SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE INFORMATION REPORT

SAE AIR1989 REV. A

Issued 1989-05-15
Revised 1992-12-18

Submitted for recognition as an American National Standard

HELICOPTER EXTERNAL NOISE ESTIMATION

1. SCOPE:

This method estimates noise for both single and tandem main rotor helicopters except for approach where it applies to single rotor designs only. It does not apply to coaxial rotor designs. Due to lack of available data, application of the method has not been evaluated for application to tiltrotor, or other VTOL configurations, when operating in the helicopter mode. Since there are substantial differences between helicopter rotors included in the data base, and tiltrotor rotors, application to VTOL configurations other than helicopters is not advised. Application is limited to helicopters powered by turboshaft engines and does not apply to helicopters powered by reciprocating engine, tip jets or other types of power plants. It provides noise information using basic operating and geometric information available in the open literature. To keep the method simple, it generates A-weighted sound levels, and Sound Exposure Levels precluding the necessity for spectral details. The method prescribes estimates for typical helicopter operations; certain maneuvers may produce noise levels different from those estimated. Estimates are given for the maximum sound levels at 1.2 m (4 ft) height above the ground. For aircraft in forward flight, the estimate is given for an aircraft at an altitude of 152 m (500 ft) on a path directly over the observer. For an aircraft in hover the estimate is given for an aircraft hovering 3.3 m (10 ft) above ground level at a distance of 152 m (500 ft) to the side of the observer. No estimate is provided for Sound Exposure Level in hover since the time duration is indeterminate.

1.1 Purpose:

This document provides a simple empirical means of estimating helicopter noise for environmental assessment in community planning. This method is intended for use only where noise data for the actual helicopter model(s) to be used are unavailable or where the makeup of the planned helicopter population is not known aside from size and general characteristics. This method should be restricted to helicopters whose design characteristics lie within the range of helicopters which comprised the data base as defined in Section 6.

2. REFERENCES:

Reference A: Handbook of Noise Metrics, Bennett, R.L. and Pearsons, K.S., NASA Contractor Report 3406 March 1981.

Reference B: Acoustics - Description and Measurement of Environmental Noise - Part 1: Basic Quantities and Procedures International Standard ISO 1996/1-1982. International Organization for Standardization (1982).

3. GENERAL BACKGROUND:

As the use of helicopters increases, so does the need for helistops and heliports. Thus, communities will be considering provisions for these helicopter facilities in developing their land use plans. One aspect of such planning requires forecasts of potential noise exposure before helicopter type specific data become available. Such forecasts can also be used to estimate noise for known models. Therefore, a need exists for a noise estimation capability which is not dependent on detailed helicopter design information. The procedure described in this AIR is based on one which was developed by Sikorsky Aircraft Division of United Technologies, Inc. and utilizes data developed jointly by industry and the government. The data used to validate the method were provided by several other manufacturers and sources.

3.1 Nomenclature:

C_1, C_2, C_3, C_4 = Constants in the regression equations

D = Distance in meters

L_{AE} = Sound Exposure Level - dB

L_{AMAX} = Maximum A-weighted Sound Level (dBA) for the conditions and distances for each flight condition as described in 5.1.2 thru 5.1.5

M_T = Rotational Tip Mach Number which can be determined by using Figure 1

M_F = Forward Flight Mach Number which can be determined by using Figure 2

P = Independent parameter used in regression equation to describe helicopter characteristics. Defined in 3.2

R = Rotor radius in meters

W = Helicopter gross weight in kilograms

π = 3.14

3.2 Selection of the Independent Parameter:

The independent parameter was selected based on examination of mathematical correlation with measured data; intuitively, it includes the most important design variable as follows:

Main rotor disk load $\frac{W}{\pi R^2}$ is the obvious initial parameter because a more lightly loaded rotor will generate less noise than a heavily loaded one. In general, disk loading varies from about 15 kg/m² (3 psf) for small helicopters up to about 50 kg/m² (10 psf) for large ones.

The term R nondimensionalizes the prediction distance, 152 m (500 ft), to the number of rotor radii.

The Mach number function, $\frac{M_T}{1 - (M_T + M_F)}$, reflects the importance of tip speed on rotor noise and provides a rapid growth in predicted level as the advancing tip Mach number $(M_T + M_F)$ approaches 1.0. Mach number is the ratio of the actual speed to the speed of sound.

