BLADES DESIGNED BY M.L. MIL FOR AUTOGIROS AND HELICOPTERS

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Abstract

In the 1930s blade airfoil effect on autogiro stability and controllability was investigated in the papers published by M. L. Mil, who was then the TsAGI aerodynamicist team leader. As a result, the AK-4, A-4 autogiro blades were designed whose application eliminated the rotor eccentricity and buffeting. Later M. L. Mil designed blades for all the autogiros developed and built by the TsAGI. The most complicated and vital component of the Mi-1 helicopter were the blades taken from the A-15 autogiro designed by M. L. Mil. Since 1957 all-metal bonded blades filled with honeycomb core were introduced for the Mi-1, Mi-4, and then the Mi-6. New lightweight blades of sandwich structure (saving 300 kgf per blade) were used in the V-12 giant helicopter. The same blades equip the Mi-26 helicopter.

The blade manufacturing processes developed by Mil and Sikorsky companies in the 60s are compared.

Introduction

Design of a helicopter main rotor blade possessing high aerodynamic performance and strength was always considered by Designer M.L. Mil as a task of great importance. «A blade is half the helicopter,»- he used to say.

The Mi-1 helicopter, the Mil Design Bureau first-born baby , was a success and served for more than forty years. That success was not accidental. M.L. Mil headed a team of aerodynamicists in the TsAGI in the 30s and 40s. He took part in rotorcraft design and research, as well as the development of the aircraft screw and strength theory. He designed blades for the A-7, A-12 and A-15 autgiros whose diameter was 14, 15 and 18 m respectively. The experience gained by him in designing autogiros and helicopters during his 15 years of work in the TsAGI was used in developing the Mi-1.

Mi-1 and Mi-4 Blades

«The Mi-1 is really a successful design, it experienced neither shaking nor vibration,» - wrote M.L. Mil. It was equipped with a 14-meter 3-bladed main rotor designed by M.L. Mil for the A-15 autogiro.

It is interesting to follow the evolution of the main rotor blade layout from that for the autogiro to that for the helicopter. The A-7 autogiro blade structural analysis has survived (Fig. 1). In accordance with the manufacturing processes of those times, the autogiro and helicopter blade structures were of mixed design: the spar was made of a steel variable cross-section tube whose wall thickness varied with length, while ribs and stringers were made of wood. The frame skin was made of plywood and linen. The frame was secured to the spar by means of plates soldered and riveted hereto. A small batch of the A-7 autogiro was produced and it took part in military actions at the beginning of the Great Patriotic War. M.L. Mil headed a team of engineering support at the front line.

When blades for the A-4 autogiro rotor whose diameter exceeded 14 m as compared to its predecessor (2-EA) were developed, the rotor experienced eccentricity and buffeting in flight. The pilot managed to land the aircraft with great difficulty. M.L. made a suggestion that the phenomenon had occurred due to insufficient blade torsional stiffness. This phenomenon was considered by M.L. Mil in his paper entitled “About Dynamic Twisting of Autogiro Rotor Blade in Flight” (1). For the first time recommendations to superimpose the blade centre of gravity on the centre of pressure (1) were given, ideas about the effect of the blade airfoil on the aircraft stability and controllability were considered. The result of the above studies was that asymmetric airfoils were used for main rotors in the Soviet helicopters. The recommendations given in the paper were sufficient to avoid flutter in the first Soviet helicopters designed by the TsAGI (2).

Blades of mixed construction were used in the Mi-1 and Mi-4 production helicopters most popular in the country (Fig. 2). This type of design had existed for about ten years till the advent of metal blades with honeycomb filler allowing them to improve substantially their service life.

The Mi-1 blades during their mass production and many years of actual service had no defects due to insufficient dynamic strength of the spar. At the same time, when the Mi-4 equipped with the rotor whose blades were of the similar design entered service great efforts had to be made to increase the spar dynamic strength.

At first, the spars consisted of two portions (Mi-4) or 3 portions (Mi-1) as tubes of the required length and variable wall thickness were not produced. Later on, when the appropriate rolling mills were put into service, spars were manufactured of a single tube of variable cross-section.

