PAPER Nr.: 7

APPLICATION OF THE PREDICTION CODE OF THE HELICOPTER ROTOR NOISE ROTAC TO A REAL-SIZE HELICOPTER: COMPARISON OF CALCULATIONS WITH MEASUREMENTS.

BY

P. GNEMMI

FRENCH-GERMAN RESEARCH INSTITUTE,
SAINT LOUIS, FRANCE

TWENTIETH EUROPEAN ROTORCRAFT FORUM
OCTOBER 4 - 7, 1994 AMSTERDAM

Printed by the Technical Highschool Haarlem

APPLICATION OF THE PREDICTION CODE OF THE HELICOPTER ROTOR NOISE ROTAC TO A REAL-SIZE HELICOPTER: COMPARISON OF CALCULATIONS WITH MEASUREMENTS.

P. GNEMMI

French-German Research Institute
5 rue du Général-Cassagnou
68301 SAINT LOUIS CEDEX (France)

Abstract

The acoustic detection of helicopters is a more and more important subject in the military domain. Thus, an international NATO experiment has taken place in France to collect a number of helicopter and airplane signatures.

The prediction code of the helicopter rotor noise ROTAC has been used for many years to calculate the noise radiated by rotor models in hover flight or in wind tunnel flight conditions. Now it is applied to real-size helicopters without taking into account the effects of the meteorological fluctuations during the acoustic propagation.

The aim of this study is to apply the code to a real-size helicopter in hover and forward flights; the signatures collection issued from the NATO experiment allows to compare the thickness noise predictions with measurements.

A good agreement between calculations and measurements is found in hovering and forward flight cases for a microphone - helicopter distance greater than about 200 m. The deviation between the peak levels of the computed thickness noise and those of measurements is less than 20% and 50% in hover and forward flight cases respectively.
The first harmonic of the spectrum is predicted with 1 dB accuracy in hover flight and with 2 dB accuracy in forward flight, beyond 200 m.

Notations

a_0	: sound speed in undisturbed medium
D	: rotor diameter
ℓ_i	: surface density of the aerodynamic force acting by the blade element $d\sigma$ on the fluid
M_{at}	: advancing tip Mach number
M_j	: velocity vector of the blade element $d\sigma$
M_h	: hover tip Mach number
M_r	: Mach number of the blade element $d\sigma$ in the receiving direction
$\tilde{p}$	: acoustic pressure
R	: distance between the receiving point and the rotor hub
R_E	: rotor radius (D/2)
r_i	: location vector of the receiving point with respect to the blade element $d\sigma$
r	: distance between the receiving point and the blade element $d\sigma$
t	: noise receiving time
V_m	: advance speed of the helicopter
v_n	: normal component of the velocity of the blade element $d\sigma$
Xc,Yc,Zc	: coordinates of the rotor hub with respect to the receiving point
$\vec{x}$	: location vector of the receiving point
α	: climb or descent angle of the helicopter
α_q	: inclination angle of the rotor disk
Θ	: azimuth angle of the receiving point with respect to the rotor hub
μ	: rotor advance ratio
ρ_0	: air density
$d\sigma$	: blade element surface
τ	: noise emission time
Φ	: angle of sight of the receiving point with respect to the rotor hub
ψ	: blade azimuth angle
Ω	: rotor blade angular velocity.

Introduction

The acoustic detection of aircraft is a crucial problem for the national defense authorities. Thus, the noise of different helicopters and airplanes was recorded on the airport of Dreux-Senonches in France as part of a NATO program for acoustic detection and propagation studies. Among the 23 participating teams, there was a team of scientists from ISL.

The theoretical study of the noise radiated by surfaces moving at subsonic speed in a homogeneous medium allows to develop a prediction code of the noise radiated by the main rotor of helicopters. The code named ROTAC has been in use at ISL since 1989, it has been validated on rotor models in many flight conditions but it has never been applied to flights of real-size helicopters.

This paper presents the application of the ROTAC code to one real-size helicopter in hover and forward flights. The acoustic signatures measured at Dreux-Senonches are compared with the thickness noise ones calculated by running the ROTAC code for the main rotor of the helicopter. The flight cases presented in this paper have been chosen on purpose as the meteorological fluctuations seemed to be relatively steady because the computation does not take into account these effects during the acoustic propagation.

The first chapter presents some information on the Dreux-Senonches experiment. The second one recalls the theoretical foundations leading to the expression of the thickness and loading noise, but the quadrupolar noise contribution is not taken into account yet. The third chapter presents the comparison between the acoustic measurements and the thickness noise computations for the helicopter in hover and forward flights. The last chapter concludes this study.

1 The Dreux-Senonches experiment

The NATO RSG 11 group, with the support of the "Section Technique d'Etudes et de Fabrication des Télécommunications", has organized an international experiment on the airport of Dreux-Senonches (now not in use any longer) in France [1]. This meeting took place in September 1988; among the 23 teams partaking in it, one team of scientists came from ISL.

The aim of this experiment was to record the acoustic signatures of helicopters and airplanes, to make a signatures collection [2], to test some acoustic detection systems [3] and to study the acoustic propagation of the noise radiated by these aircraft in accordance with the meteorology [4, 5].

One or more helicopters and airplanes (Gazelle 341 and 342, Puma, Alouette II and III, Lynx, BO 105, CH47 and 53, Hughes, Mirage 2000, Mirage F1, Alphajet, Tornado, Phantom and Harrier) flew over the airport with different and predefined flight configurations. The interest of this experiment is multiple:

- sharing means which would be too expensive for one team alone (helicopters, airplanes, measurement means, etc...);
- testing prediction algorithms for a lot of flight cases;
- comparing detection methods, transducers and prototypes;
- validating codes with common measurements.

The ISL team of scientists installed many microphones on the ground, some of them located below the aircraft paths and the others below their paths and sideways [2, 3].

Figure 1 shows a top view of the experimental set-up of Dreux-Senonches indicating the location of a microphone with respect to the helicopter; Xc is the abscissa, Yc is the ordinate and Zc is the height of the helicopter. The helicopter velocity ($\vec{V}_m$) is clearly zero in the case of a hover flight.

The noise was collected by means of a magnetic recorder with a passing broadband of 5 kHz. The instantaneous signatures shown in this paper were recorded during about 1 rotor revolution. These signatures were analyzed with a passing broadband of 1 kHz. This analysis allows a good characterization of the frequency harmonics due to the movement of the rotor blades; each spectrum presented here is an average of 18 spectra determined during about 15 s.

2 Theoretical considerations

The prediction of the thickness and loading noise radiated by helicopter rotors flying at subsonic speed is an important research subject at ISL [6-10]. Up to now, the comparison between theoretical results and measurements has been carried out only in the immediate vicinity of the helicopter rotor models [6-10]; thus the computation neglects all the effects of meteorological fluctuations during the acoustic propagation.

The theoretical study of the noise radiated by bodies moving with respect to the air is based on a non-homogeneous wave equation, several source terms of the second member indicating the boundary conditions on the body surfaces. The resolution of this equation (called Ffowcs-Williams and Hawkings equation) leads to the expression of the radiated acoustic pressure. Neglecting the influence of the quadrupolar noise, one obtains the full formulation of the thickness and loading noise [10, 11], respectively:

$$4\pi\,\tilde{p}(\vec{x},t) = \int_S \left\{ \frac{\rho_0}{r(1-M_r)^2}\left[\frac{\partial v_n}{\partial \tau} + \frac{v_n}{1-M_r}\left(\frac{r_j}{r}\frac{\partial M_j}{\partial \tau} + \frac{a_0}{r}\left(M_r - M_j^2\right)\right)\right] d\sigma \right\}_{\tau=\tau_e}$$

$$+ \int_S \left\{ \left[\frac{1}{a_0\, r(1-M_r)^2}\left[\frac{r_i}{r}\frac{\partial \ell_i}{\partial \tau} + \frac{1}{1-M_r}\left(\frac{\ell_i r_i}{r}\right)\left(\frac{r_j}{r}\frac{\partial M_j}{\partial \tau}\right)\right]\right.\right.$$

$$\left.\left. + \frac{1}{r^2(1-M_r)^2}\left[\left(\frac{\ell_i r_i}{r}\right)\left(\frac{1-M_j^2}{1-M_r}\right) - \ell_i M_i\right]\right] d\sigma \right\}_{\tau=\tau_e} \qquad (1)$$

For each surface element each term between brackets is computed at the emission time.

The far-field approximation is obtained when the $1/r^2$ terms in the above full formulation are neglected.

