TWENTY FIRST EUROPEAN ROTORCRAFT FORUM

Paper No I.8

PRESSURE MEASUREMENTS AROUND A ROTOR MODEL FOR HIGH-SPEED NOSE STUDY

BY

P. Gnemmi, Ch. Johé, J. Haertig

FRENCH-GERMAN RESEARCH INSTITUTE
SAINT LOUIS, FRANCE

August 30 - September 1, 1995

SAINT - PETERSBURG, RUSSIA

Paper nr.: I.8

Pressure Measurement Around a Rotor Model for High-Speed Noise Study.

P. Gnemmi; Ch. Johé; J. Haertig

TWENTY FIRST EUROPEAN ROTORCRAFT FORUM
August 30 - September 1, 1995 Saint-Petersburg, Russia

PRESSURE MEASUREMENTS AROUND A ROTOR MODEL FOR HIGH-SPEED NOISE STUDY

P. GNEMMI - Ch. JOHÉ - J. HAERTIG

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

Abstract

The French-German Research Institute of Saint-Louis (ISL) is involved in aerodynamic and acoustic researches to study the helicopter rotor noise.

The impulsive noise radiated by a helicopter flying at high-speed is generated by its main rotor.
ISL has built a rotor model operating in the open air, which simulates the hovering flight, to study this kind of noise. This rotor model is able to reach transonic speed at the blade tip with a Reynolds number not too far from that of full-scale rotors.

The aim of the experiment presented in this paper consists in measuring, in very near field around the rotor model, the pressure generated by the rotor blades. Two parameters are studied: the distance between the measurement point and the rotor center and the rotation velocity (or the hover Mach number).

Pressure measurements carried out very close to the blade tip are of high quality and they are obtained without great difficulty except when the hover Mach number is close to the delocalization Mach number.
Results are presented for hover Mach numbers ranging from 0.73 to 0.93 and for distances ranging from 1.025 to 1.115 rotor radius.
They give interesting information for analysing the high-speed noise generation and this first signatures collection may be used to validate aerodynamic computations.

Results found in this study are consistent with the few data published previously by other people.

1 - Introduction

The impulsive noise radiated by a helicopter flying at high-speed is produced by its main rotor. The study of this kind of noise has induced ISL to build a hovering rotor model operating in the open air for simulating the high-speed flight. This equipment allows to analyse the flow through and around the rotor and the generated noise.

In this study, pressure measurements are performed in the rotor disk plane in many points located close to the blade tip of the rotor model. The studied parameters are the distance between the measurement point and the rotor center as well as the rotation velocity.

The ISL rotor model is original because it is able to reach transonic speed at the blade tip with a Reynolds number not too far from that of full-scale rotors. The second chapter describes the experimental set-up.

The equipment for pressure measurements includes transducers, signal converters, an acquisition module, a synchronizing mark system mounted on the rotor head associated with a resolver and one minicomputer in order to obtain many instantaneous signatures and a phase average of these signatures. The third chapter presents the description of the instrumentation and the experimental conditions.

A first collection of useful data for the validation of aerodynamic and acoustic computation codes is created. The fourth chapter depicts detailed results of pressure measurements for hover Mach numbers ranging from 0.73 to 0.93 and for distances ranging from 1.025 to 1.115 rotor radius.

The last chapter concludes this study.

2 - ISL rotor model apparatus

The ISL rotor model is built to study the helicopter rotor noise in the hover flight case. This apparatus allows to reach transonic speeds at the rotor blade tip. This equipment is original because the power available at the rotor head and necessary to overcome the drag force is such that the rotor head can be equipped with large chord blades, the chord dimension being at least twice as small as that of real-size helicopter rotor blades and up to 4 times smaller.

This equipment has already been used to carry out different kinds of measurements such as:
- acoustic measurements to the validation of the prediction code of the noise generated by a subsonic helicopter rotor [1, 2];
- measurements of the rotor thrust coefficient and visualizations of the tip vortex of rotor blades (these data are necessary to the validation of the aerodynamic codes [3]);
- visualizations of the shock wave located at the rotor blade tip [4].

The apparatus is essentially built in 3 parts:
- a model of a two-bladed rotor with its driving system;
- a technical room containing the power supply;
- a control and data acquisition room.

The apparatus is described in [2, 3] for details; only some information on the rotor model is given in this paper.

The rotor model is composed from the top to the bottom of:
- a rotor head equipped with the blades, the latter including strain gauges;
- a balance for the measurement of the loads acting on the rotor head;
- a gear box which is connected to a hydraulic motor supplying the power of the rotor.

Figure 1 shows the rotor model installed for previous acoustic measurements. We notice a CCD camera associated with a stroboscope which allows the visual control of the blade tip location on a monitor.

The general characteristics of this equipment are as follows:
- maximal power : 200 kW
- power at the rotor head : 140 kW
- maximal speed of the rotor head : 314 rd/s
- maximal torque : 467 mN
- height with respect to the ground : 2.5 m
- rotation direction seen from above : clockwise.