The final design of the blade was a duralumin shaped spar of variable cross-section to which tail sections with honeycomb filler of metal foil were bonded (Fig. 3). The extruded spar design whose nose portion acted as the leading edge was similar to that designed by

Sikorsky. The service life greatly increased (up to 1,200 hours).

Mi-4 Main Rotor Flutter

When the main rotor diameter was increased up to 21 m for the Mi-4 helicopter, such a phenomenon as flutter occurred for the first time, first, on the ground and then in the air (1952). That is how it was described by M.L. Mil: "After a normal engine start and main rotor starting, we witnessed an absolutely sudden sight: The blades started to flap higher and higher and to twist like snakes. The spectators ran away in different directions and we understood that we were dealing with a new phenomenon nobody had witnessed yet. It was main rotor flutter... We manufactured counterweights during one night that were secured to the leading edge at three points along the blade span. When we installed those counterweights and started the main rotor, we understood that we had a means in our hands to eliminate flutter." However, flutter scientific theory was developed many years later by young scientists A.V. Nekrasov and L.N. Grodko who belonged to M.L. Mil School.

Mi-6 Blades

"Now, having theory at our disposal, without hesitation we started to develop blades for the Mi-6 main rotor having 35-meter diameter. Later we had no flutter troubles in the Mi-6 throughout its wide range of airspeeds. Desiring to move the centre of gravity forward, we placed the spar so that it was at 20% and 16% chordwise at the root end and the blade tip respectively thus allowing us to obtain a much more forward CG position compared to that we managed to obtain earlier with a very small weight of the counterweight".

The first Mi-6 layouts appeared in 1952. That helicopter was designed to carry troops and military equipment. The newly designed machine dimensions and weight should be in compliance with the weapons systems used in those times, mainly, artillery systems towed by tractors weighing 6 metric tons.

It was decided to design a 5-bladed main rotor. The disk loading was supposed to increase from 20 kgf/m^2 for the Mi-4 to almost 40 kgf/m^2 for the new helicopter. No helicopters having such disk loading existed at that time.

The problem of designing main rotor blades was a challenge. M.L. Mil offered a design comprising a steel spar with separate frame sections secured to the spar only at one middle point (Fig.4), (2) and therefore not participating in the overall bending of the blade. It made the frame free of substantial variable loads and made it possible to use an ordinary aircraft wing structure with bolted and riveted joints. This design was a further development of M.L. Mil's idea used in designing the Mi-4 first all-metal blades but at that time he did not manage to free the blade from bending loads.

As it was impossible to master production of a single-tube spar fast, it was decided to make it of three tubular portions. The final blade design of rectangular shape consisted of a single-tube spar of variable cross-section and thickness. The manufacturing process of this tube was continuously improved to increase its dynamic strength. Quality control means were continuously improved, so were corrosion prevention coatings. As a result, the blade service life greatly increased. Honeycomb filler was introduced into the trailing edge sections. All these measures resulted in improved blade dynamic strength and its aerodynamic performance.

The Mi-6 helicopter first became airborne in 1957. It was manufactured by the Rostov production plant through 1980. Some of these helicopters are still in actual service. It has been acknowledged that due to the work done by the Mi-6 helicopters the development of the oil and gas deposits in Siberia took 15 years shorter.

In January 1960 M.L. Mil visited Sikorsky Aircraft Corporation in Stratford. He took a special interest in everything connected with blades. He got interested in the entire manufacturing process of blades, their service live, low stress in duralumin and steel blades, noted a high service life of steel blades (1,500 hours) with inspections every 600 hours. He made a conclusion for himself: «Our helicopters have a larger payload capacity, longer range and fly at higher altitudes, and the engines are better. We are dramatically behind in equipment and blade manufacturing processes. Their blade bonding inspection is more precise. But there is nothing new as far as the blades designed for the Mi-1 and Mi-4 are concerned. Our blades will be of the world standard. It is necessary to put them in mass production.»