The acoustic calculation code ROTAC is based on a temporal formulation similar to the one developed by FARASSAT and SUCCI [11] or BRENTNER [12]. This code has been operative since 1989 and has been applied to the noise prediction of helicopter rotor models.

The notations used in the above formula are defined at the beginning of this paper. The code is largely described in [10]; nevertheless, some clauses relative to the location of the receiving point may be worth remembering.
The receiving point defined by $\vec{x}$ is located in Cartesian coordinates (-Xc, -Yc and -Zc), so that the helicopter flies in the (Xc, Zc) vertical plane (figure 1). It may also be defined in spherical coordinates (Θ, Φ and R) by:

- the azimuth angle Θ measured with respect to the (Xc, Zc) vertical plane in which the advancing direction of the rotor in situated; it is positive in the rotor rotational direction (the rotor turning counterclockwise) and it is zero when the receiving point is ahead of the rotor;
- the angle of sight Φ measured with respect to the (Xc, Yc) horizontal plane; it is negative when the point is below the horizontal plane and it is zero when the receiving point is in this plane;
- the distance R between the rotor hub and the receiving point; this distance is determined when one blade is located at the back of the rotor (the azimuth angle ψ of this blade is zero).

Many previous studies concerning the noise directivity of helicopter main rotors show that the thickness noise radiates in the vicinity of the rotational plane of the blades ($-10° < \Phi < 10°$). These studies also show that the loading noise radiates rather below this plane ($\Phi < -30°$). Due to these facts and taking into account the location of the microphones with respect to the helicopter, only the thickness noise is computed in the present study (first integral of formulation (1)).

The knowledge of the rotor geometry, of the rotor kinematics, of the location of the receiving point and of the surrounding medium is strictly necessary for the calculation of the radiated thickness noise. It is demonstrable that the predominant parameters relating to the flight configuration are the following ones:

- the hover tip Mach number, M_h;
- the advance ratio of the helicopter, μ;
- the climb or descent rate of the helicopter given by α;
- the inclination angle of the rotor disk, α_q.

The surrounding medium is characterized by the mean temperature and density of the air.

3 Comparison of calculation with measurements

Among the different available aircraft a helicopter was chosen as the basic technical characteristics of its conventional main rotor were well known. The acoustic signatures were recorded at Dreux-Senonches by the ISL team.

3 flight configurations have been chosen for this study:

- the hover flight;
- the forward flight, one microphone is located below the helicopter path;
- the forward flight, another microphone is located on one side of the helicopter path.

The levels of the amplitude scale are not plotted on noise graphs for confidentiality reasons.

3.1 The hover flight

The helicopter is located above a well-defined fixed point with respect to the microphones line, it flies in hover ($\mu = 0$ and $\alpha = 0$) at a height of about 5 m. The mean temperature is 21.8° during this test, the hygrometry is 41.8% and a light wind of about 1.5 m/s blows obliquely with respect to the microphones line.

The thickness noise is computed for microphones located between 50 m and 1235 m (Xc) away from the helicopter in hover flight and at 20 m (Yc) on the retreating side of the main rotor. The rotor is assumed to stay at a 10 m height (Zc). The hover tip Mach number (M_h) is equal to 0.613 and the inclination of the plane described by the blade tips (α_q) is considered to be zero. The speed of sound (a_0) is equal to 340 m/s and the air density (ρ_0) to 1.293 kg/m^3.

Figure 2 depicts the comparison of calculated signatures with measurements for microphones located at abscissae 985, 735 and 485 m. The calculated signatures are plotted on the left. The abscissa scale of the plots exhibits a rotation period of the rotor. The ordinate scale of the calculated signature is the same as that of the measured signature. A pretty good agreement between computation and measurements can be noticed, the deviation is less than 20%.

Figure 3 shows the comparison between the calculated main frequency level and the measured one versus the helicopter - microphone abscissa.
The radiated noise is well predicted by ROTAC up to 235 m, the discrepancy is less than 1 dB.
The thickness noise calculation diverges from the measurement for the 35 m distance because it is well known that the thickness noise radiates mainly in the rotor disk plane, as said before. The microphone is located about 16° below the rotor disk plane at 35 m from the helicopter ($\Phi \sim -16°$) and the contribution of other noise sources is predominant and is not taken into account in the calculation.

3.2 The forward flight: measurement and computation below the helicopter path

The helicopter flies over the airport at constant height and speed, the path is rectilinear and a microphone is directly located below this path (Yc=0). The height of the helicopter is uncertain, it is between 30 and 50 m and the advance speed equals 260 km/h. The atmospheric parameters are similar to those in hover flight.

In far field, the thickness noise has a strong directivity in the rotation plane of the blades and ahead of the rotor [10]. Due to this fact, only the approaching flight towards the microphone (forward flight) is studied; when the helicopter flies away, the thickness noise is concealed by other sources of noise generated by the helicopter [13].

The hover tip Mach number is the same as in hover flight and the advance ratio of the helicopter is equal to 0.355 in the computation. The α angle equals zero because the flight is horizontal. The helicopter flies nose-down, so the rotor shaft is considered to have a 2° inclination ($\alpha_q = -2°$). The surrounding medium (a_0, ρ_0) is the same as in hover flight.

Figure 4 shows the predicted thickness noise and the measured signatures obtained when the helicopter in forward flight is located at 400, 300, 200 and 150 m from the microphone. The computed signatures are plotted on the left. The deviation between calculation and measurement is less than 35%.

Figure 5 depicts the calculated and measured spectra corresponding to figure 4. The calculated spectra are also plotted on the left. The ordinate scale of the calculated spectra is the same as the measured one.
The first harmonic is well predicted by ROTAC, but it can be noticed that the calculated decrease law of higher harmonics does not follow the measured law because the atmospheric absorption is not taken into account in the ROTAC computation.

Figure 6 presents the comparison of the calculated main frequency level with the measured one versus the helicopter - microphone abscissa (as can be seen on figure 3).

A good agreement is found up to 200 m, the discrepancy is less than 2 dB.
The height and the inclination angle of the helicopter rotor disk are important parameters when the helicopter - microphone distance is lower than 200 m; these parameters are not exactly known in the experiment.
It is also normal to obtain a bad prediction of the radiated noise when the rotor is just above the microphone for the same reasons as mentioned in the last paragraph of the hovering case.

As an example, figure 7 shows the predicted thickness noise signature when the rotor is assumed to fly at a 50 m height, the abscissa is 150 m. The amplitude of the negative peak is about 40% lower than that of the thickness noise computed for the rotor flying at a 30 m height (see figure 4).

A parametric study relative to the height of the helicopter and the rotor disk inclination of the latter shows their influence on the thickness noise.
Figure 8a depicts a comparison between the amplitude of the measured negative peak and the amplitude of the calculated thickness noise. One assumes that the helicopter flies at 5 different heights between 30 and 50 m for the computation. The inclination angle of the rotor disk is -2° in these calculations.
Figure 8b presents the same kind of comparison as figure 8a when the rotor is considered to fly at a 30 m height, but the inclination angle of the rotor disk varies from -4 to 4° in the computation. The influence of the height and the inclination angle of the rotor between 100 and 200 m can be clearly observed on these figures. It is important to know these 2 parameters with enough accuracy when the helicopter - microphone distance is lower than about 300 m. The knowledge of these parameters is not essential any longer beyond 300 m because the amplitude of the thickness noise is quite similar.

3.3 The forward flight: measurement and computation on one side of the helicopter path

Another microphone is located at 100 m on the right side of the helicopter path previously defined (see figure 1, Yc=-100 m). The acoustic signature of the helicopter is also recorded during the flight over the airport.

All the parameters defined in paragraph 3.2 are the same for the computation.

Figure 9 illustrates the comparison between the calculated signatures and the measured ones at 600 and 400 m abscissae. A satisfactory agreement can be noticed at the 600 m abscissa (the deviation is about 50%) and the agreement at the other one abscissa is very good.

Figure 10 shows the comparison of the calculated main frequency level with the measured one versus the helicopter - microphone distance (as can be seen on figures 3 and 6).
A good agreement is found up to 100 m except for the 235 m abscissa for which the measurement is ambiguous as compared with those performed at 400 and 100 m.
It is normal to obtain a bad prediction of the thickness noise when the rotor is at 90° on the left of the microphone (Xc=0) because the thickness noise mainly radiates ahead of the rotor; the acoustic signature contains the contribution of other noise sources at this microphone location.

4 Conclusion

The thickness noise calculation is now applied to a real-size helicopter in hover and forward flights. However, the comparison between the helicopter noise measurements and the computed thickness noise of the main rotor is meaningless if it cannot be assumed that the microphone stays near the rotor disk plane.

