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ON THE NATURE OF ACOUSTIC RADIATION OF COAXIAL ROTORS.

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Abstract

The report presents experimental data on frequency-time and space charakteristics of pulse acoustic radiation from a helicopter of coaxial scheme at low and moderate velocities of forward flight.It is shown that in the helicopter of coaxial scheme the dominating community noise source is the pulse radiation produced by a lower rotor at its blade interaction with the upper rotor system. The upper rotor vortex system structure permits a substantial reduction of helicopter community noise levels. Investigation of pulse radiation sources is carried out with using two methods: method of varying the position of special proplets on coaxial rotor blades and method of smoke visualization of the inductive flow picture.

Symbols

c - sound velocity
$\overline{V}=V/U_t$ - relative velocity of helicopter flight
V - helicopter flight velocity
U_t - peripheral velocity of rotor
n - revolutions of rotor
m - harmonic number in the rotor radiation spectrum
M_R -Mach number of flow velocity in the end cross-section of the advancing rotor blade
R_0 - rotor radius
$\overline{r}$ - relative radius of blade section
K_b - blade number of single rotor
φ_{gp} - value of general pitch of rotor
Ψ - azimuthal angle of rotor blade
η - pitch angle of helicopter
$\overline{N}_e$ - relative power of propulsion (ratio of the power expended to the propulsion power available at nominal engine regime)
φ - angle between the helicopter velocity vector and helicopter direction to the noise measurement point

Introduction

Civil helicopter community noise levels are limited by maximum acceptable values set in the international standard of ICAO [1] and in the national airworthiness regulations for air vehicles (FAR-36 in USA, JAR-36 in EC countries, AR-36 in Russia).The existence of the above regulations and the negative community reaction to helicopter service within building regions force to search for possible methods of reducing their adverse effects on the environments. In this connection, research of helicopter community noise sources and accumulation of data on mechanisms and regularities of noise generation are very urgent.

In the last quarter of the century the research centers of USA, EC countries and Russia a great number of experimental and theoretical investigations relating to acoustic characteristics of helicopters with a single rotor is realized, the main sources and mechanisms of noise generation are determind, methods of reducing the intensity of one of the main noise sources of rotor, which occurs at aerodynamical interaction of the rotor blade with is tip vortex coming down from the preceeding blade, are worked out. This phenomenon is also known as blade- vortex interaction (BVI) noise. The main mechanisms of noise generation by single-rotor scheme helicopter were determined in early works related to this subject [2]. Investigations of the 1970’s-1980’s, partly presented in reviews [3,4,5] , were related mainly to studying separate noise components of main rotors and tail rotors with discrete and continuous frequency spectra of sound pressure. In the early 1990’s an important role of the tail rotor in broad-band noise generation of helicopter was established [6,7], methods of reducing the dominating noise source intensity of the main rotor of single-rotor scheme helicopter (blade “clap”) based on using special rules of controlling the highest harmonis of the cyclic pitch in the general scheme of controlling the main rotor (higher harmonic control “HHC” technique) [8] were investigated.

In Russia, in addition to single-rotor scheme helicopters (with one main rotor), helicopters with coaxial main rotors of Ka-26, Ka-126, Ka-32A type have received wide acceptance. The helicopters of this type have no tail rotors, neutralization of the negative momentum produced by the main rotor and helicopter control in the horizontal plane are realized owing to the coxial arrangement of two main counter-rotating rotors. Mechanisms and regularities of noise generation by a single-rotor and coaxial rotors have much in common but still there are significant differences which determine, as the joint experimental research of TsAGI and "Kamov" Company has revealed [9,10], the dominating noise generation mechanisms in the system of coaxial rotors.

The report presents the main results of experimental investigation on the space-time structure of the acoustic field of the coaxial scheme helicopter of Ka-32A type, gives the data on visualization of the inductive flow from the coaxial rotors of full-scale helicopters in a forward flight with different velocity as well as the experimental data on reducing the pulse acoustic radiation intensity of coaxial rotors with varying the shape and position of the tip part of upper and lower rotor blades.

Object and methods of tests.

