TWENTY FIRST EUROPEAN ROTORCRAFT FORUM

Paper No I. 6

IMPULSIVE NOISE OF THE HELICOPTER TAIL ROTOR

BY

V.F. Samokhin

Central Aero-hydrodynamics Institute (TsAGI)
Acoustic Division,
Moscow, Russia

August 30 - September 1, 1995
SAINT - PETERSBURG, RUSSIA

Paper nr.: I.6

Impulsive Noise of the Helicopter Tail Rotor.

V.F. Samokhin

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

TWENTY FIRST EUROPEAN ROTORCRAFT FORUM

August 30 - September 1, 1995

St. PETERSBURG RUSSIA

IMPULSIVE NOISE OF THE HELICOPTER TAIL ROTOR

V.F.Samokhin

Central Aero-hydrodynamics Institute (TsAGI)
Acoustic Division, Moscow, Russia

SUMMARY.

Sound pressure measurement results received in the tail rotor rotation plane are presented. The measurements are performed by microphones mounted on the helicopter fuselage wall flush with the surface. Processing of the measurement results is realized with the use of the method of synchronized averaging. It's found that in the impulsive acoustic radiation propagating in the rotation plane of the tail rotor no nonlinear effects are revealed which are responsible for the impulse formsymmetry distortion. This is supposed to be caused by the influence of external environments turbulization on a delay in the tip shock wave formation at the rotor blade tip.

INTRODUCTION.

It is well - known [1,2] that one of the main sources of the community noise produced by a single-rotor helicopter with a multiblade (more then 3 blades) main rotor (MR) is the tail rotor (TR). The rotation planes of MR and TR are orthogonal and TR rotation plane is normal to the ground surface. Therefore the acoustic radiation, formed and propagating in the TR rotation plane, plays an important role in the total noise level produced by the helicopter in the community.

A great number of works relates to studies of acoustic radiation in the rotation plane of a separate helicopter rotor operating in the regimes of axial or oblique streamlining and partially they are presented in the review [3].

Investigations were performed on stands in the open air and in wind tunnels. Some tests were realized in flight on full-scale helicopters. In the latter case the method of a "flying microphone" was used, when the microphone was set on an aircraft following the helicopter and the acoustic radiation in the MR rotation plane was investigated.

In tests on the stand and in flight the rotor operated practicaly in the undisturbed environments and during wind tunnel tests it operated in a weakly turbulent flow. At the same time the real TR in the regime of oblique streamlining almost always operates under conditions of disturbed external environments.

The environments disturbance is caused by MR functioning, by turbulent wakes after the fuselage, by bushing and wing of the helicopter and by engine jet. Specific conditions of the TR functioning in comparison with MR can also influence on the TR noise production regularities.

MEASUREMENT METHODS.

The work presents the experimental investigation results received in measurements of TR acoustic radiation characteristics of a helicopter Mi-24 in the rotor rotation plane. The TR rotation noise component with a discrete harmonic spectrum was examined.

The sound pressure level measurements were carried out by two microphones set (Fig. 1) on the side surface of the helicopter fuselage ($N1$ - $\overline{X} = X/d_{TR} = 2.48$) and on the tail beam ($N2$ - $\overline{X} = 0.98$, here X is the distance from the microphone to the TR rotation axis). Protecting screens of the microphone caps were mounted flush with the wall. As a measuring and registrating equipment the set of electroacoustic devices of the companies "Bruel and Kjær" and "RFT" was used.

The measurement tracks had a linear amplitude-frequency characteristic in the frequency range of 20-10000 Hz. Flight velocity and altitude, pitch angles, slip and slope angles were evaluated with the help of the measurement system on board the helicopter and were recordered on a multi-channel lightbeam recording oscillograph. Signals from the microphones as well as synchronization signals from special pick-ups of MR and TR rotations were recorded with the help of a multi-channel tape-recorder of the firm "Sony".

Tests were carried out at the helicopter level flight with the relative velocity values $\mu = V/\omega R = 0.156-0.399$, where V is the air velocity, $\omega = 2\pi n$ is the angular velocity of the MR rotation, R and n are the MR radius and the number of the MR revolutions, respectively. The flights were performed at the altitude of 100-150 m with the atmosphere parameters at the height of 10 m: air temperature (-6^{o}C), relative humidity 96%, barometric pressure 761 mm of mercury column. The helicopter take-off mass during the tests was 10500 kg.

PROCESSING METHODS.