Although the term $\frac{M_T}{1 - (M_T + M_F)}$ obviously has divergent singularity at the value $(M_T + M_F) = 1$, this condition is not encountered in actual helicopter design due to the rapid buildup in noise, vibration, and loads which are encountered. See Section 6 on Accuracy and Limitations.

These design variables combine to give the following parameter:

$$P = \left(\frac{W}{\pi R^2}\right)\left(\frac{R}{152}\right)\left(\frac{M_T}{1 - (M_T + M_F)}\right) \quad \text{(Eq.1)}$$

4. SOUND LEVEL MEASURES:

Maximum A-Weighted Sound Levels and Sound Exposure Level provide noise estimates in units most common to community noise evaluation.

5. CALCULATION PROCEDURE:

5.1 A Weighted Sound Pressure Level:

5.1.1 General Procedures: The procedure is based on the fit of data to $\log_{10}$ (P). The resulting regression equations are of the form:

$$L_{AMAX} = C_1 + C_2 \log_{10} (P) \quad \text{(Eq.2)}$$

where C_1 and C_2 are constants from the regression analysis.

All estimates are for a measurement height of approximately 1.2 m (4 ft) above ground level and a measurement distance of 152 m (500 ft). Therefore, this procedure includes ground reflection effects in the estimates.

Predictions for other distances are described in 5.1.7.

5.1.2 Hover: The equation for hover when the helicopter is near the ground is:

$$L_{AMAX} = 70 + 15 \log_{10} (P) \quad \text{(Eq.3)}$$

The level predicted is the spatial and time averaged sound level of the helicopter at 152 m (500 ft) radius with the wheels approximately 3 m (10 ft) from the ground. The sound levels were averaged because gusts and control inputs cause substantial variation to the noise produced by a hovering helicopter. Maximum sound pressure levels at a particular azimuth may exceed the averaged value by 3 to 5 dB. Figure 3 shows the data on which this equation is based.

5.1.3 Takeoff: The equation for Takeoff is:

$$L_{AMAX} = 73 + 11 \log_{10} (P) \quad \text{(Eq.4)}$$

The level predicted is the maximum directly under the flight path when the aircraft is 152 m (500 ft) above ground level. (Takeoff climb angle is typically 10 to 12°). Figure 4 shows the data on which this equation is based.

5.1.4 Approach: The equation for approach is:

$$L_{AMAX} = 75 + 13 \log_{10} (P) \quad \text{(Eq.5)}$$

The level predicted is the maximum directly under the approach path when the aircraft is 152 m (500 ft) above the ground and descending along a 6° slope. (This corresponds to a 1446 m (4745 ft) distance from the touchdown point.) The approach equation is only applicable to single main rotor helicopters. Figure 5 shows the data on which this equation is based.

5.1.5 Flyover: The equation for flyover is:

$$L_{AMAX}\ 73 + 12 \log_{10} (P) \quad \text{(Eq.6)}$$

The level predicted is the maximum directly under an unaccelerated level flyover at a height of 152 m (500 ft). Figure 6 shows the data on which this equation is based.

5.1.6 Combined Equation: The similarity of equations of 2 to 6 indicates that little accuracy would be lost if the data for all flight conditions were combined to form a single data set with a single slope and a constant of 73 dB for hover, takeoff, and flyover and a constant of 76 dB for approach. The combined equation for all flight conditions is:

$$L_{AMAX} = C_1 + 11 \log_{10} (P) \quad \text{(Eq.7)}$$

5.1.6 (Continued):

where:

C_1 = 73 for hover, takeoff, and flyover
C_1 = 76 for approach

Figure 7 shows the data on which this equation is based.

5.1.7 Adjustment for Other Distances: The sound pressure levels predicted by the equations in 5.1.2 to 5.1.5 have all been normalized to a distance from the microphone of 152 m (500 ft). Reasonable estimates of levels at other aircraft altitudes may be made by:

$$L_A = L_{A152} - 24 \log \frac{D}{152} \qquad \text{(Eq.8)}$$

where:

L_A = A-weighted SPL at D m
L_{A152} = A-weighted SPL at a distance of 152 m (500 ft) from microphone
D = Distance from helicopter to microphone, m

This approximation is for far field noise only and should not be used for distances less than 30 m (100 ft) or greater than 1000 m (3280 ft) since it is based on measured data including ground effects.

