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Ka-50 Attack Helicopter Aerobatic Flight

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1. Introduction

The Ka-50 attack helicopter is intended to act against both ground and air targets. High maneuverability of the Ka-50 helicopter provides lower own vulnerability in combat.

Aerobatic flight demonstrates maneuverability of the helicopter. This is effected by validity of the key solution in the helicopter designing.

KAMOV Company helicopter experience concentrates in the Ka-50 attack helicopter. The Table No.1 lists basic types of the serial and experimental helicopters which have been developed by KAMOV Company within the 50 years period.

This paper consists of presentations on the following subjects:

- basic technical solutions and aeroelastic phenomena;
- examination of test flight results;
- maneuverability features;
- means of aerobatic flight monitoring and analysis.

2.Basic technical solutions and aeroelastic phenomena

It is very important to have a substantiation of aeromechanical phenomena. This is feasible given adequate mathematical models making possible to explain and forecast :

- natural frequencies of structures;
- loads;
- aeroelastic stability limits ;
- helicopter performance .

KAMOV Company has developed software to simulate a coaxial rotor aeroelasticity [1,2,4,5]. Aeroelastic phenomena to be simulated are shown in the Fig.2 as (1-7) lines in the following way:

(1) - system of equations of rotor blades motion ;
(2) - elastic model of coaxial rotor control linkage ;
(3) - model of coaxial rotor vortex wake;
(4,5,6) - unsteady aerodynamic data of airfoils;
(7) - elastic /mass / geometry data of the upper/lower rotor blades and of the hubs.

The lines (1-8) in Fig.3 show functional capabilities of the software. Columns (1-5) conform to versions of the software . Both steady flight modes and manoeuvres of the helicopter are simulated .

Based on experience of KAMOV Company new key design approaches regarding the coaxial rotors of the Ka-50 helicopter were developed (ref. to Fig.4).

The blade aerofoiles were developed by TsAGI for the Ka-50 helicopter specially (ref. to Fig.5). Optimal combination of Cl ,Cd , Cm (α, M) characteristics was a necessary condition to achieve:

- high G-load factor & stall limit ;
- acceptable margin of flutter speed ;
- low loads of rotor & linkage ;
- low vibration level ;
- high helicopter performance.

Blade sweep tips developed by KAMOV Company affords for the same purposes. Usage of all key approaches regarding rotors listed in Fig.4 becomes an sufficient condition to achieve high performance of the rotor system and therefore of the helicopter as whole.

3.Examination of test flight results

Safety in the test flights and aerobatic flights is the most important question.

Test flight safety is based on:

- advanced technologies;
- flight limitations;
- human factor.

Fig.6 demonstrates a list of phenomena identifying main aeromechanical limitations of coaxial rotors and helicopter at the same way.

Acceptable margin of flutter speed and stall flutter speed were substantiated by mathematical simulation and validated by flight test results. Flight tests results are shown by (ωR/Vtas) relation in Fig.7. A part of flight test points is given in the frame, namely the following range: from **Vtas ~300 km/h** to **Vne=350 km/h** , till **Vtas =390 km/h**. Flutter is non-existent in restricted range of calculated curve what is verified by flight test results. Calculated curve presents that there is a flutter speed margin of about **50 km/h**.

Vibration level of the coaxial helicopter have been discussed in paper [2]. The alternating forces apply to hubs of the upper/lower rotors and sum of them is transferred to airframe and excites its vibration. Configuration of the Ka-50 helicopter rotors affords applying of minimal summarised alternating forces to the airframe. In this case vibration level of the airframe is minimal too.

Vibration level is not in excess of 0.01g in main flight modes. Rotor pendulum and anti-resonant isolation system are not used.

Special task for the coaxial helicopter is making a provision for the acceptable lower-to-upper rotor blade tips clearances. As a task of aeromechanics it is analogous with a task to provide the blade tips-to-tail boom clearance of the helicopters with the tail rotor.

KAMOV Company applies at analysis both calculation methods and flight tests [3,5]. The clearances are measured with the help of optic devices at each of 6 crossing points when the upper blades are arranged above lower blades during their relative rotation with doubled angular speed .

The mechanics can be outlined as following (ref. to Fig.8). The planes of the upper / lower rotor blade tips are in parallel at hover. Their clearance is even more than a clearance between rotor hubs.

At forward flight variable azimuthal airloads occur in the rotor disk, that results in flapping motion. Because of this , planes of the upper / lower rotor blade tips are inclined to equal angles in flight direction (forward / backward) .

In lateral direction (viewed along flight direction) the planes of blade tips are inclined to each other because of counter-rotation of the rotors (ref. to Fig. 8).

The upper-to-lower tips clearances on one disk side decreases and increases on the opposite one. In lateral direction an inclination angle of blade tip planes is approximately equal to blade tip flapping angle (to the left / to the right) and depends on flight mode (Fig. 8). As known from aeromechanics, there are relations between blade flapping angle and the rotor parameters, especially to Lock number, blade geometrical twist angle and blade/control linkage torsional stiffness.

