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

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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 paper.

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 2100 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 2550 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.

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 levels of the test configurations 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 1000 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	1000
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 six 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 $\frac{1}{16}$-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 are 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.

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 1000 rpm was required. It was found that an available engine, with a rating of 210 horsepower at 3000 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 2790 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 to 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 frequency of an engine running at about 1600 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 full-scale-tunnel section at Langley.

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 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 2000 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, 1600 feet compared with 200 feet).

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.

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 2790 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 sound proofed must be considered.

The measurements that have been discussed are summarized for convenience in the following table:

Airplane component	Sound-pressure level at 300 ft, db
Complete unmodified airplane, full throttle, 125 mph	87.5
Two-blade propeller (calculated), 185 hp, 2550 rpm, 125 mph	96.0
Engine without muffler and propeller, full throttle, 2790 rpm	89.0
Engine without muffler and propeller, driven by an electric motor at 2790 rpm	72.0
Engine with muffler, without propeller, full throttle, 2790 rpm	67.0
Five-blade propeller (theoretical loudness level converted to sound-pressure level), 185 hp, 1000 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 the foregoing table. 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 decibels) can perhaps be slightly reduced.

Finally, the 20-decibel difference between the sound-pressure levels of the two airplanes as shown in the table 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 the following table:

Configuration	Propeller speed (rpm)	Brake horsepower	Efficiency (percent)	Thrust horsepower
Velocity, 55 mph				
Two-blade propeller (85-in. diameter)	2130	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)	2550	185	79.2	146
Five-blade propeller (96-in. diameter)	1000	185	82.0	152
Five-blade propeller (85-in. diameter)	1000	185	77.2	143

Inspection of the table 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

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Figure 1.- Unmodified test airplane.

