CURRENT STATE AND PROGRESS IN RESEARCH OF ROTORCRAFT AERODYNAMICS AT TSAGI

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Abstract

The problems of rotorcraft performance increasing by the improvement of airfoil sections, rotor and tail-rotor blades and body aerodynamics are considered. It is shown that the use of new scientific and technological decisions significantly increases the characteristics of Russian rotorcraft and, accordingly, their competitiveness on the home and foreign markets.

1. INTRODUCTION

From the moment of the beginning of rotorcraft development in TsAGI the investigations and development with the purpose of creation a scientific and technological base for improvement of aerodynamic, flight and economic characteristics of the Russian rotorcraft are regularly carried out, that, in turn, provides with it a high technological level and hold progressive positions and competitiveness in world and home markets. To resolve those problems the multi-level complex calculated and experimental system for development and investigations of advanced aerodynamic configurations of rotors and tail-rotors is created in TsAGI. The block diagram of this system is presented in Fig.1. The examples of realization of numerical nonlinear methods are shown in Fig. 2.

The main problem considered for perfection of advanced rotorcraft is significant increasing flight speed and range that provides effectivization of Russian rotorcraft complex including the air transport system for exploration of Siberia, Far East and Trans-Polar Territory.

One of the main ways to improve rotorcraft is development of new high-efficiency airfoil sections. Several generations of airfoil-sections (series TsAGI-1, TsAGI-2, TsAGI-3, TsAGI-4/4+ and TsAGI-5) were developed in TsAGI at various years. Newest series of TsAGI-5 high-speed airfoils surpasses all analogies that are known from press publications and TsAGI investigations. TsAGI airfoil-section series created a basis for development of new, more perfect aerodynamic configurations of the rotor and tail-rotor blades. Importance and priority of this direction to increase rotorcraft efficiency level is verified by development and introduction practice of new scientist and technological decisions on a design work stage at flight experimental and production prototypes of new aerodynamic configurations of blades for a number of the home rotorcraft.

On a basis of TsAGI-2, TsAGI-3 and TsAGI-4/4+ airfoil section series TsAGI together with Design Bureaus developed advanced, for every time span, aerodynamic configurations of rotor and tail-rotor blades for a number of Russian rotorcraft: Mi-26, Mi-28/28H, Mi-35, Mi-38, Ka-50/52, Ka-62, Ka-226. Now there is the problem to develop new rotors and tail-rotors for high-speed rotorcraft with the use TsAGI-5 airfoil-sections.

Important direction in rotorcraft characteristics improvement is body drag reduction especially for high-speed rotorcraft as drag reduction cardinally impacts on improvement of rotor operation. In this case the levels of:

- hinge moments of rotor blades and accordingly loads in a control system;
- variable loads in the lifting system components;
- cabin vibrations;
- terrain noise

are decreased.

One more direction is associated with the development of high-efficiency tail-rotors and fan in fin (fenestron) for rotorcraft.

On the basis of realization of joint TsAGI and Russian rotorcraft firms developments over the whole specified directions essential results were received. So the speed V_{max}=320 km/h was reached in horizontal flight at advanced transport medium rotorcraft Mi-38 with the rear freight manifold; at present this rotorcraft passes flight certificated tests. This horizontal flight speed level corresponds to the most advanced modern positions in world rotorcraft building for transport rotorcraft of an average weight category.

Some data on perfection of the Russian rotorcraft of various weight categories with the use of TsAGI developments in the field of rotorcraft bodies, rotors, tail-rotors and airfoil-sections aerodynamics are presented in the report.

2. ROTORCRAFT BODY AERODYNAMICS

The most important problem for advanced rotorcraft is the problem of essential drag reduction with the purpose of engine power reduction. As is known, the rotorcraft drag level is particularly characterized by the value of “equivalent harmful plate” that is evaluated by sum of products of drag coefficients C_x by frontal area S for every rotorcraft body component, i.e. by summary value of C_xS.

On the basis of experimental data and analysis performed in TsAGI on determination of possibilities of body drag level reduction for medium transport rotorcraft with the rear freight manifold it is received that the summary value of C_xS for equivalent harmful plate of the advanced high-speed medium transport rotorcraft can be lowered more than in 2 times in comparison with a modern level, Fig. 3.

3. ROTOR AERODYNAMICS

There are following main actual directions of rotor improvement in TsAGI:

- designing a rational airfoil-section set;
- a choice of the blade plane form, especially form of its blade tip;
- definition of rational blade geometric twist coordinated with an airfoil set and the blade plan form.

Evolution of TsAGI airfoil-section characteristics is shown in Fig.4 where they are compared to foreign analogies characteristics on universally adopted efficiency criteria. Two newest airfoil series TsAGI-4 and TsAGI-5 provide a reserve both for updating existing rotorcraft and for development of advanced high-speed rotorcraft and other rotary-wing aircraft.