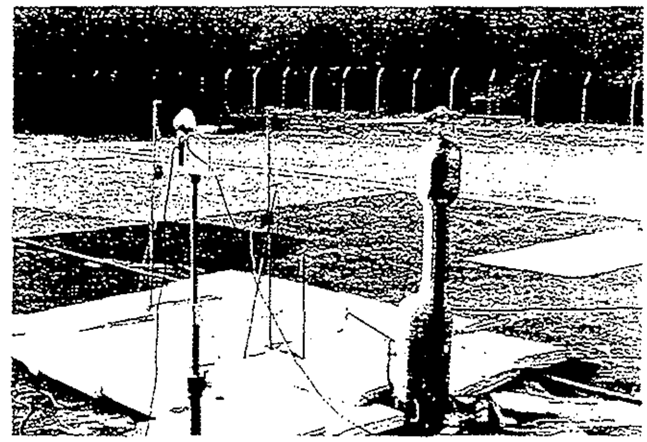


Figure 1: ISL rotor model

The blades are fixed on the rotor head by a horizontal a: allowing a flapping movement of a few degrees. The rotor head has a pitching articulation so that at rest the collective pitch can be changed from 0 to 10° at the blade tip. There is no cyclic pitch as it is not justified in case of hover flight and there is no lagging articulation.

The characteristics of the used blades are as follows:
- rotor diameter : 2 m
- blade root radius : 0.28 m
- type of profile : NACA0012
- profile chord : 0.15 m
- linear twist : -6.945 °/m
- blade mass : 1.4 kg.

Each blade is equipped with 3 bridges of strain gauges which allow the control of the centrifugal force, the bending and the torsion moments.

3 - Data acquisition

The study of the high-speed rotor noise requires the knowledge of the pressure signature in many points located around the rotor model. This is necessary in order to validate aerodynamic computation codes.

The purpose of the study presented in this paper consists in measuring, in very near field, the pressure generated by the blades of our rotor model. Accordingly, a first collection of pressure signatures measured in the rotor disk plane is created. The distance between the measurement point and the rotor center as well as the rotation velocity are the studied parameters.

3 - 1. Instrumentation description

For a given stabilized rotor velocity, a synchronized data acquisition is started when the reference blade releases a one top per revolution signal. A test consists in recording many revolutions; a minimum of 1024 samples are recorded per revolution. So it is possible to analyse each instantaneous measurement and to calculate a phase average signature.

The measurement equipment includes 10 transducers, signal converters, an acquisition module, a synchronizing mark system mounted on the rotor head associated with a resolver and one minicomputer.
The analog signature issued from one transducer goes into a signal converter and after that, it comes into an analog input of the acquisition module, the input having a blocking sampling. The sensor/resolver interface signal also goes into the acquisition module in order to carry out blocked synchronized data acquisitions.

The blocking sampling of a data acquisition consists in starting the acquisition of all input channels at the same time, recording the measured values in an acquisition module buffer and restoring sequentially the data of each channel to the minicomputer.

XCQ-080-25A transducers distributed by Kulite are used: they have a diameter of 2 mm, an eigenfrequency of 200 kHz and it is possible to measure pressures up to 1.7 bar.

Each E300 analog converter from Analogique Numérique Système (ANS) delivers amplified signatures with a passing broadband of 0 to 100 kHz. The signatures presented in this paper are not filtered.

The INF acquisition module from CELI is a fast analog to digital signal converter. It has a programmable clock to scan all input channels. In particular, it has 16 analog input channels with blocking sampling; these channels are used for the pressure measurements carried out in this study. The maximal acquisition frequency for one channel data acquisition is about 600 kHz.

The synchronizing mark system is composed of 2 wheels (1 wheel with 1 tooth, the other with 180 teeth) fixed on the rotor shaft, 3 HEDS 100 and HBCS-1100 optical detectors from Hewlett Packard (HP) and one interface developed at ISL. This system is associated with a 1989 model resolver from TSI to obtain one or more "windows" necessary to start a data acquisition.

The minicomputer HP1000 manages the data acquisition during a test by running a program which stores on a disk the data coming from the acquisition module.

3 - 2. Experimental conditions

This experiment was carried out in winter, so this has allowed to reach a nearly sonic hover Mach number (Mh).

We have recorded the pressure signatures at 10 measurement points around the rotor model for hover Mach numbers ranging from 0.728 to 0.935 with a step of about 0.25. The collective pitch is null at the blade tip. The coning angle is not measured, but many previous tests have demonstrated that this angle varies from -2° to 2°, according to the rotation speed of the rotor.

The temperature varies from 3°C to 3.3°C during this experiment and the atmospheric pressure is constant; it equals $0.994 \cdot 10^5$ Pa.

A test is only described by its hover Mach number as there is no ambiguity.

Pressure measurements are synchronized with the blade rotation in order to obtain a phase average of 8 instantaneous signatures. The recording duration of a signature is nearly one rotor revolution, so that the real rotation speed can be determined. Each instantaneous signature is recorded with a cadence of 1024 samples when the hover Mach number is lower than 0.83 and it is recorded at 2048 moments for the others.

The minimal period of sampling is equal to 17 μs when 10 signatures are recorded simultaneously (1.5 μs per channel + 2 μs; the duration of 2 μs is used for the blocking command of the data acquisition). So the sampling rate ranges from 40 kHz to 100 kHz, depending on the number of measurement points and on the rotation velocity.

3 - 3. Transducers arrangement

The blade velocity of a rotor in hover flight is uniform with respect to the medium without aerologic disturbances. At that time, the noise directivity is circular in planes which are parallel to the rotor disk plane. So only the noise propagation in such parallel planes must be studied for this kind of flight configuration.

The transducers are arranged in a horizontal plane: their height with respect to the ground corresponds to the location of the symmetry plane of the blade tip when the rotor is at rest. Figure 2a shows the transducers arrangement.

