NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1358

PROPELLER-LOUDNESS CHARTS FOR LIGHT AIRPLANES

By Harvey H. Hubbard and Arthur A. Regier

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

Washington
July 1947

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 1358

PROPELLER-LOUDNESS CHARTS FOR LIGHT AIRPLANES

By Harvey H. Hubbard and Arthur A. Regier

SUMMARY

Calculations of the rotational-noise and vortex-noise loudness levels at distances of 300 and 1000 feet have been made for a large number of propellers in forward flight of 50 to 200 miles per hour and for engine ratings of 100 to 300 horsepower. Propellers of two, four, six, and eight blades, diameters of 6, 8, and 10 feet, and rotational speeds of 1000 to 3000 rpm are considered. Calculated results are presented in chart form for convenience of designers of propellers for applications in which loudness is an important consideration.

INTRODUCTION

The theory for calculating rotational sound pressures of a propeller operating at zero forward speed was developed by Gutin in reference 1. A simplification of the Gutin formula is given in reference 2 from which the sound-pressure level of a propeller may be easily calculated. This formula shows that the rotational-sound-pressure level of a propeller can be made as low as desired by reducing the tip speed and increasing the number of blades.

Recent tests of the sound emission from two-blade, four-blade, and seven-blade propellers (reference 3) show that the theory for rotational noise is in close agreement with experiment for a tip Mach number range between 0.5 and 0.9 but that for lower tip Mach numbers the measured over-all sound-pressure levels were much greater than the calculated rotational-sound-pressure levels. This discrepancy is due to the vortex noise of the propeller. Up to the present time, the sound output of practical propellers has been almost entirely due to rotational noise and, consequently, vortex noise has not been important. Because of public demand for a large reduction of airplane noise, it now becomes important to indicate the vortex-noise level of a propeller. In the present paper a tentative level of the vortex noise is given for all propellers considered. This estimate is based on the work of references 4 and 5.

The loudness level rather than the sound-pressure level is a better criterion for comparing the noise from propellers. The method of Fletcher and Munson (reference 6) is used for calculating the loudness level. The calculation of the loudness of propellers is cumbersome. In the present paper the loudness levels of a large number of propellers in the light-airplane range have been calculated and presented in chart form. The rotational loudness level and the vortex-loudness level as well as the resultant loudness level may be obtained directly from the charts.

The efficiencies for this same class of propellers are given in reference 7. Since a large number of combinations of propeller rotational speeds, diameter, and number of blades satisfy a given loudness level, the designer may choose the combination which will give him a maximum of efficiency and a minimum of loudness consistent with requirements.

SYMBOLS AND DEFINITIONS

M_t tip Mach number (rotation only)

D propeller diameter, feet

β angle of observer from axis of rotation (0° in front)

N propeller rotational speed, rpm

P_H engine rating, horsepower

V airplane forward speed, miles per hour

n number of blades

s distance from source of sound, feet

L_n loudness level, decibels

η propeller efficiency

η_i ideal propeller efficiency

T total thrust, pounds

A_b total blade area, square feet

ρ air density, slugs per cubic foot

C_L propeller lift coefficient

W section velocity at 0.7 radius, feet per second

The terms "noise, sound, and sound pressures" are used synonymously.

Sound-pressure level or sound-intensity level is the decibel value of sound. The pressure of 0.0002 dyne per square centimeter is 0 decibels.

Loudness level of a sound takes into account the sensitivity of the ear to frequency and is equal to the intensity level of the equally loud 1000-cycle reference tone. (See reference 6.)

Rotational noise is the propeller noise due to the steady aerodynamic forces on the blade. In Gutin's theory the noise is divided into the torque and thrust components and the frequencies are multiples of rotational speed.

Vortex noise is the propeller noise due to the oscillatory forces on the blade associated with the vortices in the wake of an airfoil or the vortices of a Kármán vortex street. For propellers, the vortex noise is usually of much higher frequency than the rotational noise and is distributed over a wide band of frequencies.

ANALYSIS AND ASSUMPTIONS

All equations used in sound calculations for this paper have been published previously. Calculations are for standard sea-level conditions.

Rotational noise.- The rotational noise of the propeller is the noise due to the steady aerodynamic forces on the blade. The sound from this source has been determined theoretically for a propeller operating at static conditions by Gutin in reference 1. This theory is the basis for the calculation of reference 2 and 3. In the present paper in which the sound is calculated for an airplane propeller in forward flight, the sound is assumed to be the same as of a propeller operating at equal thrust, torque, and rotational speed in the static condition. This assumption is reasonable for airplanes flying at low Mach numbers. Measurements of the sound from an airplane at zero velocity and in flight for comparable conditions showed that the noise in flight was 6 decibels lower. See reference 8. This difference is in the order of the expected noise reduction due to reduced thrust for the flight condition.

Dodd & Roger

Turn same as Gutin

4-5 harmonics higher, but doesn't affect fundamental

The thrust of the propeller is calculated from the power and forward velocity assuming the propeller to be operating at 90 percent of its ideal efficiency. (See appendix.)

Loudness levels are computed by the method of reference 3 by using the first four harmonics of the rotational sound pressure. These calculations are made for a direction of 105° from the axis of rotation of the propeller (0° in front). The calculated loudness is approximately a maximum for this angle. The effective radius of the propeller is assumed to be 0.8 of the total radius and calculated sound-pressure values were doubled for ground reflection. For loudness calculations at a distance, all sound pressures are assumed to vary inversely as the distance. This assumption is justified in reference 8 for the distance considered in this paper.

Vortex noise.- The vortex noise is due to the shedding of vortices from the propeller blade. The vortex-noise polar distribution and formulas are given for cylindrical circular rods in reference 4. Formulas and measured vortex-noise levels for rods having airfoil sections as well as circular cross sections are given in reference 5. The vortex-noise loudness levels shown in the charts and calculated with the help of the information in references 4 and 5 should be considered tentative and are probably accurate to ±10 decibels. Static tests as well as flight tests of propellers having very low rotational noise levels on airplanes having low engine noise levels will be necessary to determine the seriousness of the vortex-noise problem. Public reaction to vortex noise is an important factor in this problem.

The following assumptions were made in order to obtain tentative answers:

(1) The vortex-noise energy is assumed to vary as the sixth power of the tip speed and the first power of the blade area of the propeller. (See reference 5.) The constant of proportionality was evaluated from measurements on a helicopter blade. The blade area is estimated from aeroydnamic considerations. (See appendix.)

(2) Vortex-noise polar distribution is assumed to be the same as obtained for rods. (See reference 4.)

Loudness.- Loudness calculations by the Fletcher-Munson method were computed separately for the corresponding rotational-noise levels and the vortex-noise levels. In most cases the rotational-noise frequency band and the vortex-noise frequency band are so far removed from each other that the lower frequencies have very little if any masking effect on the vortex frequencies. The total loudness levels are computed on this assumption. The vortex-noise frequencies are assumed to be in that range where the intensity levels in decibels are equal to the loudness levels in decibels.

DISCUSSION

The polar distribution of rotational-noise components for the first harmonic of a two-blade propeller are shown in figure 1. Relative magnitudes of the "torque" noise and "thrust" noise are illustrated for a condition of forward flight. Because of the lesser contribution of the thrust noise, the shape of this polar distribution is markedly different from that for a static case given in figure 1 of reference 2. Since the thrust noise in front of the plane of rotation is out of phase with the torque noise, conditions of low forward speed would tend to produce two extra lobes in the total-sound-pressure pattern An estimation of the vortex-noise magnitude (maximum on the axis of rotation) and distribution is also included to illustrate its relative importance at these operating conditions.

Figures 2 to 49 (see table 1 for index) are design charts showing the effects of different parameters on loudness levels of propellers having various numbers of blades. Loudness decreases markedly with a decrease in tip speed for all blade configurations until the speed is reached at which vortex noise becomes dominant. For each chart the propeller diameter, airplane forward speed, engine horsepower, and distance from the source are constants. The ranges of these variables for which calculations were made are as follows:

Engine rating, P_H, horsepower	100 to 300
Engine rotational speed, N, rpm	1000 to 3000
Airplane forward speed, V, miles per hour	50 to 200
Propeller diameter, D, feet	6, 8, and 10
Number of propeller blades, n	2, 4, 6, and 8
Distance from propeller, s, feet	300 to 1000

The design charts of figures 2 to 49 enable a designer to select the optimum configuration for a given application in which the engine rotational speed is fixed or will indicate the gearing necessary to enable a given configuration to operate at a given loudness level.

From figures 50 to 55, which have been cross-plotted from figures 2 to 49, the following general conclusions may be drawn:

(1) Loudness levels generally decrease for a larger number of blades except at the rotational speeds where vortex noise tends to dominate rotational noise. (See fig. 50.)

(2) A reduction in power may cause an appreciable reduction in loudness depending on the rotational speed. (See fig. 51.)

(3) At constant rotational speed, a decrease in diameter causes a decrease in loudness. (See fig. 52.)

(4) At a constant tip Mach number a decrease in propeller diameter causes an increase in loudness. (See fig. 53.)

(5) Loudness is reduced slightly by increased forward speed of the airplane and the difference that exists seems to be nearly constant for the different rotational speeds considered. (See fig. 54.)

(6) Loudness levels in general tend to decrease with an increase in distance and this reduction is about equal for all number of blades at N = 2500 rpm. At lower rotational speed (N = 1500 rpm) where vortex noise is a large part of the total noise, a much smaller amount of loudness reduction occurs for the multiblade configurations. (See fig. 55.)

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., May 21 1947

APPENDIX

Although this paper is not primarily aerodynamic, several assumptions have been made in order to do the necessary sound calculations. Even though only approximate, the accuracy is nevertheless satisfactory for sound work.

For each combination of horsepower, forward speed, and propeller diameter, the corresponding thrust value was calculated using the following relation from reference 9, page 204:

$$\eta P_H = TV$$

where

$$\eta = 0.90\eta_i$$

Values of η_i for corresponding power coefficients may be obtained from figure 56.

From the expression for differential thrust given in reference 9 (p. 213) the following equation, which assumes that the lift is approximately equal to the thrust, may be derived:

$$\frac{T}{A_b} = \frac{\rho}{2} C_L W^2$$

If $C_L = 0.4$ and W is the section velocity at 0.7 radius, figure 57 gives the approximate blade area necessary to produce a given thrust at various tip speeds.

REFERENCES

1. Gutin, L.: Über das Schallfeld einer rotierenden Luftschraube. Phys. Zeitschr. der Sowjetunion, Bd. 9, Heft 1, 1936, pp. 57-71.

2. Theodorsen, Theodore, and Regier, Arthur A.: The Problem of Noise Reduction with Reference to Light Airplanes. NACA TN No. 1145, 1946.

3. Hicks, Chester W., and Hubbard, Harvey H.: Comparison of Sound Emission from Two-Blade, Four-Blade, and Seven-Blade Propellers. NACA TN No. 1354 1947.

4. Stowell, E. Z., and Deming, A. F.: Vortex Noise from Rotating Cylindrical Rods. NACA TN No. 519, 1935.

5. Yudin, E. Y.: On the Vortex Sound from Rotating Rods. NACA TM No. 1136, 1947.

6. Fletcher, Harvey, and Munson, W. A.: Loudness, Its Definition, Measurement and Calculation. Jour. Acous. Soc. Am., vol. V, no. 2, Oct. 1933, pp. 82-108.

7. Crigler, John L., and Jaquis, Robert E.: Propeller-Efficiency Charts for Light Airplanes. NACA TN No. 1338, 1947.

8. Regier, Arthur A.: Effect of Distance on Airplane Noise. NACA TN No. 1353, 1947.

9. Glauert, H.: The Elements of Aerofoil and Airscrew Theory. Cambridge Univ. Press, 1926.

TABLE I

INDEX TO FIGURES 2 TO 49

V (mph)	P_H (hp)	Figure		
		D = 6 ft	D = 8 ft	D = 10 ft
50	100	2	18	34
	150	3	19	35
	225	4	20	36
	300	5	21	37
100	100	6	22	38
	150	7	23	39
	225	8	24	40
	300	9	25	41
150	100	10	26	42
	150	11	27	43
	225	12	28	44
	300	13	29	45
200	100	14	30	46
	150	15	31	47
	225	16	32	48
	300	17	33	49

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Calculated sound pressures due to torque and thrust
Calculated sound pressures due to torque
Calculated sound pressures due to thrust (Thrust lobes ahead of plane of rotation are 180° out of phase with torque lobes)
Estimated sound pressures due to vortex noise

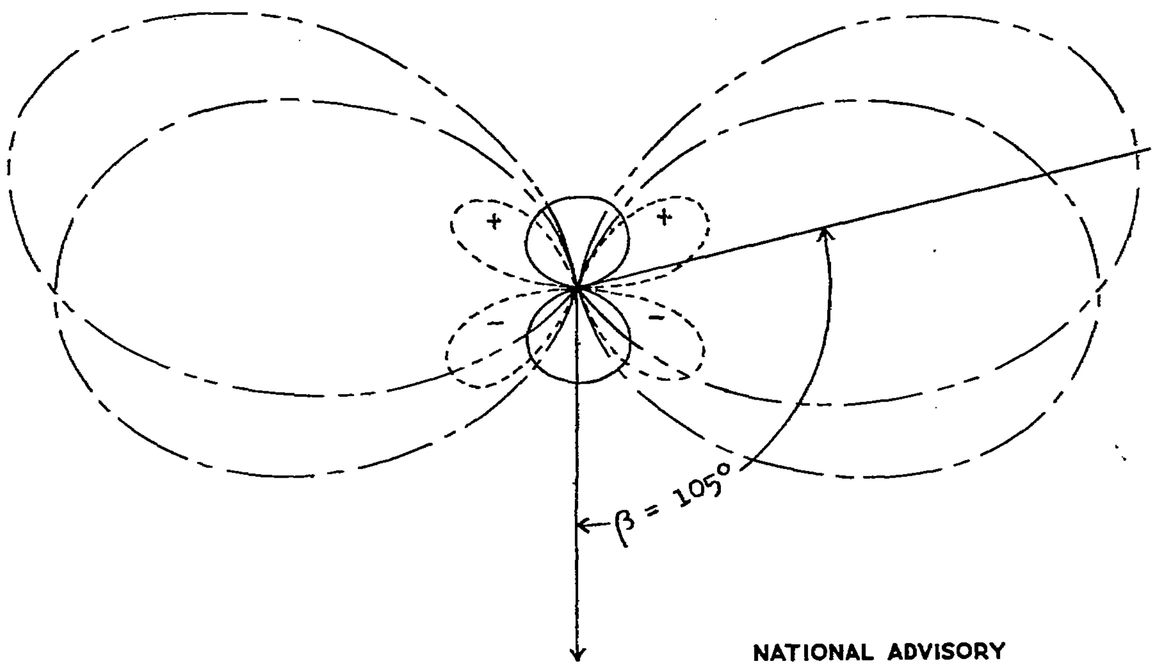
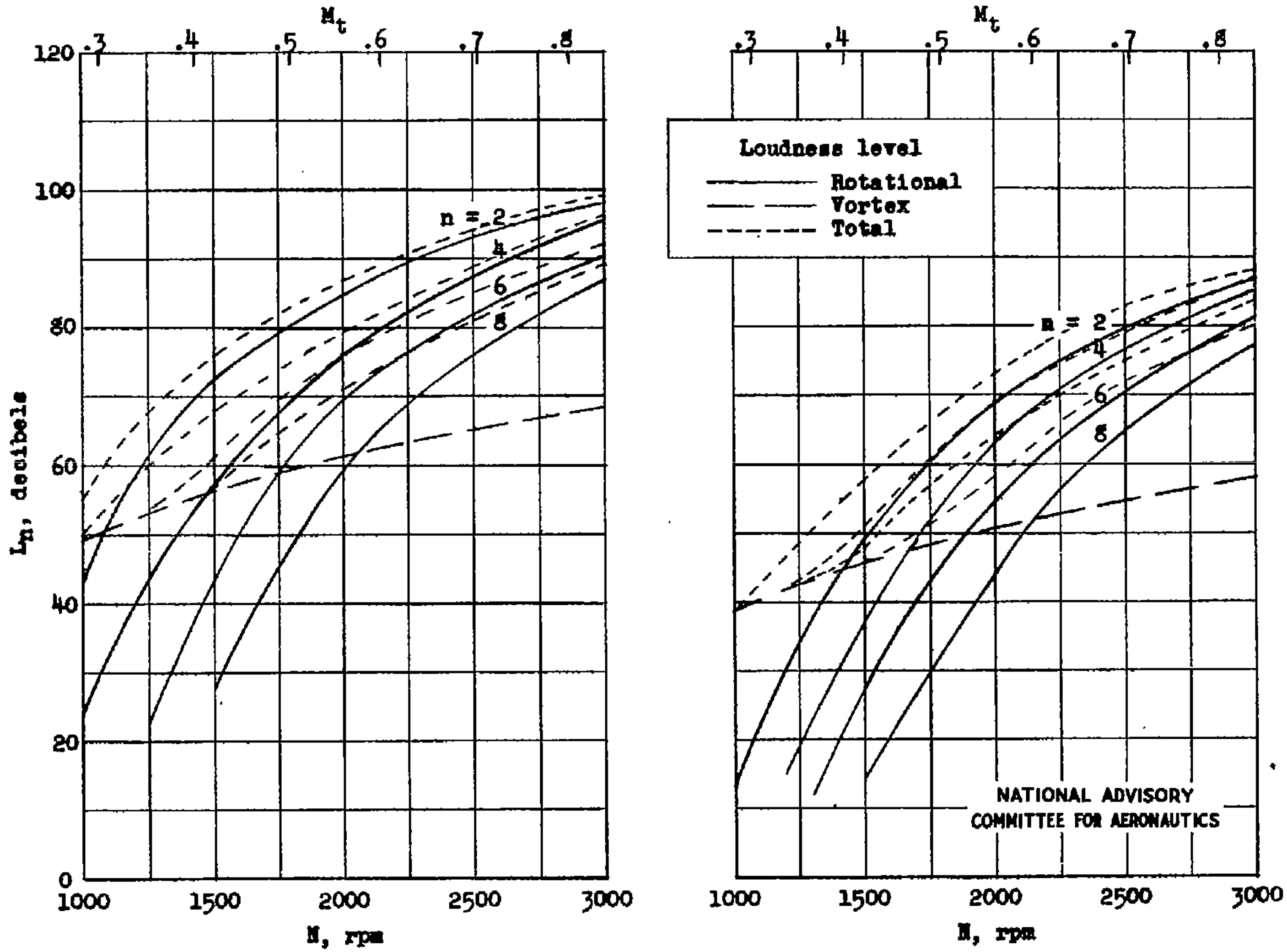


Figure 1.- Calculated sound pressures of first harmonic from two-blade propeller in simulated forward flight. s = 30 feet; D = 6 feet; M_t = 0.57; P_H = 150 horsepower; T = 332 pounds; V = 150 miles per hour.



(a) $s = 300$ feet.

(b) $s = 1000$ feet.

Figure 2.- Loudness as a function of propeller rotational speed for various numbers of blades. $D = 6$ feet; $V = 50$ miles per hour; $P_H = 100$ horsepower.

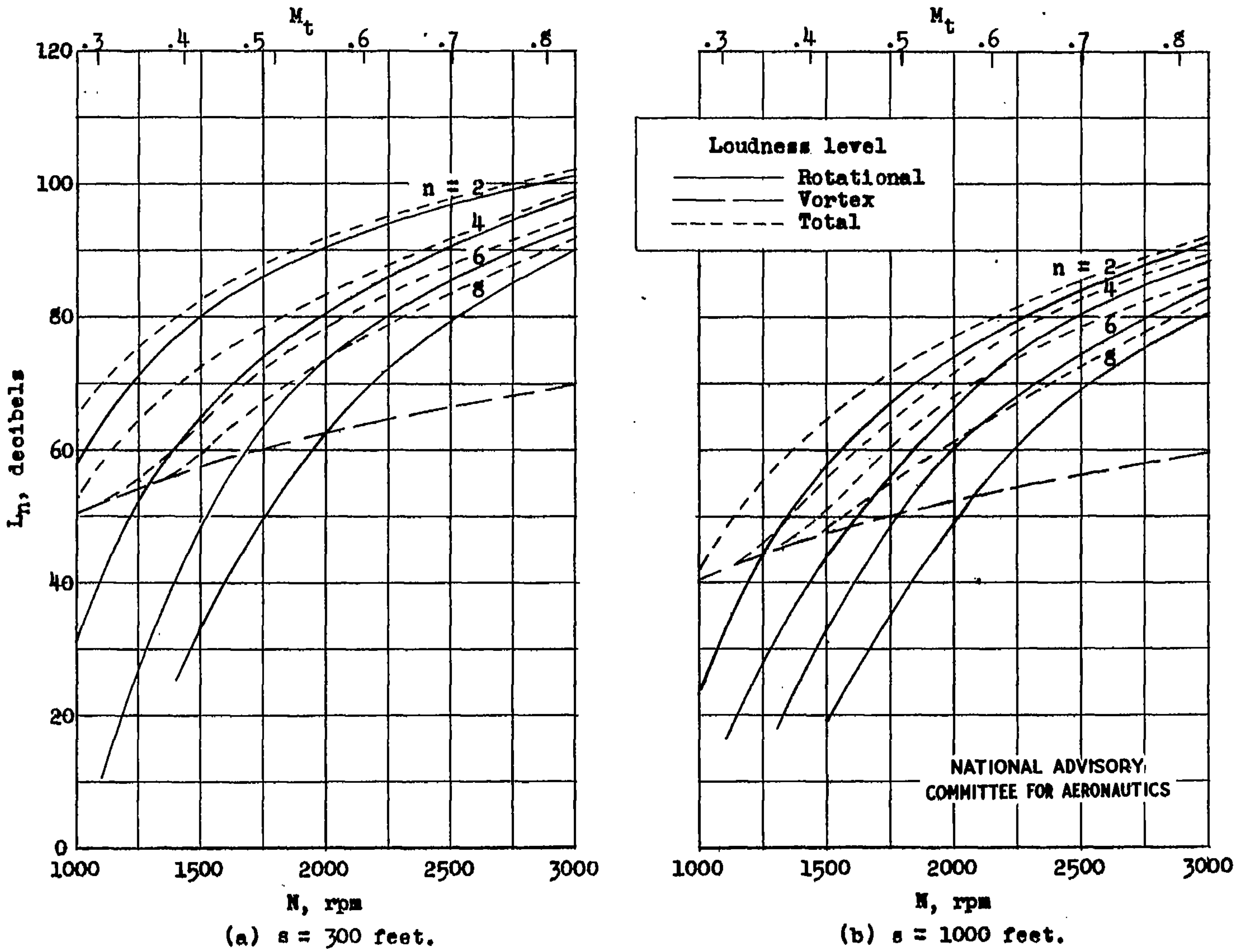
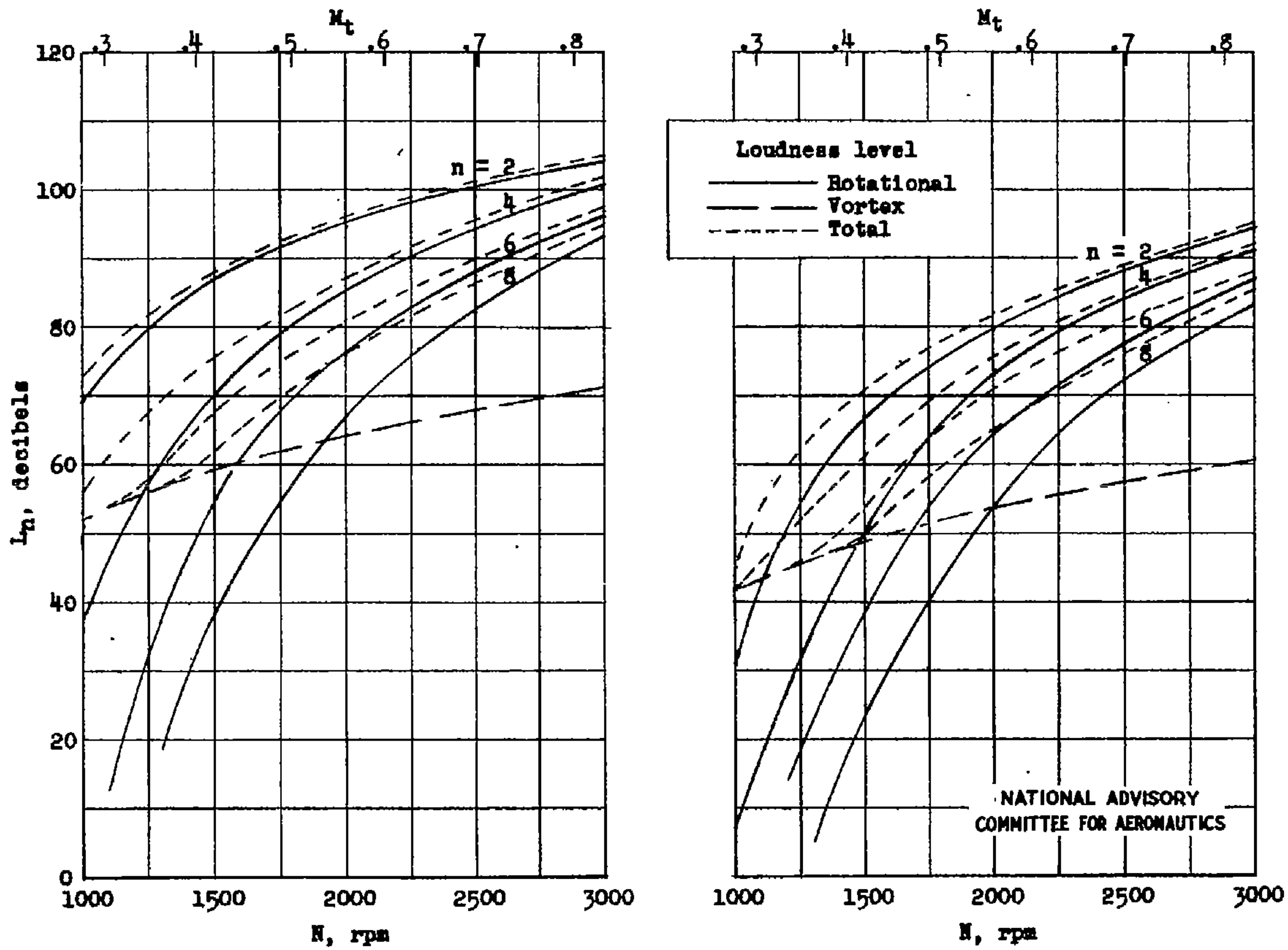


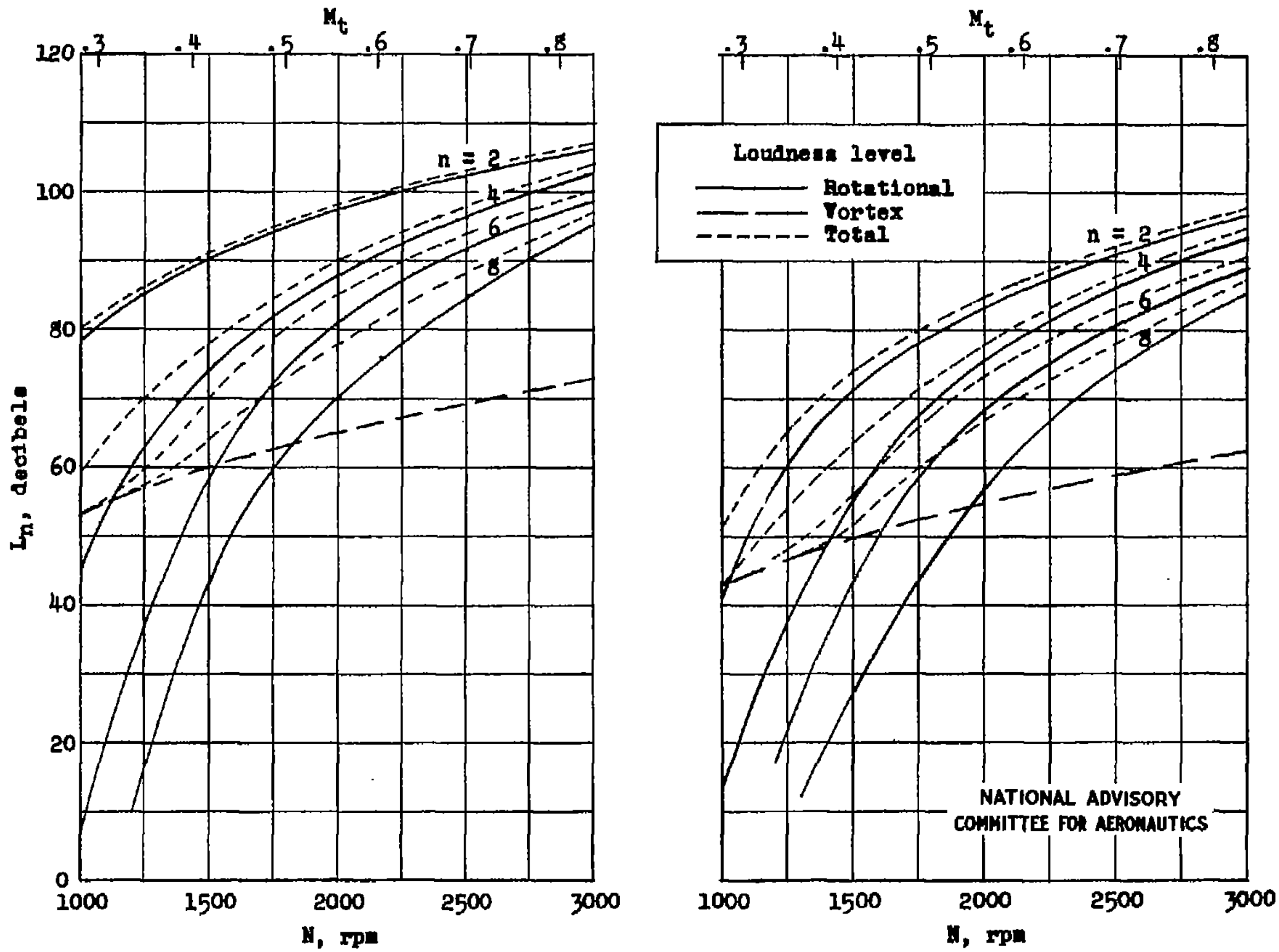
Figure 3.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 50 miles per hour; P_H = 150 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

