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PREDICTION PROCEDURE FOR NEAR-FIELD AND FAR-FIELD PROPELLER NOISE

1. PURPOSE

The high static thrust and relatively low installed engine power for propellers has been a factor in their consideration as propulsors for vertical and short take-off and landing (V/STOL) aircraft. The simplicity and low cost of the propeller has historically been a factor in its selection for the majority of general aviation aircraft. With the increased emphasis on noise generated by all types of aircraft there has been an increasing interest in controlling the noise of new V/STOL and conventional transport aircraft as well as general aviation aircraft. To assist the designer of new aircraft as well as others interested in the noise characteristics of various propeller configurations the procedure described in this Aerospace Information Report (AIR) has been developed.

2. BACKGROUND

Theoretically based as well as empirically based propeller noise prediction methods have been under continuous development since the early days of aviation. The theoretically based procedures require detailed knowledge of the propeller configuration and generally require use of a large computer. The configuration of the propeller, e.g. airfoil family, twist distribution, planform, is generally not available to anyone other than the propeller's manufacturer. The large computer may also not be available to all who would like to make estimates of propeller noise. Therefore, empirically based procedures which make use of all available data to develop generalized curves showing the influence of the most important factors on noise have been developed. The procedure which is described in this AIR has been developed by Hamilton Standard Division of United Technologies Corporation on the basis of available propeller test data. While this method does omit design details which are needed for very accurate predictions using theoretically based procedures, the accuracy of the method, as discussed later, has proved acceptable for preliminary design studies.

3. GENERAL INFORMATION

3.1 The input parameters for propeller noise prediction using the method described later are:

1) Propeller diameter
2) Number of blades per propeller
3) RPM or tip speed
4) Power input per propeller
5) Location, relative to the propeller(s), of the point at which the noise is to be defined
6) Flight speed
7) Ambient temperature
8) Number of propellers

3.2 In general the prediction of far-field noise consists of determining a series of partial levels and correction factors which are a function of configuration and operating parameters of the propeller. These are summed arithmetically to make a propeller noise prediction.

3.3 In developing the prediction curves, available propeller noise test data was used. This included data from electrically driven static test stands as well as piston engine and turboshaft installations under static and flight conditions. The user of the prediction method may assume that engine noise is included for designs where tip speeds exceed 700 ft/sec (213 m/sec) since propeller noise generally dominates engine noise at high tip speeds. For lower tip speed propeller designs the engine manufacturer should be consulted to establish the contribution of the engine to the propulsion system noise.

4. FAR-FIELD NOISE

4.1 Application of the method for propellers ranging from the smaller general aviation types to the larger commercial transport types show that the estimated peak perceived noise levels are generally within about 3 PNdB of the measured levels. The scatter in the predictions is due to measurement errors, as well as lack of precision in the prediction procedure. In addition, it has been found that a propeller having a good aerodynamic design (efficiency) will tend to be at the bottom edge of the scatter band. A poor aerodynamic design will tend to produce levels at the top edge of the scatter band.

4.2 The question of the influence of ground reflection on propeller noise is not specifically addressed in and is considered beyond the scope of this prediction method. In tests where both the microphone and propeller are mounted above a hard surface it is possible to obtain perfect reinforcement of direct and reflected propeller tone noise. Under these conditions, if the tones dominate a perceived noise calculation, this prediction method may give levels which deviate from test by more than 3PNdB. However, experience indicates that the estimates obtained from this procedure are typical of noise levels at ear height for an observer standing on short grassy terrain.

4.3 Recent work has shown that there is a difference between propeller noise measured statically and that measured in flight on an aircraft. At take-off and landing speeds the forward flight effect on propeller noise tends to reduce noise generation while the installation of a propeller on a nacelle in close proximity to the wing may increase noise generation. These effects are quite complex and therefore have not been included in the prediction procedure. Fortunately, the two effects tend to cancel each other in the data available. Further definitive data may allow introduction of these effects in a revised procedure at some future date. Until such a revision, it may be assumed that the procedure predicts levels more consistent with forward flight measurements than with static measurements.

4.4 Users of this procedure who are more familiar with turbojet or turbofan noise may be surprised to find that large low tip speed propellers have a PNL less than the overall level. This is due to the dominance of low frequency noise in propellers which is weighted less than the dominant high frequency noise of turbojets and turbofans. Only limited evaluation of the available flight test data has been used to establish the correction from PNL to dBA.

5. PREDICTION OF FAR-FIELD PROPELLER NOISE

The steps in estimating the far-field noise generated by a propeller are the following:

1) Determine the rotational tip Mach number by calculation or from Fig. 1 and 2.

2) Obtain FL1 from Fig. 3. This is a partial level based on the power input to the propeller and its rotational tip speed.

3) Obtain FL2 from Fig. 4. This is an adjustment for diameter and number of blades.

4) Obtain FL3, from Fig. 5. This adjustment accounts for atmospheric absorption and spherical spreading of the sound to the location of interest.

5) Obtain the correction (DI) for the directivity pattern from Fig. 6, where 0 degrees is on the propeller axis in the forward direction. (Note: The pattern is symmetrical about the propeller axis, thus the directivity index for 260 degrees is the same as that for 100 degrees).

5. Continued

6) Apply the following corrections, NC, for number of propellers:

1 propeller add 0
2 propellers add 3
4 propellers add 6

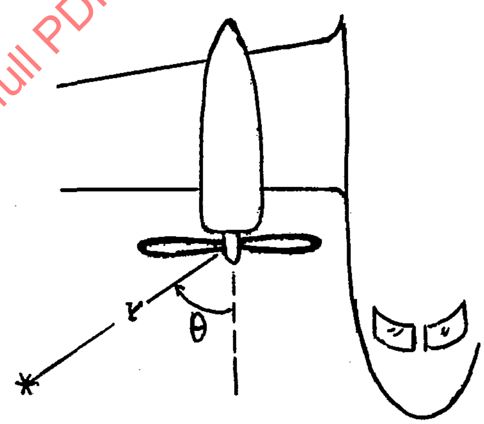
7) The overall sound pressure level is the sum of the data from steps 2 through 6.

8) The Perceived Noise Level (PNL) may be obtained from Fig. 7 for two bladed propellers, Fig. 8 for three bladed propellers, Fig. 9 for four bladed propellers, or Fig. 10 for six and eight bladed propellers. The Helical Tip Mach Number (the vector sum of the Aircraft Forward Speed and the Rotational Tip Speed) needed to enter Fig. 7 through 10 are found by use of Fig. 11 and 2. To calculate A-weighted sound pressure level in dBA subtract 14 dB from the PNL. If EPNdB is desired, subtract 4 dB from PNL for a take-off case of 2 dB from PNL for an approach case.

