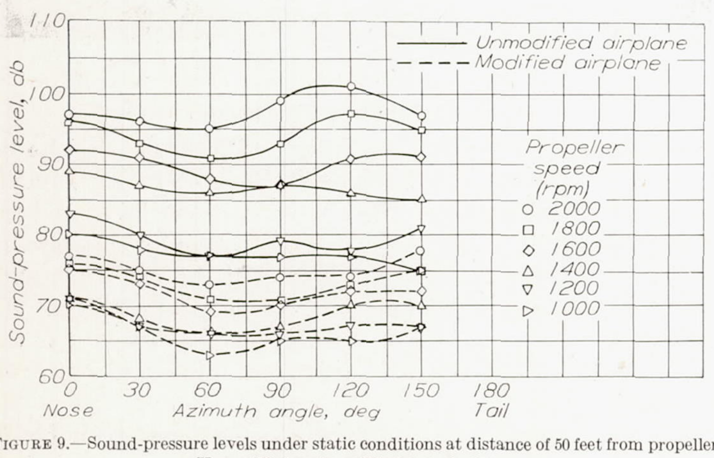


FIGURE 9.—Sound-pressure levels under static conditions at distance of 50 feet from propeller. Unmodified and modified test airplanes.

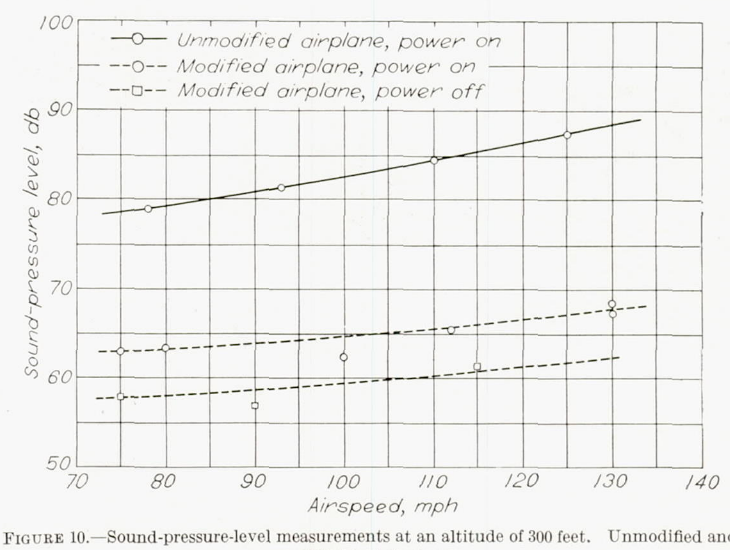


FIGURE 10.—Sound-pressure-level measurements at an altitude of 300 feet. Unmodified and modified test airplanes.

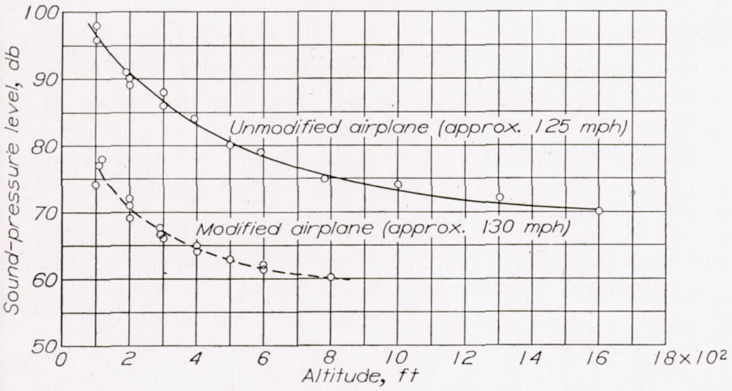


FIGURE 11.—Effect of altitude on sound-pressure levels. Full power and maximum speeds. Unmodified and modified test airplanes.

