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Kamov Composite Blades

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Kamov helicopters have been flying with composite blades of original design and technology for over 40 years now. These blades are installed on Kamov naval ship borne Ka-27 and Ka-29 models, army combat Ka-50 and Ka-52 models, civil Ka-18, Ka-26, Ka-32, Ka-226 models.

The blade design provides for such aeroelastic layout and eigen frequency specter that ensure low alternating loads (blade deformations) and, consequently, high blade dynamic strength and long service life in all operation conditions. The blades are also protected against environmental effects.

Kamov Company created its composite blade structures and technologies for experimental and serial production using such materials as glass and carbon reinforced plastics developed by All-russian scientific-research institute of aviation materials (VIAM). Kamov Company holds the USSR Certificate of Authorship (issued in 1963) and patents in the USA, Germany, France, Italy and Japan (issued in 1973 to 1976) protecting its rights.

Two main features of Kamov original technology are the method of laying the pre-formed shapes of flat glass / carbon fabric and the method of their pressing from inside to a rigid mould surface.

Compared to winding the technology developed and used by Kamov is simple, practically does not pose restrictions upon the blade design and ensures stable characteristics of plastic material, composite blade strength and high accuracy of its aerodynamic profile.

The blades have been serially produced for over 40 years, considerable experience have been gained and original manufacturing tooling is available. A quality control system is in place.

1. Blade aeroelastic design

1.1 The helicopter blades are affected by aeroelastic and inertial alternating periodic loads in flight. The maximum flying speed is limited not only by the helicopter power-to-weight ratio (weight/power) but also by the increase of alternating load amplitudes influencing the blades and rotor control linkage, by aeroelastic instability of blade motion (flutter) and stall flutter. The nature of alternating aerodynamic and inertial loads is shown in Fig.1. It is skewness of airflow over advancing ($V+\Omega R$) and retreating ($\Omega R-V$) blades that periodically repeats for each rotor blade. This is illustrated in Fig.2 showing thrust and blade twisting moment linear values along the blade length based on the results of ULYSS model analysis.

1.2 The aeroelastic design task is the first blade design task that provides for:

- high figure of merit at hover and in flight;
- low level of alternating loads and aeroelastic stability.

High performance is attained by using advanced TSAGI aerodynamic profiles designed specially for a definite helicopter model and by the blade planform and twist. Fig.3 shows Ka-50 and Ka-226 helicopter blades and generalized aerodynamic profiles.

Provision of low blade/control linkage alternating load level and aeroelastic stability requires the following:

- analysis and development of mass-elastic configurations of cross sections using blade design mathematical models;
- prediction of oscillation eigen values and modes of oscillation in vacuum and in the air, damping i.e. prediction of flutter type self-excited oscillations stability boundaries;
- prediction and provision of alternating load low values.

Kamov engineers have developed a generalized aeroelastic mathematical model of a coaxial main rotor (1350 scientific research reports and 50 papers published).

The generalized aeroelastic mathematical model of a coaxial aeroelastic rotor actually includes two basic models: i.e. ULYSS (loads and stability) and MFE (frequencies and stability boundaries). The concept and functional abilities of the models are shown in the Tables in Figs.4, 5.

The models are based on nonlinear equations with periodic coefficients in partial derivatives (around $3\times6=18$ equations and 36 boundary conditions) as shown in Figs.6 to 8.

In ULYSS model (loads and stability of motion) a corresponding systems of ordinary nonlinear differential equation is time integrated numerically.

In MFE model (stability, eigen frequencies, modes) the equations are partially linearized and everything is brought to solving a problem of eigenvalues and eigenfunctions of a differential equation system with complex coefficients.

Examples of predictions made using ULYSS and MFE models are shown in Figs.9 to 12.

2. Blade physical design

Blades of the first Kamov serial helicopter Ka-15 (1953) and Ka-18 (1956) were made of wood and delta wood, i.e. plywood impregnated with polymerized resin and pressed. These blades were actually prototypes of composite blades. In 1959 Kamov Company started to develop glass composite blades and in 1964 their serial production started at a plant in Ulan-Ude.

Development of Kamov blade design and materials is shown in Figs.13 to 20 and in the Table in Fig.21. Disk loads (max take-off weight/rotor disk area) and max flying speeds of Kamov helicopters are shown in Fig.22.

Requirements for increased take-off weight and faster flying speeds lead to improvement of the blade design and application of new materials having increased module E, G (glass fabrics and carbon fabrics) that allowed to solve aeroelasticity problems of alternating load reduction and aeroelastic stability, i.e. helped to ensure the high flight performance. Introduction of new materials allowed to attain required values of blade mass and rigidity (ref. Fig.23) within the weight and overall dimensions limitations set for the helicopter as a whole.

The Table in Fig.21 presents the information regarding the development of designs and materials for Kamov blades.

The latest development is a blade for the Ka-226 helicopter model and its serial production started in 2004. The blade design features a hollow tail section for the whole blade length and is moulded in one pass.

The Kamov priority in Russia and in the word in the field of composite blade manufacture is certified by a USSR inventors certificate (1963), Russian Federation patent (2003) and foreign patents like Germany (1973), France (1975), USA (1976), Italy and Japan. As early as 15 to 20 years ago Kamov Company predicted the tendencies later followed by the world community in the development of composite blade design and materials.

3. Blade production technology

3.1 The basic materials - glass and carbon - were developed by the All-russian Scientific-research Institute of Aviation Materials (VIAM) using their glass and carbon fabrics and matrix materials. VIAM also certified these materials and developed instructions for impregnation and storage of glass/carbon prepregs and preliminary recommendations for pressing conditions in the manufacture of glass/carbon plates.

Real blade structures considerably differ from flat plates. Besides parts made of polymer composite materials, the blade design includes also anti-erosion strip, metal balancing weights, de-icing heating elements and hub attachment points (Fig.3). Kamov engineers have developed moulds, assembly jigs and other fittings that were manufactured and used in the blade production process. The plate pressure molding conditions were modified to suit molding of blades in order to ensure the proper quality of the produced glass blades.

Development of hybrid glass/carbon blade designs required modification of prepreg manufacture and blade spar pressure molding technologies.

3.2 Composite blade manufacture technology was developed by Kamov Company and used for mass production of blades at serial production plants.

The technology developed by Kamov Company was based on profiling flat prepreg sheets, assembly of sheet stacks on mandrels, preliminary sheet stack pressing, assembly and final press molding of spars or whole blades. Pressurized bags are placed inside the blade blank to create pressure that presses the blank to the inner surface of the mould corresponding to the outer surface of the blade.

Two main process steps of the Ka-226 helicopter blade production are illustrated in Fig.24 (preliminary pressed stacks and final blade pressure molding).

This technology is usually called product lay-up and it has the following advantages:

- there are practically no limitations on the blade section rigidity (mass) that is ensured by arbitrary orientation of pre-preg fils and the number of sheets in stacks;

- the pressure created by inner bags ensures uniformity of the pressure that presses the plastic to the mould inner surface and a uniform plastic density that allows to get stable plastic characteristics both blade lengthwise and widthwise;

- high accuracy of the blade external surface;

- multicontour structure molding capability, i.e. pressure molding of the whole blade including its tail section. This approach does not require small sized moulds for pressing individual tail sections and a large complex jig for assembly and bonding of tail section to the spar;

- simplicity of technological processes ensuring stability of the blade performance.

From the very beginning of blade composite design activities Kamov Company accepted the lay-up technology for flat blade blanks.

However at some serial manufacturing plants they still try to manufacture composite blades using winding technology.

Winding technology does not suit the requirement of the blade manufacture as illustrated in Figs.25, 26.

As it is known, a normal force ($d\tilde{n}/dS=T/\rho$) pressing the filament to the surface is inversely proportional to the curvature radius of the mandrel (ρ).

For lateral blade sections curvature radius fall within the range of ($\rho\approx1/50$ to 50) of the blade chord. The sections may have flat areas ($\rho=\infty$).

Fig.26 shows pressing by mould rigid inner surface forces acting from inside upon the filaments wound up on a rigid mandrel of a spar blank.

As follows from Figs.25, 26 and operational experience of using winding technology (Ref.40) the main drawbacks of this technology are:

- inability or difficulty to attain the required rigidity level of the blade spar;

- inability to ensure uniform density of winding;

- inability to provide a uniform pressure upon the filaments (tapes) by pressing the mould external surface to the rigid mandrels and consequently inability to attain stable content of matrix material and plastic strength parameters;

- low accuracy of the blade external surface;

- inability to wind a multycontour spar or complete blade including tail sections.

4. Quality control

A quality control system was developed by Kamov and is introduced at the serial plant-manufacturer. The main procedures are presented in Table in Fig.27.

One of the quality control procedures is a periodic selective blade section test. Several blades are selected from each blade lot and cut into 2-3 parts lengthwise. Sections are made out of each part and tested at alternating and constant loads at the resonance type vibration test rigs.