Composite Blades

The Mi-6 blades design was continuously improved. The sketches taken from his diaries covering 1964 and presented here show how M.L. Mil was looking for the required blade layout. He was the first to offer a steel tubular spar, combined all the structural members by means of filling them with foamed polyurethane and glassfibre-reinforced plastic. The invention entitled «The Helicopter Main Rotor Blade» and made by M.L. Mil, N.N. Leontyev, A.E. Malakhovsky et al.(4) in 1964 gave a start for using composite materials in the blades developed by the Mil Design Bureau (Fig. 6). The main rotor blades comprised a steel tubular spar of variable cross-section. It was made integral with the nose section made of glassfibre frame having the required airfoil. The internal space was filled with foamed plastic. The internal space of the tail section made of metal frame was filled with aluminum honeycomb. The tail section was bonded and riveted to the glassfibre frame of the nose section.

The V-12 experimental side-by-side rotor helicopter (1967) whose take-off weight was 100,000 kgf had two five-bladed rotors of 35-meter diameter. They had blades of the new design. The weight of each blade was substantially lower than that of the Mi-6 production blade.

The composite blade design was further developed when the Mi-26 helicopter was designed by the Mil Design Bureau headed by Marat N. Tischenko. The core of the main rotor blade was a steel D-shaped spar. The nose section consisted of the glassfibre skin and foamed plastic core. The tail section comprised separate sections having glassfibre skin of variable thickness and honeycomb filler made of Nomex-type polymer paper.

The first experience gained by M.L. Mil and his team in developing the first composite blades for the V-12 helicopter is used in all the developments related to new helicopter blades designed by the Mil Moscow Helicopter Plant.

References

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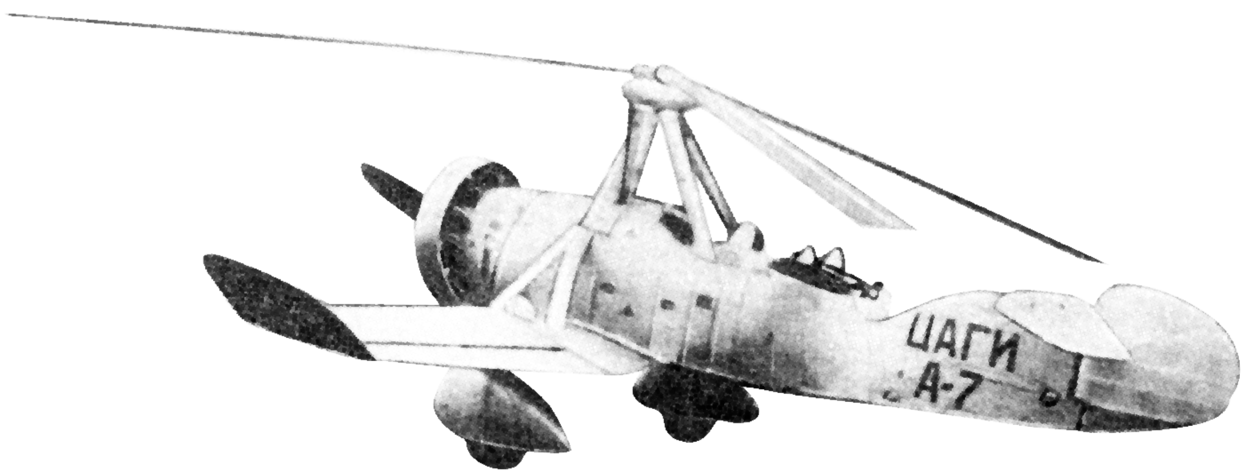
2. “Helicopters. Calculation and Design” by M.L. Mil’ at al., NASA TT F-494, 1967

3. Avtorskoe svidetelstvo SSSR “Lopast nesutshego vinta vertoleta”[1] No.150015, 15.12.1962 g. (USSR Inventor’s Certificate «The Helicopter Main Rotor Blade» No. 150015, 15.12.1962).