Figure 2b depicts the top view of the experimental set-up and the table indicating the distance between the transducers and the rotor center (R) divided by the rotor radius (R_r). The direction of the arrangement is chosen as indicated on the figure as it allows a fine spacing (R/R_r) with enough distance between transducers.

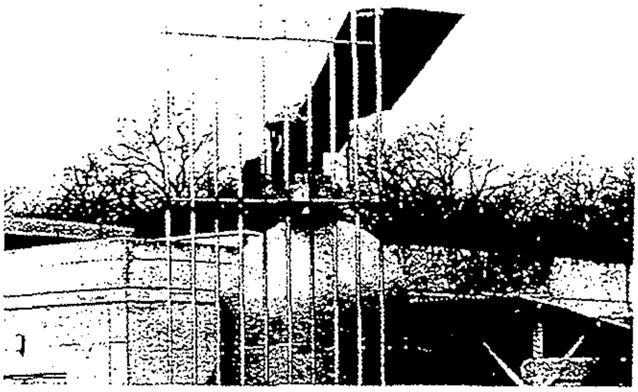
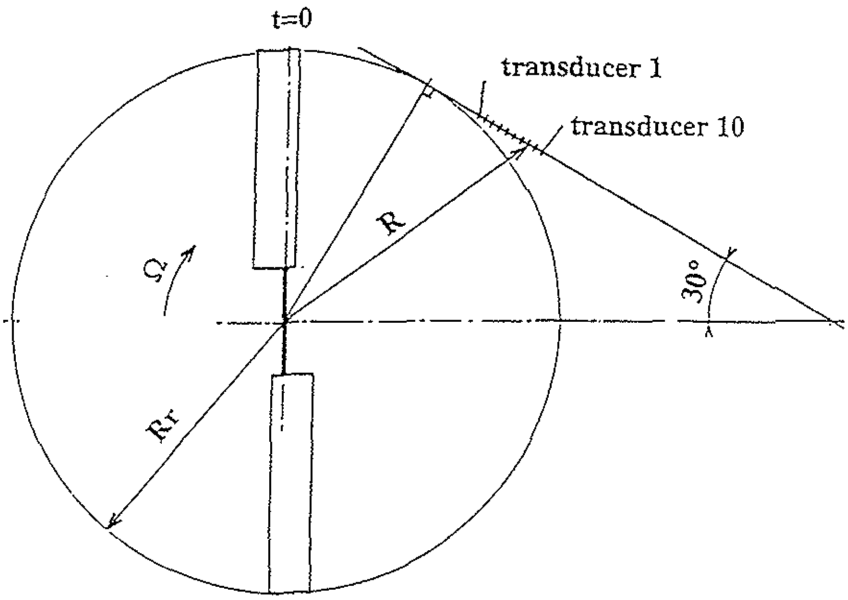


Figure 2a: Transducers arrangement



Transducer	R/R_r
1	1.025
2	1.032
3	1.039
4	1.048
5	1.057
6	1.067
7	1.078
8	1.090
9	1.102
10	1.115

Figure 2b: Top view of the experimental set-up

The choice of this transducers arrangement is also suggested by the study of the delocalization phenomenon [5 to 7]. This phenomenon concerns all people interested in the high-speed noise radiated by helicopter rotors.

Figure 3 extracted from [6] recalls the explanation of the phenomenon:
We consider a rotor in hover flight and a rotating frame fixed to the rotor blades turning at a rotation velocity of Ω. The sonic cylinder is defined as the cylindrical surface whose axis is the rotor axis and whose radius R_s is such that $\Omega R_s = a_0$ (a_0 being the sound velocity). A fixed spatial point has a subsonic velocity with respect to the rotating frame for $R<R_s$ (the point is inside the sonic cylinder) and it has a supersonic velocity for $R>R_s$ (the point is outside the sonic cylinder).

One or more supersonic zones appear in the vicinity of the blade from a certain rotation velocity of the rotor (figure 3, Mh=0.85). This supersonic zone gradually grows beyond the blade span as the rotation velocity increases (figure 3, Mh=0.88). When the supersonic zone reaches the sonic cylinder the delocalization phenomenon appears. The noise directly radiates in the far field for Mach numbers greater than the delocalization Mach number (figure 3, Mh=0.90).

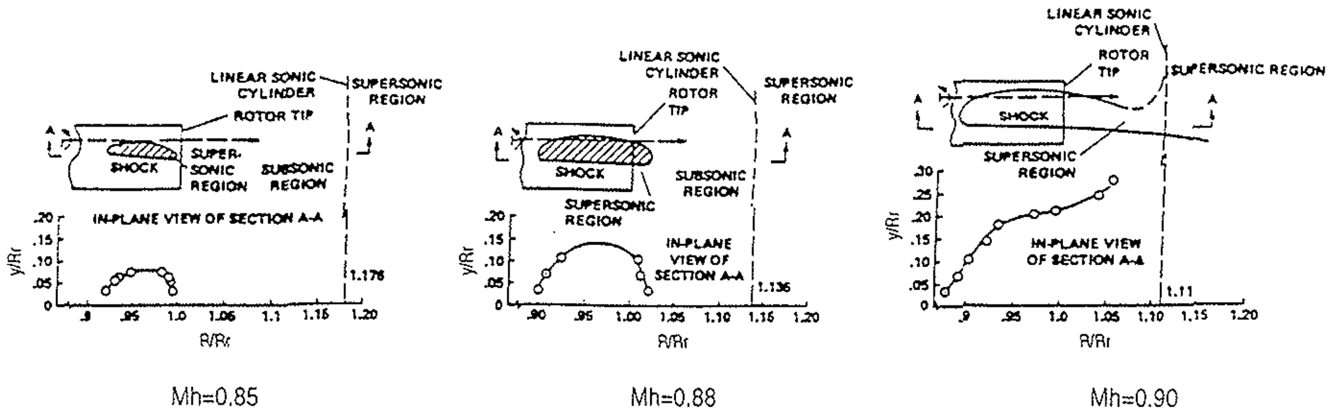


Figure 3: Delocalization phenomenon, figure extracted from [6]