6. SAMPLE CALCULATION OF FAR-FIELD NOISE

To assist those using the method of section 5 the following sample calculation is provided:

Diameter	13.5 ft (4.11 m)
Number of blades	4
Power	3260 SHP (2431 KW)
RPM	1020
Distance (r)	584 ft (178 m)
Azimuth (θ)	105°
Aircraft Speed	180 kts
Temperature	86°F (30°C)
Number of Propellers	4



Step 1. From Fig. 1 — tip speed = 720 ft/sec (219 m/sec)
From Fig. 2 — tip Mach number = 0.64

Step 2. From Fig. 3 — FL1 = 96 dB

Step 3. From Fig. 4 — FL2 = -2

Step 4. From Fig. 5 — FL3 = -1

Step 5. From Fig. 6 — DI = +0.5

Step 6. For four propellers — NC = +6

Step 7. Overall sound pressure level $(FL_1 + FL_2 + FL_3 + DI + NC) = 99.5$ dB

Step 8. From Fig. 11 and 2 the Helical Tip Mach Number is found to be 0.69 for a tip speed of 720 ft/sec (219 ft/sec), a forward speed of 180 knots and a temperature of 86°F (30°C). From Fig. 9, the correction for PNL = +1 thus the PNL - 99.5 + 1 = 100.5 PNdB, the A-weighted level = 100.5 -14 = 86.5 dBA.

7. NEAR-FIELD NOISE

7.1 Near-field noise is of interest in determining the noise level at the surface of a fuselage located near a propeller. This information is needed to assess acoustic fatigue potential and to design a fuselage wall structure to minimize aircraft interior noise.

7.2 The propeller near-field is generally restricted to those points which are one propeller diameter or less from the propeller blade tips. At greater distance the far-field prediction procedure should be used.

8. PREDICTION OF NEAR-FIELD NOISE

The steps in determining near-field propeller noise levels (usually on the fuselage) are as follows:

1) Determine the rotational tip Mach number by calculation or from Fig. 1 and 2.

2) Obtain NL1 from Fig. 12. This gives a partial level based on the power absorbed by the propeller and its diameter.

3) Obtain the number of blades correction, BC, from the table below:

for B = 2	add 6
3	2.5
4	0
6	-3.5
8	-6

4) Obtain NL2 from Fig. 13. This is an adjustment for tip speed and distance in the plane of rotation.

5) Obtain the location correction XC, for fore and aft distance from Fig. 14.

6) Obtain the reflection correction, RC, for the effect of a reflecting surface (fuselage) in the sound field from Fig. 15.

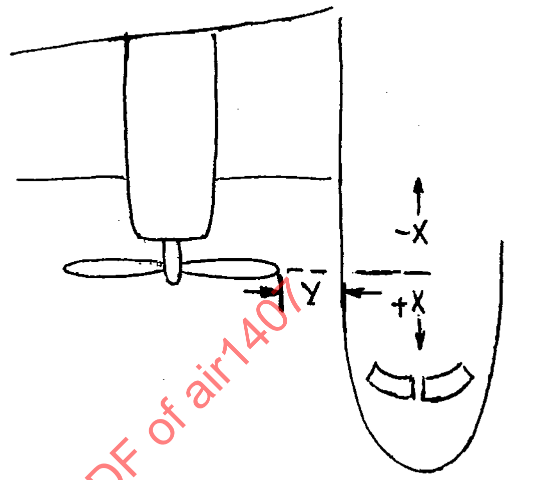
7) The overall sound pressure level is the sum of the levels obtained in steps 2 through 6.

8) The near-field harmonic distribution of the noise estimated in step 7 is found from Fig. 16 using Fig. 11 and 2 to determine the Helical Tip Mach Number with forward speed.

9. SAMPLE CALCULATION OF NEAR-FIELD NOISE

To assist those using the method of Section 8 the following sample calculation is provided:

Diameter	9 ft (2.74 m)
Number of blades	3
Power	300 SHP (224 KW)
RPM	1584
Radial distance (Y)	1.25 ft (0.381 m)
Fore/aft distance (X)	0
Aircraft speed	125 kts
Temperature	60°F (15.6°C)



Step 1.	From Fig. 1	tip speed = 750 ft/sec (229 m/sec)
	From Fig. 2	tip Mach number = 0.67
Step 2.	From Fig. 12	NL1 = 130 dB
Step 3.	Number blades correction	BC = +2.5
Step 4.	Y/D = 1.25/9 = .139, thus from Fig. 13	NL2 = -0.5
Step 5.	X/D = 0, thus from Fig. 14	XC = 0
Step 6.	The aircraft fuselage cross section is circular, thus from Fig. 15	RC = +4
Step 7.	Overall Sound Pressure Level (NL1 + BC + NL2 + XC + RC)	= 136 dB

Step 8. Determine the helical Mach number using Fig. 11 and Fig. 2. For a tip speed of 750 ft/sec (229 m/sec) a forward speed of 125 knots and a temperature of 60°F (15.6°C) the Helical Tip Speed is 780 ft/sec (238 m/sec), and the Helical Tip Mach Number is 0.7. The harmonic levels can then be found in Fig. 16.