The aim of processing was to receive time samples of sound pressure and narrow-band pressure spectra in a wide frequency range. To receive this information a two-channel real time analyzer, type 2034, of the firm "Bruel and Kjær" was used. The analyzer provides that the signal quantization frequency would be 65 kHz and the volume of the time sample would be 2048 values; the frequency samplewould have 801 narrow bands and the frequency solution would be determined by an overall frequency interval of the narrow-band spectrum: at the spectrum frequency interval 3.2 kHZ the frequency solution is ~ 4 Hz. The most significant element of processing a signal from the microphone which provides separation of the TR periodic signal against the background of random acoustic interference and the MR background radiation is the method of synchronized averaging. The sound pressure spectrum was found by use of the Fourier transform of the averaged time sample of the signal. This time sample was the ensemble average of special samples from the measured time sample. The samples were realized in such a way that their beginning was synchronized with some fixed position of blades in the rotor disk plane. To synchronize separate samples a periodic signal was used which was taken from the special pick-up of the rotor revolutions. In this case in the averaged time sample of the sound pressure the periodic component of the useful signal is kept without changes and random noise generated by different noise sources of the helicopter (MR, reductors, transmissions, engines) as well as the naturel noise, of the measurement system are suppressed.

The method of synchronized averaging permits to reduce random noise levels by the value of $\sim 10\lg A$, where A is the number of samples used to receive an averaged time sample. Figure 2 [4] shows as an example three plots of the spectral density of sound pressure correspponding (a) to the reference time sample, (b) to the averaged time sample received with the use of the synchronized averaging according to the TR revolutions and (c) to the MR revolutions. It is seen that for $A = 100$ the random noise level reduction, for instance, in the frequency range of 1500-2000 Hz is 20 dB and the harmonic noise component levels of the TR (Fig. 2b) and of the MR (Fig. 2c) practically are not changed in this case. The time samples of sound pressure corresponding to the ones shown in Fig. 2 are pressented in Fig. 3 [4], where a) is the reference time sample; b) is the sample received by synchronized averaging according to the TR revolutions and c) is the sample received by synchronized averaging according to the MR revolutions. All the samples are received from one and the same microphone. It can be seen that this method of averaging permits to separate an impulse component of the TR acoustic radiation and a periodic component of the MR acoustic radiation from the total signal.

THE MAIN RESULTS.

Investigations of the acoustic field in the isolated rotor rotation plane in the regimes of axial and oblique streamlining, of the helicopter MR in the regime of a horizontal flight show [3], that one of the most important characteristics of this field is the presence of a rerefaction impulse sequence in the time sample of sound pressure. In case of a low flight velocity of the helicopter and respectively lower Mach numbers of the effective flow at the tip section of the advancing rotor blade ($\mu = 0.183$ $M_e < 0.87$), the rarefaction impulse is of a symmetrical form (Fig.4 [5]). Such form of the disturbance pressure wave is associated with medium displacement by the advancing blade body and the acoustic radiation of this type is reffered to as "displacement noise" of the helicopter rotor. With the helicopter flight velocity increase ($\mu > 0.229$) and the Mach number increase ($M_e > 0.87$) the rarefaction impulse symmetry is destroyed and the impulse takes of a saw-like form. The pressure disturbance impulse has two fronts: the trailing front corresponds to the phase of rarefaction and the leading front corresponds to the phase of compression. At higher values of the effective flow Mach number, transformation of the leading front takes place which consists in its steepness increase and transformation of the rarefaction impulse into the compression impulse ($\mu = 0.264$, $M_e = 0.925$). It is supposed [3], that in this case a superposition of impulses of two types takes place: relatively extensive in time (several millisec) rarefaction impulse-"displacement noise" and relatively short in time (fractions of a millisec) compression impulse the source of which is the tip shock wave. This shock wave appears in the medium at the tip section of the advancing blade and is oriented along the blade span. This phenomenon known as delocalization, wherein the supersonic pocket on the blade extends out to the far-field beyond the rotor. It is quite possible that the sound velocity dispersion in the medium with local rupture regions plays a certain role in transformation of the leading impulse front. The similar effect of a weakly nonlinear propagation of disturbances is known in the problem of the shock.

The measurements on board the helicopter Mi-24 have show (Fig. 3 [4]) that rarefaction impulses propagate essentially in the TR disc plane and this proves predominance of thickness effects in the impulse radiation generation.