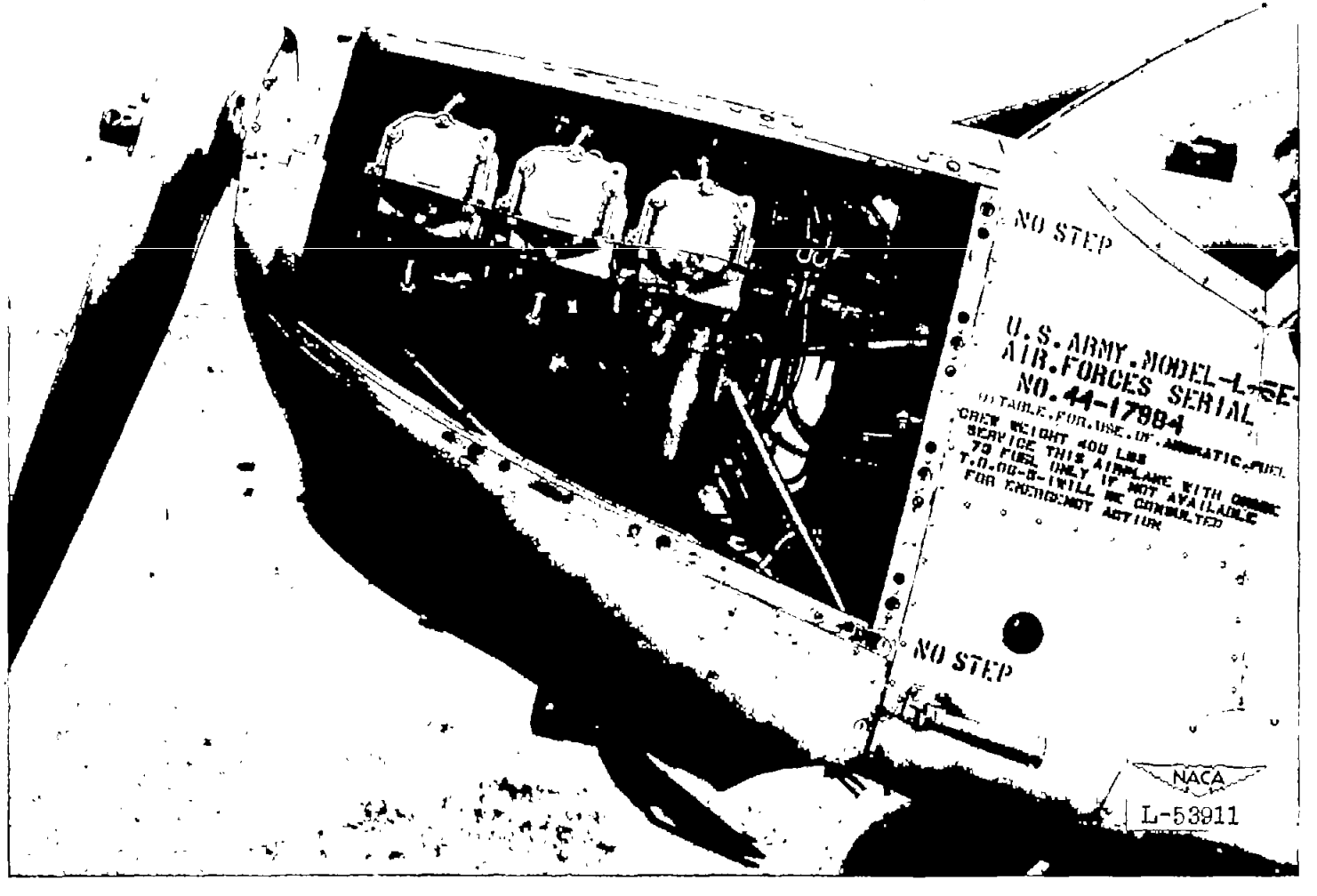

Figure 2.- Exhaust system of unmodified test airplane.

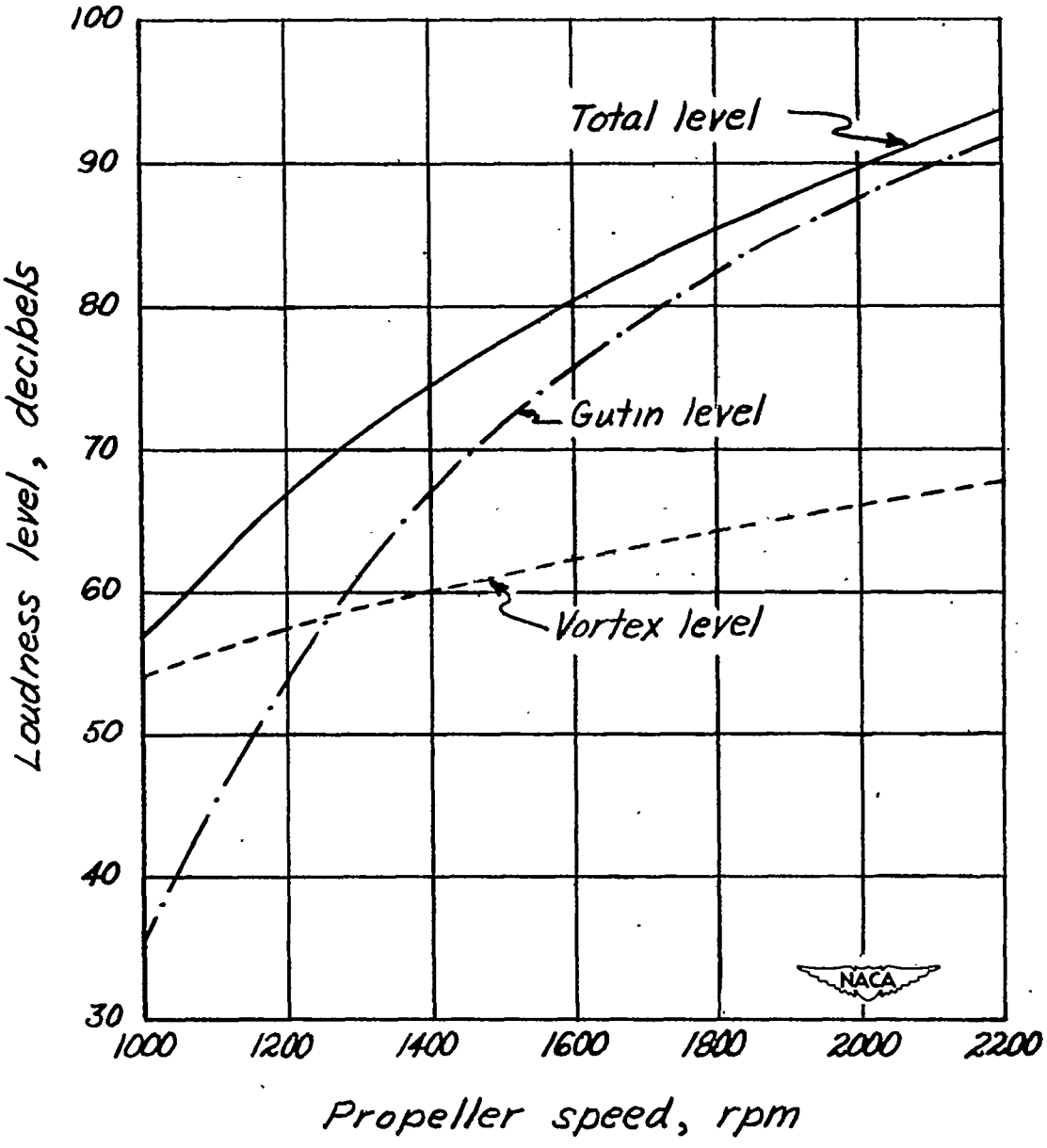

Figure 3.- Theoretical loudness level, five-blade propeller. Diameter, 8 feet; speed, 130 miles per hour; horsepower, 185; distance, 300 feet. Interpolated from data of reference 8.