Acousticl tests were carried out on a helicopter of coaxial scheme of Ka-32 type with a take-off mass of ~11000kg. The helicopter rotor system consists of two counter-rotatig three-bladed rotors of 15.9m diameter (Fig.1). Rotor rotation directions at top view: the lower rotor-in an anti-clockwise direction, the upper rotor- in a clockwise direction. In acousticl tests the helicopter made forward flights at 150m altitude. Sound pressure measurements were made with using three condenser microphones located on the line perpendicular to the flight trajectory projection on the ground surface with a step of 150m and the central microphone in this case was located directly under the flight trajectory (Fig.1a). In the helicopter flight over the line of microphone location, the direction from the helicopters to the right measuring microphone was in one vertical plane with the lower rotor blade at azimuth angle Ψ =90° and with the upper rotor blade at azimuth angle Ψ =270°. All the microphones were located at the ground surface level.

Measurement, recording and analysis of acousticl information were realized with a complex of electro-acousticl equipment of "B&K". To obtain an information on helicopter altitude, flight velocity and attitude a photo-scale method was used and for measuring the working parameters of engines and rotor system the measurement system available on the helicopter board was used. All the kinds of measurements were synchrophased with the help of signals of unified time which were trasmitted through radio-channel and fixed as time marks on magnetic tapes for board and ground measuremet systems and served for starting the system of photometric measurements.

Inductive flow visualization was realized with the use of smoke generators set on the tip parts of upper and lower rotor blades. The smoke generators were switched on with the help of electro-distant control system and could work continuously for about 20 sec. The inductive flow picture was recorded with two cameras set on two helicopters of escort (Fig.1b) of Mi-8 type, one of which was on the side of the helicopter Ka-32A and the other was above and with side shift relative to the helicopter Ka-32A. The camera work was synchrophased with the use of the system of unified time signals.

Acousticl tests were carried out at the values of relative velocity of helicopter flight $\overline{V}$=0.15÷0.35 and the inductive flow visualization at $\overline{V}$=0.006÷0.287. All the flights were performed under conditions of quiet atmosphere, the wind velocity in the test region at 10m altitude relative to the ground surface was not more than 3m/sec and the acousticl background level was lower than the useful signal level at $\overline{V}$=0.2 not less than by 20 db over a wide frequency region.

Measurement results.

The acousticl field of helicopter with one rotor is known to be nonsymmetrical relative to the longitudinal helicopter axis and this is caused not only by the presence of tail rotor on the helicopter, but also by an asymmetry of the acousticl field of single rotor, the advancing blades of which generate more intensive noise than the retreating ones. If there were no aerodynamical rotor interaction and additional acousticl radiation associated with it in coaxial rotors, the acoustical field of the coaxial scheme helicopter would be a simple superposition of the acousticl fields of the upper and lower rotors and, since the coaxial rotors are counter-rotating, the overall acousticl field of helicopter would be symmetrical relative to its longitudinal axis.

However the experiment shows (Fig.3) that the acousticl field of the coaxial scheme helicopter is nonsymmetrical relative to the longitudinal helicopter axis: the microphone located on the right side of the flight trajectory shows more higher community noise levels than left microphone does and this difference grows with flight velocity increase from 4÷5 EPNdb at V≈135km/h to 6÷8 EPNdb at V≈200km/h. Thus, the aerodynamical interaction between coaxial rotors is a source of additional acousticl radiation which is absent for single rotors and which propagates mainly on the right side of the helicopter flight trajectory, i.e. on the side of advancing blades of the lower rotor.

Time histories of sound pressure measured on the left and the right sides of the flight trajectory at $\overline{V}$=0.260, φ_{gp}=9.5°, η=–4.8° are given in Fig.4.

Onc can see that low at relative velocity of helicopter flight the sound pressure pulses measured on the left side of the flight trajectory at $\varphi < 60°$ are the rarefaction waves and at $\varphi > 60°$ the compression waves appear in the plots. As it is known from the investigations of single rotors, the rarefaction waves correspond to the so called noise of rotor blade displacement and the compression waves - to the noise from aerodynamical loading affecting the blade. At relatively high flight velocity ($\bar{V} > 0.3$) the compression waves appear in the plots already at $\varphi \approx 30°$.

The plots of time histories of sound pressure measured on the right side of the helicopter flight trajectory are of similar kind (Fig.4), except that for the flifgt velocity $\bar{V}=0.260$ already at $\varphi \approx 30°$ there appear sign-alternating pressure pulses in the plots. This proves the presence of radiation sources connected with interactions of "blade-vortex" type (BVI) and with generation of a strong nonsteady aerodynamical loading on advancing blades of the lower rotor in the system of coaxial rotors in helicopter forward flight. In a general case the pressure pulse form in the acousticl far-field of helicopter depends on such parameter as tip vortex intensity, minimum distant from the vortex centre to the blade surface and even on vortex rotation direction [11].