4 - Pressure measurements

We present detailed results of pressure measurements for hover Mach numbers of 0.803, 0.879 and 0.935. After that, we examine the influence of the hover Mach number on transducers located at R/Rr of 1.025, 1.057 and 1.115. Finally, a global analysis of these tests is made to avoid repeating the same remarks. All the detailed results of tests carried out during this experiment are presented in [8].

The pressure generated by one blade or the other can be different if the blades are not exactly the same, that is why only the signatures generated by the same blade are reproduced.

The delocalization Mach number is near 0.88 in the case of our rotor [5 to 7]. So the data sampling rate is twice as high for tests whose hover Mach number is greater than 0.85. This leads to record the pressure signatures by groups of 5 transducers in case of Mh>0.85. When the first data acquisition for 5 transducers is finished, the second one is started without modifying the rotation velocity of the rotor.

The signatures are only plotted during a few milliseconds to show the interesting part of the pressure generated by one blade passage. The abscissa of each plot depicts the duration: it can be noticed that the receiving time of the signal is counted when the blade is seen by the camera (t=0 on figure 2b).

4 - 1. Mh=0.803

Figures 4 and 5 depict 8 instantaneous pressure signatures and the mean signature obtained respectively on the first (R/Rr=1.025) and the tenth (R/Rr=1.115) transducers for a hover Mach number of 0.803.

The mean signature is time shifted for the sake of clarity on these figures. These results show that the phenomenon is well reproducible. The amplitude of the negative peak on the tenth transducer is nearly 4 times lower than the one obtained on the first transducer.

Figure 6 shows mean signatures carried out on all transducers; the difference between the shapes due to the wave propagation can be noticed. The markers on the first transducer signature depict the data sampling rate.

4 - 2. Mh=0.879

Figures 7 and 8 also show pressure signatures on the same transducers as before for a hover Mach number of 0.879. On figure 7, a shock sometimes appears clearly on instantaneous signatures and at times, the shock is not so visible.

This Mach number is probably very close to the delocalization Mach number [5 to 7] and very slight disturbances of the medium may have a large effect on the radiated pressure.

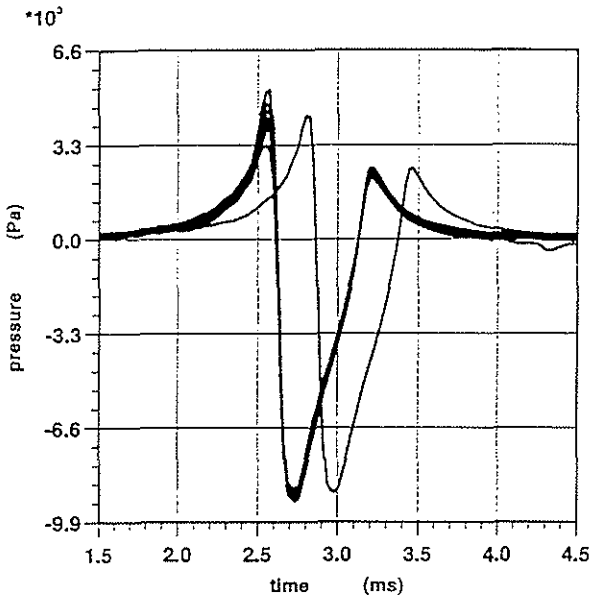


Figure 4: Pressure measurements; 8 instantaneous signatures and mean signature, Mh=0.803, transducer 1, R/Rr=1.025

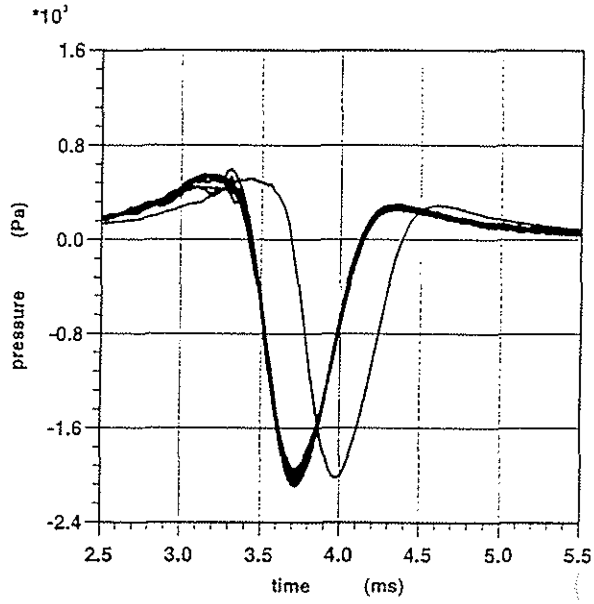


Figure 5: Pressure measurements; 8 instantaneous signatures and mean signature, Mh=0.803, transducer 10, R/Rr=1.115

