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TRANSONIC PROPELLER WITH AN ADVANCE RATIO OF 4.0

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SUMMARY

Overall sound-pressure levels and frequency spectra have been obtained under static conditions on a transonic propeller with an advance ratio of 4.0. This advance ratio represents a practical minimum tip speed for transonic flight speeds. The three-blade, 6.85-foot-diameter, 1,710-rpm propeller is powered by a turbine engine and is designed to operate at a forward Mach number of 0.82 at an altitude of 35,000 feet. The results consist of overall sound-pressure levels and frequency spectra obtained from analyses made of recordings taken during ground runups of the propeller with an advance ratio of 4.0. These results are compared with similar results obtained from a supersonic propeller having an advance ratio of 2.2 reported in NACA Technical Note 4059 and from a modified supersonic propeller having an advance ratio of 3.2 reported in NACA Technical Note 4172.

The advance-ratio-4.0 propeller of the present investigation produced a maximum sound-pressure level of 117.5 decibels when corrected to 1,400 horsepower. This overall noise output represents a lowering of the maximum overall sound-pressure level by approximately 5 decibels from that of the advance-ratio-3.2 propeller and by 14 decibels from that of the advance-ratio-2.2 propeller at comparable engine horsepowers. The frequency spectrum for the present propeller was the same as that for the advance-ratio-3.2 propeller, that is, high sound-pressure levels for the low-blade-passage harmonics with a rapid decrease in level with increasing order of harmonic. The 5-decibel reduction, under static conditions, is not considered sufficient to warrant the increased weight and operational penalties that would accompany this selection over the more efficient advance-ratio-3.2 propeller. At high forward speeds, however, the noise level of the present advance-ratio-4.0 propeller, especially in the frequency range where passenger comfort is important, should probably be substantially lower than that of the advance-ratio-3.2 propeller.

INTRODUCTION

The supersonic propeller of reference 1 utilized an optimum advance angle and thin blade sections to obtain maximum efficiency at high forward speeds. This type of propeller has an added advantage of producing a high thrust from a low-torque-input propeller with a relatively small diameter. However, as shown in reference 1, the static noise output of this type of propeller as a result of its high tip speeds would prohibit its use for commercial transports. The static tip Mach number of this propeller was 1.2; at a design forward Mach number of 0.95 at an altitude of 40,000 feet, the tip Mach number would be 1.67.

The modified supersonic propeller having an advance ratio of 3.2 in reference 2 relaxed the requirement of optimum advance angle to lower the tip speed but maintained the same blade thickness as the supersonic design in reference 1. The efficiency of this propeller at its design speed was not lowered below the efficiency of the supersonic propeller. (See refs. 3 and 4.) The static noise output produced by this propeller was comparable to that of present-day transport-type propellers. The static tip Mach number of this propeller was 0.80; at the design forward Mach number of 0.95 at an altitude of 40,000 feet, the tip Mach number would be 1.32. At this flight speed the noise output would require considerable sound insulation for passenger comfort.

In order to lower in-flight noise, the tip Mach number must be lowered. The advance-ratio-4.0 propeller used in the present investigation represents a practical minimum tip speed for transonic flight speeds at which future transport-type aircraft are expected to operate; with this advance ratio the static tip Mach number is 0.566. At the design forward Mach number of 0.82 at an altitude of 35,000 feet, the tip Mach number would be 1.05. The results of this propeller investigation are compared with the results of two previously tested propellers presented in references 1 and 2.

SYMBOLS

B	number of blades
b	blade width (chord), ft
C_L	design lift coefficient
D	propeller diameter, ft
h	blade-section maximum thickness, ft

J	design advance ratio, V/nD
M_t	propeller tip Mach number
n	propeller rotational speed, rpm
P	power absorbed by propeller, hp
R	propeller tip radius, ft
r	radius to blade element, ft
T	thrust of propeller, lb
V	forward velocity, fps
x	propeller radius, r/R
β	blade angle, deg
ρ	density, lb-sec^2/ft^4
σ	solidity, $Bb/2\pi r$

Subscript:

t	tip

APPARATUS AND PROCEDURE

The transonic propeller used in the present investigation is a three-blade configuration with a 6.85-foot diameter and an advance ratio of 4.0. The blades are constructed of solid SAE 4340 steel having an ultimate tensile strength of 180,000 pounds per square inch. A photograph of the propeller mounted on the test airplane is shown in figure 1. The blade-form curves and pertinent dimension ratios are given in figure 2. Significant parameters of the present propeller and of the propellers of references 1 and 2 are given in table I. The powerplant used is a turbine engine which, for the present configuration, drives the propeller clockwise at 1,675 rpm at 98 percent (14,000 rpm) of the rated engine speed. Special torque and thrust recording equipment installed in the airplane, described in reference 3, was used to obtain the horsepower and thrust during the engine operations. Torque and thrust values are included in the information on each run in table II.