PREPARED BY

SAE COMMITTEE A-21, AIRCRAFT NOISE MEASUREMENT

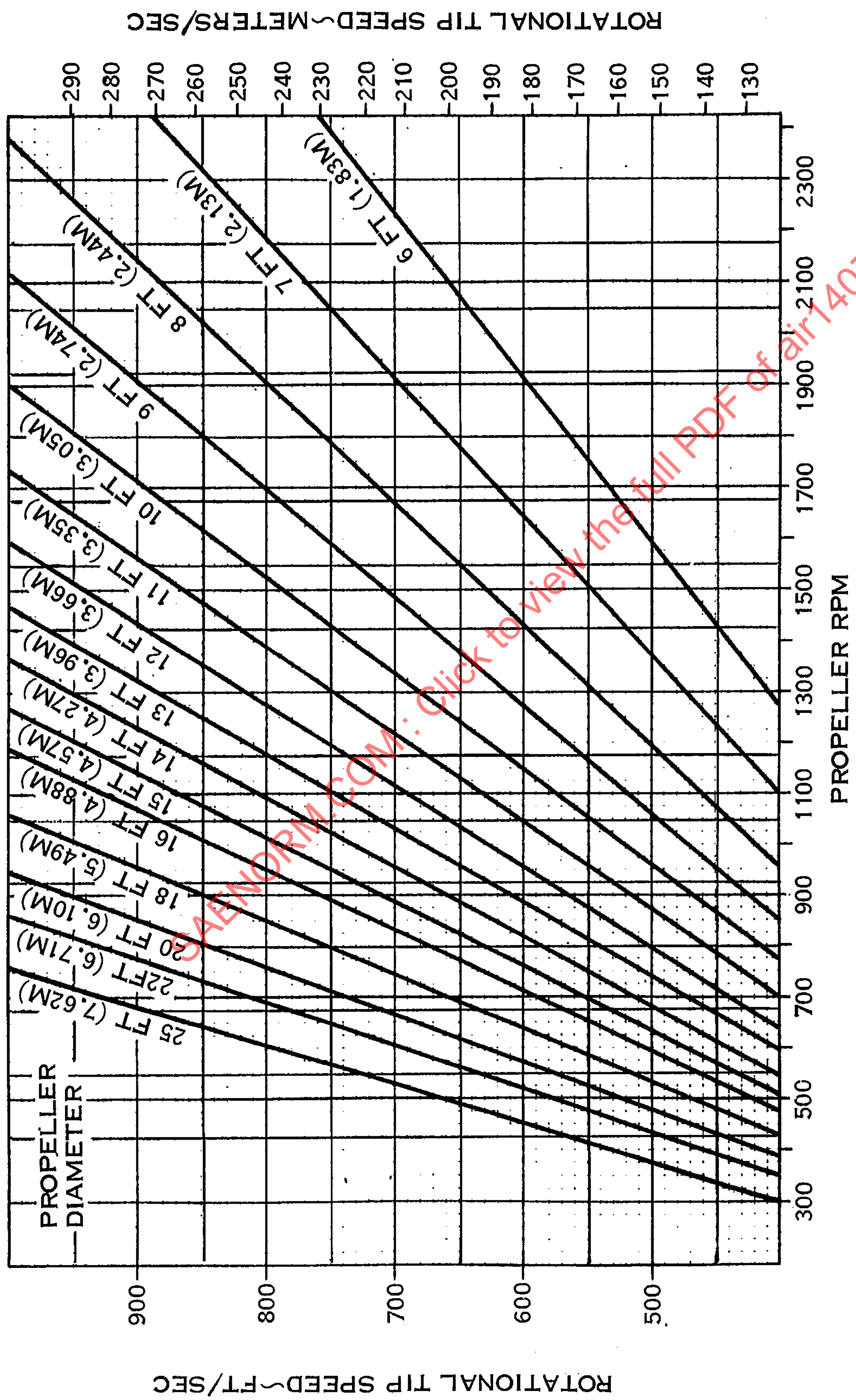


FIGURE 1 RPM TO TIP SPEED CONVERSION

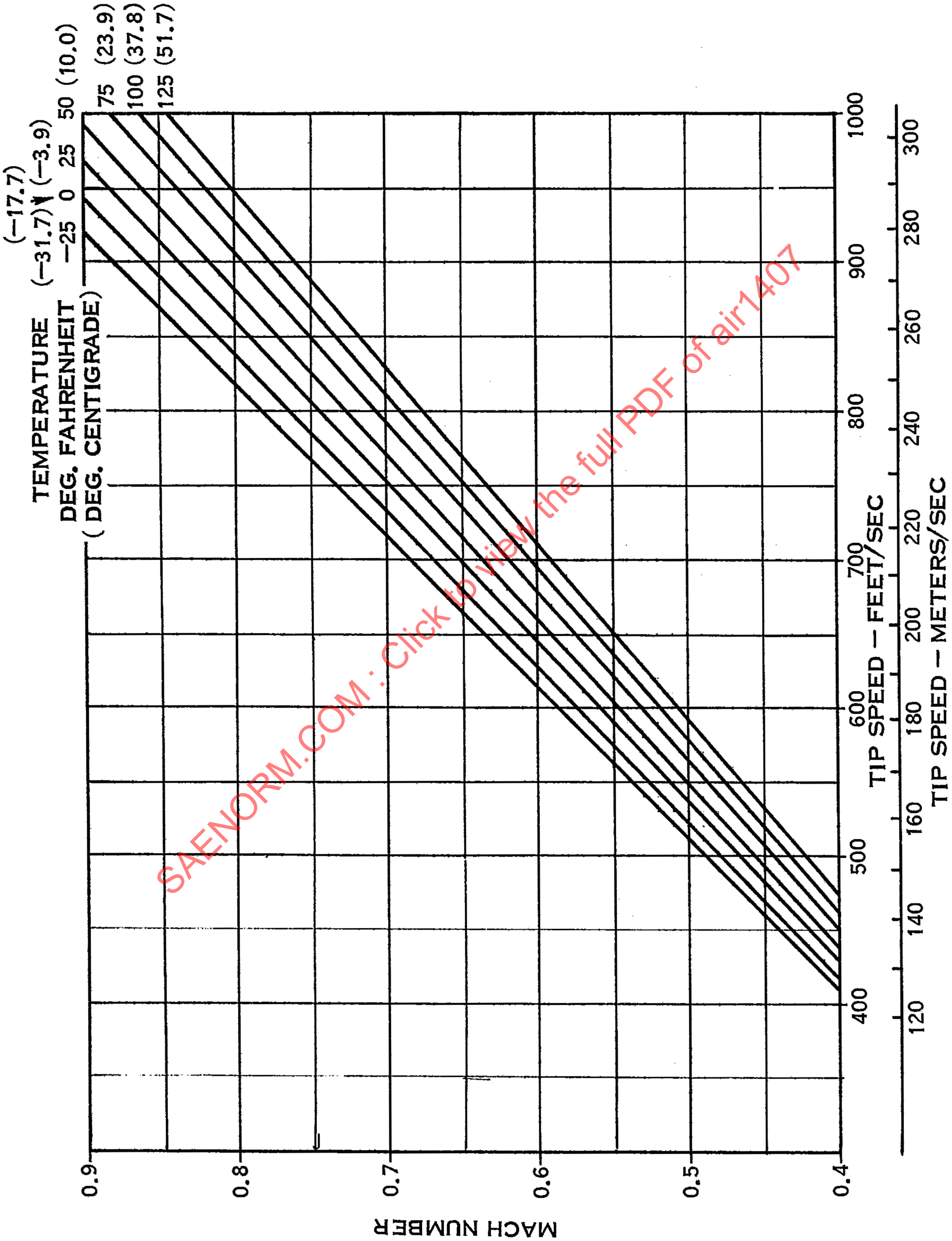