5.2 Sound Exposure Level:

5.2.1 General Procedure: Since a method for estimating the maximum A Weighted Sound Pressure Level is already provided, in 5.1.1, the extension to Sound Exposure Level is made through the generalized equation:

$$L_{AE} = C_3 + C_4 L_{AMAX} \qquad \text{(Eq.9)}$$

In determining the constants C_3 and C_4 regression equations are fit to the same test data points which were used to establish the A Weighted SPL estimating equations of 5.1. The Sound Exposure Level for each data point was calculated using the procedures prescribed in Reference A.

5.2.2 Takeoff: The equation for takeoff is:

$$L_{AE} = 31.6 + 0.70 L_{AMAX} \qquad \text{(Eq.10)}$$

The level predicted is directly under the flight path. Figure 8 shows the data on which this equation is based.

5.2.3 Approach: The equation for approach is:

$$L_{AE} = 26.4 + 0.78\, L_{AMAX} \qquad \text{(Eq.11)}$$

The level predicted is directly under the flight path. Figure 9 shows the data on which this equation is based.

5.2.4 Flyover: The equation for flyover is:

$$L_{AE} = 20.6 + 0.83\, L_{AMAX} \qquad \text{(Eq.12)}$$

The level predicted is directly under the flight path. Figure 10 shows the data on which this equation is based.

6. ACCURACY AND LIMITATIONS:

The 90% confidence limits of the data point with respect to the regression lines range from 3.5 to 5 dB. The data scatter may be due to several factors: accuracy of aircraft location, accuracy of operating parameter identification, atmospheric propagation effects, as well as effects of design which are not accounted for such as rotor blade airfoils and tip shapes. As more data taken under carefully controlled conditions become available, the confidence limits may reduce.

When compared with the individual equations of 5.1 through 5.5, the combined equation (5.6) agrees within 1 dB for takeoff and approach, 2 dB for flyover, and 3 dB for hover.

The use of these methods should be limited to helicopters which fall generally within the parameters of the helicopter which comprised the data base as follows:

Gross Weight:	907 to 22 680 kg (2000 to 50 000 lb)
Disk Loading, $\left(\frac{\text{Gross Weight}}{\text{Rotor Area}}\right)$:	14.6 to 73.2 kg/m^2 (3 to 15 psf)
Hover Tip Speed:	183 to 244 m/s (600 to 800 fps)
Advancing Tip Mach Number:	<.9
Location:	Under Flight Path
Distance:	152 m (500 ft) unless adjusted

7. EXAMPLES:

Assume a helicopter with the following design parameters:

a. Gross weight = 5000 kg
b. Rotor radius = 8 m
c. Rotor speed = 250 rpm
d. Temperature = 20 °C

1. Estimate L_{AMAX} for hover at a distance of 150 m.

Step 1: Calculate disk load

$$Disk\ Load = \frac{Gross\ Weight}{\pi R^2} = \frac{5000}{\pi(8)^2} = 24.9\ kg/m^2$$

Step 2: Calculate rotational tip mach number

$$Rotational\ Tip\ Speed = \frac{2\pi(rpm)\ (Radius)}{60} = \frac{2\pi(250)\ (8)}{60} = 209.4\ m/s$$

From Figure 1
at 20 °C
Rotational Tip Mach Number = .61

Step 3: Calculate (P)

$$P = (24.9)\left(\frac{8}{152}\right)\left(\frac{.61}{1-.61}\right) = 2.05$$

Step 4: Calculate L_{AMAX}

From Equation 3 (or Figure 3)

$$L_{AMAX} = 70 + 15\log_{10}(2.05) = 74.7\ dBA$$

7. (Continued):

2. Estimate L_{AMAX} for a takeoff passing over the microphone at a height of 120 m at a speed of 150 km/h.

Step 1: From previous example:

$$Disk\ Load = 24.9\ kg/m^2$$
$$M_T = 0.61$$

Step 2: Calculate M_F

From Figure 2 at 150 km/h

M_F = .12

Step 3: Calculate (P) for a height of 152 m

$$P = (24.9)\left(\frac{8}{152}\right)\left(\frac{.61}{1-(.61+.12)}\right)$$
$$= 2.96$$

Step 4: Calculate L_{AMAX}

From Equation 4 (or Figure 4)

L_{AMAX} = 73 + 11 log (P)