The investigations of the advanced rotor conducted in TsAGI showed that the maximum value of relative efficiency on experimental data reaches a value of 0.75 – 0.76 and corresponds to a level of the best rotors of modern rotorcraft.

Equivalent lift-to-drag ratio of rotors of modern and advanced configurations at a similar level of rotorcraft drag is presented in Fig. 5. It is seen that advanced rotor configuration at flight speed of about 400 km/h provides the same value of equivalent lift-to-drag as conventional configuration rotors at the speed of 300 km/h. In this case essential reduction of a hinge moment level is reached also, Fig.6.

Under development of new rotor blade configurations the acoustics standards are taken into account also, Fig.7.

Thus, for the considered type of the rotor with TsAGI airfoil-section blades increase of its aerodynamic characteristics both in horizontal flight and in hover is provided.

4. TAIL–ROTOR AERODYNAMICS

The great scientific and technological reserve directed on creation of new generation tail-rotor blades for domestic rotorcraft is accumulated in TsAGI. Works on creation of the unified blades with a high level of aerodynamic perfection for tail-rotors of a medium weight category rotorcraft of the Mi-8/17 family are to the greatest degree advanced.

One of the main problems of tail-rotor improvement is increase of thrust and achievement of essential decrease of the consumed power at the most intense flight modes: hover and rotorcraft turns on a static ceiling (including the flight with the cross wind).

The basic investigated directions of aerodynamic tail-rotor blade efficiency are use of high-efficiency TsAGI-4 airfoil-sections and

rational geometric twist of the blades.

In TsAGI the improved aerodynamic blade configurations are developed; calculated studies on support of aeroelastic stability (flutter, divergence) and suitable dynamic characteristics are performed; design development and experimental evaluation of full-scale models of Mi-17-type rotorcraft blades developed on the basis of polymeric composite materials are executed, Figs.8,9.

The weight of the considered composite blade on 20% is less than the weight of the product blade made on the basis of the extruded duralumin spar that should lead to essential decrease of loads acting on the rotor hub and to growth of its service life. Static tests of the prototypes are carried out for various combinations of operating loads. Rig tests of blades under natural Mach number values and predicted loading conditions show the availability of adequate safety margin. Tests of experimental blades in hover are conducted on full-scale aerodynamic rig over a range of Mach number M_0 = 0.4-0.7. Improved variant of such blades developed on the basis of glass fibro plastics structure was tested in the large aerodynamic wind-tunnels of TsAGI over a range of flow velocities up to 90m/s.

The possibility of essential increase of relative efficiency of improved tail-rotor in comparison with the product rotor is verified, Fig.10. Aerodynamic characteristics of improved tail-rotor configuration over an operating range of Mach number M = 0.6-0.7 are rather stable. The scientific and technological base is created to start the development work.

5. SOME RESULTS OF TSAGI'S RECOMMENDATION INTRODUCTIONS

On the basis of conducted researches TsAGI together with domestic rotorcraft firms are performed works on improvement of characteristics of some modern and advanced rotorcraft. The results of flight tests are given by Design Bureau MRP (Moscow Rotorcraft Plant) named after M.L. Mil, "Kamov" and Kazan Rotorcraft Plant.

Results of flight tests of rotorcraft-laboratory Mi-17 with Mi-38 rotorcraft blades executed on the basis of TsAGI-3+ airfoil series are presented in Fig.11. Apparently, the essential gain of relative efficiency in hover about ~10% and equivalent lift-to-drag in horizontal flight is provided. In comparison with product blade vehicles the gain of lift-to-drag of Mi-17 rotor with Mi-38 rotor blades in cruise flight amount to 1.5-2.8 with growth of relative speeds V/ωR in a range 0.25-0.38. For Ka-226 rotorcraft which blades are executed on the basis of TsAGI-4+ series flight test data, Fig.12, showing essential growth of relative efficiency in hover are presented at values of thrust coefficient $C_T/\sigma \geq 0{,}14$.

The results of experimental investigations of full-scale rotor of "ANSAT" rotorcraft as well as test results of body aerodynamics conducted in the great wind tunnel T-105 TsAGI are shown in Fig.13. As a result of modifications carried out by the firm the fuel consumption per kilometer is essentially lowered, Fig.14.

6. CONCLUSION

Airfoil-sections developed in TsAGi and investigations of aerodynamic configurations of rotor and tail-rotor blades conducted by TsAGI together with rotorcraft firms as well as working off of body aerodynamics have shown an opportunity of essential increase of aerodynamic, flight and economic characteristics of rotorcraft.

The received new results are at the advanced scientific and technological level that provides competitiveness of the Russian rotorcraft in home and foreign markets.

The developed scientific and technological decisions will be used as base at development of advanced rotorcraft, Fig.15, at modernization of existing rotorcraft and in the further researches on creation of a scientific and technological reserve.