4. Avtorskoe svidetelstvo SSSR “Lopast nesutshego vinta vertoleta”[1] No.163896, 22.07.1964 g. (USSR Inventor’s Certificate «The Helicopter Main Rotor Blade» No. 163896, 22.07.1964).

Figures



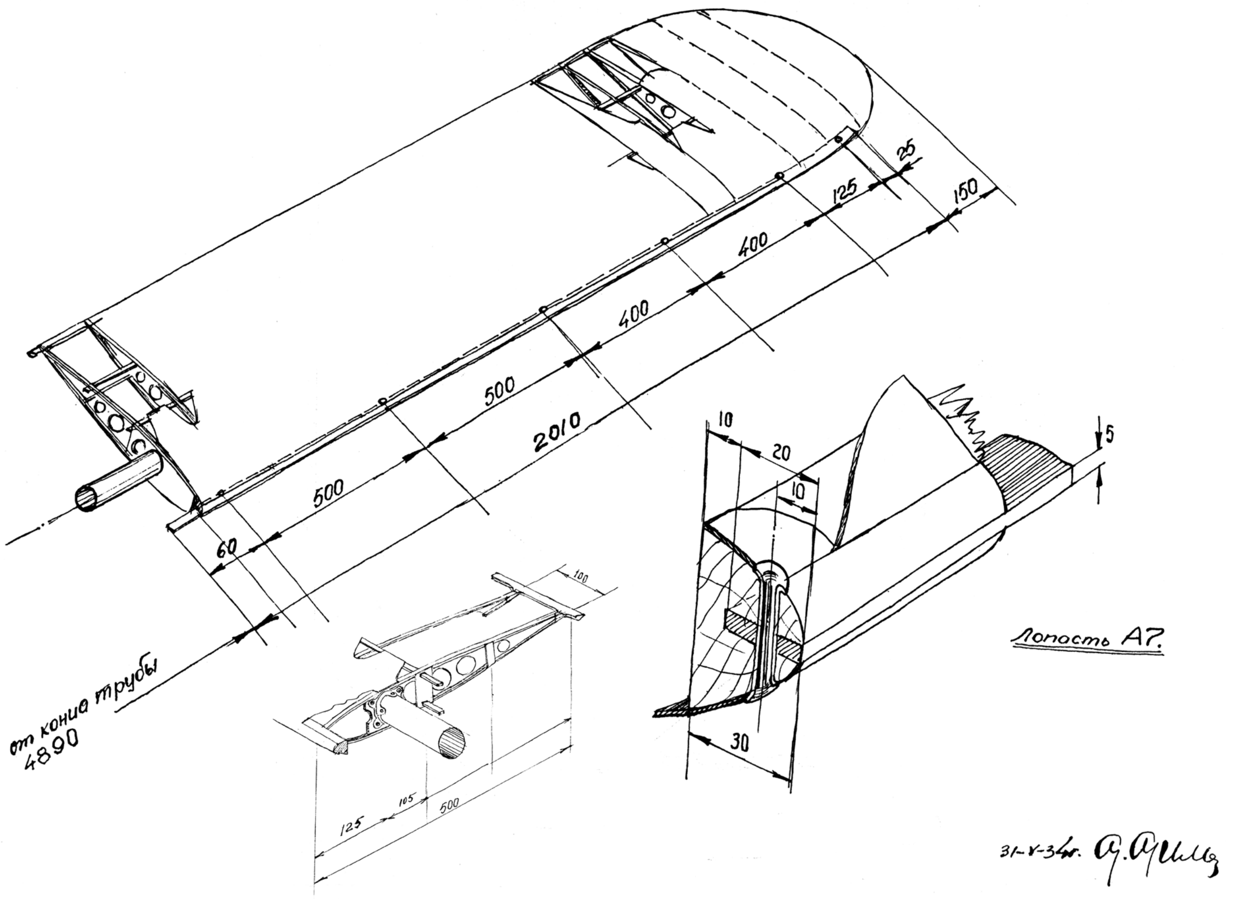


Fig. 1. The A-7 autogiro blade structural analysis: blade, rib, counterweight attachment.

