Geometric modelling of helicopter ammunitions vulnerability

A.M. Volodko & V.A. Gorshkov
Research Institute of aircraft maintenance
Moscow, Russia

Abstract

This paper considers helicopter or its unit and operational systems hit probability as a principal index.

The optimal model of the helicopter is a geometric figure, which consists of parallelepipeds circumscribing a helicopter and its components outline on a taken scale.

Such a geometric model of the helicopter implies obeying some rules and restrictions, which are presented in the paper.

The helicopter and its sections are presented by means of geometric models, the components nomenclature being taken accordingly their real distribution along the fuselage profile, and considering even vulnerability of the components symmetrically arranged about the main axes.

A geometric model of the components arrangement in a section is considered as applied to three principal design options.

Results of estimation of helicopters obtained by means of modelling have proved a satisfactory convergence with the real vulnerability of the helicopters, which took part in the combats in Afghanistan.

General propositions

Spare parts accumulation is based on estimation of the demand proceed from the assumption, that helicopters will get damages both operational and caused by hitting in combats, and their systems will fail under various reasons (reliability, environmental, or the human factor).

Let's assume that any damage to a helicopter component entails the necessity to replace it. Thus a component vulnerability can be determined as a probability of the damage:

$$P_{dam} = f(S_v{}^{hel}, S_v{}^{comp}, r, \eta_s, P_{hit})$$

$S_v{}^{hel}, S_v{}^{comp}$ are the vulnerable areas of the helicopter and its component accordingly;

r is a parameter of the components spacing;

η_s is a screening parameter of the helicopter components;

P_{hit} is the hit probability.

The vulnerable areas $S_v{}^{hel}, S_v{}^{comp}$ are determined as the coordinates of the object outline in the rectangular coordinate system. These both values depend a great deal on the targit position relatively the firing unit, the helicopter components arrangement, and their number. This dependency is more characteristic for the components rather than the helicopter, as a change in the fire angle cause a change in their arrangement, i.e. the screening effect. The layout of every specific type of helicopter determines the screening effect.

This complicates estimation of helicopter vulnerability since a great number of components must be considered and the initial data must be proceed & prepared for acceptance.

The way out is in development of analytical methods estimating vulnerability of the helicopter components.

This paper considers but the concept of the method proposed and some important

results the authors have obtained at investigation into the helicopters combat survivability due to the limited volume.

Geometrical model of the helicopter

There are different formalizations of the aircraft structure, such as a cylinder, a cone, or a combination of them both etc. Parallelepipeds outlining the helicopter and its components on a selected scale was found the best geometric model represented in the plane perpendicular to the firing direction. This model features in the following advantages:

- simplicity and low labouriousness;

- symmetrical representation of both the helicopter and its components;

- a possibility to study the components vulnerability with regard to their arrangement along the main axes of inertia (X, Y, Z);

- fast preparation and input of the data compared with the other methods.

However development of the helicopter geometric model in this case implies some requirements and limitations to be observed:

- the linear dimensions of the model (length, height, width) must be equal to the real dimensions of the helicopter on the scale convenient for the coordinates reading;

- the components and systems of the airframe are represented by parallelepipeds not exceeding the linear dimensions of the real helicopter;

- compact components of a system consisting of several units, such as the instrument panels, computer and navigation complexes etc. are represented by a single parallelepiped not exceeding the real dimensions of the airframe;

- external components (the landing gears, the main and tail rotors, wings etc.) are represented by the parallelepipeds joined to the airframe model in places of their real joint;

- the coordinate plane projection of the helicopter is to be plotted subject to the firing direction, the aiming point being in the helicopter center of gravity.

A large spectrum of possible firing directions must be taken into account, that causes a considerable increase in the labouriousness. However in some cases a number of aspects can be neglected due to the following reasons:

at a single target firing there is a so-called "fire-starting point", which is determined by the target range and the ammunition properties. It is obvious that every range corresponds to its value of the vulnerable area subject to the gun distance.