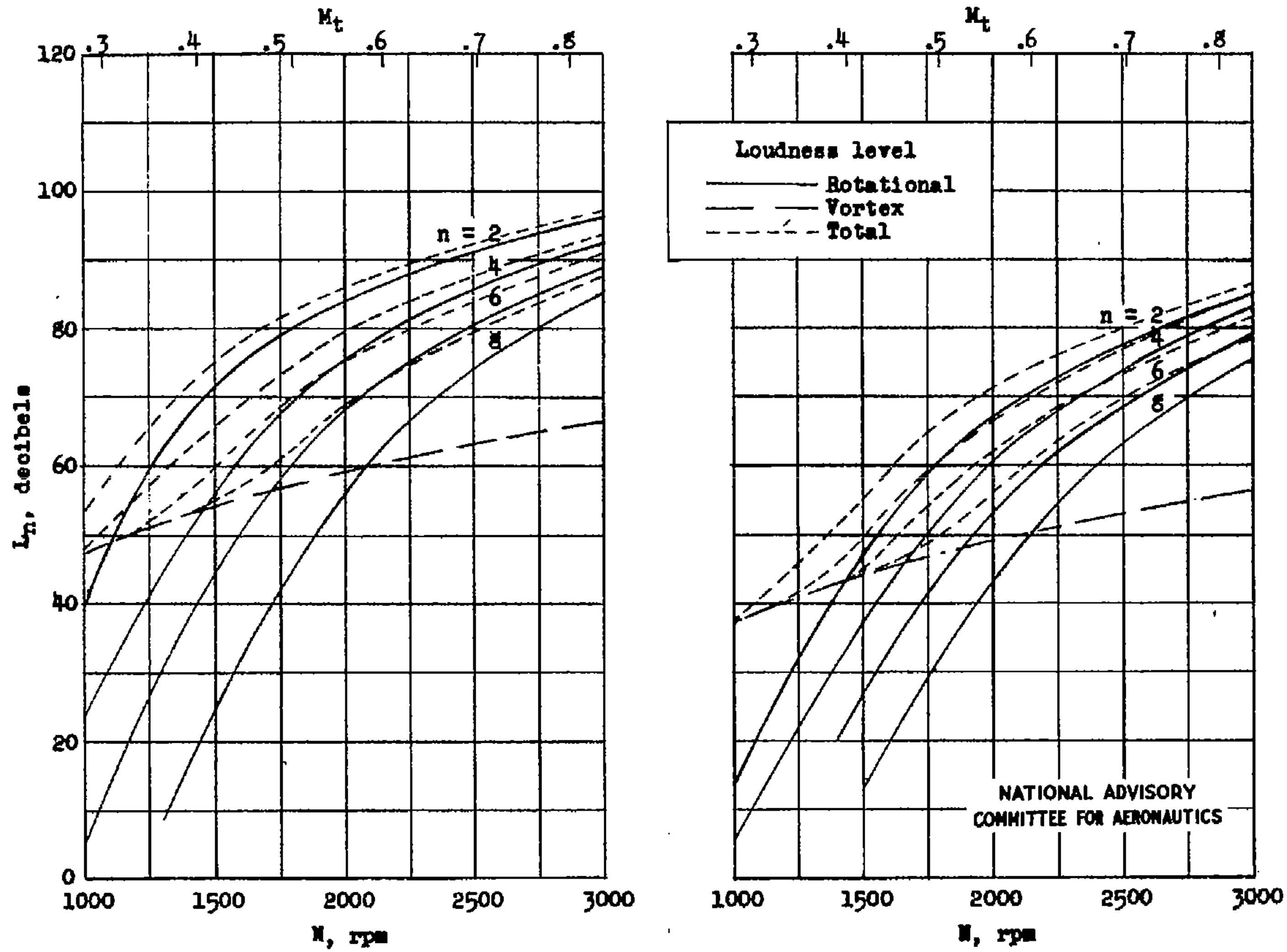
Figure 4.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 50 miles per hour; P_H = 225 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

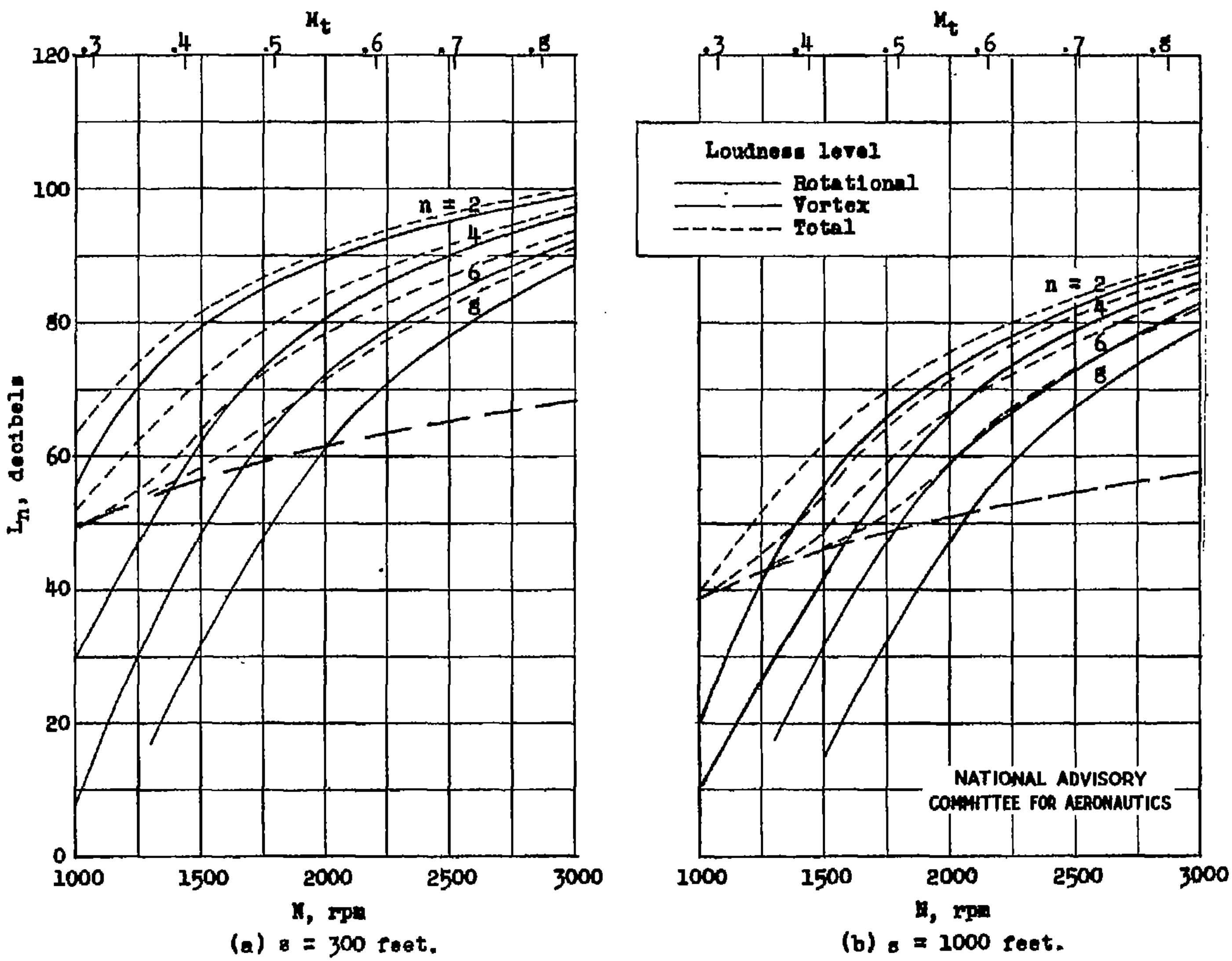
Figure 5.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 50 miles per hour; P_H = 300 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

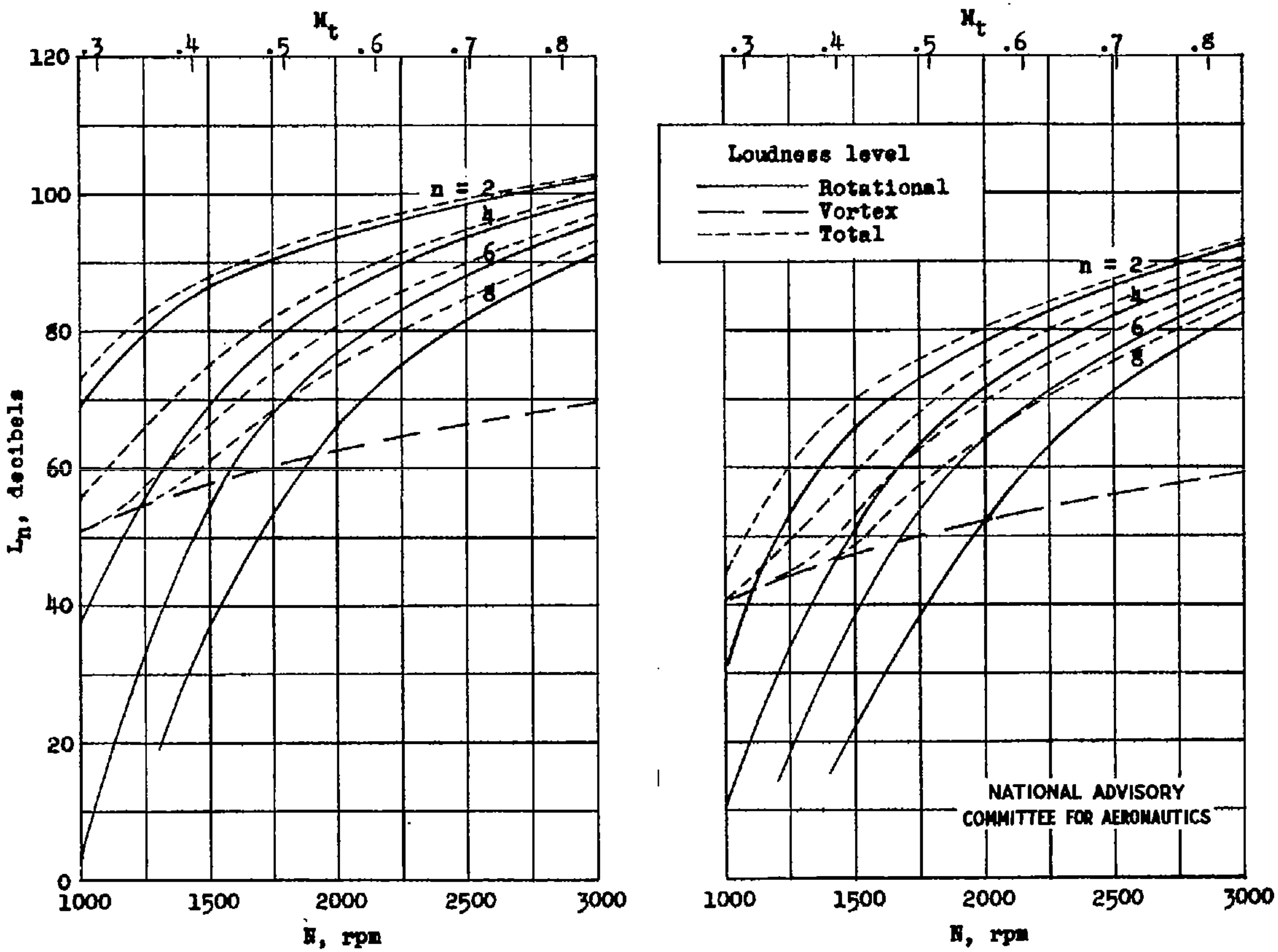
Figure 6.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 100 miles per hour; P_H = 100 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

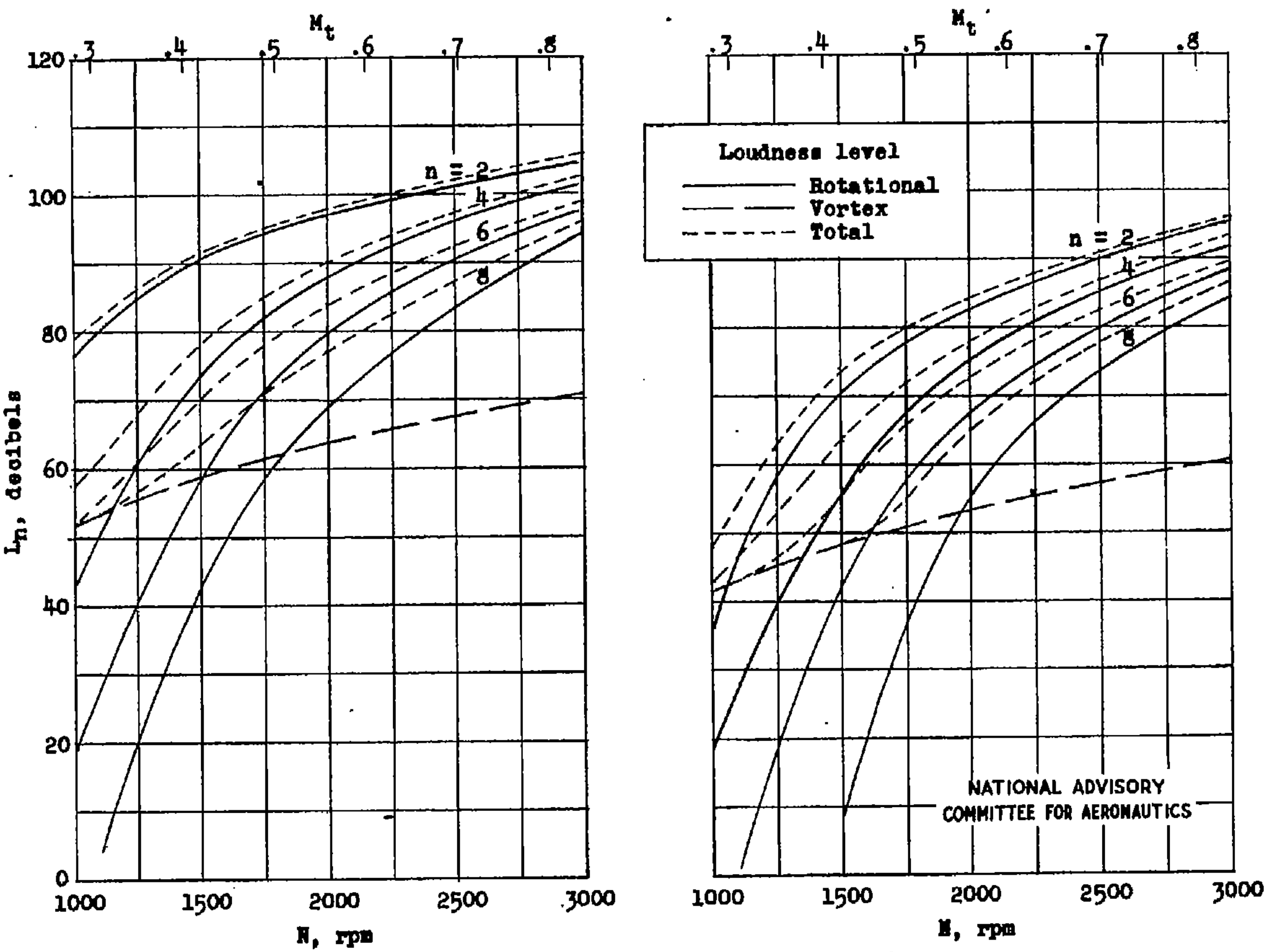
Figure 7.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 100 miles per hour; P_H = 150 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 8.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 100 miles per hour; P_H = 225 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 9.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 100 miles per hour; P_H = 300 horsepower.

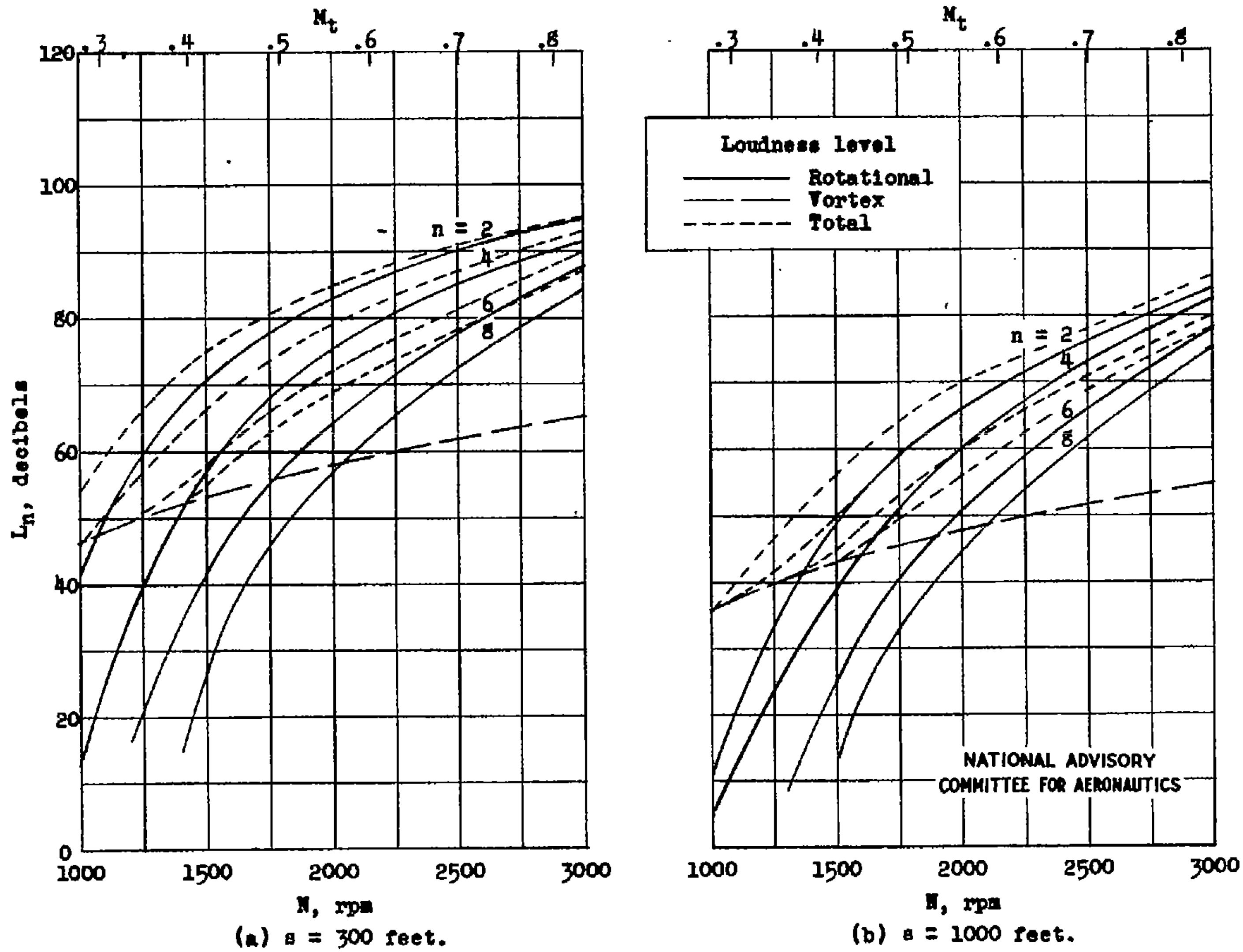
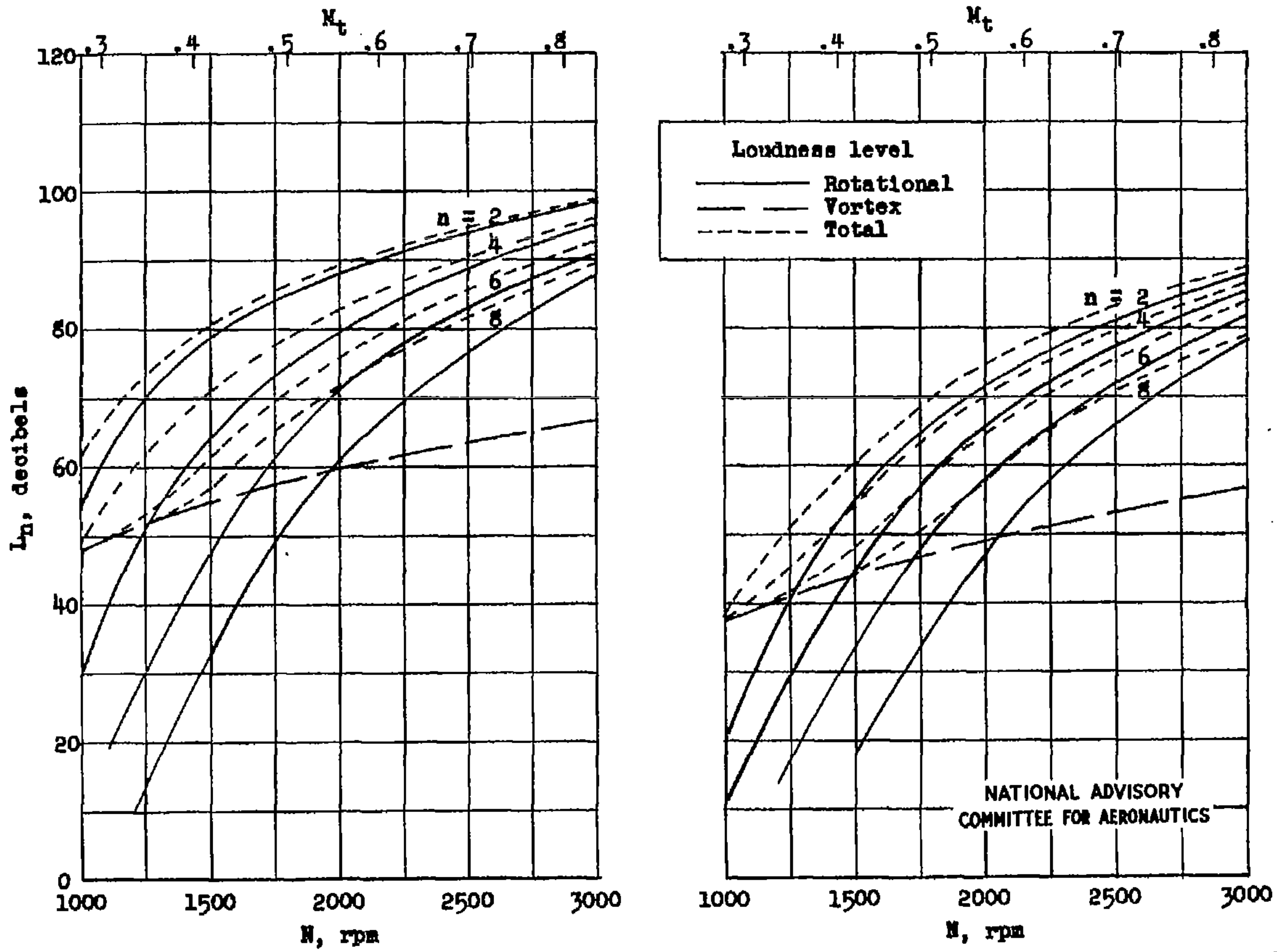


Figure 10.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 150 miles per hour; P_H = 100 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 11.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 150 miles per hour; P_H = 150 horsepower.