The preliminary analysis of the time samples of sound pressure measured in the TR rotation plane on board the helicopter Mi-24 in horizontal flight confirms the fact that the rarefaction impulses are formed by an advancing rotor blade when it is passing the fixed space region inside the TR disc. From the geometric acoustics presented it is found that coordinates of this region inside the disc plane correspond to azimutal angles of the blade in the range of 74°-106°. This is confirmed by the ground noise measurement results for helicopters Mi-24 and Mi-28 in forward flight. Fig. 5 shows an experimental dependence of the impulse noise amplitude in the vertical plane of the helicopter flight on the value of φ (φ is the angle between the flight velocity and sound propagation direction in the TR rotation plane). The maximum amplitude occurs when φ has low values i.e. when the TR advancing blade position is close to the position of the normal to the ground surface.

Fig. 6 a),b) presents the results of sound pressure impulse component measurements in the TR rotation plane. The data obtained correspond to the effective flow Mach numbers at the TR blade tip which are 0.8-0.96. It can be seen that pressure disturbance impulse maintains its symmetrical form in the whole range of the effective flow Mach number variation which is of interest (both for instantanious time realizations of the sound pressure

(a) and for realizations obtained by the method of synchronous averaging (b)).This proves the absence of nonlinear thickness effects associated with the tip shock wave radiation which were observed [3] in the MR acoustic field.

Unlike the main rotor, the tail rotor of a helicopter operates in strongly turbulized environments. Turbulization is caused by an induced flow of the MR, by turbulent wakes appearing after the fuselage, by the wing and the bush of the helicopter MR as well as by jets of propulsion systems. It is quite possible that the medium turbulization delays the process of the tip shock wave generation at the TR blades and shifts it into the region of higher effective flow Mach numbers $(M_e > 0.96)$. The absence of an additional source of the acoustic radiation associated with the tip shock wave is also proved by the character of the rarefaction impulse amplitude variation in dependence of the effective flow Mach number M_e (Fig. 7). The impulse amplitude increase gradient which takes place in case of M_e increase is significantly smaller for the TR, than for the MR. The flow Mach number (M_e) increase does not change the spectrum character of the harmonic component of radiation in the TR disc plane: the maximum spectral pressure density is observed at the frequencies of the first two radiation harmonics (Fig. 2). This fact also proves the absence of the pressure impulse sequence generated by the tip shock wave in the TR disc plane impulse radiation.

And the last. Analysis of the dependence of separate harmonics of the impulse noise on the tip Mach numbers of the TR advancing blade (Fig. 8) shows the following.

The nonlinear effects which break the symmetrical form of the negative pressure impulse at high tip Mach numbers of TR blades apparently take place at TR functioning but they are manifested at high harmonics. This is indicated by the velocity of the harmonic level increase at Mach numbers from 0.87 to 0.92 and this velocity significantly increases with increase of the harmonic number. But these harmonics have relatively low numbers and produce no effects on the impulse form of the overall signal.

RESUME.

Since no nonlinear thickness effects are manifested themselves in the impulse acoustic radiation propagating in the TR rotation plane up to the high effective flow Mach numbers $(M_e < 0.96)$, a possibility appears to realize prediction of the acoustic field in the helicopter TR disc plane using the well-known linear theories. This conclusion can turn out valid also in application to the aircraft propeller in a pusher configuration.

REFERENCES.

1. A.G.Munin, V.F.Samokhin, R.A.Shipow, etc.
Aviation acoustics. Methods of aircraft and helicopter community noise prediction, M., Mashinostroyenie, 1986.

2. V.F.Samokhin, M.G.Rozhdestvensky
External Noise of Single-Rotor Helicopters.
Pres. at the 75th AGARD Fluid Dynamics Panel Simposium on Aerodynamics and Aeroacoustics of Rotorcraft, Berlin, Germany, 1994.
3. F.N.Schmitz, Y.H.Yu
Helicopter impulsive noise: theoretical and experimental status.
J. of Sound and Vibr., 109(3), 361-422, 1986.
4. V.F.Samokhin, A.M.Ermilov, I.K.Kozhevnikova
Acoustic Radiation of the Tail Rotor at High Flight Velocity of Helicopter,
Pres. at the First Forum of the Russian Helicopter Society, Moscow, Russia, 1994.
5. F.H.Schmitz, D.A.Boxwell, C.R.Vause
High-speed helicopter impulsive noise.
J. of the American Helicopter Society, IV, 22 , p.p. 28-36, 1977.
6. A.R.George
Helicopter Noise-State of the Art.
AIAA Paper 77-1377, 1977.