The amplitude of the negative peak is underestimated by about 20% beyond 485 m in hover flight. On the other hand, the level of the first harmonic of the spectrum is well predicted as compared with the measured one, the deviation is less than 1 dB beyond 235 m.

It is useless to compare measurements of helicopter noise with thickness noise computations when the helicopter flies away because the thickness noise is concealed by other sources of noise generated by the helicopter.

The deviation between the negative peak amplitude of the calculated thickness noise and the negative amplitude of the measured noise is less than 50% between 600 and 150 m in the case of a forward flight. The level of the first harmonic of the spectrum is predicted with 2 dB accuracy at higher distances than 200 m. The calculated decrease law of higher harmonics does not follow the measured law because the computation does not take into account the atmospheric absorption.

The studied cases also show the influence of the height and of the inclination angle of the helicopter rotor on the acoustic results when the helicopter - microphone distance is lower than about 300 m.

Such a study is possible only when the effects of the meteorological fluctuations are slight during the acoustic propagation. However, it will be interesting to connect the ROTAC code with an acoustic propagation code.

Bibliography

[1] M. ANDRIEU, C. MAILLET, G. PARMENTIER, J. VERMOREL
Expériences communes de détection d'hélicoptères
1er Colloque franco-allemand sur la lutte anti-hélicoptères au moyen de l'arme principale du char de bataille, 17-19 octobre 1989
ISL report - R 111/89, 1989

[2] G. PARMENTIER
Recueil de signatures acoustiques d'hélicoptères et d'avions
ISL report - S-RT 914/89, 1989

[3] G. PARMENTIER
Détection acoustique d'hélicoptères en vol stationnaire (2 et 4 km), en vol tactique et en vol d'approche. Résultats expérimentaux de la campagne "AMI PHASE 2" à Dreux, du 12 au 22 septembre 1988
ISL report - S-RT 924/89, 1989

[4] G. PARMENTIER, P. NAZ
Détection acoustique : propagation du bruit des hélicoptères
1er Colloque franco-allemand sur la lutte anti-hélicoptères au moyen de l'arme principale du char de bataille, 17-19 octobre 1989
ISL report - R 111/89, 1989

[5] P. NAZ, F. RIEDLINGER, E. BURDE
Propagation du bruit des helicoptères dans la basse atmosphère. Comparaison calcul-expérience AMI-2
ISL report - RT 505/93, 1993

[6] M. SCHAFFAR, J. HAERTIG, P. GNEMMI
Aerodynamic loads and blade/vortex interaction noise prediction
15th European Rotorcraft Forum, Amsterdam, The Netherlands, September 12-15, 1989
ISL report - PU 310/89, 1989

[7] M. SCHAFFAR, J. HAERTIG, P. GNEMMI
Interaction pale/sillage sur un rotor bipale avec prévision du bruit rayonné (vol stationnaire et vol d'avancement, comparaison calcul - expérience)
ISL report - R 120/89, 1989

[8] M. SCHAFFAR, J. HAERTIG, P. GNEMMI
Effect of non-rectangular blade tips on BVI noise for a two-bladed rotor
16th European Rotorcraft Forum, Glasgow, Great Britain, September 1990
ISL report - CO 217/90, 1990

[9] P. GNEMMI, J. HAERTIG, Ch. JOHÉ
Validation of the ROTAC code for the rotor noise prediction
18th European Rotorcraft Forum, Paper 15, Avignon, France, September 15-18, 1992
ISL report - CO 228/92, 1992

[10] P. GNEMMI
Contribution à la prévision du bruit rayonné par un rotor d'hélicoptère en régime subsonique
Doctorate thesis
ISL report - R 108/93, 1993

[11] F. FARASSAT, G.P. SUCCI
The prediction of helicopter rotor discrete frequency noise
Vertica, Vol. 7, No. 4, pp. 309-320, 1983
38th Annual Forum, American Helicopter Society, Anaheim/CA, USA, May 4-7, 1982

[12] K.S. BRENTNER
Prediction of helicopter rotor discrete frequency noise. A computer program incorporating realistic blade motions and advanced acoustic formulation
NASA Technical Memorandum 87721, October 1986

[13] P. GNEMMI
Application du code de prévision du bruit des rotors d'hélicoptères (ROTAC) à un hélicoptère réel. Comparaison calcul - expérience.
ISL report - S-R 901/94, 1994

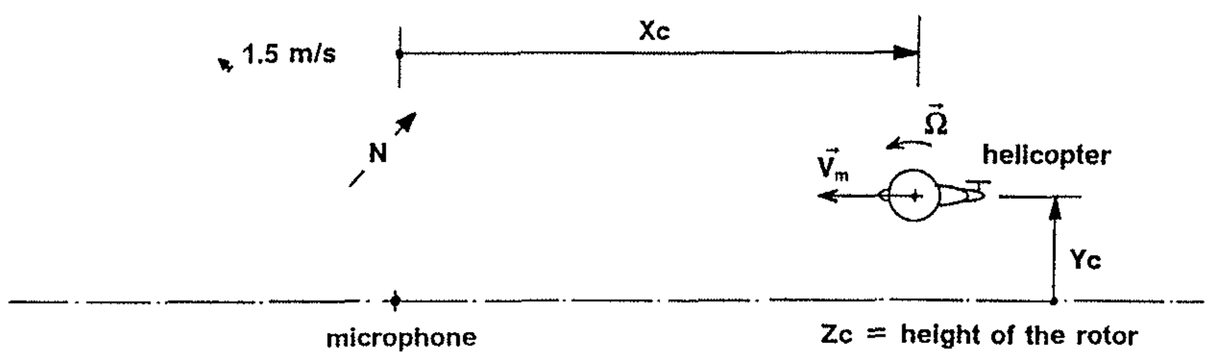
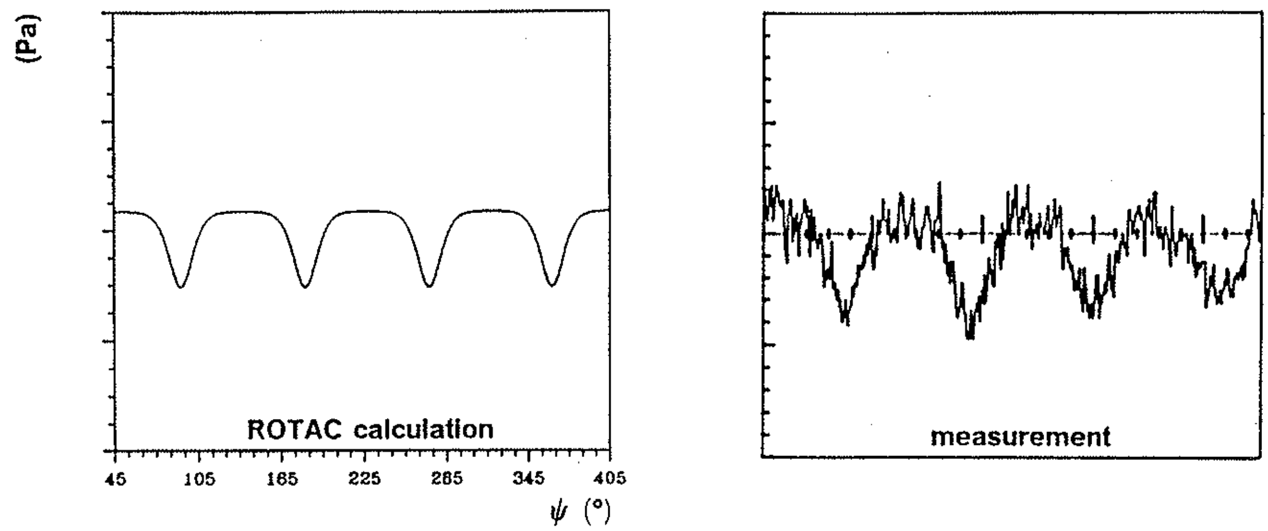
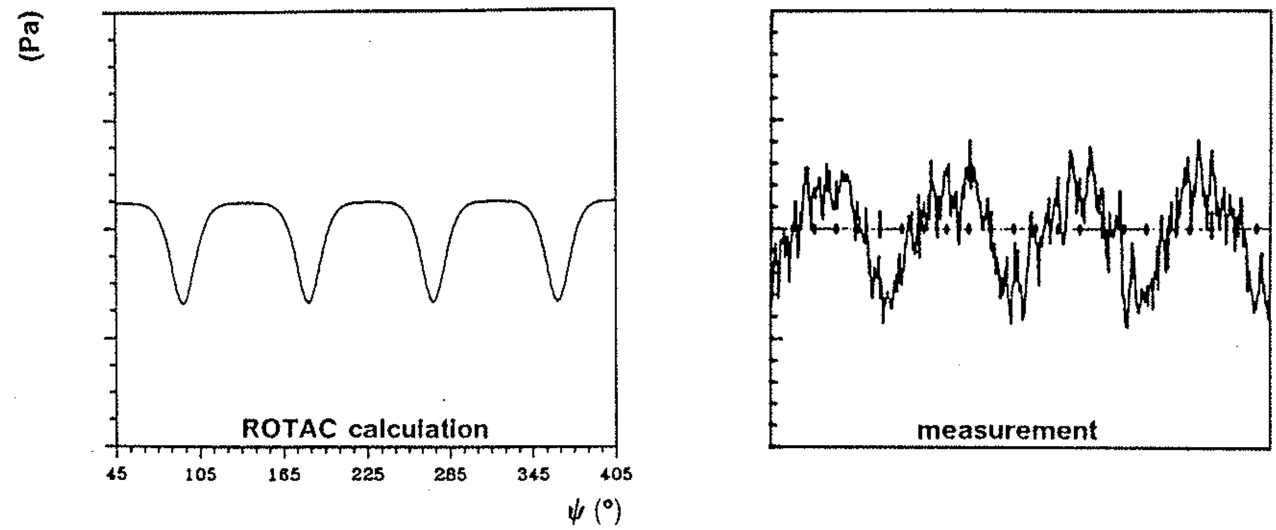