= 73 + 11 log 2.96

= 78.2 dBA

Step 5: Adjust to 120 m height

From Equation 8

$$L_{AD} = L_{A152} - 24\ \log \frac{D}{152}$$
$$= 78.2 - 24\ \log \frac{120}{152}$$
$$= 80.7\ dBA$$

3. Estimate L_{AE} for the case of Example 2

From Equation 10 (or Figure 8)

$$L_{AE} = 31.6 + 0.70\ L_{AMAX}$$
$$= 31.6 + 0.70\ (80.7)$$
$$= 88.1\ dB$$

PREPARED BY SAE SUBCOMMITTEE A-21S10,
HELICOPTER NOISE PREDICTION OF
COMMITTEE A-21, AIRCRAFT NOISE

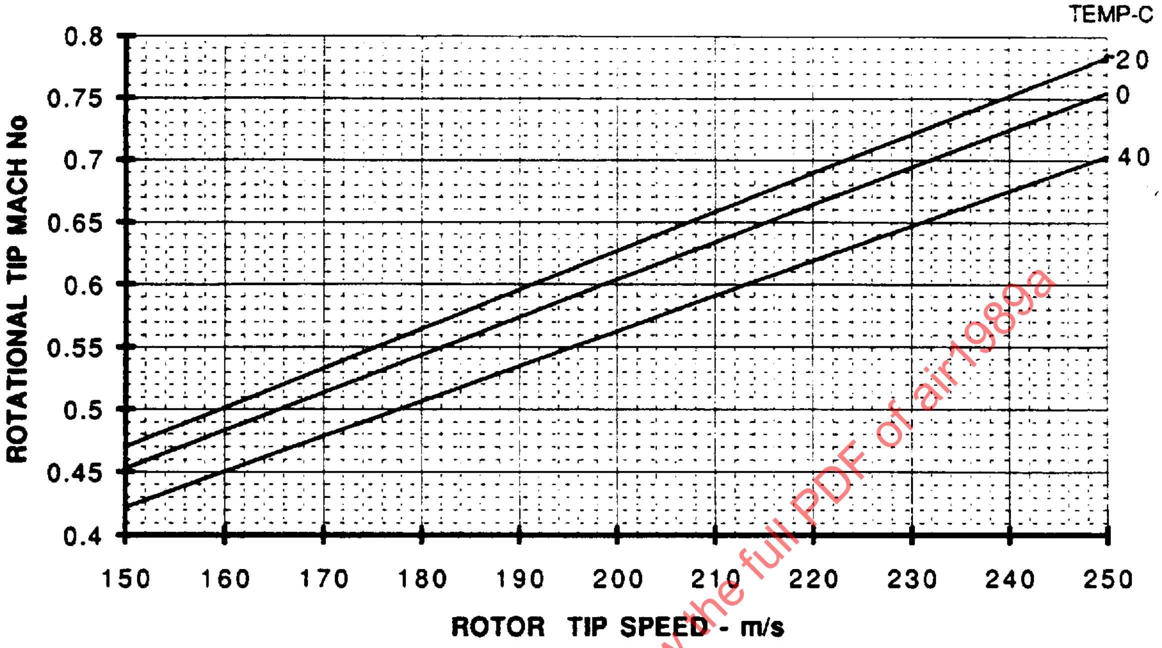

FIGURE 1 - Rotor Tip Mach Number

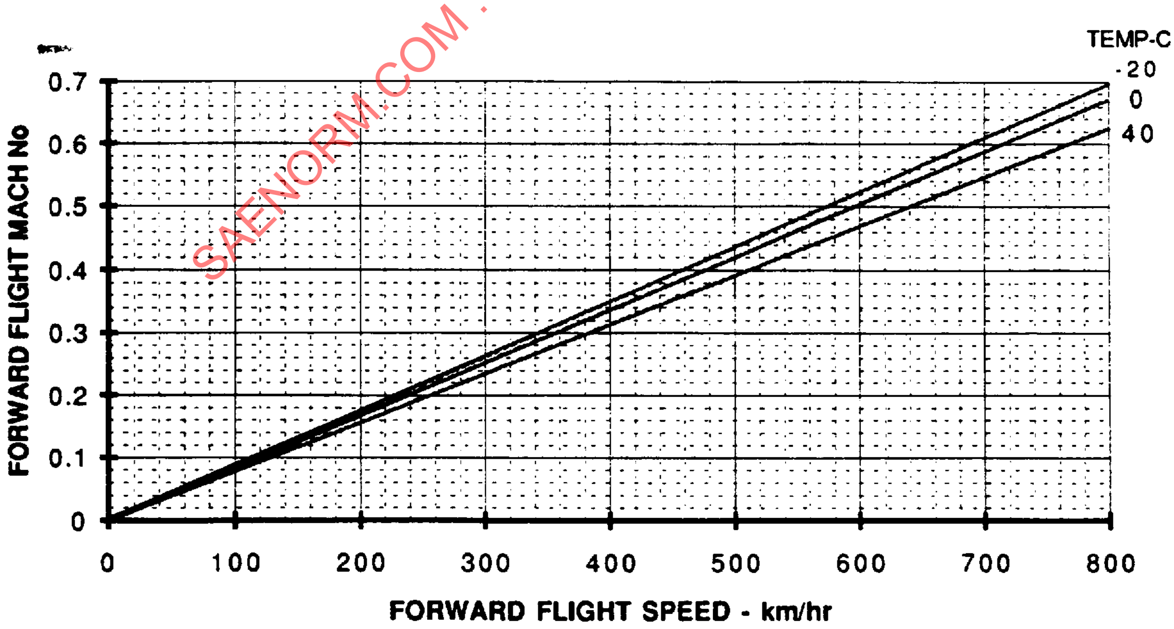

FIGURE 2 - Forward Flight Mach Number

SAE AIR1989 Revision A