A schematic diagram of a vibration rig for creating alternating and constant loads-stresses for blade sections is presented in Fig.28.

The length of sections and boundary conditions at the rig ensure similarity of load distribution in the sections both lengthwise and widthwise.

Alternating loads-stresses exceed by several times those measured in flight tests (equivalent, according to the standard flight profiles).

The type of loading and number of cycles (number of hours) prior to blade section damage at the rigs correspond to the established service life limit of the blade, i.e. the type and number of the blade load cycles in actual operation (Fig.29).

The procedure of the limit service life establishment also includes the data obtained during static and dynamic tests of specimens simulating the composite material of the blade.

Analysis of local loading for example loading in the area of the blade root attachment to the rotor hub, is performed using NASTRAN finite element models of the design.

5. Structural flight tests

The main tasks here are:

- evaluation of auto-oscillation boundary margins (flutter on the ground and in flight, stall flutter);
- measuring of static and dynamic loads in operational flight conditions - confirmation of equivalent load values in order to establish service limit life;
- modification of the blade design (if required) based on the results of measurements and analysis of stability boundary values.

6. Operations and monitoring

The main tasks here are:

- service life limit of consistency with the prescribed flight profiles (i.e. correspondence of equivalent loads);
- monitoring of the blade condition - confirmation of the environmental protection efficiency and consistency with the established endurance.

7. Design certification

The blades are certified to international standards (operational characteristics, design, process technology).

Conclusions

1. Kamov Company has created a system for design, manufacture, testing and operation of helicopter composite blades.
2. The Russian and world priority of Kamov Company in the area of helicopter composite blade manufacture is confirmed by the USSR inventors certificate (1963), patens (Refs. 35, 36) of Russian Federation (2003) and foreign countries (1973-1976).

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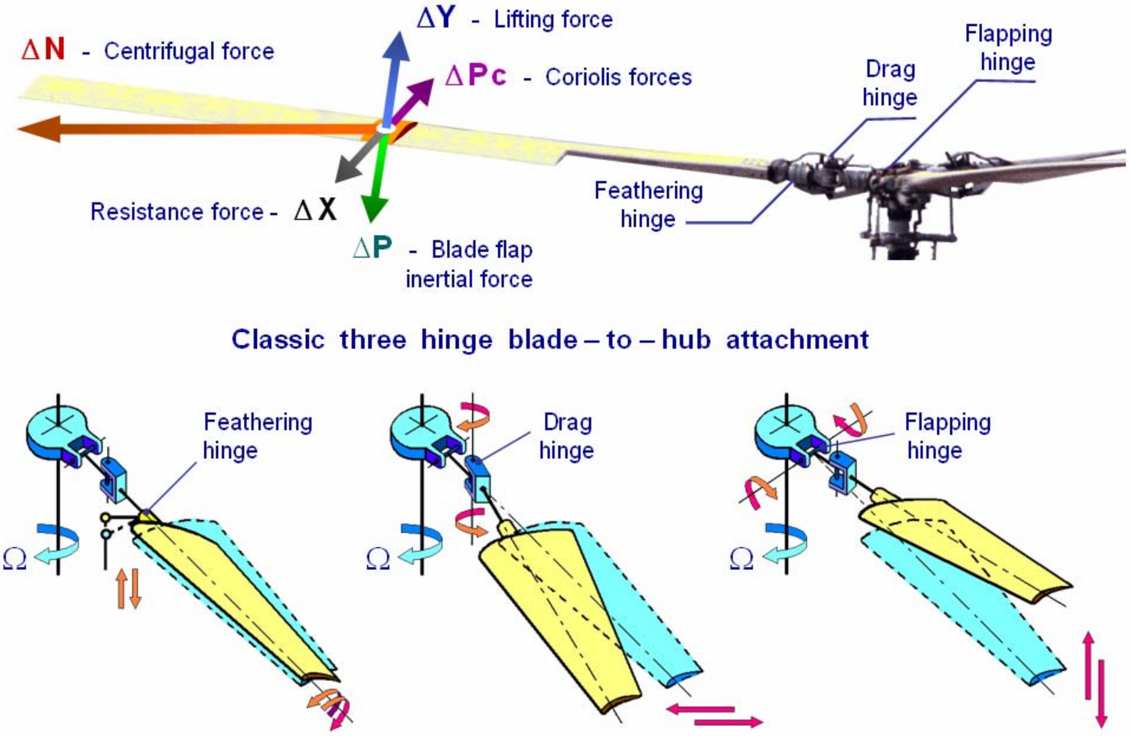
Forces affecting the main rotor blade element



Main rotor blade flow pattern in horizontal flight

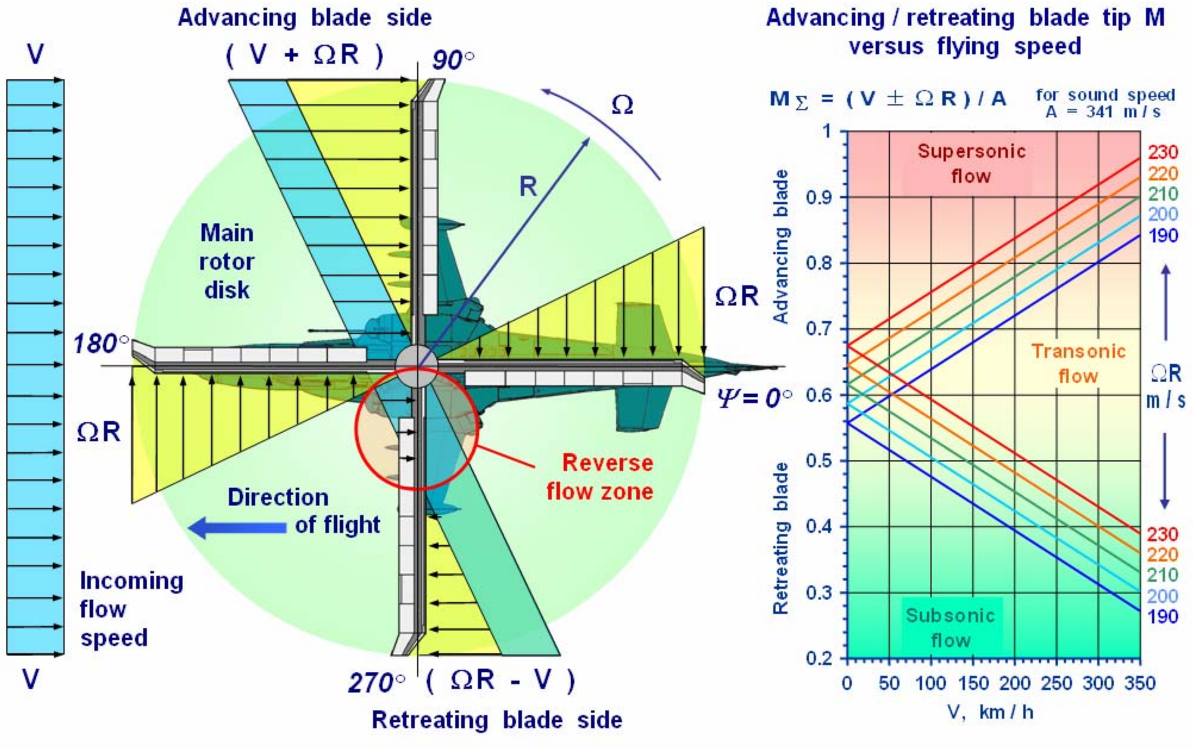
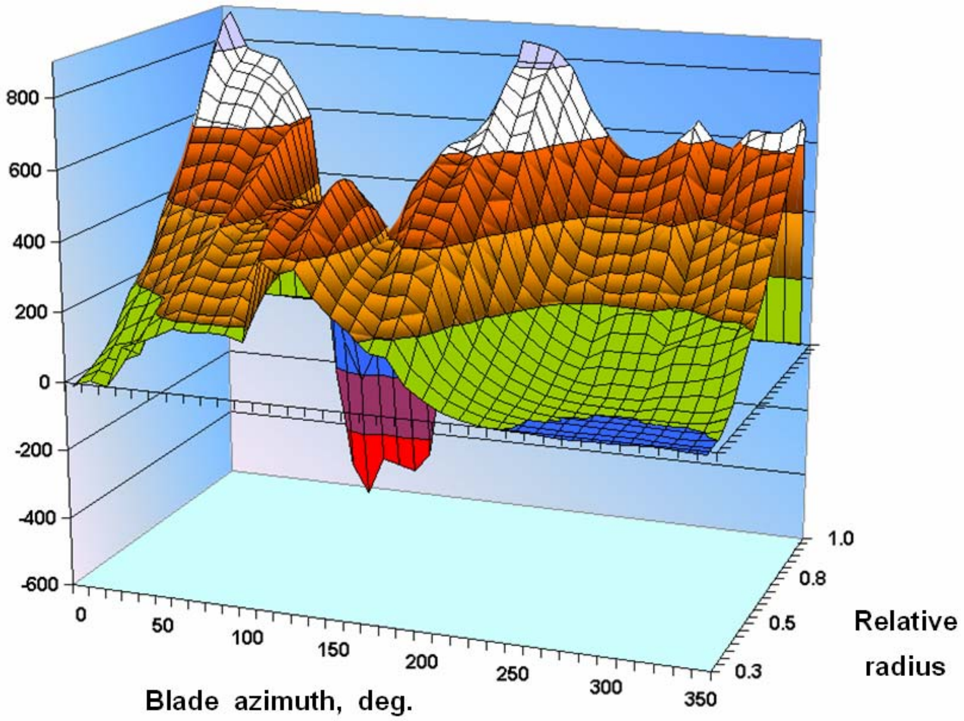
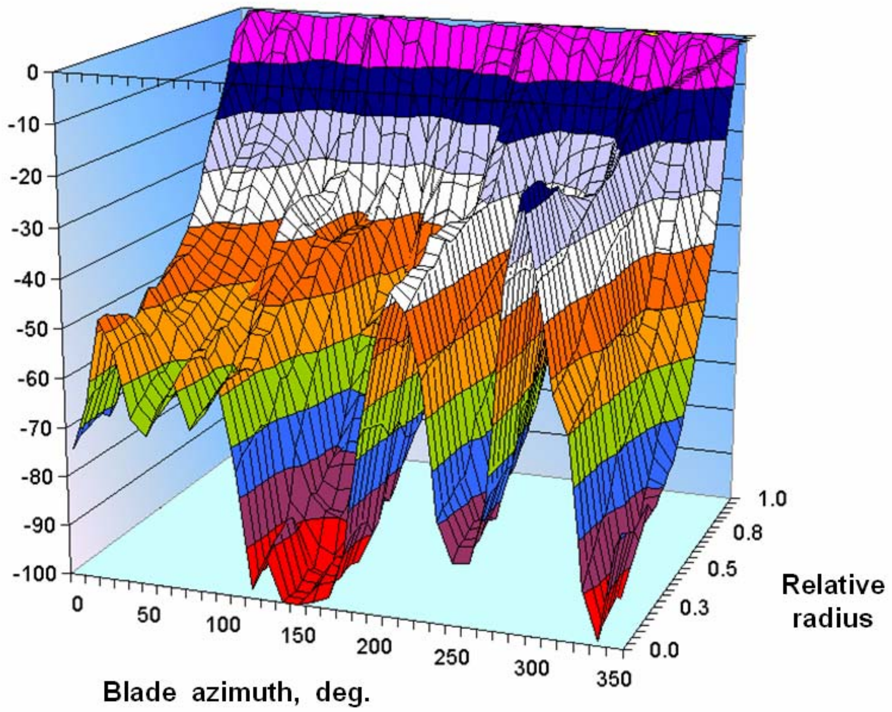


