COMPOSITE BLADES FOR HELICOPTER MAIN AND TAIL ROTORS DEVELOPED BY MIL DESIGN BUREAU

B.S. Sirotinsky
Mil Moscow Helicopter Plant

Abstract

The advantages of the composite materials applied in helicopter main and tail rotor blade designs (high allowable variable elongation, specific strength, corrosion resistance, "soft" failure mode) are well known.

The Mil helicopters are produced in large numbers. This fact, as well as the requirement for maintaining stable strength properties of the blade have called for developing such a blade design and such production procedures that can ensure automated blade manufacturing.

This design and technology using numerically controlled machines for laying up tapes have been developed, and the latter are used for manufacturing of experimental and production blades. A unique design of the reliable attachment fitting has been developed. The blades are fitted with an electro-thermal de-icing system made of non-metal composites as well.

Introduction

The problem to develop blades for helicopter main and tail rotors is one of the key factors in designing helicopters. Therefore strong emphasis has been placed on the solution of this problem from the moment our firm was founded; since then we have travelled a long way in designing, developing, setting up an industry for quantity production of metal and non-metal blades, as well as their trouble-free service.

As our founder, the well-known Dr. Mikhail Mil has put it, the results of this activity are our national asset.

In my paper I shall cover our approaches to blade designing. Some of them may be well known today, but as there have been no close contacts and exchange of ideas between specialists, this work seems to be quite useful.

This brief review does not cover the problems of the blade aerodynamic outlay as this subject is beyond the scope of my paper.

Selection of Materials for Blade Design

Materials are analysed for the following parameters:

- specific strength
- specific fatigue strength
- allowable variable elongation
- corrosion resistance
- failure mode
- reproducibility of the designs from these materials defining stability of their properties.

As can be seen from Figures 1 and 2, composite materials (glass- and aramid-reinforced plastics) and titanium alloys are superior due to their strength properties.

Failure mode is the determining factor in selecting a material for a primary structural member. As a rule, any failure of metal blade spars at the existing levels of loads with the presence of a dangerous manufacturing error or service trouble occurs very fast, the crack growth rate greatly accelerating. As for anisotropic designs made of glass- and aramid-reinforced plastics with the properly selected direction of reinforcement, they fail quite slowly with a local loss of stiffness; thus, any failure can be detected at initial stages. Unfortunately, the available carbon-reinforced plastics, whose reinforcement direction is close to that of the main loads applied, do not possess this property. This is the main reason why, for the blade structural members, we do not use carbon-reinforced plastics whose reinforcement is made along the blade longitudinal axis.

High corrosion resistance, as well as reproducibility that allows to manufacture blades of sophisticated shapes possessing a precise stable outline make the application of the composites preferable.

At early stages of composite material application, when reliable data on stability of strength properties were not available, we used composite materials for manufacturing of blade frame members, while the primary structural member, i.e.. the spar, remained metal.

This design was developed for the Mi-12 experimental and Mi-26 production helicopters.

Perhaps, this intermediate design is not worthy of being mentioned, but all the previous experience accumulated by our firm till that time has been used in its development and implementation, and unique manufacturing processes have been developed. For instance, it is worthy to mention the process of manufacturing the 14-m steel spar: its D-shaped cross-section outline has variable lengthwise thickness ratio, its wall thickness varies from 3.5 to 40 mm and its hub attachment lugs are integral with the spar tube (Fig. 3). As a particularly pure steel alloy, special methods of machine treatment and surface shot peening have been used, the spar possesses high and stable fatigue strength.

The leading edge section consists of the glassfiber skin and foam plastic core. The trailing edge section comprises separate sections having glassfiber skin of variable thickness and honeycomb filler made of Nomex-type polymer paper. The blades are fitted with a sectional electro-thermal de-icing system; they have abrasive metal strips of variable cross-section running along the leading edge (Fig. 4).

The selection of manufacturing processes for all-composite blades is defined, to a large extent, by the fact that helicopters and thus their blades developed by our firm are produced rather in large quantities. This calls for a large-scale automation of the manufacturing processes and the blade should be designed so that to prevent any occurrence of dangerous defects in quantity production. Such a defect (and practically the only one) in composite structures subject to variable loads is the formation of folds in the reinforcing material.

Having analysed various designs and technologies used for manufacturing of the primary structural blade member, i.e. the spar, the following method was selected: spiral laying up of resin-preimpregnated unidirectional glassfiber tapes.

Machines making spars by laying up tapes around the mandrel, having rather a small stiffness varying in different directions differ from the most widely used winding machines by the fact that they have a rigidly fixed mandrel and tape laying up devices rotating around it and at the same time moving in the longitudinal direction.

The tape laying up angle (reinforcement direction) can vary in the range from 10^0 to 90^0. The composite layers oriented at an angle of 45^0 to the spar axis and intended for increasing torsional stiffness can incorporate carbon fibers (Fig. 5).

The spar is cured in a closed heated mold under some pressure applied to the inner surface of the spar (Fig. 6).