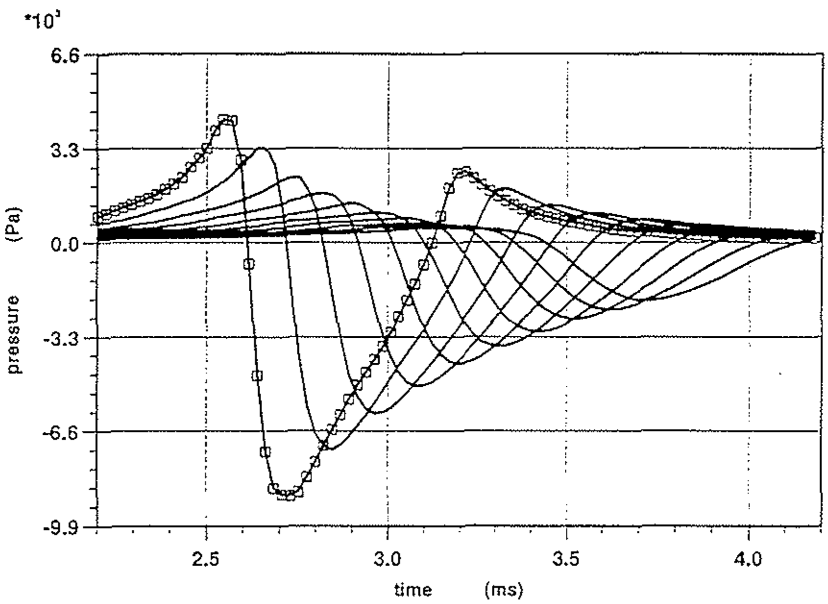


Figure 6: Pressure measurements; mean signatures on 10 transducers, Mh=0.803

Figure 9 depicts mean signatures obtained on all transducers; a shock wave is propagated from the first to the fourth transducer with a great attenuation and it does not appear on the seventh one.

The sonic cylinder radius R_s is $1.138 \cdot R_r$ so all transducers are located inside the sonic cylinder. No shock is propagated outside the latter: the supersonic zone existing in the blade vicinity extends beyond the blade tip without reaching the sonic cylinder.

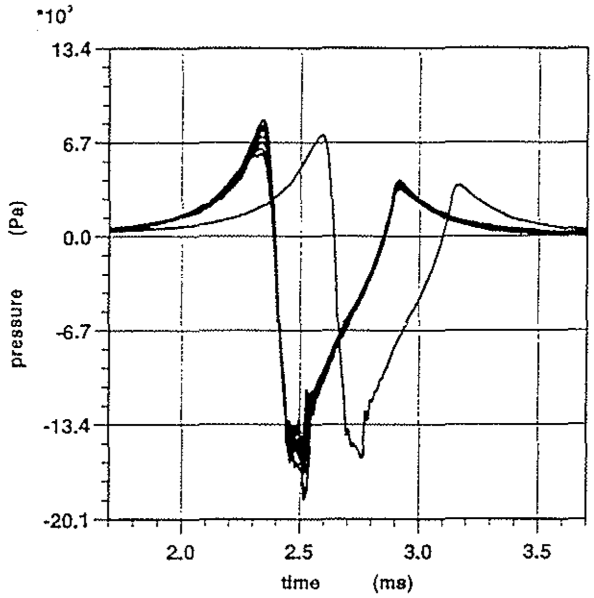


Figure 7: Pressure measurements; 8 instantaneous signatures and mean signature, Mh=0.879, transducer 1, R/Rr=1.025

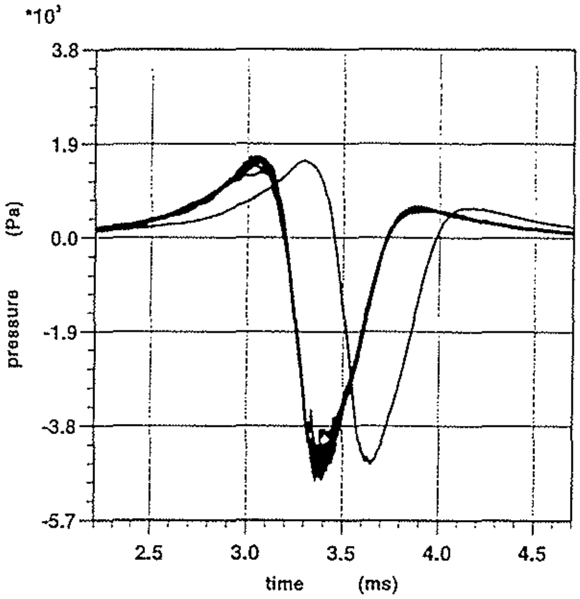


Figure 8: Pressure measurements; 8 instantaneous signatures and mean signature, Mh=0.879, transducer 10, R/Rr=1.115