The plots presented in Fig.5 give an idea on the contribution made by pulse and continuous component of the acoustic radiation of coaxial rotors into the helicopter community noise level on the right side of the flight trajectory. One can see, that the pulse radiation component is the dominating one in the helicopter community noise on the right side of its flight trajectoy and the noisiness maximum in this case corresponds to the interaction noise "blade-vortex" radiation in the direction $\varphi \approx 40°$.

The pulse acousticl radiation of coaxial rotors on the right side of the helicopter flight trajectory at $\bar{V}=0256$ and $\varphi \approx 70°$ is characterized by the harmonical spectrum (Fig.6) where the harmonic passing frequency is a multiple of the rotor blade passing frequency $f_p = m \times n \times K_b$. One can note that the intensity of the first four harmonics monotonously decreases as the number of harmonic "m" grows. This proves that these harmonical components of radiation refer to rotor "rotation noise" and are determined by the stationary part of the aerodynamical loads affecting the blade. The harmonics with number $m \geq 6$ (frequency higher than 40 Hz) are connected with the nonstationary part of the aerodynamical load which, as it follows from the data in Fig.4, appears as the result of aerodynamical interaction with a vortex. The maximum frequency of "interaction noise" (f_m) is in inverse proportionality to duration (τ) of the sign-alternating pulse and at τ=0.005sec it is f_m =200 Hz.

Single-rotor helicopters radiate noise determined by the interaction of "blade-vortex" type (BVI) and called "blade clap" only in flight with reducing altitude when the aerodynamical interaction between the advancing rotor blade and the tip vortex generated on the forward blade occurs. In the system of coaxial rotors the interactions of "blade-vortex" type take place at all the regimes of helicopter flights including the regimes of take-off and forward flight, at which the noise of "blade-clap" is usually not observed for single-rotor helicopters scheme. The only possible source of "interaction noise" in the system of coaxial rotors at the regimes of take-off and forward flight can be the non-stationary loadings of the lower rotor blades in their aerodynamical interaction with the inductive flow from the upper rotor.

It is known, that in the case of rotating blade the lift force value and velocity circulation are maximum close to the blade tip at the relative radius $\bar{r}=0.8 \div 0.95$. The velocity circulation decrease down to zero at the blade tip occurs at a relatively short area and, as a consequence, the circulation variation gradient here is raither high. This causes a rapid vortex sheet convolution close to the blade tip into an intensive tip vortex cord. This tip vortex is the principal component of the inductive flow from the upper rotor which causes a periodical appearance of additional non-stationary aerodynamical loading on advancing blades of the lower rotor. This non- stationary loading on the blade leads to the intensive pulse acousticl radiation generation by the lower rotor advancing blades.

To verify the last statement , two types of experiments were carried out. In the first experiment the effect on the tip vortex intensity was realized with the help of varying the shape and the spatil position of the blade tip. The possibility of obtaining the acousticl effect in this way was demonstrated in [12] with using, as an example, a single-rotor helicopter. In our experiment first the lower rotor blade tip was affected and this practically made no influence on the helicopter noise on the right side of its flight trajectory. Then the shape and the spatial orientation of the upper rotor blade tip were changed and this led to a noticeable variation of the noise level on the right side of the helicopter flight trajectory. Owing to selection of a special blade tip shape and its position in space, a considerable, up to 5 EPNdb, helicopter community noise level reduction was achieved in the range of its cruise flight velocities (Fig.7).

In the second experiment a visualization of the inductive flow picture in the system of coaxial rotors was realized. It is found that at least in the range of relative helicopter light velocities $\bar{V}=0.006 \div 0.287$ (Fig.8) the lower rotor blades cross the tip vortices coming from the upper rotor blades. Fig.9 clearly shows a cell structure of the inductive flow in the helicopter wake, when the smoke generators were placed only on the upper rotor blades. The continuous tip vortices coming down from the upper rotor blades after crossing the lower rotor rotation plane turn into a chain of discrete vortical formations. This means that the lower rotor blades constantly “cut” the upper rotor tip vortices and this seems to be the dominating pulse noise source of the coaxial scheme helicopter in forward flight with lower or moderate velocity.