In blade designing particular attention has been paid to the design and fabrication methods of the blade-to-hub attachment fitting. A variety of designs has been analysed. A great scope of research and test activities has resulted in the selection of a somewhat rugged but reliable solution: when the spar is fabricated, sets consisting of fiberglass and metal foil are placed between the plies of the tape being laid up in the root part of the spar. Thus, the spar cross-section is significantly increased in this area allowing to attach the blade to the hub by means of two bolts going through the thicker wall.

The Mi-26 tail rotor blade is a typical example of a blade having the spar fabricated in this way.

The trailing edge section is formed by the glass- or aramid-reinforced plastic skin bonded to the spar, and the honeycomb core.

The blade is fitted with an electro-thermal de-icing system and has an abrasive strip running along the leading edge (Fig. 7).

The development of the the electro-thermal de-icing system has called for solving the problem of providing the proper fatigue strength of the heating elements with the increased strains in the composite blades. The problem has been solved by using electroconductive fabrics of standard rated resistance; electroconductive buses made of metal screen are bonded to the fabric by the electroconductive adhesive.

The design of the main and tail rotor blades for the newly developed helicopters is of similar type. At the same time the blades are designed so that they can be fitted to the earlier helicopters of the same class. For instance, the Mi-38 blades can be installed in the Mi-8MT helicopter. The rotors are designed so that the resonance phenomenon, self-oscillations and instability are prevented in the earlier and new experimental helicopters.

Fatigue tests of the blade specimens are conducted on the resonance test rigs specially designed with due account of significant variable strains occurring due to loading.

The fatigue test results have shown that the composite blade service life is practically unlimited by its fatigue strength, therefore the blades can be replaced on condition.

Concluding Remarks

The design, prediction methods and programmes, technology and equipment for large-scale production of composite blades for helicopter main and tail rotors have been developed.

The design, prediction techniques and fabrication processes of non-metal heating elements for the blade de-icing system are available.

The methods and equipment required for conducting blade fatigue and service life tests are also available.

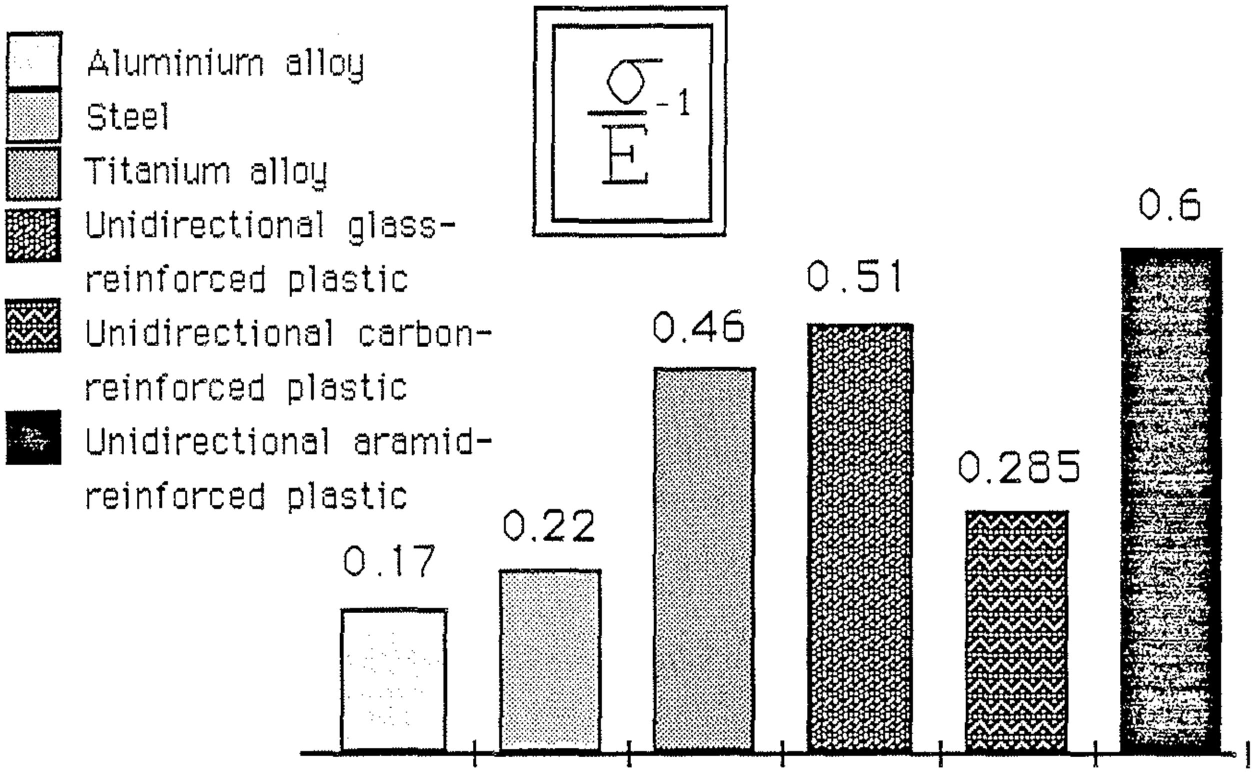


Fig.1. Allowable variable unit elongation of materials for blades.