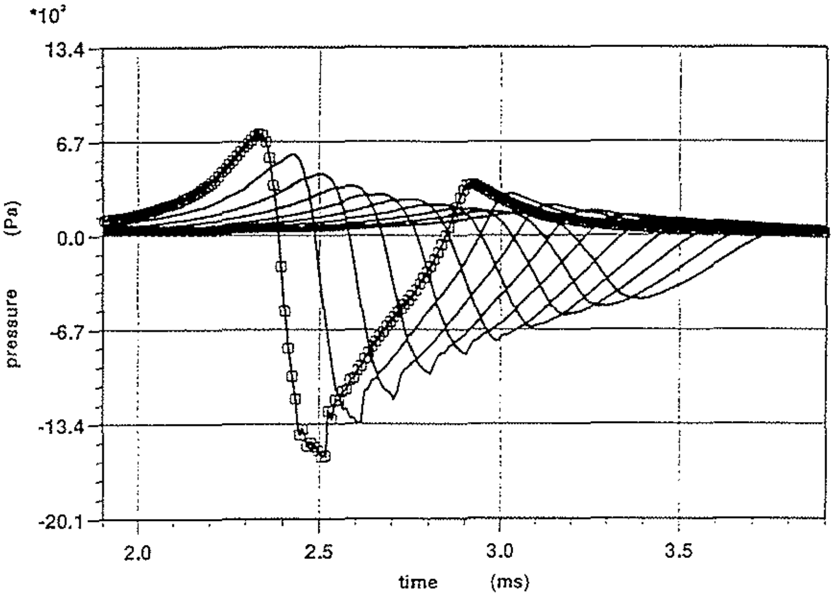


Figure 9: Pressure measurements; mean signatures on 10 transducers. Mh=0.879

4 - 3. Mh=0.935

Figures 10 and 11 show the same kind of results as before for a hover Mach number of 0.935. The amplitude of the negative peak on the last transducer is nearly twice as low as the one obtained on the first transducer. Once more, the similarity of the 8 recorded signatures can be noticed.

Figure 12 depicts the mean signatures obtained on all transducers; a strong shock wave is propagated from the first to the tenth transducer. The suction amplitude decreases by about 10% from one transducer to the other. The attenuation of the positive part of the signature does not follow the attenuation law of its negative part.

The sonic cylinder has a radius of 1.070.Rr, its border is located near the sixth transducer, so the shock is propagated outside the sonic cylinder: the supersonic zone existing in the blade vicinity extends beyond the sonic cylinder.

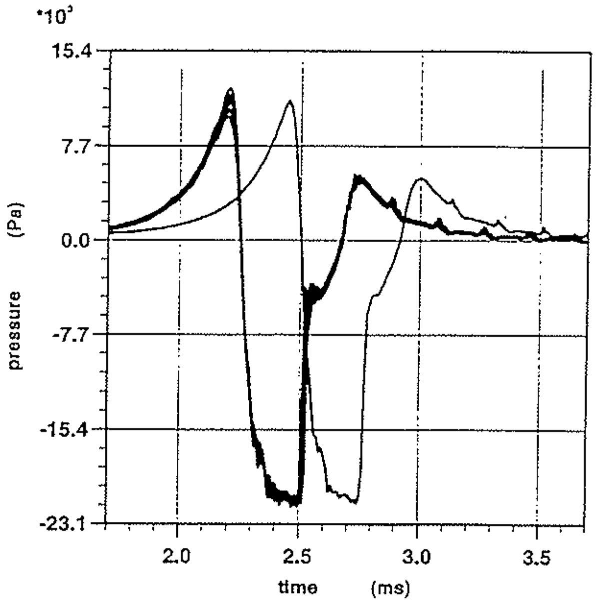


Figure 10: Pressure measurements; 8 instantaneous signatures and mean signature, Mh=0.935, transducer 1, R/Rr=1.025

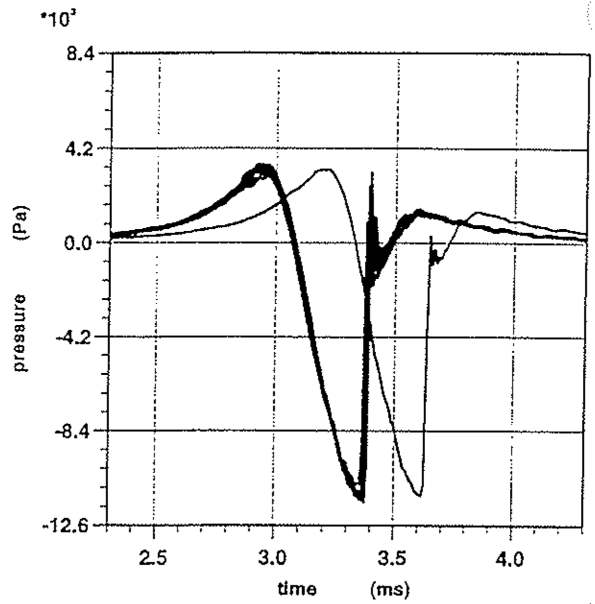


Figure 11: Pressure measurements; 8 instantaneous signatures and mean signature, Mh=0.935, transducer 10, R/Rr=1.115