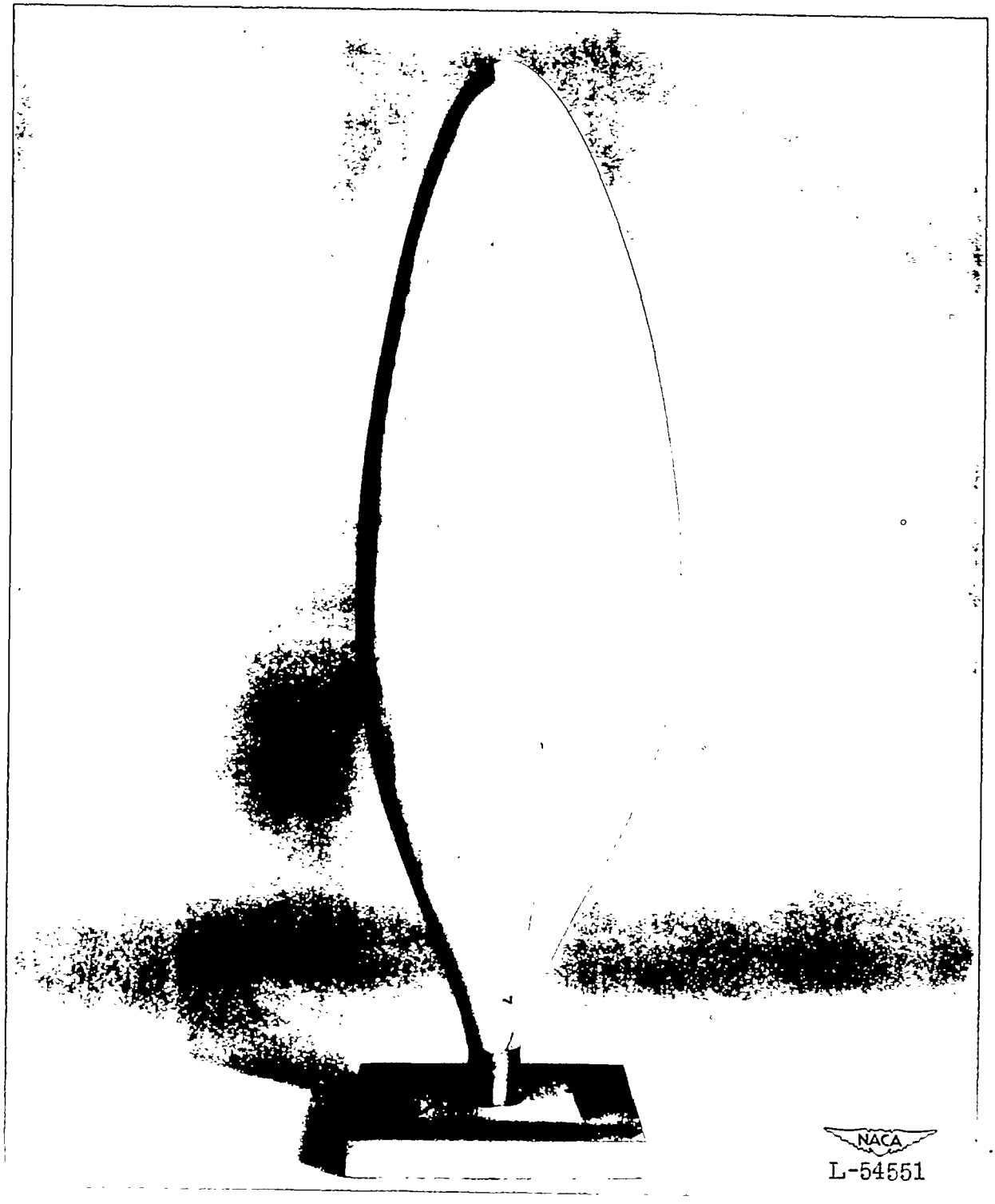

Figure 4.- Typical propeller blade with metal root and rubber leading-edge strip.

Figure 5.- Modified test airplane.