Calculation and flight test results show the values of coaxial rotor parameters mentioned above which ensure acceptable safety clearance.

Fig.8 demonstrates measured blade tip flapping angles made during flight tests and comparison with calculation data .

Influence of Δ-coupling factor and linkage stiffness is illustrated by the Fig.9. Generalised measurement results for the forward flight and manoeuvres are presented in the Fig.10, Fig.11.

The acceptable upper-to-lower rotor blade tips clearances were substantiated by mathematical simulation and validated by flight tests results for all approved envelope of manoeuvres .

The acceptable lower rotor blades to tail boom clearances were validated .

4.Maneuverability features

Load factor / speed envelope was substantiated and validated by flight test results:

- within operational limitations (pitch, roll, rotor speed, rotor loads, ...);
- within special aerobatic limitations.

A part of flight test points is illustrated by the Fig.12:

at **3.5 > g-factor > 2** and at **g-factor ≈ 0** .

Each point corresponds to one of the performed manoeuvres . The most part of them are shown at the Fig.12. No established limitations have been exceeded .

Fig.12 also shows the test flight results of Tiger's helicopter [6].

The table on the Fig.13 presents parameters of manoeuvres within special limitations for aerobatic flights. It is notable in this case parameters of " flat turn " and pull-out from the skewed loop at **g–factor = 3.5**.

5. The means of aerobatic flight monitoring and analysis

The NSTAR software was created to provide processing and analysis of helicopter test flight data. Using records made by aircraft test instrumentation the NSTAR software makes possible to restore the flying path and to calculate flight parameter additional values [7].

NSTAR software is comparable both with test flight record system and with standard record system. NSTAR results are used for the following purposes :

- analysis of actions , assistance in pilot training;
- examination for critical parameter limits;
- as input data for simulation.

Fig.14 presents an example for skewed loop path recovery.

6. Conclusions.

1. New technologies on the coaxial rotors of the Ka-50 helicopter were developed.
2. Load factor / speed envelope was substantiated and validated by flight test results.
3. Ka-50 helicopter test flight safety was validated within operational and special aerobatic limitations for all approved envelope of manoeuvres.

7. References

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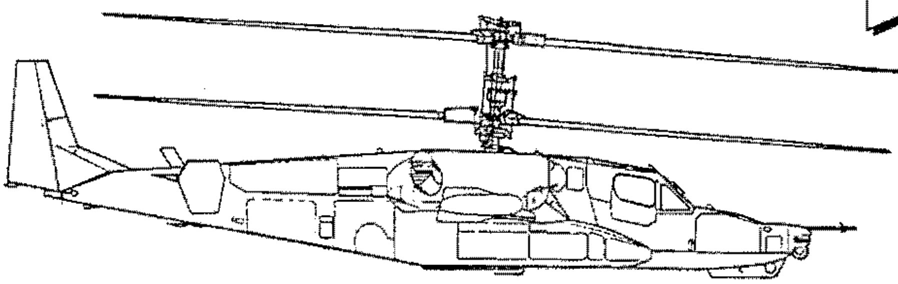

KAMOV HELICOPTERS FAMILY

(BASIC CONFIGURATIONS)

NAME	1st flight	PURPOSE	TYPE	Note
KACKP-1 / 2	1929 / 30	Reconnaissance	Experimental	Autogyro
A-7 / 7-3A	1934 / 40	Reconnaissance	Production	Autogyro
Ka-8	1947	NAVAL	Experimental	
Ka-10	1948	NAVAL	Experimental	
Ka-15	1953	NAVAL	Production	
Ka-18	1956	Multipurpose	Production	
Ka-22	1960	Multipurpose	Experimental	Convertiplane
Ka-25	1960	NAVAL	Production	ASW
Ka-26	1965	Multipurpose	Production	Type certificate
Ka-27	1973	NAVAL	Production	ASW
Ka-29	1976	Close support	Production	
Ka-32	1979	Multipurpose	Production	
Ka-50	1982	Attack	Production	
Ka-126	1987	Multipurpose	Experimental	
Ka-31	1990	Early Warning	Production	
Ka-37	1993	Reconnaissance	Experimental	Remotely-piloted
Ka-32A	1993	Multipurpose	Production	Type certificate
Ka-226	1997	Multipurpose	Production	
Ka-50H	1997	Attack	Experimental	Round-the-Clock Action
Ka-52	1997	Attack	Experimental	
Ka-32A11BC	1998	Multipurpose	Production	Type certificate
Ka-62	1998	Multipurpose	Experimental	Single-Rotor