Fig.1



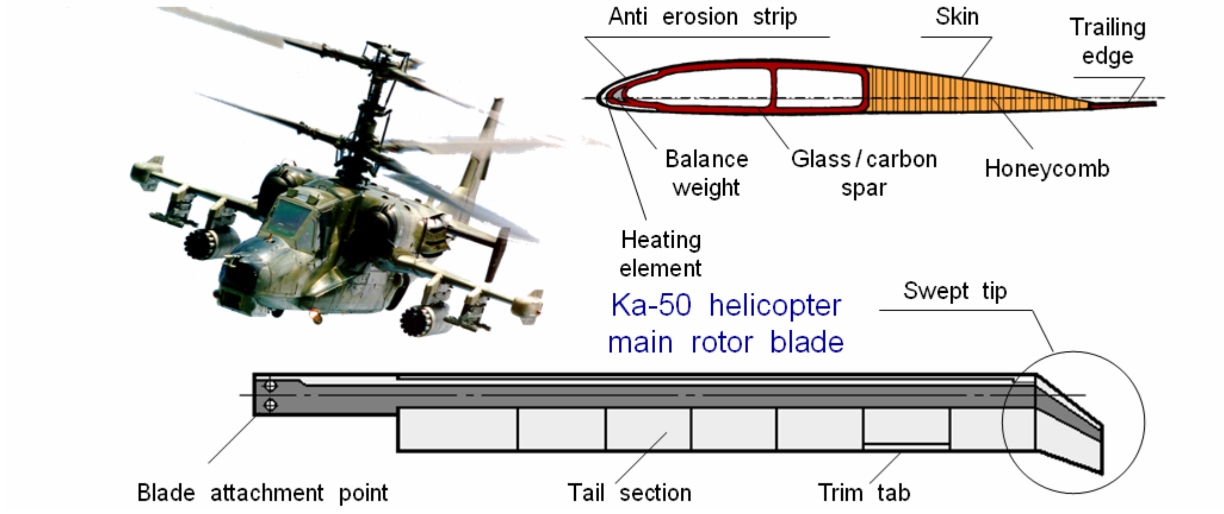
Thrust in blade sections, kg / m

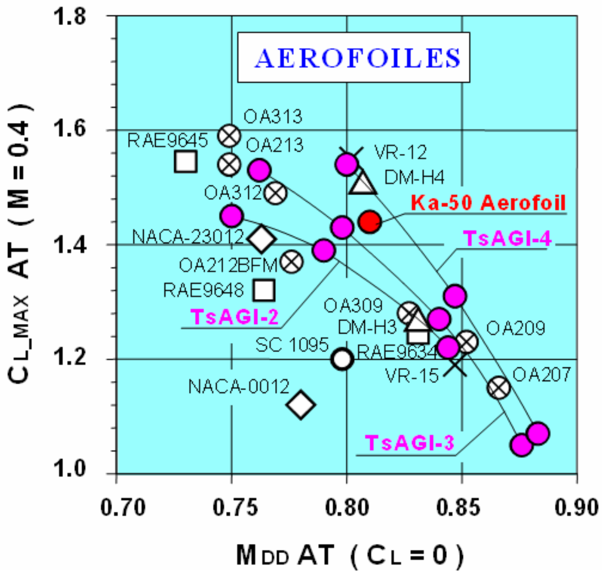


Torsion moment in blade sections, kg·m

Fig.2

Ka - 50 blade profile





Ka - 226 blade profile (TsAGI - 4M)

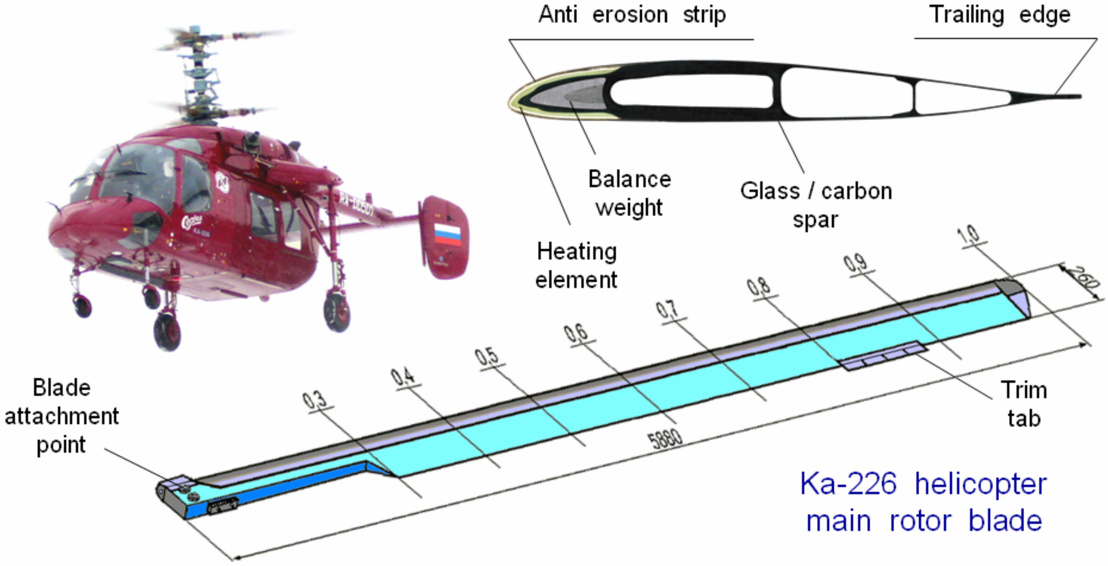


Fig.3

Modeled phenomena		Versions of generalized model				
		ULYSS		MFE		
		ULYSS-6	ULYSS-1	VakMFE (vacuum)	AirMFE (air)	UL_MFE
1	EIx, EIy, GIp (r / R, ωt)	√	√			
2	$\bar{\varphi} = \left\| \vartheta_{I,J} \right\| \times \bar{M}$	√		√	√	√
3	Vi (r / R, ψ)	√				√
4	Cy, Cxp, Cm ($\alpha, \dot{\alpha}, M, \dot{M}$)	√	√		√	√
5	Cy_max ($\alpha, \dot{\alpha}, M$)	√	√			√
6	Airfoil aeroelastic deformation	√	√			
7	Lower / upper rotor data	√	√	√	√	√