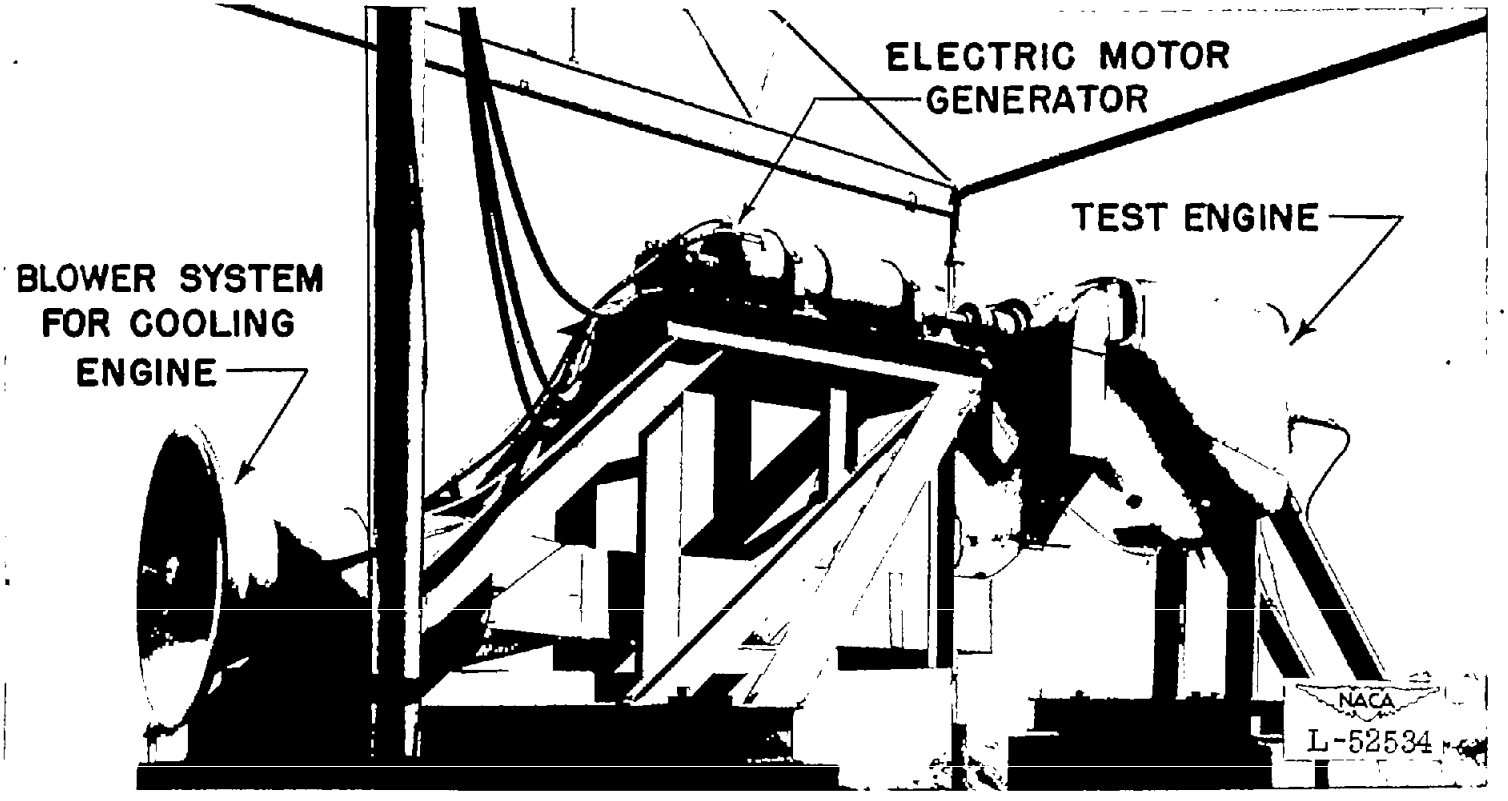

Figure 6.- Test stand for engine and mufflers. (Setup is shown without muffler in place behind engine.)