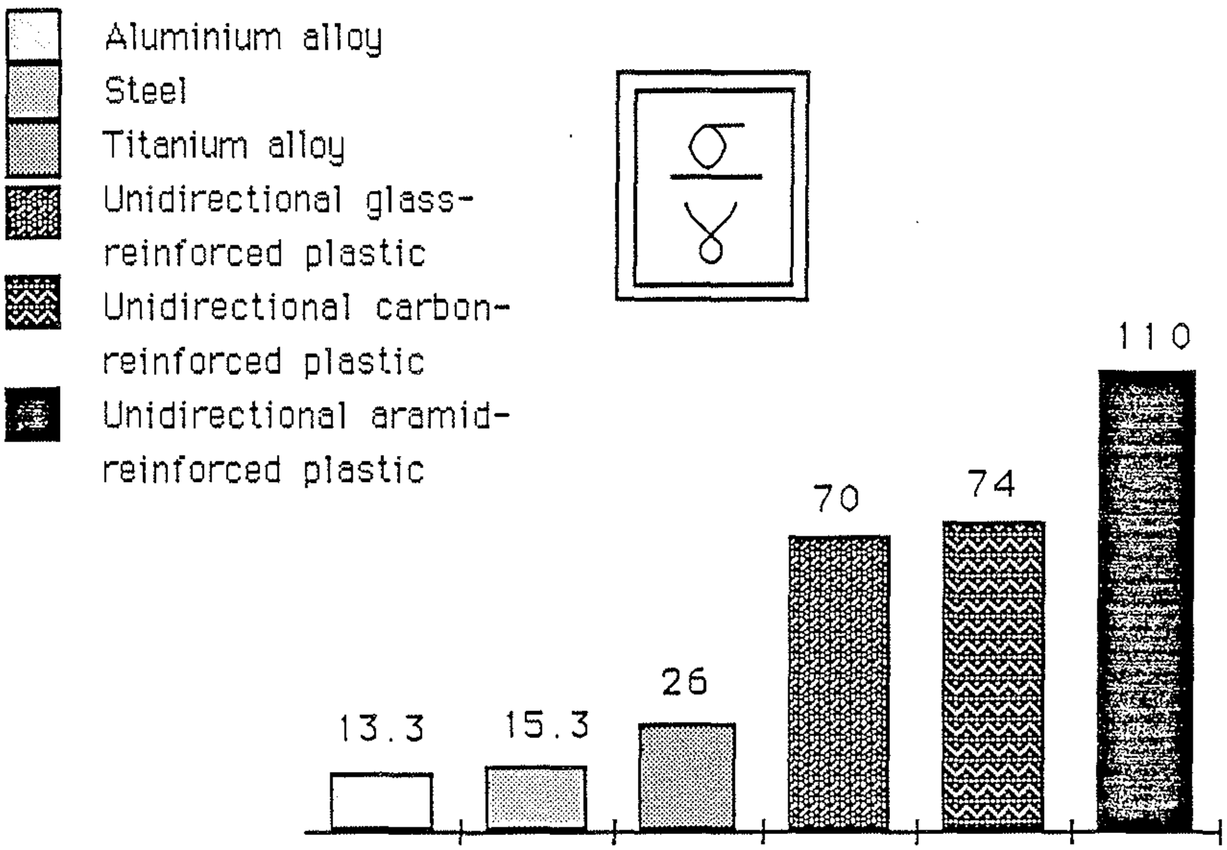


Fig.2. Specific strength of materials for blades.