The noise-recording and analyzing equipment used during the investigation was essentially the same as that described in reference 2. Sound recordings were taken at various azimuth-angle stations on the ground around a 100-foot-radius circle about the propeller hub. The location selected for the sound measurements was a concrete apron with no buildings or other large reflective surfaces within 300 yards. The calibration of the noise recording and analyzing equipment was performed essentially in the same manner as that described in reference 2.

Sound measurements were made to determine the radial distribution of the noise at several engine power settings. Each radial distribution for a given power setting was obtained during a continuous engine run. The test conditions and results of these measurements are given in table II. Other pertinent information is given as follows:

Clearance of ground by propeller, ft	2.5
Wind from 0° to nose, knots	3 to 5
Temperature, $^{\circ}F$	59
Barometric pressure, in. Hg	30.29

RESULTS AND DISCUSSION

General Characteristics

As a result of reduction gearing, the test propeller used for the present investigation and for the investigations of references 1 and 2 allows a selection of only two propeller rotational speeds, 3,500 rpm and 1,710 rpm. Since the turbine engine is essentially a constant-speed engine, these rotational speeds could be reduced only slightly without large penalties in the power output. As a result of the ground clearance, 10 feet was the maximum diameter allowable on this vehicle. These limitations necessarily scaled the propeller by a fixed amount to produce the desirable parameters for the aerodynamic flight test made on the propellers.

In order to scale the powers for the noise investigations, it was necessary to operate the present propeller and that of reference 2 at scaled powers to match the power of reference 1. This was done by the following approximate relation:

$$\frac{P_1}{\rho_1\left(n_1D_1\right)^3{D_1}^2\sigma_1} = \frac{P_2}{\rho_2\left(n_2D_2\right)^3{D_2}^2\sigma_2}$$

From this relation the powers were selected. However, exact adjustment of these powers was not possible with the test propeller and, therefore, other powers were used as shown in the following table:

Advance ratio, J	Power selected, hp	Power used, hp
2.2	1,400	1,400
3.2	840	1,050
4.0	160	370

The general characteristics of the noise, except for noise levels, are not expected to differ greatly because of scaling. The noise levels of the scaled propellers were adjusted to the same power input by the relation

$$\text{Decibel increase} = 20 \log_{10} \frac{P_{J=2.2}}{P_{J=3.2 \text{ or } 4.0}}$$

Since this is a torque relation, it is valid only near the plane of rotation; therefore, adjustment was made only in this region. Where comparisons between propellers are made in the present report, adjusted noise levels are used. Unadjusted levels of all measurements are given in table II.

Distribution of Overall Sound-Pressure Levels

The distribution of the adjusted overall sound-pressure levels of the three propellers around a 100-foot-radius circle is shown in figure 3. The maximum overall sound-pressure level for the advance-ratio-4.0 propeller was 117.5 decibels, and it was measured approximately symmetrically in both rear quadrants of the propeller. This noise level is approximately 5 decibels lower than the maximum level of the advance-ratio-3.2 propeller and is 14 decibels lower than the maximum level of the advance-ratio-2.2 propeller at comparable engine horsepowers.

The 5-decibel reduction, under static conditions, is not considered sufficient to warrant the increase in weight and operational penalties that would accompany this selection over the more efficient advance-ratio-3.2 propeller. At high forward speeds, however, the noise level of the present advance-ratio-4.0 propeller, especially in the frequency range where passenger comfort is important, should probably be substantially lower than that of the advance-ratio-3.2 propeller. This would be reflected in some weight saving in sound insulation.

Variation of Sound-Pressure Level With Frequency

The adjusted overall sound-pressure levels and frequency spectra of the three propellers are shown in figure 4 for station 105°. The lower level of the advance-ratio-4.0 propeller is seen due to the decrease in the lower frequencies of the propeller. The propellers having advance ratios of 4.0 and 3.2 show large decreases in the higher frequencies as compared with the supersonic advance-ratio-2.2 propeller. As mentioned previously, at high forward speeds this would be more pronounced for the advance-ratio-4.0 propeller because of the reduced tip Mach numbers of the design.

Effect of Power Variations

The unadjusted overall sound-pressure levels and frequency spectra of the noise measured at station 105° on the transonic advance-ratio-4.0 propeller are shown in figure 5 for power settings of 930, 815, 550, and 370 horsepower. Propeller rotational speed was maintained at 1,675 rpm for these power settings.