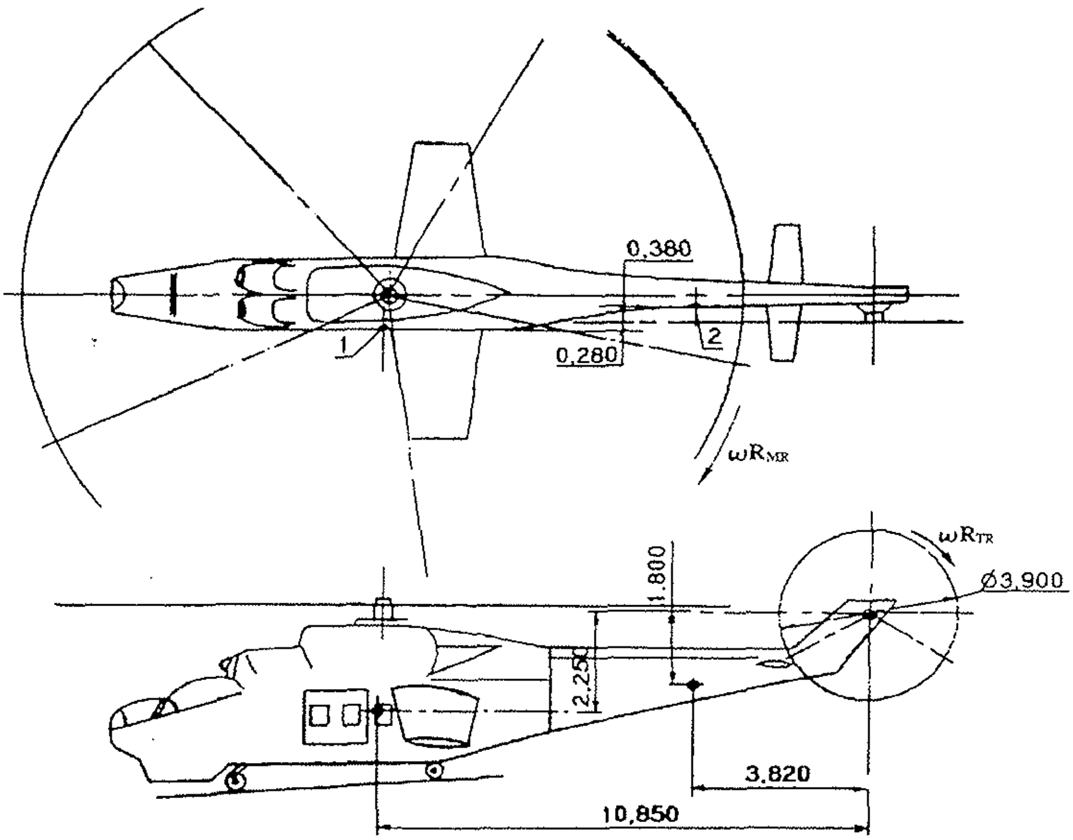

Fig. 1. Position of sound pressure receivers on the helicopter frame.