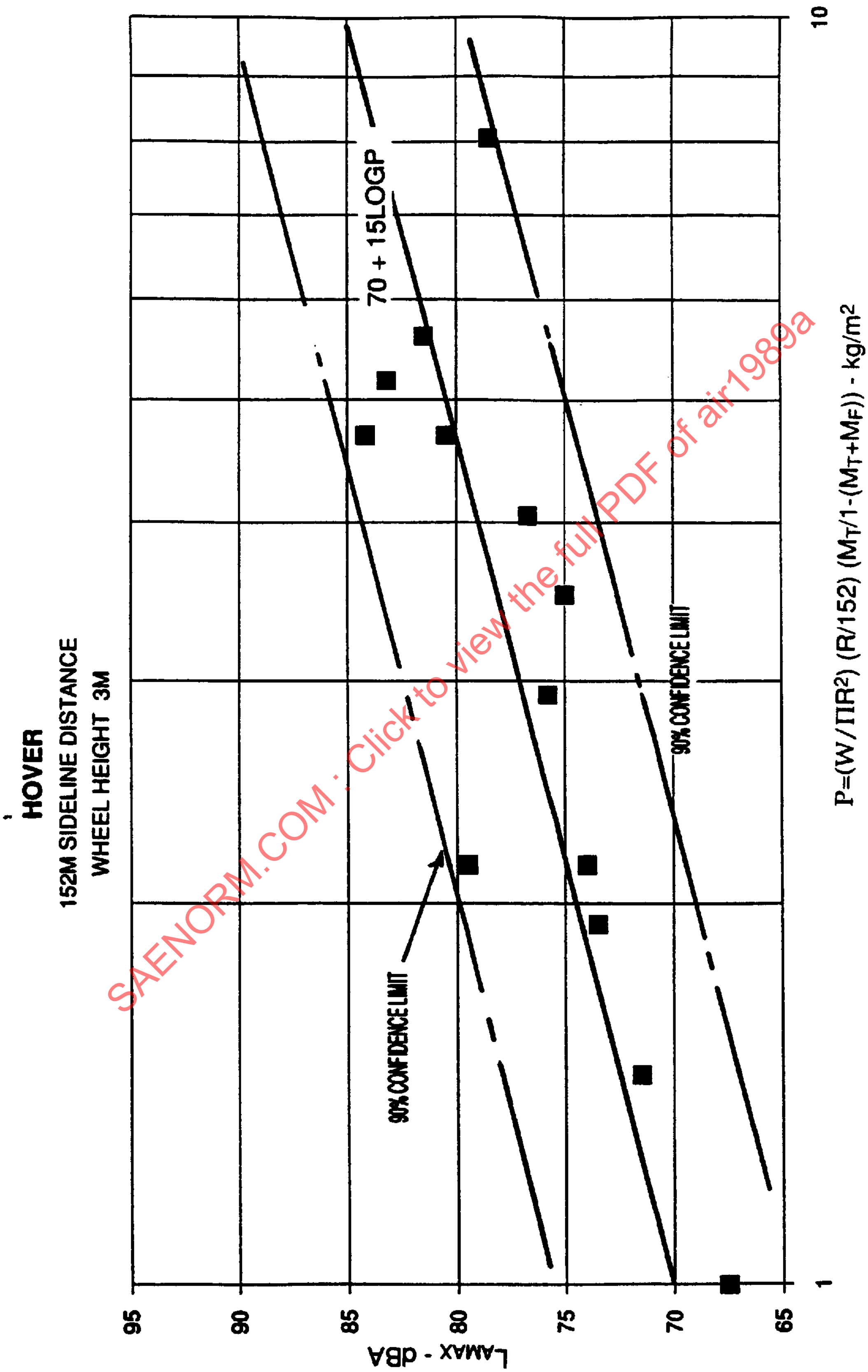

FIGURE 3 - Hover 152 m Sideline Distance Wheel Height 3 m

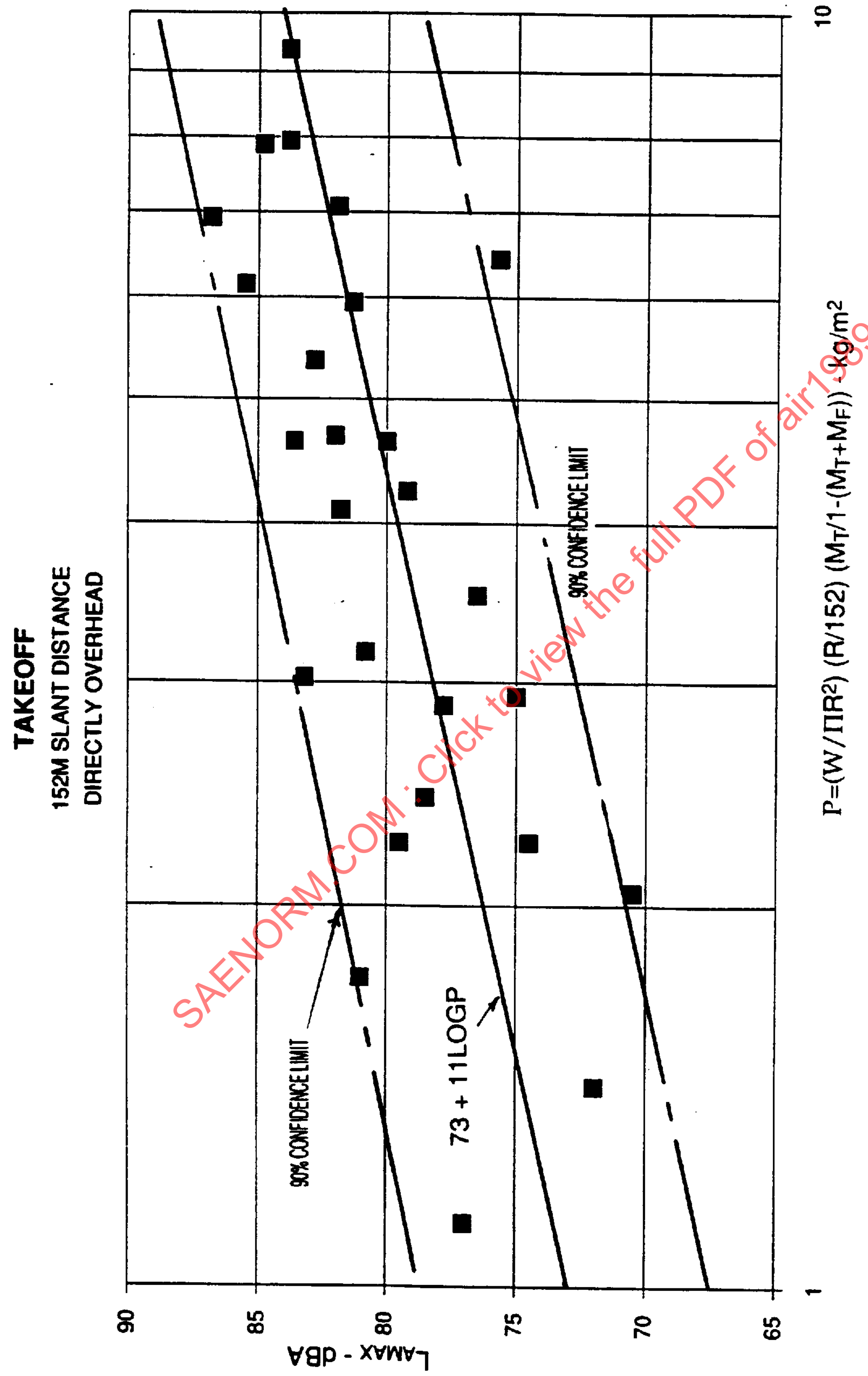

FIGURE 4 - Takeoff 152 m Slant Distance Directly Overhead

