Cause-factor analysis of helicopter accident rate

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Abstract

A unique data base on flight accidents and serious failures of Mi-2, Mi-6, Mi-8, Mi-14, Mi-17, Mi-26 Russian helicopters during 20-year period of their mass exploitation in both civil and military aviation has been systematized and analyzed.

The main groups of unfavourable factors are determined. The paper contains distributions of flight accidents connected with unsatisfactory actions of the pilots, complicated meteorological conditions, and flight accidents caused by unsatisfactory reliability of the aeronautical engineering.

The data presented in the paper have proved the known world statistics. At the same time the mentioned relative accident rates for helicopters of different weight (light, medium, and heavy), and for the helicopters of the same types, being used simultaneously on both military and civil purpose are of great importance.

General propositions

This analysis is aimed at obtaining the quantitative and qualitative estimations of the direct and indirect influence the revealed factors exert upon the unfavourable course of the emergency situations, and the results of flight accidents.

Factor as a generally adopted term, implies any condition, event or circumstance for certain connected with an accident. Meanwhile, the **reason** of an accident is, as a rule, a whole complex of interdependent factors caused the accident. One factor among them is the principal one, the rest of factors are the promoting ones.

The following factor analysis of helicopter accident rate includes two main groups of accident cause-factors:

- unsatisfactory operation of aircrews;
- unsatisfactory reliability of aeronautical engineering.

Each group consists of a whole complex of unfavourable factors and conditions when the factors become apparent.

The following have also been considered within the limits of the mentioned groups:

- unfavourable meteorological conditions as a consequence of the crew infringement of the established environmental limitations and insufficient reliability of aeronautical machinery, operating in the established complicated conditions;
- unsatisfactory operation of the ground personnel at the pre-flight preparation or at helicopters repair, which entail a dangerous failure at flight.

First of all we will consider statistics, i.e. the cause-factors distribution of the accidents.

Wrong actions of the aircrews have been the main reason of about 70% of all accidents happened during the latest 20 years (1975 - 1995). This figure varies arbitrarily in the range of 65% – 75% depending on the helicopter type, the exploitation department (a military or a civil one), the year of operation, etc. Insufficient reliability of the aeronautical machinery has caused on average 20% of accidents, varying from 10% to 30% depending on the mentioned factors. Finally, 10% of all accidents have been caused by the management shortcomings and abnormal situations, which are beyond consideration in this paper devoted to the helicopters.

These data correspond with the accident distribution of the world aviation on the whole, and in particular in the helicopter aviation. This reveals the human factor to be the weakest point of flight safety.

Unfavourable role of the human factor is evident even in the cases of accidents caused by the technical reasons and, hence, it is expedient to study it most carefully.

The human factor entails high both spiritual and pecuniary cost, for during the considered period approximately 20% of accidents had led to the death of the crew members or passengers, approximately 50% are the accidents resulted in a helicopter loss, and the rest 30% of accidents are the breakage that had brought to different destruction of helicopters to be repaired in the field or in a permanent establishment.

The following analysis assumes a division of the helicopters into three principal groups:

1. light helicopters, such as Mi-2 with the flying mass up to 3.5 t;

2. medium helicopters, such as Mi-8, Mi-17 with the flying mass up to 12 t;

3. heavy helicopters, such as Mi-6, Mi-26 with the flying mass up to 55 t.

Analysis of flight accidents caused by the pilots' poor operation

First of all we will dwell on the flight tasks distributions of the accidents both in the civil and military aviation (Fig.1).