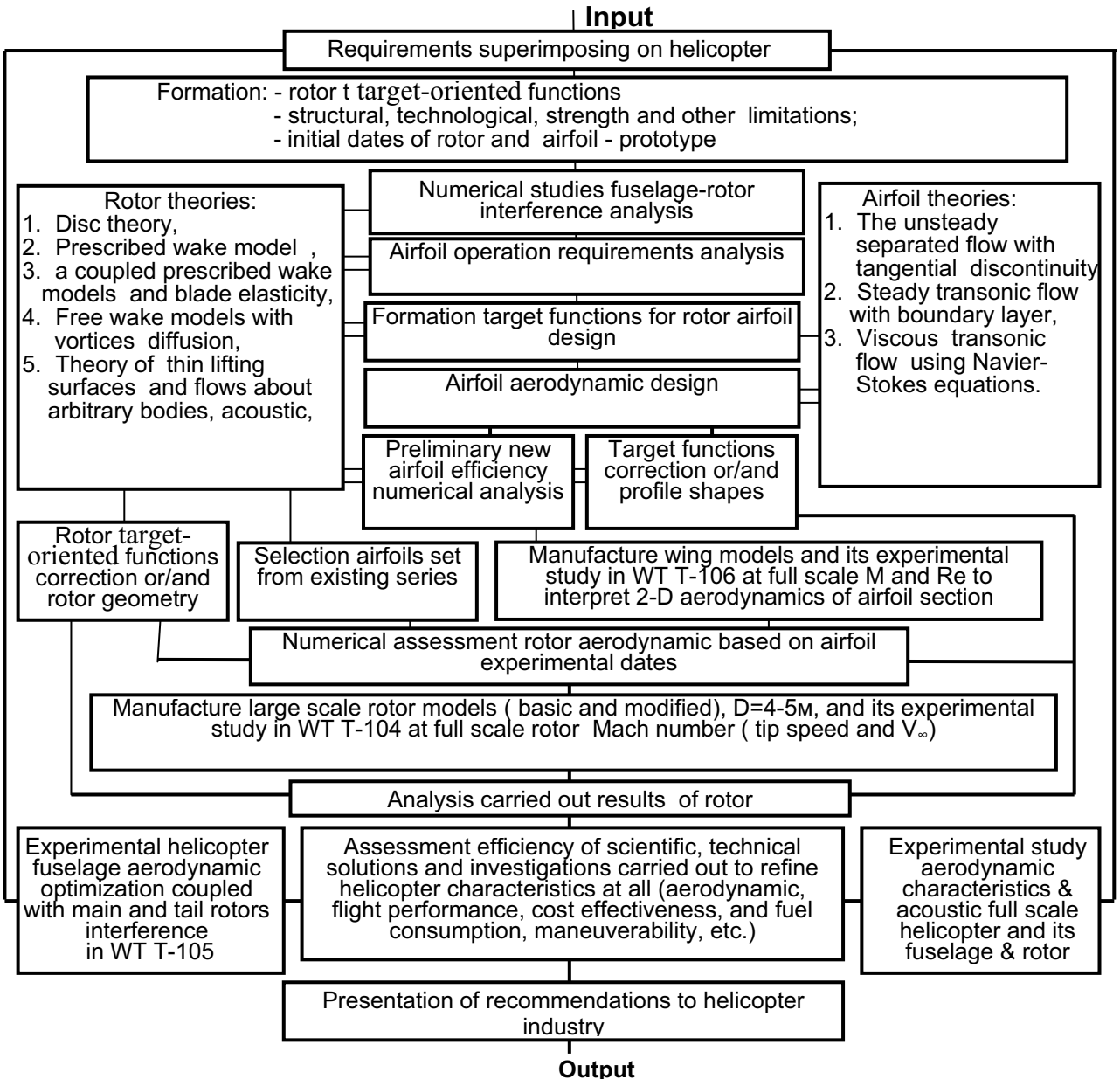
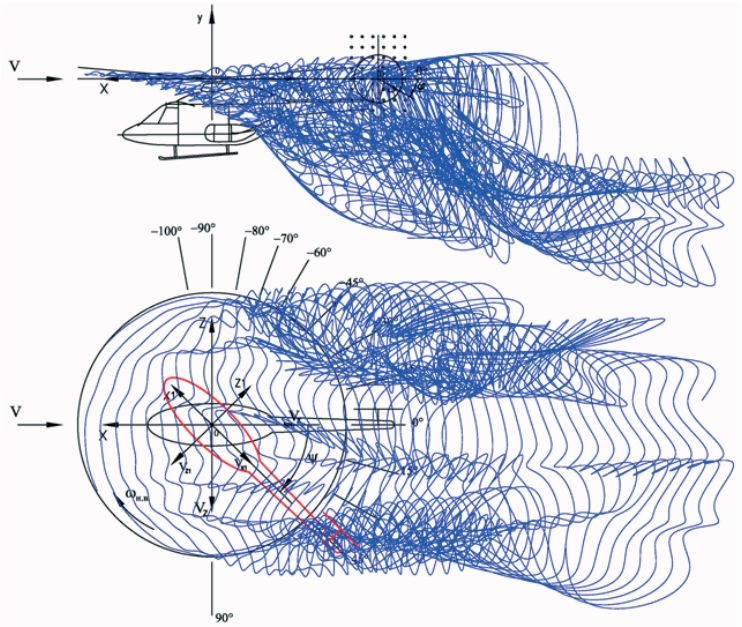
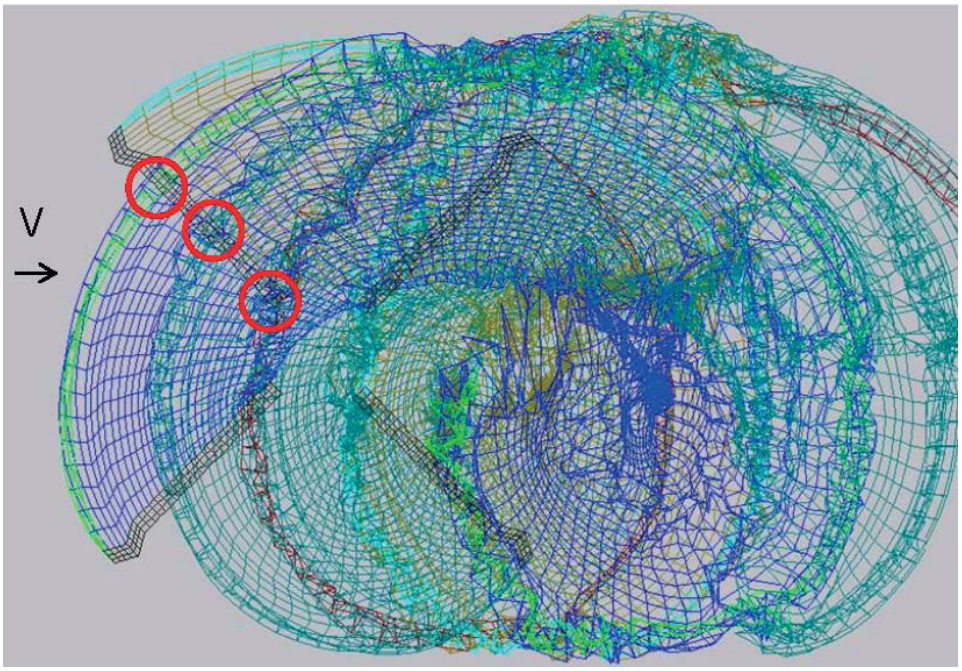