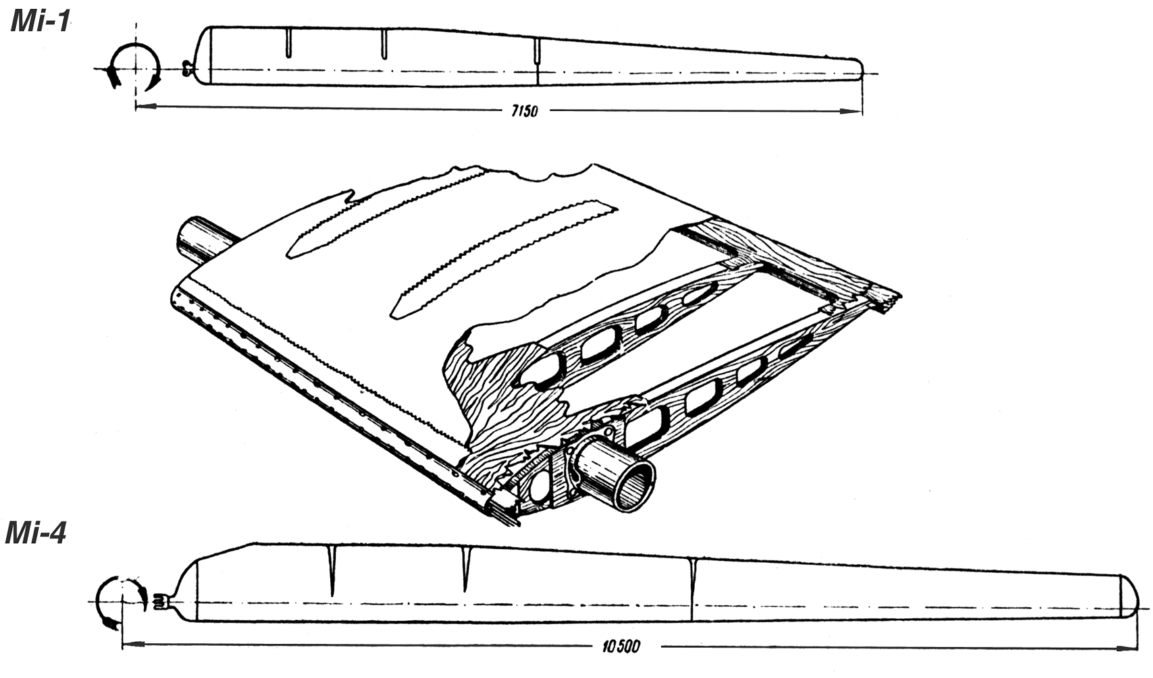


Fig. 2. Blades of mixed construction in the Mi-1 and Mi-4 production helicopters (1949-1956).