Thus, the supposition that at least in the range of forward flight velocities $\overline{V} < 0.3$ of the coaxial scheme helicopter the pulse noise source on the right side of the helicopter flight trajectory is the lower rotor is experimentally confirmed. In this case the noise generation mechanism is determined by aerodynamicl interaction between the lower rotor blades and the inductive flows from the upper rotor. An efficient method of this noise reduction is an intensity variation of tip vortex formed on the retreating blade of the upper rotor.

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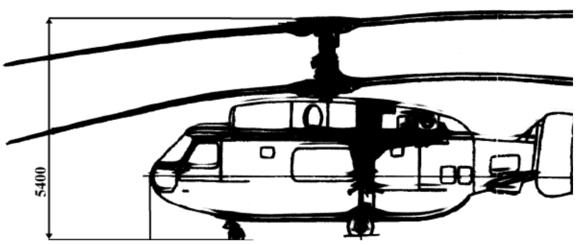

Fig.1 General view of the coaxial scheme helicopter.

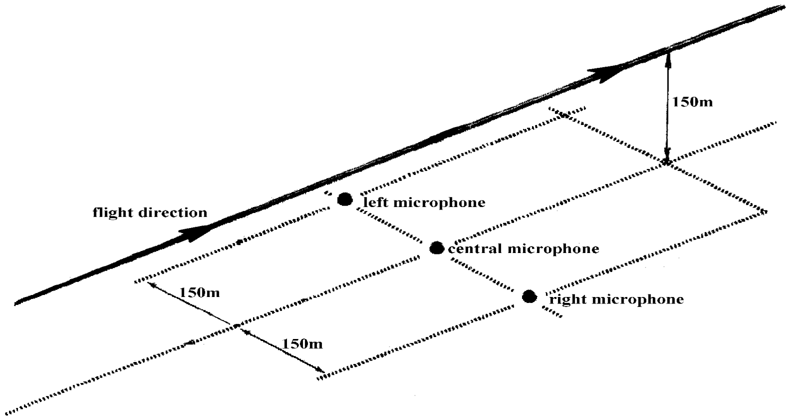

Fig.2a. Scheme of acousticl test realization

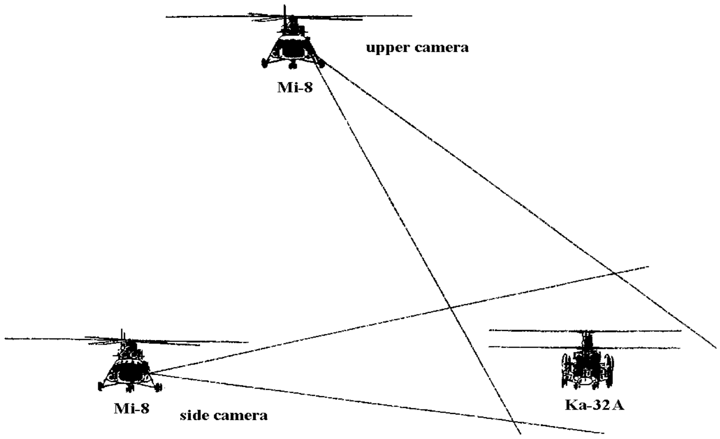

Fig.2b. Scheme of camera using during the inductive flow visualization

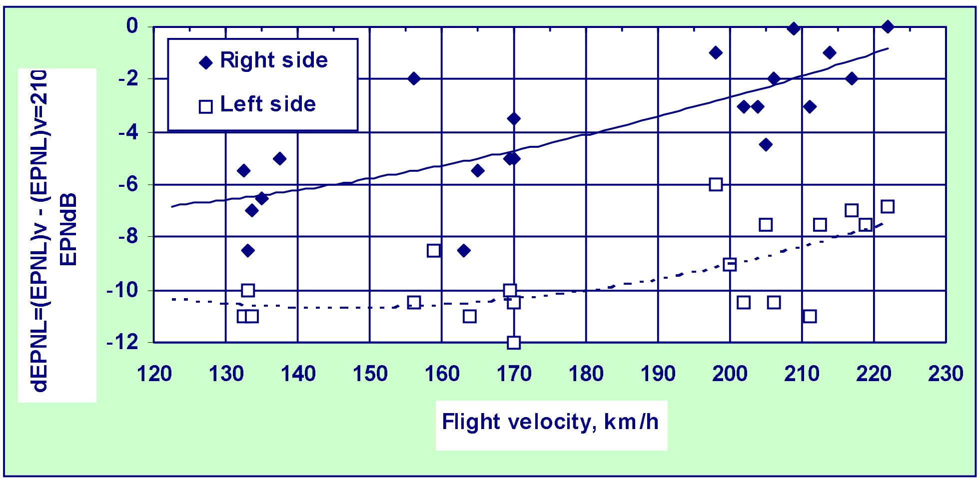

Fig.3 Nonsymmetry of the acoustic field produced by a helicopter of coaxial scheme