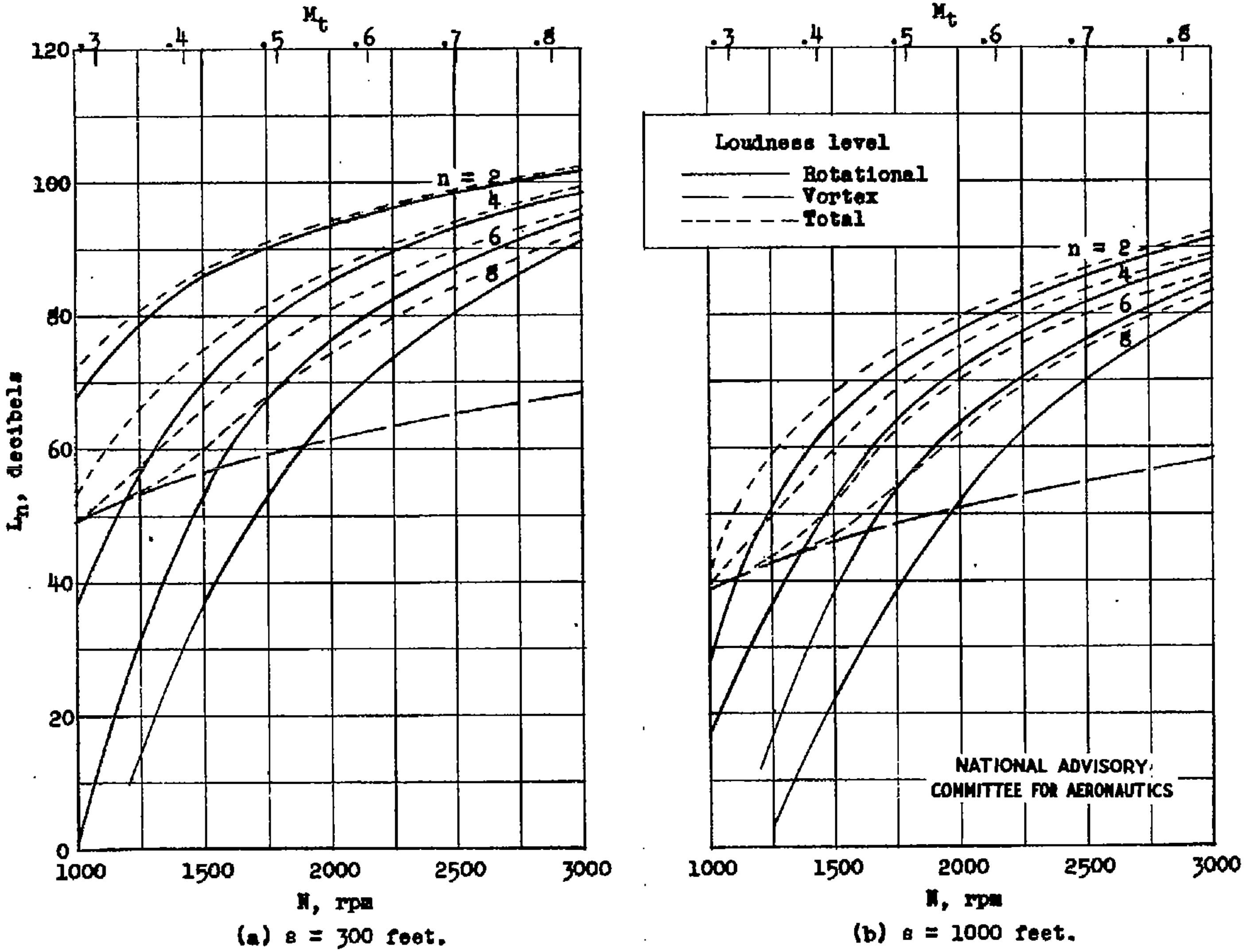
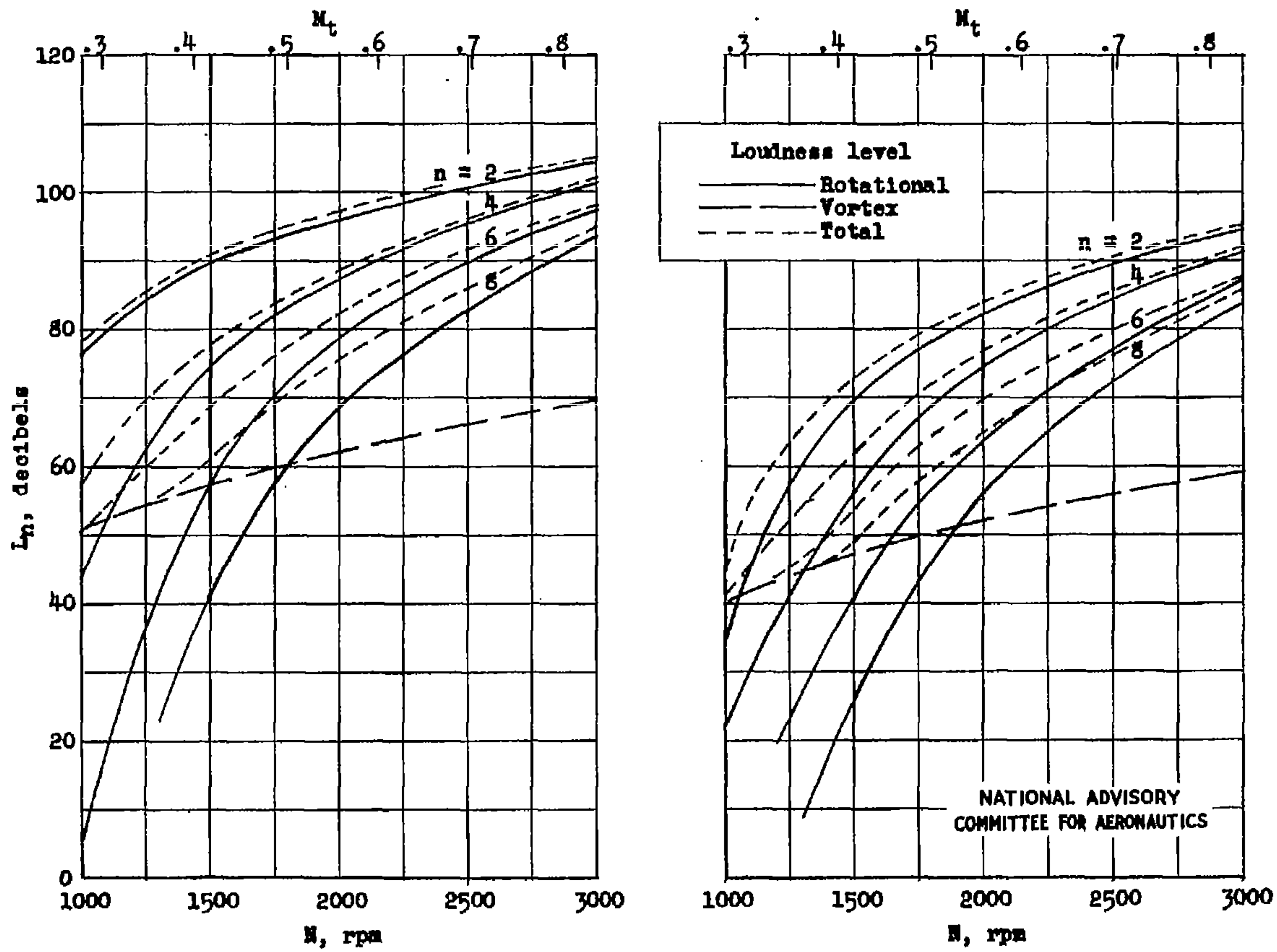


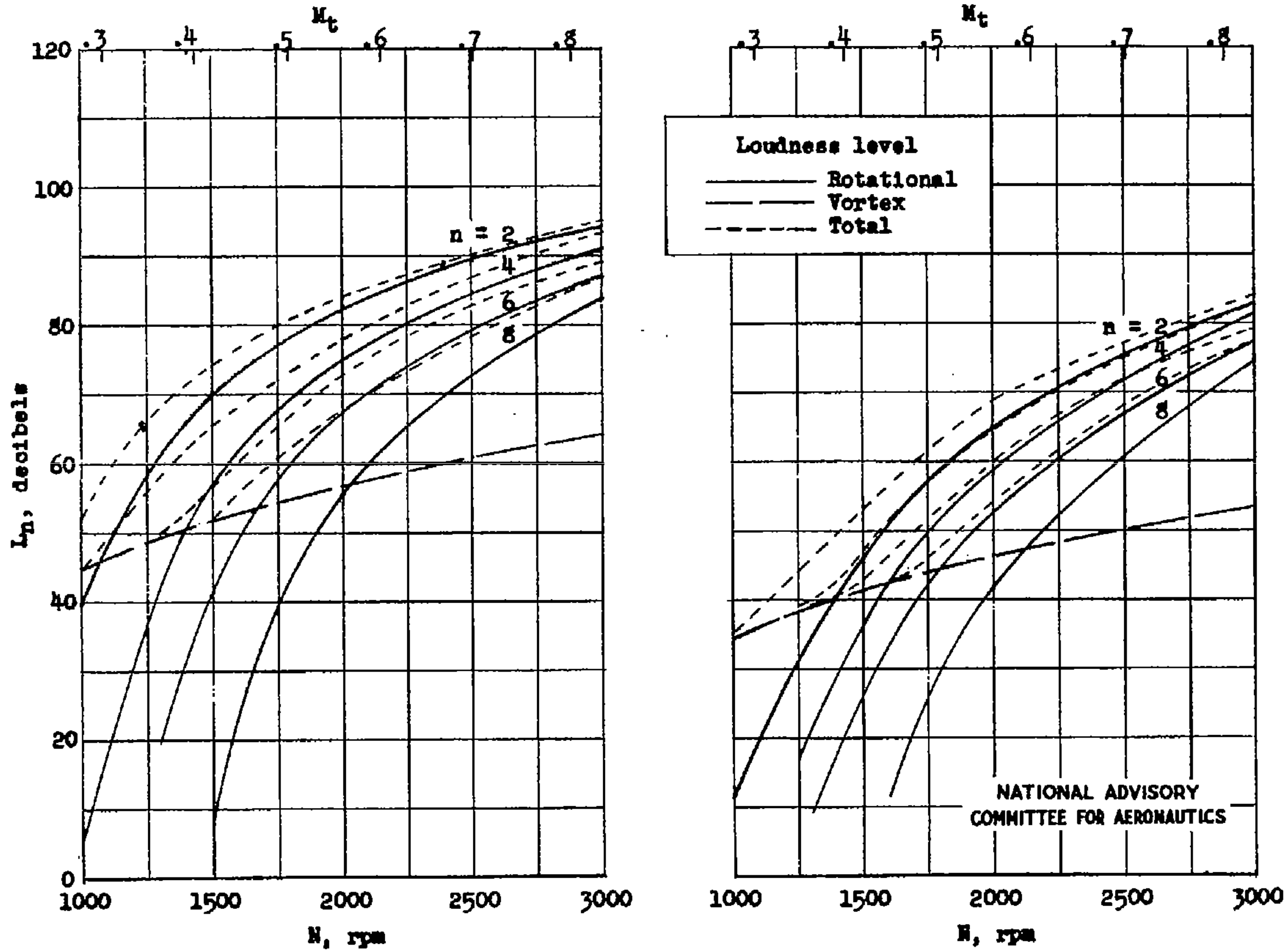
Figure 12.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 150 miles per hour; P_H = 225 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 13.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 150 miles per hour; P_H = 300 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 14.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 200 miles per hour; P_H = 100 horsepower.

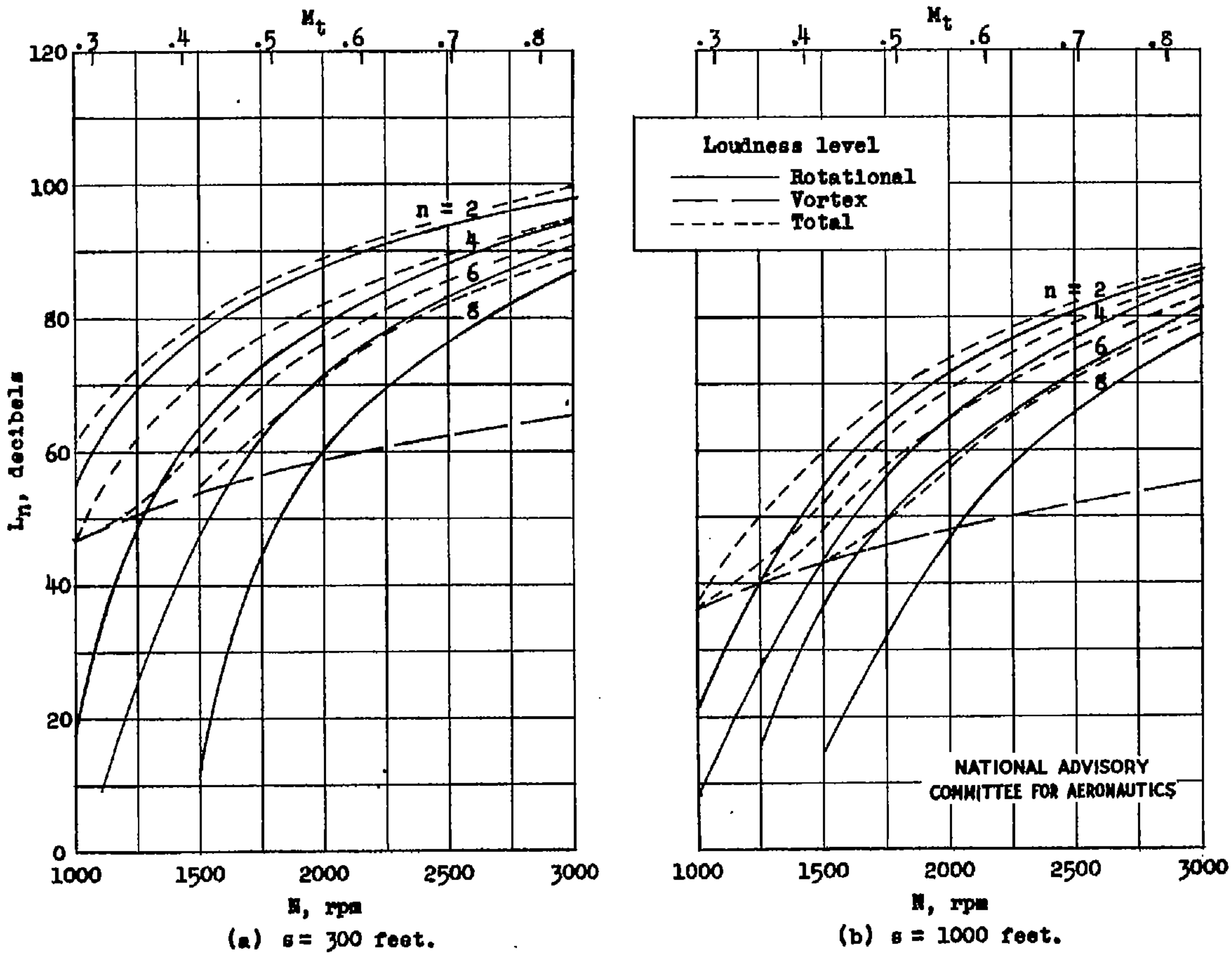
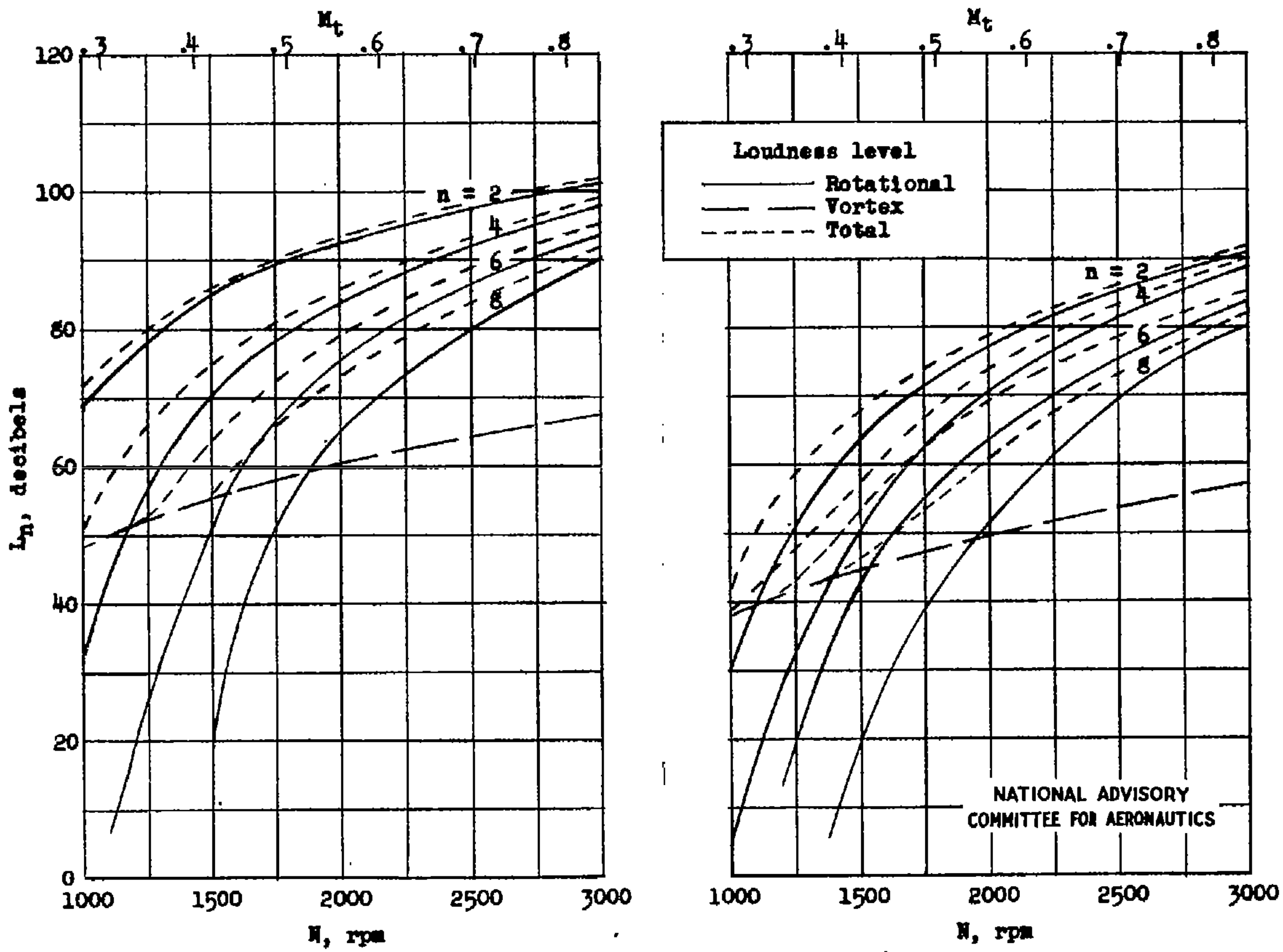


Figure 15.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 200 miles per hour; P_H = 150 horsepower.



(a) s = 300 feet. (b) s = 1000 feet.

Figure 16.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 200 miles per hour; P_H = 225 horsepower.

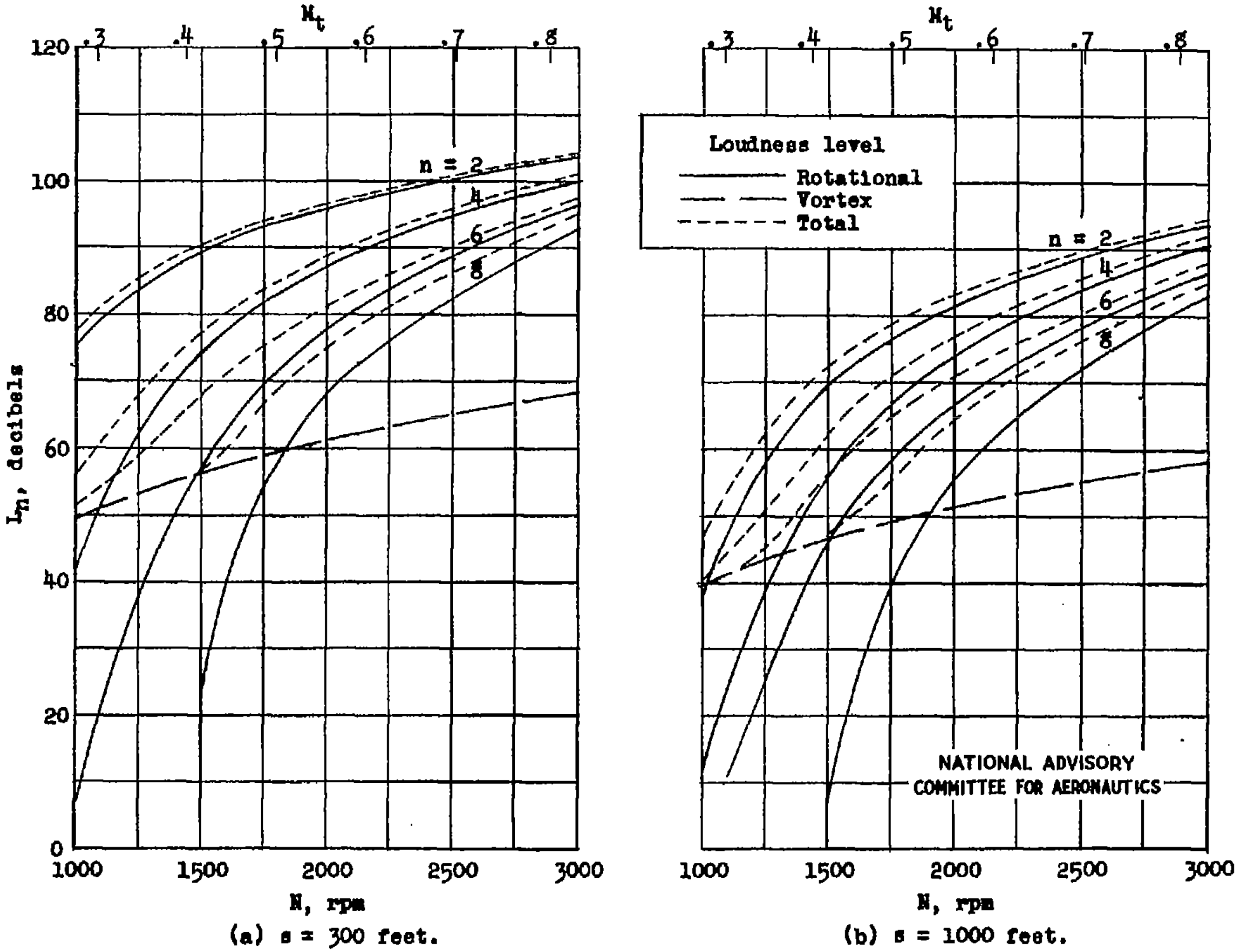


Figure 17.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 6 feet; V = 200 miles per hour; P_H = 300 horsepower.

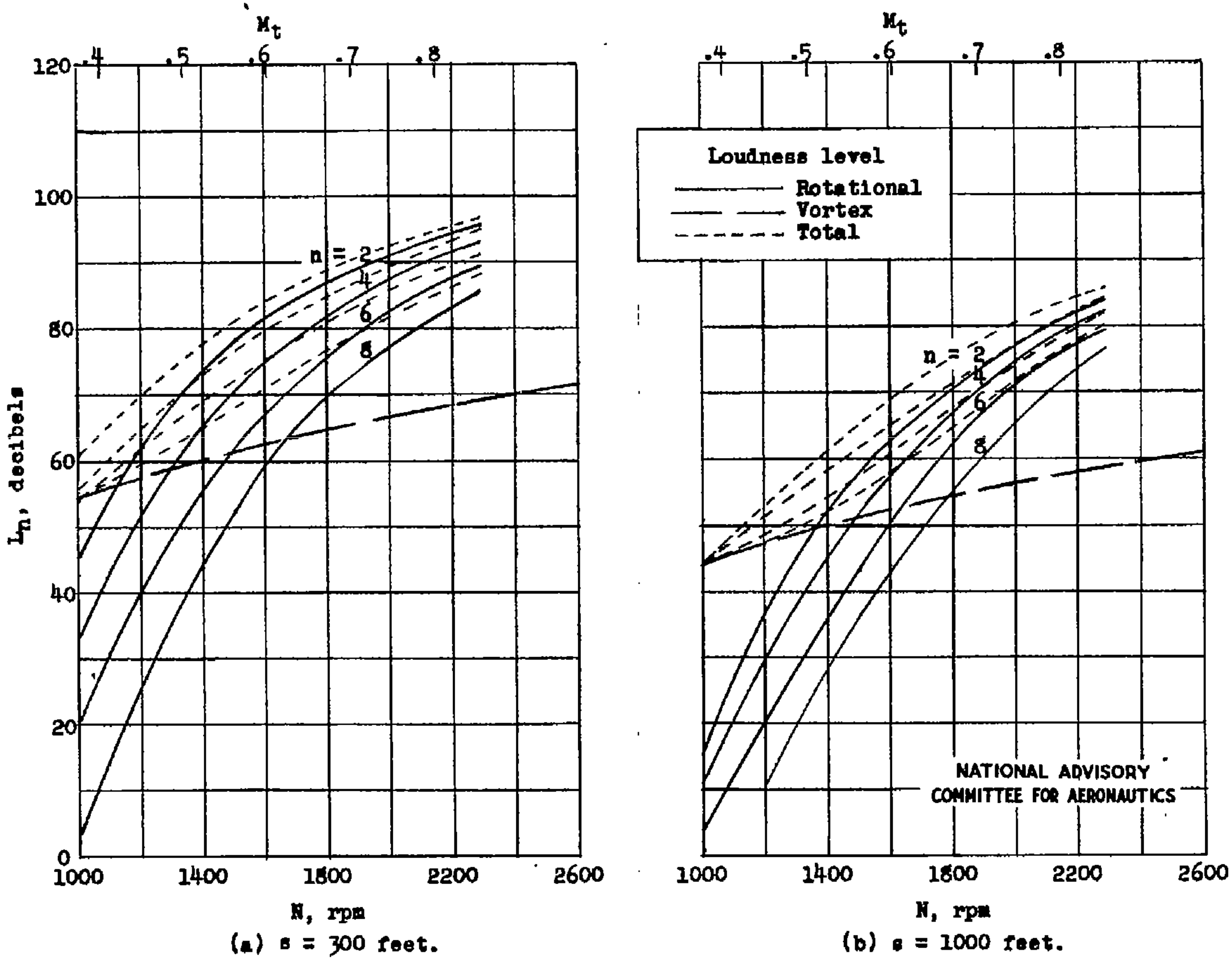
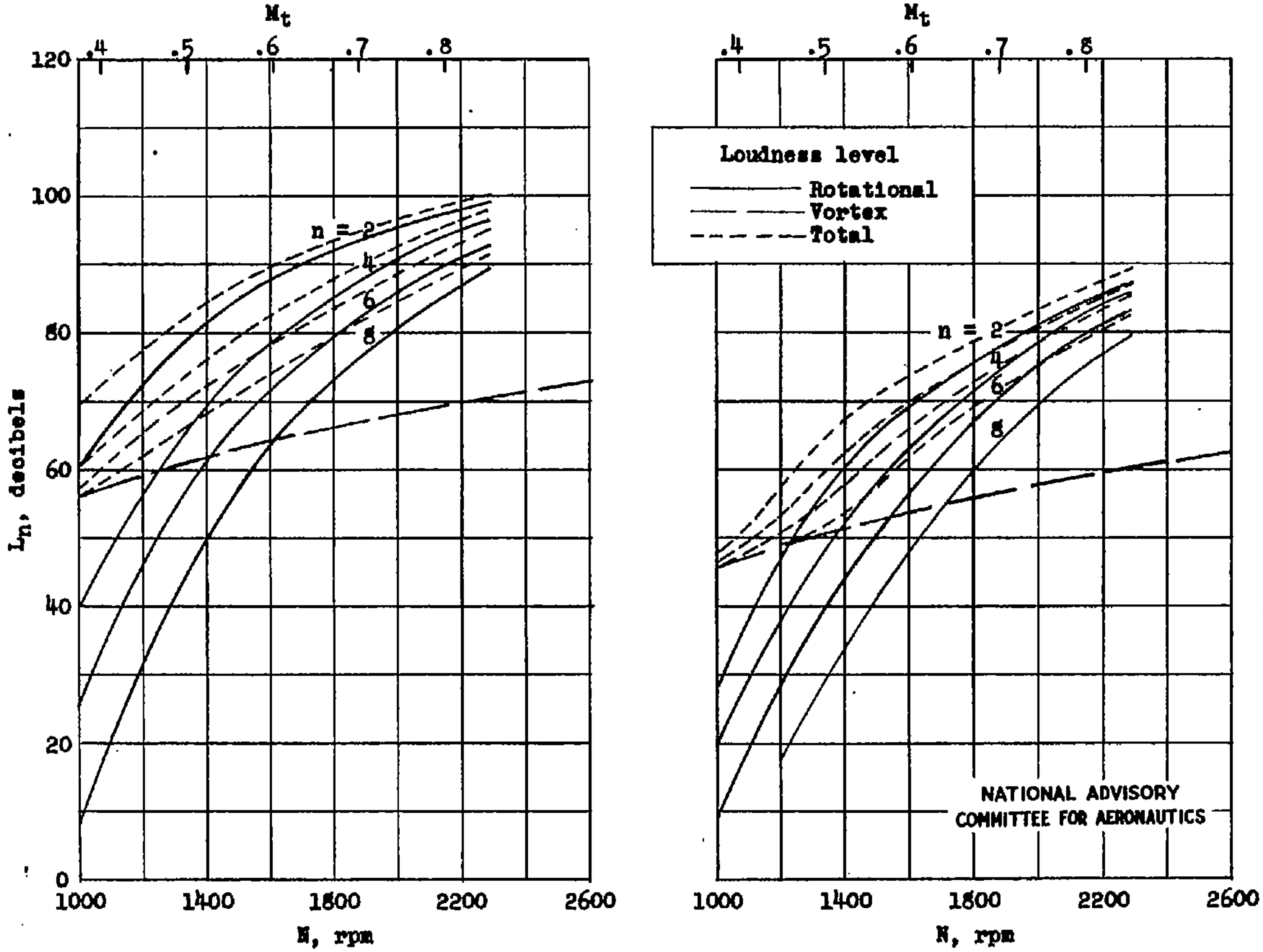


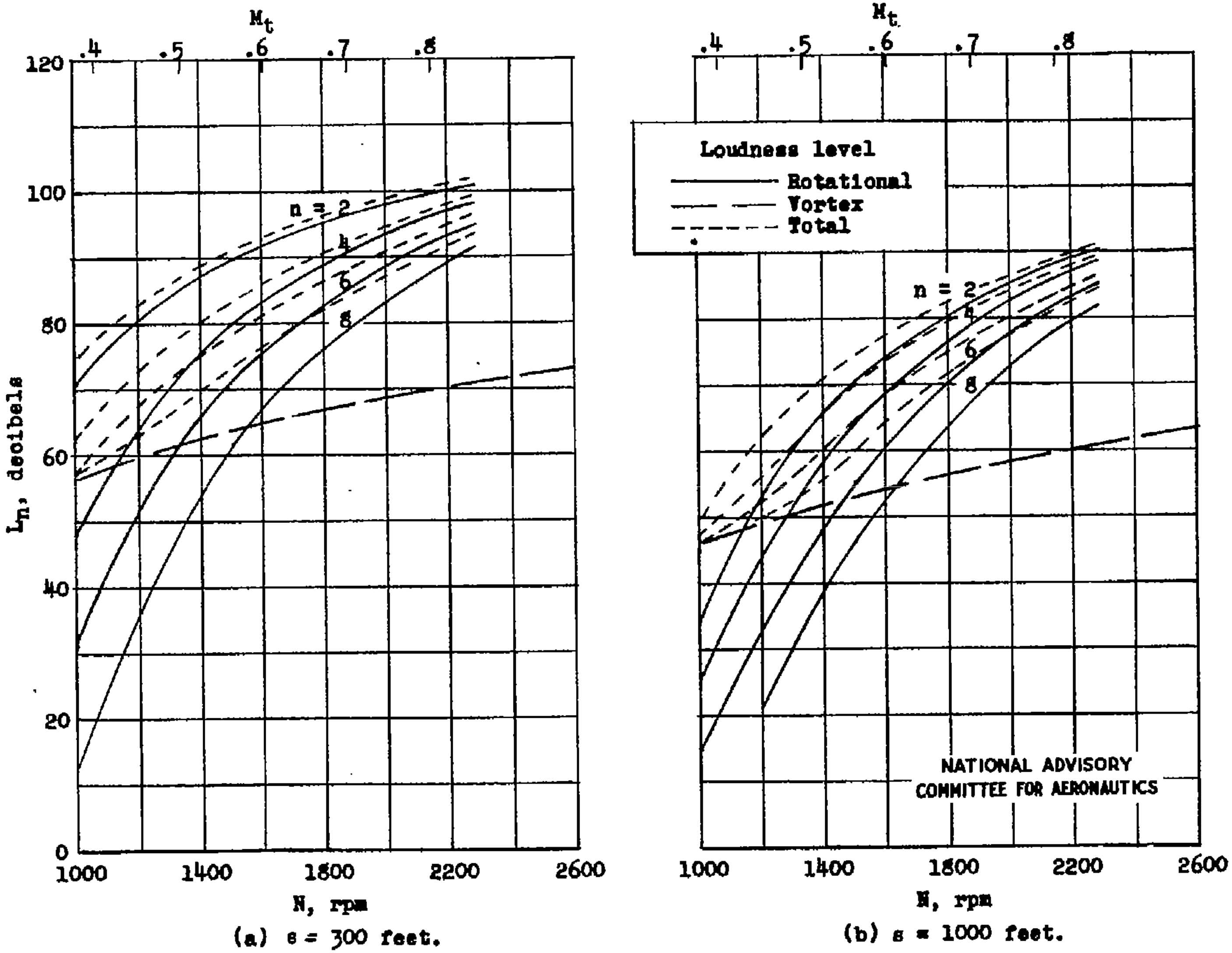
Figure 18.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 50 miles per hour; P_H = 100 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