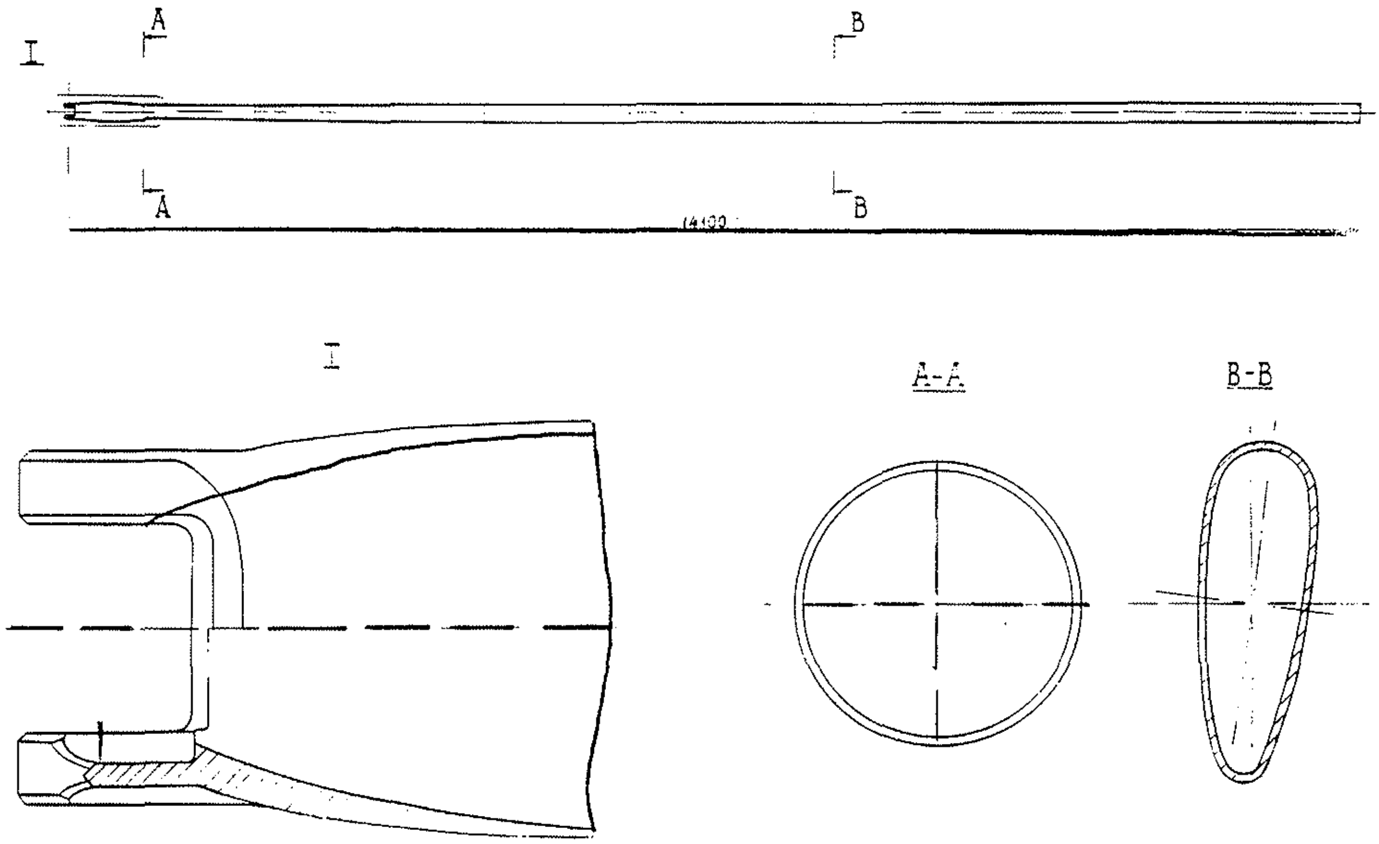


Fig. 3. Steel spar for Mi-26 main rotor blade.