Test-stand measurements.—Measurements on the test stand were also made of the noise-level output of the engine and muffler system without propeller. At the design operating speed of 2,790 rpm and full power the unmuffled engine produced 89 decibels at 300 feet. With the muffler, this value was reduced to 67 decibels, which is the same as that measured for the complete airplane in flight. This fact seemed to indicate that the dominant sound remaining with the modified airplane is due to insufficient muffling. However, when the unmuffled engine was driven at rated speed by an electric motor, a sound-pressure level of 72 decibels was produced at 300 feet. This noise level, which is due to valves, gears, intake, pumping, and so forth, is actually 5 decibels higher than the noise level of the muffled engine at full power. Insufficient measurements were made to determine definitely the relative levels of the exhaust noise and the engine clatter, but from the character of the sound it appeared that clatter predominated. It is suggested, therefore, that if further reductions in power-plant noise level are desired the probability that the engine compartment should be soundproofed must be considered.

The measurements that have been discussed are summarized for convenience in table I.

TABLE I

SOUND-PRESSURE LEVELS OF AIRPLANES AND AIRPLANE COMPONENTS

Airplane component	Sound-pressure level at 300 ft, db
Complete unmodified airplane, full throttle, 125 mph	87.5
Two-blade propeller (calculated), 185 hp, 2,550 rpm, 125 mph	96.0
Engine without muffler and propeller, full throttle, 2,790 rpm	89.0
Engine without muffler and propeller, driven by an electric motor at 2,790 rpm	72.0
Engine with muffler, without propeller, full throttle, 2,790 rpm	67.0
Five-blade propeller (theoretical loudness level converted to sound-pressure level), 185 hp, 1,000 rpm, 130 mph	60±10
Airframe (power-off condition), 130 mph	62.5
Complete modified airplane, full throttle, 130 mph	68.0

The calculated sound-pressure level for the two-blade propeller has also been included in table I. It should be noted that this calculated value is about 8 decibels higher than the level for the complete unmodified airplane. This fact indicates that, although the propeller-noise theory for static conditions seems to be satisfactory, the theory for propellers in flight seems to yield rather conservative values for those cases, at least, in which rotational noise predominates. Also, since the sound-pressure level of the complete modified airplane was 2 decibels lower than the possible maximum level for the five-blade propeller, the uncertainty regarding the vortex-noise level (±10 db) can perhaps be slightly reduced.

Finally, the 20-decibel difference between the sound-pressure levels of the two airplanes as shown in table I represents a reduction in sound energy of 99 percent and can be, according to reference 10, likened to a reduction from a noise slightly louder than "very heavy street traffic" to a noise quieter than an "average automobile."

Performance.—Since the primary concern has been with the noise problem, little attention has been given to the relative performance of the two airplanes. It appears sufficient to show the calculated efficiencies of the two propellers at top speed and take-off speed when driven by engines of the same rated power output. Also given, to show the effect on performance of a change in propeller diameter, are the calculated efficiencies of an 85-inch, five-blade propeller. These values, calculated by use of reference 7, are presented in table II.

TABLE II

CALCULATED PROPELLER CHARACTERISTICS

Configuration	Propeller speed (rpm)	Brake horsepower	Efficiency (percent)	Thrust horsepower
Velocity, 55 mph				
Two-blade propeller (85-in. diameter)	2,130	154	58.4	90
Five-blade propeller (96-in. diameter)	794	147	65.6	97
Five-blade propeller (85-in. diameter)	790	146	54.5	80
Velocity, 130 mph				
Two-blade propeller (85-in. diameter)	2,550	185	79.2	146
Five-blade propeller (96-in. diameter)	1,000	185	82.0	152
Five-blade propeller (85-in. diameter)	1,000	185	77.2	143

Inspection of table II leads to the following conclusions:

(a) As far as top speed is concerned there is practically no difference between the three propellers. The large five-blade propeller should produce speeds about 1 to 2 miles per hour faster, and the small five-blade propeller, about 1 to 2 miles per hour slower than the two-blade propeller.

(b) The small five-blade propeller produces approximately 90 percent of the thrust horsepower of the two-blade propeller at take-off. This smaller power output, which is the normal expectation with fixed-pitch, slow-turning, multiblade propellers, results in reduced take-off and climb performance.

(c) By increasing the diameter of the five-blade propeller to 96 inches, the thrust horsepower at take-off is increased over that of the two-blade propeller. This fact emphasizes the importance of large diameter.