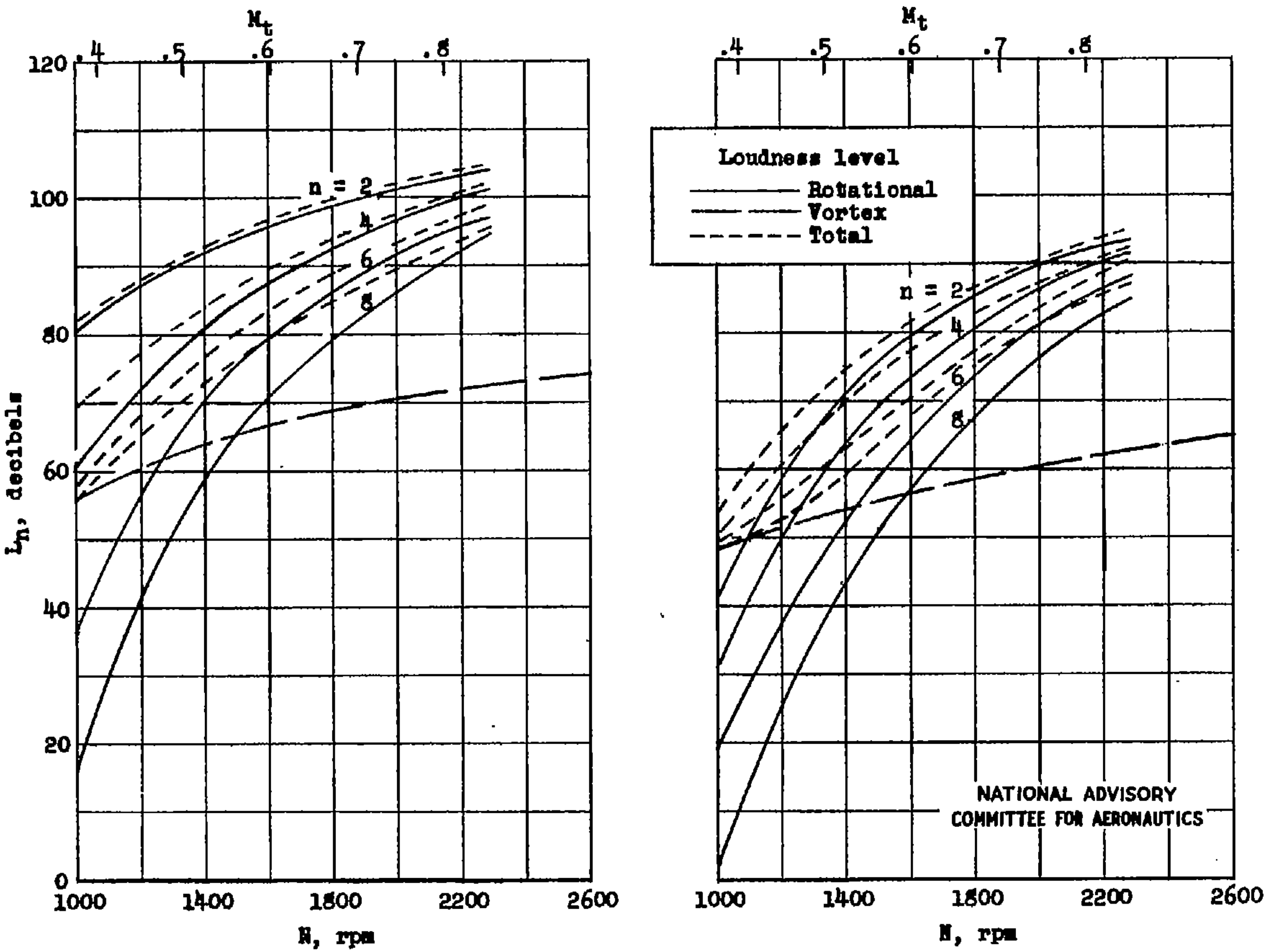
Figure 19.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 50 miles per hour; P_H = 150 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

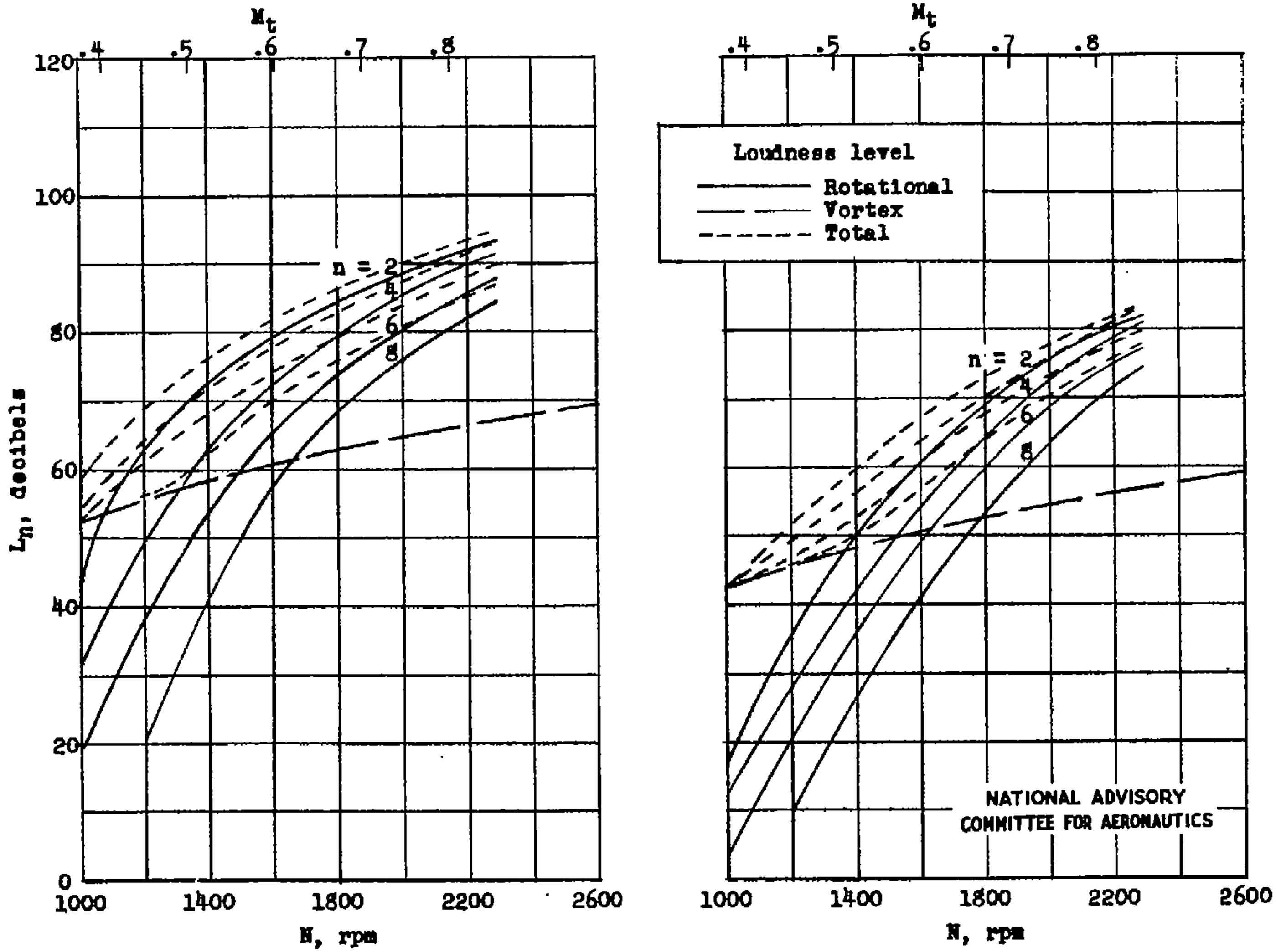
Figure 20.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 50 miles per hour; P_H = 225 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

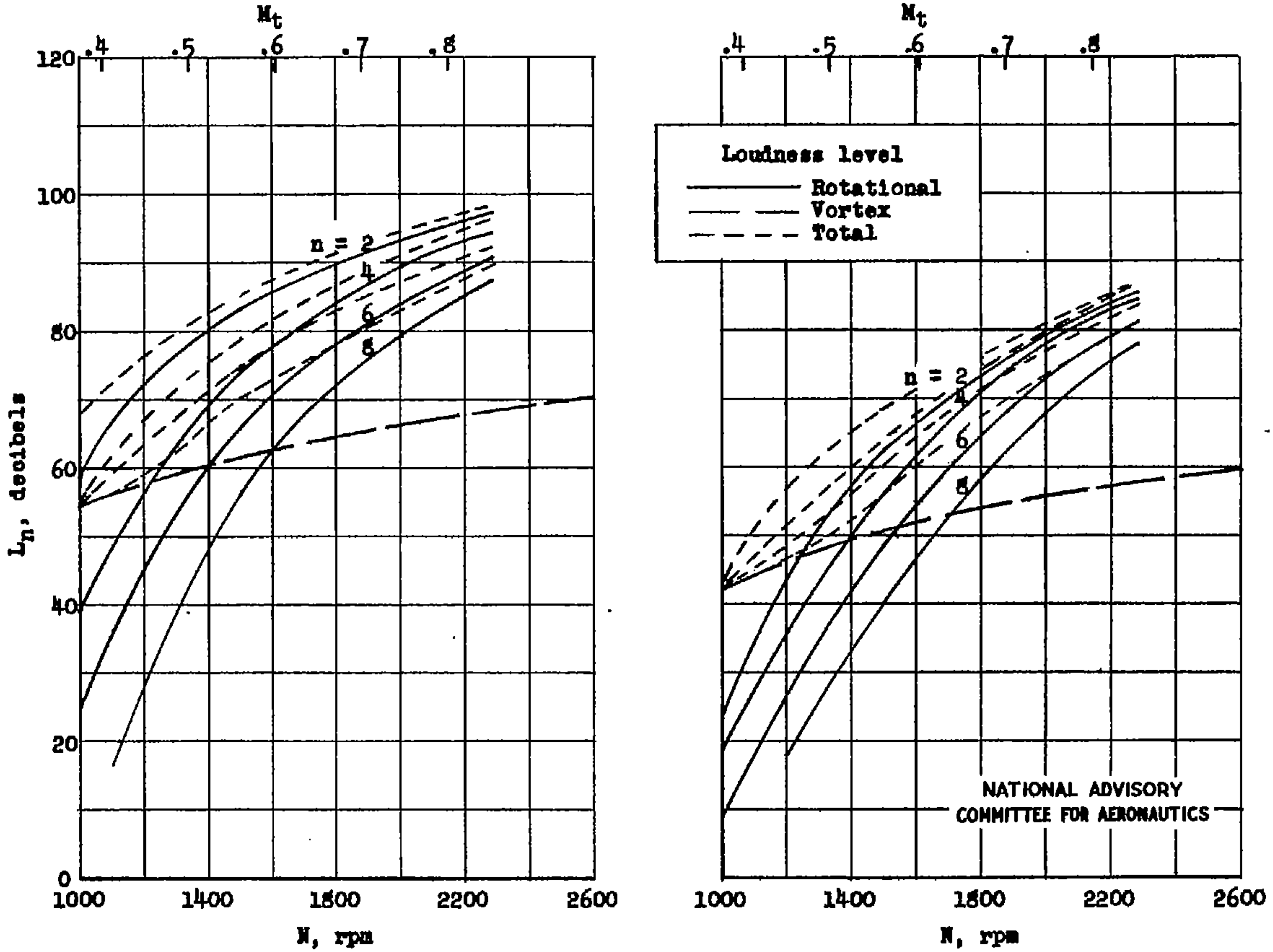
Figure 21.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 50 miles per hour; P_H = 300 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 22.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 100 miles per hour; P_H = 100 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 23.- Loudness as a function of propeller rotational speed for various numbers of blades. $D = 8$ feet; $V = 100$ miles per hour; $P_H = 150$ horsepower.

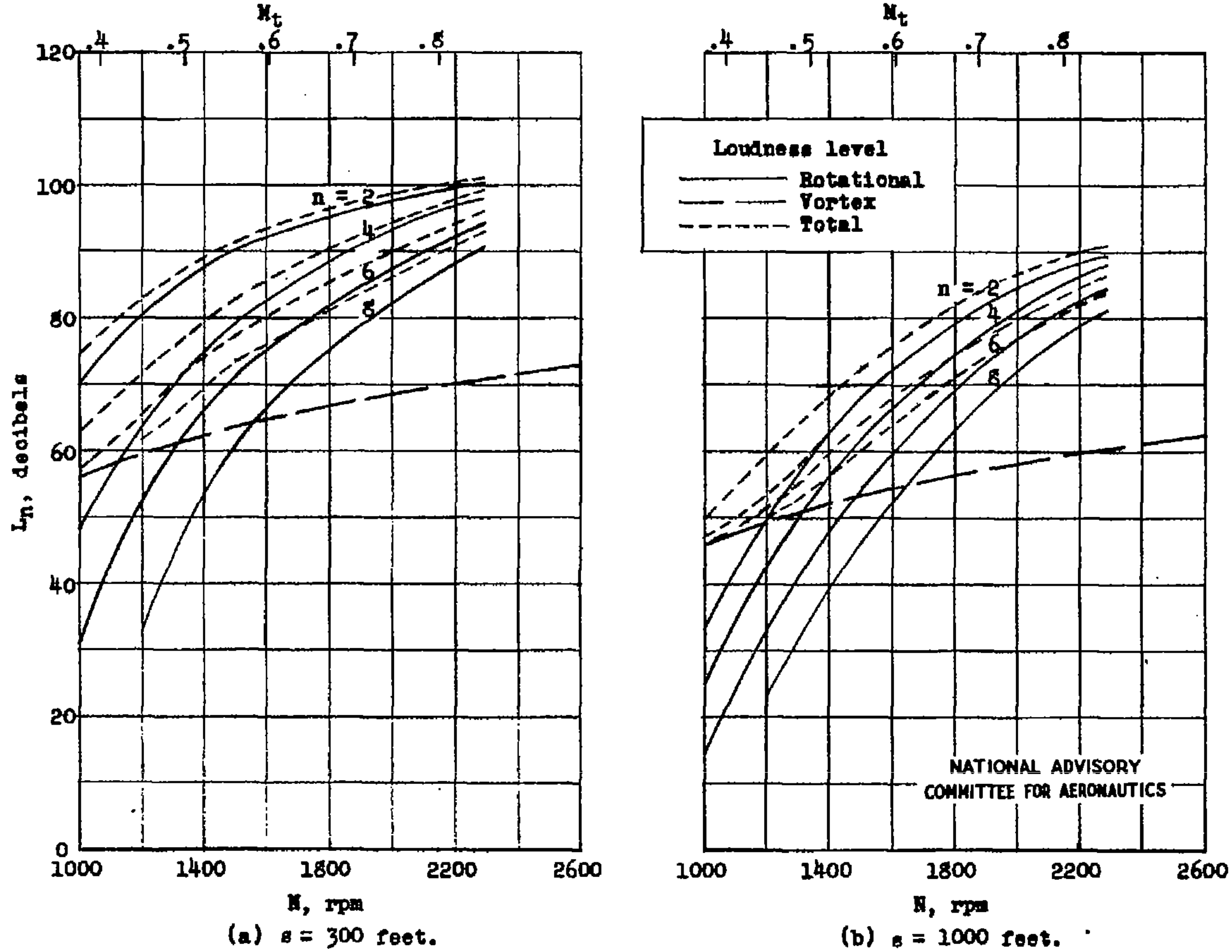
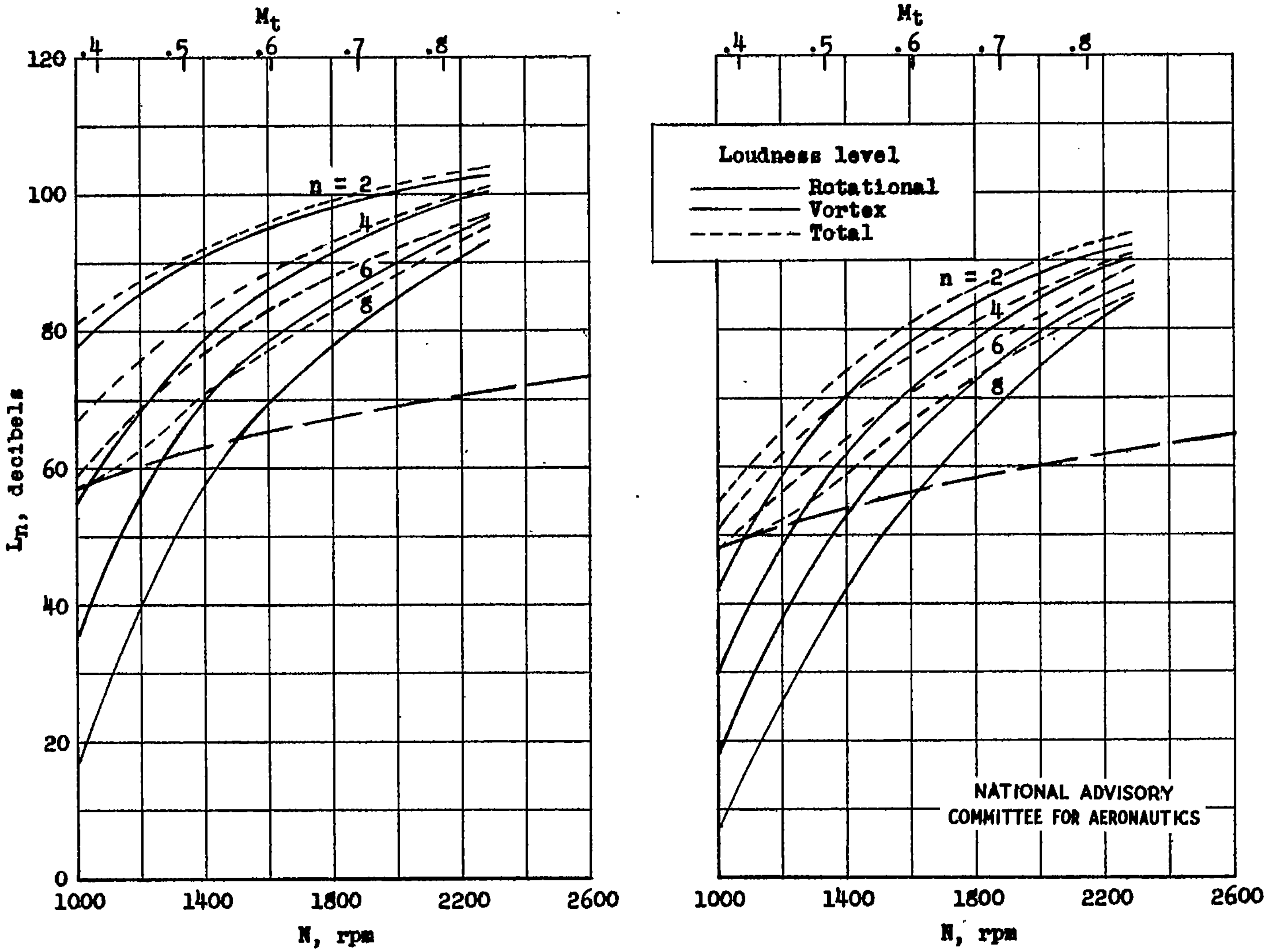


Figure 24.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 100 miles per hour; P_H = 225 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 25.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 100 miles per hour; P_H = 300 horsepower.

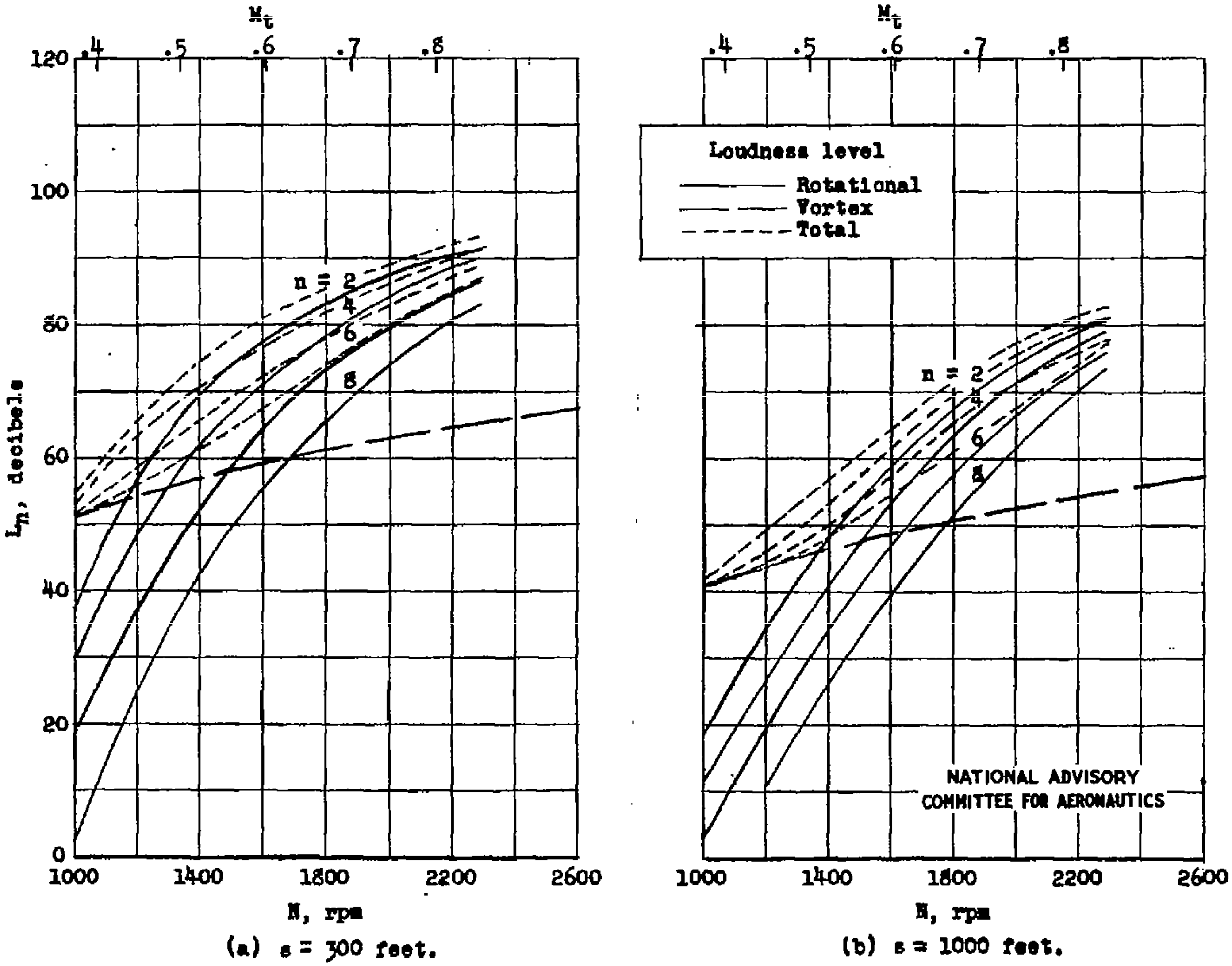
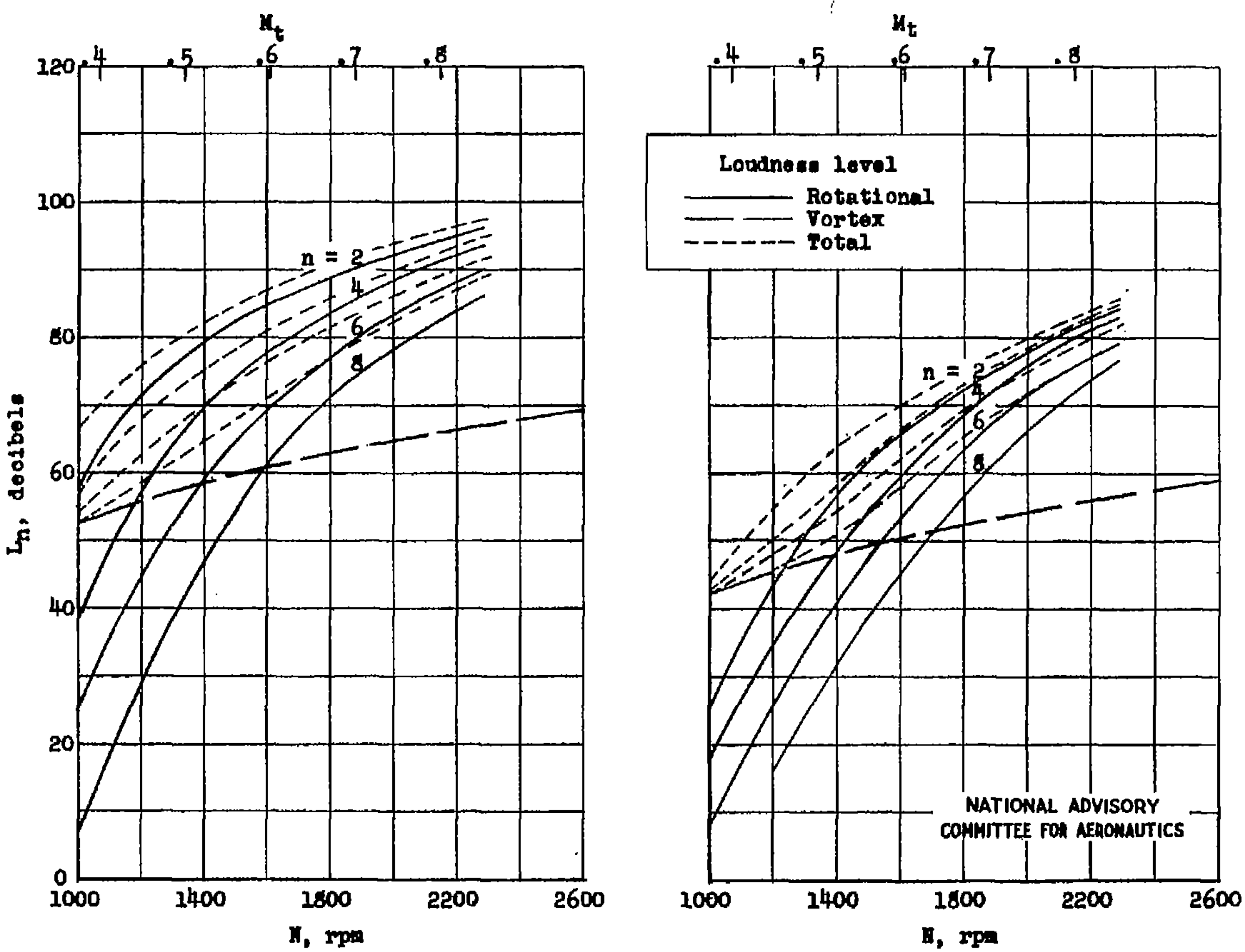


Figure 26.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 150 miles per hour; P_H = 100 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 27.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 150 miles per hour; P_H = 150 horsepower.