○ – **measurements on the right side of the flight trajectory (right microphone)**

● – **measurements on the left side of the flight trajectory (left microphone)**

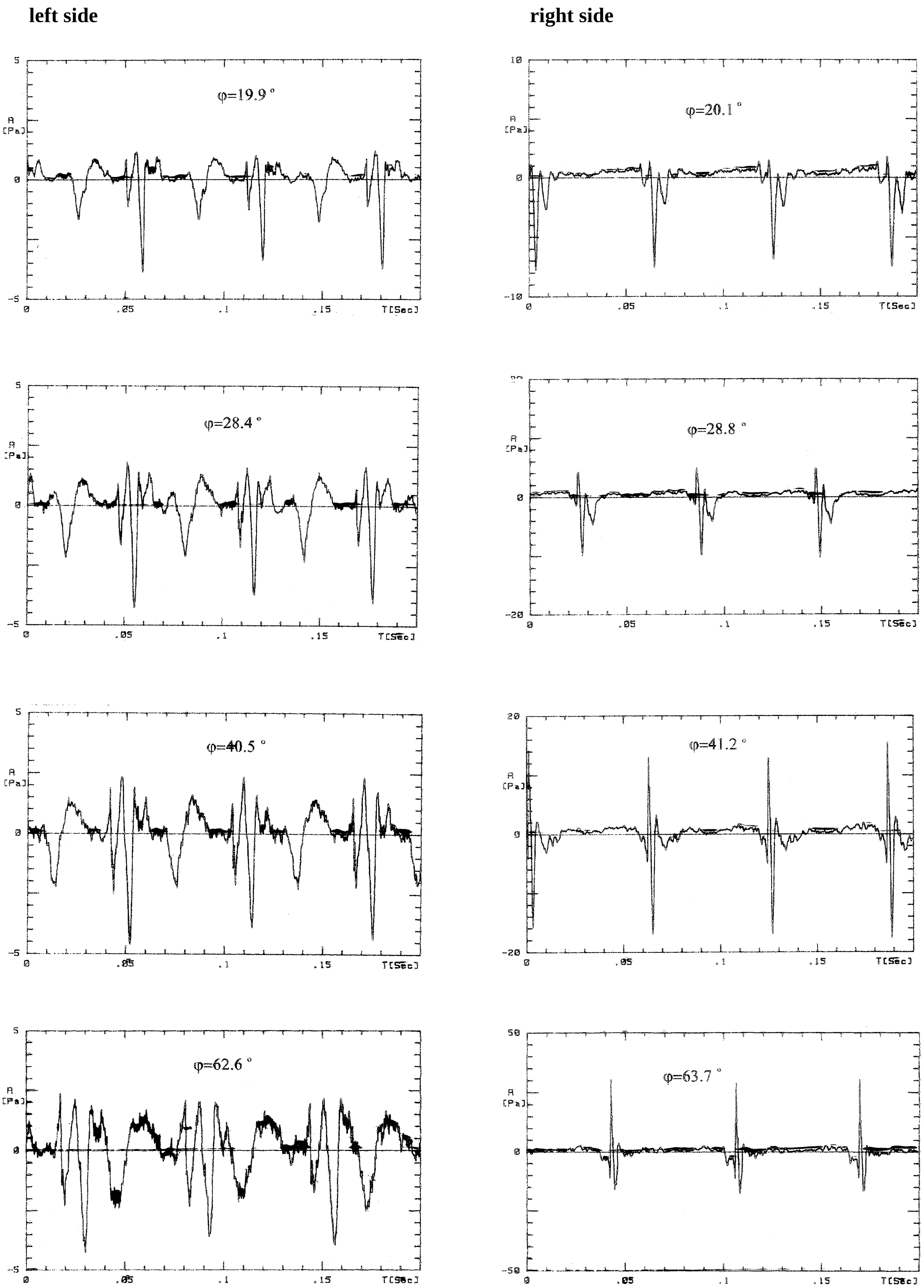

Fig.4 Time histories of sound pressure measured on the left and on the right of the flight trajectory of the coaxial scheme helicopter

$$\varphi_{gp} = 9{,}5^0; \eta = -4{,}8^0; \overline{V} = 0{,}26; M_R = 0{,}811; \overline{Ne} = 0{,}782$$