Fig.4

Analysis results		Versions of generalized model				
		ULYSS		MFE		
		ULYSS-6	ULYSS-1	VakMFE (vacuum)	AirMFE (air)	UL_MFE
1	Stall flutter boundaries	Coaxial Rotors	Blade			Blade
2	Control / actuator linkage loads, Bending moments	Coaxial Rotors	Blade			Blade
3	Elastic deformations	Coaxial Rotors	Blade			Blade
4	Alternating hub loads	Coaxial Rotors				
5	Blade tips clearances	Coaxial Rotors				
6	Flutter in flight tests	Coaxial Rotors	Blade			Blade
7	Flutter in ground tests	Coaxial Rotors	Blade		Blade	Blade
8	Eigenfrequencies and modes			Blade	Blade	
9	Damping	Coaxial Rotors			Blade	Blade

Fig.5

Coordinate system for the elastic blade motion equations

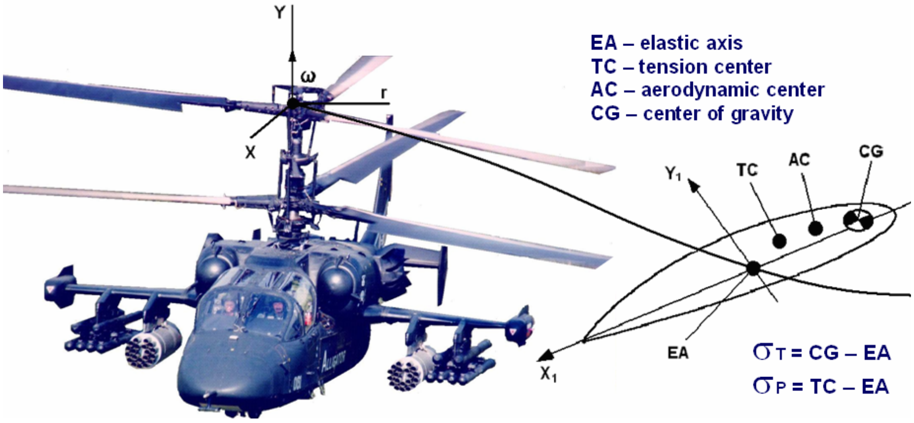


Fig.6

System of equations describing a motion of one of the six coaxial rotor blades

$$m\left(\frac{\partial^2 Y}{\partial t^2}+\sigma_T\frac{\partial^2\varphi}{\partial t^2}\right)=\frac{\partial}{\partial S}\left[N\frac{\partial}{\partial S}(Y+\sigma_P\varphi)\right]-\frac{\partial}{\partial S}\left[(\sigma_T-\sigma_P)\varphi\frac{\partial N}{\partial S}\right]-$$
$$-\frac{\partial^2}{\partial S^2}\left[\left(EJ_{Y1}Cos^2\varphi+EJ_{X1}Sin^2\varphi\right)\frac{\partial^2\overline{Y}}{\partial S^2}-\frac{1}{2}\left(EJ_{X1}-EJ_{Y1}\right)\frac{\partial^2\overline{X}}{\partial S^2}Sin2\varphi\right]+\frac{\partial Y_A}{\partial S};$$

$$m\frac{\partial^2 X}{\partial t^2}=\frac{\partial}{\partial S}\left[N\frac{\partial}{\partial S}(X-\sigma_P)\right]+m\omega^2(X-\sigma_T)+\frac{\partial}{\partial S}\left[(\sigma_T-\sigma_P)\frac{\partial N}{\partial S}\right]+$$
$$+m\omega^2(\sigma_T-\sigma_P)+2m\omega\frac{\partial r_P}{\partial t}-\frac{\omega^2 mL}{S}(X-\sigma_T)-$$
$$-\frac{\partial^2}{\partial S^2}\left[\left(EJ_{X1}Cos^2\varphi+EJ_{Y1}Sin^2\varphi\right)\frac{\partial^2\overline{X}}{\partial S^2}-\frac{1}{2}\left(EJ_{X1}-EJ_{Y1}\right)\frac{\partial^2\overline{Y}}{\partial S^2}Sin2\varphi\right]+\frac{\partial X_A}{\partial S};$$

$$\left(J_T+m\sigma_T^2\right)\frac{\partial^2\varphi}{\partial t^2}+m\sigma_T\frac{\partial^2 Y}{\partial t^2}=\sigma_P\frac{\partial}{\partial S}\left[N\frac{\partial}{\partial S}(Y+\sigma_P\varphi)\right]+(\sigma_T-\sigma_P)\frac{\partial(Y+\sigma_P\varphi)}{\partial S}\frac{\partial N}{\partial S}-\omega^2\left(J_{Y2}+m\sigma_T^2\right)\varphi+$$
$$+\frac{\partial}{\partial S}\left(GJ\frac{\partial\overline{\varphi}}{\partial S}\right)+\frac{\partial^2\overline{X}}{\partial S^2}\frac{\partial^2\overline{Y}}{\partial S^2}\left(EJ_{X1}-EJ_{Y1}\right)\left(1-2Sin^2\varphi\right)+$$
$$\left(\left(\frac{\partial^2\overline{X}}{\partial S^2}\right)^2-\left(\frac{\partial^2\overline{Y}}{\partial S^2}\right)^2\right)\left(EJ_{X1}-EJ_{Y1}\right)\frac{1}{2}Sin2\varphi+\frac{\partial M_A}{\partial S};$$

Fig.7

Boundary conditions at the root of one of the six blades :

$$Y(0,t)=0;\quad X(0,t)=0;$$

$$\varphi(0,t)=\varphi_o+\Theta_1Cos\Psi+\Theta_2Sin\Psi-\overline{K}\frac{\partial Y}{\partial S}(0,t)+\upsilon(\Psi)\left(GJ_o\frac{\partial\overline{\varphi}}{\partial S}(0,t)-M_{TP}^{\text{ош}}(t)\right);$$

$$\left(EJ_{Y1}Cos^2\varphi+EJ_{X1}Sin^2\varphi\right)\frac{\partial^2\overline{Y}}{\partial S^2}-\frac{1}{2}\left(EJ_{X1}-EJ_{Y1}\right)\frac{\partial^2\overline{X}}{\partial S^2}Sin2\varphi=M_{TP}^{\text{ГШ}}-\overline{K}\left(GJ_o\frac{\partial\overline{\varphi}}{\partial S}(0,t)-M_{TP}^{\text{ош}}(t)\right);$$

$$\left(EJ_{X1}Cos^2\varphi+EJ_{Y1}Sin^2\varphi\right)\frac{\partial^2\overline{X}}{\partial S^2}-\frac{1}{2}\left(EJ_{X1}-EJ_{Y1}\right)\frac{\partial^2\overline{Y}}{\partial S^2}Sin2\varphi=M_{TP}^{\text{вш}}(t);$$

Boundary conditions at the tip of one of the six blades :

$$\frac{\partial\overline{\varphi}}{\partial S}(R,t)=0;$$
$$\frac{\partial^2\overline{X}}{\partial S^2}(R,t)=\frac{\partial^2\overline{Y}}{\partial S^2}(R,t)=0;$$
$$\frac{\partial^3\overline{X}}{\partial S^3}(R,t)=\frac{\partial^3\overline{Y}}{\partial S^3}(R,t)=0.$$