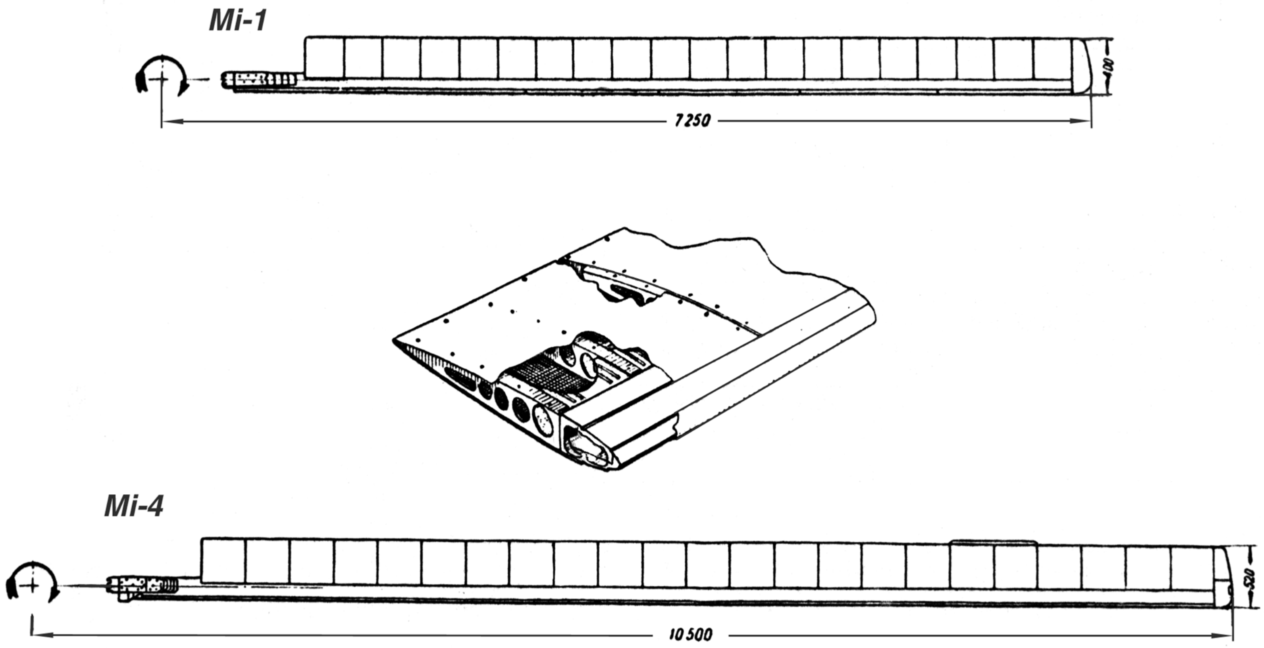
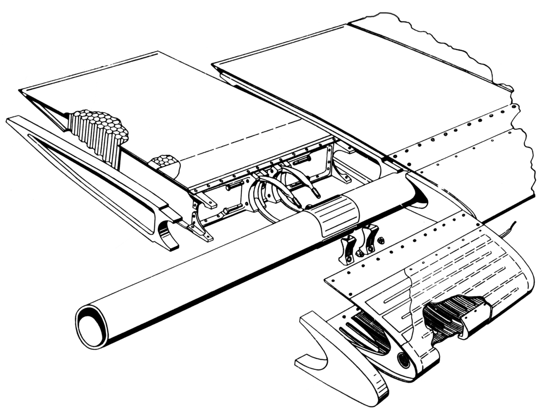
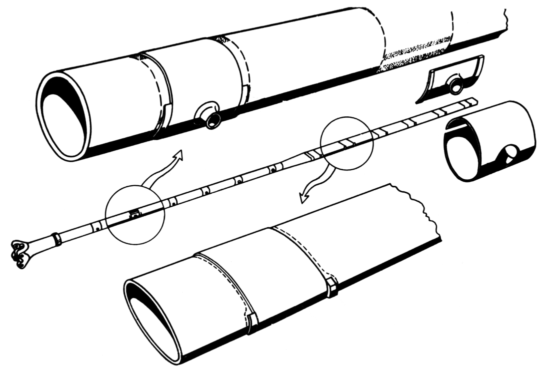


Fig. 3. The blade with a duralumin shaped spar and honeycomb filler of metal foil (1956)



1 - Separate frame sections



2 - Section-to-spar attachment with the help of metal tapes.