FIGURE 2 PROPELLER TIP MACH NUMBER

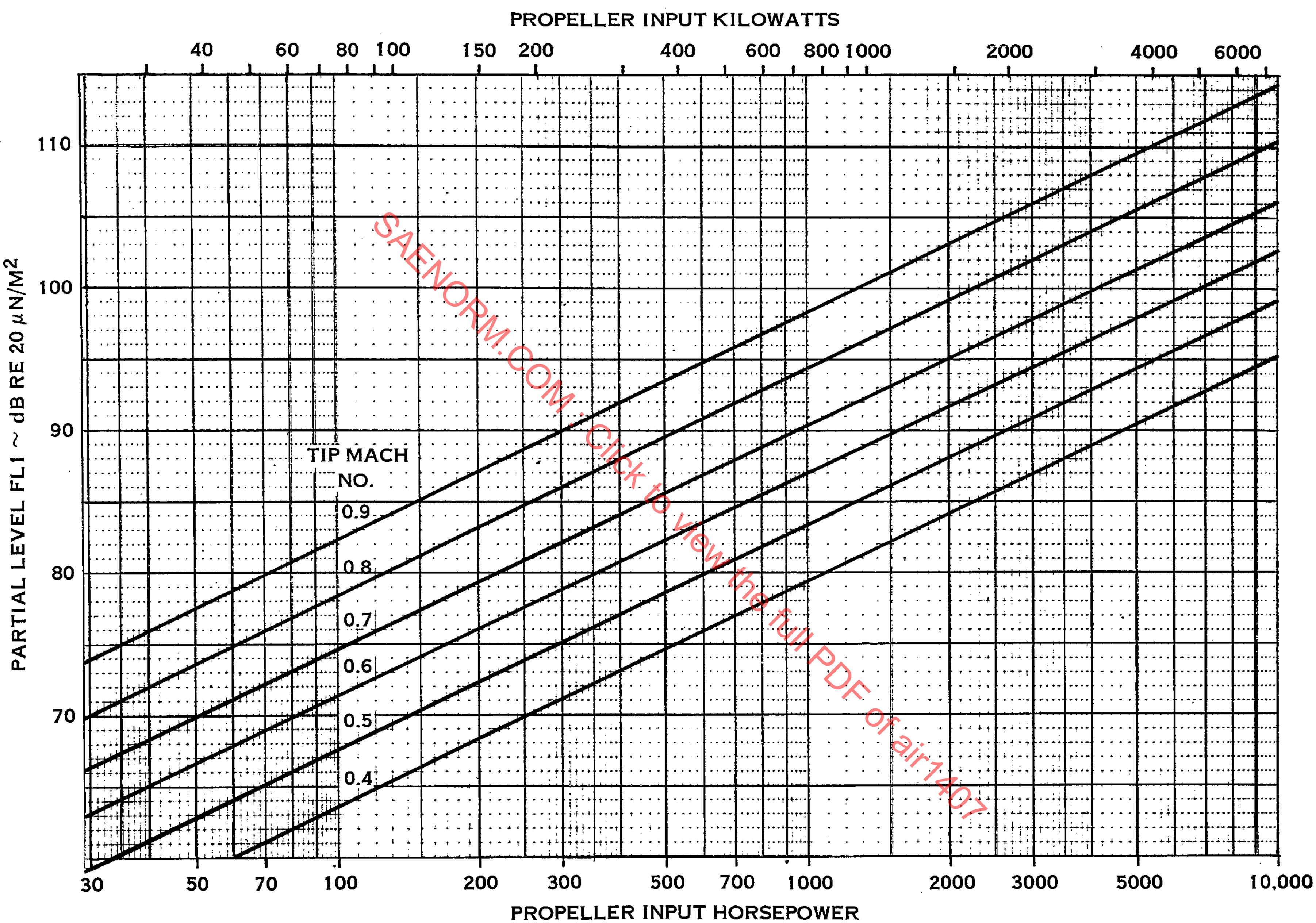


FIGURE 3. FAR FIELD PARTIAL LEVEL BASED ON POWER AND TIP SPEED

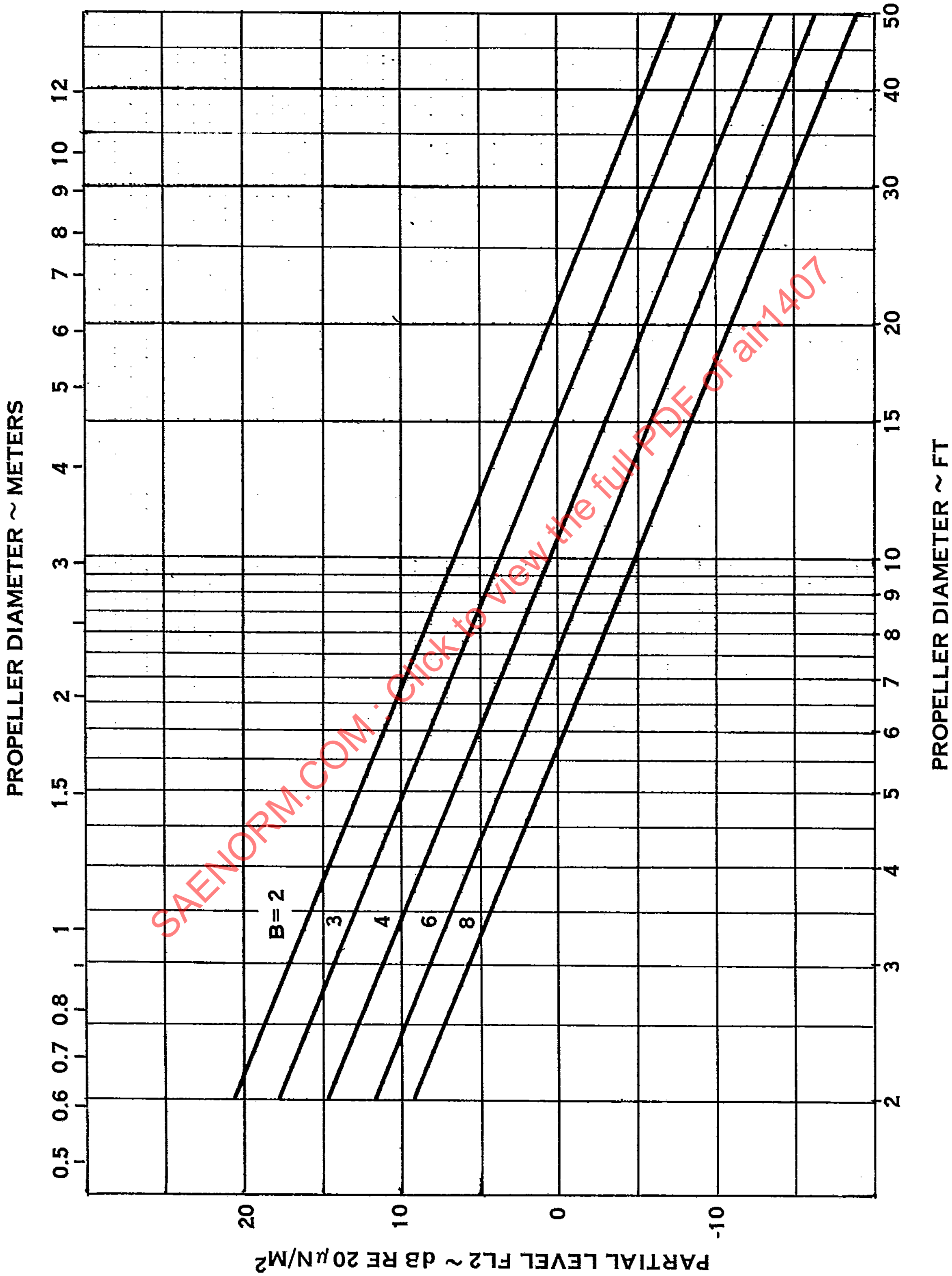