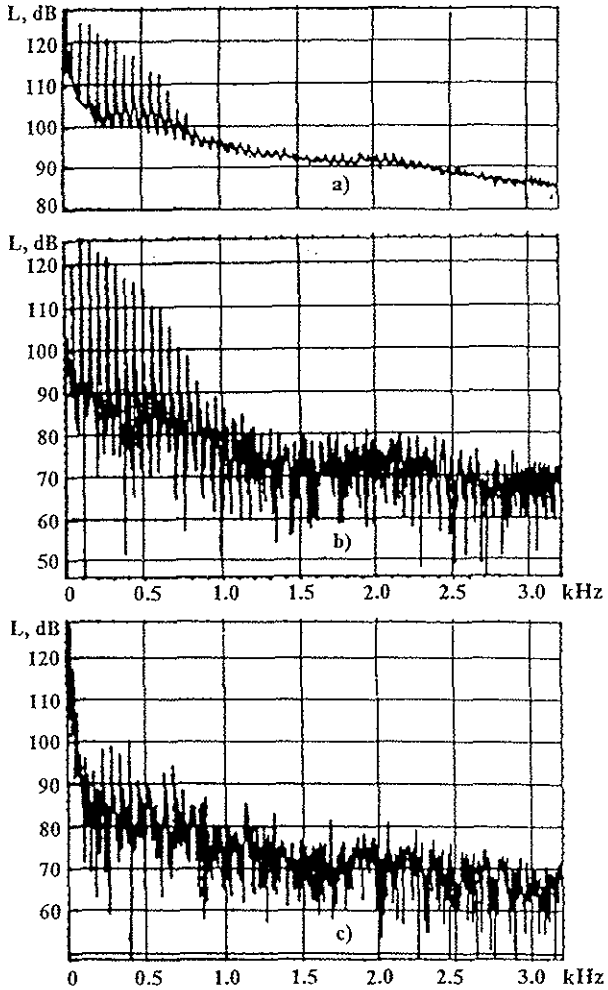

Fig. 2. Spectral density of sound pressure ($\mu=0.33$, $Me_{TR}=0.91$) in the disc plane of tail rotor ($\overline{\chi}=0.98$, $\varphi=-5.5^{o}$), [4]

a) for reference time realization

b) synchronous averaging over $n_{TR}(A=100)$

c) synchronous averaging over $n_{MR}(A=100)$

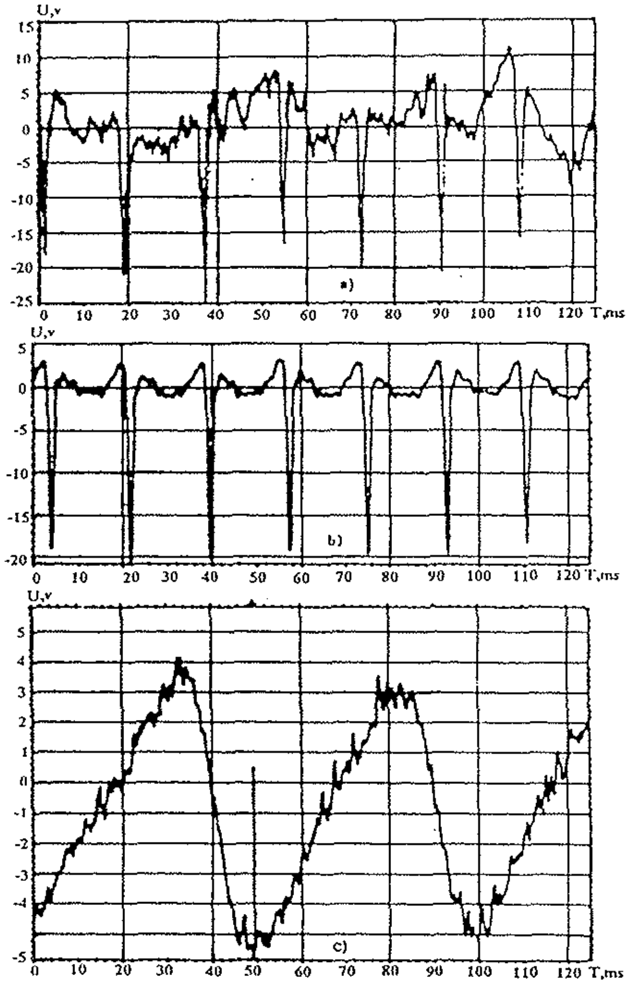

Fig. 3. Time realization of sound pressure ($\mu=0.33$, $Me_{TR}=0.91$) in the disc plane of tail rotor ($\overline{\chi}=0.33$, $\varphi=-5.5^{\circ}$), [4]