Fig.8

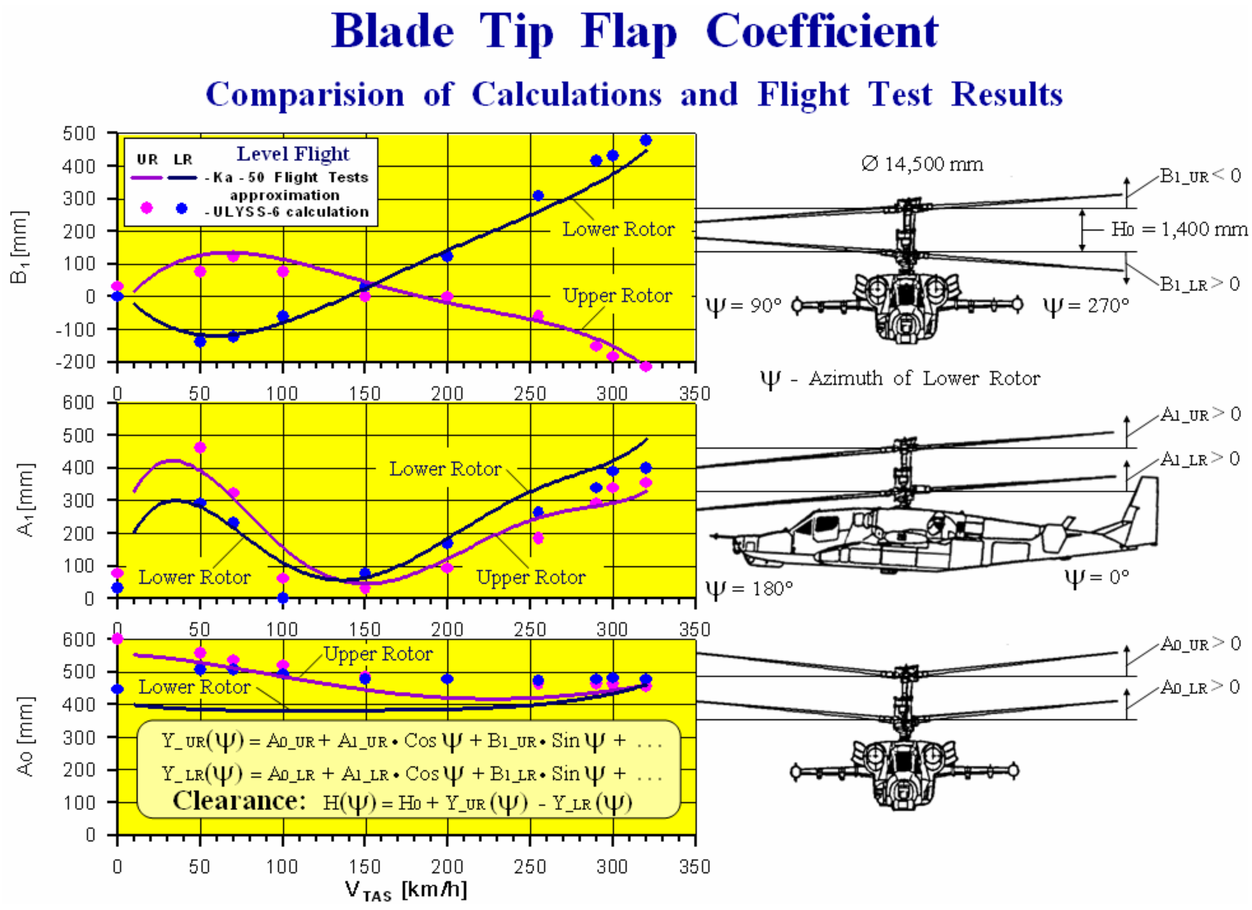

Blade Tip Flap Coefficient
Comparision of Calculations and Flight Test Results
B1 [mm]
500
400
300
200
100
0
-100
-200
UR LR
Level Flight
- Ka - 50 Flight Tests approximation
- ULYSS-6 calculation
Lower Rotor
Upper Rotor
0
50
100
150
200
250
300
350
A1 [mm]
600
500
400
300
200
100
0
Lower Rotor
Lower Rotor
Upper Rotor
A0 [mm]
Upper Rotor
Lower Rotor
Y_UR(ψ) = A0_UR + A1_UR • Cos ψ + B1_UR • Sin ψ + ...
Y_LR(ψ) = A0_LR + A1_LR • Cos ψ + B1_LR • Sin ψ + ...
Clearance: H(ψ) = H0 + Y_UR(ψ) - Y_LR(ψ)
V_TAS [km/h]
Ø 14,500 mm
B1_UR < 0
H0 = 1,400 mm
B1_LR > 0
ψ = 90°
ψ = 270°
ψ - Azimuth of Lower Rotor
A1_UR > 0
A1_LR > 0
ψ = 180°
ψ = 0°
A0_UR > 0
A0_LR > 0

Fig.9

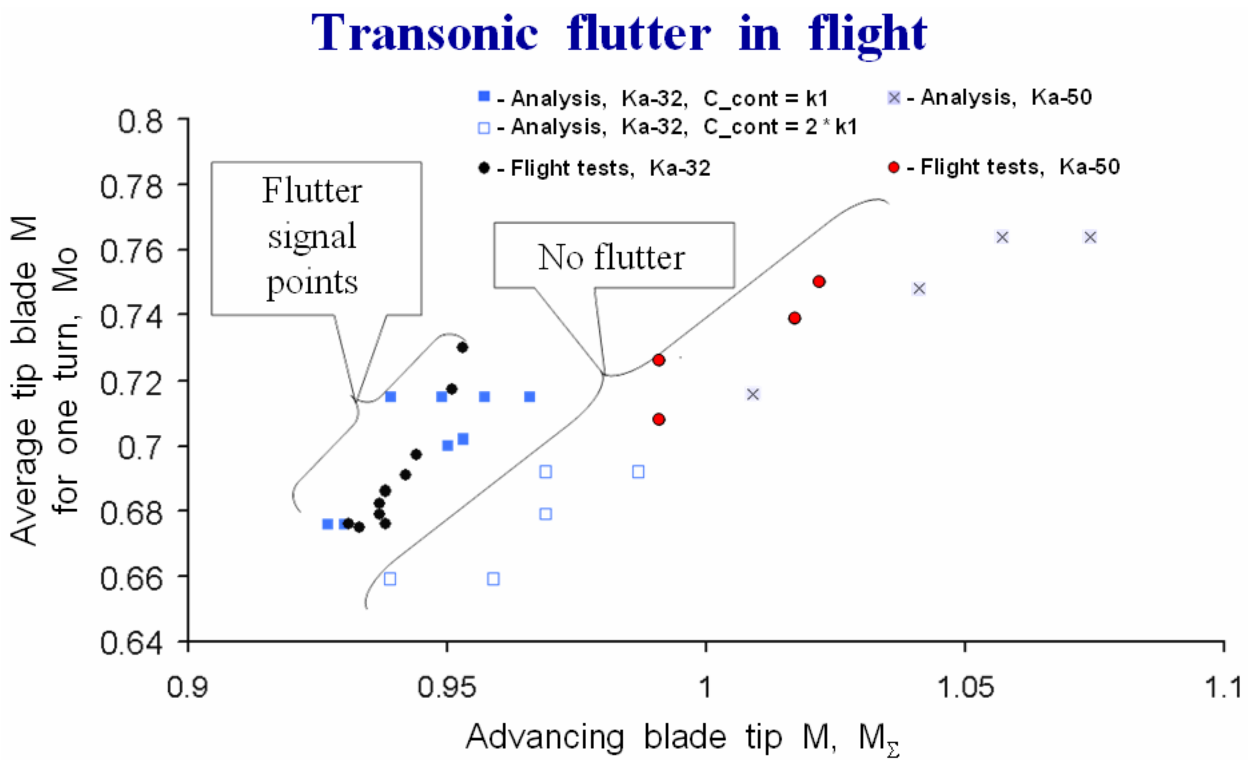

Transonic flutter in flight
■ - Analysis, Ka-32, C_cont = k1
□ - Analysis, Ka-32, C_cont = 2 * k1
● - Flight tests, Ka-32
× - Analysis, Ka-50
● - Flight tests, Ka-50
Flutter signal points
No flutter
Average tip blade M for one turn, Mo
0.8
0.78
0.76
0.74
0.72
0.7
0.68
0.66
0.64
0.9
0.95
1
1.05
1.1
Advancing blade tip M, MΣ

Fig.10

Ka-32 helicopter

Correlation of analytical and flight test data for blade oscillations in the air

Main rotor oscillations are excited through the autopilot

Ground tests for flutter
at effective blade body balance position shift dX_eff = 4.1 %

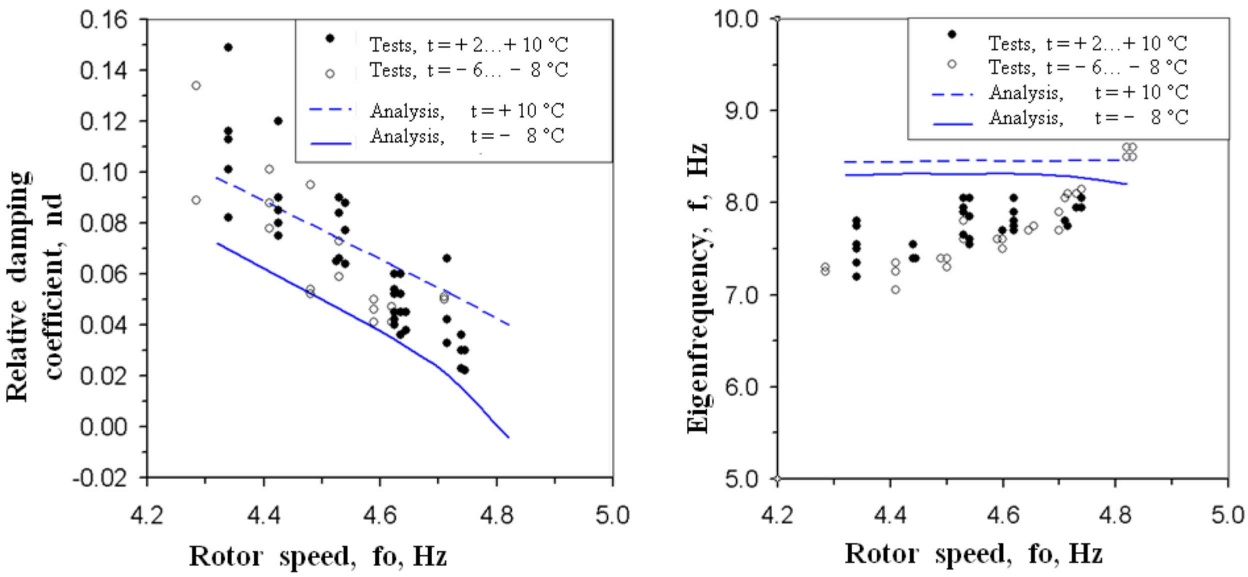


Fig.11

Ka-32 helicopter

Correlation of analytical and flight test data for blade oscillations in the air

Air temperature (M value) versus main rotor critical speed

Ground tests for flutter
at effective blade body balance position shift dX_eff = 4.1 %