Increasing the power from 370 to 550 horsepower increased the overall noise level by 2.5 decibels which, within the accuracy of the measurements, is predicted by the theoretical variation mentioned previously. The increase is seen to be caused by raising the lower frequency of the spectrum. Further increase in power to 815 and 930 horsepower increased the overall level by 10 and 12 decibels, respectively. Although the increase is seen to be caused primarily by an increase in the lower harmonics, the spectrum shows larger increases in the higher harmonics. This change in the spectrum is believed to be due to the propeller operating with partially stalled blades at the higher powers. This result shows the necessity for scaling powers, as previously mentioned. In addition, it shows the setting used which, although not a duplicate of the scale power, is sufficiently close to give accurate overall sound-pressure levels and frequency spectra for comparison purposes.

CONCLUDING REMARKS

The advance-ratio-4.0 propeller of the present investigation produced a maximum sound-pressure level of 117.5 decibels when corrected to 1,400 horsepower. This noise level is approximately 14 decibels lower than the maximum level for the advance-ratio-2.2 propeller of NACA Technical Note 4059 and is 5 decibels lower than the maximum level of the advance-ratio-3.2 propeller of NACA Technical Note 4172 at comparable engine horsepowers.

The 5-decibel reduction, under static conditions, is not considered sufficient to warrant the increased weight and operational penalties that would accompany this selection over the more efficient advance-ratio-3.2 propeller. At high forward speeds, however, the noise level of the present advance-ratio-4.0 propeller, especially in the frequency range where passenger comfort is important, should probably be substantially lower than that of the advance-ratio-3.2 propeller because of its lower tip speed. It should be noted, however, that some cabin insulation will be required to reduce aerodynamic-induced noises in the cabin; the additional insulation required to reduce the propeller noise in the cabin must be considered against the disadvantages of the selection of a high-advance-ratio propeller.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., January 29, 1959.

REFERENCES

1. Kurbjun, Max C.: Noise Survey of a Full-Scale Supersonic Turbine-Driven Propeller Under Static Conditions. NACA TN 4059, 1957.

2. Kurbjun, Max C.: Noise Survey Under Static Conditions of a Turbine-Driven Full-Scale Modified Supersonic Propeller With an Advance Ratio of 3.2. NACA TN 4172, 1958.

3. Hammack, Jerome B., Kurbjun, Max C., and O'Bryan, Thomas C.: Flight Investigation of a Supersonic Propeller on a Propeller Research Vehicle at Mach Numbers to 1.01. NACA RM L57E20, 1957.

4. Hammack, Jerome B., and O'Bryan, Thomas C.: Effect of Advance Ratio On Flight Performance of A Modified Supersonic Propeller. NACA TN 4389, 1958.

TABLE I

PARAMETERS OF THE THREE PROPELLERS

Source of data	Type of propeller	Design forward Mach number	Altitude, ft	J	$\sigma_{0.7R}$	$(h/b)_t$	$(h/b)_{spinner}$	M_t
Present report	Transonic	0.82	35,000	4.0	0.195	0.02	0.070	0.55
Reference 1	Supersonic	.95	40,000	2.2	.154	.02	.042	1.20
Reference 2	Modified supersonic	.95	40,000	3.2	.154	.02	.055	.80

TABLE II

TEST CONDITIONS AND RESULTS OF NOISE ANALYSIS FOR ADVANCE-RATIO-4.0 PROPELLER

[On ground; 100-foot-radius circle]