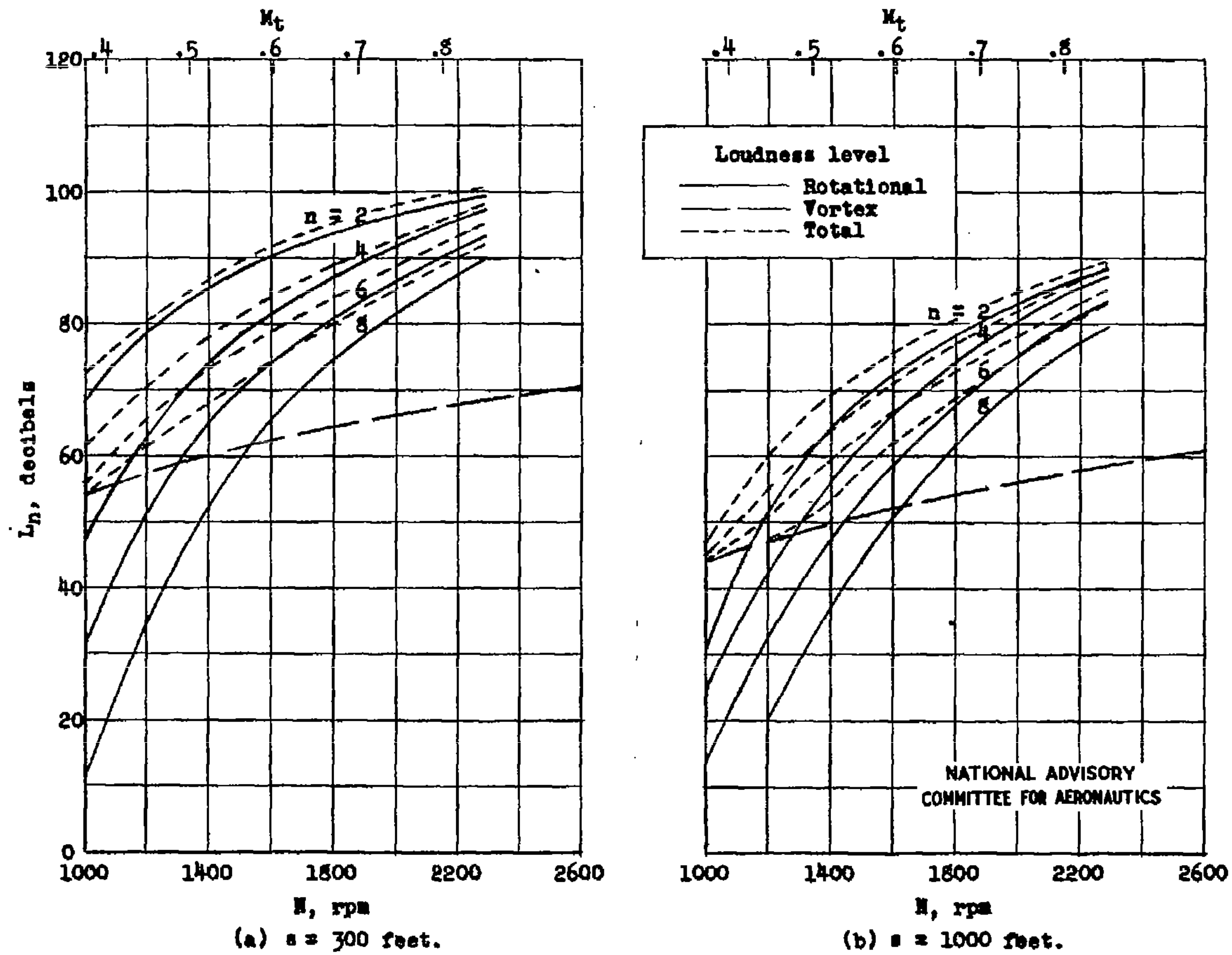


Figure 28.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 150 miles per hour; P_H = 225 horsepower.

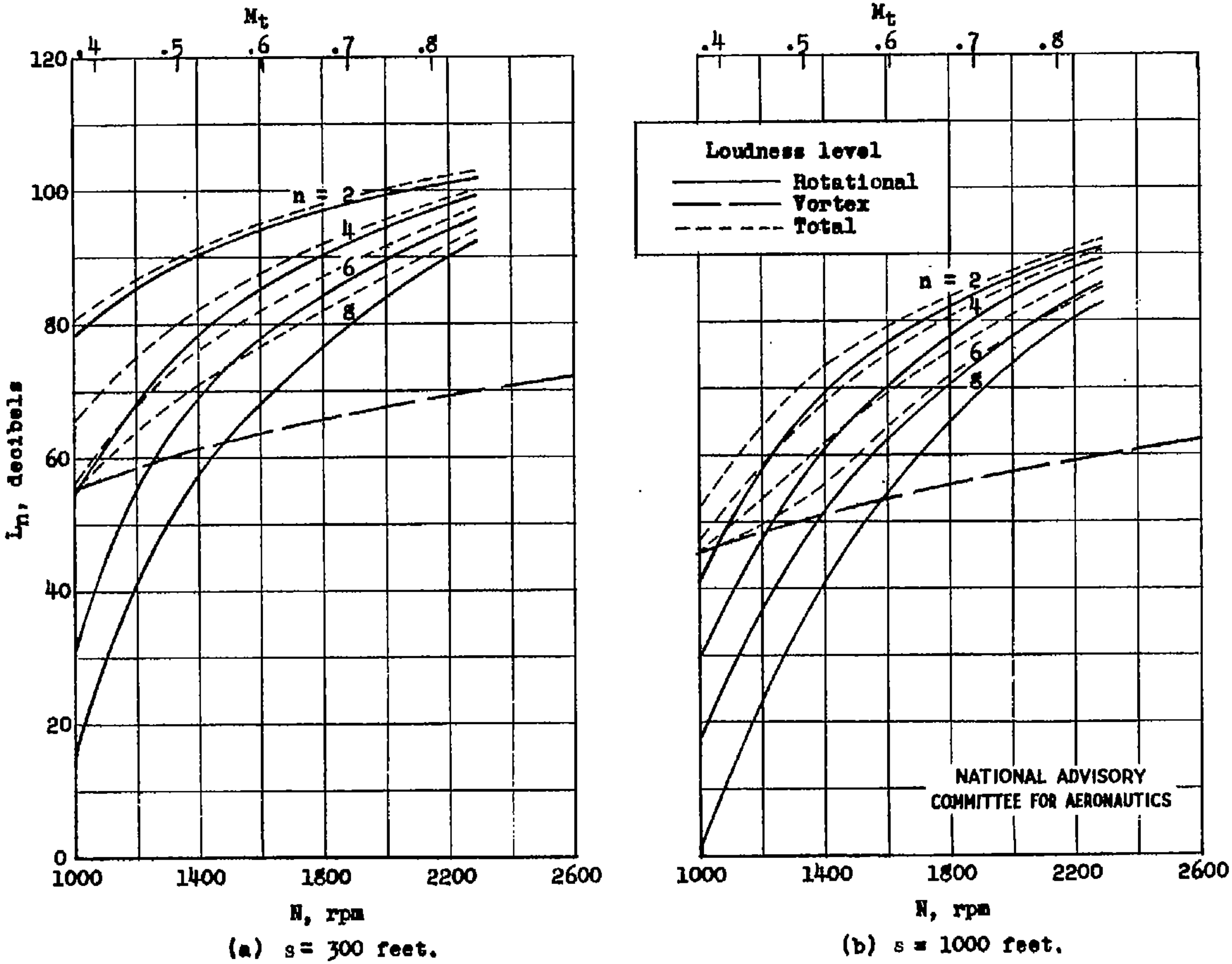
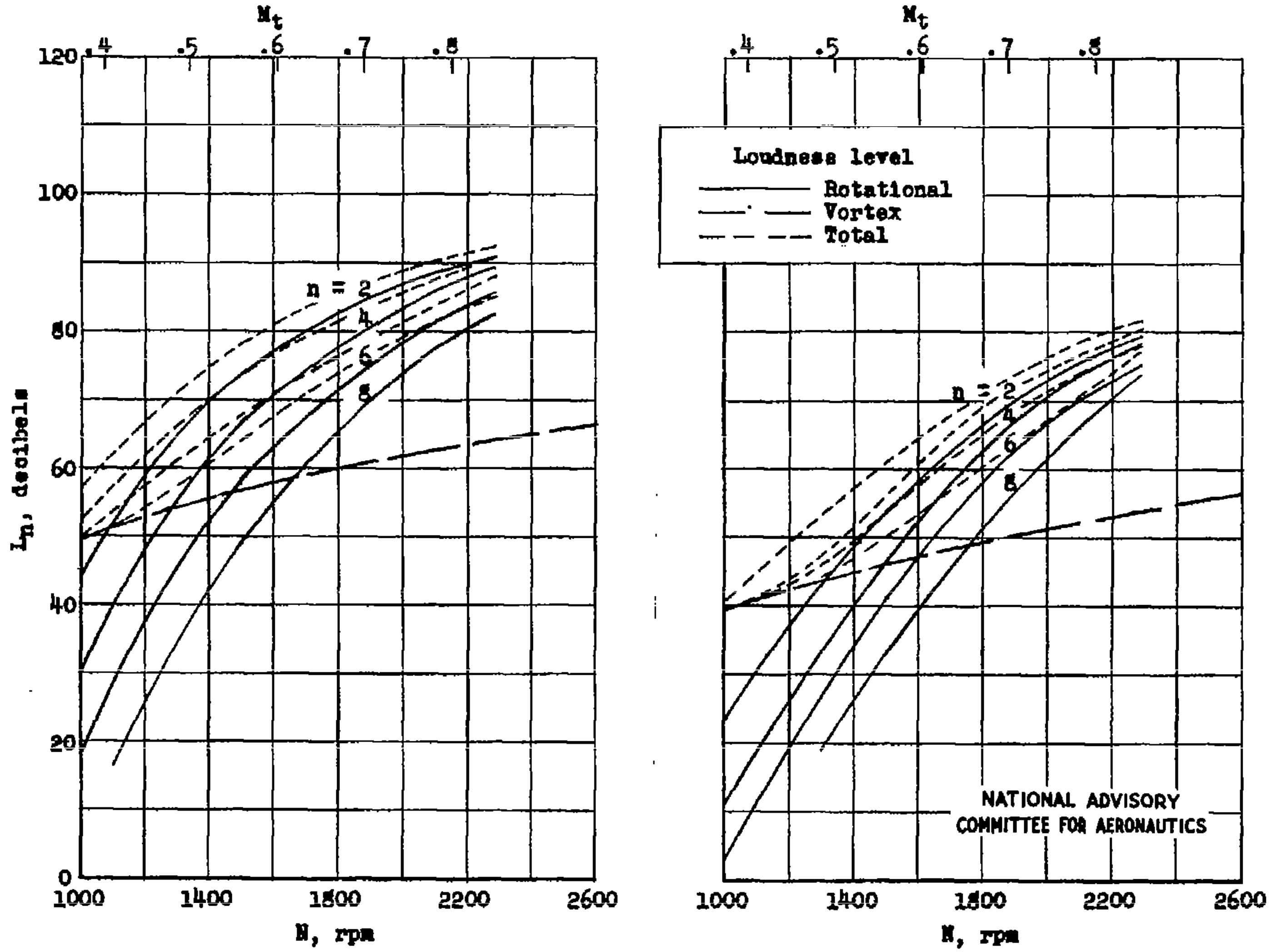


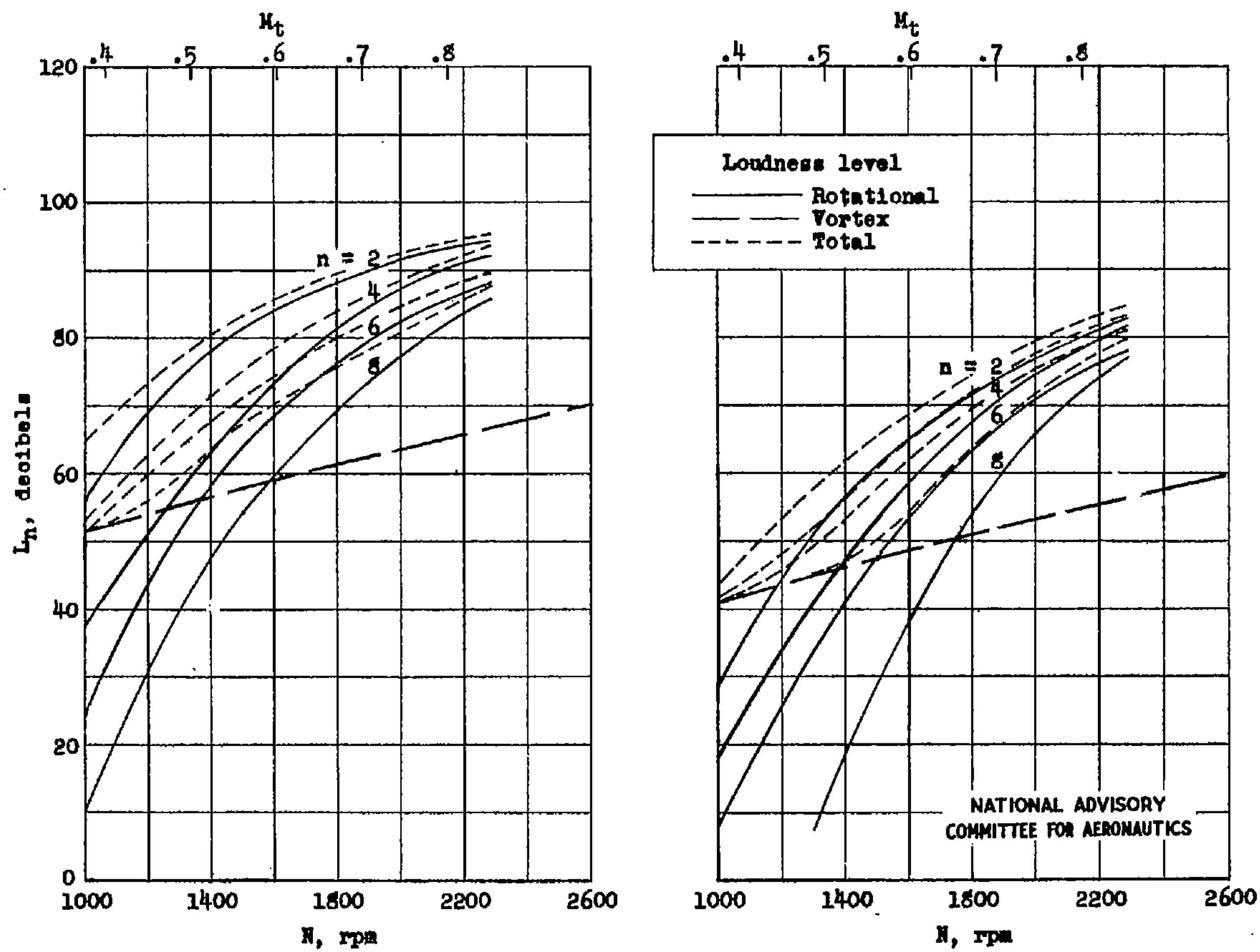
Figure 29.- Loudness as a function of propeller rotational speed for various numbers of blades. $D = 8$ feet; $V = 150$ miles per hour; $P_H = 300$ horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 30.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 200 miles per hour; P_H = 100 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 31.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 200 miles per hour; P_H = 150 horsepower.

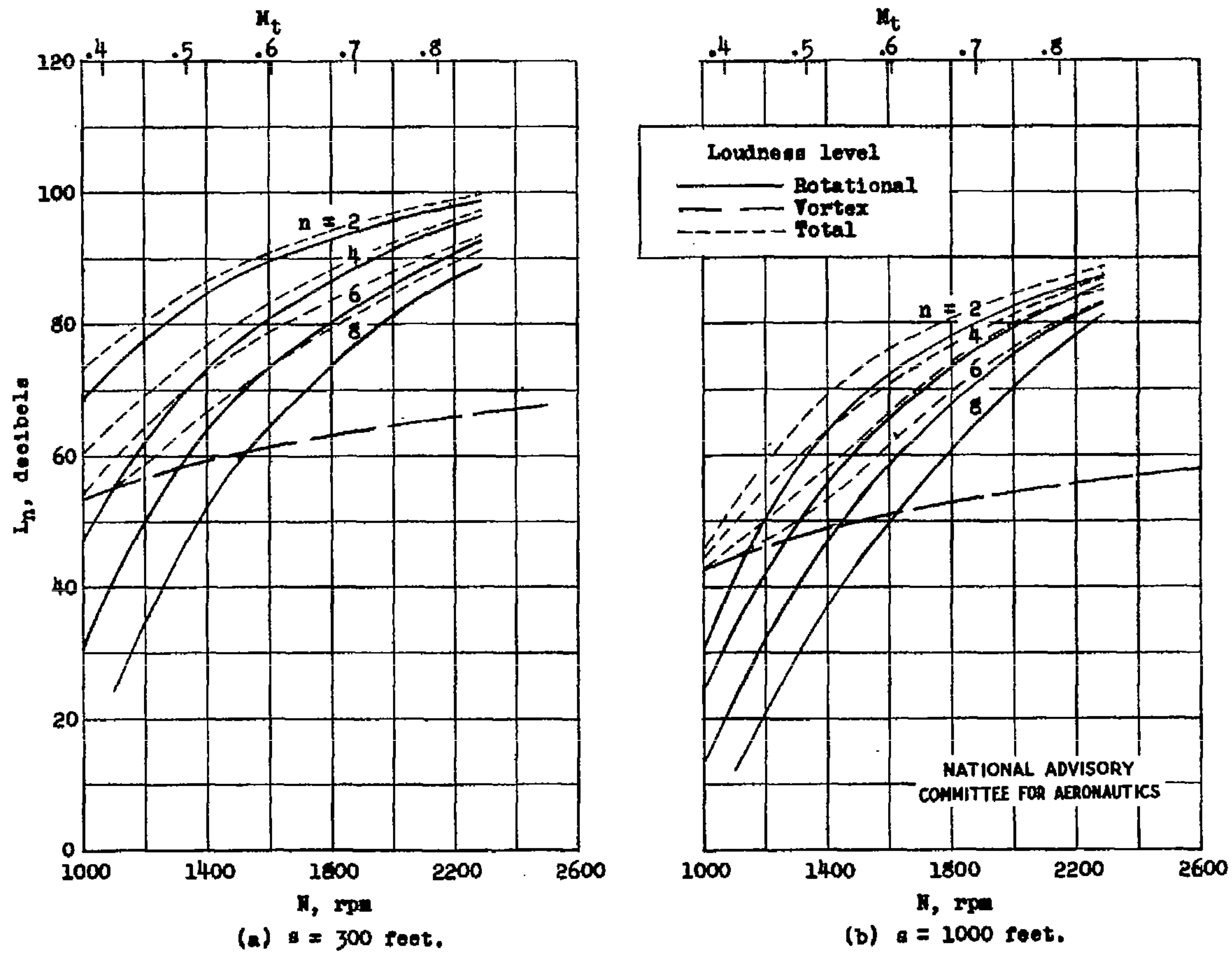
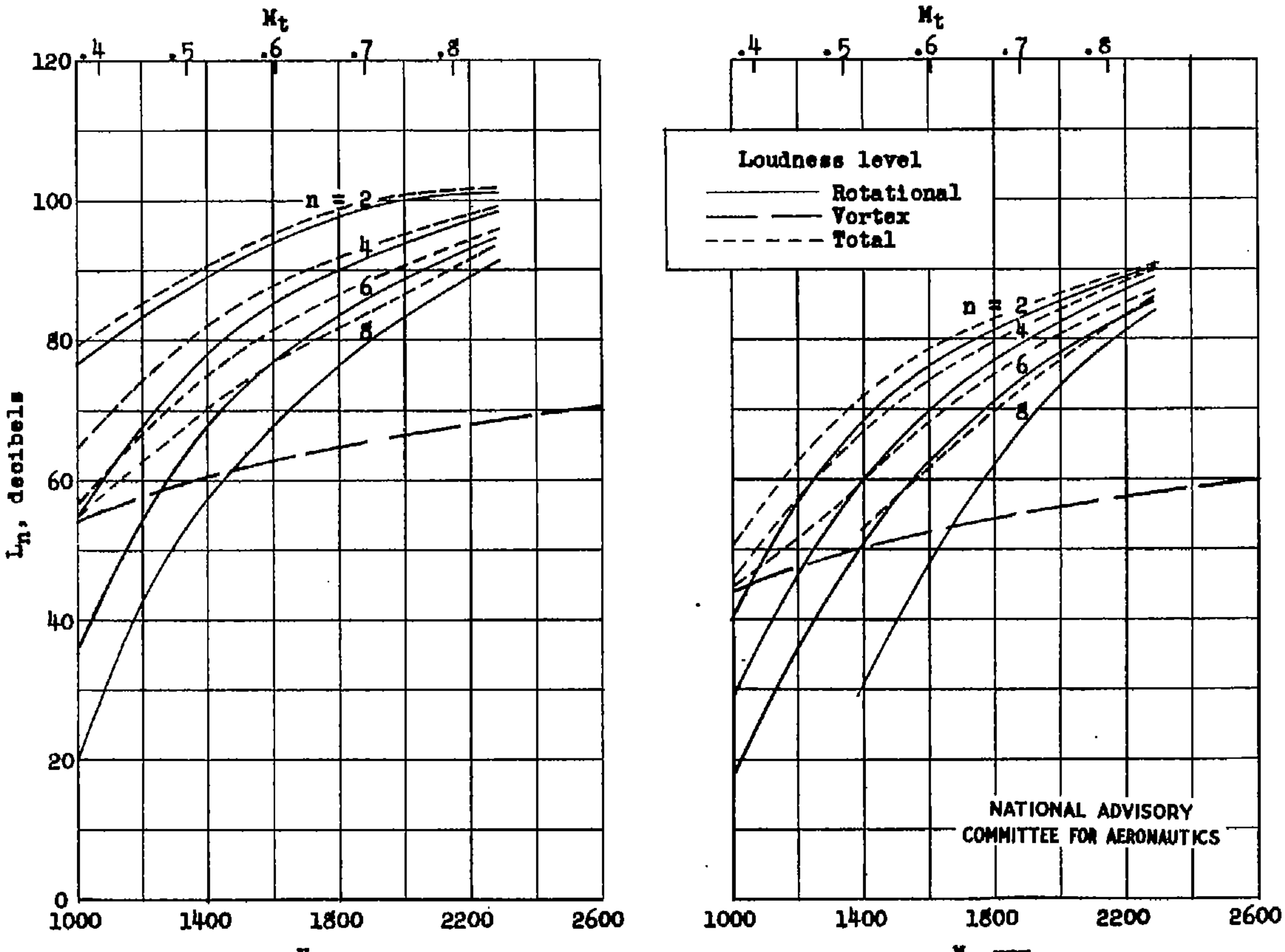


Figure 32.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 200 miles per hour; P_H = 225 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 33.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 8 feet; V = 200 miles per hour; P_H = 300 horsepower.

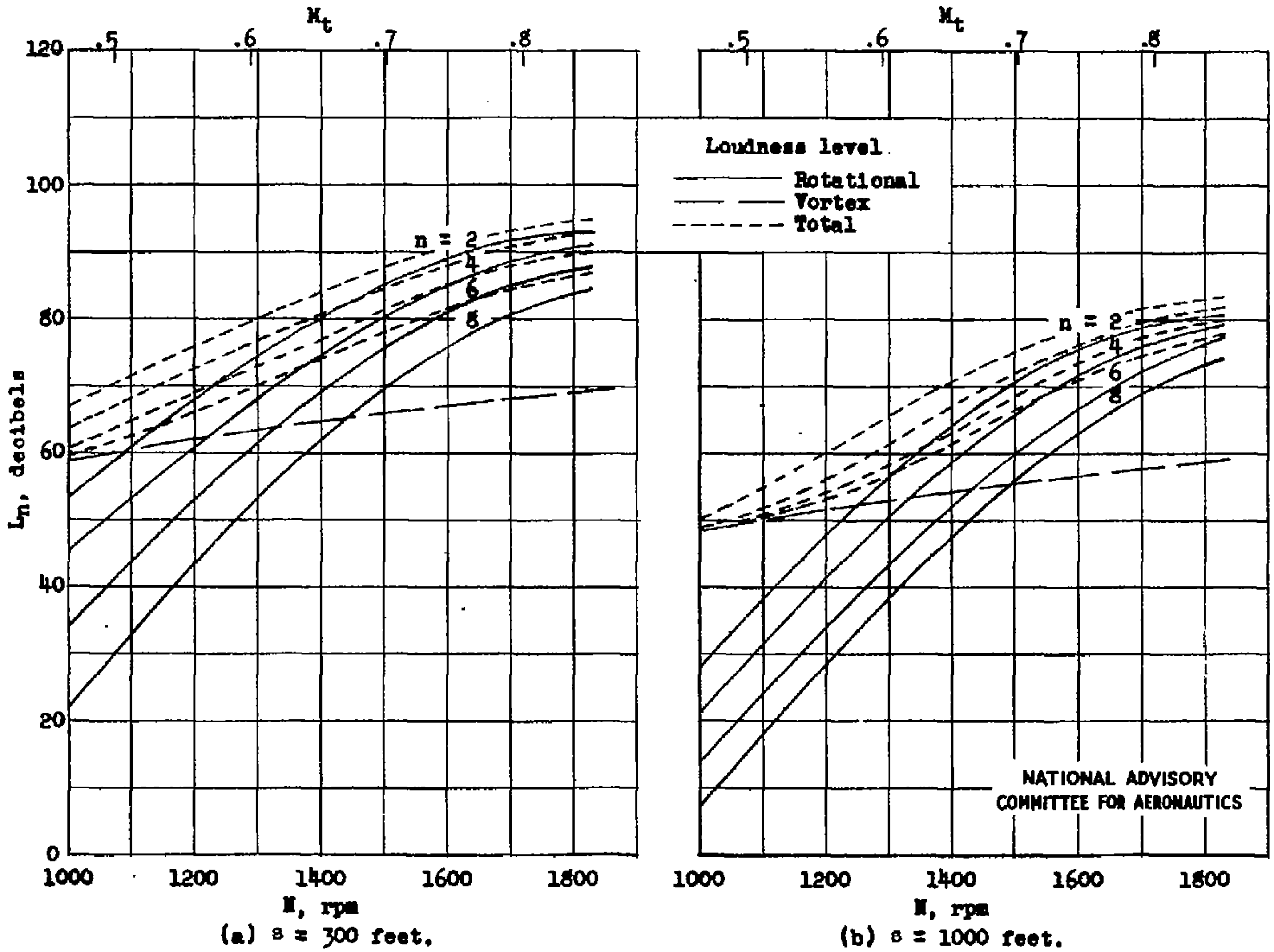


Figure 34.- Loudness as a function of propeller rotational speed for various numbers of blades. $D = 10$ feet; $V = 50$ miles per hour; $P_H = 100$ horsepower.