The geometric modelling enabled us to establish the symmetry of the aircraft vulnerable area distribution law within all firing ranges, and thus to reduce the number of the aspects under consideration to 3 or 4 ones. However considering the more complicated helicopter configuration (compared with the airplanes) 4 or even 5 aspects seem necessary to be analysed.

Geometrical model of the helicopter compartment

The vulnerable zones are represented as parallelepipeds, giving a formalized idea of the helicopter compartment geometry model.

The system units and equipment are further considered the components arranged within a compartment.

Let's reduce modelling of the hitting force on a helicopter or its compartments to definition of the burst hitting points in the projection of a helicopter, and in every vulnerable zone chosen in the projection. The hitting low $G_{\mu n}$ corresponds to each zone (compartment) to be damaged due to any men-

tioned reason. The low determines the dependency between the probability of a fatal damage and a number of the bullets hitted the zone (compartment). The necessary and sufficient number of the bullets hitted to destroy a n-th zone (compartment) can be determined by natural firing.

Helicopter vulnerability caused by the remote ammunitions is characterized by the explosion effects, such as the fragmentation field and the shock wave.

The following critical characteristics describe the fragmentation field vulnerable effect to destroy a compartment:

- specific critical energy of the fragments hitted the compartment;

- the compartment surface critical area covered with the fragmentation field;

- the full critical energy of the hitted fragments;

To estimate the penetrating effect of a fragment, its sides are characterized by the duralumin equivalent h_g.

Helicopter vulnerability caused by the shock wave effect is described by the specific critical impulse (i.e. the impulse on the area unit) under which at least one side of the compartment is destroyed.

The fragment effect characteristics are determined in the static tests. The fragments scattering is simulated for every position of the ammunitions at the moment of an explosion, the number of hits in every side being determined.

Vulnerability characteristics are to be estimated for various positions of the ammunitions about the helicopter at the moment of an explosion. The parameters to vary at the simulation are the approaching angle and the mean square deviation of the missed fragment.

Uneven arrangement of the components along the fuselage is a typical feature of aircraft. To estimate influence this property exerts upon the aircraft vulnerability (upon demand for the spare parts as well) the developed geometric models of both the helicopter and its components are used. The components nomenclature is chosen with regard to their real arrangement along the fuselage cross-sections and equal vulnerability of the components arranged symmetrically about the main axes.

Figure 2 shows the dependency between the component hit probability and the firing range obtained in experiments with a model. Obviously, an increase in the firing range entails a 50% reduction of the hit probability. At the same time the absolute value of the reduction does not exceed 3%. The components c.o.g. spacing results in a considerable decrease in the hit probability. If $0X$ axis projection of the distance between a component and the aiming point is taken the range unit, then the medium P_{hit} value calculated for all areas open to attack gets over 5 times reduced.

Infuence of the components arrangement on their vulnerability

A component hit probability increases proportionally the vulnerable area proceed from the geometry interpretation of probability. However this dependency is typical for the compartments with a rather small number of components. At a high component density within the compartment the S_v^{comp} value considerably depends on the component arrangement as well. It has been proved that a change in the fire angle entails both a corresponding change in the value of the area open to attack and the screening effect, i.e. overlapping of the projections of the components placed in consequent order. Helicopters feature in uneven density of the compartments. Ergonomics requirements resulted in placing the components along the same vertical & horizontal axes of the fuselage (by means of special shelves, mounting brackets etc.)

The components arranged in the same vertical plane form a so-called layer. Every layer screens the previous one. The number

of the layers differs, though usually does not exceed three ones along the fuselage side.

Figure 3 shows the geometric model of three principal design options.

Option 1. The components placed in the vertical and horizontal planes have equal linear dimensions.

In terms of the vulnerable areas this option implies, that

$$S_{v1}{}^{comp} = S_{v2}{}^{comp} = S_{v3}{}^{comp} = S_{v4}{}^{comp}$$

Due to the rigid mounting of the components within a compartment this is independent on the fire angle. The vulnerable areas ratio is also constant at unequal linear dimensions.

A change in the fire angle corresponds to a fixed open-screened area ratio, only the first layer featuring in a considerable reduction of the screened area at an increase in the fire angle.