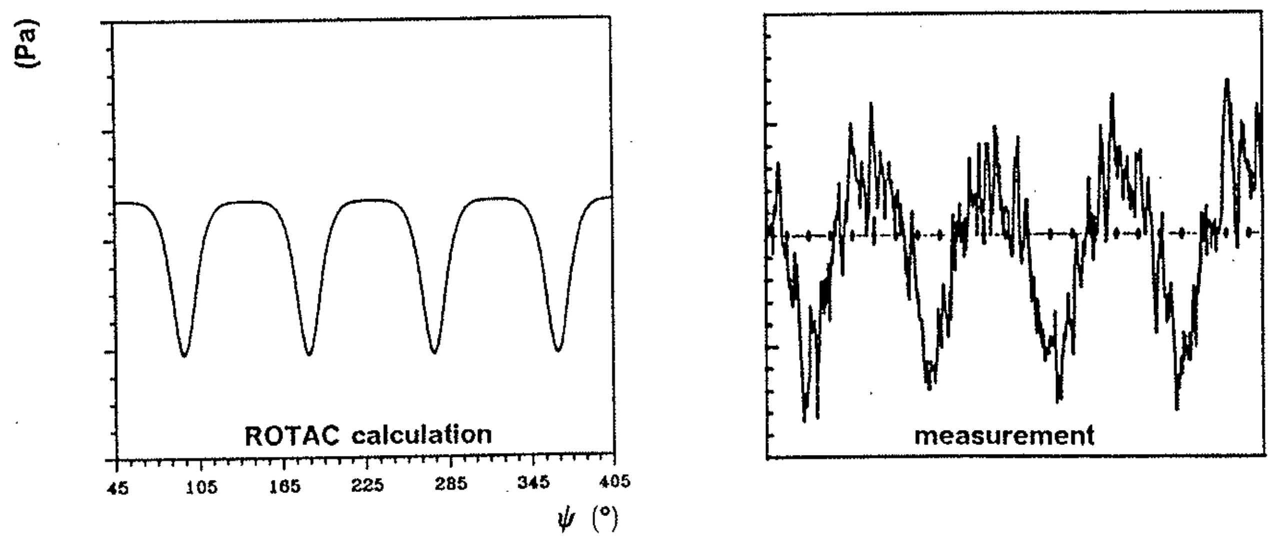
Fig. 1: Top view of the experimental set-up of Dreux-Senonches



Xc = 985 m, Yc = 20 m, Zc = 10 m



Xc = 735 m, Yc = 20 m, Zc = 10 m



Xc = 485 m, Yc = 20 m, Zc = 10 m

Fig. 2: Comparison of thickness noise calculations with experimental signatures for the helicopter in hover

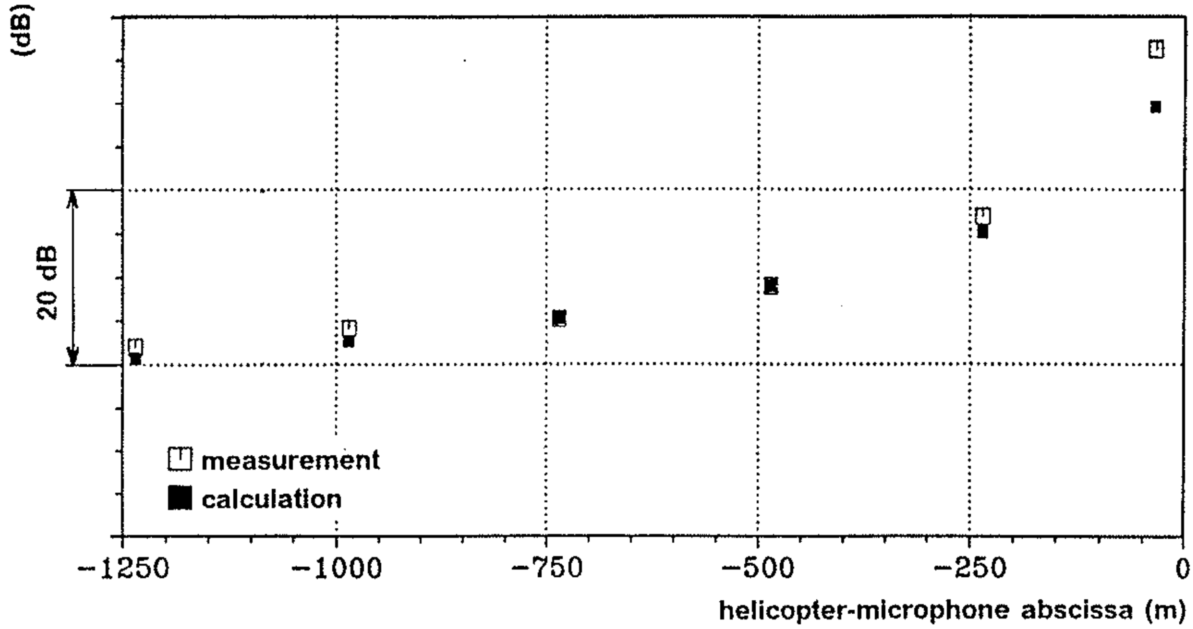


Fig. 3: Comparison of thickness noise calculations with experimental results for the helicopter in hover; first harmonic level