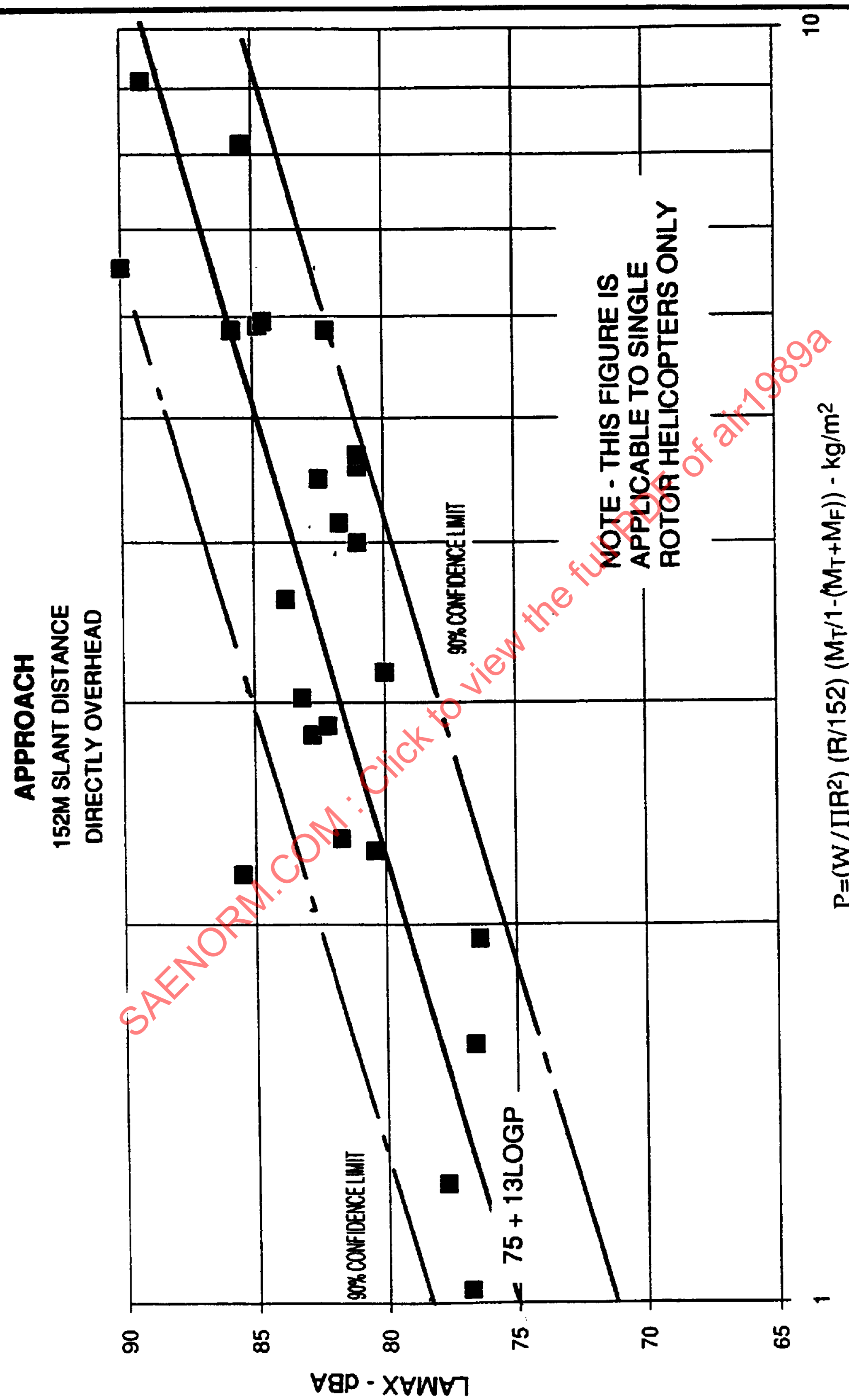

FIGURE 5 - Approach 152 m Slant Distance Directly Overhead

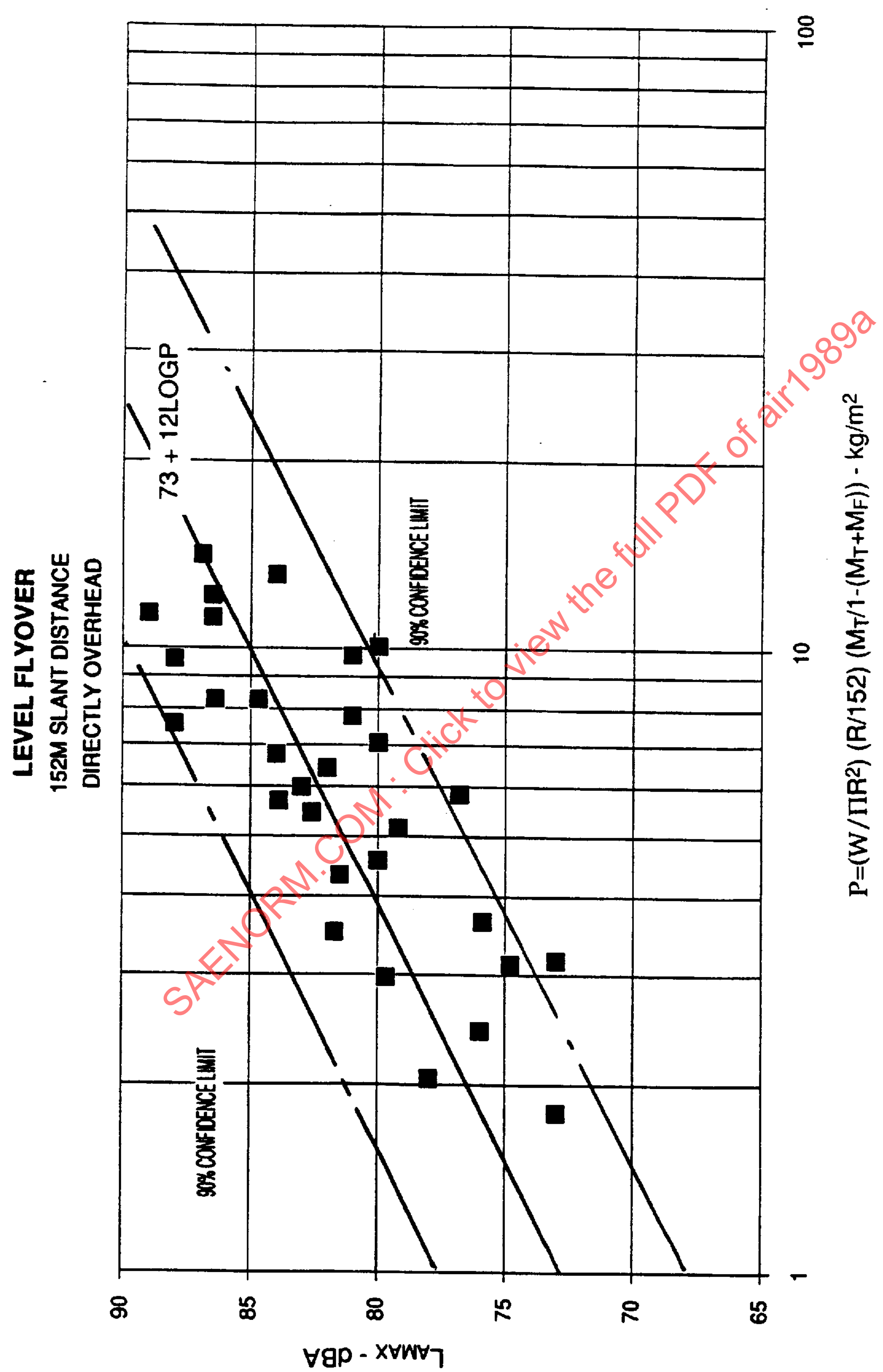

FIGURE 6 - Level Flyover 152 m Slant Distance Directly Overhead