K_{si} is a coefficient characterizing the screening effect (the screened area $S_{si}{}^{comp}$ is a part of all vulnerable area $S_{vi}{}^{comp}$ arranged in the i-th plane at a change in the fire angle).

Results obtained at modelling have proved that the first layer components are most open to attack (they are the closest ones to the skin). K_{si} falls over three times at the fire angle change within the range of $\frac{1}{8}\pi \div \frac{4}{8}\pi$.

Geometric modelling and calculations have proved that the number of components in a compartment does not influence K_{si} value at a fixed arrangement. At the same time K_{si} differs but little for the second and the third layers at the same fire angles, the screened area being 35% and 25% accordingly.

Option 2. The components of the second layer have less linear dimensions compared with the components arranged in the first and the third ones. This option is characterized by significant screened areas of the third layer components (they exceed the screened areas of the first option by a factor of nearly 1.5), and the more the vulnerable area scale, the more the screened area in the third layer.

A reduction of the area open to attack can be obtained by decreasing the linear di-

mensions of the second layer components. Hence a decrease in the dimensions along an axis causes an approaching of the third layer components to the first layer ones. At certain dimensions of the second layer vulnerable areas the components of the first layer create the screening effect. Thus the screening effect depends on both the vulnerable areas ratio and the arrangement of the components in a compartment (their spacing).

A change in the screening coefficient entailed by the fire angle varying shows that the component screened area exceeds 40% for this option as well.

Option 3. The components of the second layer have more linear dimensions compared with the ones of the first and the second layers, i.e.

$$S_{v1}{}^{comp} = S_{v2}{}^{comp} = S_{v4}{}^{comp}; S_{v3}{}^{comp} > S_{v2}{}^{comp}$$

Two features characterize this option. Firstly, steady values of K_{si} coefficient in terms of various component arrangement. Secondly, the screening effect depends on a change in the components placing inside the compartments.

Investigations into the helicopter geometrical models have revealed that in certain cases an increase in the components spacing inside a compartment gives 3...10 times reduction of K_{si} coefficient, the $0Y$-axis displacement exerting the most influence. In fact, the $0Y$-axis displacements cause the loss of the screening effect.

K_{si} values vary within a rather wide range of 0.2...0.45. Thus a proper arrangement of the components in a compartment entails a considerable reduction of their vulnerability.

Steadiness of the K_{si} values proves the above-mentioned assumption that the number of the placed components is limited for aircraft of any type. Besides, K_{si} coefficient simplifies calculation of the required spare parts, for it allows to substitute sophisticated simulation models for the simple analytical dependences with regard to the real arrangement of the components inside an aircraft.

In order to estimate the reliability & accuracy of the developed math model the authors have analysed extensive statistical data they obtained in Afghanistan, where the Mi-8 and Mi-24 helicopters had been widely used in combats [1].

These data themselves as well as their comparison with various available math models of helicopters combat and operational survivability are of interest. This papers considers but most principal results of the developed model appraisal (fig. 4,5).

Fig.4 shows the subdivision of Mi-24 helicopter fuselage into the sectons open to damage. The statistical polygon of distribution of the section damage relative rate (damage caused by the mojakheds' guns) match the corresponding results of modelling.

The validation of the data presented in fig. 4 as well as of the other data is based on the least square smoothed estimation of the confidence & tolerance domain of existence. The results correspond to the ones obtained from practice with a guarantee probability of 0.95, which is indicative of a rather high accuracy of the modelling.

Finally fig. 5 illustrates comparison of the theretical and experimental data the modelling aims at, i.e. estimation of demand for the spare parts and units necessary for the operational repair of the helicopters hit in combats. One can easily see that the calculated polygons agree well with the experimental ones, though differ considerably from the aprioristic planned data, i.e. from the number of spare parts and units supplied by the manufacturers as so-called group sets of spare parts.

Thus this method allows to predict precisely the listed products and their quantity to repair damaged helicopters with regard to the expected combats they are planned to be used in.

The dumps are enabled to avoid overstocking on the one hand, and the helicopters will not stand idle due to the lack of spare parts on the other hand. Thus the proposed method helps to improve significantly both the combat and economical effectiveness of the helicopters in the armed conflicts.