FIGURE 4. FAR FIELD PARTIAL NOISE LEVEL BASED ON BLADE COUNT AND PROPELLER DIAMETER

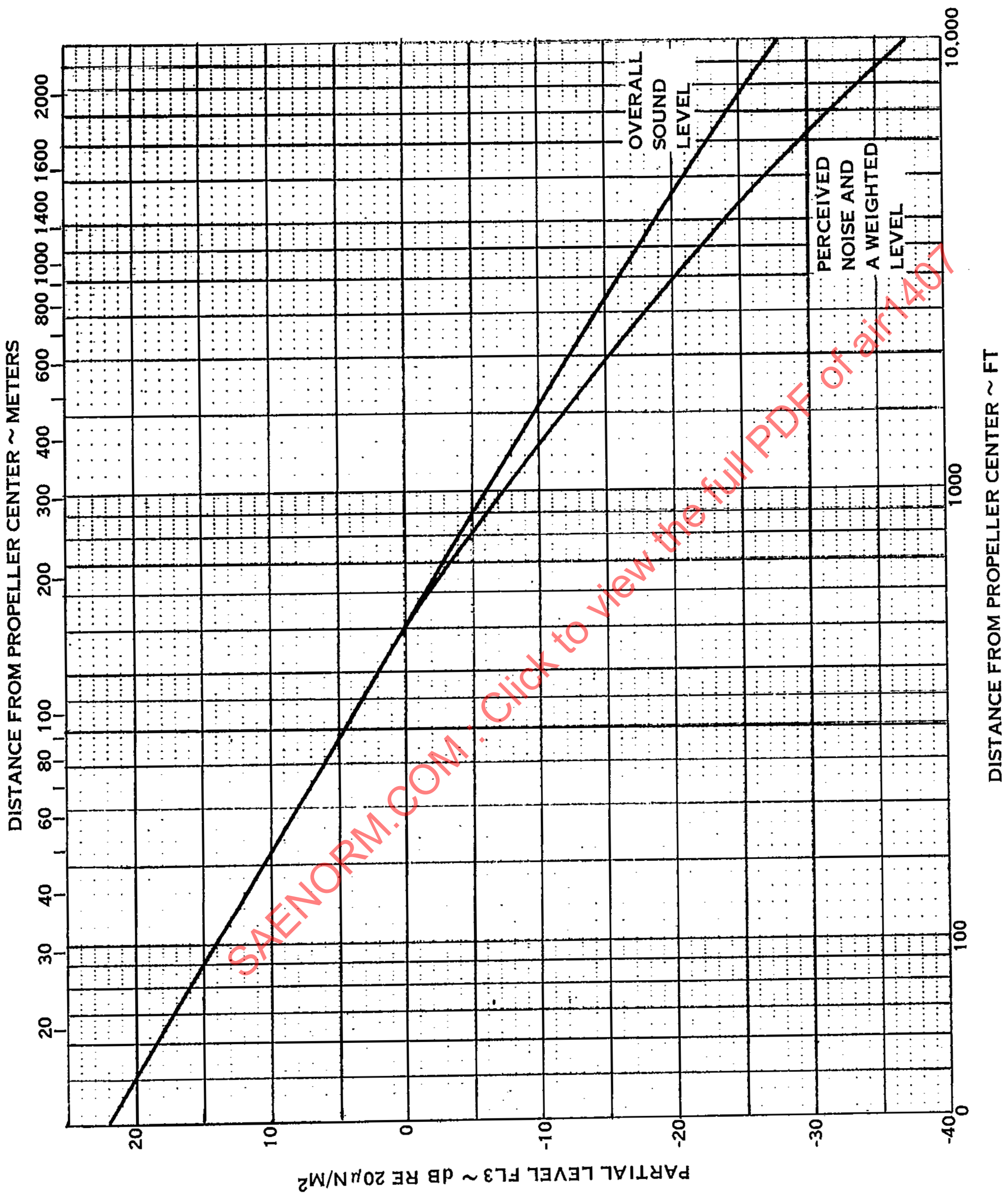


FIGURE 5. ATMOSPHERIC ABSORPTION AND SPHERICAL SPREADING OF SOUND