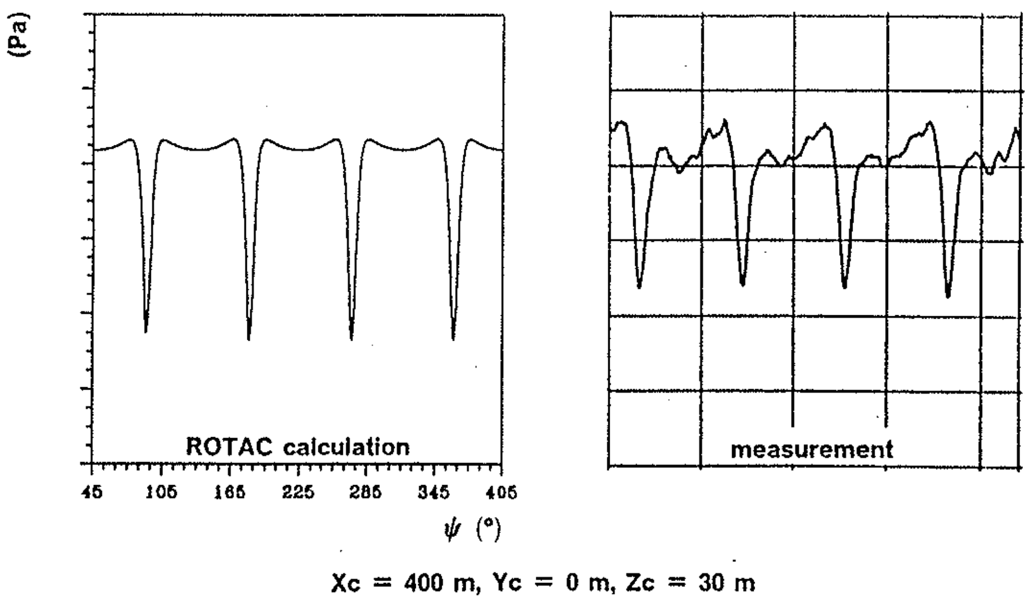
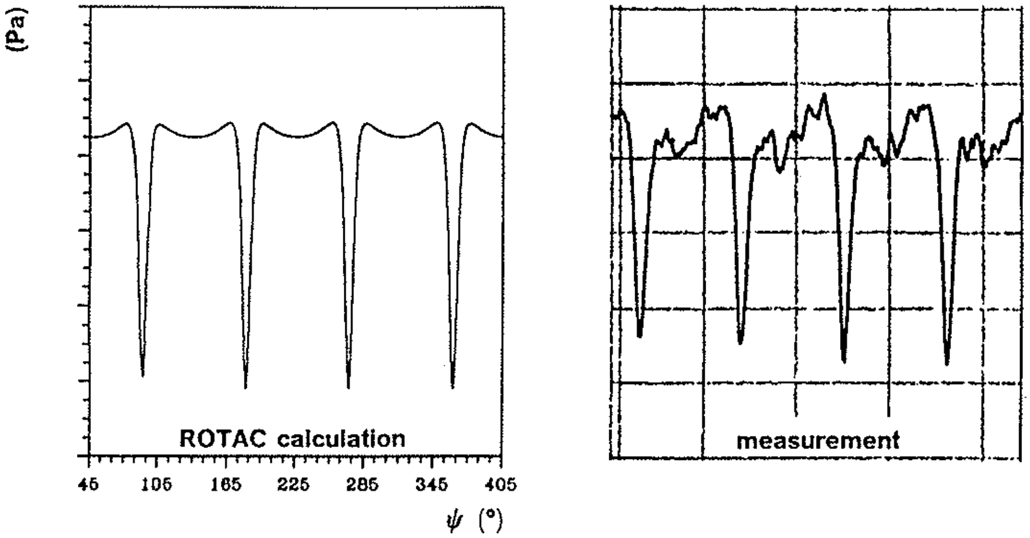
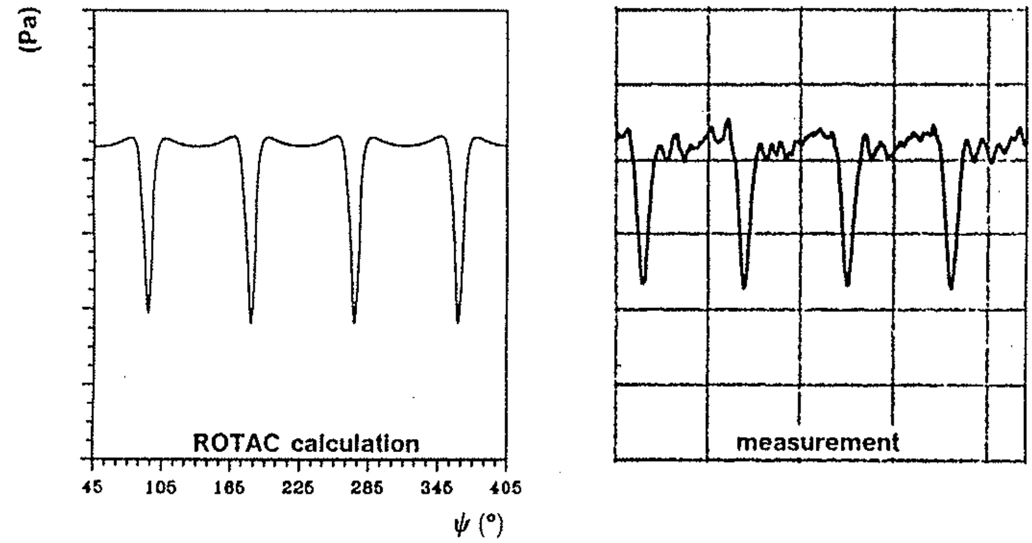


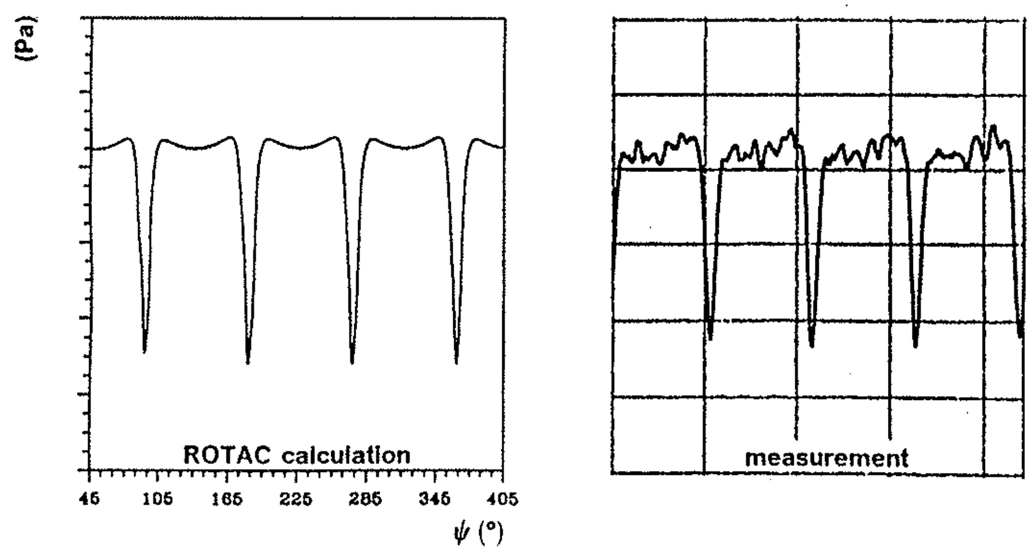
Fig. 4: Comparison of thickness noise calculations with experimental signatures for the helicopter in forward flight (microphone located below the helicopter path); Xc = 400 m, Xc = 300 m, Xc = 200 m and Xc = 150 m