References

[1]   Volodko A.M., Gorshkov V.M. "Helicopter in Afghanistan", Moscow, Vojenizdat, 1993.
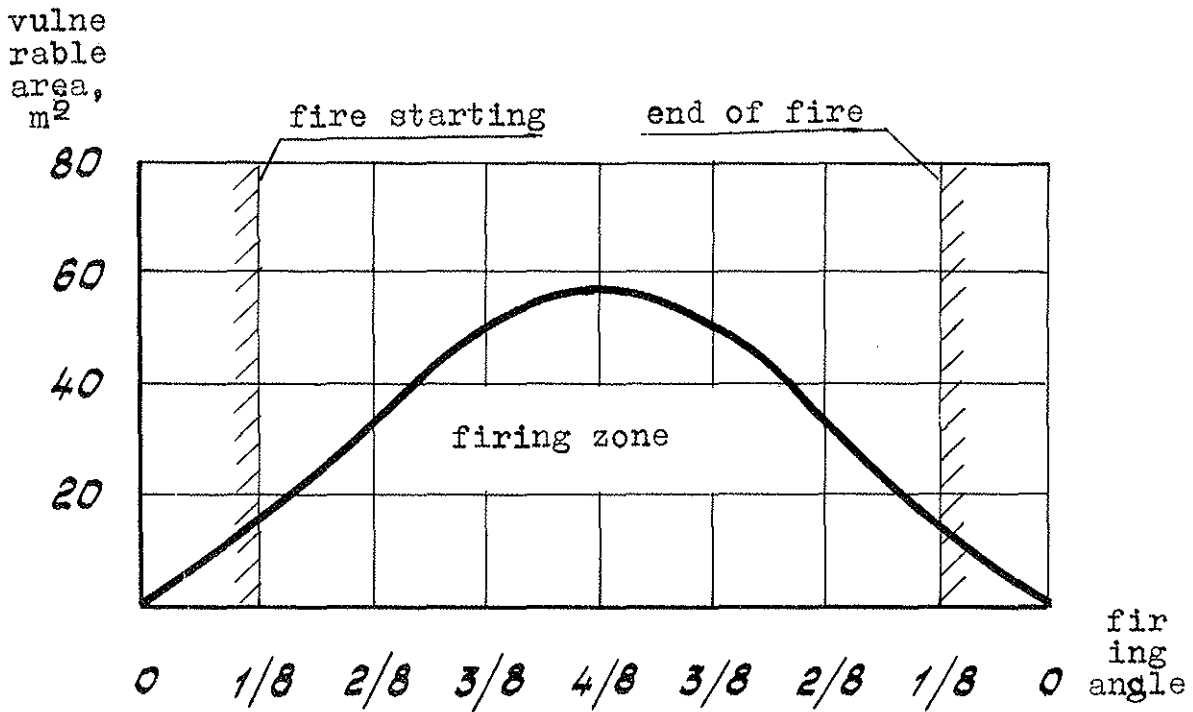
vulne
rable
area,
m^2

Fig.I. Change in helicopter vulnerable area subject to
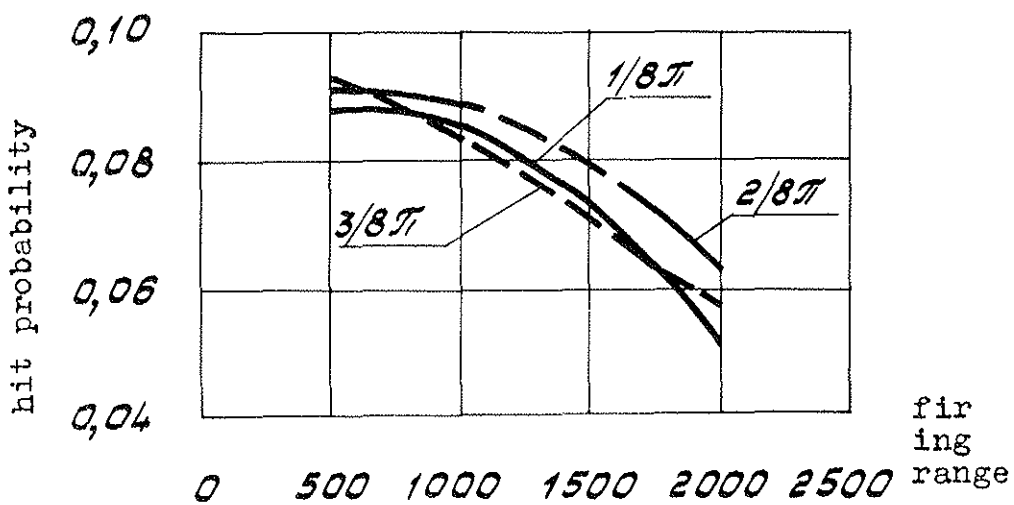the fire angle