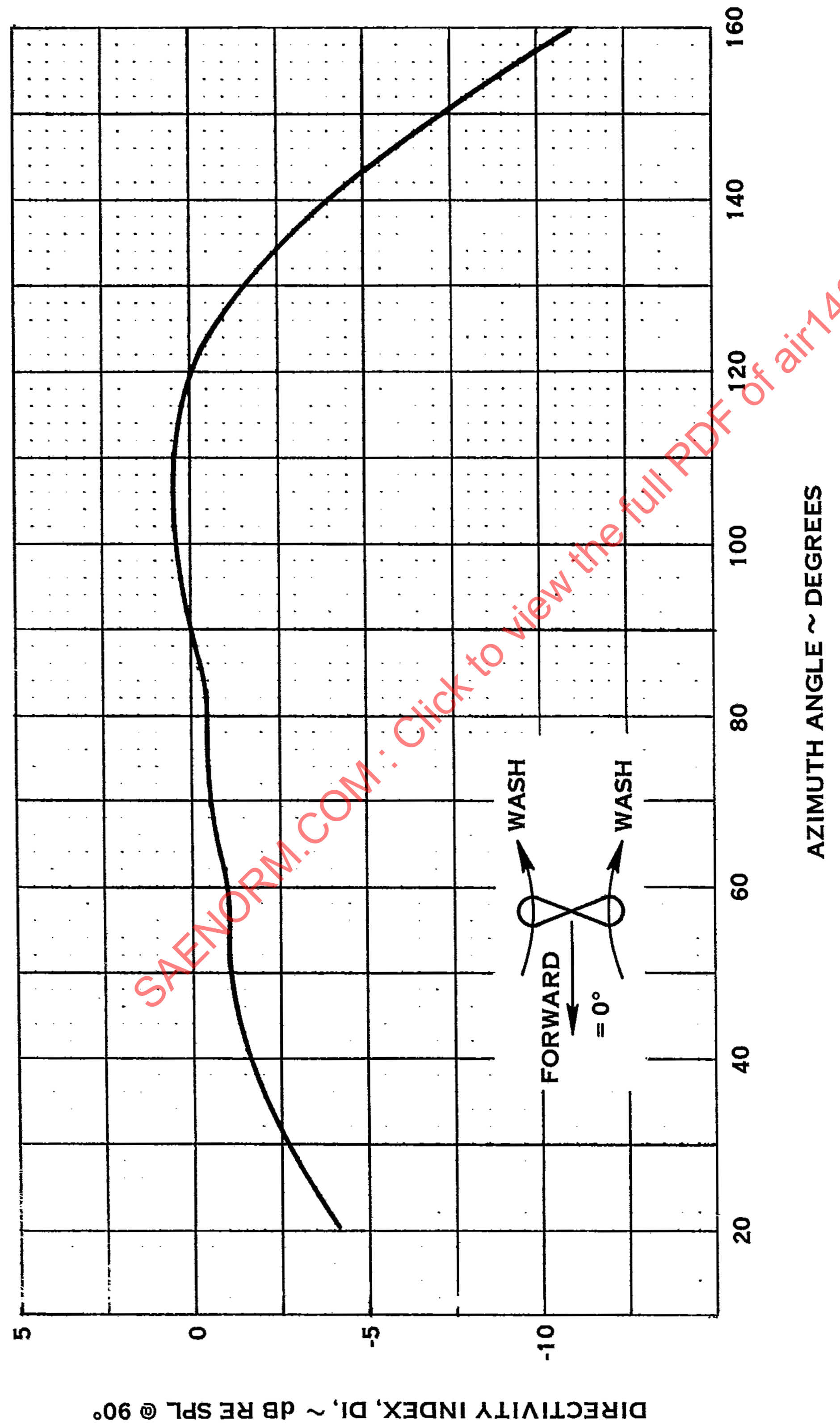


FIGURE 6. DIRECTIVITY INDEX

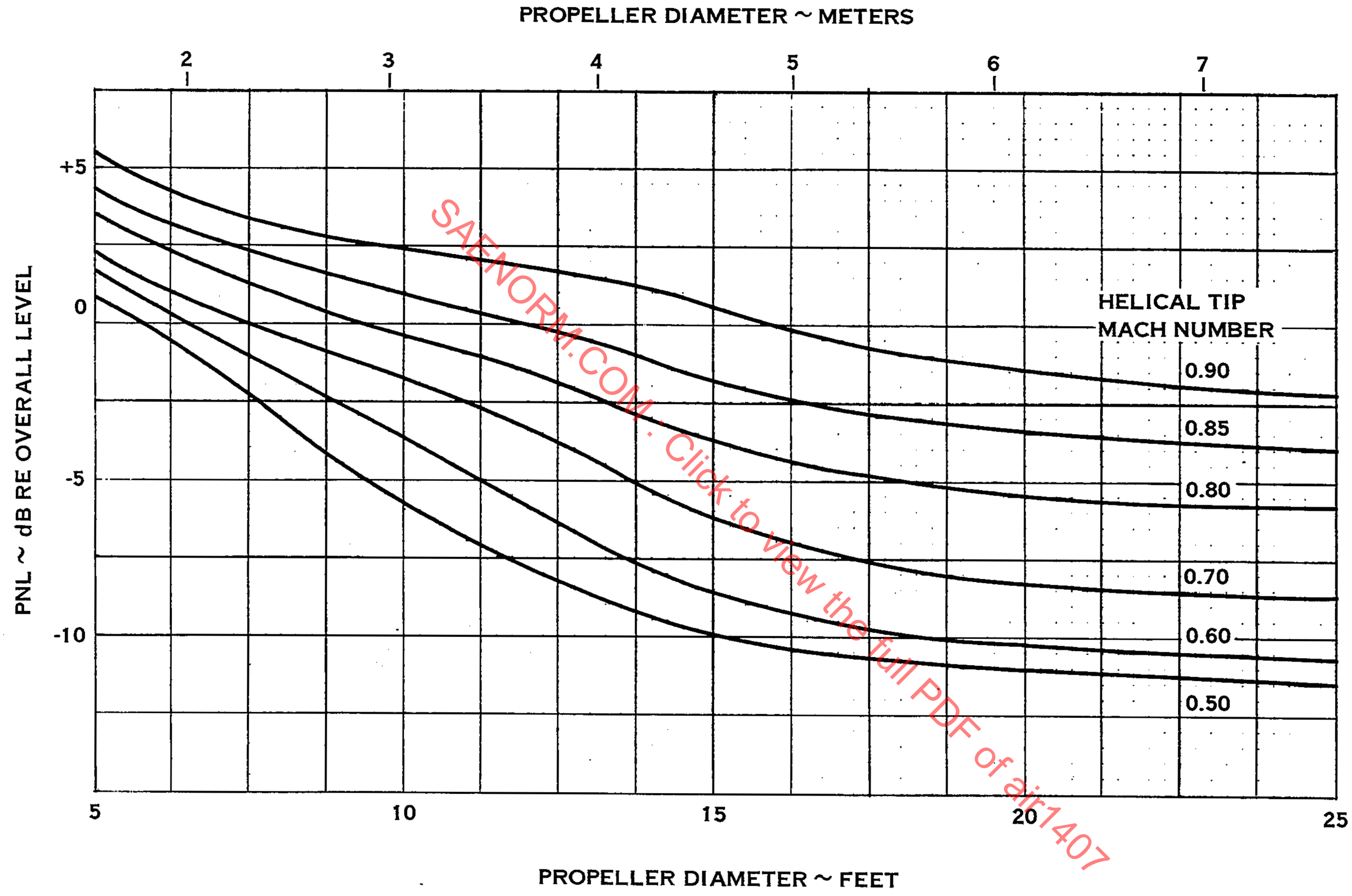


FIGURE 7. PERCEIVED NOISE LEVEL ADJUSTMENT - 2 BLADED PROPELLERS

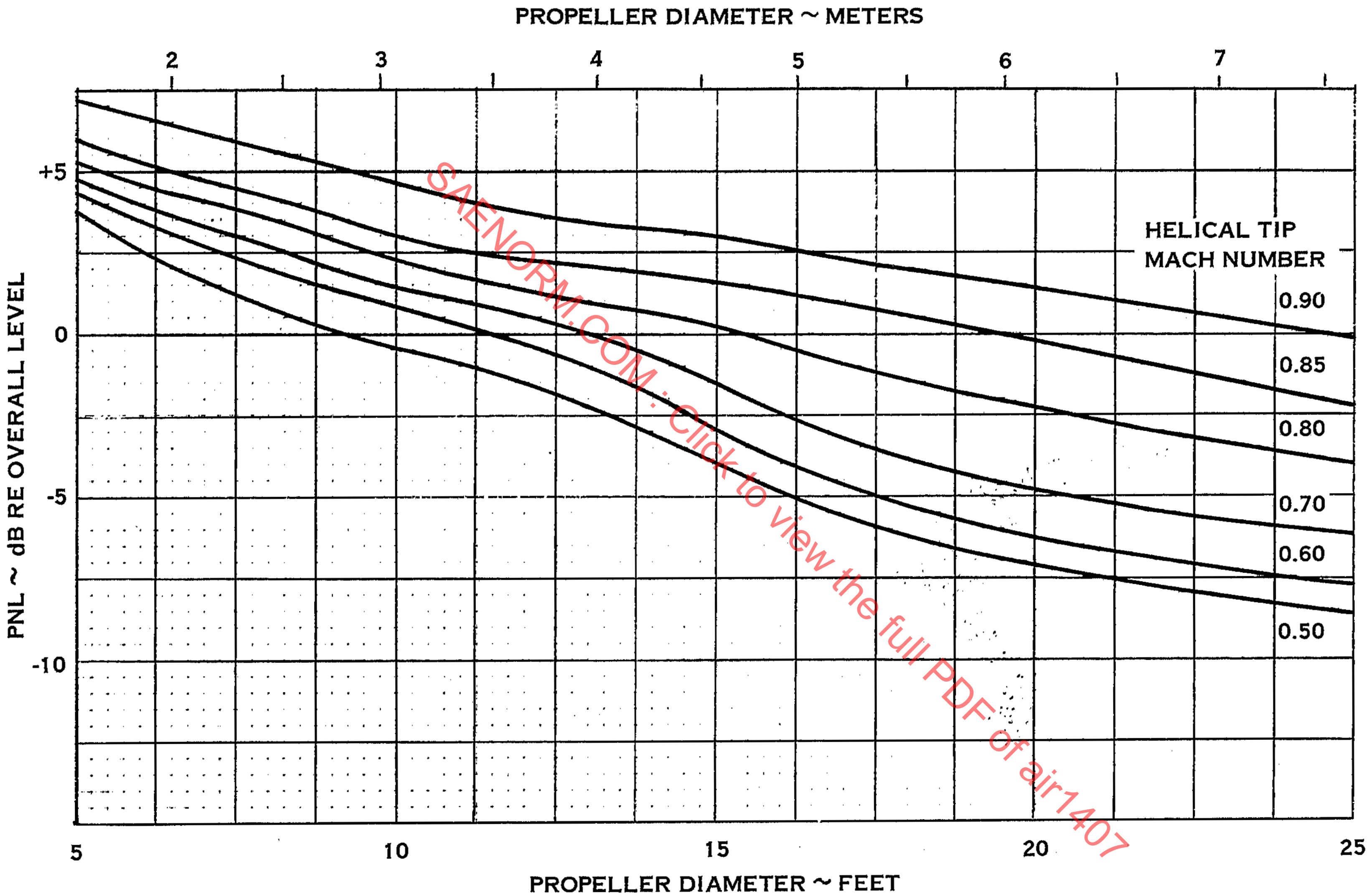