Xc = 300 m, Yc = 0 m, Zc = 30 m

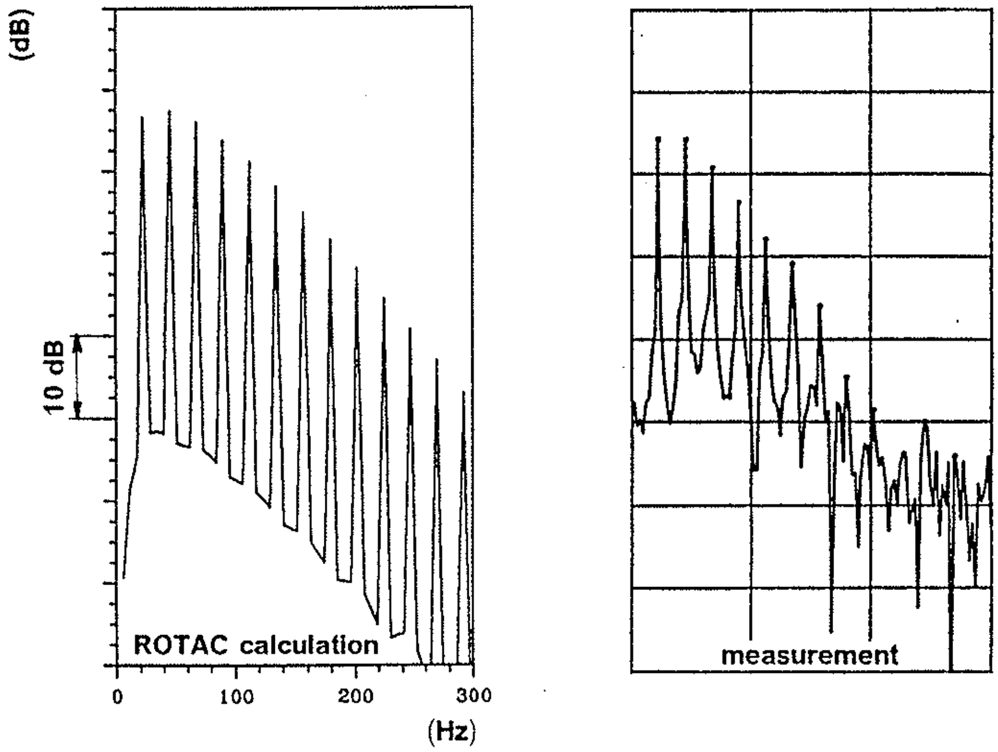


Xc = 200 m, Yc = 0 m, Zc = 30 m

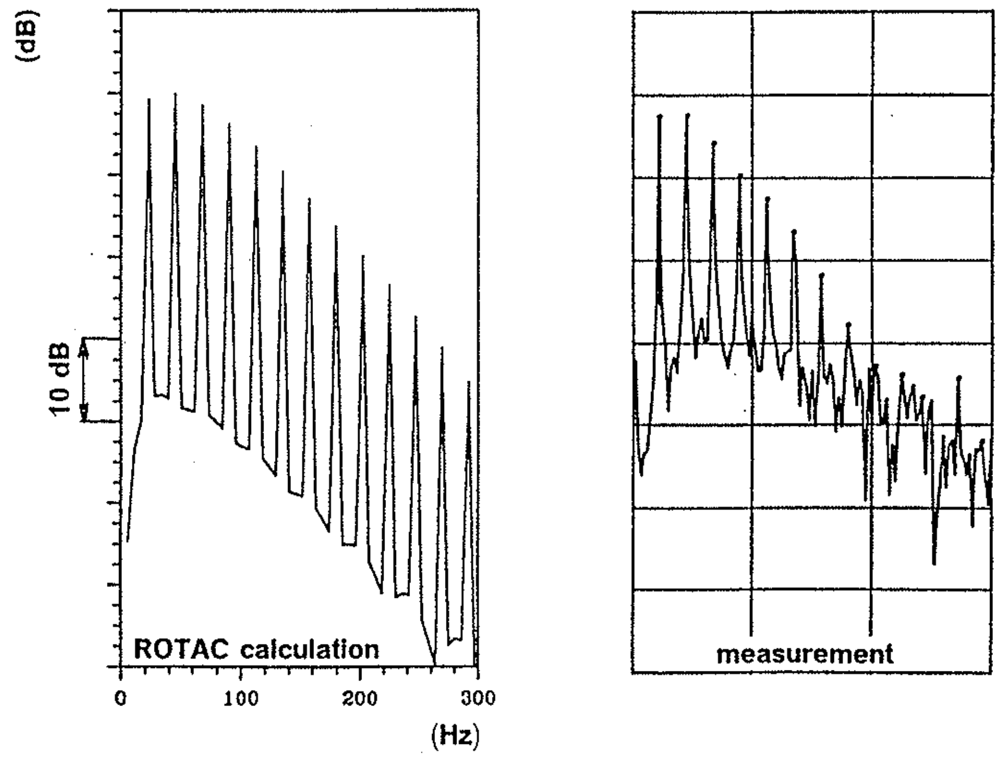


Xc = 150 m, Yc = 0 m, Zc = 30 m

Fig. 4: Concluded

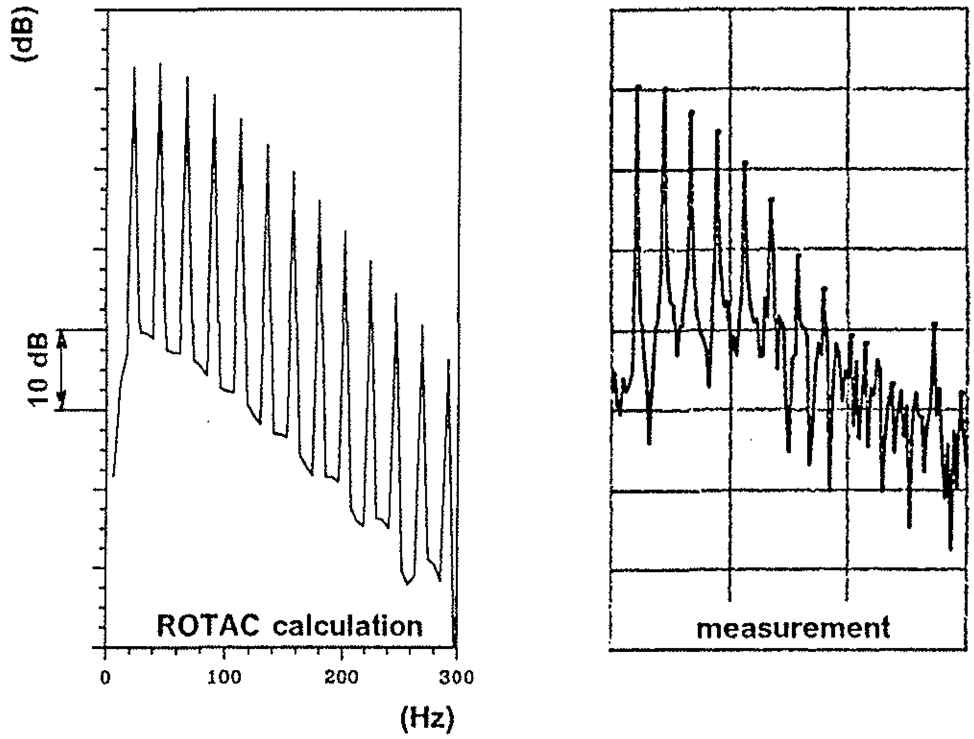


Xc = 400 m, Yc = 0 m, Zc = 30 m

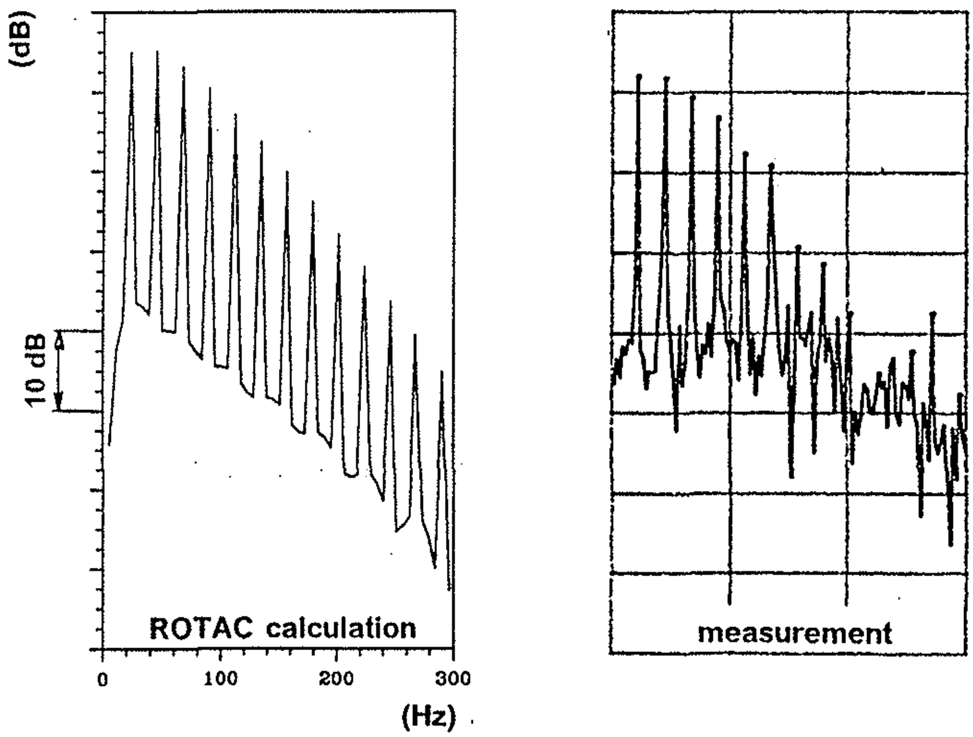


Xc = 300 m, Yc = 0 m, Zc = 30 m

Fig. 5: Comparison of calculated thickness noise spectra with experimental spectra for the helicopter in forward flight (microphone located below the helicopter path); Xc = 400 m, Xc = 300 m, Xc = 200 m and Xc = 150 m