Fig.2. Change in vulnerability of helicopter components
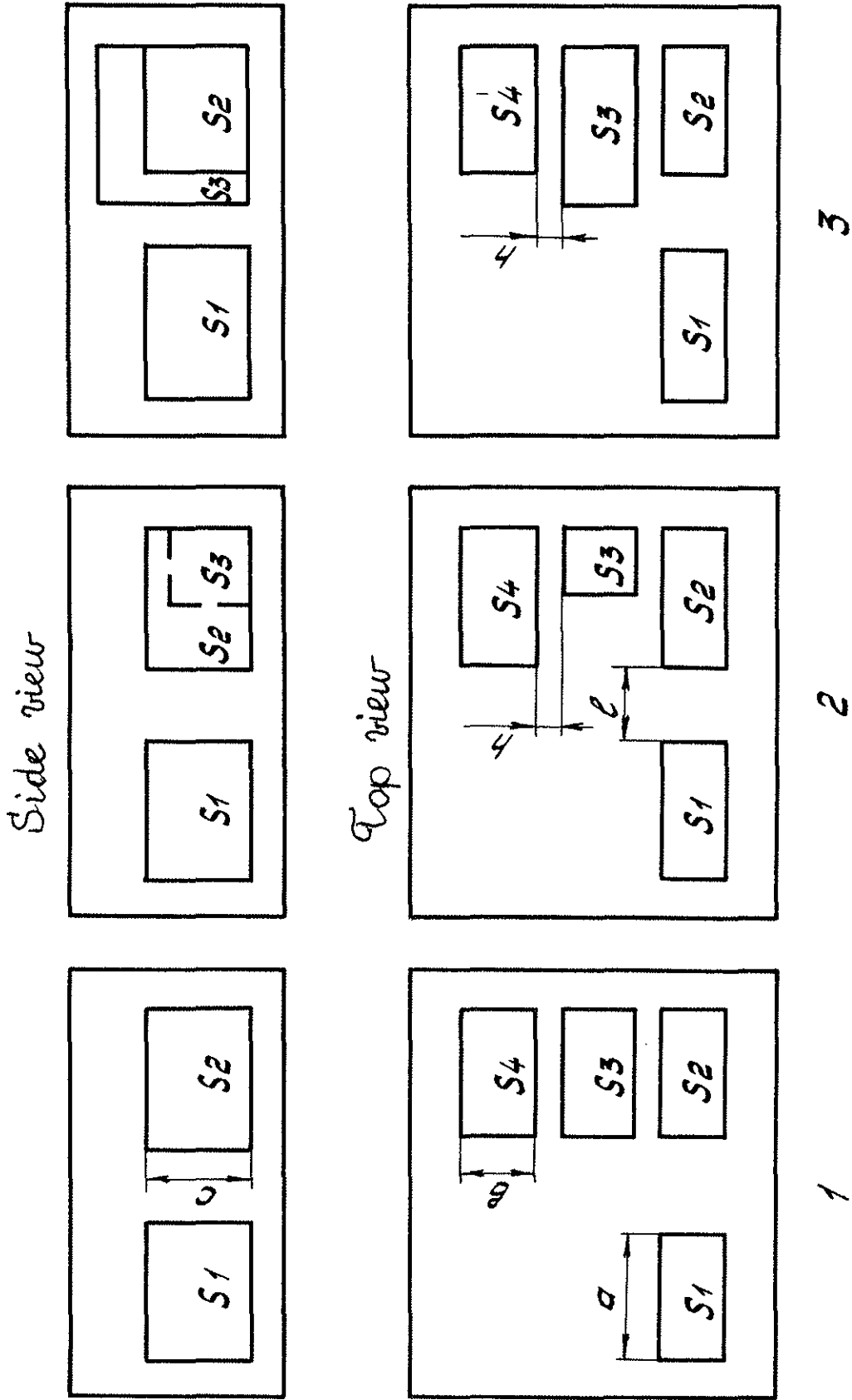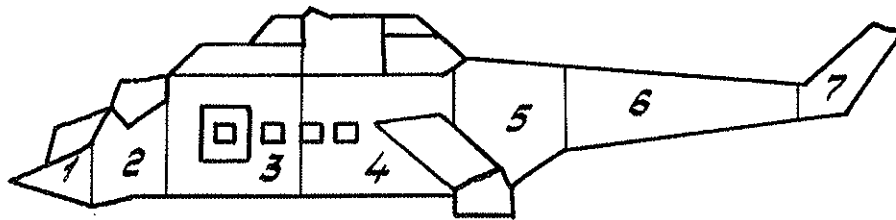subject to the fire angle and firing range.