It results from this that :

most dangerous tasks for the light helicopters attributed to the civil aviation are the pipelines, large forests or reservoirs observation, transport flights, and aerial dustings. The military helicopters of the same type are being mainly used for training of the pilot school students and there have been the greatest accident rate during the training;

the greatest number of accidents with medium helicopters and with heavy ones have fallen on the transport and liaison flights, besides as far as the military aviation is concerned, on the weather reconnaissance (Mi-8, Mi-17) and on the training flights (Mi-6, Mi-26);

the training flights in the civil aviation have entailed on average a tenth of the accidents happened to the military helicopters. It is accounted for by the fact that the average annual flying time in the military aviation is nearly 10 times less than the flying time of the civil helicopters. That is why training flights of the military helicopters aim at keeping practical skills of those crews who have rather long intervals between flights, and hence, commit various errors and neglect established operating conditions;

Figure 2 presents the statistics on the flight stage distribution of accidents.

It has become evident, that the horizontal flight, landing approach, and the landing itself entail the greatest relative number of accidents happened to all helicopter types in both the civil and military aviation.

Besides manoeuvring at a low altitude is accompanied by a rather high accident rate for the light helicopters and heavy ones. If Mi-2 helicopters have often been unluckily used to perform manoeuvring, Mi-6 and Mi-26 helicopters manoeuvring, though being a scarce event, is always pregnant with the most grave consequences, because their overall dimensions, the cockpit vision as well as some flight limitations make these helicopters unserviceable for this purpose.

Finally the takeoff and landing are most dangerous for the light and medium helicopters. Helicopters of these types are mainly short-ranged, so they often have to carry out the takeoff and landing, sometimes the landing sites lack appropriate airfield facility. All these make the mentioned flight regimes hazardous.

Since every accident results in a collision with the underlying surface, consideration of corresponding distribution of accidents seems expedient (Fig.3).

These data show, that helicopters of every type both in the civil and military aviation get into trouble mainly over the flat and rugged country. Some distinctions of this distribution draw attention:

an overwhelming relative number of airfield accidents happened to the medium and heavy civil helicopters are accounted for by the fact that these helicopters are more often based on the local route airfields, which endure a rather heavy aircraft traffic, and hence collisions due to the crews rashness and bad air traffic control are the concomitants;

a considerable relative number of the mountain accidents happened to the medium civil helicopters are explained by their missions in the mountains (search, life-saving, timber carrying, building and assembling, transportation) due to their dimensions, load-carrying capacity, power-to-weight ratio, and equipment available. Military heavy helicopters are also partially being used in the mountains. These helicopters are hardly able to make a successful forced landing in a case of an emergency on a small piece of land in the mountains;

the military light and heavy helicopters have not been involved in accidents, or in just a few ones flying over shores and water mainly due to fortunate basing far from the areas of water.

The following points to be closely considered are the emergency weather and lighting distribution of accidents.

Statistics show, that helicopters get into accidents mostly in the visual meteorological conditions and at quite satisfactory lighting. At the same time there is a curious regularity: the relative number of accidents with the civil helicopters caused by the crews errors in the instrumental meteorological conditions diminishes from the light helicopters to the heavy ones, whereas the military helicopters feature in the opposite tendency. An explanation lies obviously in the different use of heavy helicopters, namely: unfavourable or even dubious weather forecast necessarily entails the flight cancellation for the civil Mi-6, Mi-26 helicopters, or they will be immediately landed on an alternate airfield if the meteorological conditions are getting worse. In military aviation the set tasks usually prevail over the flight safety reason.

Besides the military crews are purposely trained to fly at night and in the advisory situations following the principle "to exercise at the peace-time". So a considerable accident rate typical for the military helicopters is natural, while the night flights of the civil ones are scarce.

Now we will dwell on the ordinal number of a flight during the flying day.

First flights have taken the greatest number of accidents caused by the crew errors, second flights have entailed considerably less ones, and so forth. One should take into account, that heavy helicopters usually have no more than two flights per a flying day.

Thus these statistical data have disproved the a'priori assumption, that repeated flights lead to the pilots' tiredness, and hence, to the piloting errors. At the same time the class and the flying time of the crew commanders, who committed fatal errors at the last flight are of a particular interest (Figure 4).