FIGURE 8. PERCEIVED NOISE LEVEL ADJUSTMENT - 3 BLADED PROPELLERS

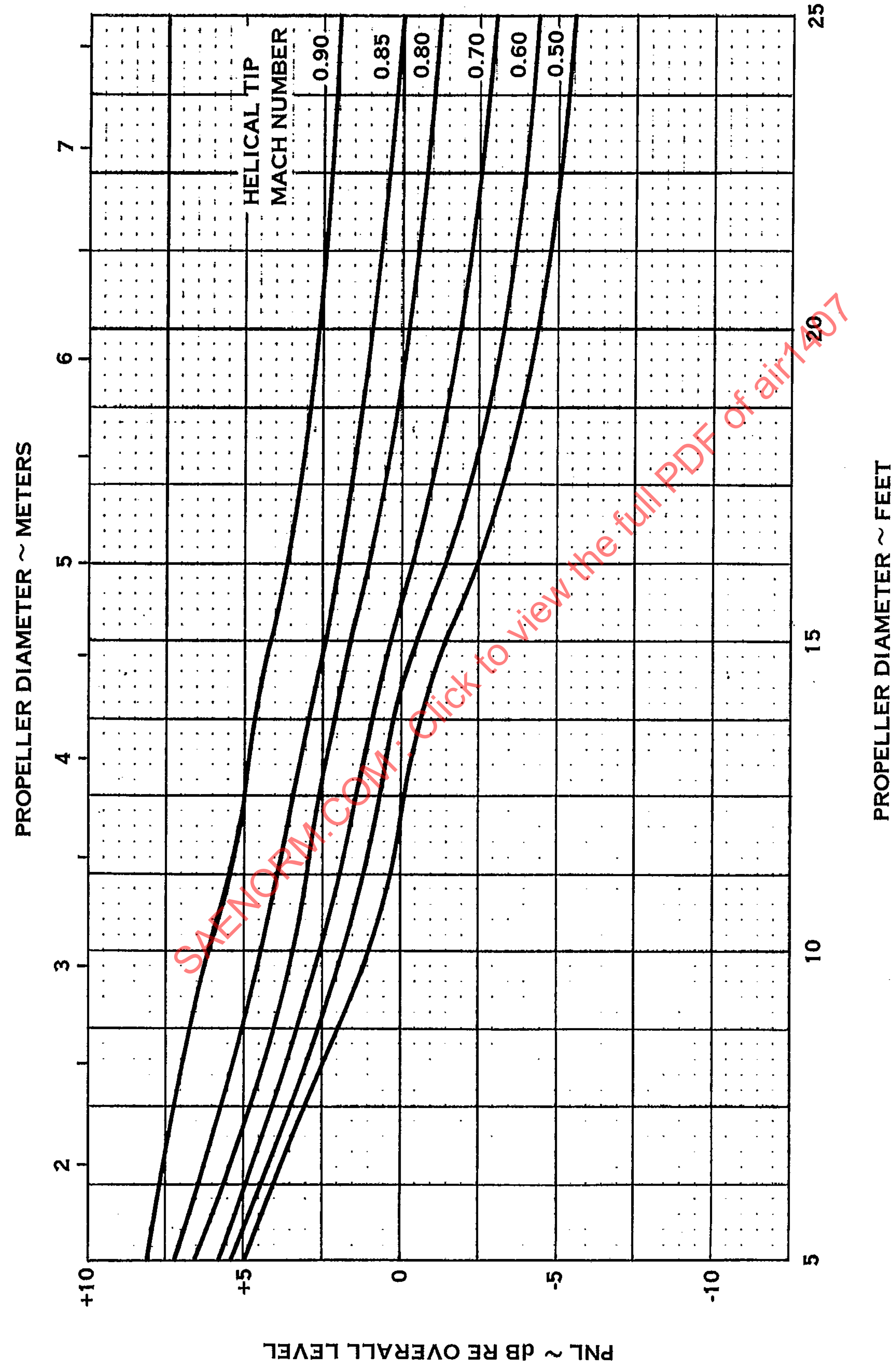


FIGURE 9. PERCEIVED NOISE LEVEL ADJUSTMENT - 4 BLADED PROPELLERS