Fig.1 Multi-level complex calculated and experimental system for development and investigations of advanced aerodynamic configurations of rotors and tail-rotors is created in TsAGI



Calculation free nonlinear vortex sheet shedding from the rotor with sideboard wind



Wake topology and flow over compound rotor blades configuration
in rotor-attached coordinate system

Fig.2 Numerical methods in main rotor theory

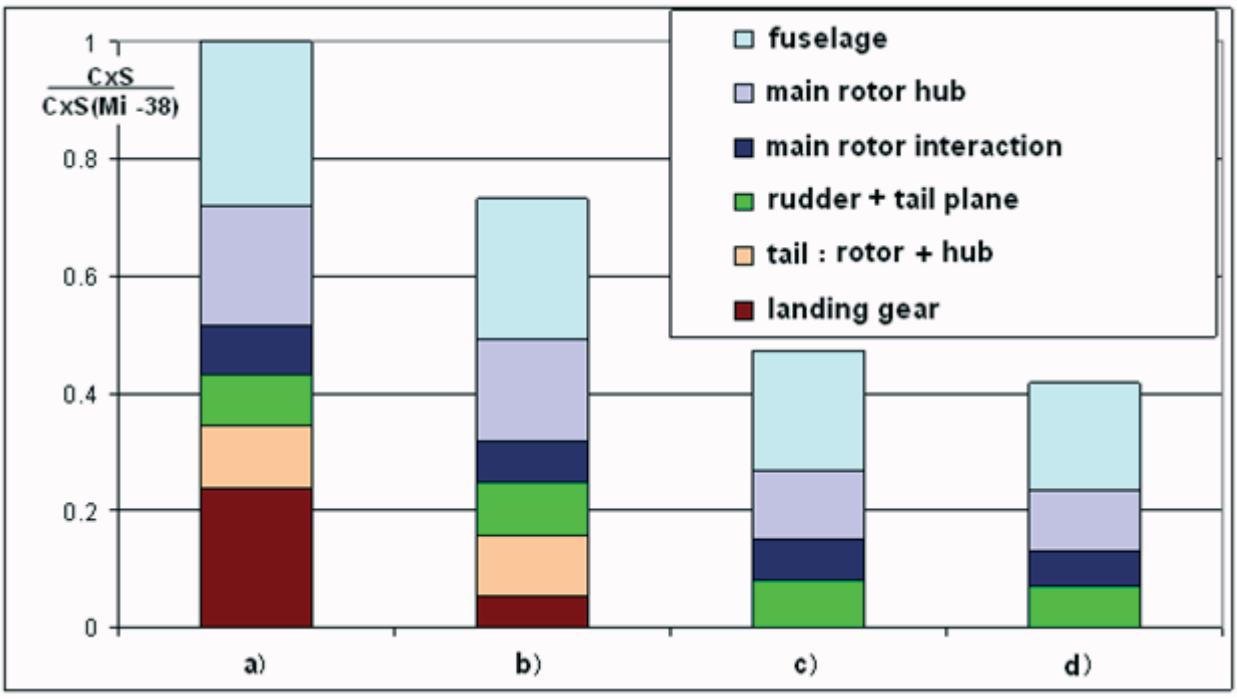


Fig.3 Versions of helicopter airframe aerodynamic composition: a) Mil-38, 14.2 T; b) Mil-38M, 14.2 T; c) advanced helicopter, 14.2 T; d) advanced helicopter, 11.2 T