Xc = 200 m, Yc = 0 m, Zc = 30 m



Xc = 150 m, Yc = 0 m, Zc = 30 m

Fig. 5: Concluded

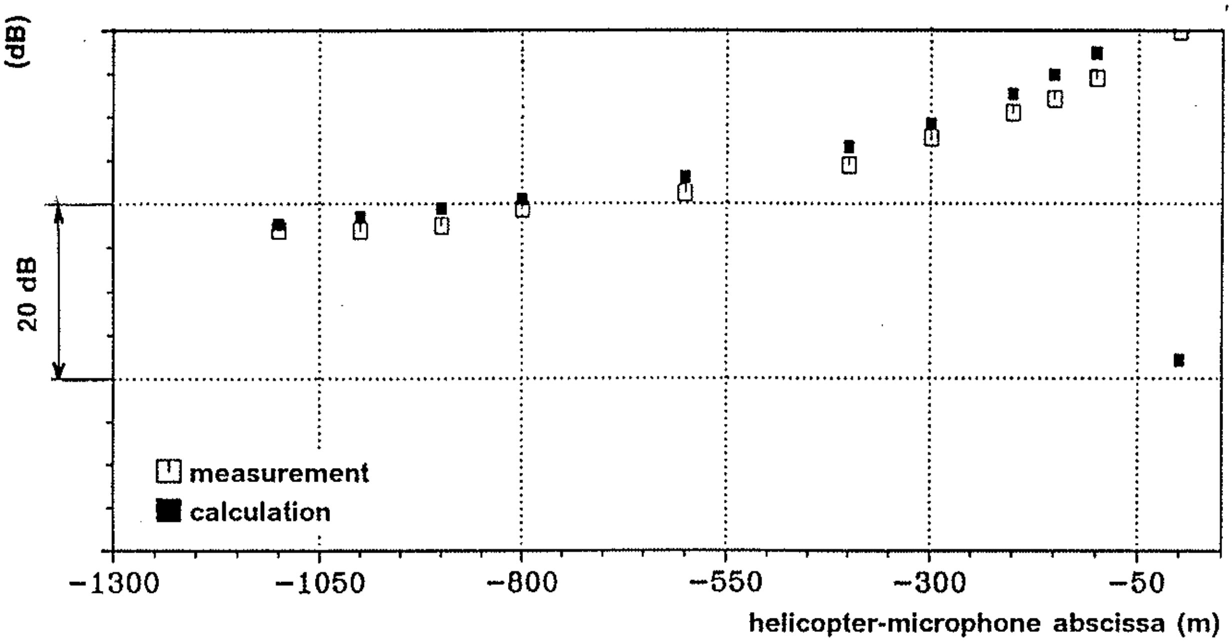


Fig. 6: Comparison of thickness noise calculations with experimental results for the helicopter in forward flight (microphone located below the helicopter path); first harmonic level

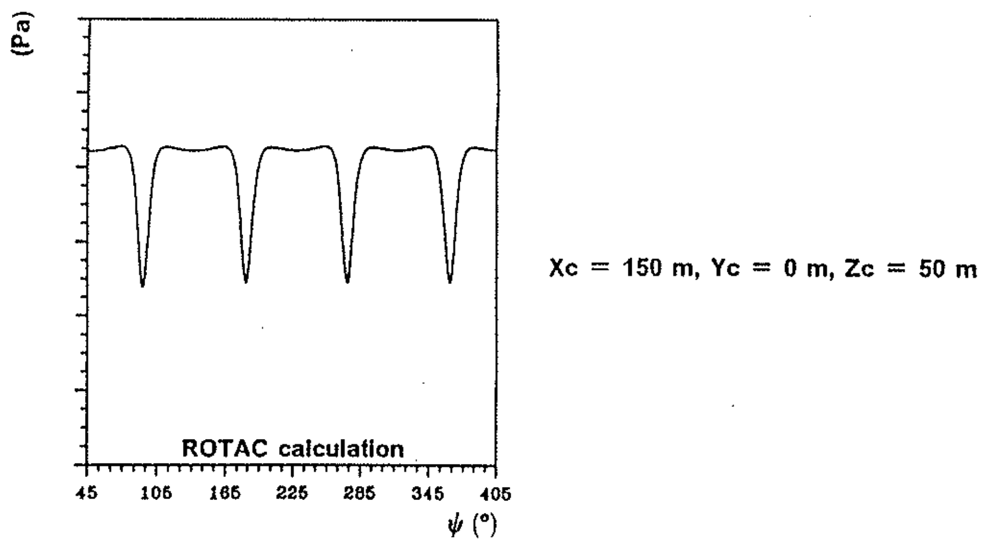
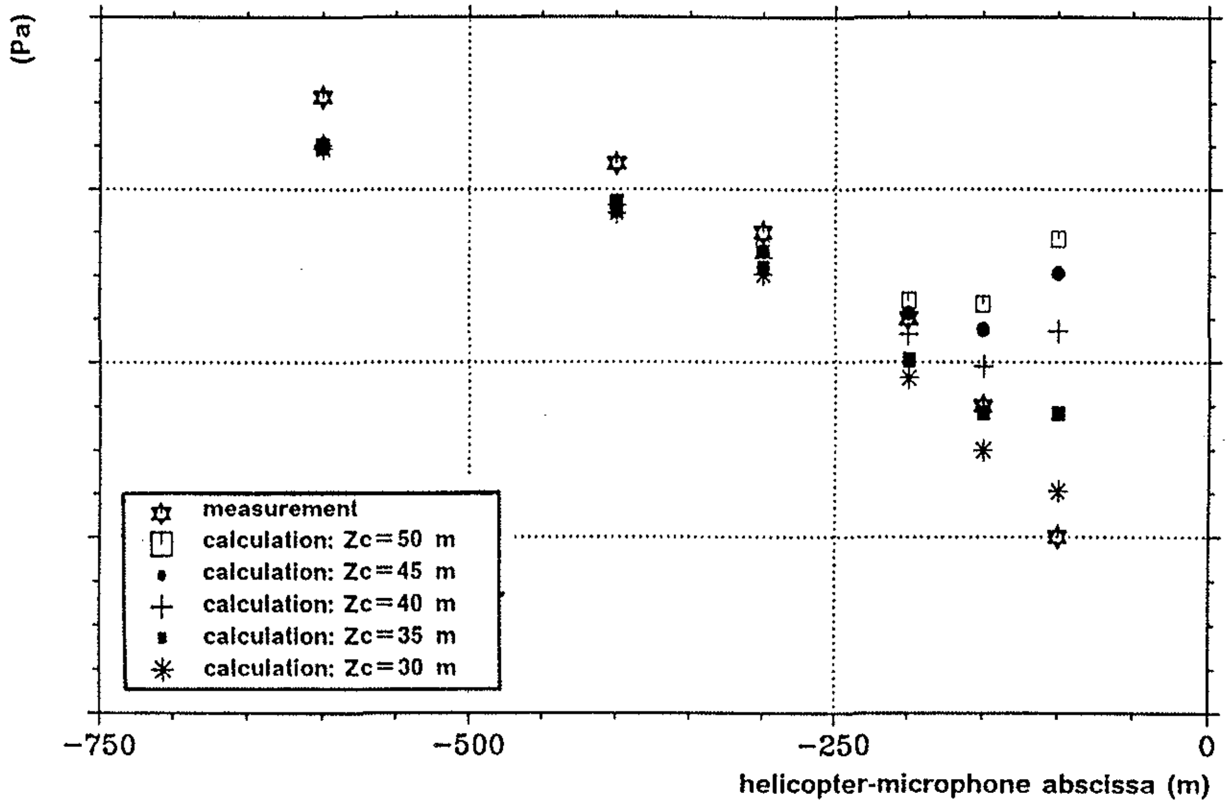
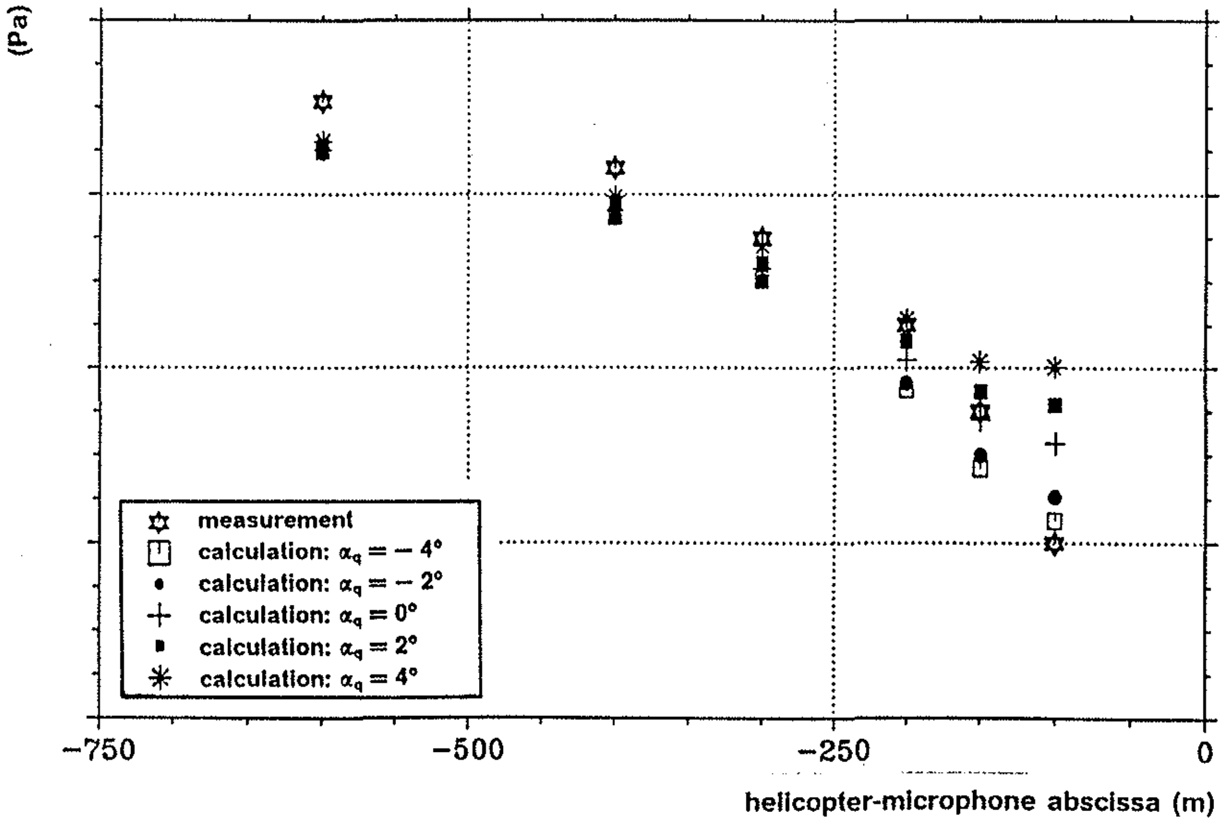