a) reference time realization

b) synchronous averaging over $n_{TR}(A=100)$

c) synchronous averaging over $n_{MR}(A=100)$

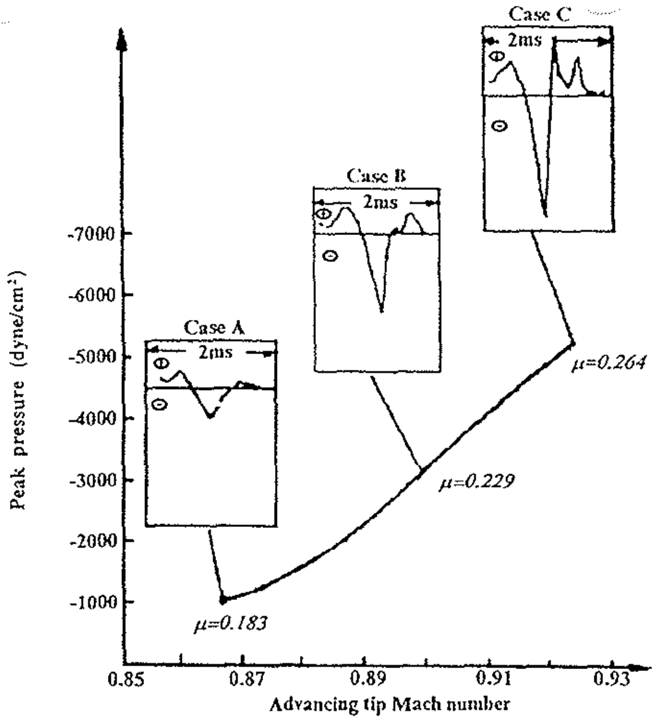

Fig. 4 Development of the wave of saw-like form at high blade tip Mach numbers,[5] $\mu=var$, $M_t=const$ a) $M_{at}=0.867$ b) $M_{at}=0.90$ c) $M_{at}=0.925$

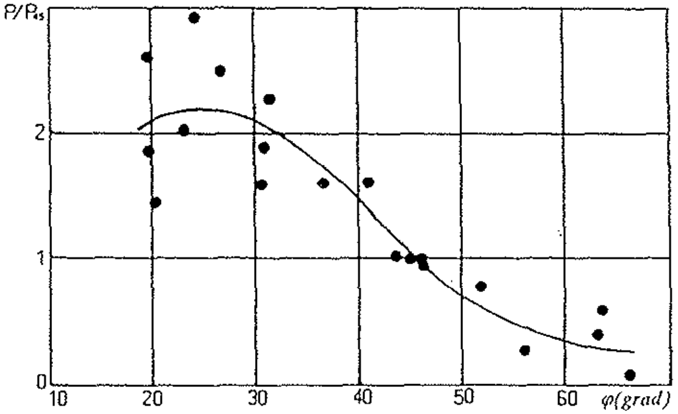

Fig. 5. Impulse radiation directivity in TR disc plane. Ground measurements at helicopter forward flight. The data are presented with respect to the distance $R=100$.

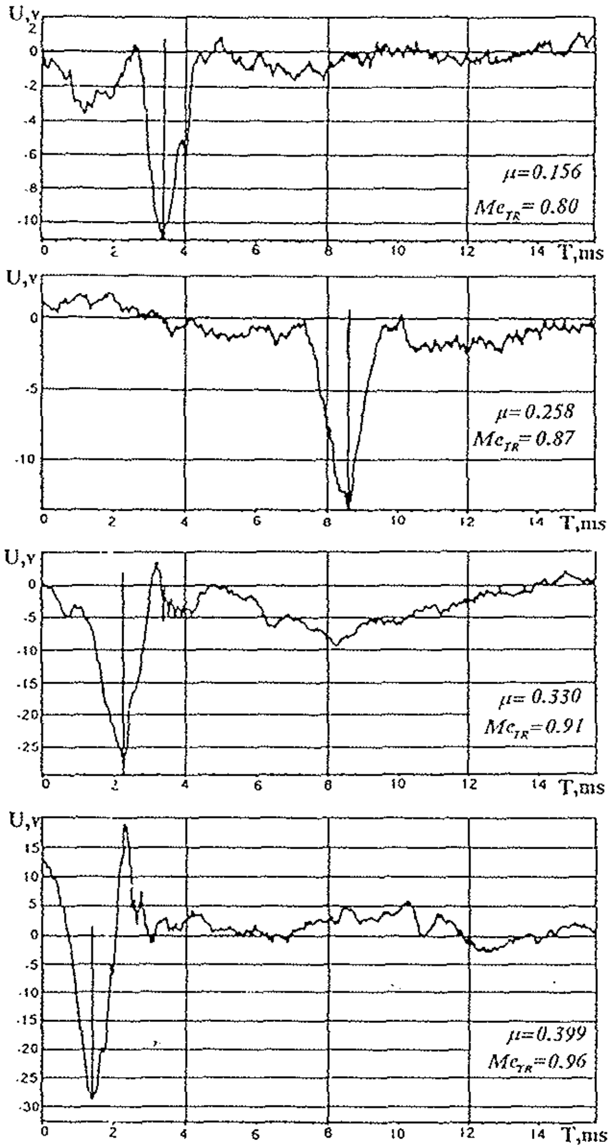

Fig. 6a). Sound pressure impulse form in the disc plane of helicopter rotor ($\bar{\chi}=0.98$, $\varphi=-5.5°$), instantaneous time realization.