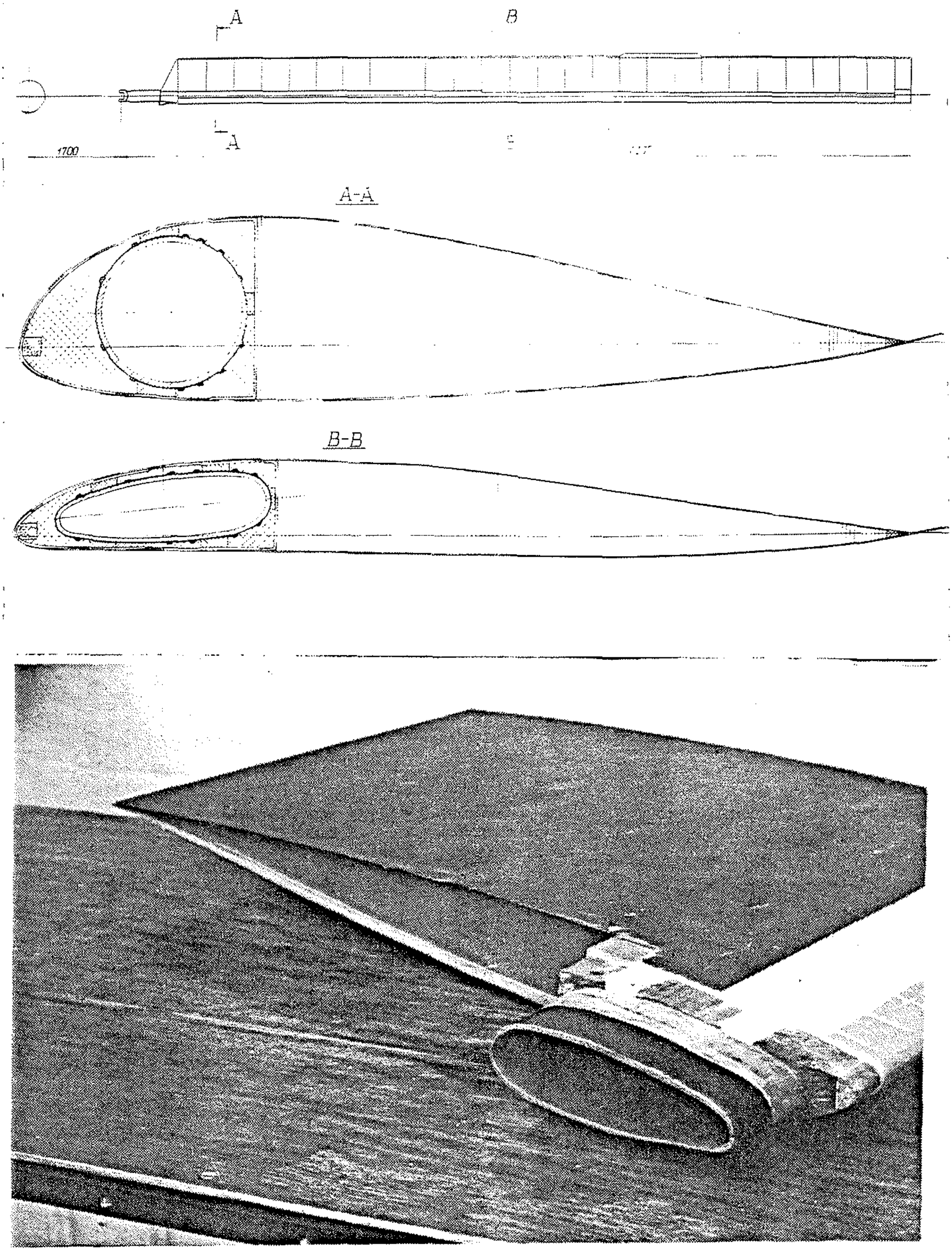
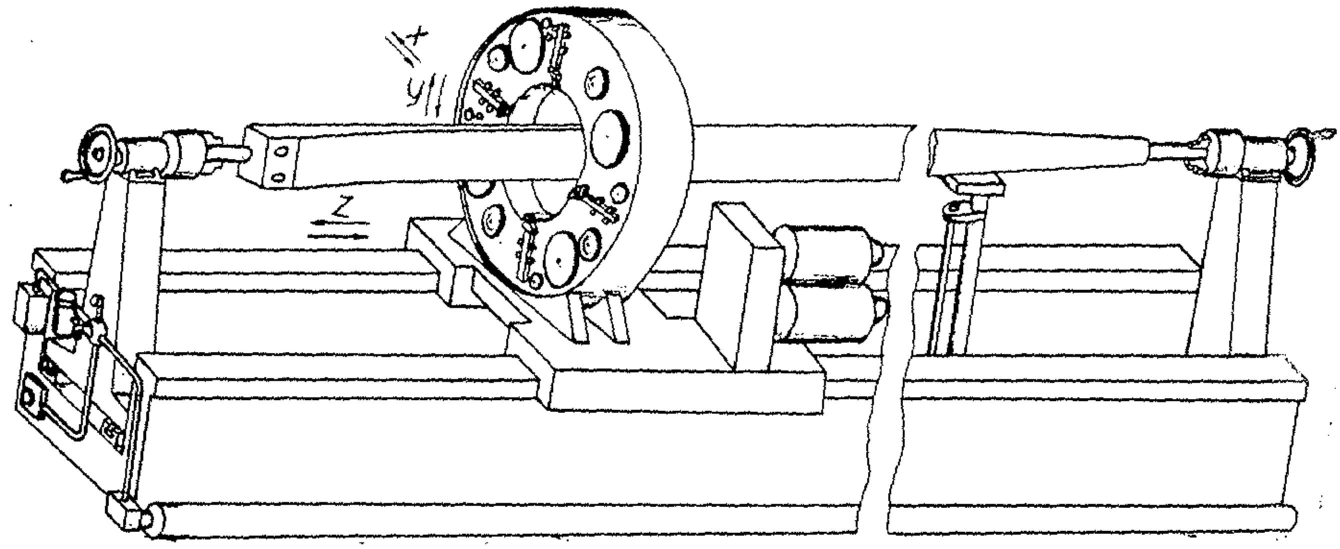


Fig. 4. Mi-26 main rotor blade.