On the whole, rather skilled and experienced pilots do commit fatal errors. Besides, the given statistics features in:

the civil pilots have the average annual flying time several times as much as the military pilots do;

an overwhelming majority of the commanders who flight all mentioned helicopters both in the civil and military aviation have the second class. At the same time there are many commanders of the third class piloting Mi-2 light helicopters, and the first-class ones piloting heavy Mi-6, Mi-26 aircraft;

in general the first-class commanders committed fatal errors especially in the military, also in the civil aviation were the officers busy with organisational, methodical, or educational work, so they had considerable intervals between flying activity in comparison with ordinary helicopter pilots;

in the civil aviation accidents happen mainly through the fault of experienced pilots with the total flying time over 3000 hours. Apparently they relax vigilance and discipline, and the officers invest them with unwarranted confidence, relax demand, the more so, as they are often the helicopter units commanders themselves;

a rather high rate of accidents through the fault of the military helicopter commanders with the total flying time less than 2000 h is obviously accounted for by an unfavourable combination of this relatively short flying experience with rather long intervals between flights, i.e. in other words, the military pilots gain positive flying experience much slower than the civil helicopter pilots do.

Statistical analysis of the age influence on the pilots' performance is also of interest (Figure 5). It is indicative of the following :

on average the most dangerous age grows older going from the light and medium helicopters to the heavy ones both in the civil aviation and in the military one;

low relative accident rates are due to the simple circumstance: in the civil aviation helicopter pilots younger than 25 are only used for piloting Mi-2 light helicopters (seldom) and as co-pilots on Mi-8, Mi-17, Mi-6 helicopters. Vice versa, in the military aviation pilots of nearly 50 years old are partially allowed to fly Mi-6 and Mi-26 heavy helicopters. Having reached this age pilots usually leave flying activities;

there are not a'priori expected peaks at the ends of the considered distribution, which would have reflected influence seemed evident of the youth and old age on the helicopter pilots performance.

We will go further into some typical statistical characteristics of the incidents happened through the faults of the crews, and involved air accidents.

Let us first of all go into detail on preincident flight duration distribution of flight accidents. Statistics reveals, that emergencies fraught with the grave consequences usually happen during half an hour after the takeoff both in the civil and military aviation. Let us go further into the height distribution of flight accidents. It appears that most hazardous are extremely low (<100 m) and low (100 - 300 m) altitudes of flight for every considered type of helicopters both military and civil, since three fourths of all emergencies fraught with flight accidents happen within this range of altitude.

Thus this statistical analysis enables us to draw the following conclusions:

- non-coordinated piloting, the crew rashness, spatial disorientation, indisciplined landing approach, particularly on an unprepared land are the most hazardous circumstances for every type of both civil and military helicopters;
- no statistical correlation between the age, flying skill and experience, fatigue of the crew commanders on the one hand, and their poor performance and errors causing different flight accidents on the other hand has been revealed;
- the helicopters have got into trouble mainly at the daytime, and in the visual condition during the first 30 minutes after the departure;
- breach of the established limitations on the flying mass, the wind speed, and the safe altitude have been the main accident promoting factor for the civil helicopters;
- breaching the established operational limitations on combat manoeuvring and bad-weather flights are the main accident promoting factors for the helicopters attributed to the military aviation;
- destruction of the settled civil aviation as a common system in the former Soviet Union, and considerably reduced flying time of both civil helicopters and the military ones have much aggravated the flight safety, and the tendency of the accidents happened through the crews' fault relative rate grow.

Analysis of flight accidents and serious incidents caused by the aeronautical engineering unsatisfactory reliability.

Statistics shows that the vital operational systems failures entail an overwhelming majority of the flight accidents caused by the technical reasons.

In general the considered engineering failures have been caused by the following reasons:

design or manufacture disadvantages;

little testing after manufacture or repair;

unsatisfactory testability of helicopters;

bad checkout of the helicopters maintenance or repair;

errors the engineering personal commit at operation;

foreign object damage.