Fig.1

Simulated Aeroelastic Phenomena of Coaxial Rotor

Simulated Phenomena		SIMULATION VERSION				
		ULISS-6	ULISS-1	ULMFE	FLUT	MFE
1	$EI_x(r/R, \omega t)$ $EI_y(r/R, \omega t)$ $GI_p(r/R, \omega t)$	✓	✓			
2	$\overline{\varphi}_o = \|\|\upsilon_{ij}\|\| \times \overline{M}$	✓			✓	✓
3	$V_i(r/R, \psi)$	✓				
4	C_L, C_D, C_M $(\alpha, \dot{\alpha}, M, \dot{M})$	✓	✓	✓		
5	C_{L_MAX} $(\alpha, \dot{\alpha}, M)$	✓	✓	✓		
6	Airfoil Aeroelastic Deformation	✓	✓	✓	✓	
7	Upper/Lower Rotor Data	✓	✓	✓	✓	✓

Fig.2

Analysis Results of Coaxial Rotor Aeroelastic Simulation

Analysis Results		SIMULATION VERSION				
		ULISS-6	ULISS-1	ULMFE	FLUT	MFE
1	Stall flutter boundary	Coaxial Rotors	Blade	Blade		
2	Bending moments, Pitch link loads, Actuator loads	Coaxial Rotors	Blade	Blade		
3	Elactic Deformations	Coaxial Rotors	Blade	Blade		
4	Alternate loads on Hubs	Coaxial Rotors				
5	Blade tips Clearances	Coaxial Rotors				
6	Flight test flutter	Coaxial Rotors	Blade	Blade		
7	Ground test flutter	Coaxial Rotors			Blade	
8	Natural frequencies			Blade		Blade

Fig.3

Advanced Key Technologies Based On:

Windtunnel Test Results & Mathematical Simulation

- ➢ New TsAGI Blade Aerofoiles
- ➢ Composite Blade Aeroelastic Design & Performance
- ➢ Hub Design Includes Torsional Elastic Feathing & Elastic Damping lead/lag Hinges
- ➢ Kinematics/Stiffness/Gear Ratios of Control Linkage
- ➢ General Aerodynamic Airframe Design