Test conditions					Unadjusted sound-pressure level, db (Reference pressure level, 0.0002 dynes/cm^2)								
Station, deg	T, lb	P, hp	Blade angle, deg	Fundamental blade-passage frequency, cps	Overall	Order of harmonic							
						1st	2d	3d	4th	5th	6th	7th	8th
90	1,270	370	18.8	85.5	104.0	102.0	90.0	85.0	84.0	89.0	83.0	89.0	88.0
105	1,270	370	18.8	85.5	105.0	103.0	92.0	88.0	84.0	87.5	89.5	84.0	85.0
120	1,270	370	18.8	85.5	106.0	104.5	91.0	88.0	88.5	89.5	----	----	----
135	1,270	370	18.8	85.5	106.0	104.0	92.0	90.0	92.0	88.5	89.5	89.0	89.0
225	1,270	370	18.8	85.5	106.0	101.0	101.0	98.5	98.5	98.0	96.0	98.0	97.5
240	1,270	370	18.8	85.5	106.0	103.0	97.5	98.0	92.0	92.0	92.0	92.5	91.0
255	1,270	370	18.8	85.5	106.0	103.5	95.5	94.0	90.5	93.5	93.0	91.0	92.5
270	1,270	370	18.8	85.5	105.0	101.5	94.5	92.5	92.5	90.5	85.0	91.0	83.0
90	1,510	550	23.4	85.5	106.5	106.0	93.5	95.0	97.5	99.0	----	97.0	97.0
105	1,510	550	23.4	85.5	107.5	106.5	96.0	88.0	87.0	87.0	89.0	----	----
120	1,510	550	23.4	85.5	108.0	106.5	95.0	90.5	88.0	90.0	----	----	----
135	1,510	550	23.4	85.5	107.5	105.0	92.0	89.5	88.5	90.0	----	----	----
225	1,510	550	23.4	85.5	107.0	101.5	95.5	93.5	91.5	----	----	----	----
240	1,510	550	23.4	85.5	108.5	106.0	97.0	96.0	92.5	94.0	92.5	93.5	92.5
255	1,510	550	23.4	85.5	108.5	106.5	96.5	91.0	89.0	91.5	90.0	90.0	91.0
270	1,510	550	23.4	85.5	106.0	105.0	95.5	89.5	89.5	87.0	84.0	89.5	84.0
0	1,690	815	30.5	85.5	108.0	94.0	-----	-----	-----	----	----	----	----
30	1,690	815	30.5	85.5	110.5	93.5	-----	95.0	96.5	95.0	----	----	----
60	1,690	815	30.5	85.5	108.0	104.0	94.0	-----	-----	94.5	----	94.0	----
90	1,690	815	30.5	85.5	113.0	112.0	103.5	-----	-----	96.5	94.0	----	95.0
105	1,690	815	30.5	85.5	115.0	114.0	104.5	100.0	99.0	98.0	98.5	----	----
120	1,690	815	30.5	85.5	113.0	112.5	101.0	-----	-----	----	----	----	----
135	1,690	815	30.5	85.5	112.0	110.5	98.0	-----	95.0	96.0	93.5	93.5	97.5
225	1,690	815	30.5	85.5	109.0	105.5	-----	-----	-----	----	----	----	----
240	1,690	815	30.5	85.5	111.0	109.0	96.0	95.0	93.0	94.0	----	----	----
255	1,690	815	30.5	85.5	114.5	114.0	101.5	98.0	96.0	96.0	----	----	----
270	1,690	815	30.5	85.5	113.5	113.0	101.5	-----	-----	----	----	----	----
300	1,690	815	30.5	85.5	109.0	106.5	93.5	-----	-----	----	----	----	----
330	1,690	815	30.5	85.5	107.5	95.0	-----	94.0	-----	----	----	----	----
360	1,690	815	30.5	85.5	107.0	91.5	-----	-----	96.0	95.0	----	----	----
90	1,670	930	34.0	85.5	116.5	115.5	107.5	-----	-----	----	----	----	----
105	1,670	930	34.0	85.5	117.0	116.0	108.5	100.0	104.0	99.0	----	----	----
120	1,670	930	34.0	85.5	117.5	115.5	-----	-----	-----	----	----	----	----
135	1,670	930	34.0	85.5	117.0	114.0	-----	-----	-----	----	----	----	----
225	1,670	930	34.0	85.5	113.0	109.0	-----	-----	-----	----	----	----	----
240	1,670	930	34.0	85.5	115.5	113.5	-----	-----	-----	----	----	----	----
255	1,670	930	34.0	85.5	116.5	115.0	105.0	-----	-----	----	----	----	----
270	1,670	930	34.0	85.5	116.0	114.0	105.5	-----	-----	----	----	----	----