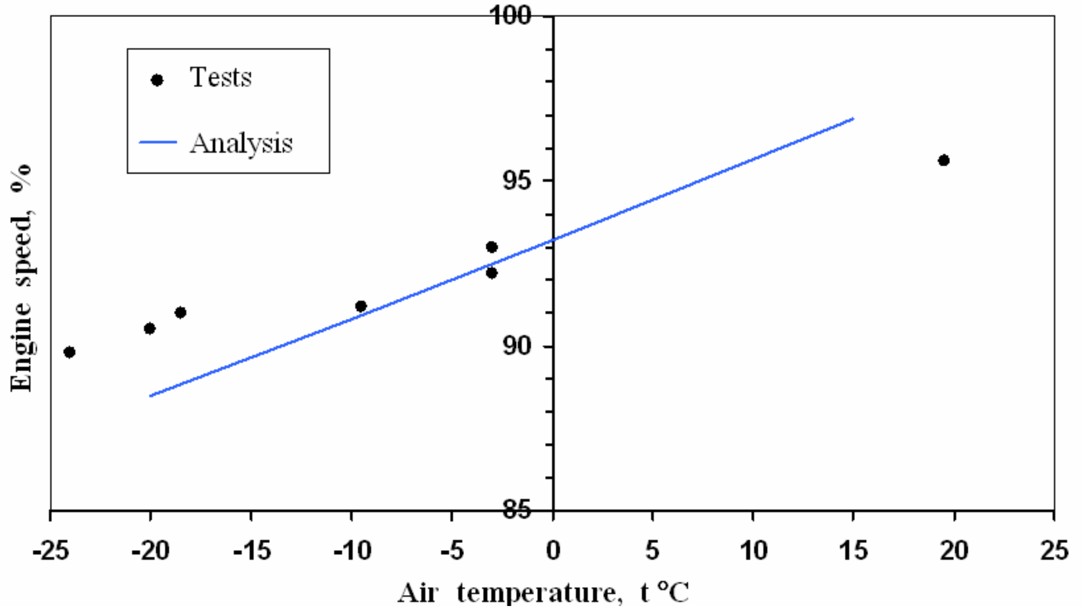


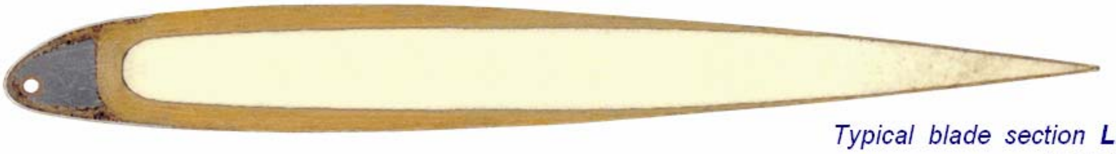
Fig.12

Polymer composite main rotor blades of Kamov helicopters in the Kamov Company Museum

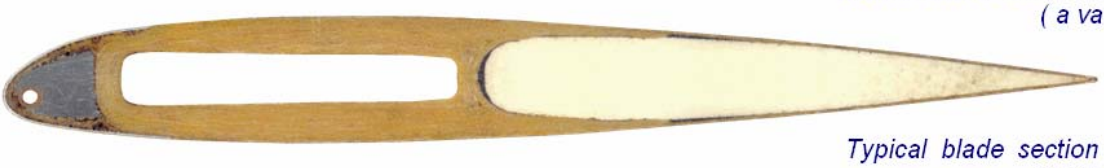
Fig.13

Multipurpose **Ka - 15** helicopter (1953)

Multipurpose **Ka - 18** helicopter (1958)



Typical blade section ***LP - 1***
(a variant)



Typical blade section ***B - 3***
(a variant)

Typical production main rotor blade ***B - 7*** *section*
(blade chord $B = 260 \ldots 104$ *mm,* $B_7 = 170$ *mm)*

Fig.14

Ka - 25 combat ship borne helicopter (1961)

Ka - 25K flying crane (1967)

*Typical main rotor blade **D 1 - M** section*
(blade chord B = 370 mm)

Fig.15

Ka - 26 multipurpose helicopter (1965)
(type certified in several countries)

Ka - 126 multipurpose helicopter (1987)

*Typical main rotor blade **N - 1M** section*
(blade chord $B = 350 \ldots 175$ mm, $B_7 = 250$ mm)

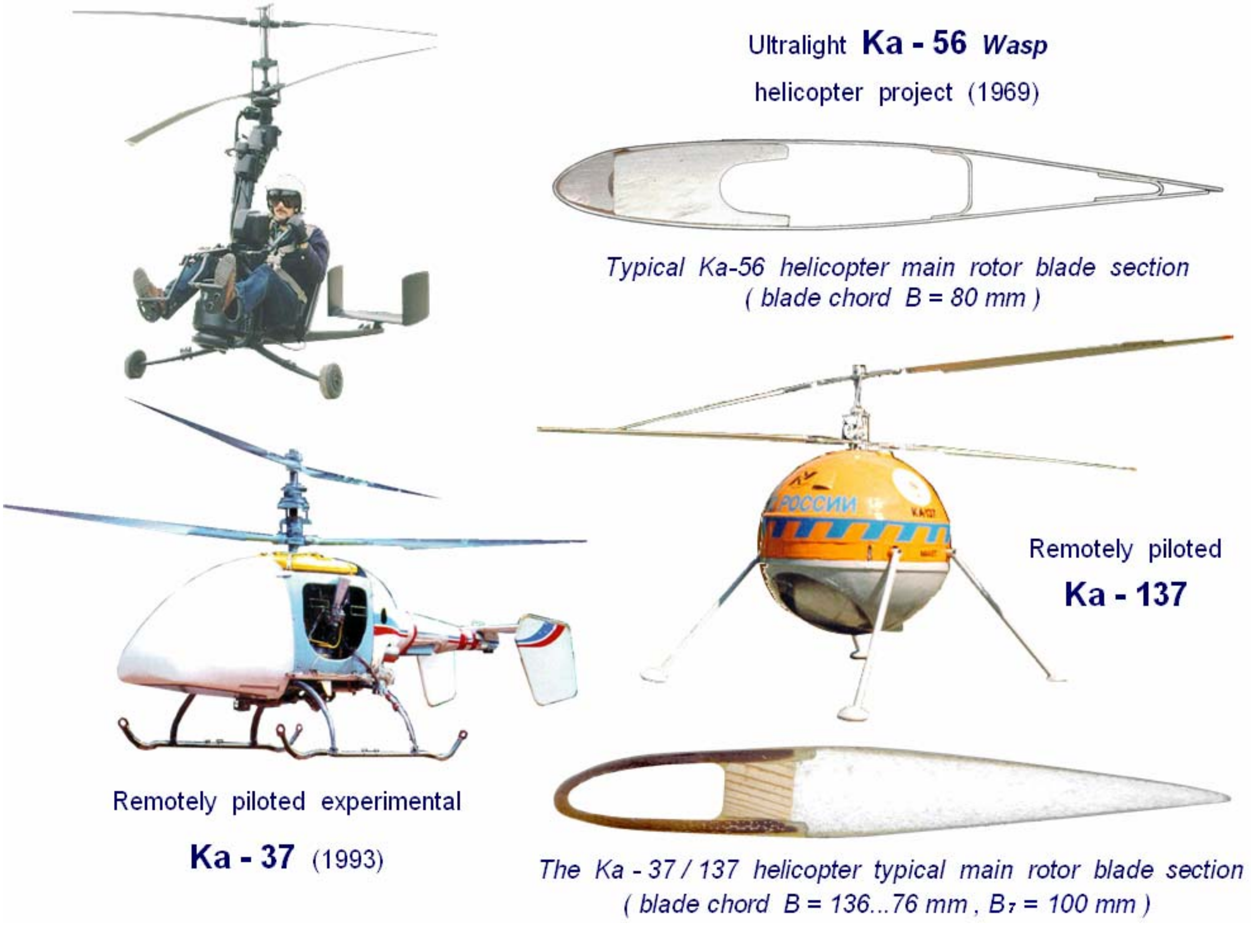
Fig.16


Ka - 27 (1973)
multipurpose ship borne helicopter
Ka - 28 helicopter
(export version of the Ka - 27)
Ka - 29 (1976)
transportation combat helicopter
Typical main rotor blade 500 UG section
(blade chord B = 480 mm)
Nomex
honeycomb used since 1998
Ka - 31 (1986)
radar surveillance helicopter
Ka - 32 (1980)
civil multipurpose helicopter
Ka - 32 A / A11BC (1990, 1998)
(type certified in several countries)