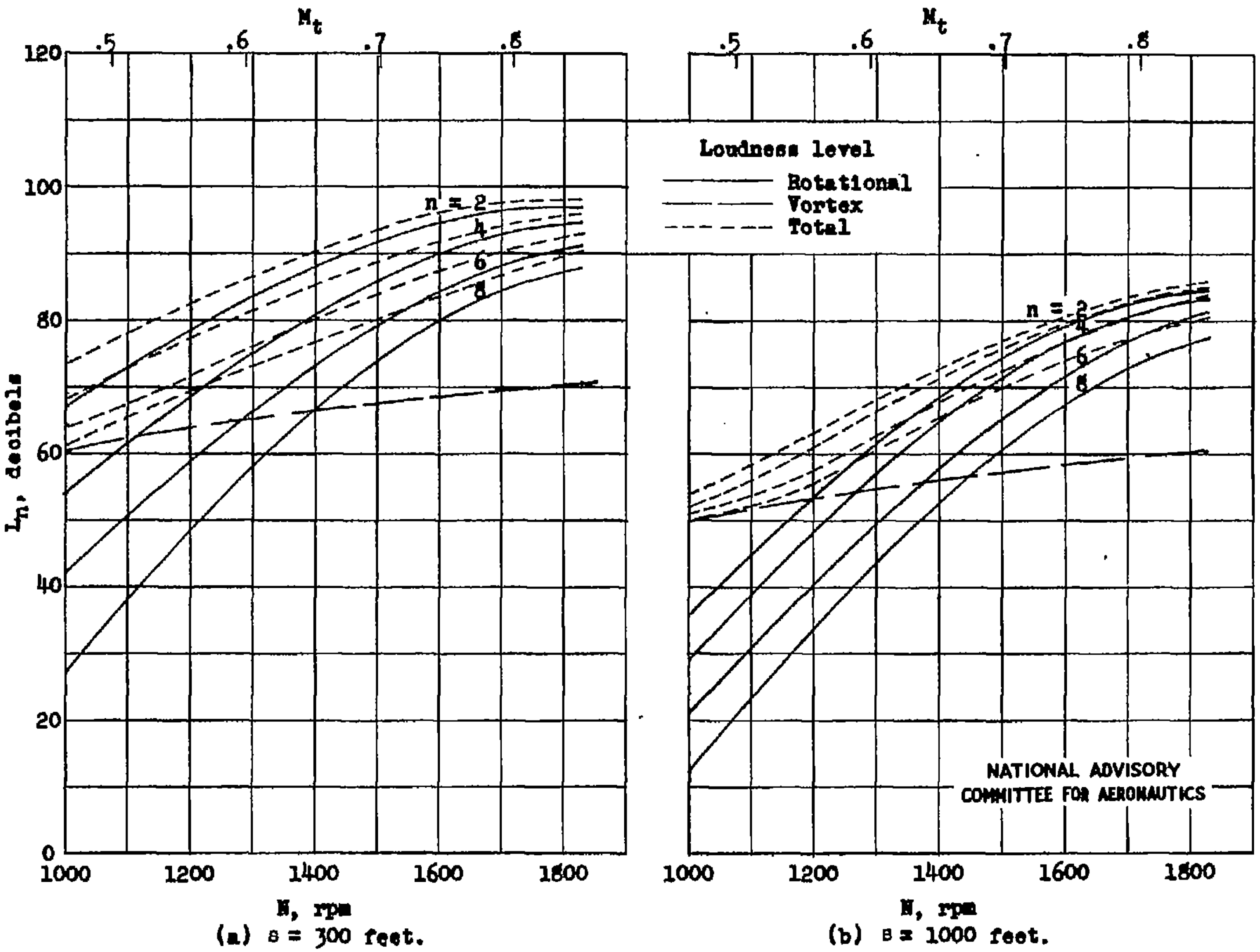
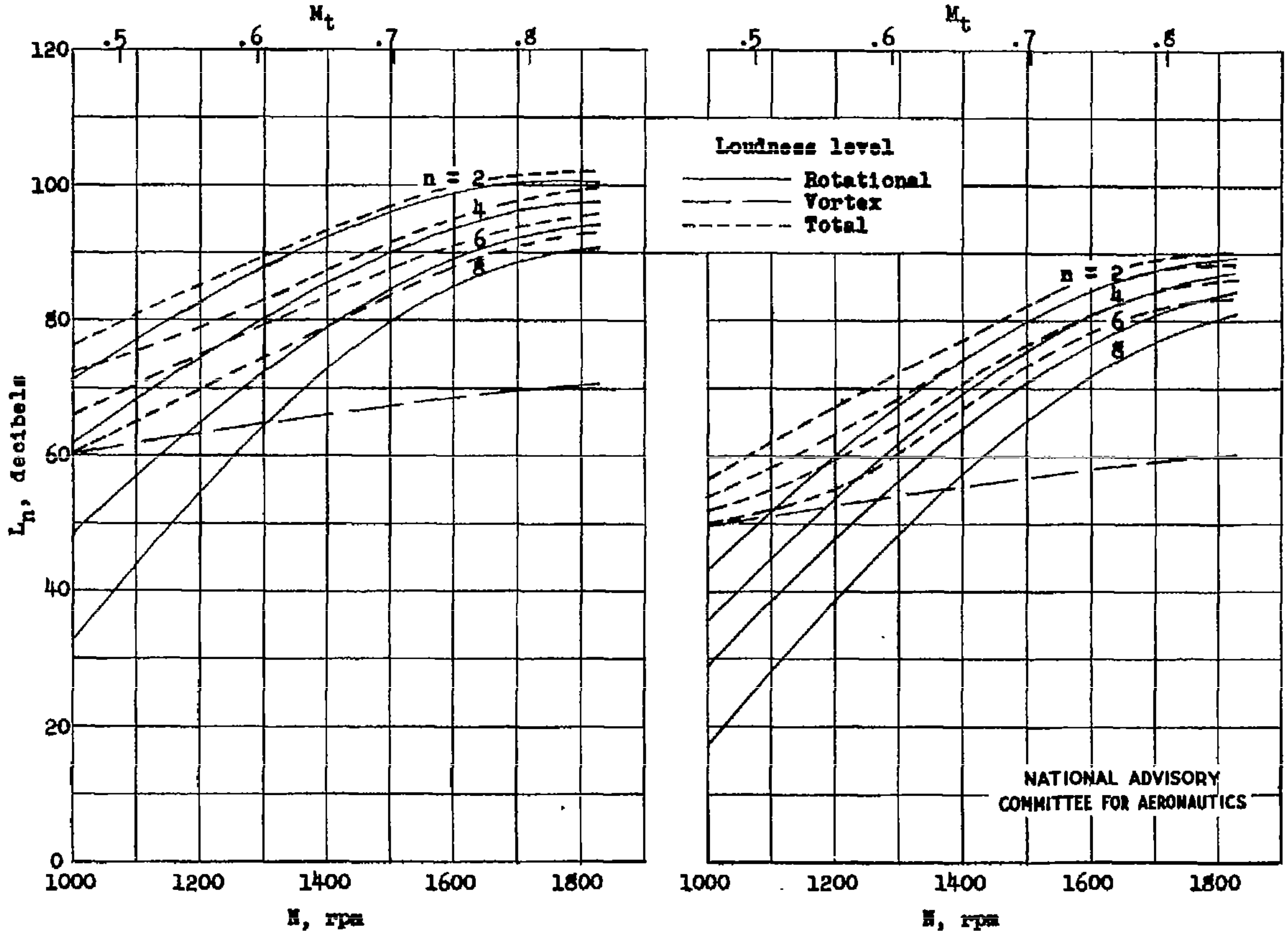


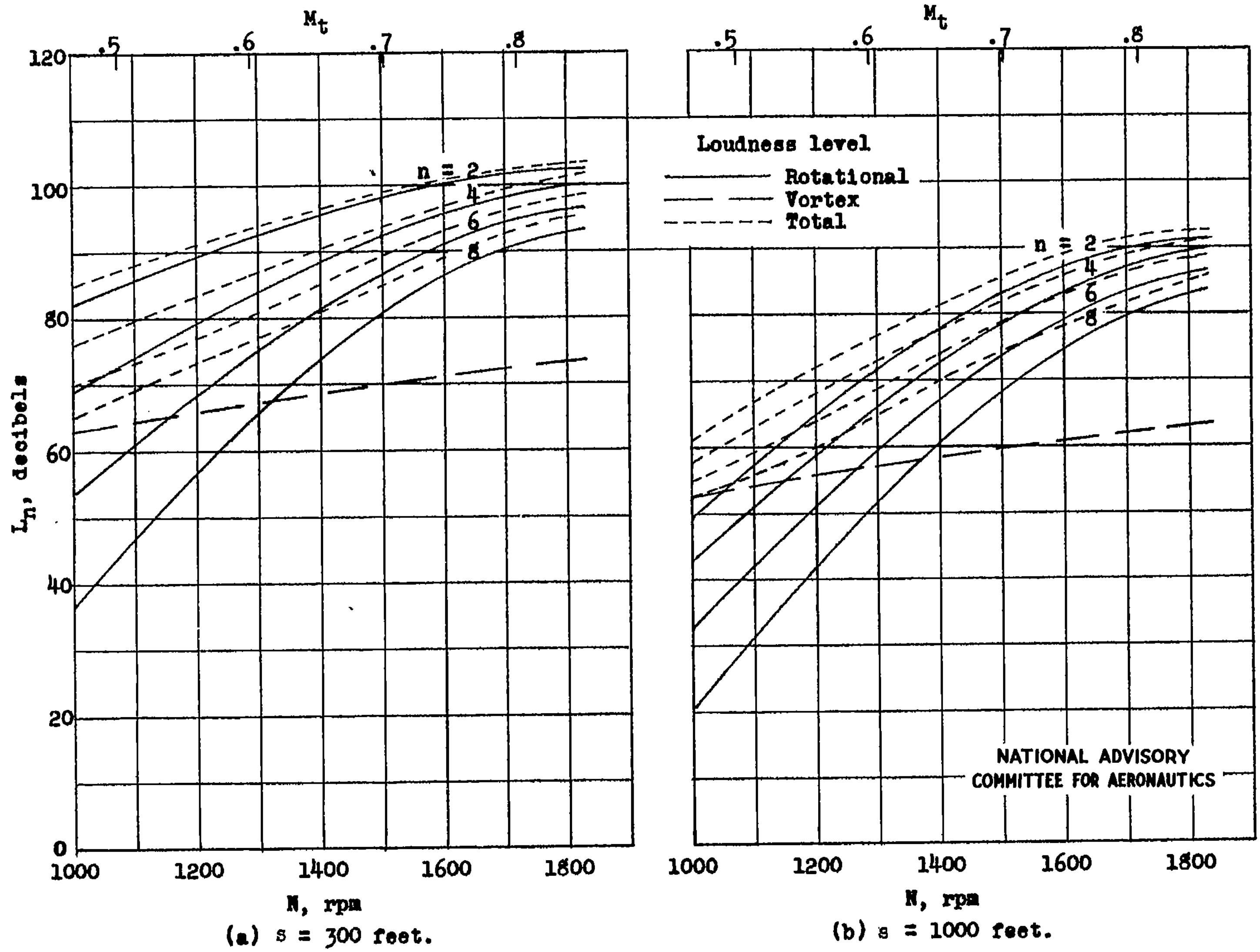
Figure 35.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 50 miles per hour; P_H = 150 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

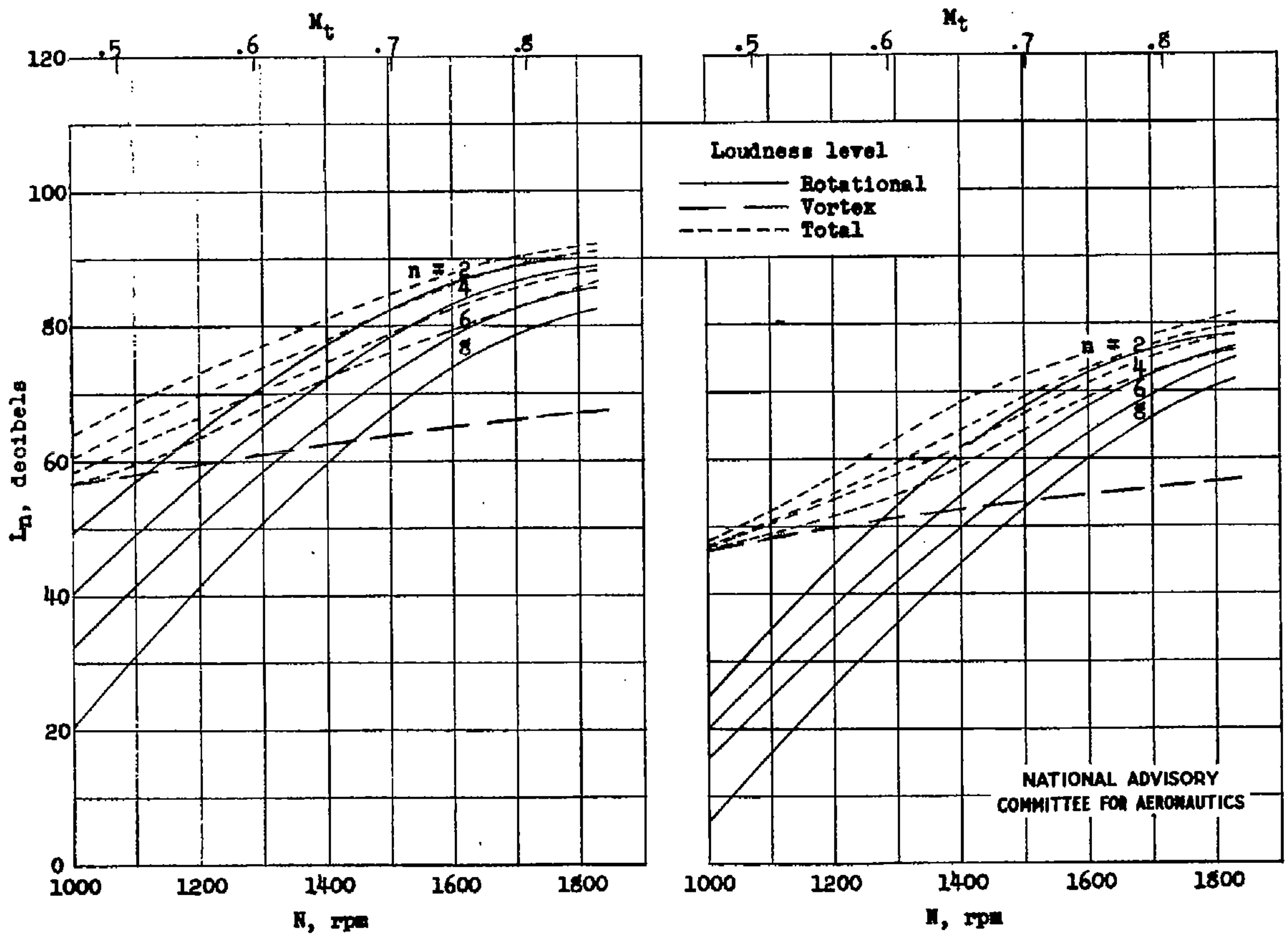
Figure 36.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 50 miles per hour; P_H = 225 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 37.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 50 miles per hour; P_H = 300 horsepower.



(a) s = 300 feet. (b) s = 1000 feet.

Figure 38.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 100 miles per hour; P_H = 100 horsepower.

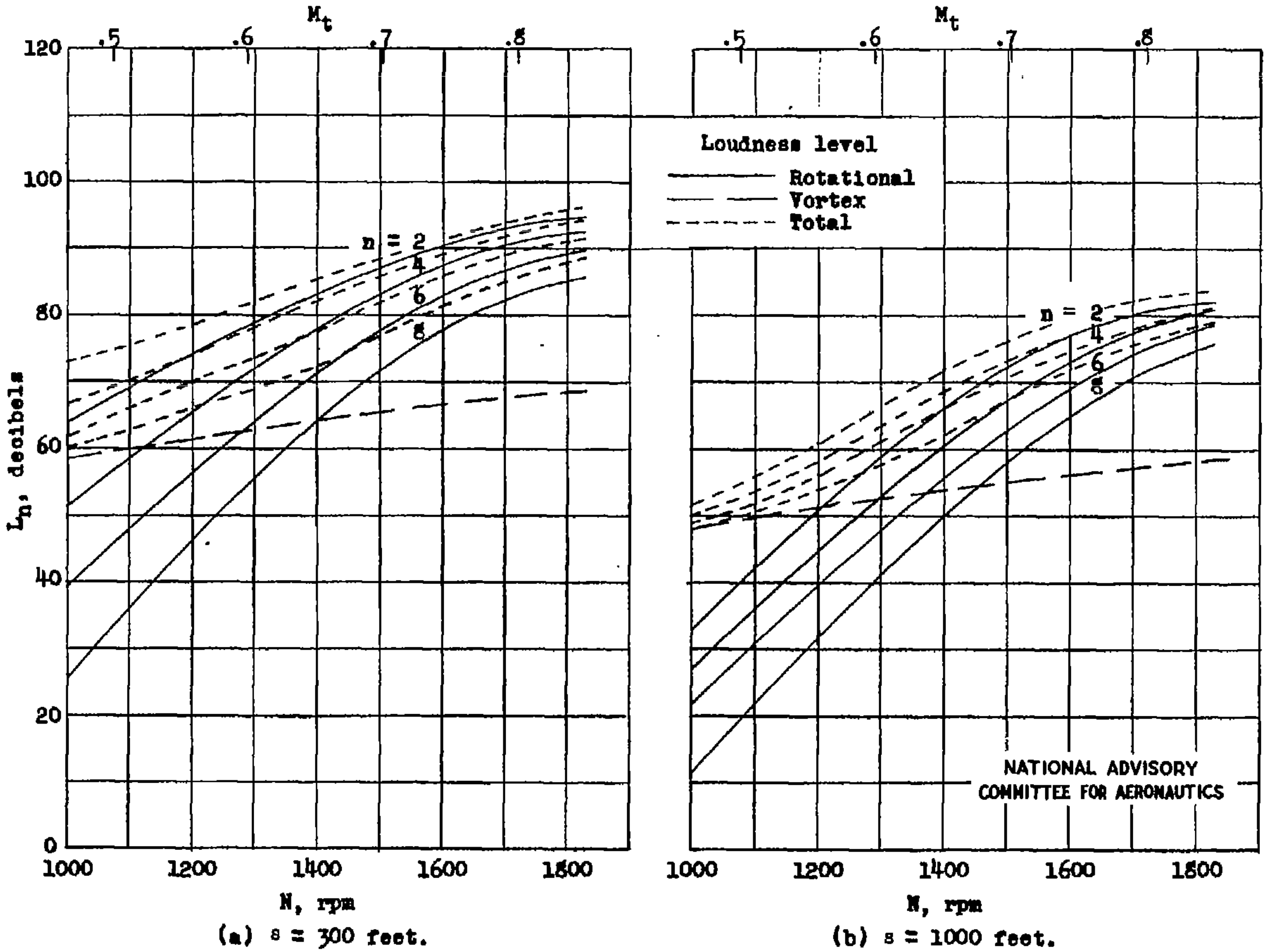


Figure 39.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 100 miles per hour; P_H = 150 horsepower.

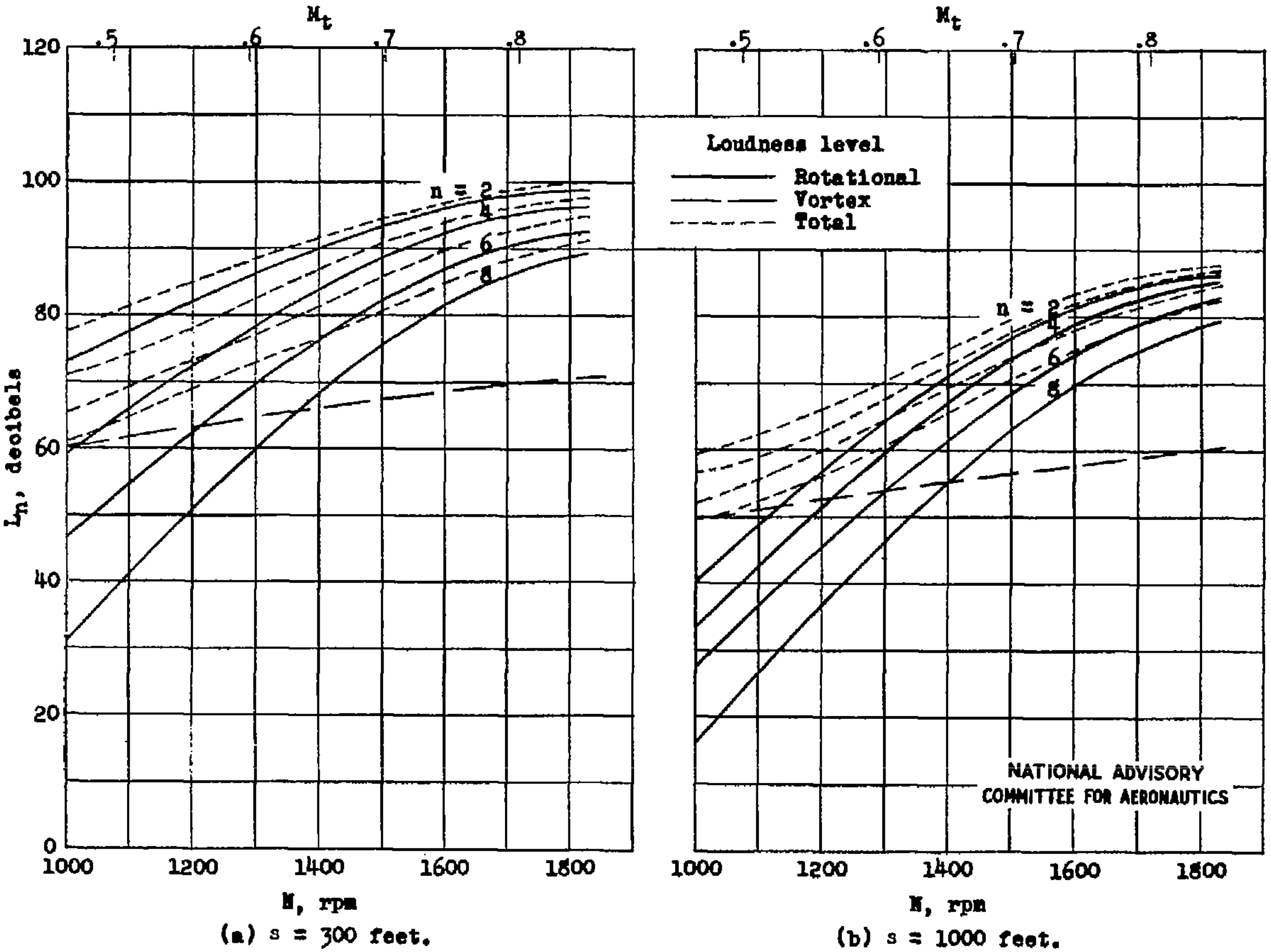


Figure 40.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 100 miles per hour; P_H = 225 horsepower.

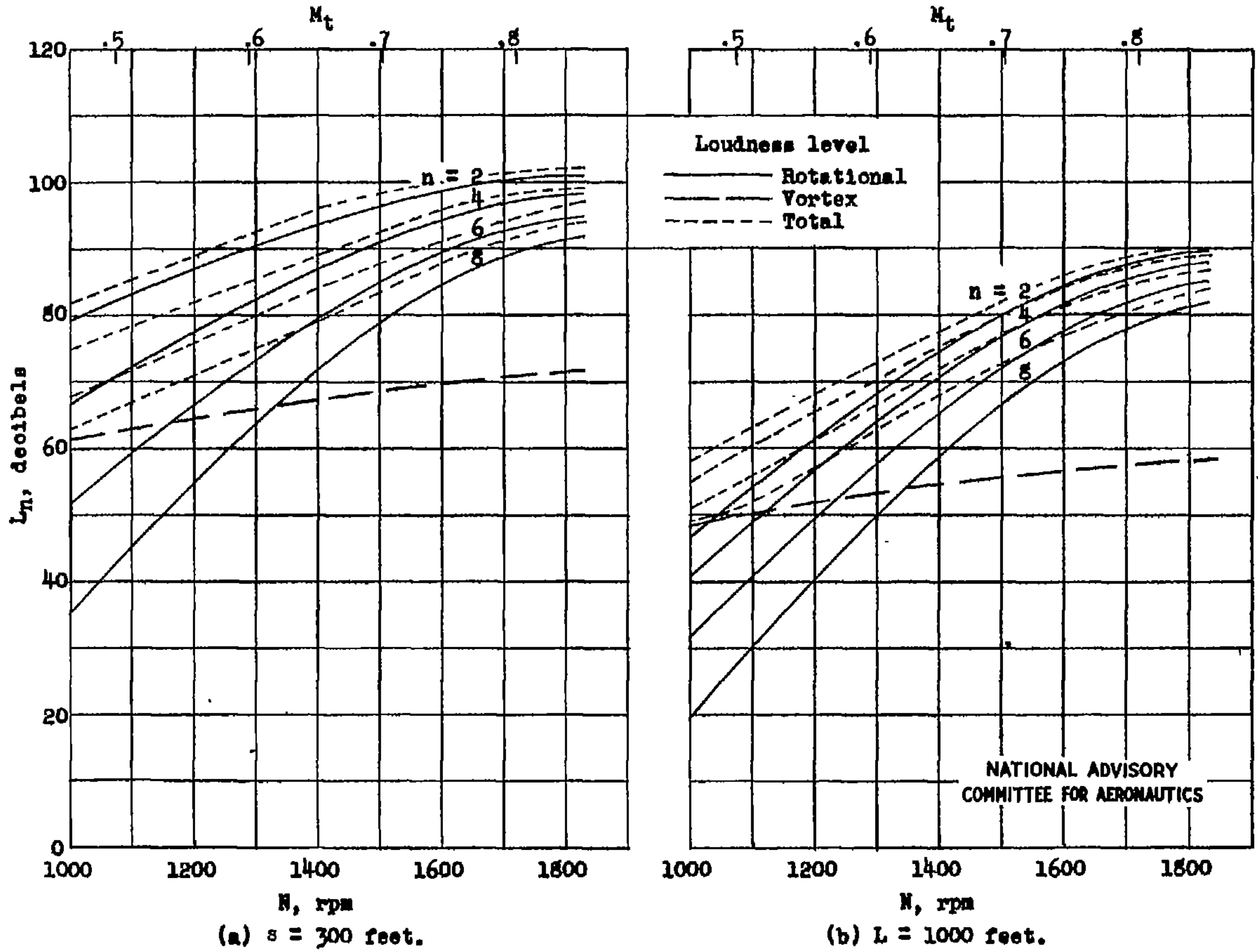
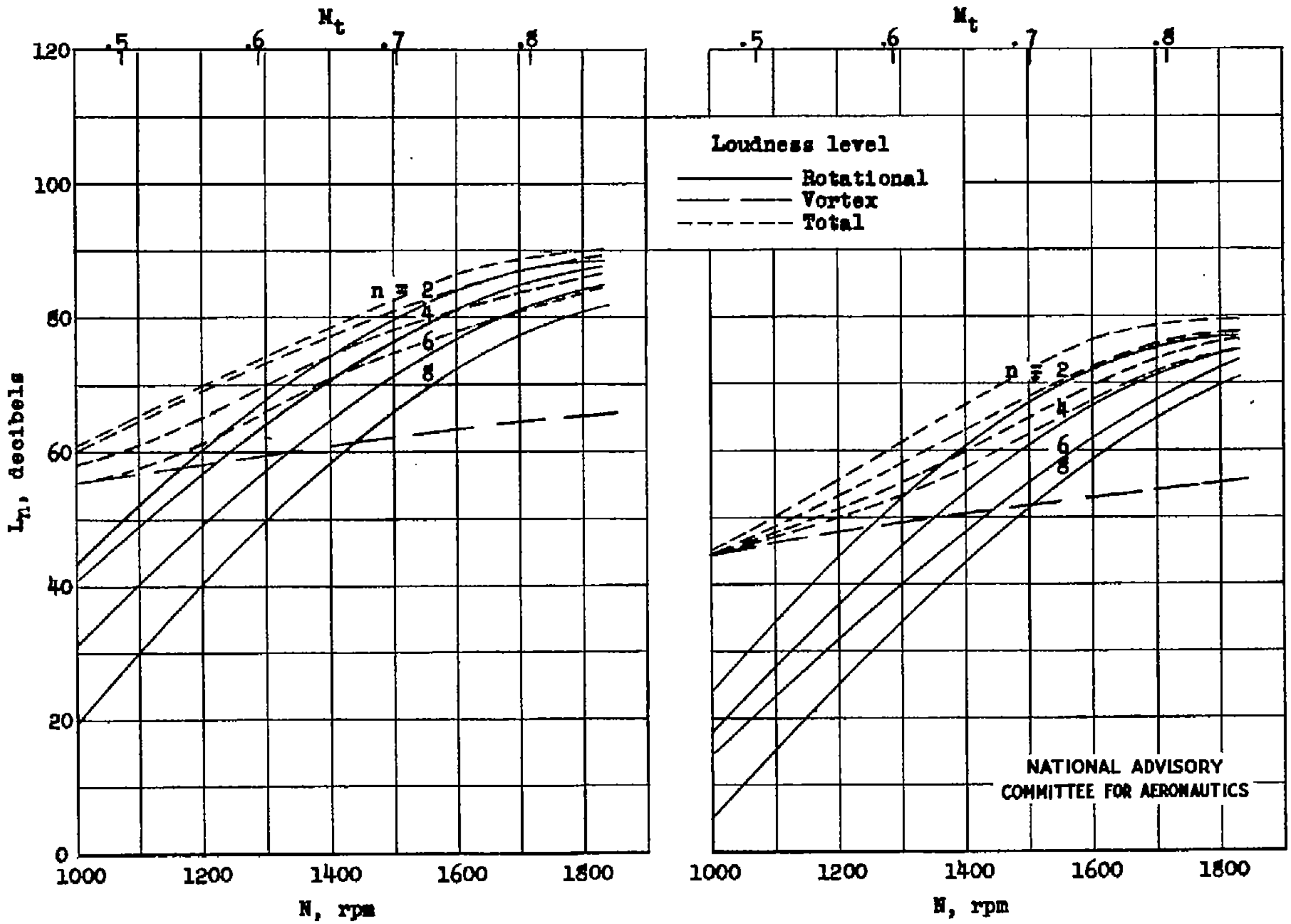


Figure 41.- Loudness as a function of propeller rotational speed for various numbers of blades. $D = 10$ feet; $V = 100$ miles per hour; $P_H = 300$ horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 42.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 150 miles per hour; P_H = 100 horsepower.