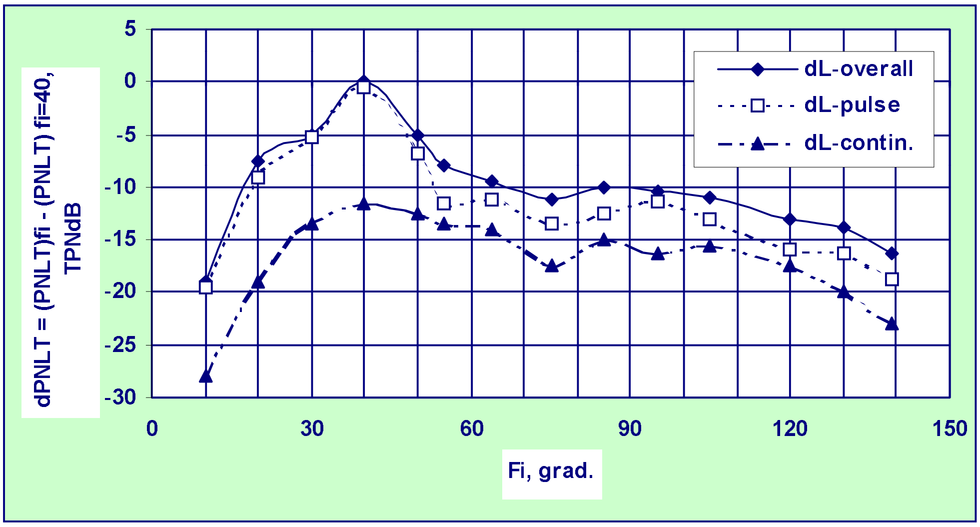

Fig. 5 Perceived community noise levels on the right side of the flight trajectory of the coaxial scheme helicoptec for different components of the acoustic radiation:

$$(\bar{V} = 0{,}26;\ M_R = 0{,}811)$$

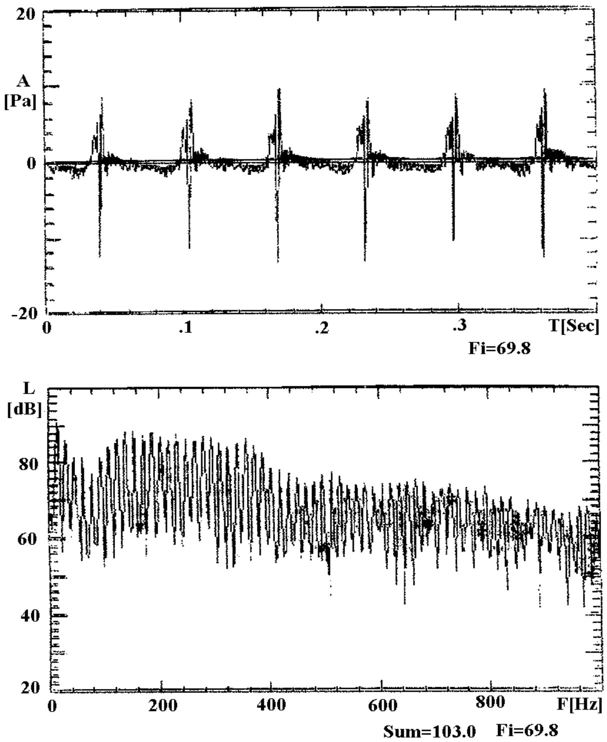

Fig.6 Time history and narrow-hand spectrum of sound pressure level on the right side of the flight trajectory of the coaxial scheme helicopter