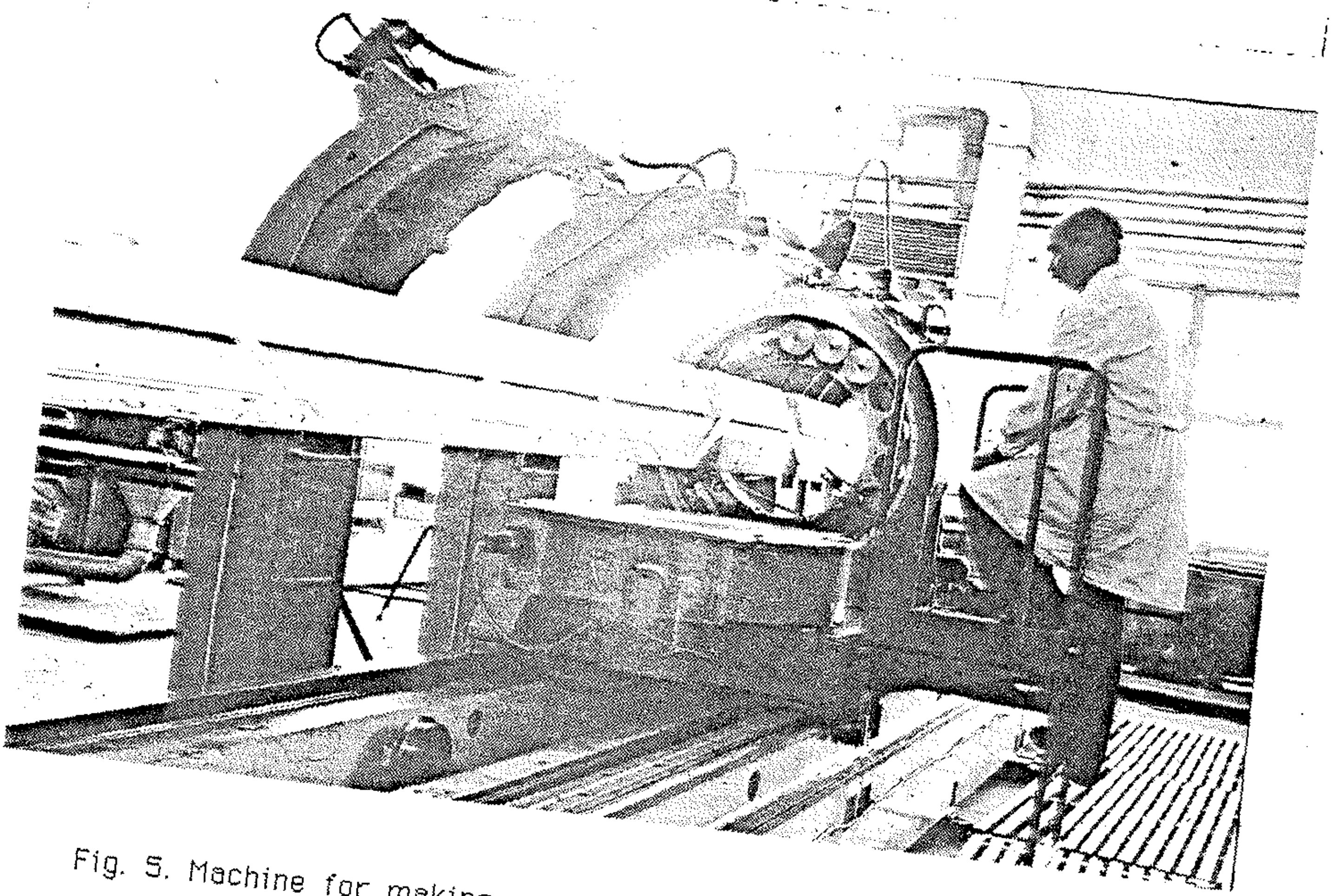


Fig. 5. Machine for making spars by laying up composite tapes.