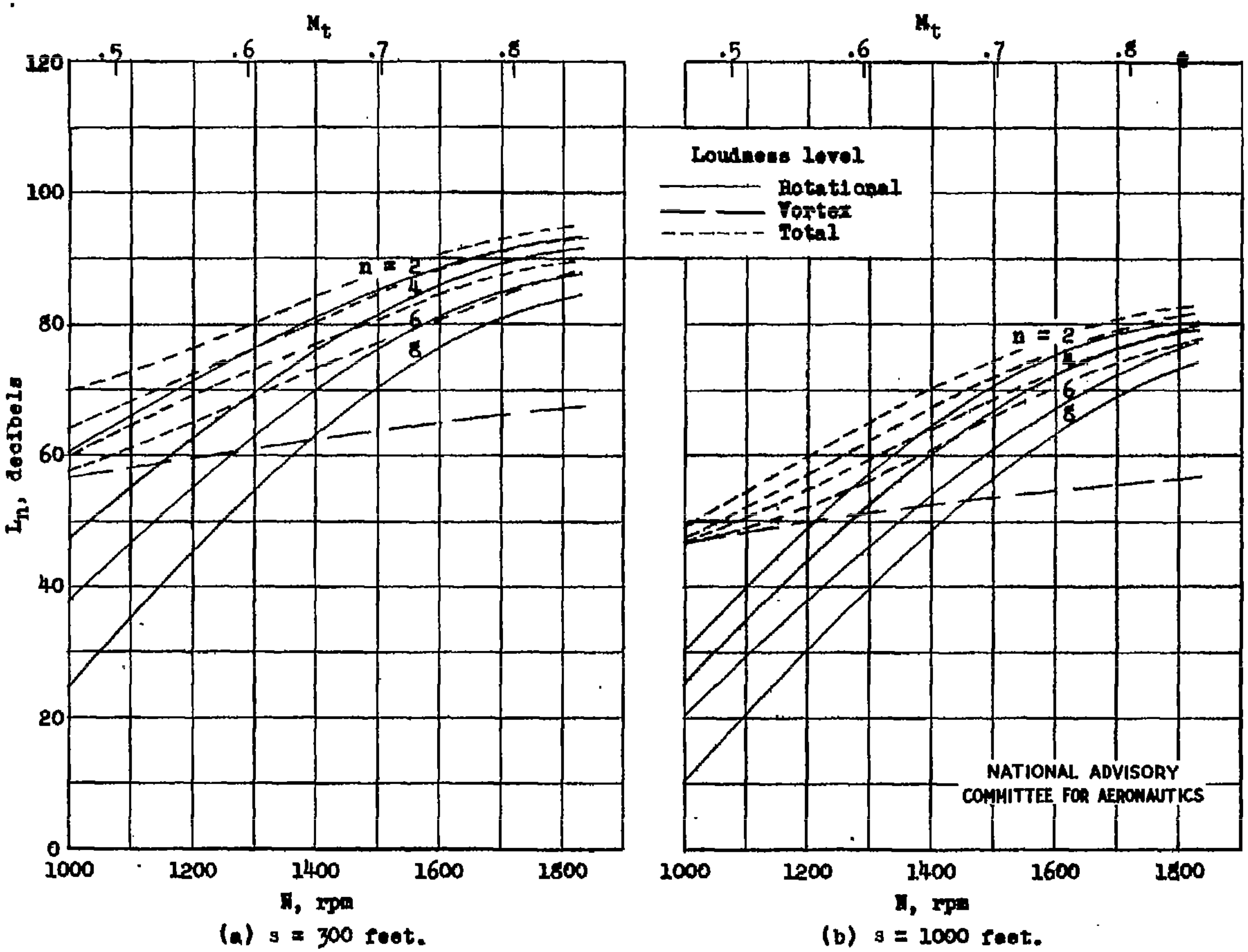
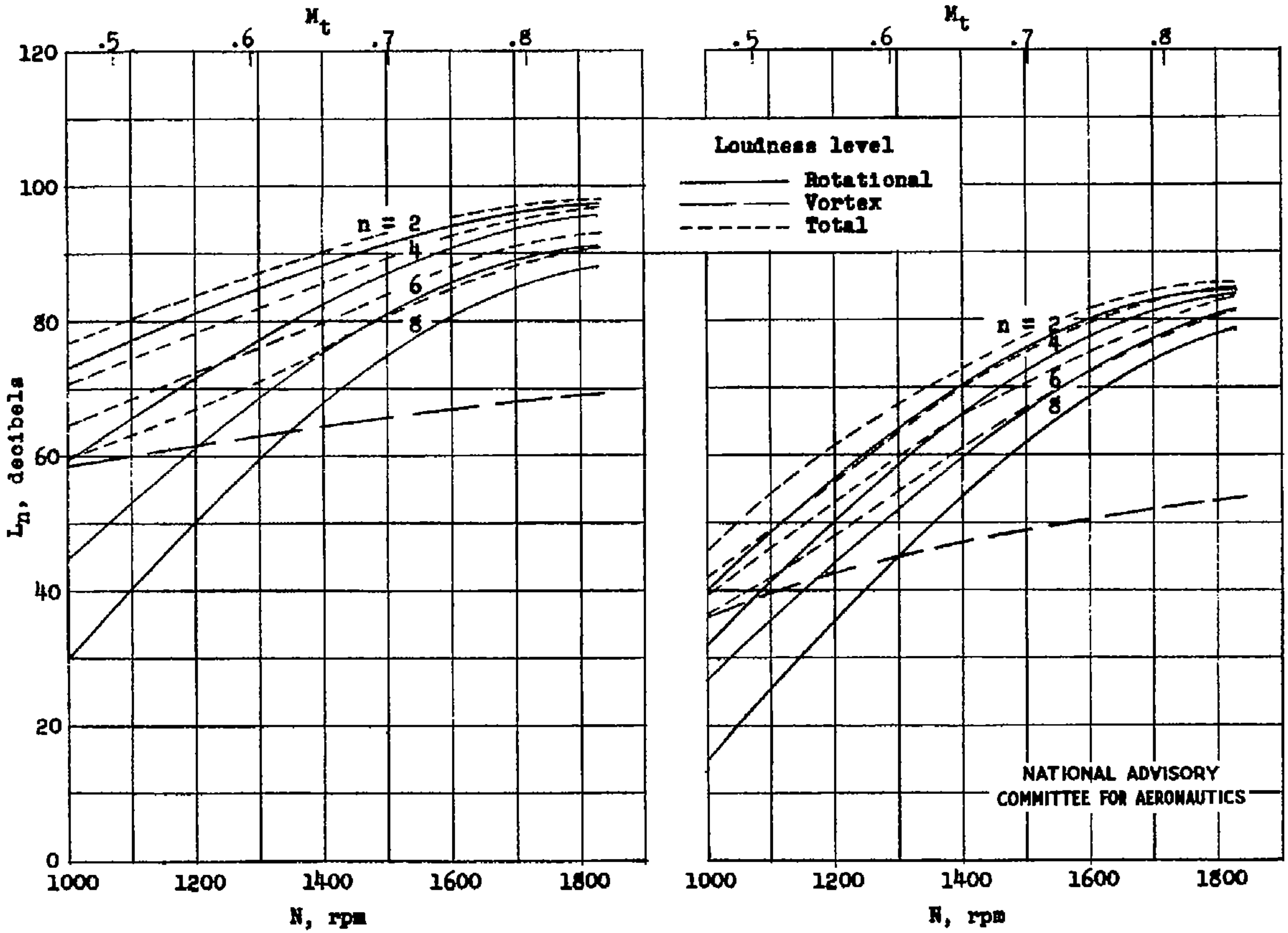


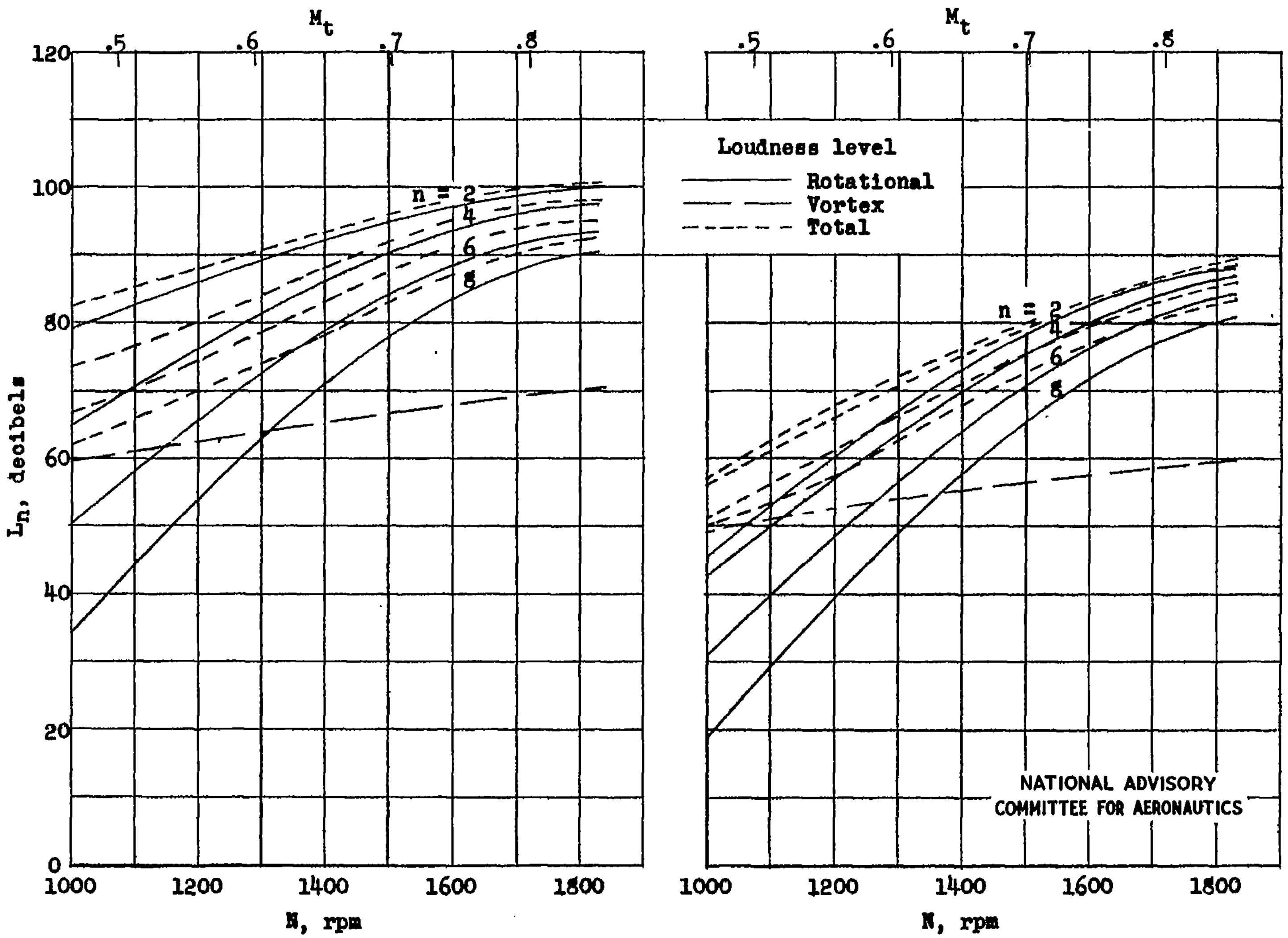
Figure 43.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 150 miles per hour; P_H = 150 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 44.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 150 miles per hour; P_H = 225 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 45.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 150 miles per hour; P_H = 300 horsepower.

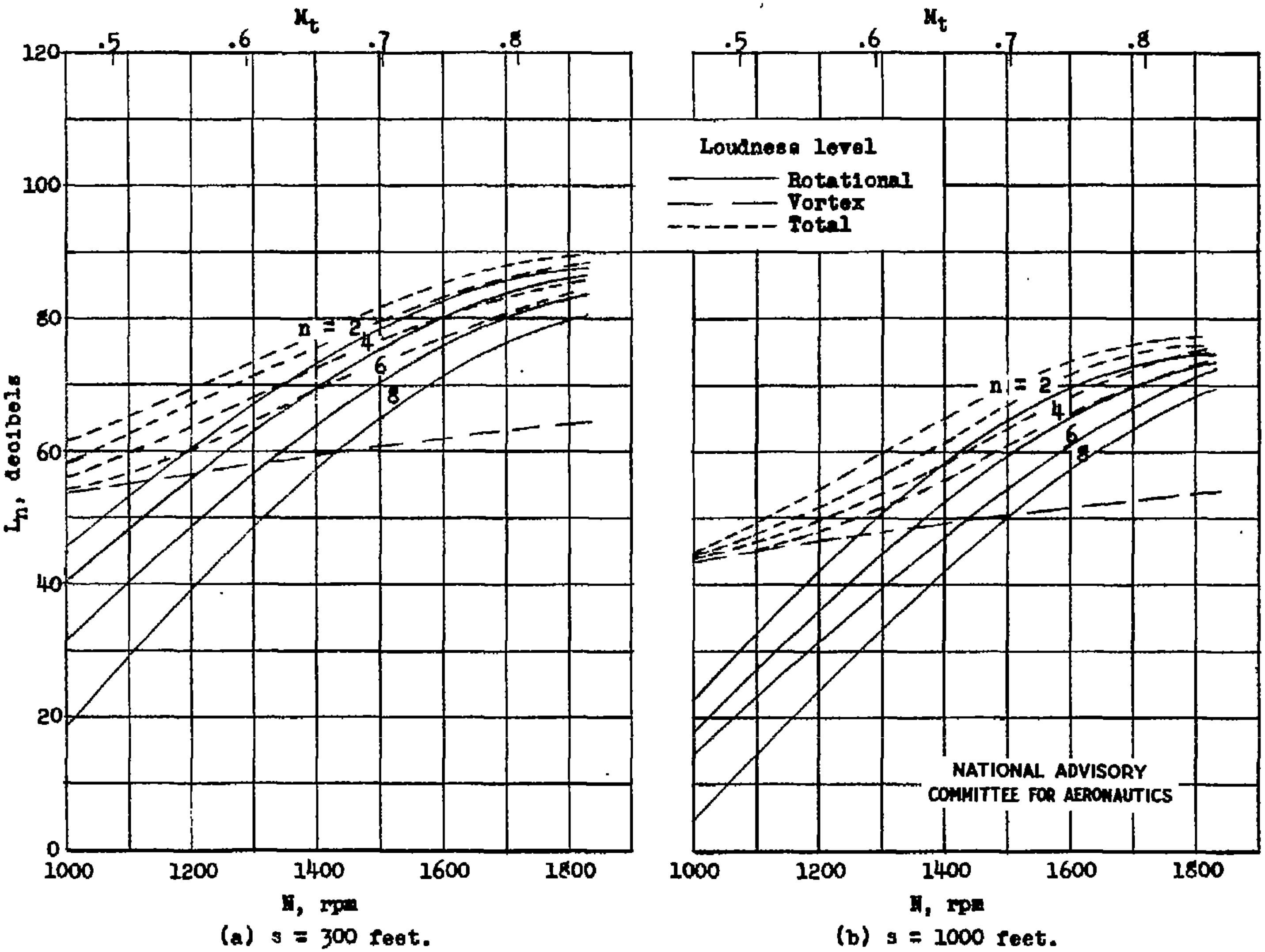


Figure 46.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 200 miles per hour; P_H = 100 horsepower.

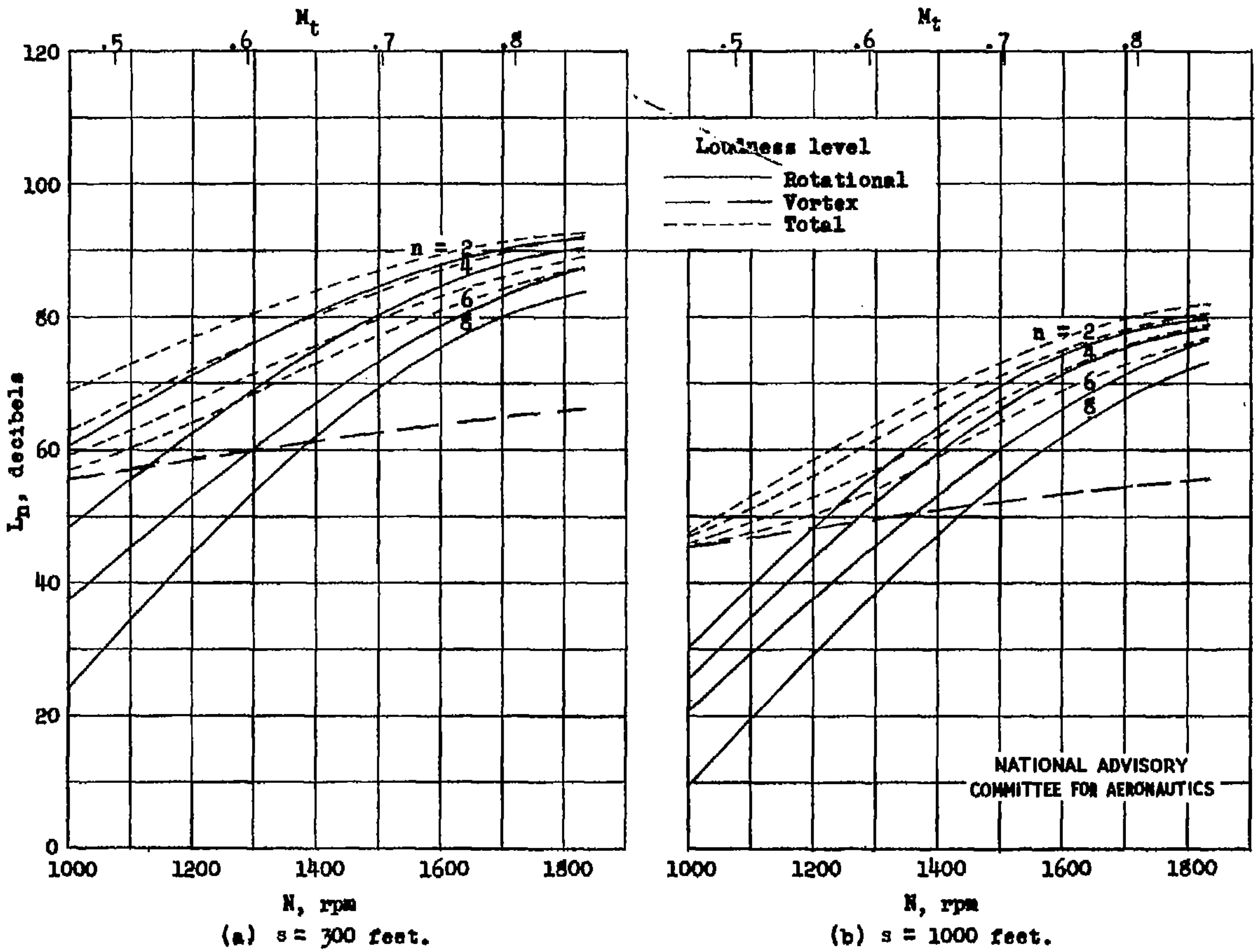
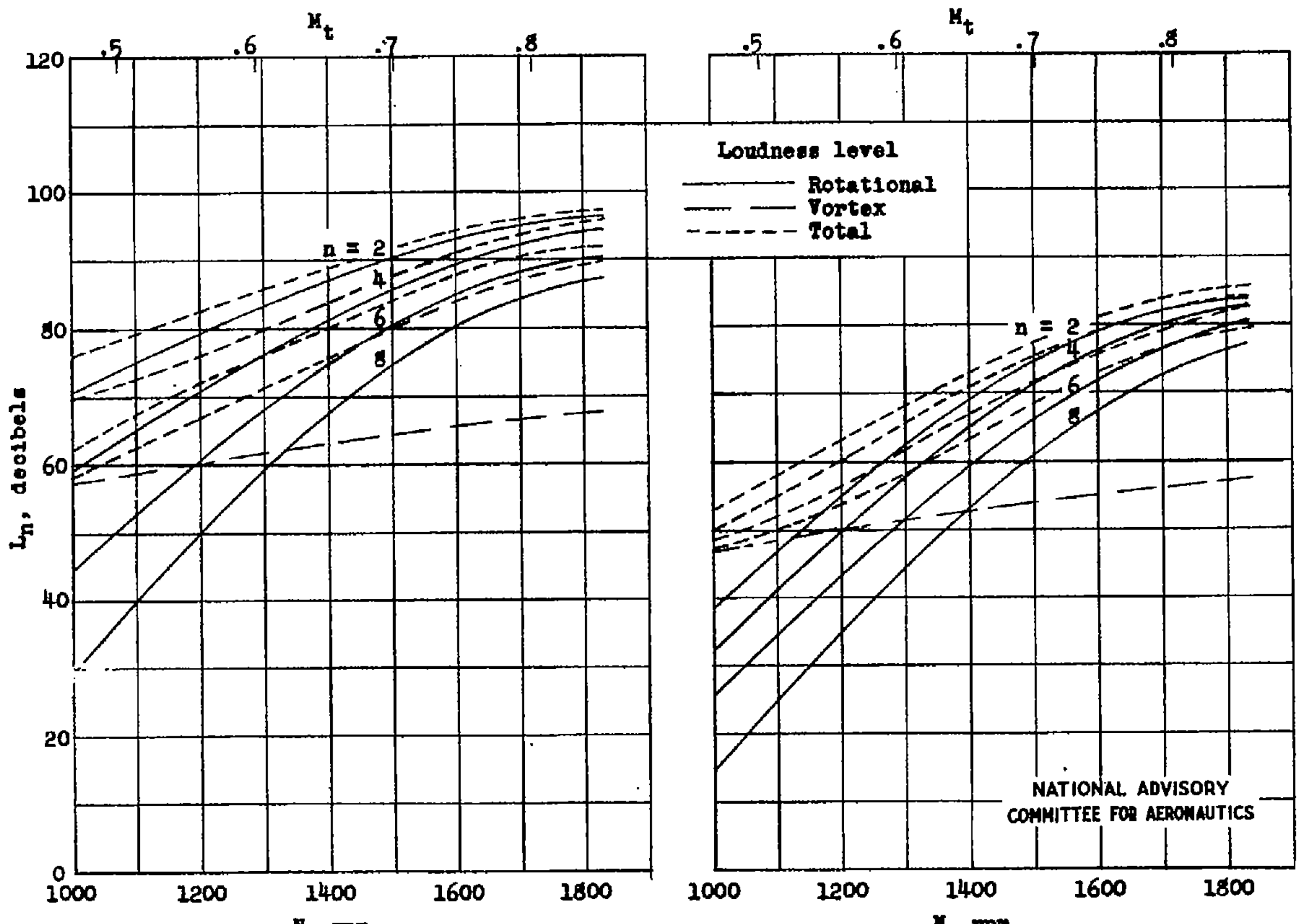


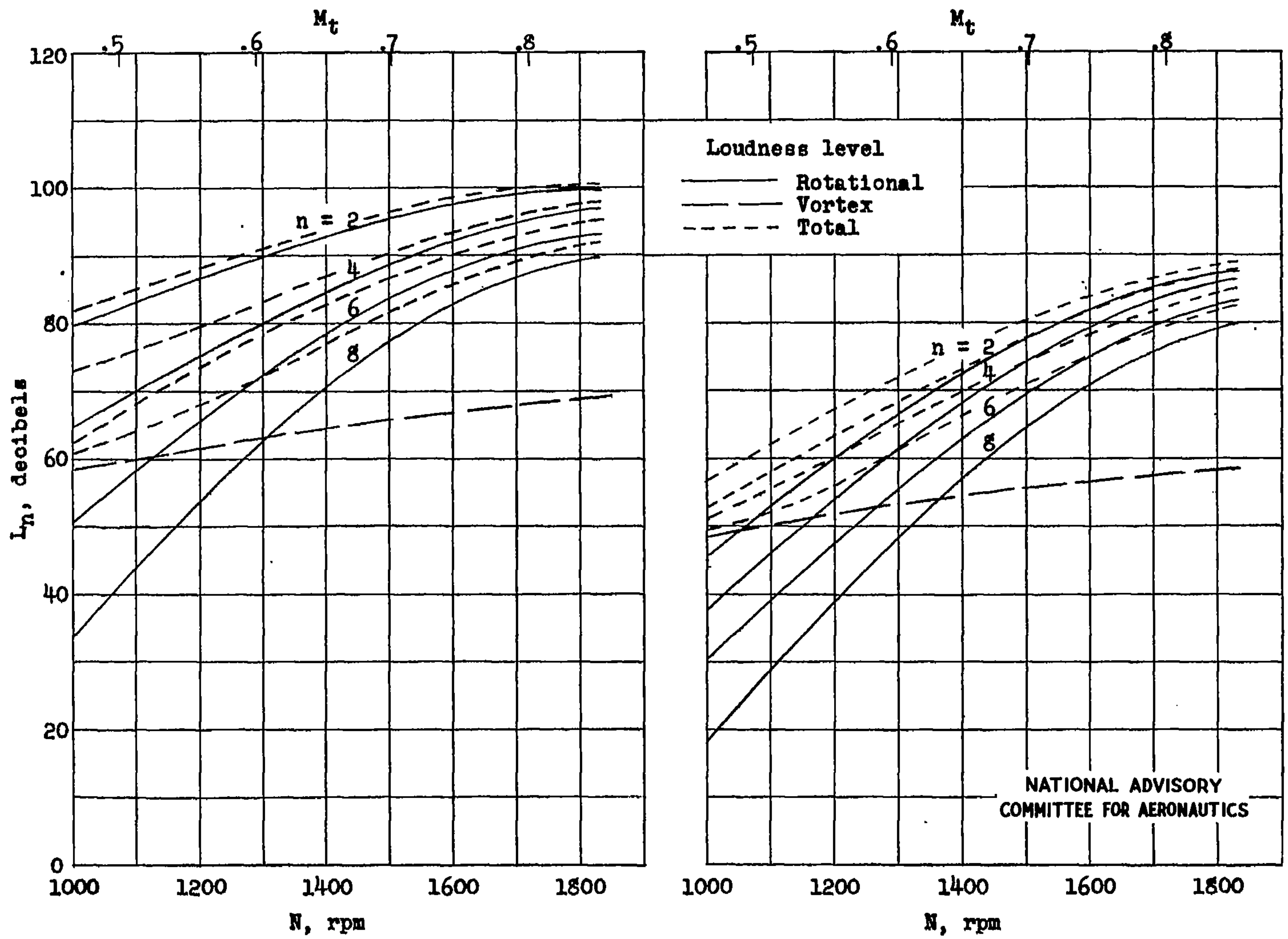
Figure 47.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 200 miles per hour; P_H = 150 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

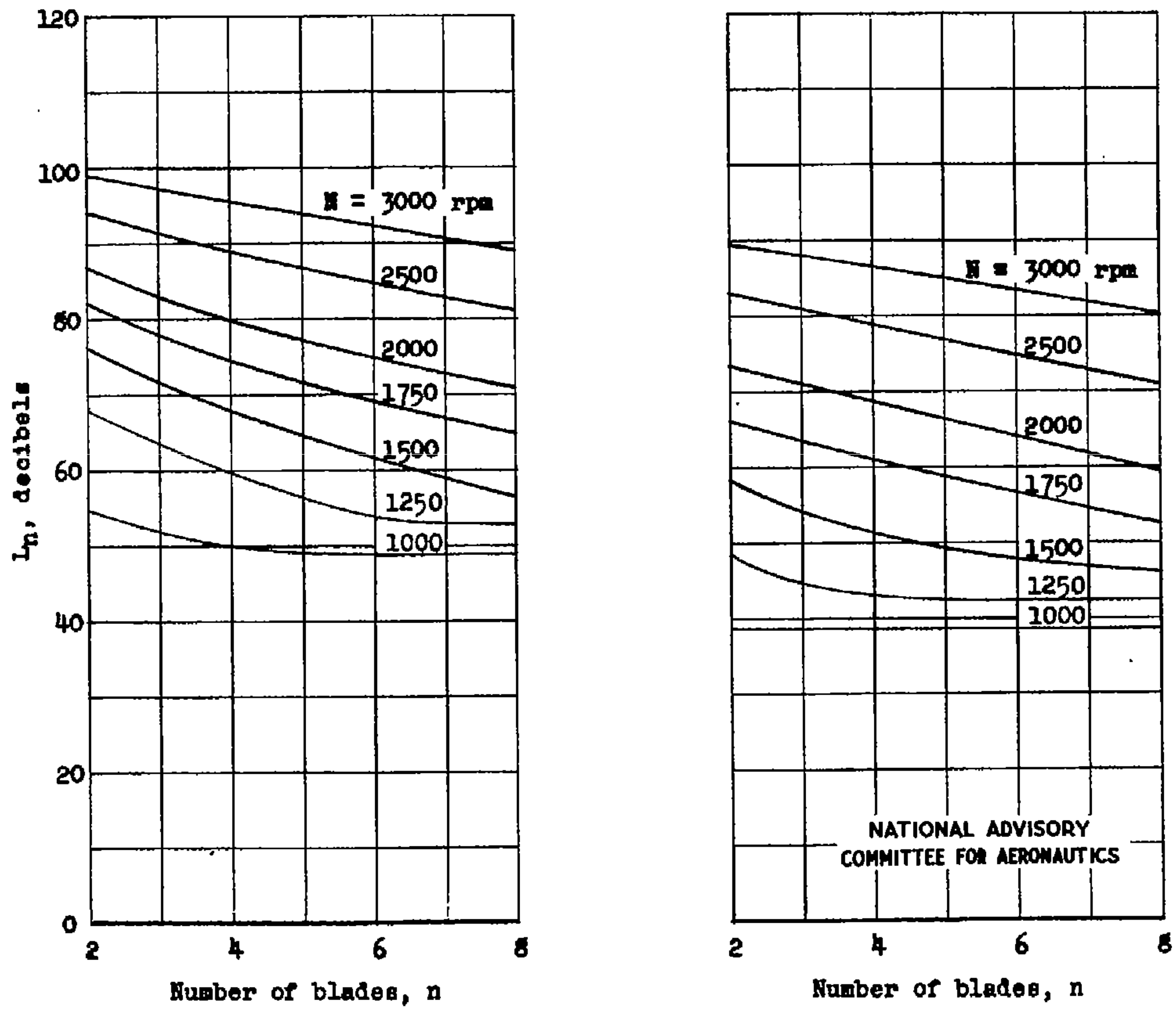
Figure 48.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 200 miles per hour; P_H = 225 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 49.- Loudness as a function of propeller rotational speed for various numbers of blades. D = 10 feet; V = 200 miles per hour; P_H = 300 horsepower.