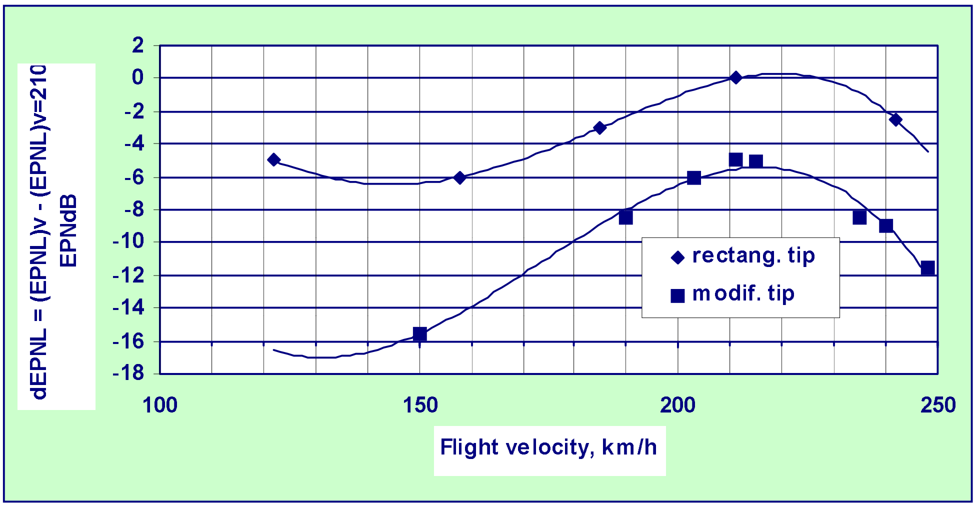

Fig.7 The effect of the upper rotor blade tip shape on the community noise level on the right side of the flight trajectory of the coaxial scheme helicopter

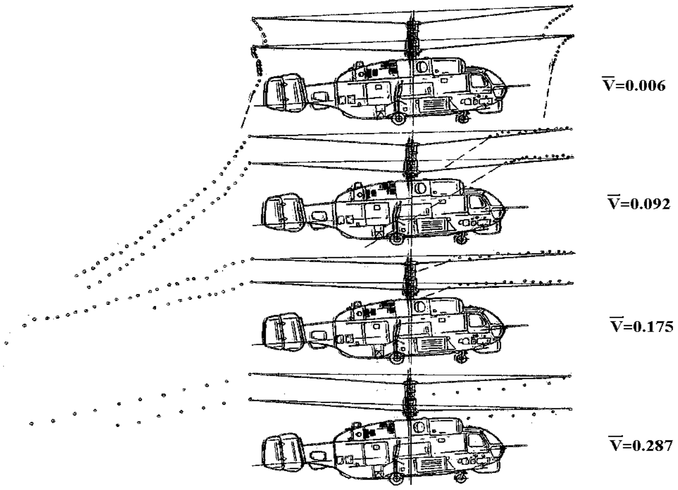

Fig.8 Trajectories of tip vortices in the vertical plane in the azimuth point 0^0 and 180^0 in the system of coaxial rotors

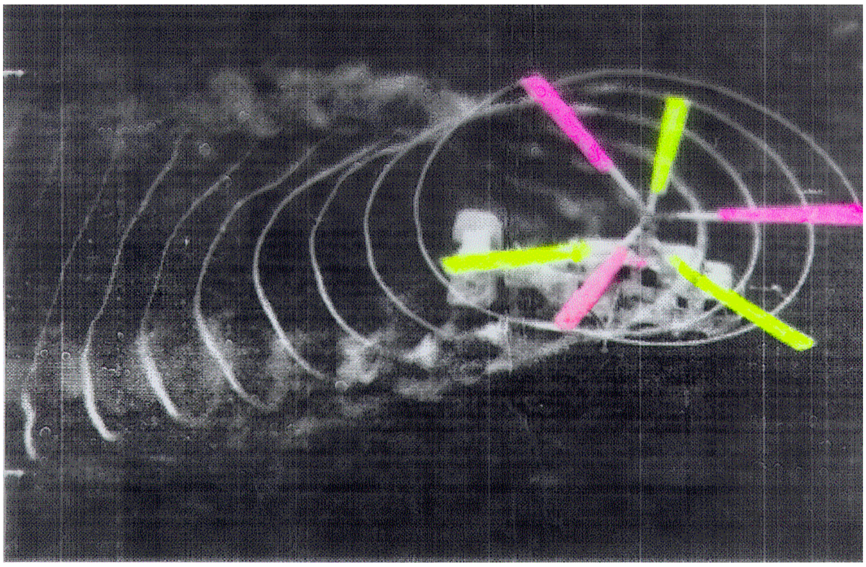

Fig.9 Visualization of the inductive flow in the system of coaxial rotors in a forward flight of the Ka-32A helicopter