Pilots report that performance of the modified airplane equals or exceeds the performance of the unmodified airplane. Although some of the superiority may be explained by the higher propeller efficiency, most of it is believed to be due to the higher power output of the geared engine. (See section entitled "Engine.")

CONCLUDING REMARKS

It has been demonstrated that a conventional airplane, representative of personal airplanes in the 150 to 200 horsepower class, may be made quiet by application of known principles of sound reduction.

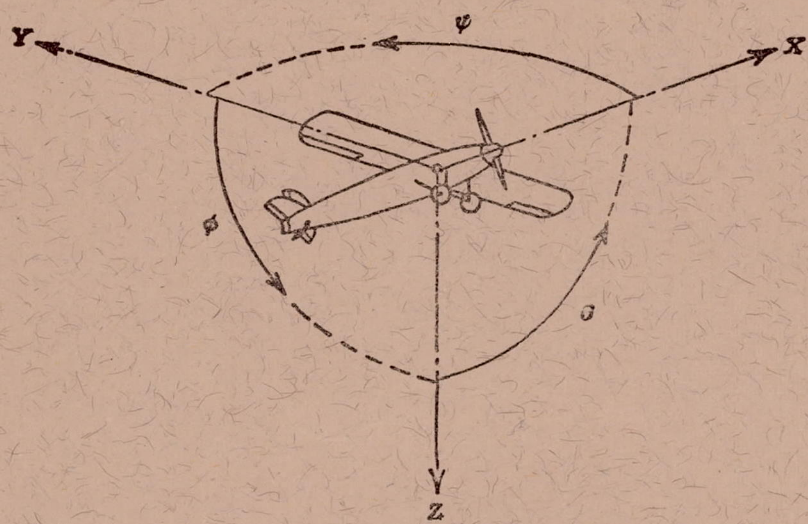
It is possible that the airplane as demonstrated was more quiet than necessary. The determination of acceptable noise levels is an important phase of future research relating to airplane noise.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *February 12, 1948.*

REFERENCES

1. Stowell, E. Z., and Deming, A. F.: Vortex Noise from Rotating Cylindrical Rods. NACA TN 519, 1935.
2. Deming, Arthur F.: Propeller Rotation Noise Due to Torque and Thrust. NACA TN 747, 1940.
3. Theodorsen, Theodore, and Regier, Arthur A.: The Problem of Noise Reduction with Reference to Light Airplanes. NACA TN 1145, 1946.
4. Hicks, Chester W., and Hubbard, Harvey H.: Comparison of Sound Emission from Two-Blade, Four-Blade, and Seven-Blade Propellers. NACA TN 1354, 1947.
5. Regier, Arthur A.: Effect of Distance on Airplane Noise. NACA TN 1353, 1947.
6. Yudin, E. Y.: On the Vortex Sound from Rotating Rods. NACA TM 1136, 1947.
7. Crigler, John L., and Jaquis, Robert E.: Propeller-Efficiency Charts for Light Airplanes. NACA TN 1338, 1947.
8. Hubbard, Harvey H., and Regier, Arthur A.: Propeller-Loudness Charts for Light Airplanes. NACA TN 1358, 1947.
9. Stewart, George Walter, and Lindsay, Robert Bruce: Acoustics. D. Van Nostrand Co., Inc., 1930.
10. Federal Telephone and Radio Corporation: Reference Data for Radio Engineers. Second ed., J. J. Little & Ives Co. (New York), 1946, p. 177.

U. S. GOVERNMENT PRINTING OFFICE: 1950



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l = \frac{L}{qbS}$ (rolling) $C_m = \frac{M}{qcS}$ (pitching) $C_n = \frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

- D Diameter
- p Geometric pitch
- p/D Pitch ratio
- V' Inflow velocity
- V_s Slipstream velocity
- T Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$
- Q Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$
- P Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$
- C_s Speed-power coefficient $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$
- η Efficiency
- n Revolutions per second, rps
- Φ Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp=76.04 kg-m/s=550 ft-lb/sec
1 metric horsepower=0.9863 hp
1 mph=0.4470 mps
1 mps=2.2369 mph

1 lb=0.4536 kg
1 kg=2.2046 lb
1 mi=1,609.35 m=5,280 ft
1 m=3.2808 ft