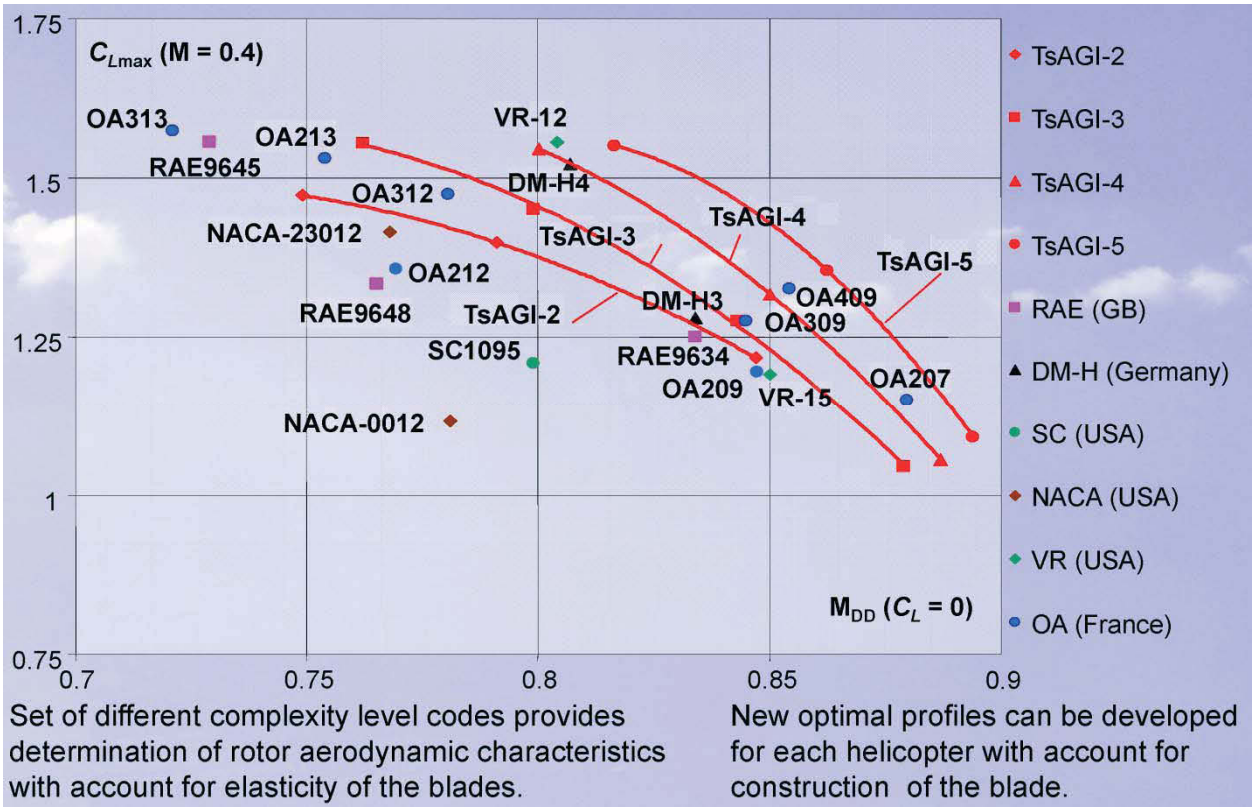


Fig. 4 Development of New Profiles for Main and Tail Rotors

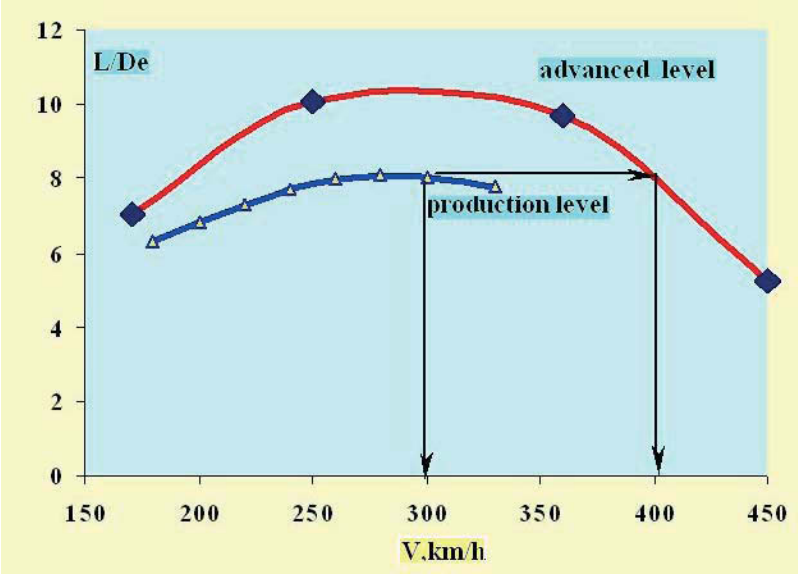


Fig. **5** Advancement in Main Rotor L/De ratio

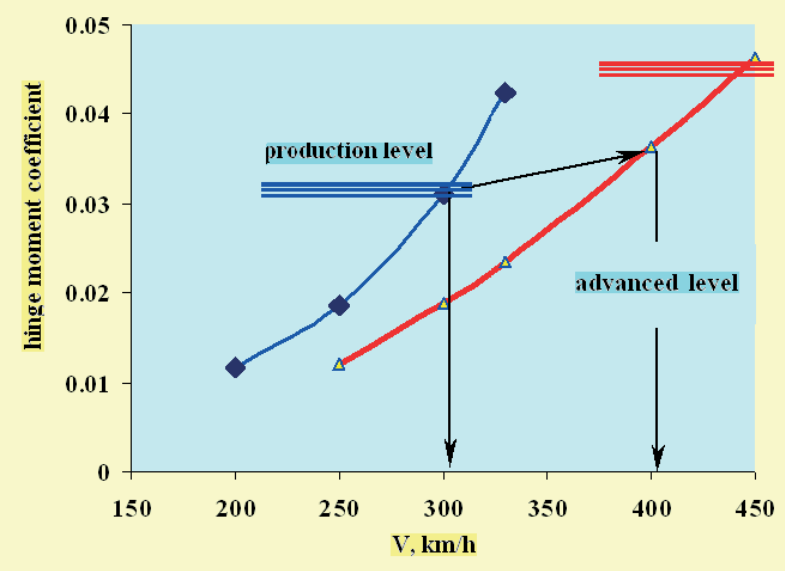