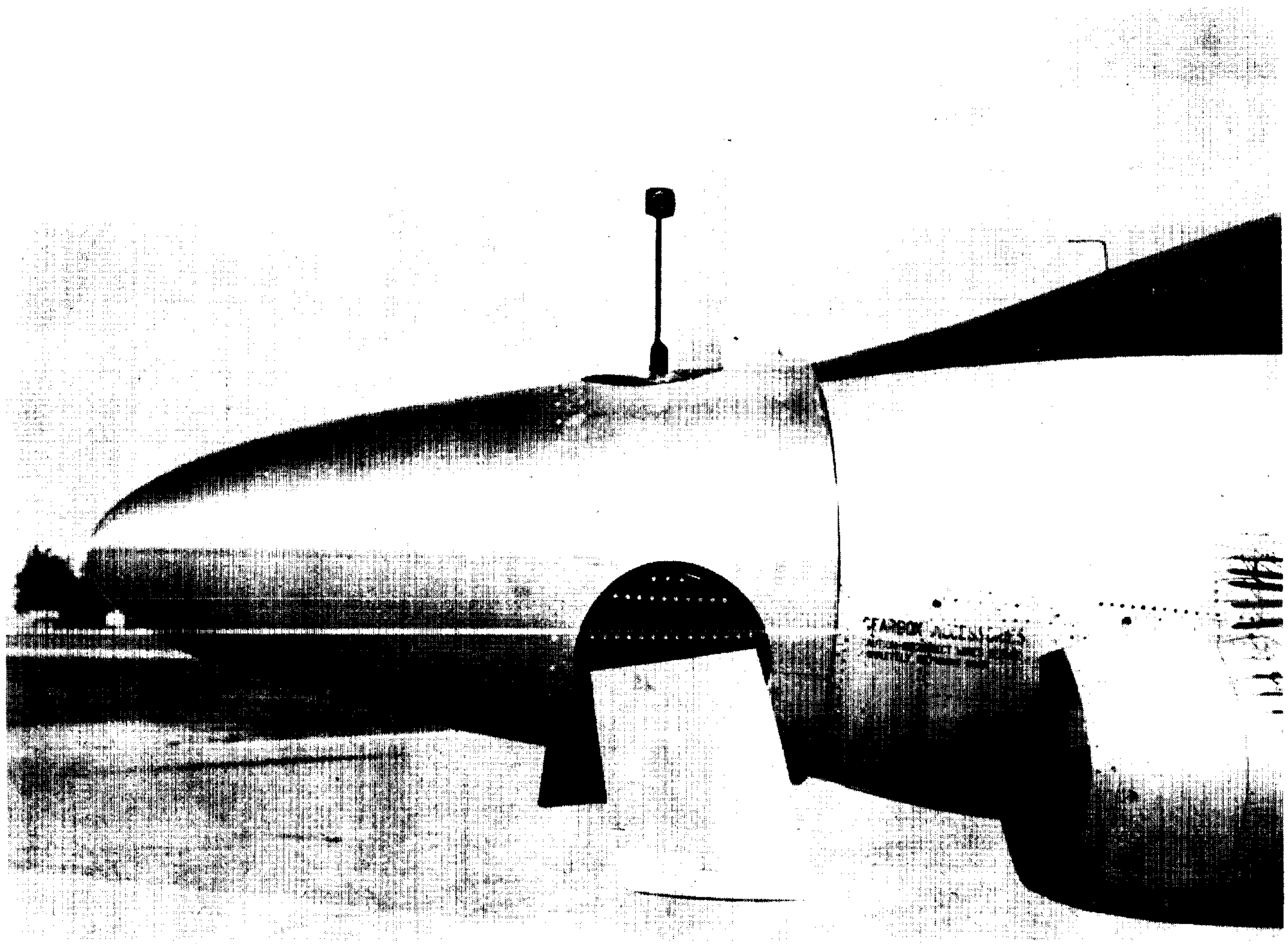

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Figure 1.- Transonic advance-ratio-4.0 propeller mounted on test airplane.