40.6

Side view

Top view

S1 S2 S3

S1 S2 S3

S1 S2 S3 S4

S1 S2 S3 S4

S1 S2 S3 S4

1   2   3

Fig.3. Principal design options of helicopter components.

40.7

probability
of the damage
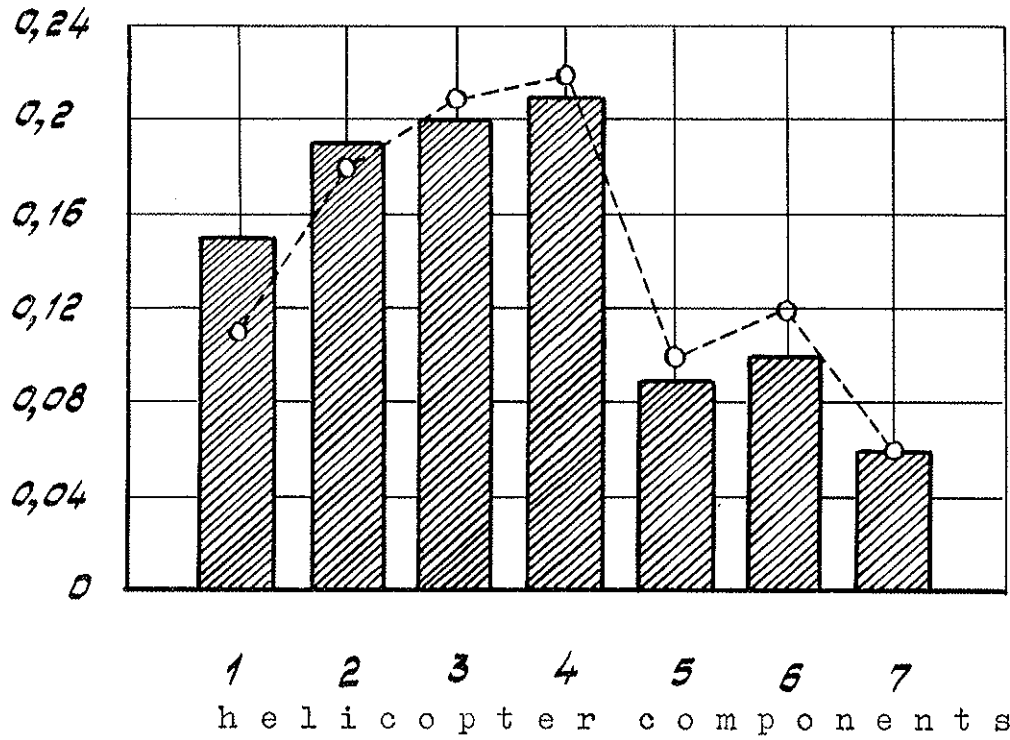