Fig 6 Decrease loads in control system

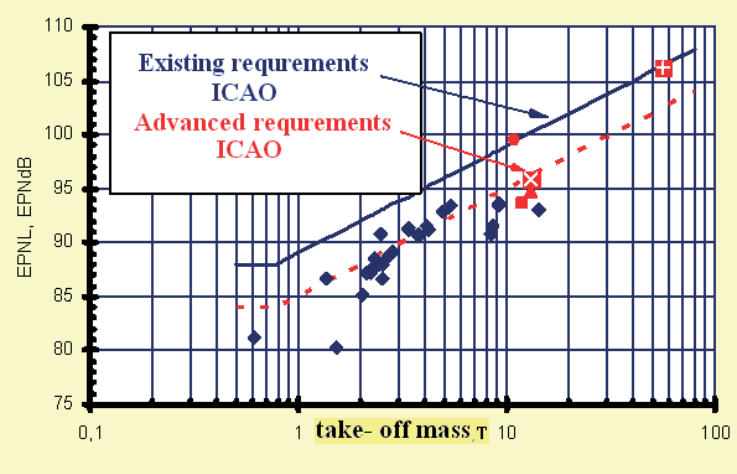


Fig 7 Rotorcraft airport noise

Fig. 8 All-composite tail rotor blade model with improved aerodynamic configuration