Fig. 4. The Mi-6 blade with single-tube spar

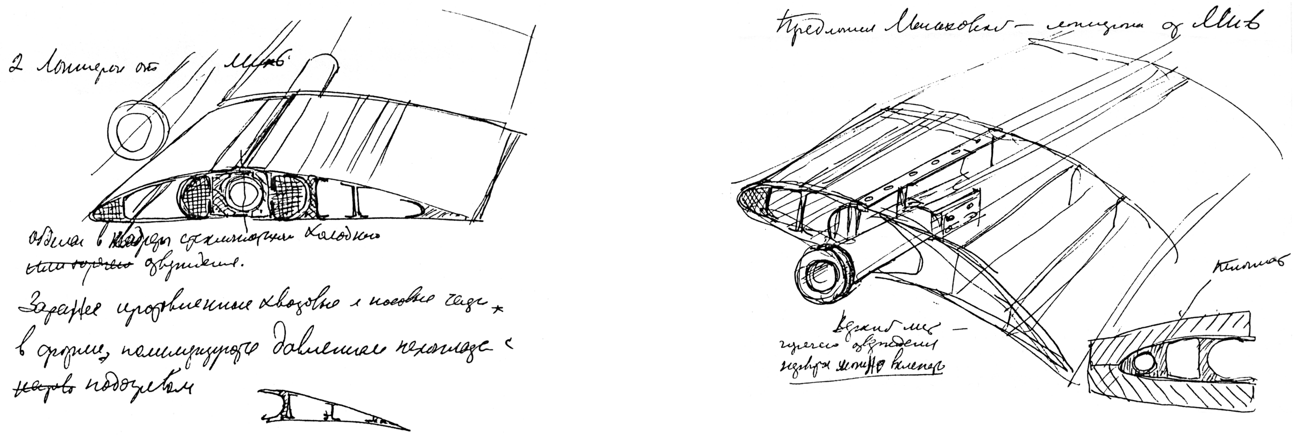


Fig. 5. The sketches of composite blade layout. M.L. Mil was the first to offer a steel tubular spar, combined all the structural members by means of filling them with foamed polyurethane and glassfibre-reinforced plastic.

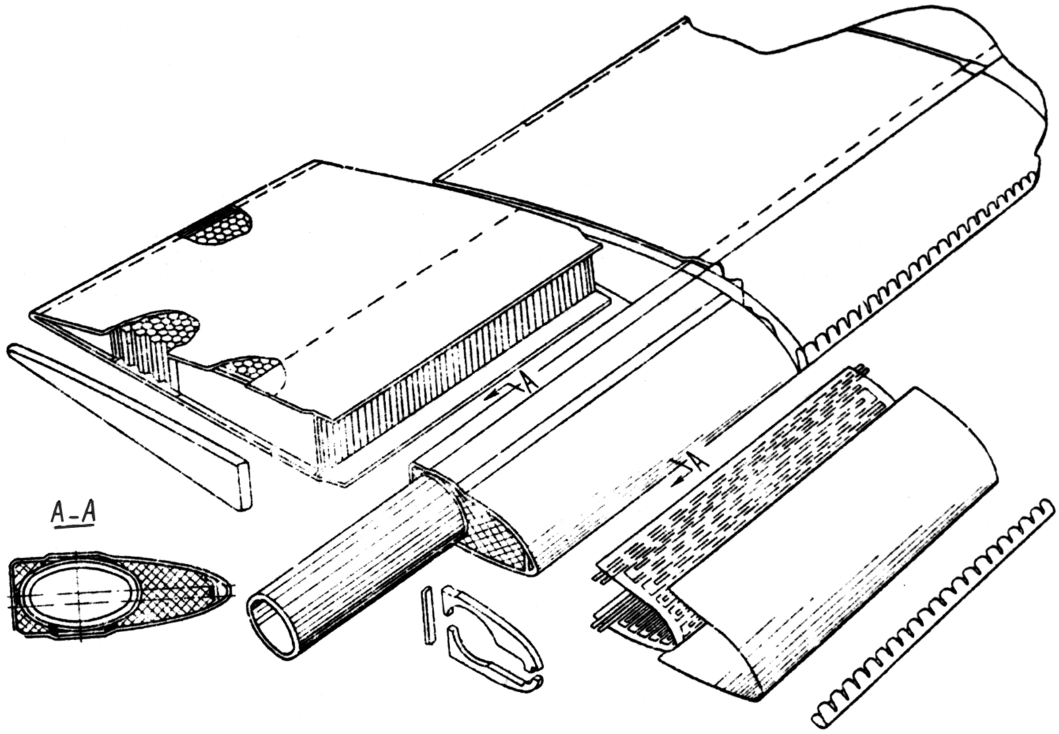


Fig. 6. V-12 Main Rotor Blade. The spar is covered with skin to which nose section frame members are bonded.