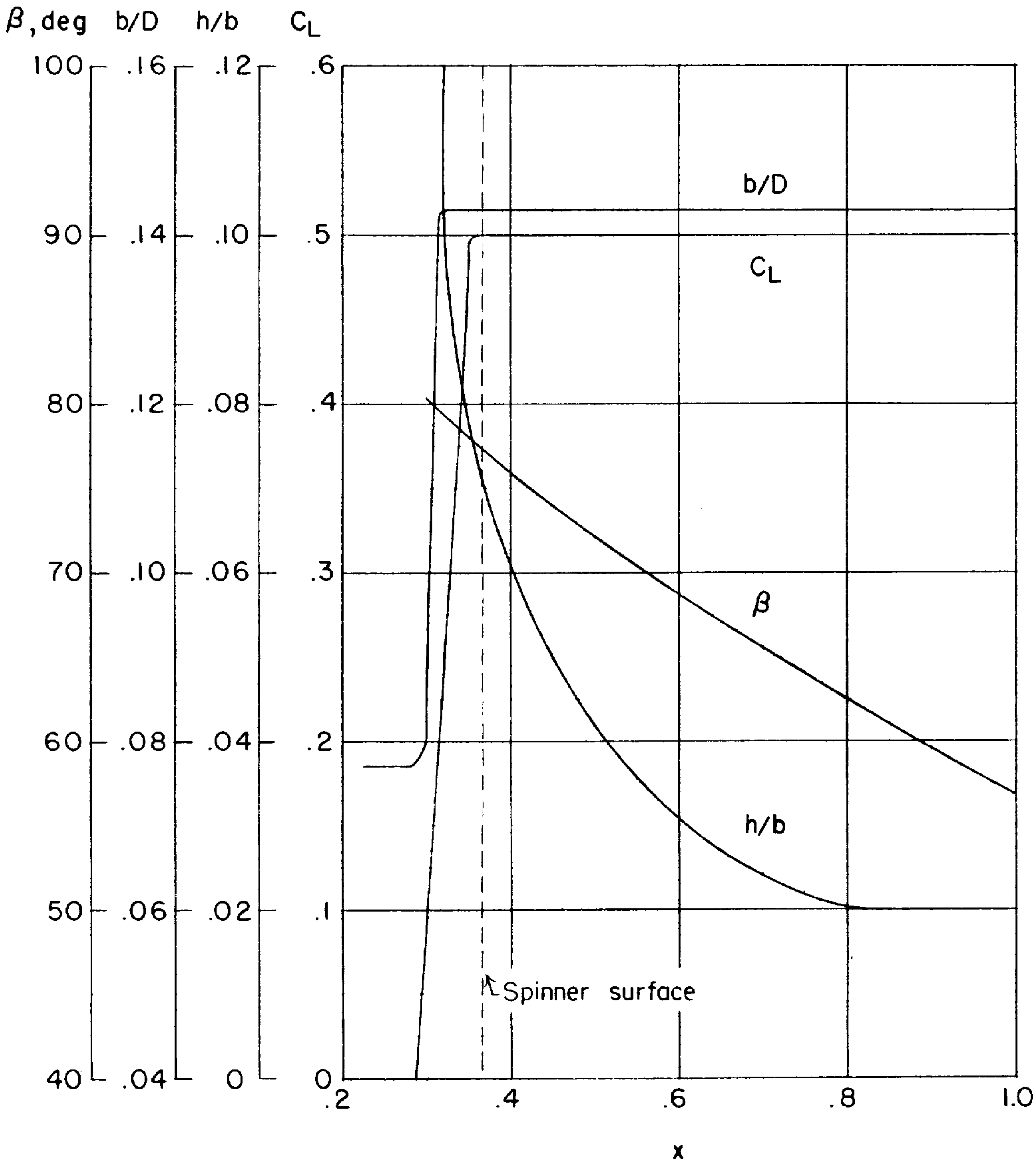

Figure 2.- Blade-form curves of transonic advance-ratio-4.0 propeller used in present investigation.