Fig. 9 All-composite experimental rotor blade

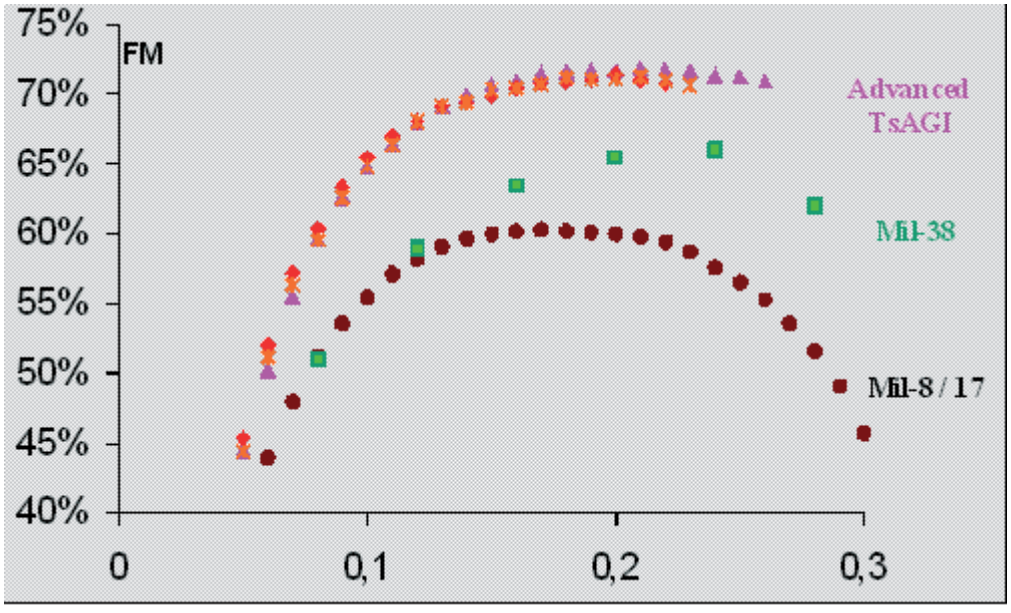
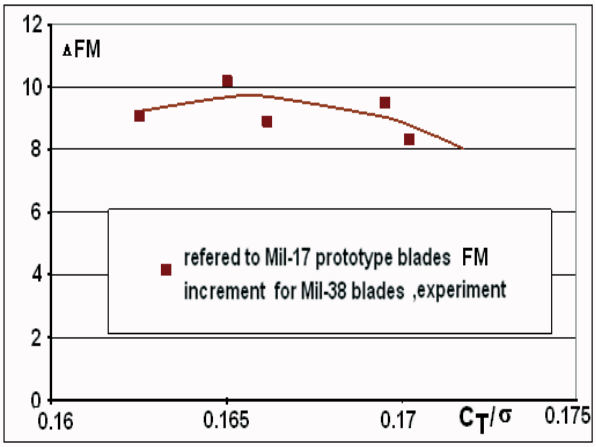


Fig. 10 Comparison Figure of Merit of three types tail rotors in hover (M=0.65)



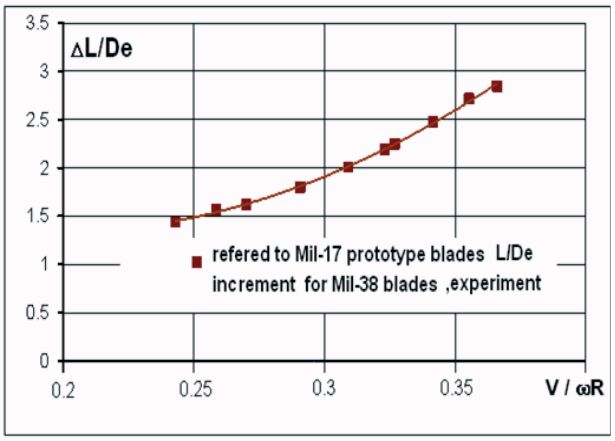


Fig. 11 Flight tests results of Rotor Mil-38 equipped with TsAGI-3 airfoils on Mil-17 flying laboratory

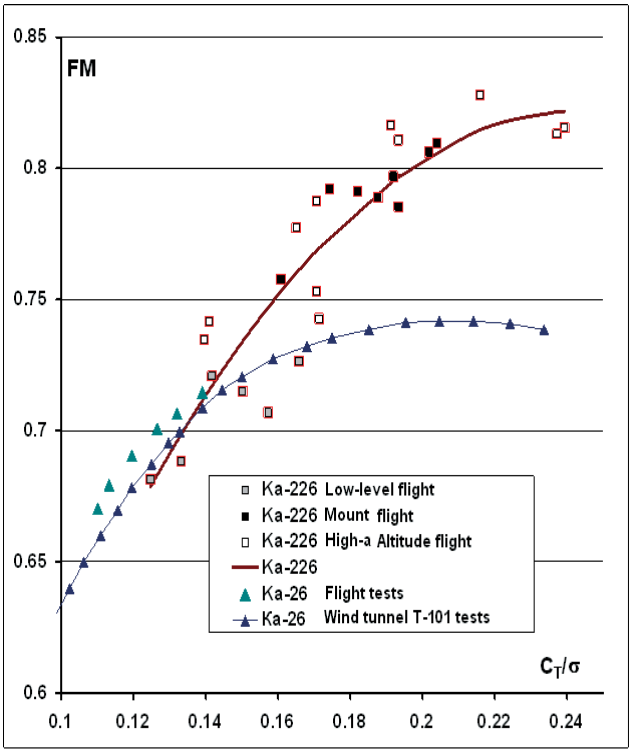


Fig. 12 Flight tests results Ka-226 rotorcraft of "Kamov" Open Stock Company equipped with new coaxial lifting surfaces with improved fourth-generation (4+) TsAGI airfoils