In accordance with the listed this part does not cover:

inflight crew errors (such as turn-off of the fuel pumps, the ice-protection system, or the alert altitude warning device, improper pressure setting on the altimeter, etc. These occurrences have been already considered;

external damages (mainly of the rotor and the tail rotor blades) caused by collisions with the ground obstacles, such as trees, aerial power lines, airfield barrier, or with the transport vehicles and aircraft due to the pilots' rashness and indiscipline;

combat damages, which are to be subjected to a special analysis.

Apparently it doesn't matter at the moment whether the considered helicopters of one type are attributed to the civil aviation or the military one, and statistics approves this assumption.

We offer statistical distribution of flight accidents to the following generalised vital operational systems:

- **rotor system** includes the rotor and the tail rotor blades and hubes;
- **control system**, i.e. mechanical linkage, electrohydraulic actuators, hydraulic and pneumatic systems;
- **transmission**, i.e. the main, intermediate, and the tail rotor gearboxes, shafts and clutches;
- **powerplant**, which includes turbo-shaft engines, the fuel feed, lubrication, and the engine control system;
- **fuselage** including the primary structure, the landing gear and the external cargo suspension system;
- **helicopter equipment**, i.e. instrumentation, electrical equipment, as well as the armament of the military helicopters.

The weight of the failure consequences has been additionally analysed to estimate statistically the danger of the mentioned systems in-flight failures (Fig.6,a).

Thus the transmission failures as well as the failures of the powerplant and the control system are most dangerous, they make up three thirds of all air accidents including three fourths of the fatal flight accidents;

the relative number of flight accidents happened through the failure of these three systems is approximately even for every type of helicopters;

the more helicopter weight the heavier consequences of the engineering failures.

Failures of engineering are known to be entailed by the design and manufacturing defects, bad maintenance and repair, the personnel's errors.

Since this statistical analysis covers long mass operation of the considered helicopters, it includes those design and manufacturing defects, which had resulted in flight accidents though they have been already corrected. Those defects had caused breakage of the gears under the dynamic load, breakage of the bearings, blades of the turbines and compressors, splined couplings, the blades anti-icing strips, or the engines flameout due to the gas-turbine flow instability under the showers or icing, the snow shower, etc.

Nevertheless usually the flight accidents nominally caused by the vital operational system failures have been in fact provoked by the notorious human factor, namely:

- bad maintenance at spraying lubricant into the splined couplings of the tail rotor drive shaft, or at checking out the eccentricity and clearance in the tail transmission, at filling the gearboxes with the oil, or at the engine control, or at inspection of the air and oil filters, etc.;

- wrong installation of the components or units at their replacement, not straight or twisted installation of the filters and sensors, twists of the sealing rings, lack of locking parts, misalignment of the engine and the main gearbox, the pipelines and orifices misplacement, etc.;

- an attempt to make an authorised repair of the operating powerplant and the transmission components. Standard materials and the procedure specifications make no provision for such a repair;

- bad shop overhaul of the helicopter units, i.e. improper gears heat-treatment, misalignment of the tail rotor transmission units, etc.;

- bad post-flight maintenance, in particular poor checkout of helicopter fuel and oil cleanliness, refuelling without anti-icing additive in winter, that caused clogging of the fuel system filters.

Low reliability of the aeronautical engineering as a cause factor of flight accidents have been more often provoked by both the pilot and engineering personnel's errors, and each typical flight accident requires a close consideration.

A great many flight accidents and serious incidents have been analysed, and a conclusion has been drawn, that at an inflight failure of a component or a unit there is usually a chance to counteract unfavourable course of the incident, and to prevent an accident, or even a crash of the helicopter. However as a rule there is no exact data available, the air crews have not got a clear sequence of measures to be taken immediately, or necessary habits acquired at the training. Usually confusion and inertness of pilots result from the lack of knowledge what to do rather than out of fright.

Statistics has confirmed this intuitive conclusion. Figure 6,b gives the data available on the happy forced landings the pilots had to make at the failures of vital operational systems of all mentioned helicopters attributed both to the civil and military aviation.