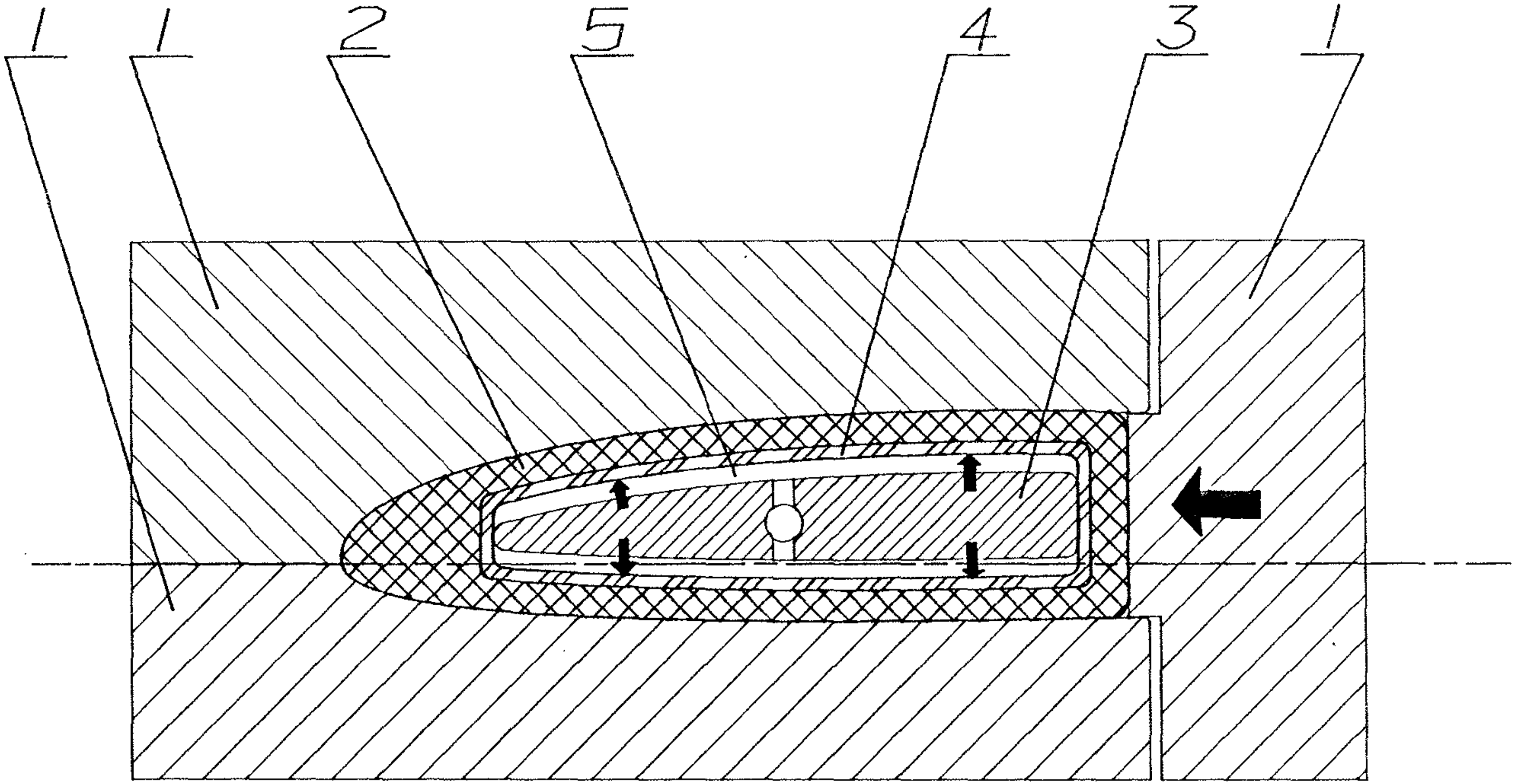


Fig.6. Schematic diagram of facility for curing composite blade spars.