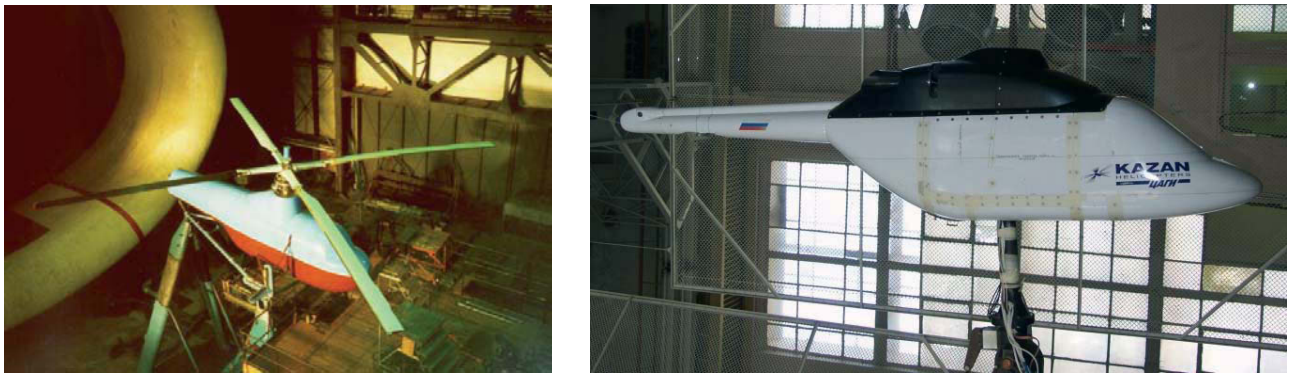


Fig. 13 Aerodynamic research helicopter rotor and refining fuselage in wind tunnels

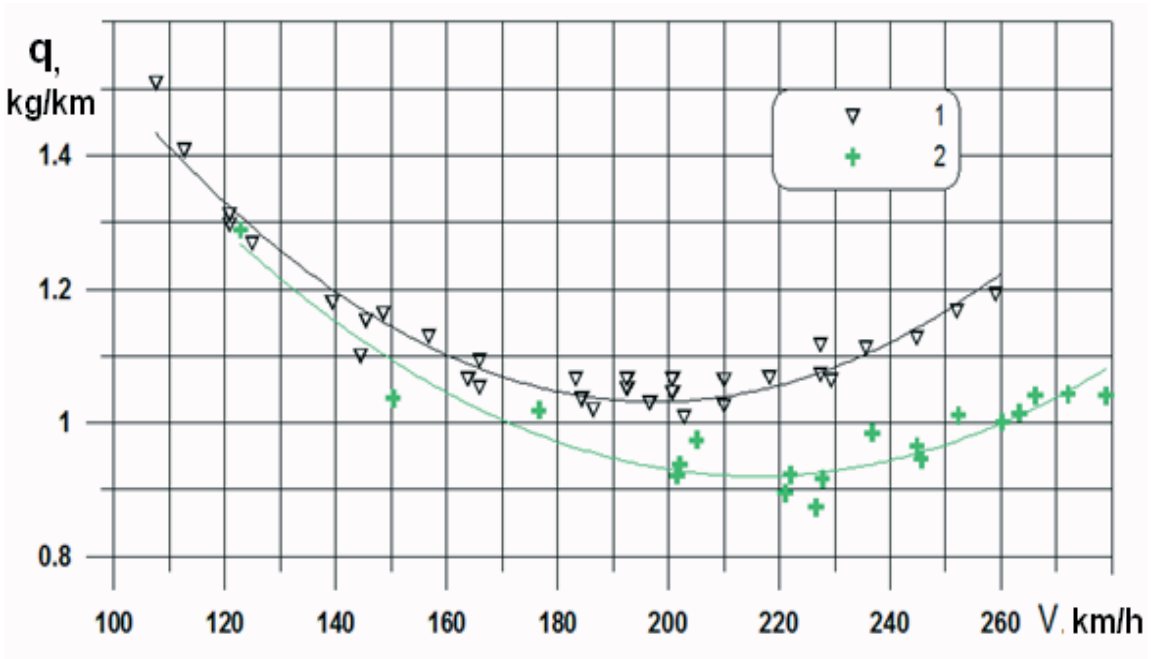


Fig. 14 Fuel consumption as a function of cruising speed
for 2 variants helicopter “ANSAT”s fuselage:
1 – initial concept, 2 – all modifications introduced.

High-speed civil helicopter model Mil-X1 of Open Stock Company ”MRP” by Mil

High-speed civil helicopter model Ka-95 of “Kamov” Open Stock Company

Fig. 15 Outlook helicopter models