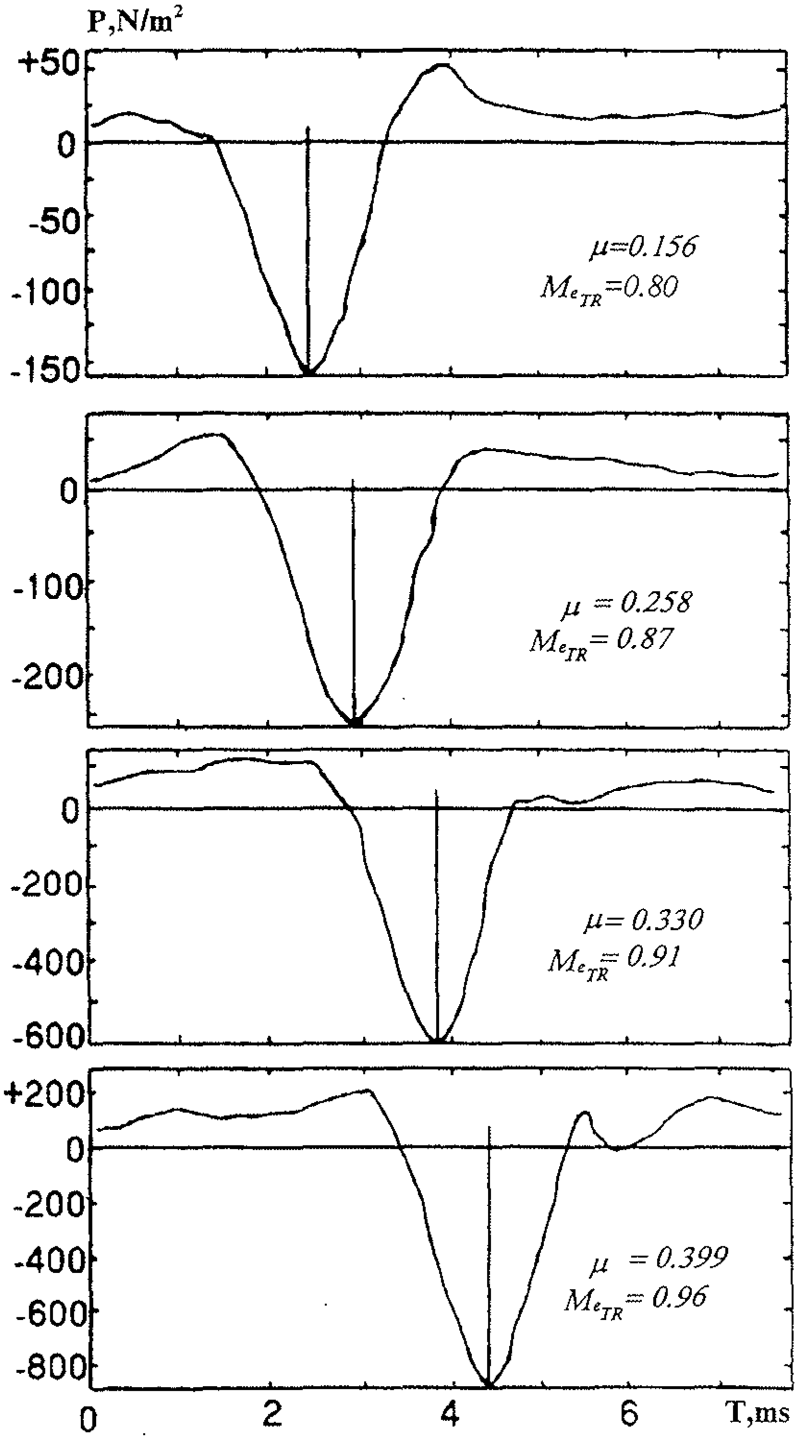

Fig.6(b). Sound pressure impulse form in the disc plane of helicopter rotor ($\bar{\chi}=0.98$, $\varphi=-5{,}5^{\circ}$), synchronous averaging over $n_{TR}(A=100)$.