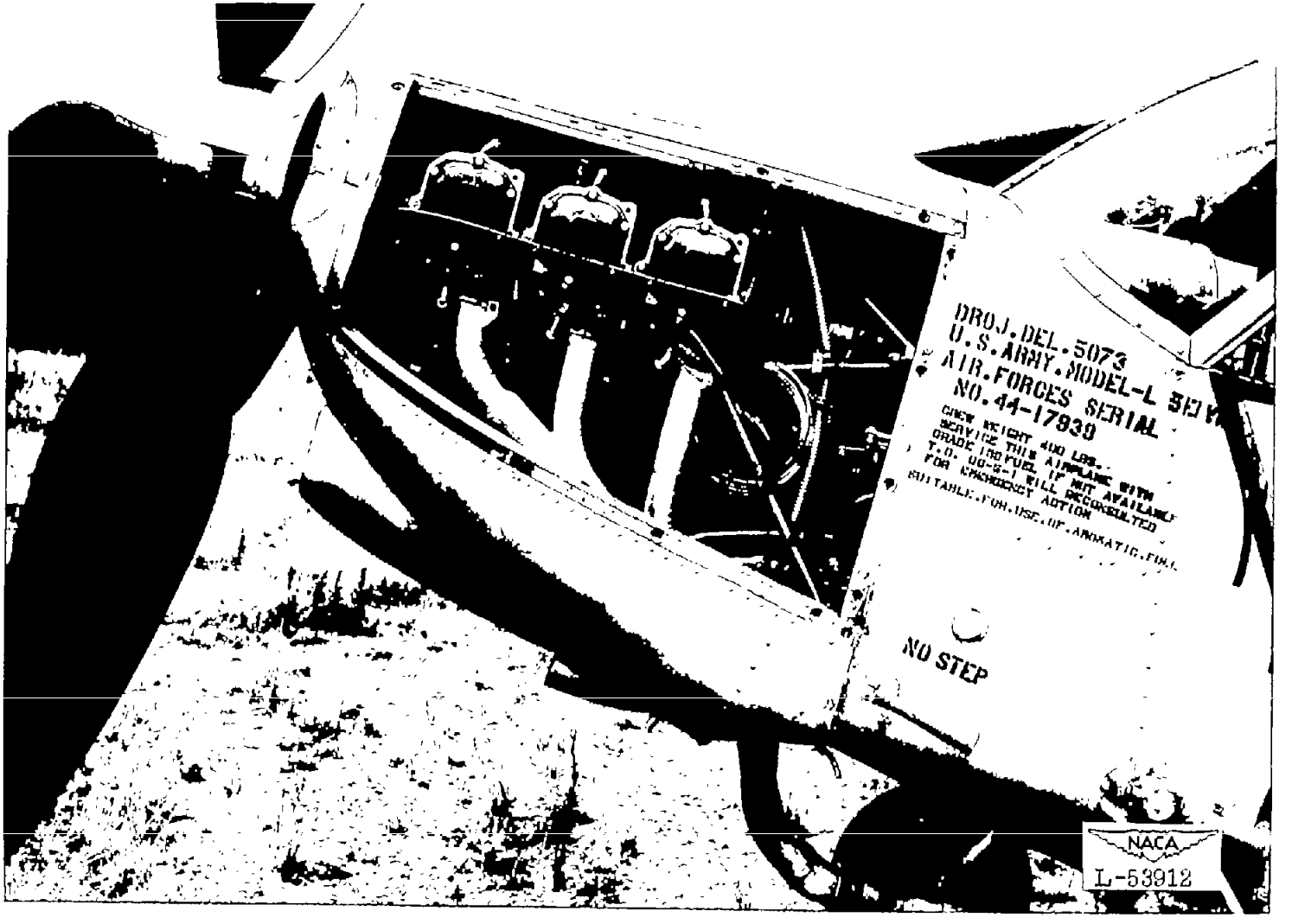

Figure 7.- Exhaust-collector system, modified test airplane.