Fig.17


Ka - 50 Black Shark (1982)
single pilot combat attach helicopter
Ka - 52 Alligator (1997)
multipurpose combat helicopter
Typical main rotor blade section of blades 800, 702
of Ka - 50 / 52 / 60 helicopters
(blade chord B = 530 mm)
M 1 : 1
M 5 : 1
Typical tail rotor blade section of Ka - 60 helicopter
(blade chord B = 89 mm)
Ka - 60 Kasatka (1998)
army multipurpose helicopter

Fig.18



Ultralight **Ka - 56** ***Wasp***
helicopter project (1969)

Typical Ka-56 helicopter main rotor blade section
(blade chord B = 80 mm)

Remotely piloted
Ka - 137

Remotely piloted experimental
Ka - 37 (1993)

The Ka - 37 / 137 helicopter typical main rotor blade section
(blade chord B = 136...76 mm , B_7 = 100 mm)

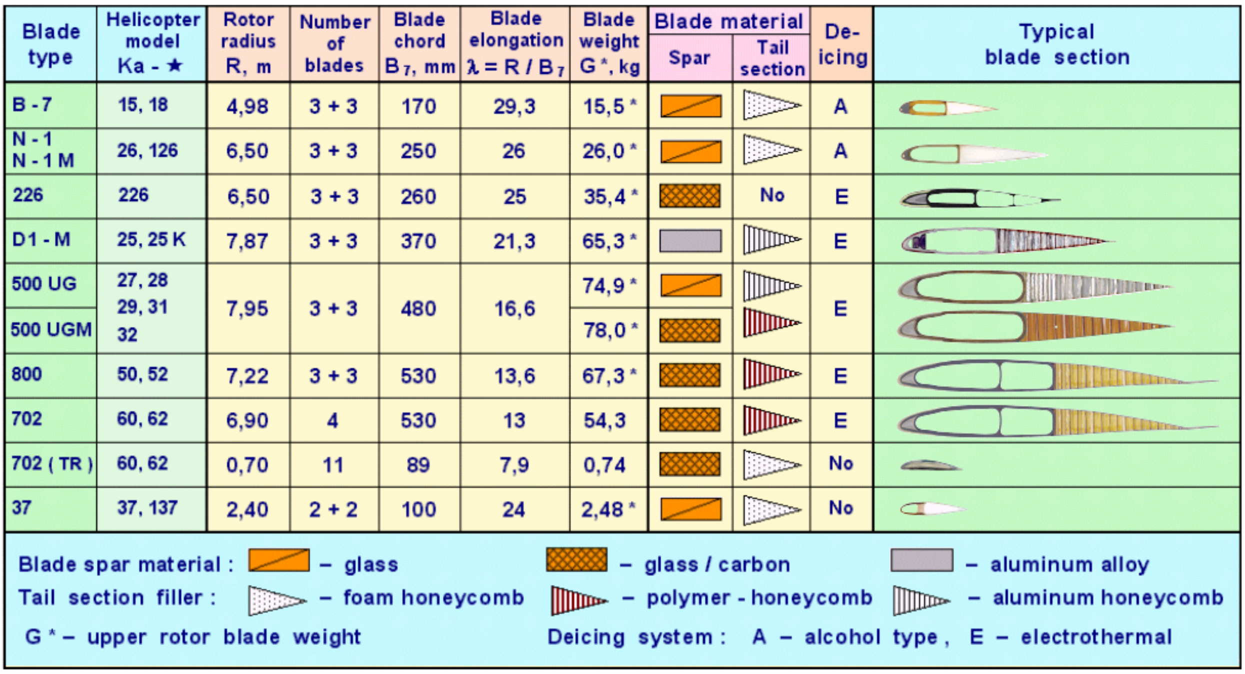
Fig.19

(1997) Multipurpose **Ka - 226** civil helicopter (2001)
(type certified in 2003)

Typical main rotor blade ***226*** *section*
(blade chord B = 260 mm)

Fig.20

Development of designs and applied materials in Kamov helicopter main & tail rotor blades



Blade type	Helicopter model Ka - ★	Rotor radius R, m	Number of blades	Blade chord B_7, mm	Blade elongation $\lambda = R / B_7$	Blade weight G *, kg	Blade material		De-icing	Typical blade section
							Spar	Tail section		
B - 7	15, 18	4,98	3 + 3	170	29,3	15,5 *	🟧	▷	A	
N - 1 N - 1 M	26, 126	6,50	3 + 3	250	26	26,0 *	🟧	▷	A	
226	226	6,50	3 + 3	260	25	35,4 *	▦	No	E	
D1 - M	25, 25 K	7,87	3 + 3	370	21,3	65,3 *	⬜	⊳	E	
500 UG	27, 28 29, 31	7,95	3 + 3	480	16,6	74,9 *	🟧	⊳	E	
500 UGM	32					78,0 *	▦	▶		
800	50, 52	7,22	3 + 3	530	13,6	67,3 *	▦	▶	E	
702	60, 62	6,90	4	530	13	54,3	▦	▶	E	
702 (TR)	60, 62	0,70	11	89	7,9	0,74	▦	▷	No	
37	37, 137	2,40	2 + 2	100	24	2,48 *	🟧	▷	No	

Blade spar material : 🟧 – glass ▦ – glass / carbon ⬜ – aluminum alloy

Tail section filler : ▷ – foam honeycomb ▶ – polymer - honeycomb ⊳ – aluminum honeycomb

G * – upper rotor blade weight Deicing system : A – alcohol type , E – electrothermal