Fig.4

Blade Aerofoil Data

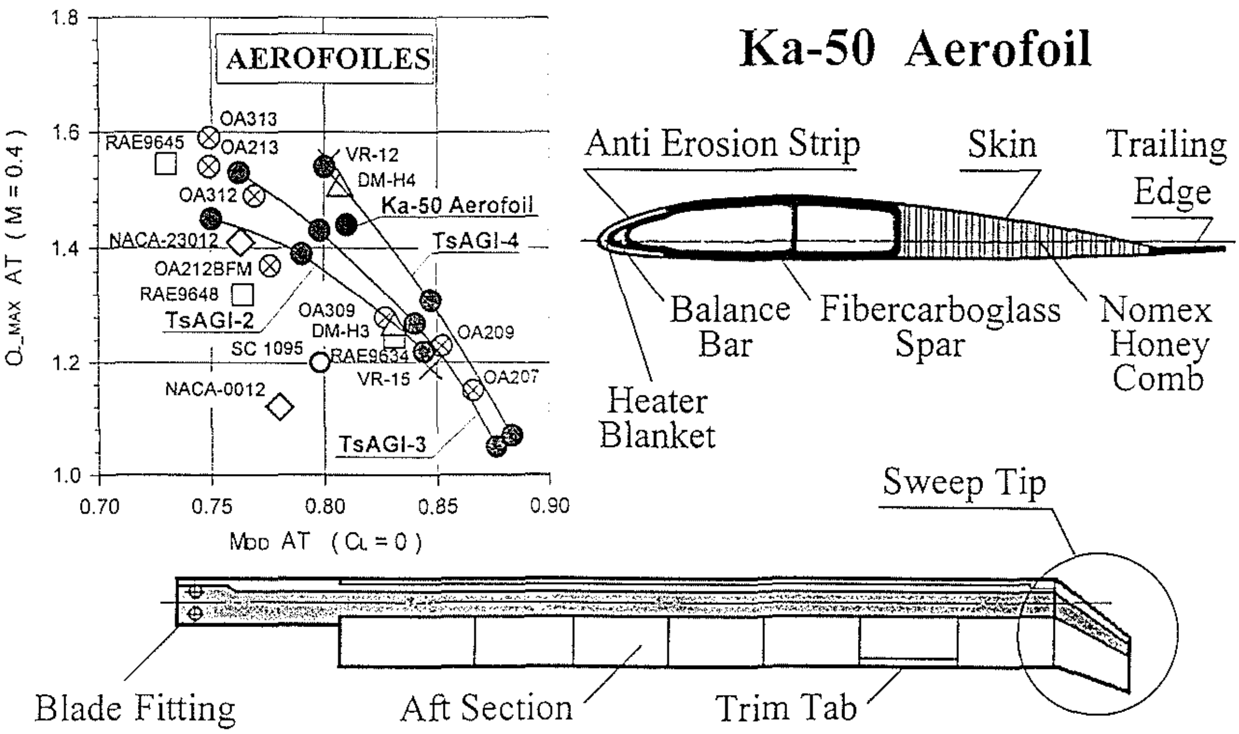

Fig.5

Test Flight Safety is provided by the Results of the Aeromechanical Examinations

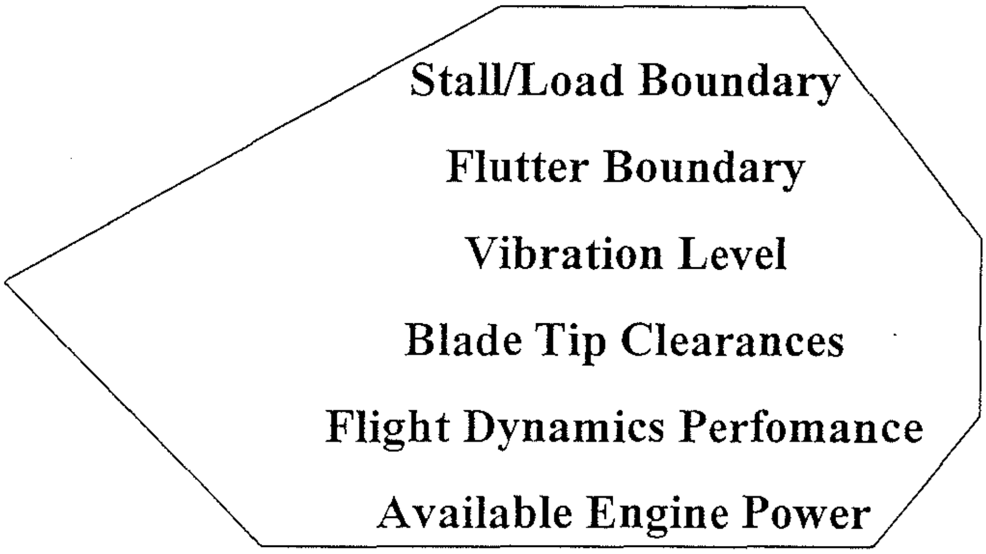

Fig.6

Demonstrated Rotor Speed Range

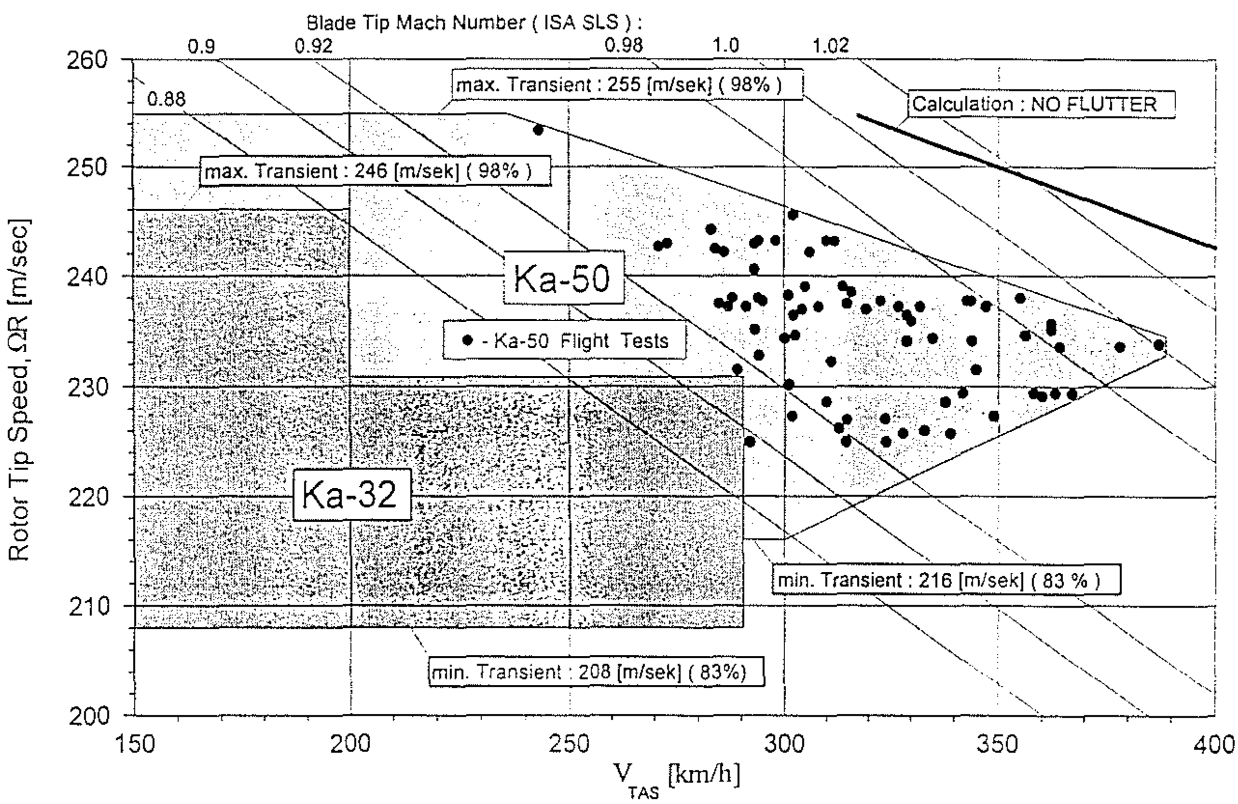

Fig.7

Blade Tip Coefficients