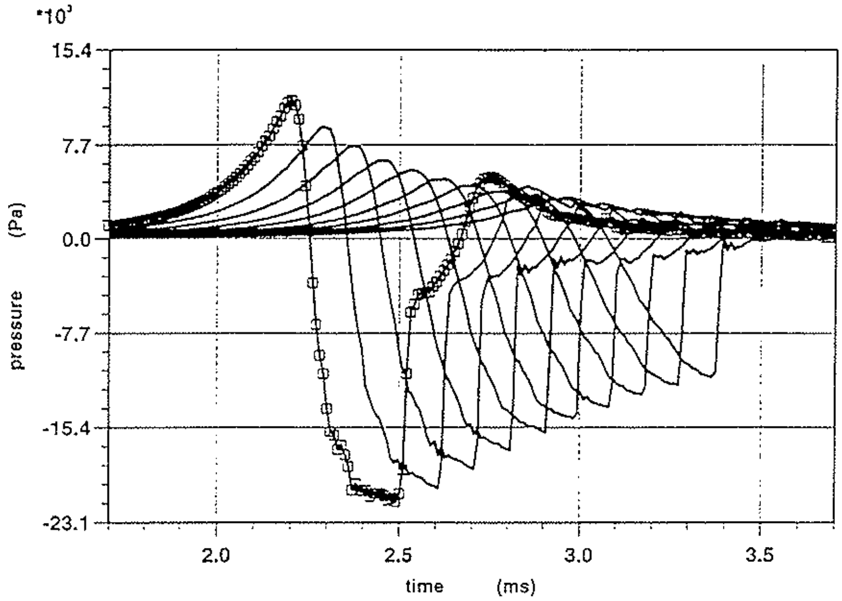


Figure 12: Pressure measurements; mean signatures on 10 transducers, Mh=0.935

4 - 4. Influence of the hover Mach number on 3 transducers

Figures 13 to 15 show the influence of the hover Mach number on the first, the fifth and the last transducers.

There is no shock wave on the first transducer up to a hover Mach number of 0.852 and a shock takes place above this value. This shock is visible only for hover Mach numbers of 0.905 and 0.935 on the fifth transducer.

There is no measurement presented on the last transducer for the hover Mach number of 0.905 because measurements carried out on transducers 5 to 10 are uncertain.

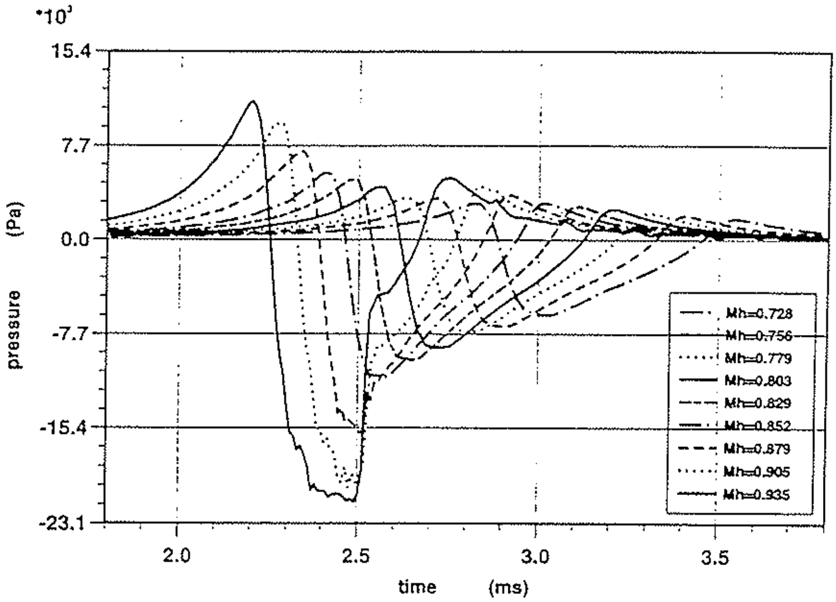


Figure 13: Pressure measurements; mean signatures for 9 hover Mach numbers on the first transducer, R/Rr=1.025

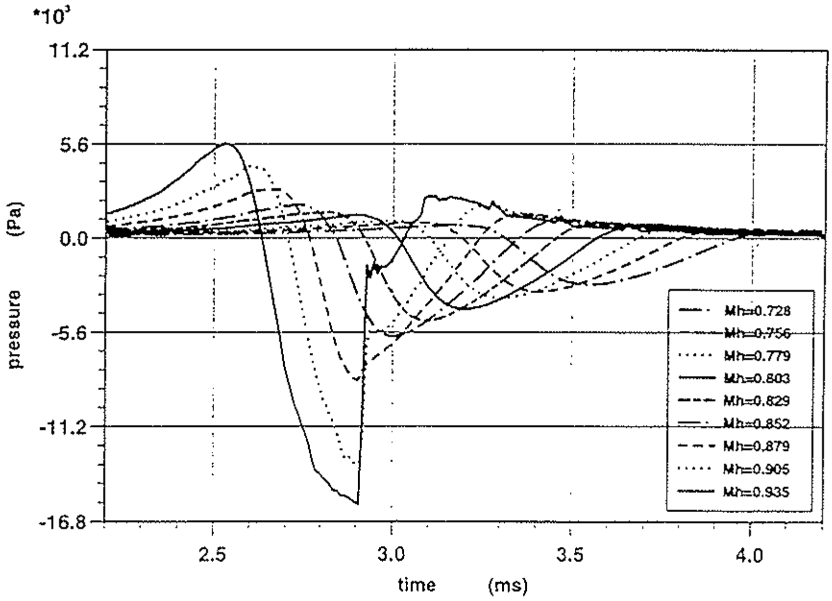


Figure 14: Pressure measurements; mean signatures for 9 hover Mach numbers on the fifth transducer, R/Rr=1.057