Fig.21

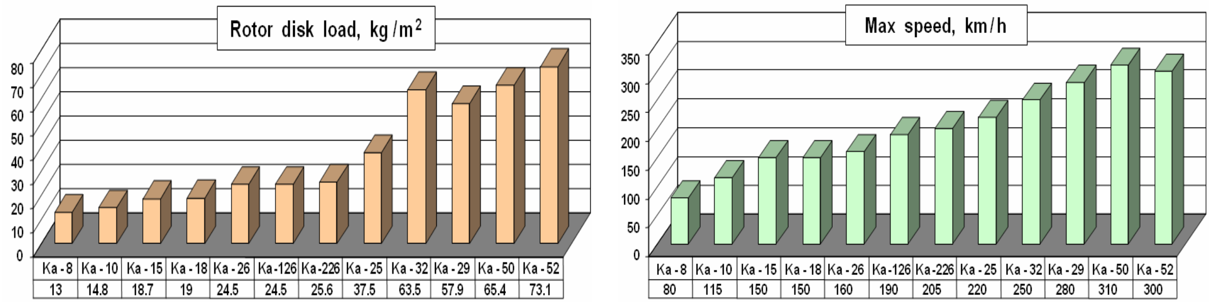


Fig.22

Weight of Kamov production composite blades

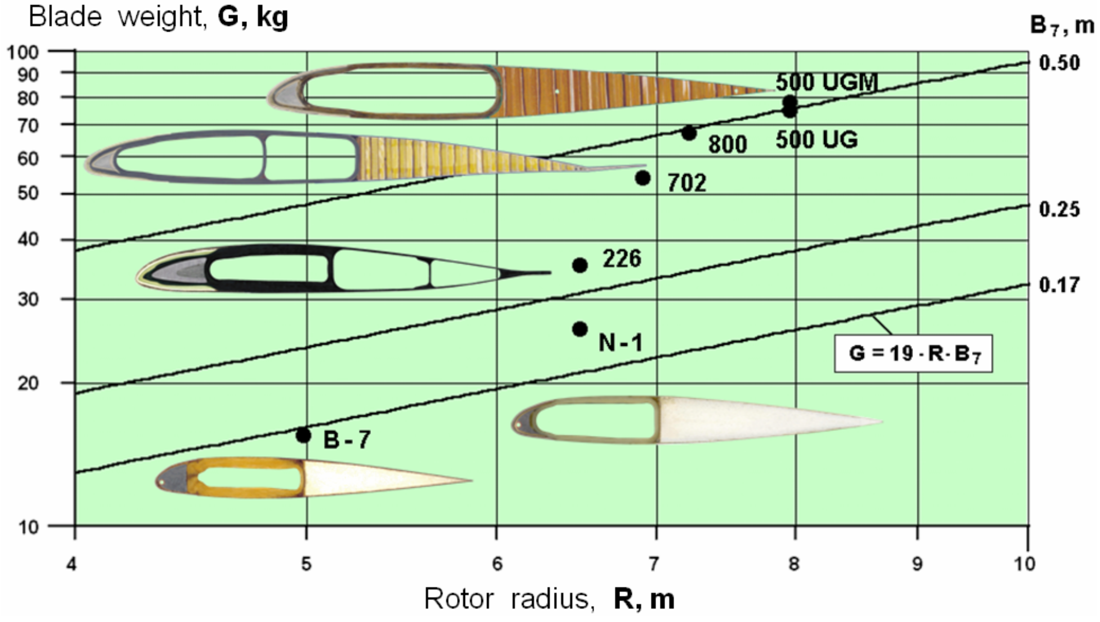
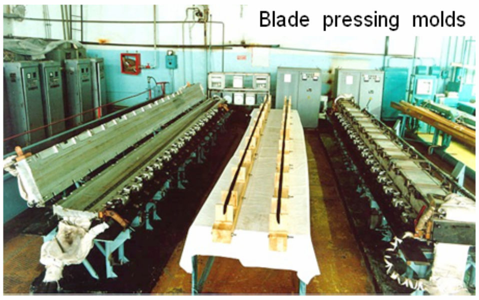


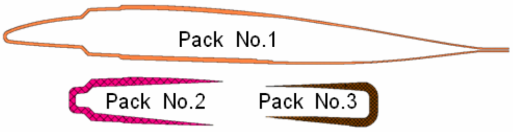
Fig.23

Manufacture of a blade using lay-out technique

(Kamov Company)



Preliminary pressing of packs



Final blade 226 pressing pattern

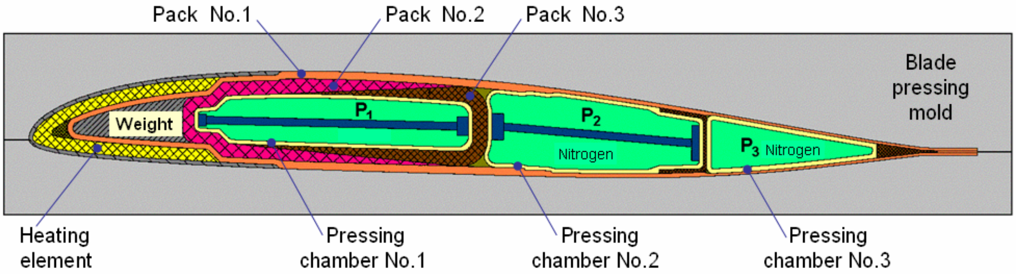
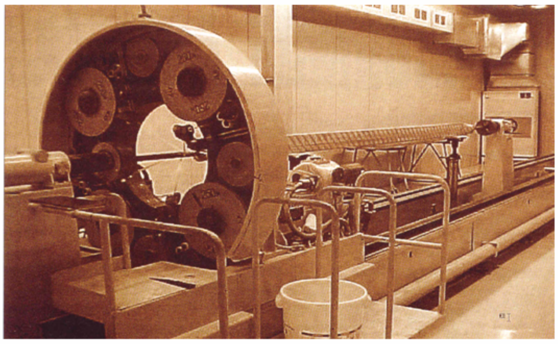


Fig.24

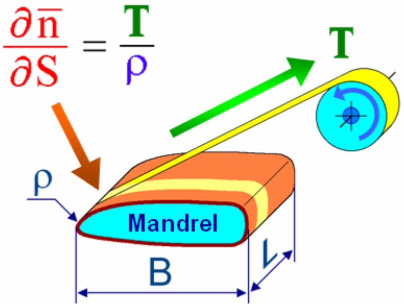
Manufacture of a blade spar using winding technique

(Mil helicopter plant)



Winding machine with 4 synchronously operating laying mechanisms

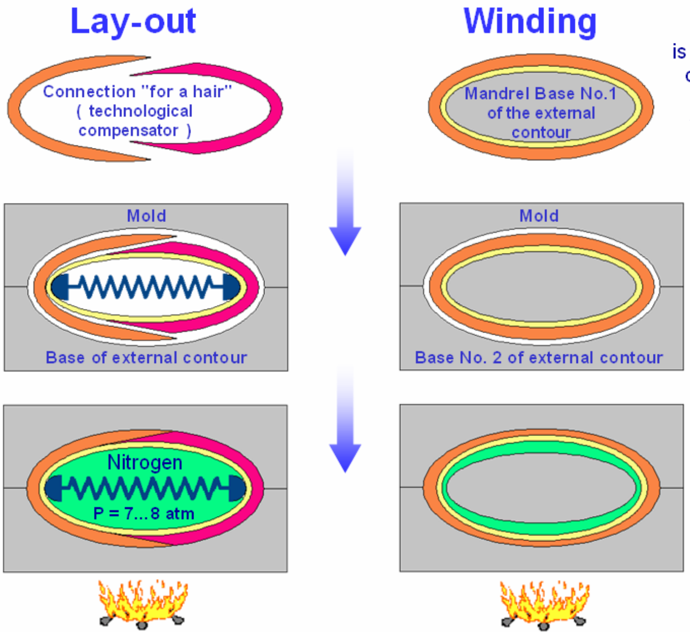
Winding pattern



$$\frac{\partial \bar{n}}{\partial S} = \frac{T}{\rho}$$

Fig.25

Final pressing of blade spars made using lay-out and winding techniques



Lay-out	Winding
The packs are made by laying out prepreg sheets on mandrels and preliminary pressing	The pack is made by winding of prepreg tapes on the mandrel with a pressing chamber
Assembly of packs with a release attachment and insertion in the mold	Insertion of a pack on the mandrel with a pressing chamber
Hot pressure molding	Hot pressure molding

Fig.26

Provision of quality and consistency of blade manufacture

Production facility quality control			Independent Inspection quality control	
Incoming control of materials (for compliance with the delivery Specifications)	**Prepreg and blade assembly quality control**	**Finished blade quality control**		
Samples:	**Samples:**	**Samples:**	**Non - destructive control** (each blade):	**Destructive control** (one blade in a lot for complete compliance with the Specifications):
- weight control; - physical properties and chemical composition; - structural strength	- weight control; - physical properties and chemical composition	- weight control; - physical properties and chemical composition; - structural strength	- weight control; - ultrasonic; - x- ray; - visual inspection	- weight control; - physical properties and chemical composition; - structural strength
Data	**Data**	**Data**	**Data**	**Data**
↓	↓	↓	↓	↓
Blade production certificate (to be preserved for the whole blade service life)				

Fig.27

Blade section dynamic tests for fatigue

← Resonance test rig for testing coupled blade root sections

The scheme of tests

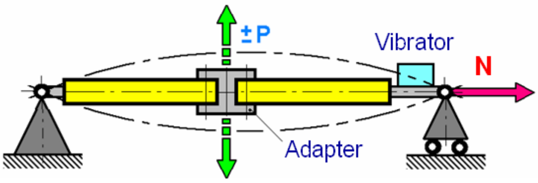


Fig.28

Utilization of the blade section dynamic fatigue test results

Main rotor blade section dynamic test rig

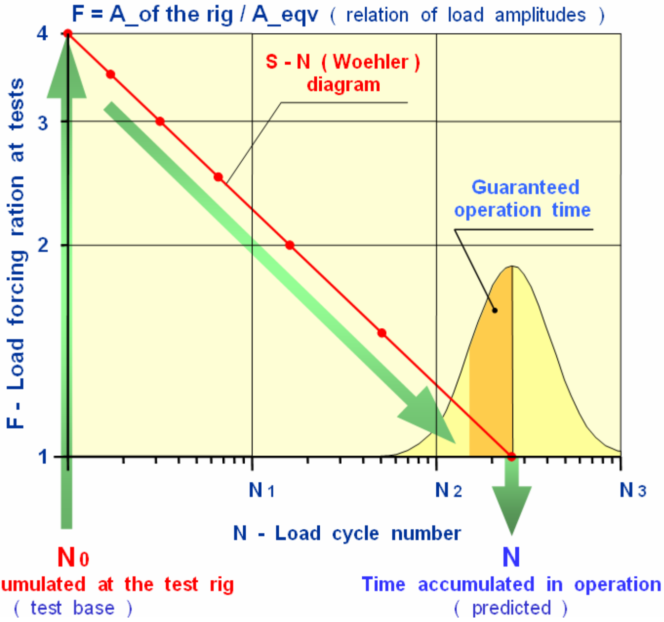


Fig.29