1 - Mold
2 - Spar
3 - Mandrel for type layup
4 - Elastic bag
5 - Compressed gas

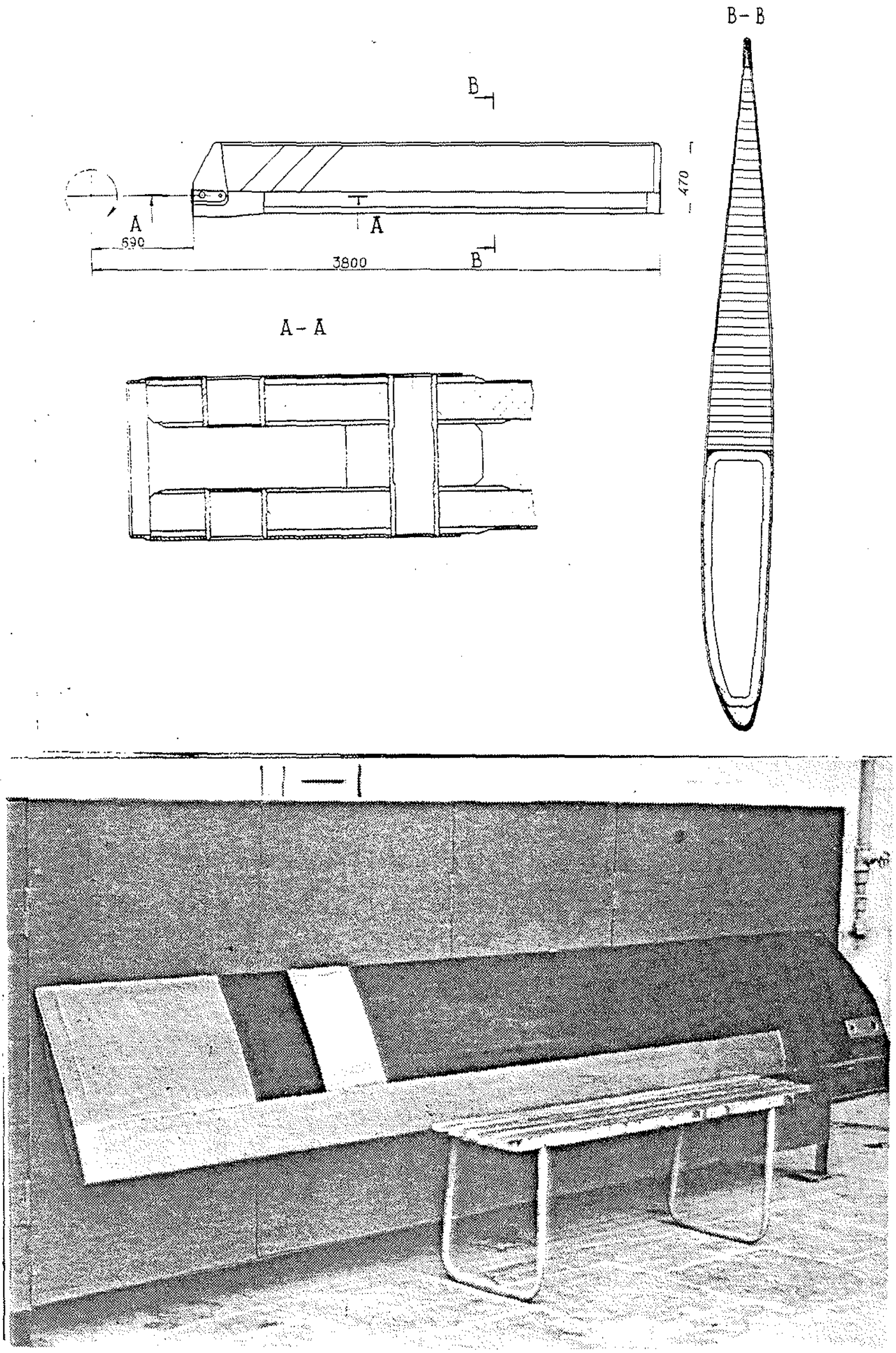


Fig. 7. Mi-26 tail rotor blade.

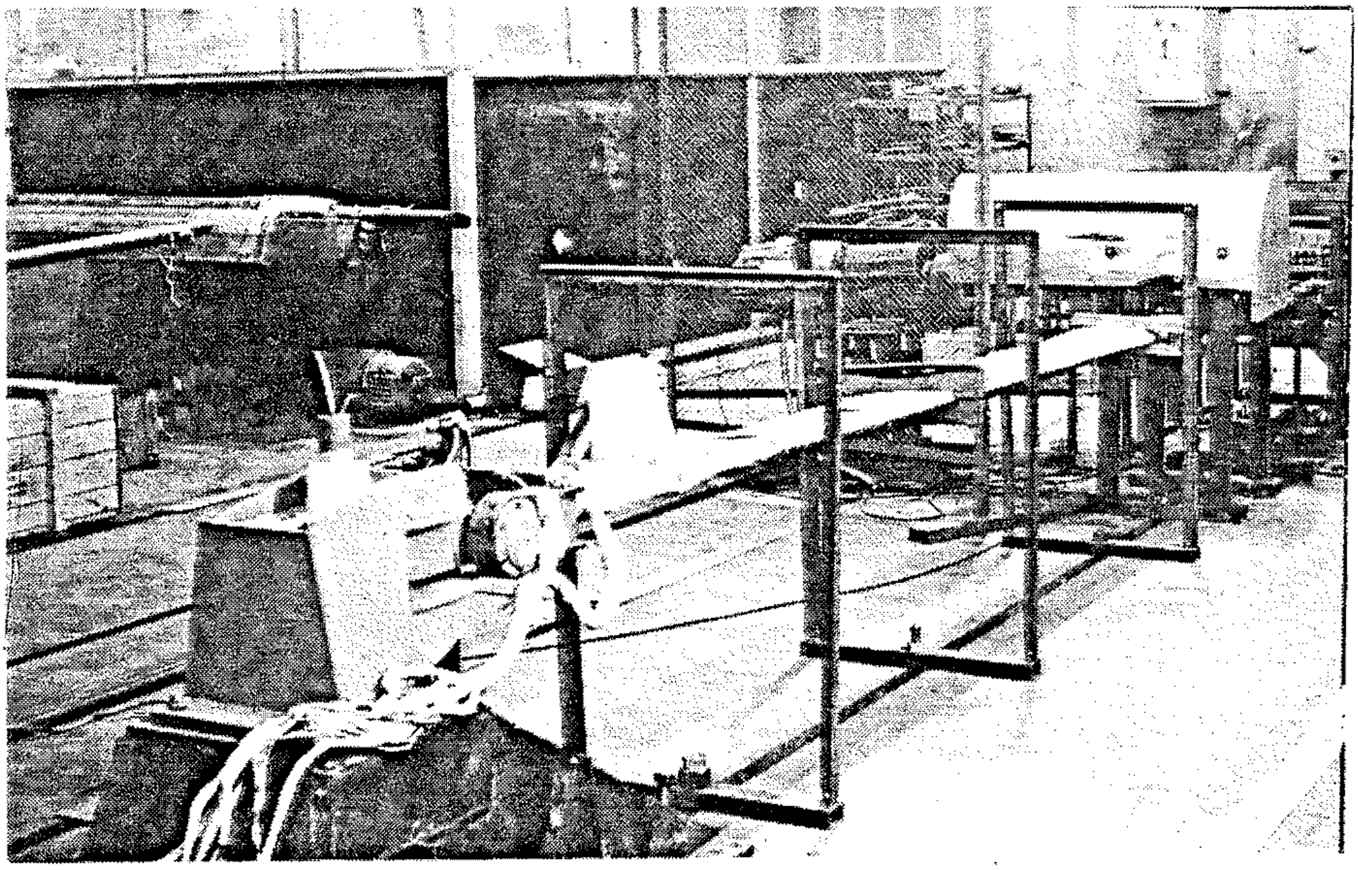


Fig. 8. Rig for fatigue (dynamic) testing of blade specimens.