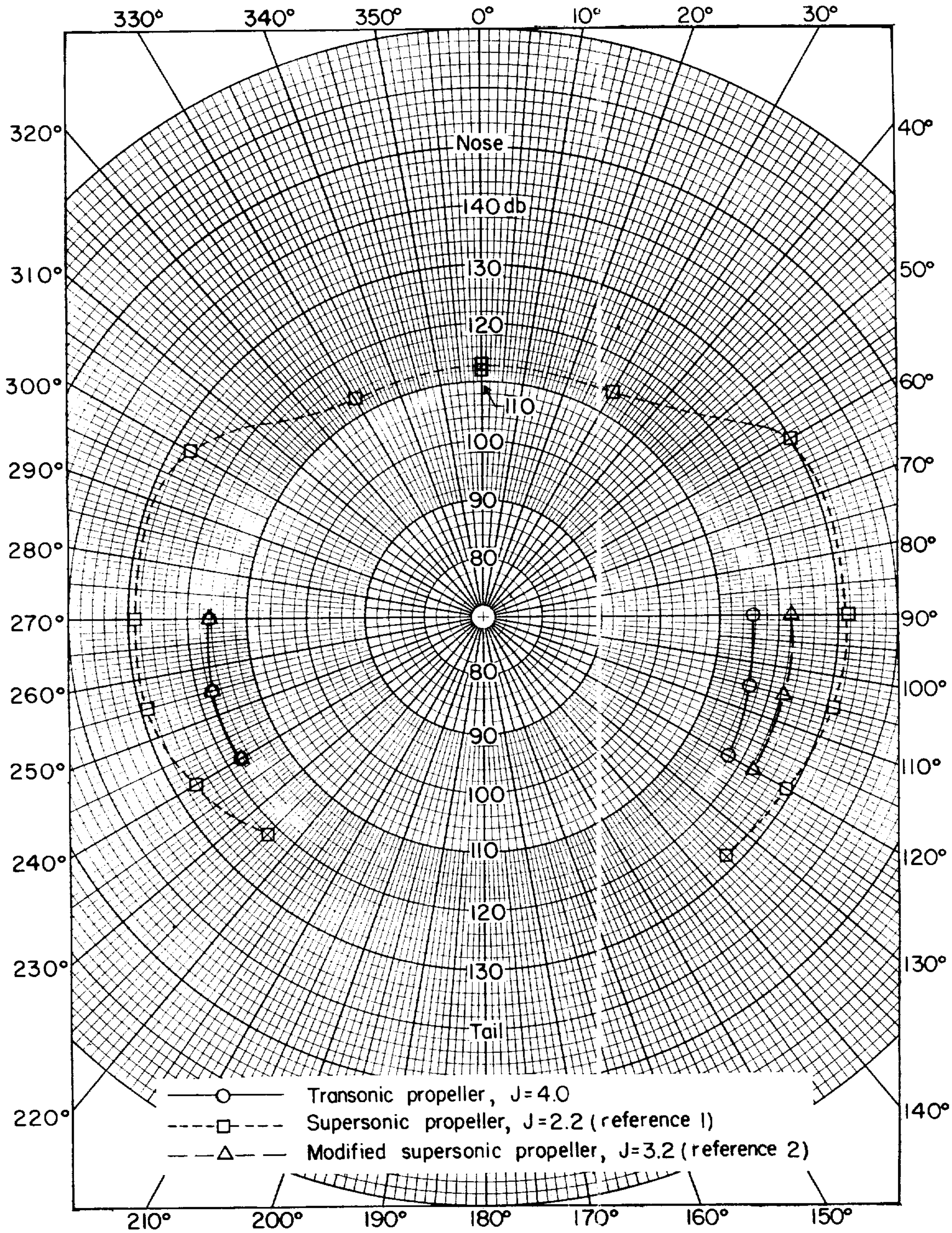

Figure 3.- Adjusted overall sound-pressure levels for three propellers around a 100-foot-radius circle. P = 1,400 horsepower.

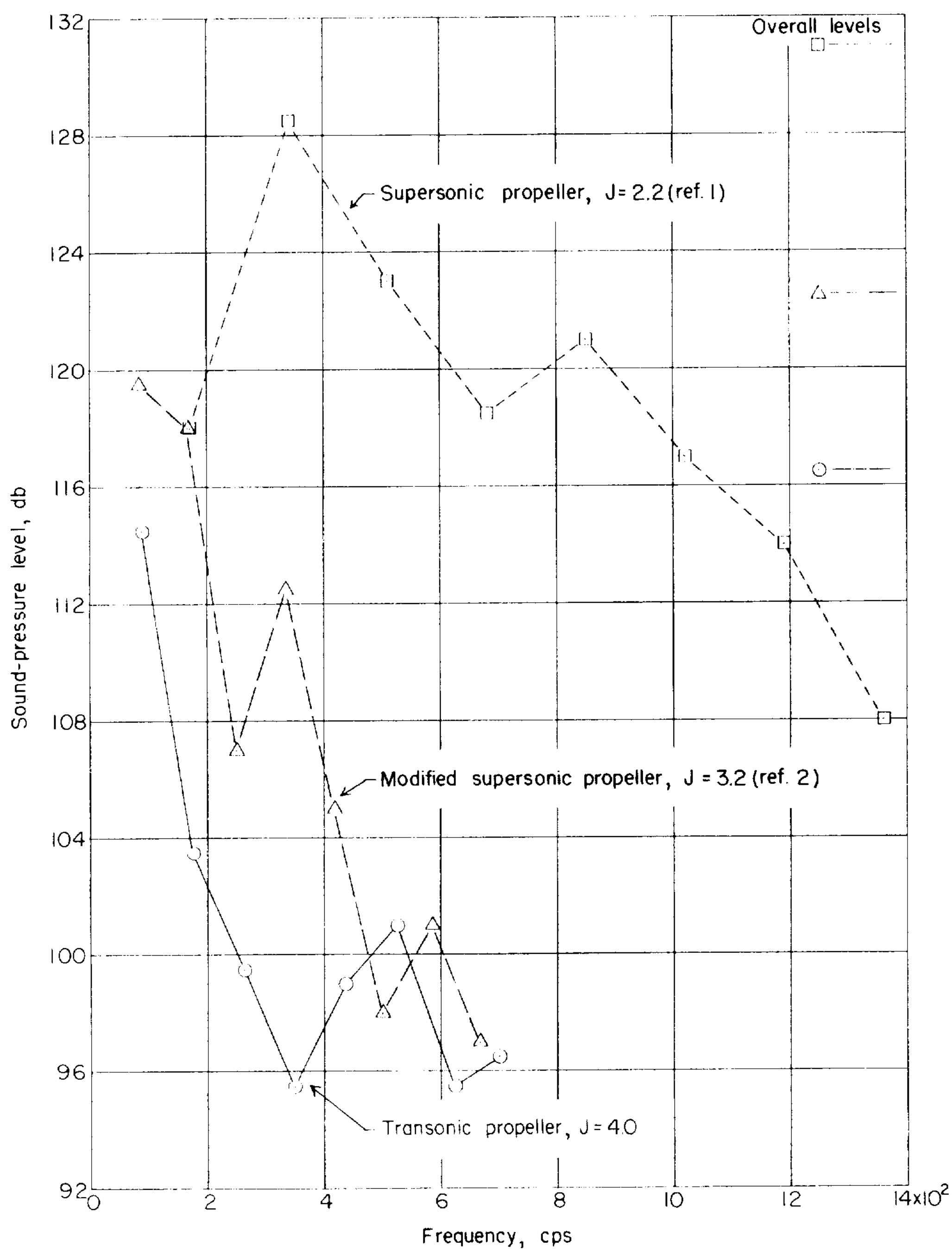

Figure 4.- Comparison of adjusted overall sound-pressure levels and frequency spectra of three propellers. Propeller-blade harmonics are connected with lines for identification purposes only. Station 105°; around a 100-foot-radius circle; P = 1,400 horsepower.