Comparision of Calculations and Flight Test Results

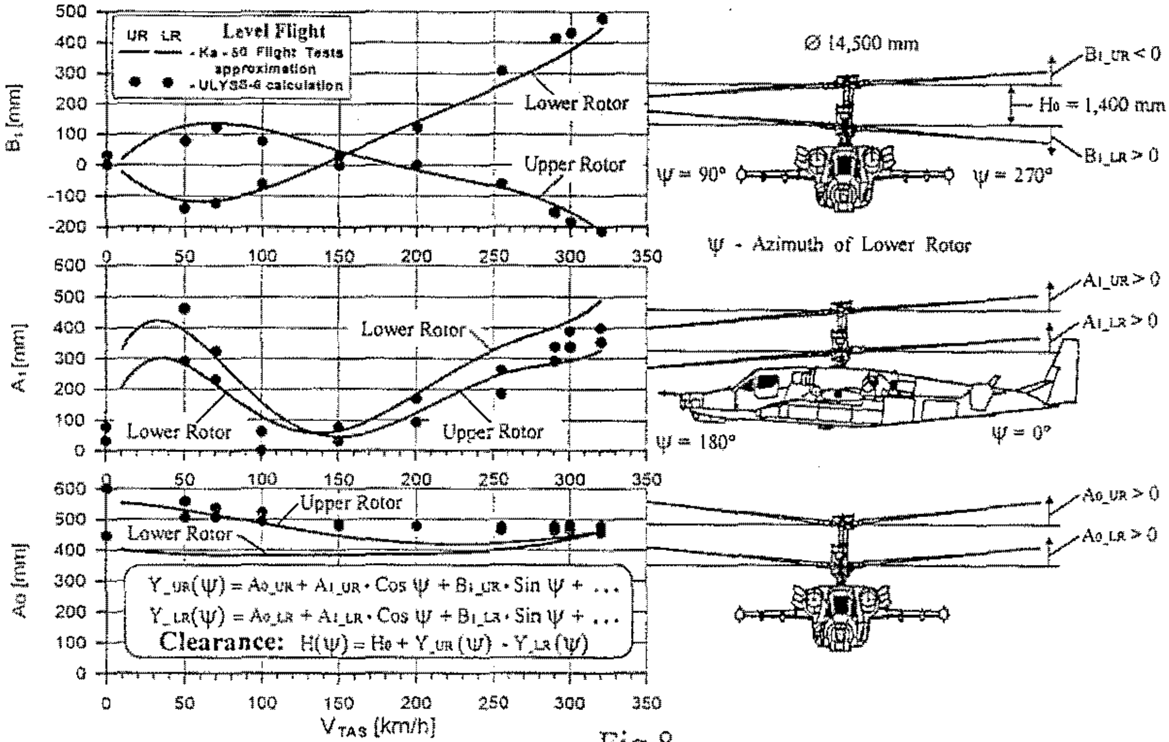

Fig.8

The Upper-to-Lower Rotor Blade Tips Clearancies

Versus a Factor of Δ - coupling

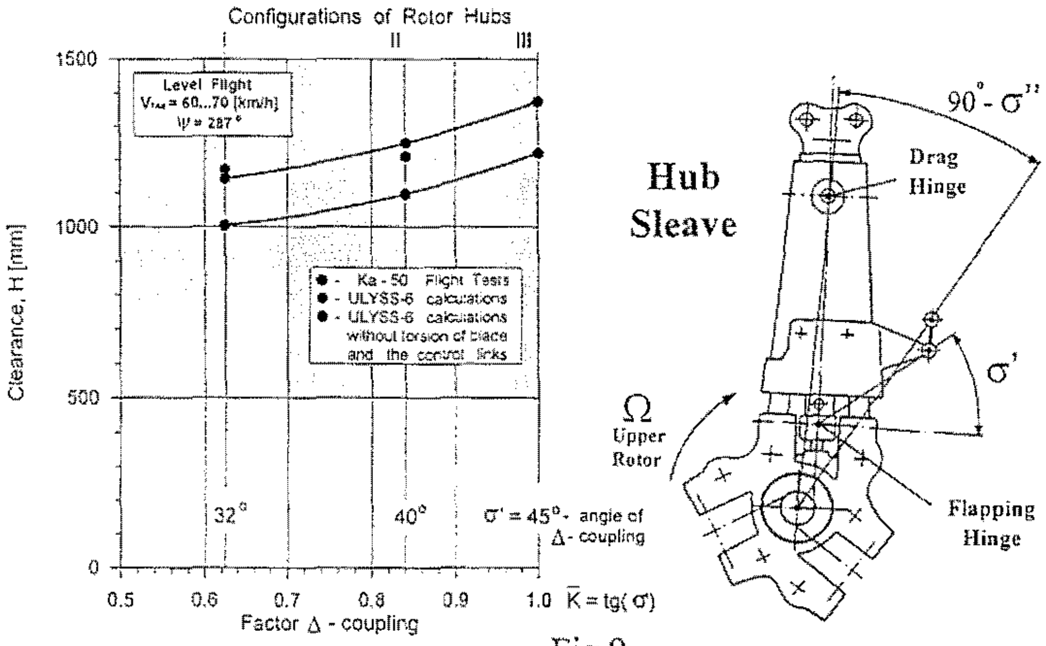

Fig.9

The Upper-to-Lower Rotor Blade Tips Clearancies
Versus Level Forvard Speed & Blade Azimuth