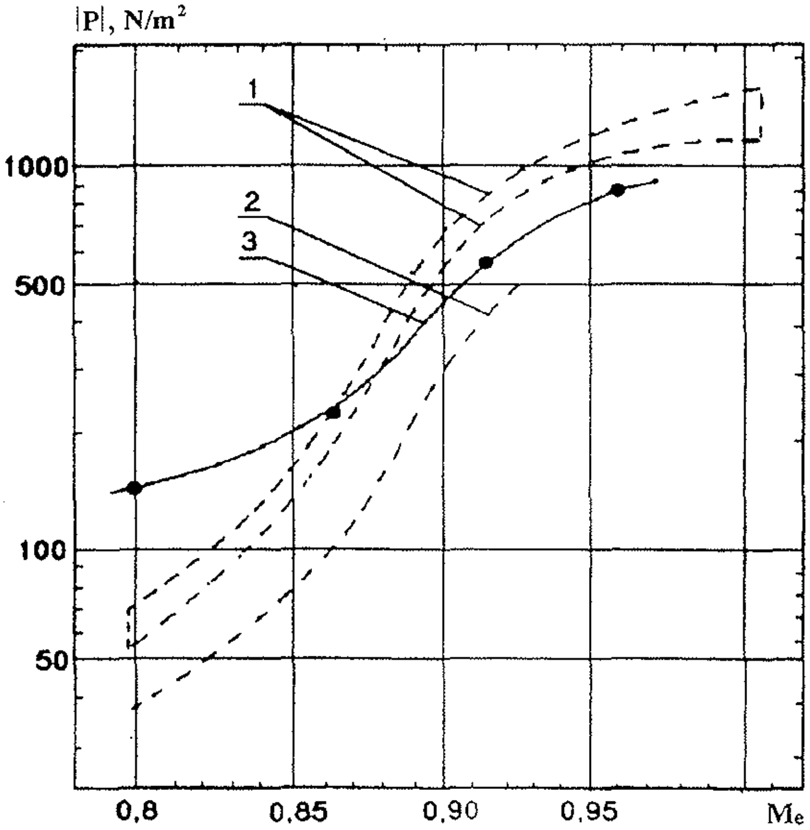

Fig.7. Peak negative-pressure level versus tip Mach number for rotor in hover and forward flight, in - plane.

1. model, stand [6] ($\bar{\chi}=1.5,\ \varphi=0^\circ$)
2. model, wind tunnel [5]($\bar{\chi}=1.5,\ \varphi=0^\circ$)
3. helicopter Mi-24 ($\bar{\chi}=0.98,\ 2.48,\ \varphi=0^\circ\text{–}5.5^\circ$)

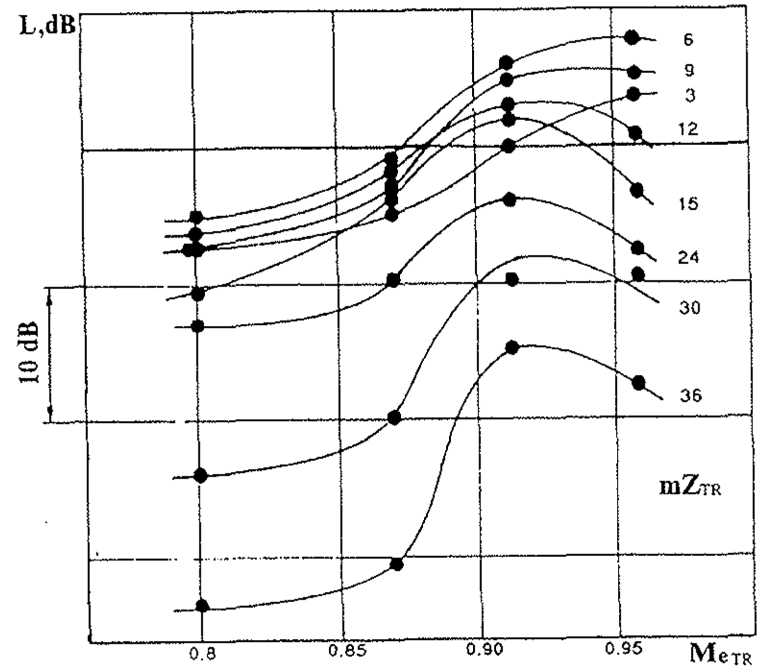

Fig.8. Influence of Mach number of TR advancing blade on the level of harmonic components of the impulse noise in TR disc plane ($N2,\ \bar{\chi}=0.98,\ \varphi=-5.5^\circ$) $\mu=0.156\text{–}0.399,\ M_{eTR}=0.80\text{–}0.96$