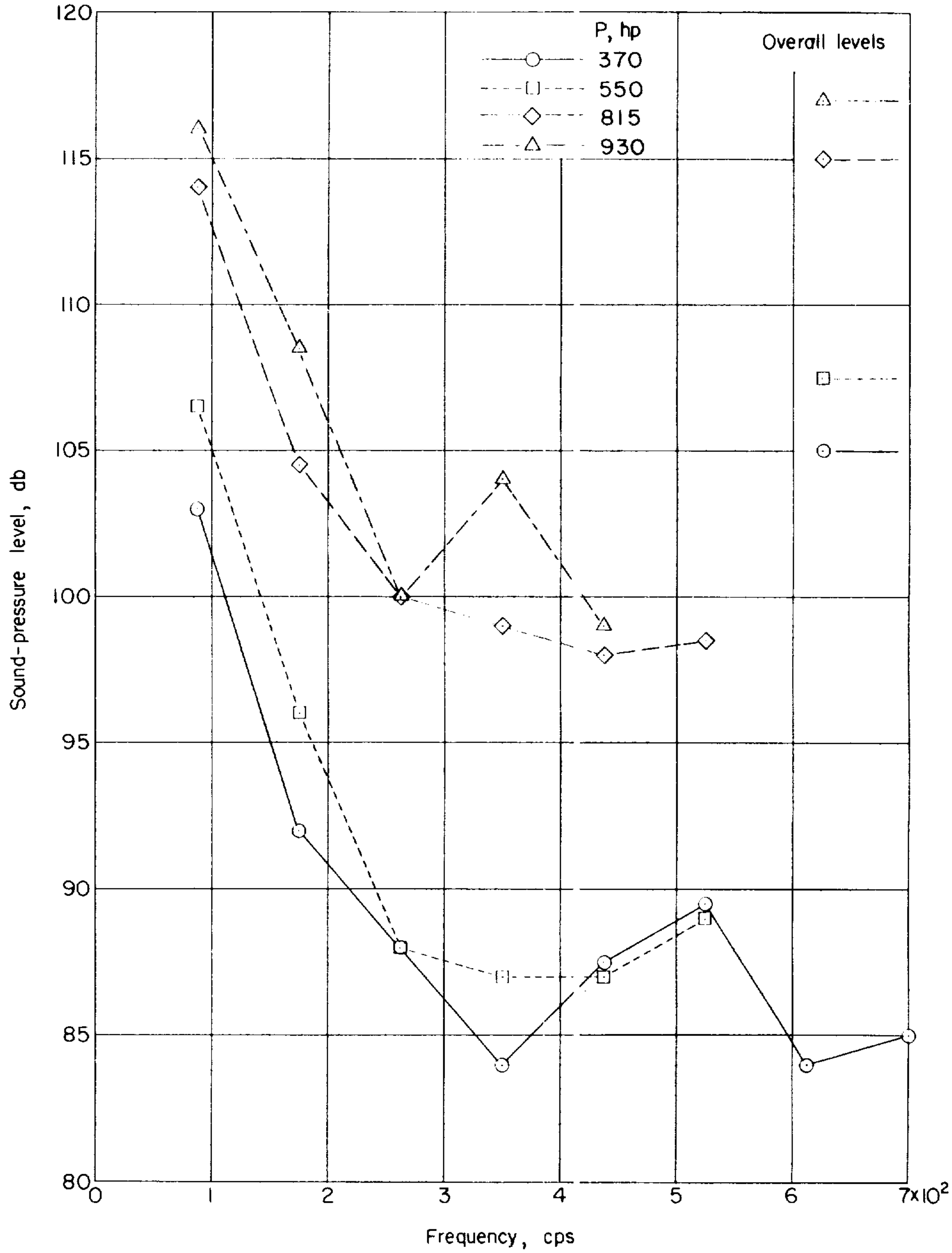

Figure 5.- Comparison of unadjusted overall sound-pressure levels and frequency spectra for transonic advance-ratio-4.0 propeller at several power settings. Propeller-blade harmonics are connected with lines for identification purposes only Station 105°; around a 100-foot-radius circle; n = 1,675 rpm