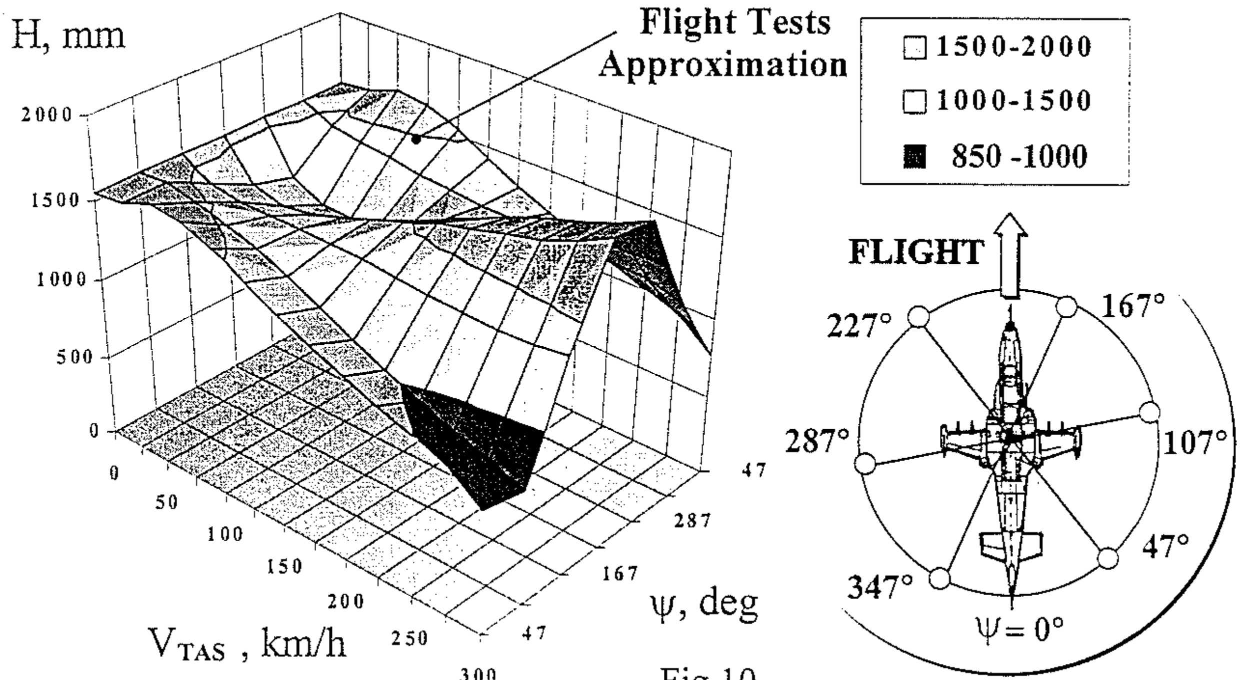

Fig.10

Measured Upper-to-Lower Rotor Blade Tips Clearancies

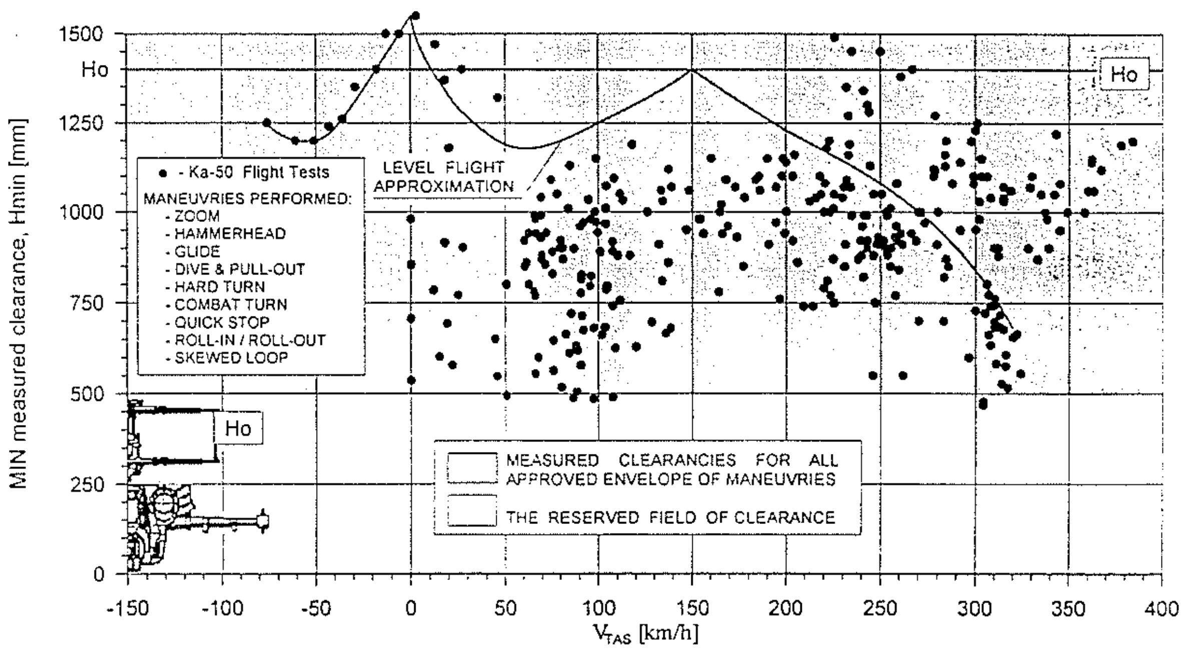

Fig.11

Load Factor / Speed Envelope

(Structural Qualification)

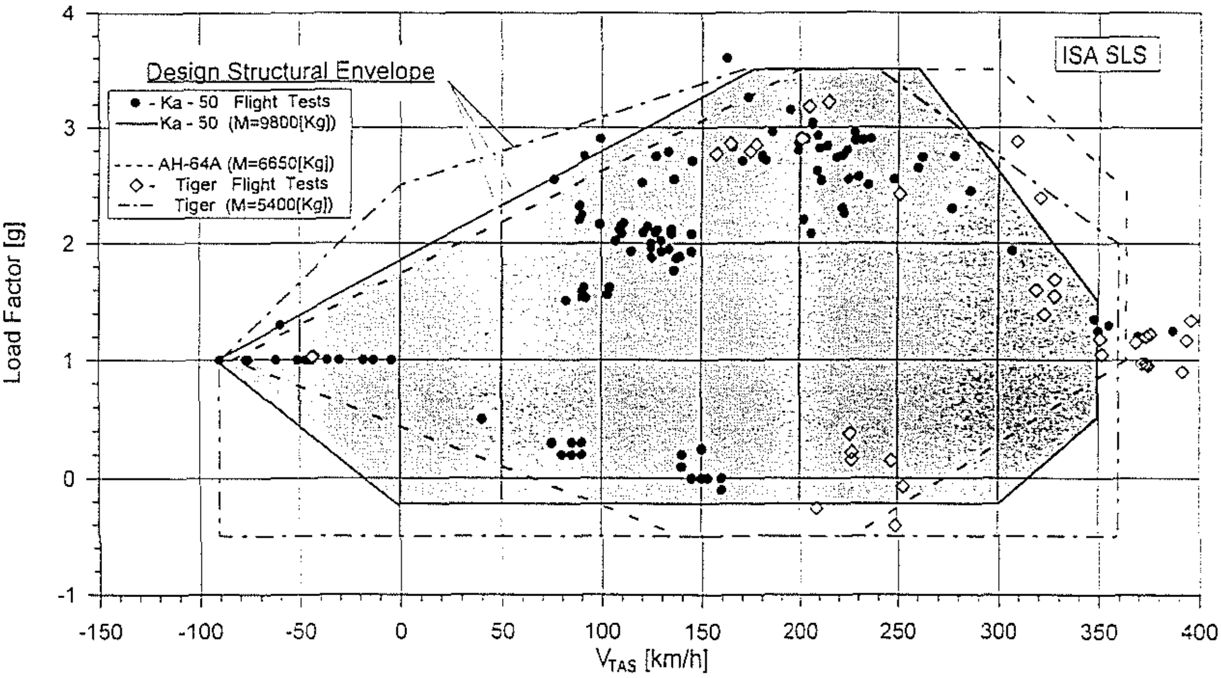

Fig.12

Ka-50 Aerobatic Maneuvries

MANEUVER	The Measured Parameter Values (min/max)				DESCRIPTION
	Airspeed V_{TAS} [km/h]	Load Factor [g]	Pitch attitude [deg]	Roll attitude [deg]	
Hard Turn (Right/Left)	280 ÷ 60	1.0 → 2.9 → 1.0	20 ÷ 50	0 ÷ -70	Unsteady Turn with Pitch & Roll
Flat Turn (Right/Left)	220 ÷ 0	1.0 → 1.5 → 1.0	±5	±20	Jaw Attitude ±80 ÷ ±90 [deg]
Hammerhead (Right/Left)	280 ÷ 0	1.0→ 2.9 → 1.0 → 2.9 → 1.0	0 ÷ ±90	±90	
Dive	0 ÷ 390	1.0 → 0.25 → 2.9 → 1.0	0 ÷ -90	±30	Push-Down, Dive & Pull-Out
Skewed Loop (Right/Left)	280 ÷ 70	1.0 → 2.9 → 1.2 → 3.5 → 1.0	0 ÷ 360	±150	
Quick Stop (Right/Left)	150 ÷ 40	1.0 → 2.0 → 1.2 → 1.0	0 ÷ 40	±55	Pitch / Roll Decceleration
Pull-Up with the Tail Forward	-90 ÷ 0	1.0 → 1.5 → 1.0	0 ÷ -70	±10	Backward Acceleration & Pull-Up with the Tail Forward/Up