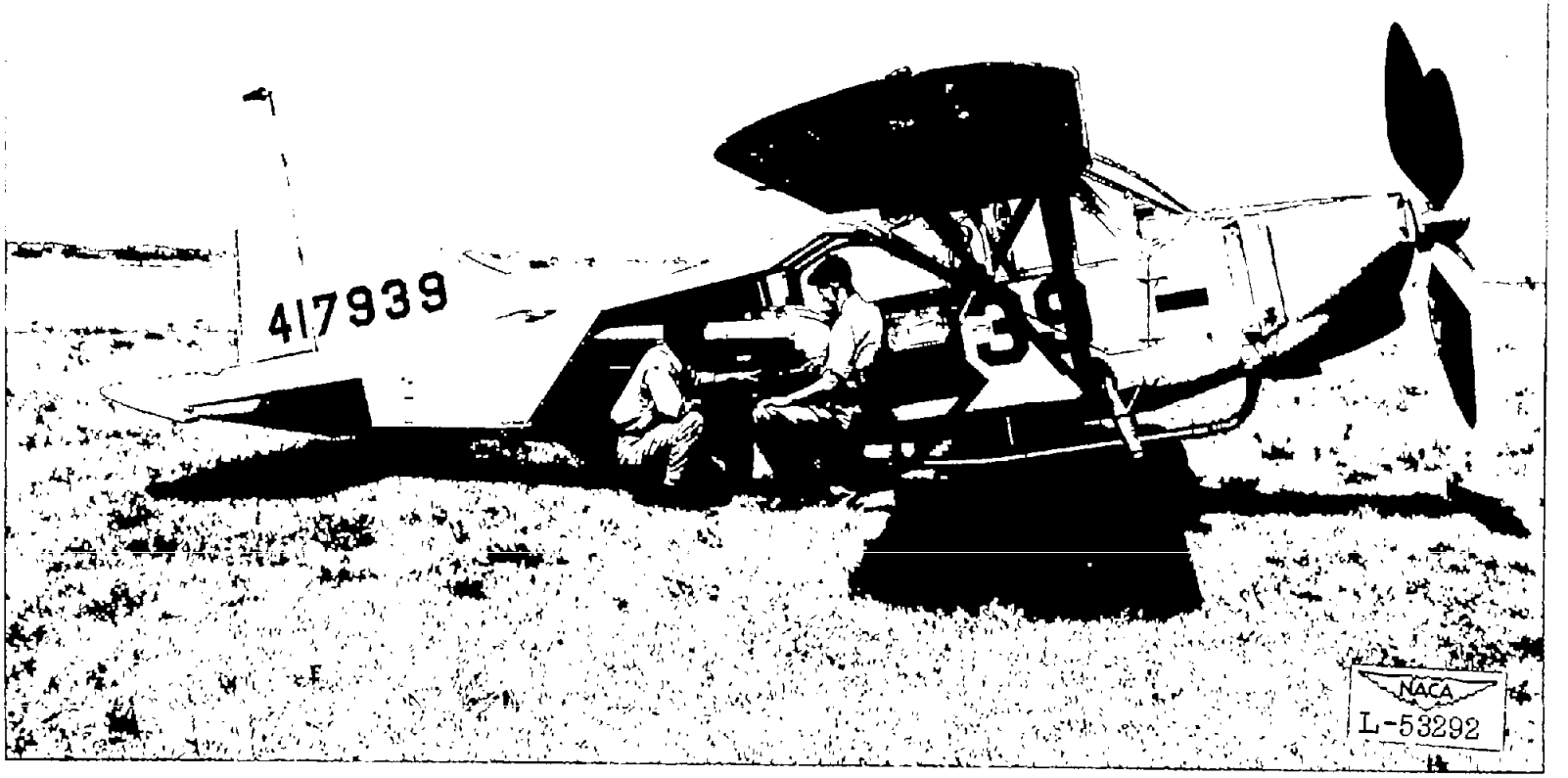

Figure 8.- Muffler installation, modified test airplane.