Fig. 4. Results of estimation of vulnerability of
helicopter Mi-24.
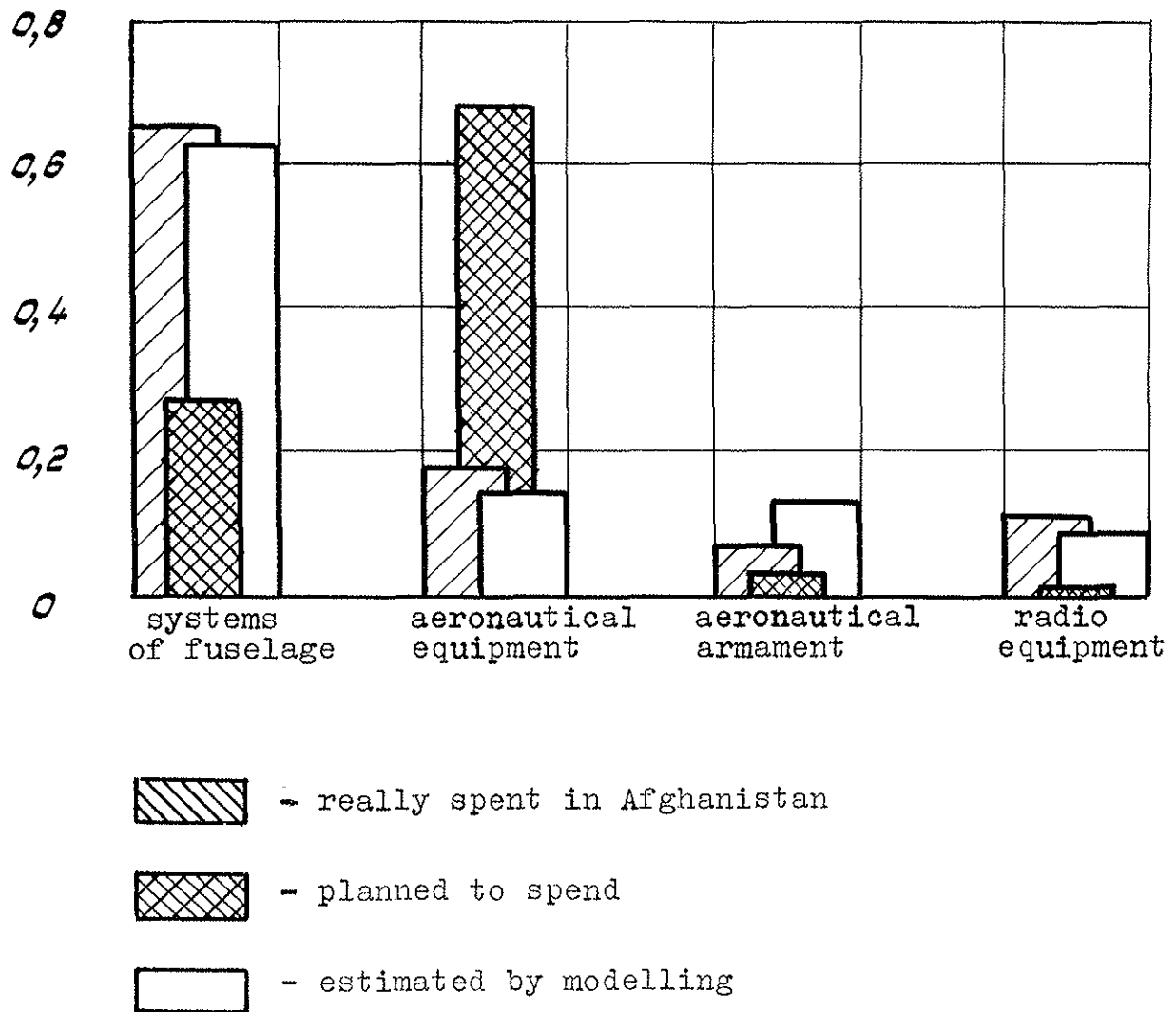
relative share
of spare parts

Fig.5. Results of estimations of spare parts spending
for helicopter Mi-8 in Afghanistan.