Fig. 7: Thickness noise calculation for the helicopter in forward flight (microphone located below the helicopter path)



a) influence of the height of the rotor, $\alpha_q = -2°$



b) influence of the inclination of the rotor, Zc = 30 m

Fig. 8: Comparison of the amplitude of the measured negative peak with the amplitude of the calculated negative peak for the helicopter in forward flight; (microphone located below the helicopter path)

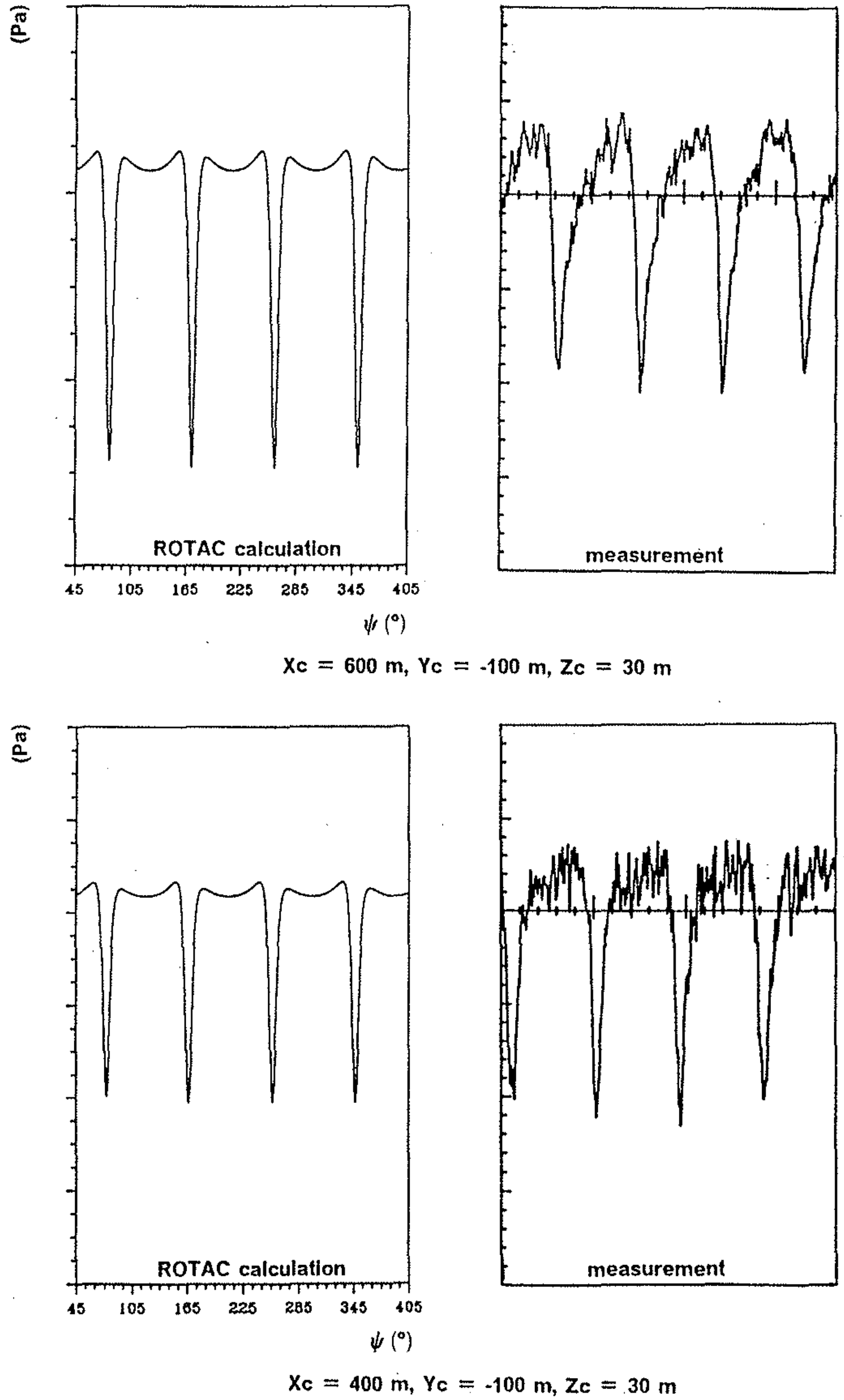


Fig. 9: Comparison of thickness noise calculations with experimental signatures for the helicopter in forward flight (microphone located on the side of the helicopter path)

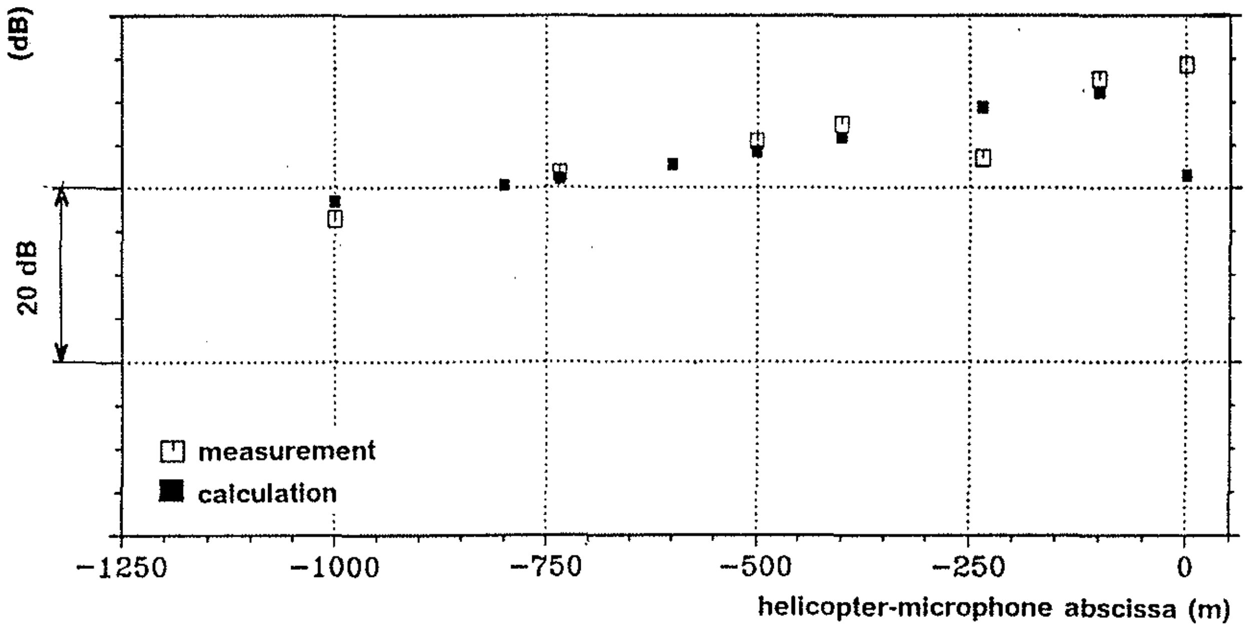


Fig. 10: Comparison of thickness noise calculations with experimental results for the helicopter in forward flight (microphone located on the side of the helicopter path); first harmonic level