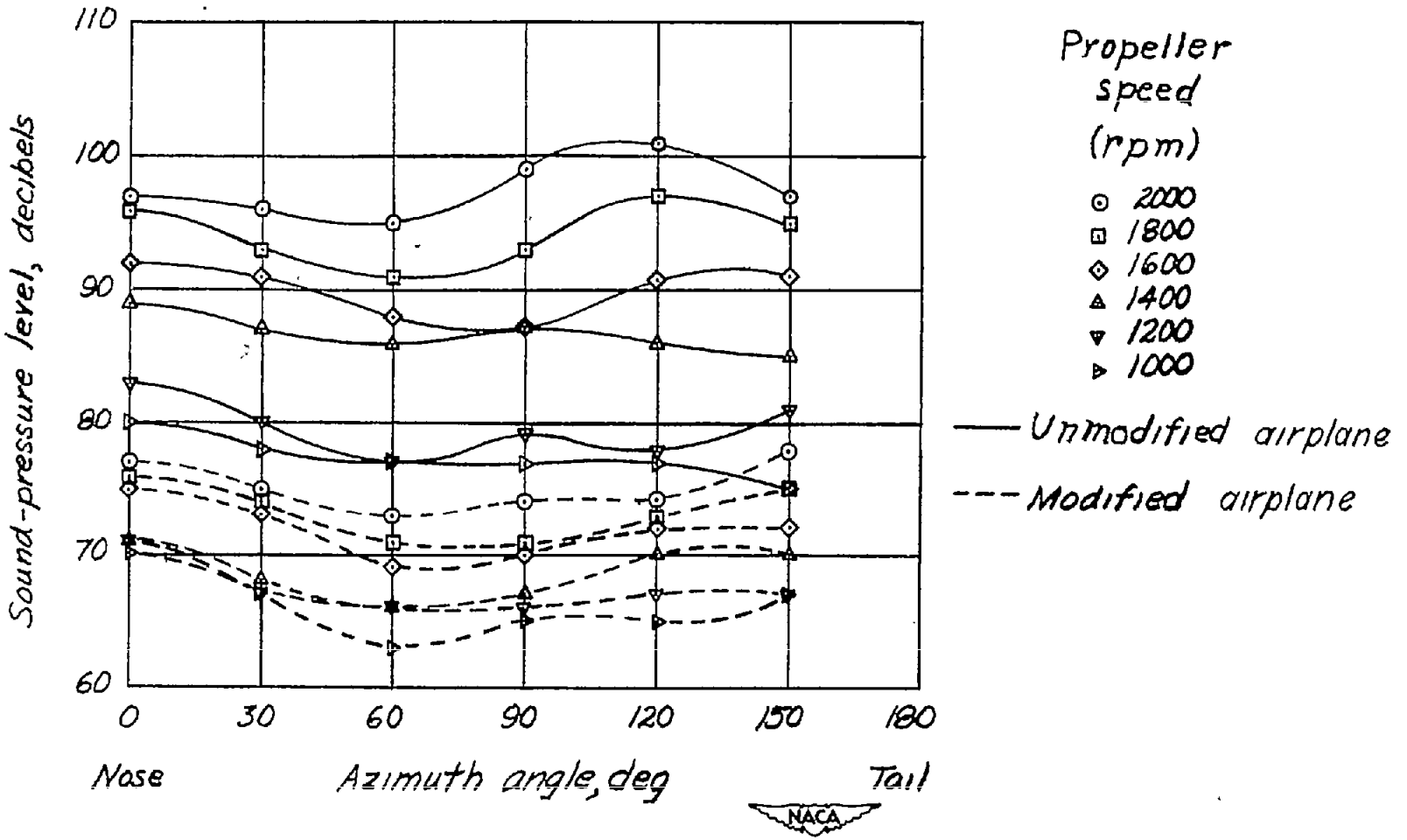

Figure 9.- Sound-pressure levels under static conditions at distance of 50 feet from propeller. Unmodified and modified test airplanes.

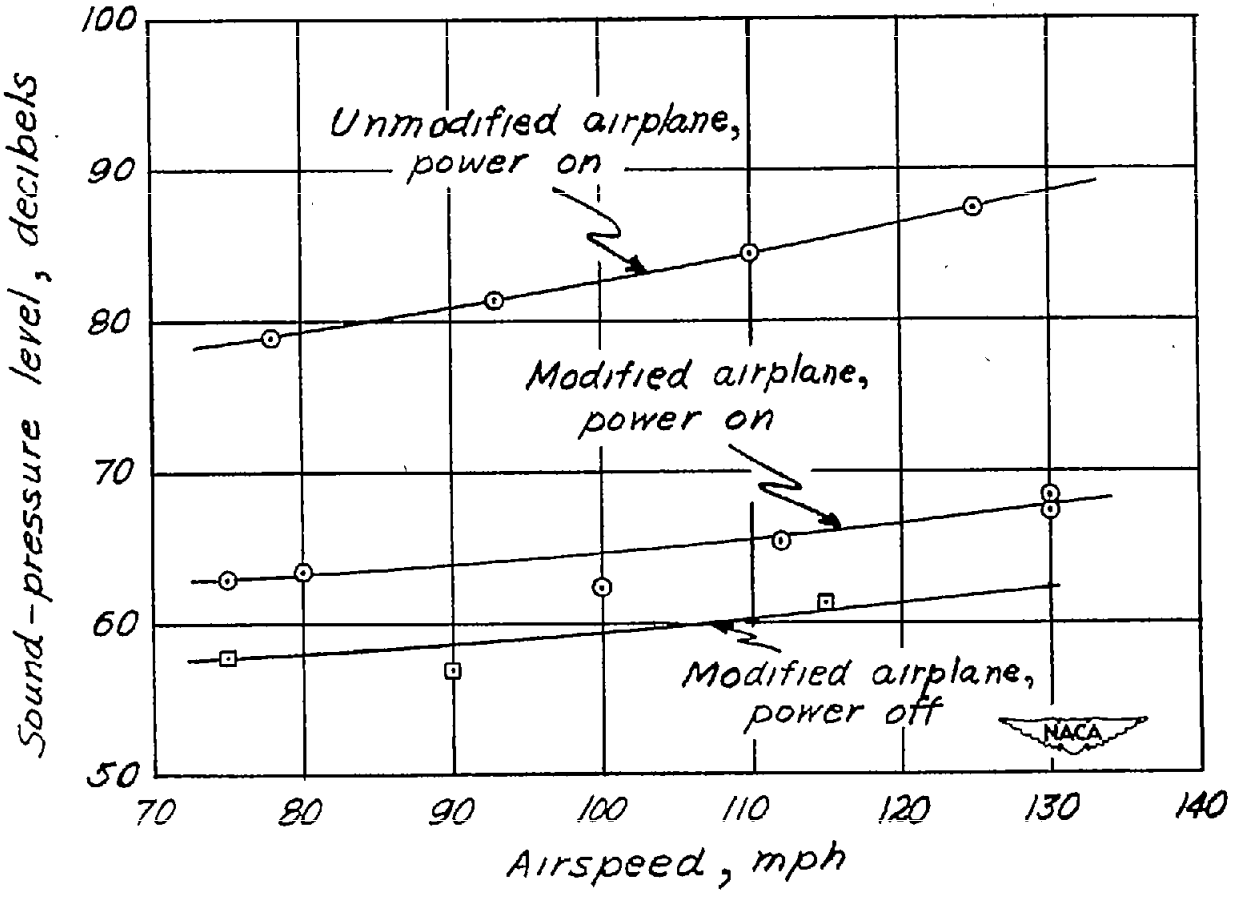

Figure 10.- Sound-pressure-level measurements at an altitude of 300 feet. Unmodified and modified test airplanes.