Fig.13

Flight Path While Performing Skewed Loop

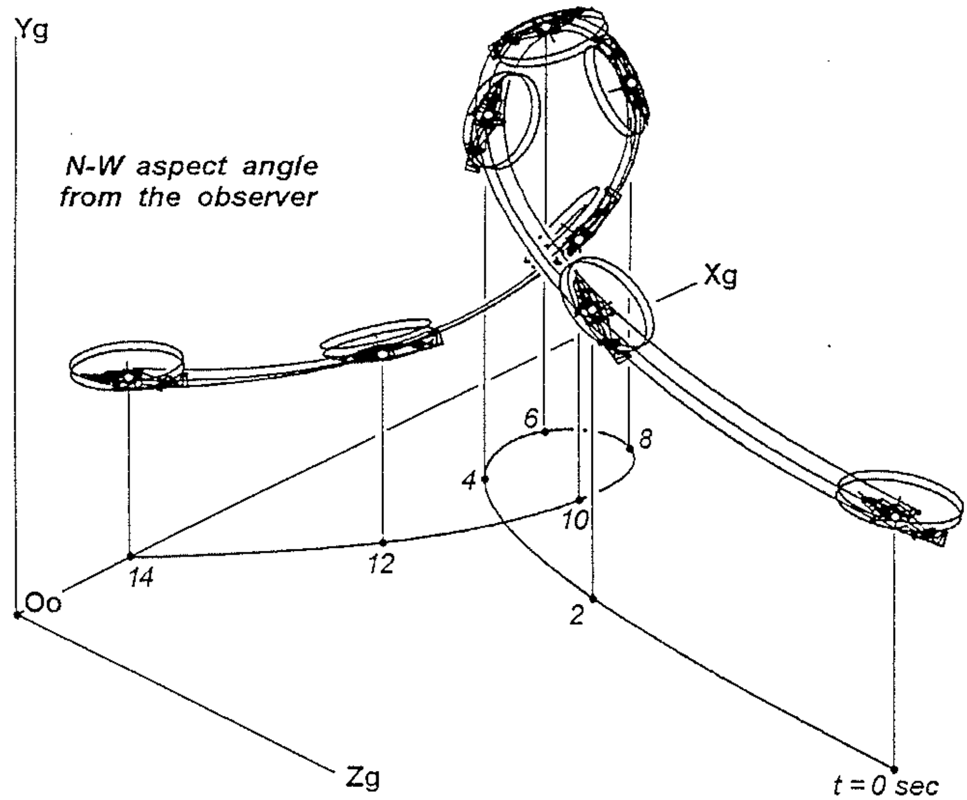

Fig.14

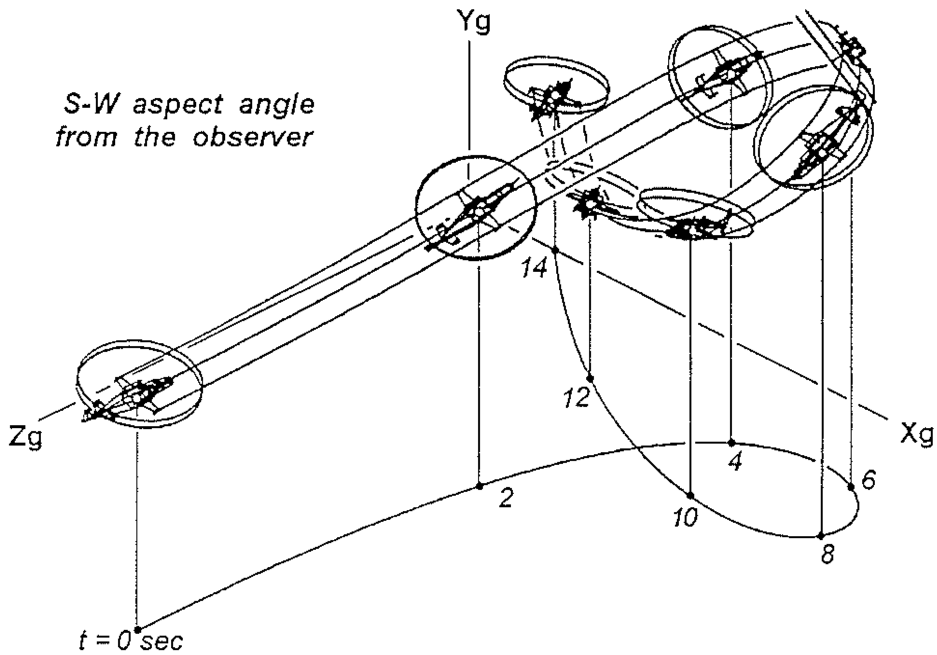

Fig.15