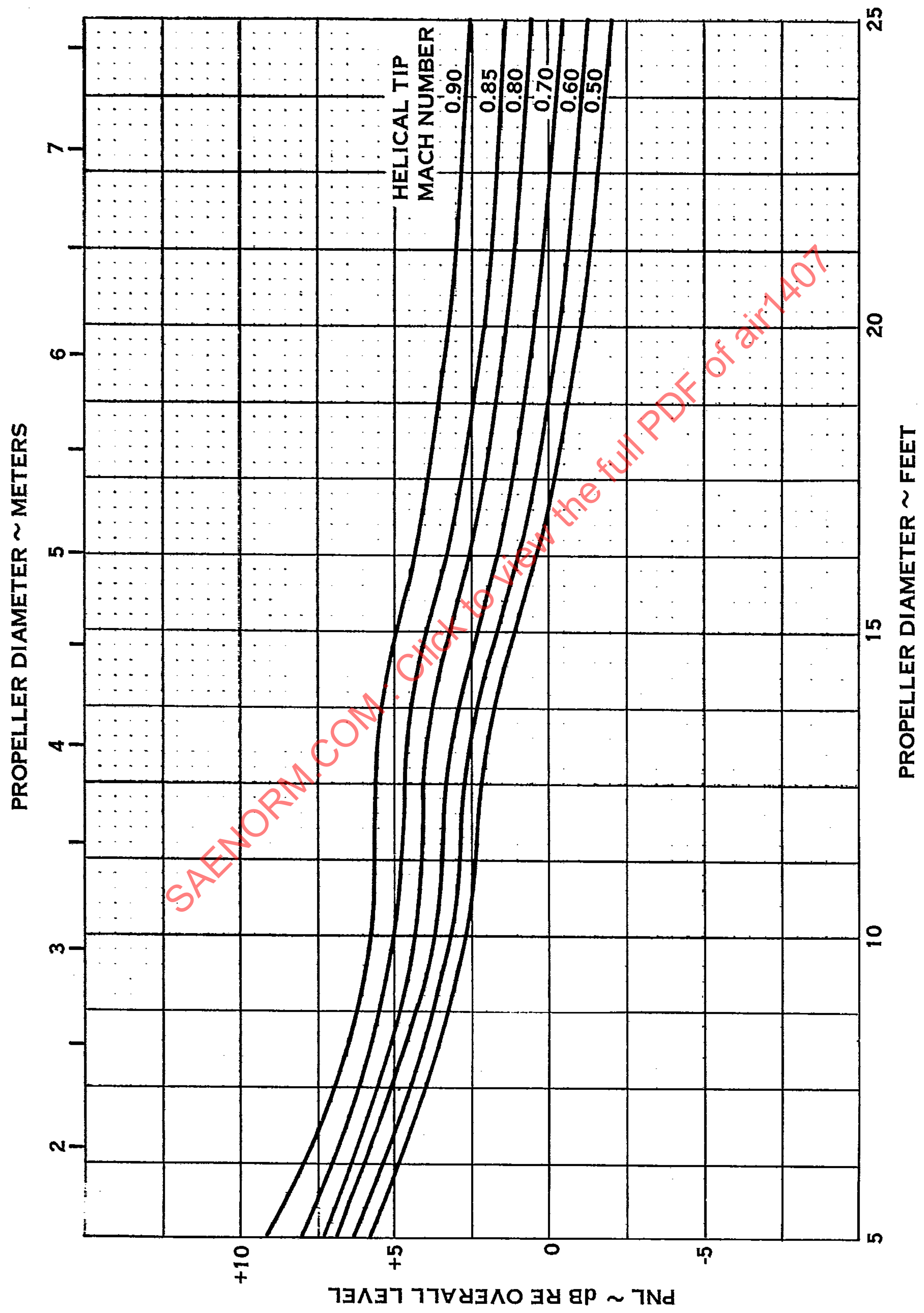


FIGURE 10. PERCEIVED NOISE LEVEL ADJUSTMENT~6 AND 8 BLADED PROPELLERS

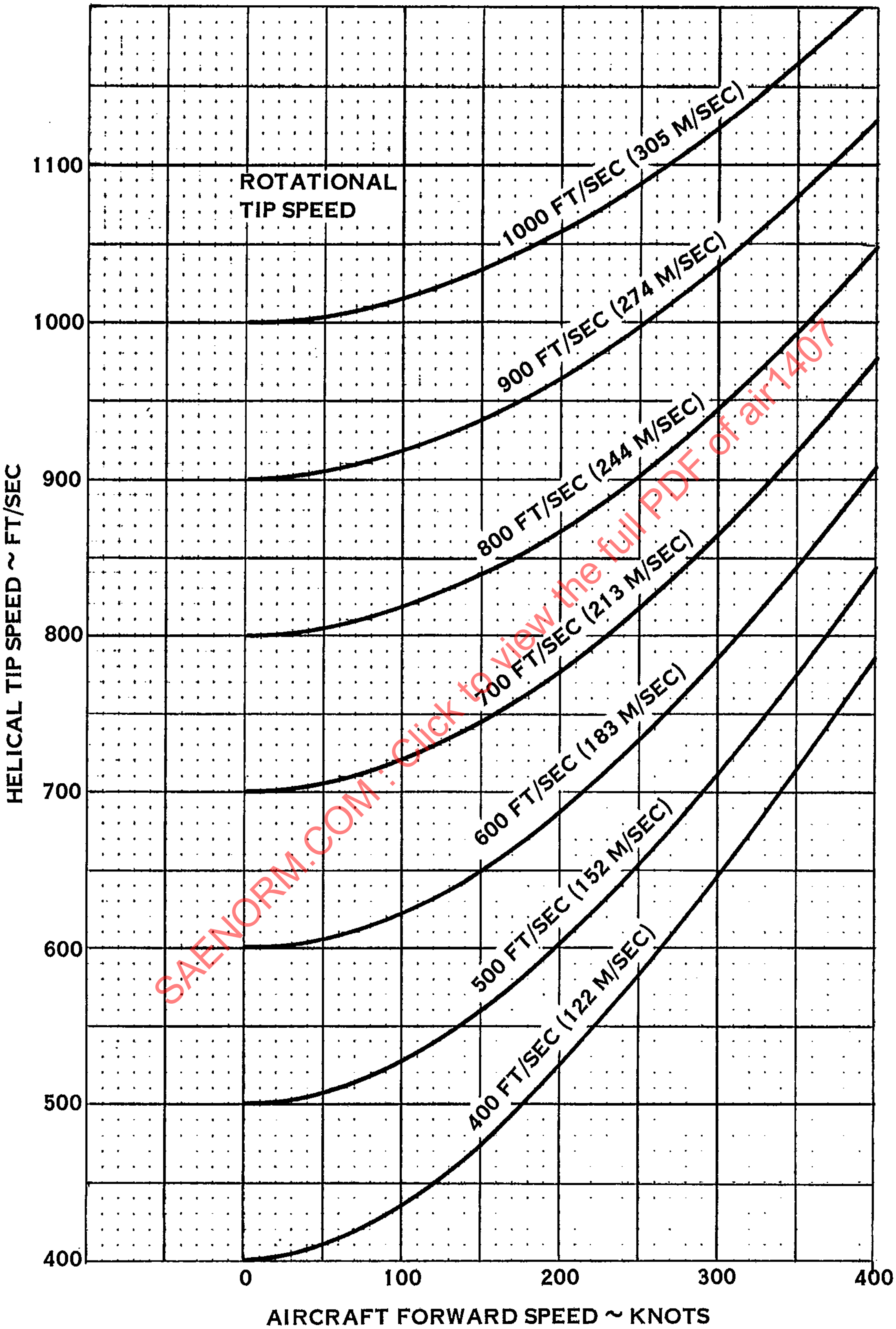


FIGURE 11. PROPELLER HELICAL TIP SPEED