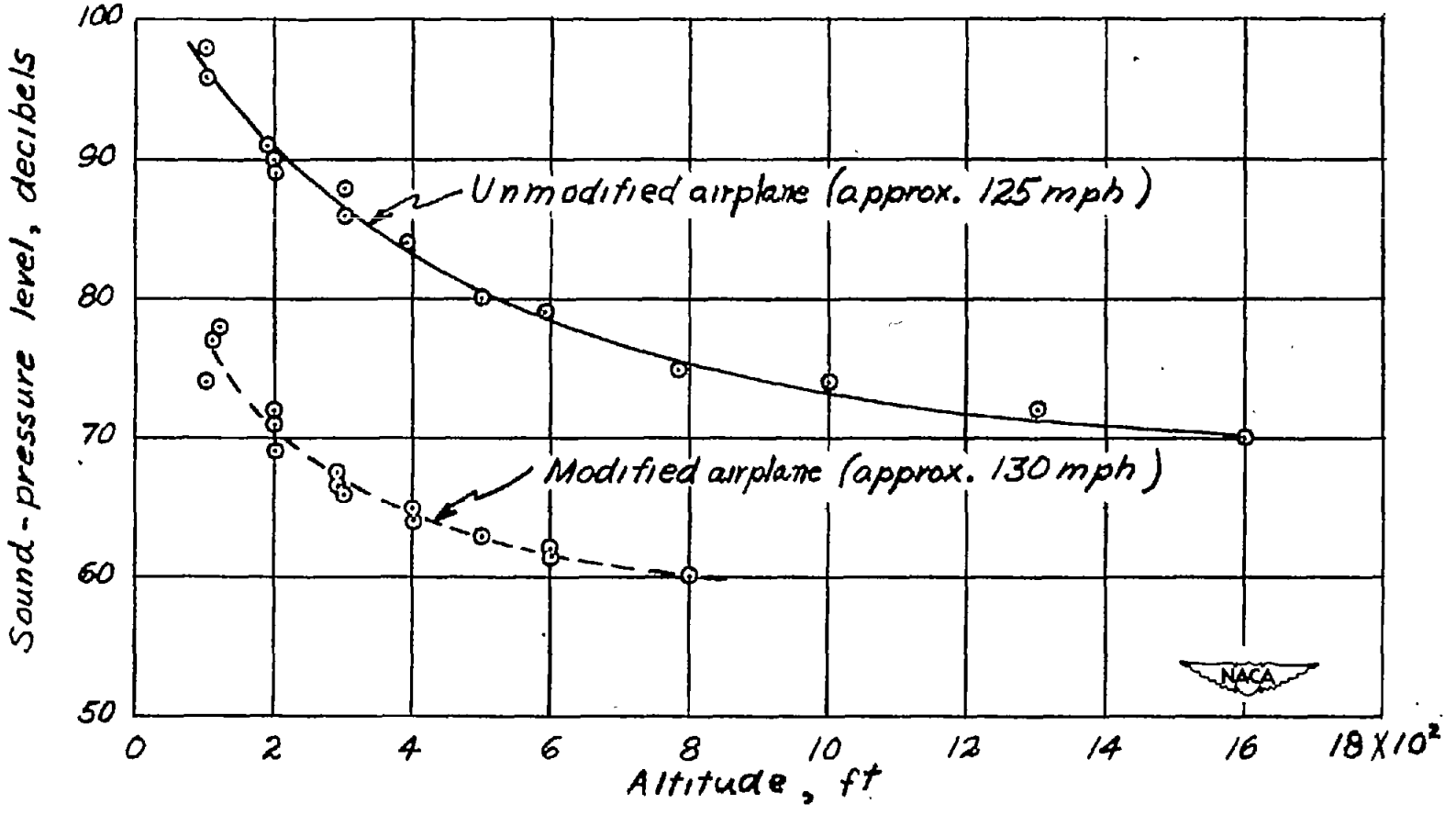

Figure 11.- Effect of altitude on sound-pressure levels. Full power and maximum speeds. Unmodified and modified test airplanes.