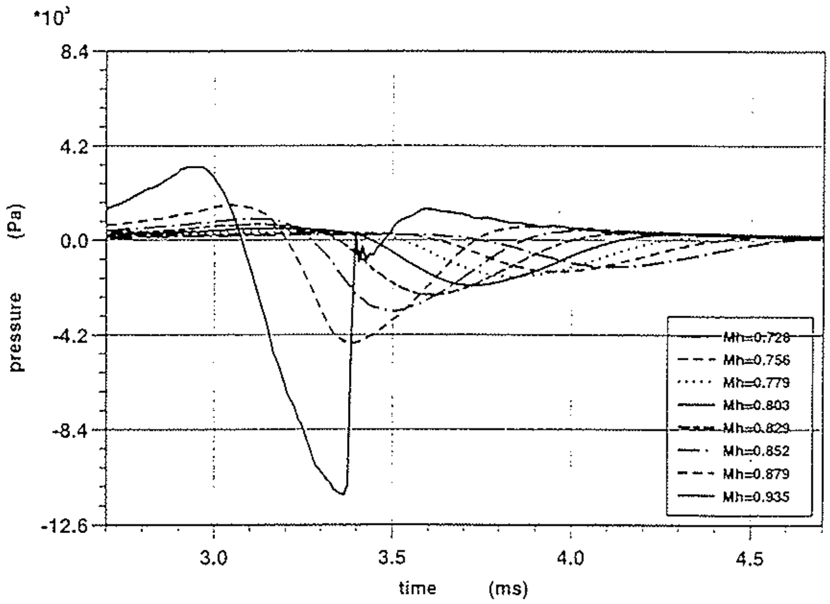


Figure 15: Pressure measurements; mean signatures for 8 hover Mach numbers on the tenth transducer, R/Rr=1.115

4 - 5. Global analysis of the tests

The movement of a blade produces an overpressure on the transducer followed by a suction whose amplitude can be up to 3 times higher. It follows a new increase of the pressure or a shock wave, according to the low or the fast rotation velocity of the rotor. Then, the pressure comes back to the ambient amplitude.

The amplitude of the negative peak measured on a transducer increases as the rotation velocity increases, the duration of the negative part of the signature decreases at the same time.

Considering the receiving moment of the minimal pressure called t_{np}, we can define a part of the signal for the anterior moments (left part) and another part of it for the posterior moments (right part) of t_{np}. The analysis of the suction leads to some remarks:

- the signal parts situated on the left and the right of t_{np} are asymmetric on the first transducer for any rotation velocity (figures 4, 7, 10 and 13);
- the signal parts on the left and the right of t_{np} tend to be gradually symmetric as one goes away from the blade tip (or as R/R_r increases) when the hover Mach number is lower than the delocalization Mach number; from a V shape at lower speeds (figures 5 and 15) it changes into a sawtooth shape at the higher ones (figures 11 and 15);
- there is no shock wave for hover Mach numbers lower than 0.852 (figures 13 to 15).

5 - Conclusion

The rotor model of a helicopter is operational at ISL to study the radiated noise of a rotor in hover flight. The rotor model is able to reach a transonic speed at the blade tip with a Reynolds number not too far from that of full-scale rotors.

The data acquisition automatically managed by a minicomputer allows to record all kinds of measurements synchronized with the blade rotation.

Pressure measurements presented in this paper and carried out very near the blade tip are of high quality on condition that measurements altered by aerologic disturbances are carefully eliminated. These measurements are carried out without great difficulty except for hover Mach numbers close to the delocalization Mach number.

These pressure measurements give interesting informati for analysing the high-speed noise generation and this fi signatures collection may be used to validate aerodynamic computations.

Results found in this study are consistent with the few ones previously published by other people:

- the delocalization Mach number of the ISL rotor model is between 0.88 and 0.90 for non-lifting blade tip;
- the supersonic zone attached to the blade extends up to the sonic cylinder for a hover Mach number greater than the delocalization Mach number. The shock wave is propagated in far field producing a very impulsive noise.

We wish to improve this collection by performing pressure measurements in the same horizontal plane for hover Mach numbers ranging from 0.85 to 0.90 for a bett understanding of the delocalization phenomenon.

We also wish to carry out pressure measurements like those presented in this paper associated to far field acoustic measurements necessary to the validation of simultaneously aerodynamic and acoustic computation codes.

Bibliography

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

[2] 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

[3] P. GNEMMI, J. HAERTIG, Ch. JOHÉ, F. ALBE
Measurements on the ISL rotor model
15th International Congress on Instrumentation in Aerospace Simulation Facilities (ICIASF'93), ISL, Saint-Louis, France, September 20-23, 1993
ISL report - PU 351/93, 1993

[4] F. ALBE, J. HAERTIG
Visualisation des ondes de choc aux extrémités des pales d'hélicoptères
5ème Colloque National de Visualisation et de Traitement d'Images en Mécanique des Fluides, Poitiers, France, June 2-5, 1992
ISL report - CO 220/92, 1992

[5] F.H. SCHMITZ, Y.H. YU
Transonic rotor noise - Theoretical and experimental comparisons
6th European Rotorcraft and Powered Lift Aircraft Forum, Bristol, England, September 1980
Vertica, Vol. 5, pp. 55-74, 1981

[6] F.H. SCHMITZ, Y.H. YU
Helicopter impulsive noise: theoretical and experimental status
International Symposium on Recent Advances in Aerodynamics and Aeroacoustics, Stanford University, Palo Alto/CA, USA,1983
Journal of Sound and Vibration, Vol. 109, No. 3, pp. 361-422, September 1986

[7] J. PRIEUR
Calculation of transonic rotor noise using a frequency domain formulation
AAIA Paper No. 86-1901, July 1986
AAIA Journal Vol. 26, No. 2, pp. 156-162, February 1988

[8] P. GNEMMI, Ch. JOHÉ, J. HAERTIG
Mesures de pression autour du banc rotor de l'ISL pour l'étude du bruit à grande vitesse
ISL Report to be publishedk