(a) s = 300 feet.

(b) s = 1000 feet.

Figure 50.- Effect of number of blades on propeller loudness. V = 50 miles per hour; P_H = 100 horsepower; D = 6 feet.

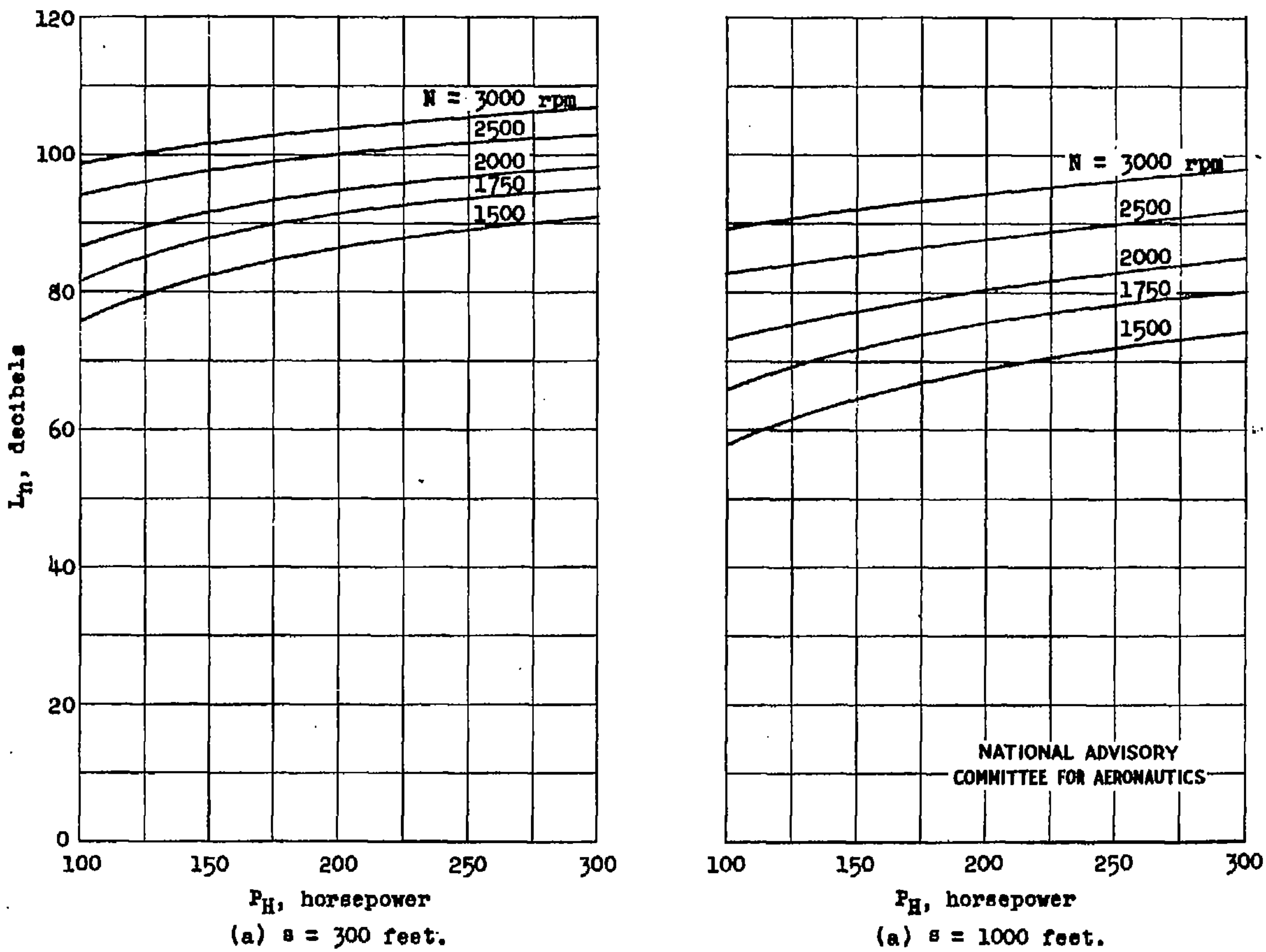


Figure 51.- Effect of power absorbed on propeller loudness. V = 50 miles per hour; D = 6 feet; n = 2 blades.

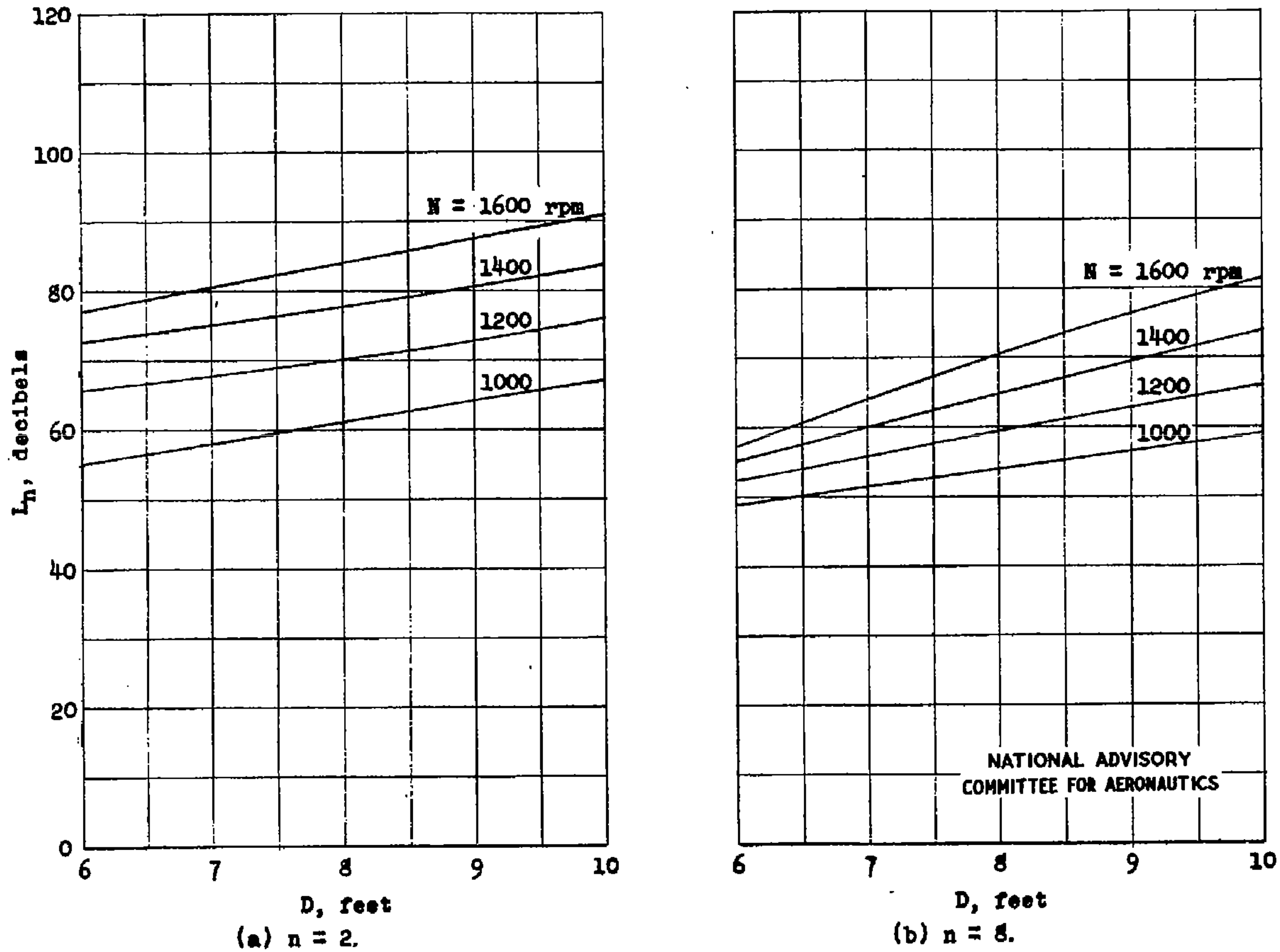


Figure 52.- Effect of diameter at constant rotation speed N on propeller loudness. V = 50 miles per hour; P_H = 100 horsepower; s = 300 feet.

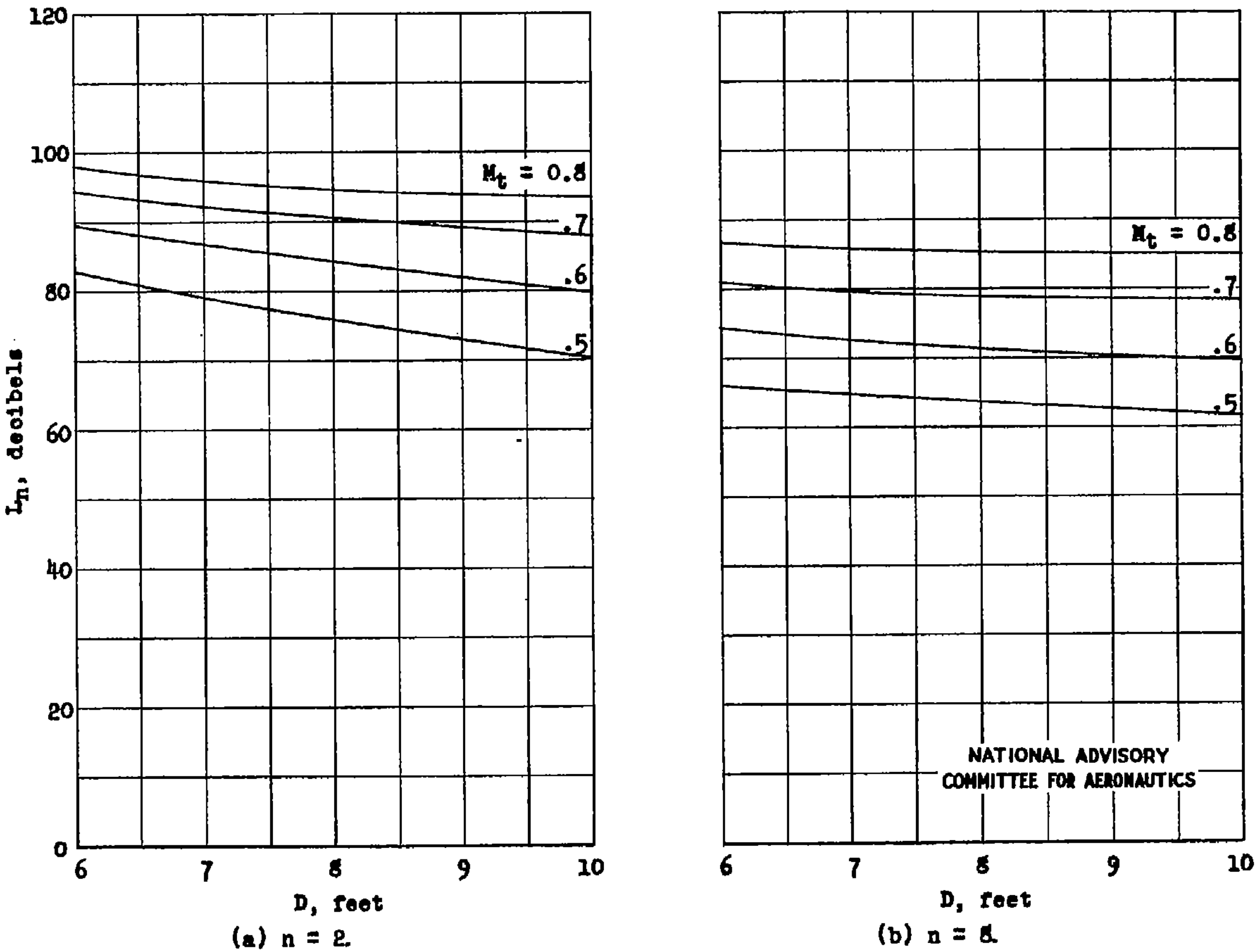
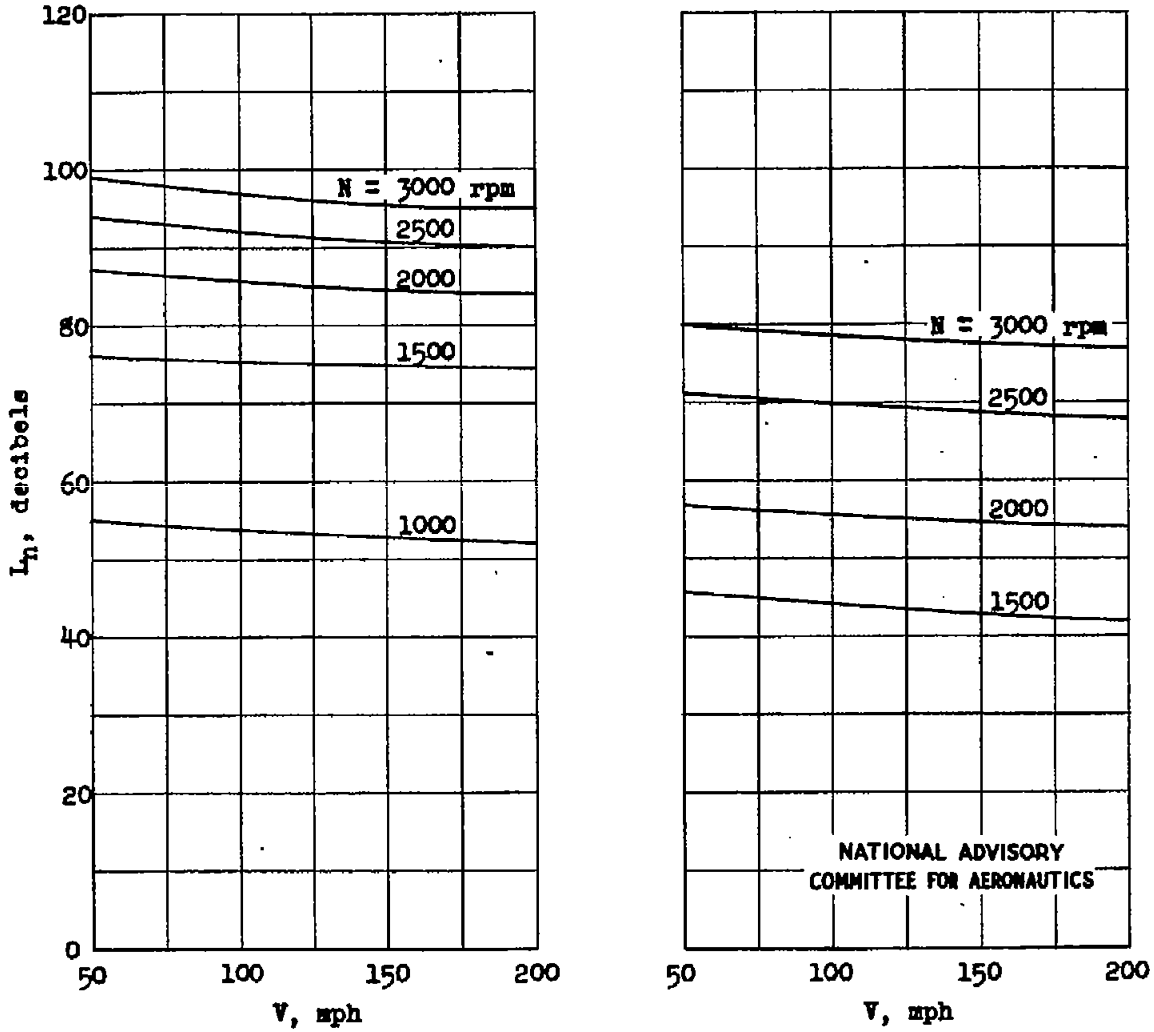


Figure 53.- Effect of diameter at constant tip Mach number on propeller loudness. V = 50 miles per hour; P_H = 100 horsepower; s = 300 feet.



(a) n = 2.

(b) n = 8.

Figure 54.- Effect of forward speed on propeller loudness. D = 6 feet; P_H = 100 horsepower; s = 300 feet.

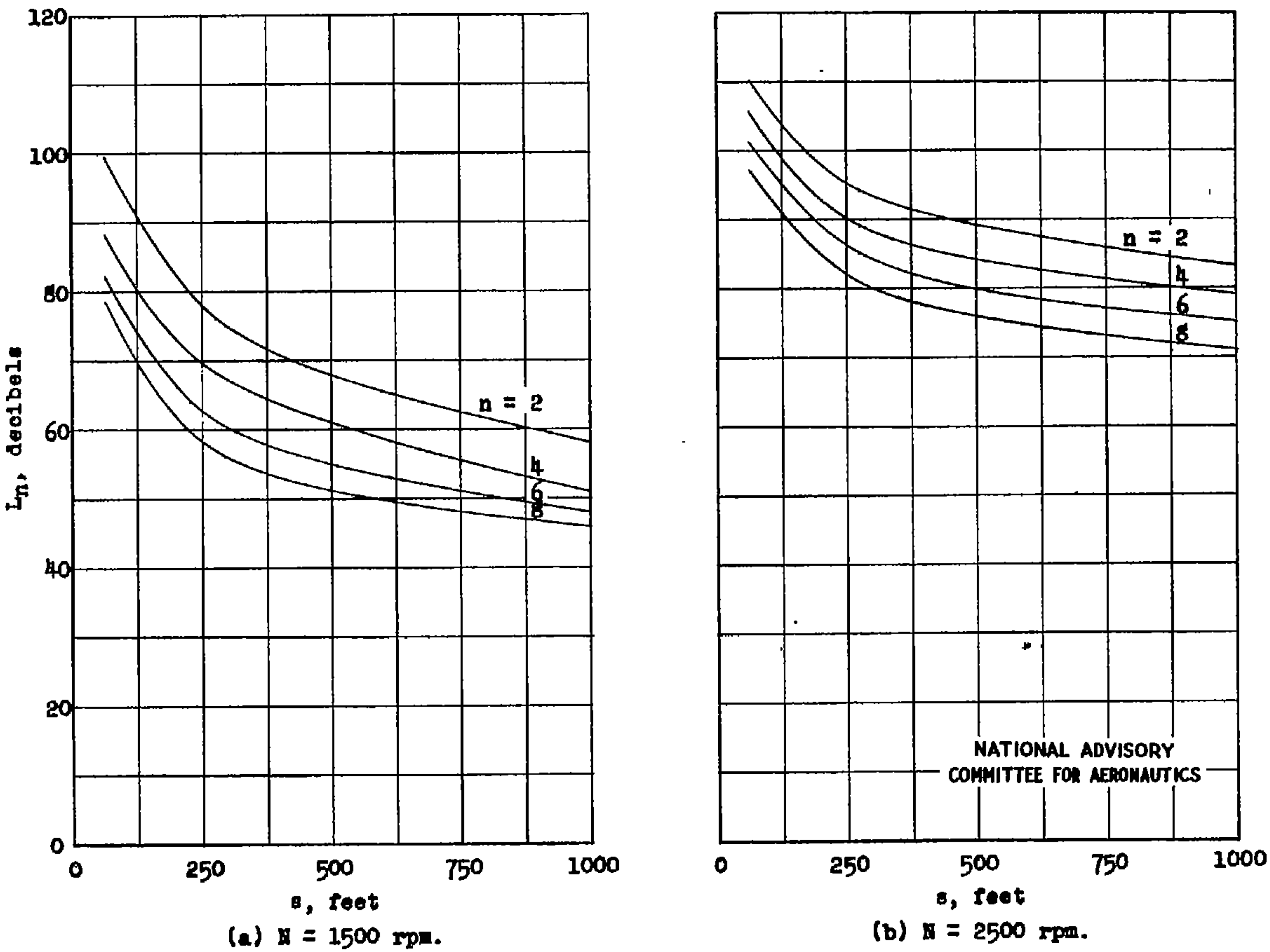


Figure 55.- Effect of distance on propeller loudness. V = 50 miles per hour; P_H = 100 horsepower; D = 6 feet.

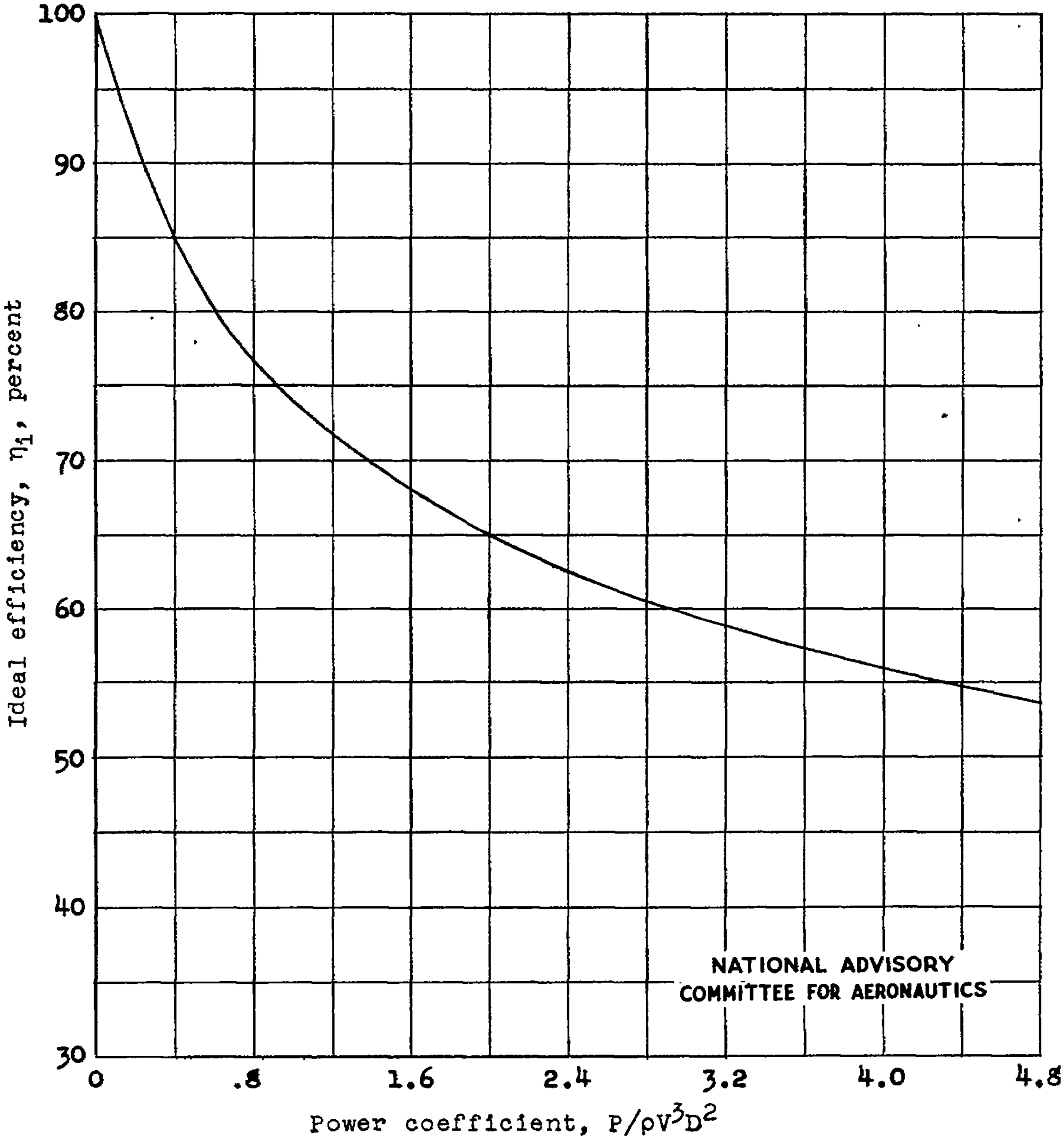


Figure 56.- Ideal efficiency as a function of power coefficient. (From reference 9, fig. 108.)

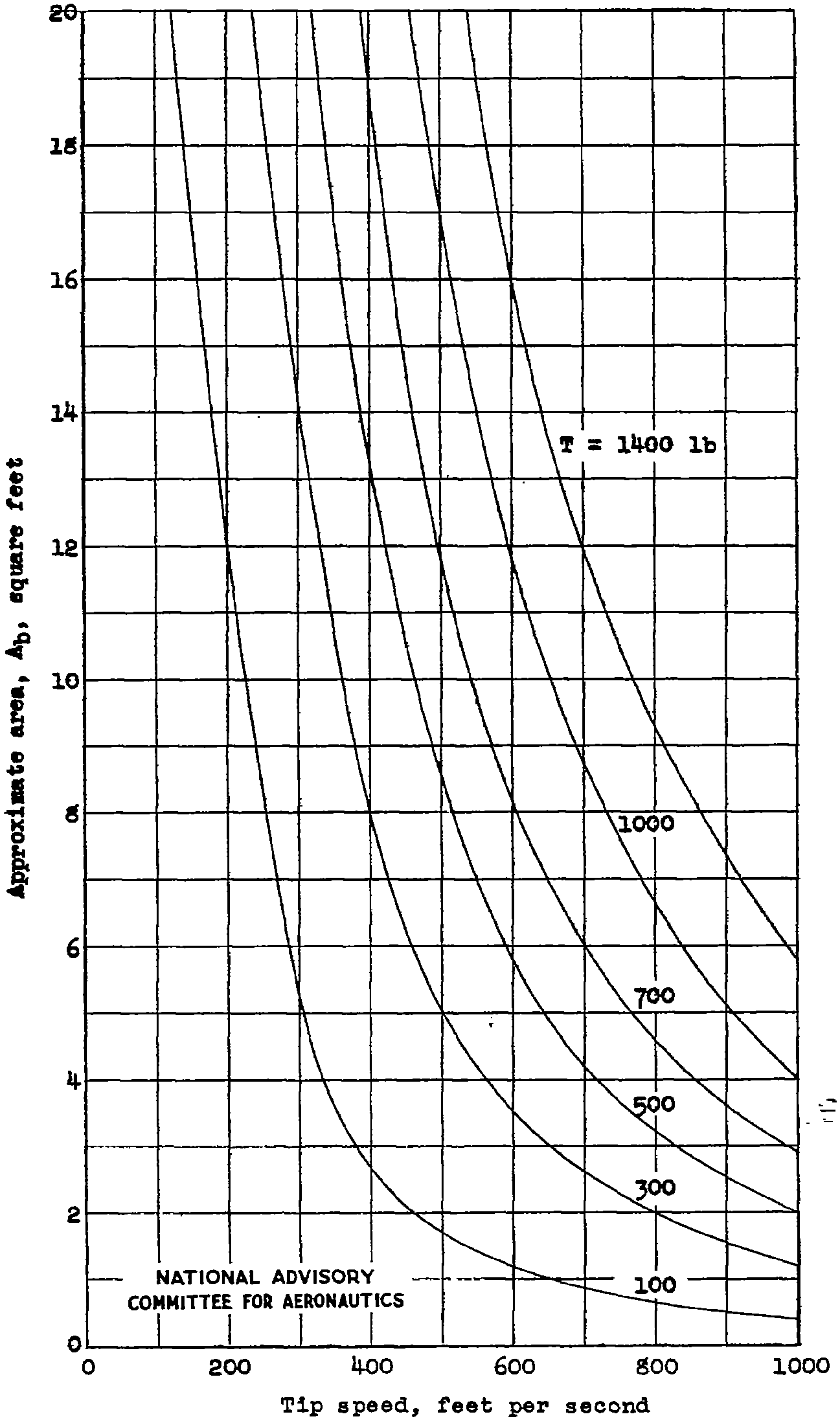


Figure 57.- Approximate blade area as a function of tip speed for various thrust values. $C_L = 0.4$.