Thus the powerplant and the transmission failures are the most dangerous ones, at the same time they happen more often, whereas failures of helicopter equipment though frequent, have not entailed grave consequences.

Figure 6,b includes incidents of one or even both engines flameout, or disconnection of the tail rotor transmission. However high skills of the pilots, self-control and courage together with the visual weather conditions, unlimited visibility, an appropriate landing site and a lucky combination of the flying parameters and stage at the moment of the emergency allowed the crew to make a safe forced landing.

The comparative analysis of the Russian and Western helicopters accident distribution.

There is no possibility to make a complete methodical comparison of the statistics on the Russian helicopters presented above, and corresponding Western data since they have not been published to the full extent openly. However even some information I have been lucky to come across, enable us to make an analysis, which could throw light on the regularities of the helicopter accidents common both for the Russian and Western helicopters and typical features of the Russian ones.

In 1993 - 1995 the **Flight International** and **Aviation Safety Vortex** published helicopter accidents reviews, mentioning but the type of the helicopter involved in the accidents, its location, service, the emergency flight condition and stage, the cause of the accident either known or supposed, the date of the event, and its consequences. For proper analysis we will exclude those cases where helicopters were hit in the local wars, or the ones, when the investigation failed to reveal the reason, and finally accidents happened to the superlight helicopters of less than 2000 kg.

The authors of the mentioned reviews give notice about imperfection, vagueness, sometimes even discrepancy in the data they adduce, and hence impossibility to make an adequate statistical analysis on their base. However systematisation of the information available allows to estimate approximately the general relative indices of the Western helicopter accident rate, namely:

nearly two thirds of flight accidents happen through the fault of the flight crews, or due to unfavourable weather conditions, the rest of them are caused by inflight failures of the aeronautical engineering;

among the flight accidents entailed by the flight crews poor performance and unfavourable weather conditions the landing approach and the landing itself cause nearly one third of the accidents, low altitude flight, and terrain flight, hovering, or manoeuvring cause one fourth each, the takeoff entails approximately 12%, and finally the motion about the ground is fraught with 5% of the flight accidents;

three fourths of the flight accidents happened through the fault of the technical reasons three fourths are the powerplant failures, the control system failures (mainly the directional control) cause 12% of the accidents, 12% happen due to the transmission failures (particularly the tail rotor transmission), and nearly 4% of these flight accidents are entailed by failures of the avionics.

One can easily see, that the Western helicopters relative statistical data conform to the Russian helicopters ones. Besides there are some important coincidences:

helicopter collisions with the ground obstacles (relief heights, trees, aerial power lines or pylons), as well as the collisions with aircraft and vehicles at the terrain flight are the main reason helicopters get involved in flight accidents through the flight crews fault;

the widely advertised unique helicopter feature to make easily a safe landing on an unprepared land including engines failure turned out to be far from the truth. In fact it requires extremely high skills of the pilots together with favourable environmental conditions;

the powerplant and the tail rotor transmission operational reliability are the cornerstone of the helicopter flight safety, no matter which type of helicopters is concerned.

In conclusion the important common features, that unite both Russian and Western helicopters in spite of the mentioned distinctions (there are some more small distinctions which have not been mentioned, such as the rotation direction, or the landing gear design) are worth to be emphasized :

the accident rate of both the Russian and Western helicopters (for example, the number of flight accidents happened during 100000 flying hours) is significantly higher in comparison with the general-purpose aeroplane accident rate. It results from this, that the helicopter flight safety is an important problem to be carefully considered;

the main accident cause is the human factor for both the Russian and Western helicopters, the main common technical reason is insufficient reliability of the powerplant and the tail rotor transmission;

some unimportant distinctions between the Russian and Western helicopters make no difference for the accident problems and flight safety measures, rather than the fundamental distinctions between a unique helicopter design and the aeroplane.

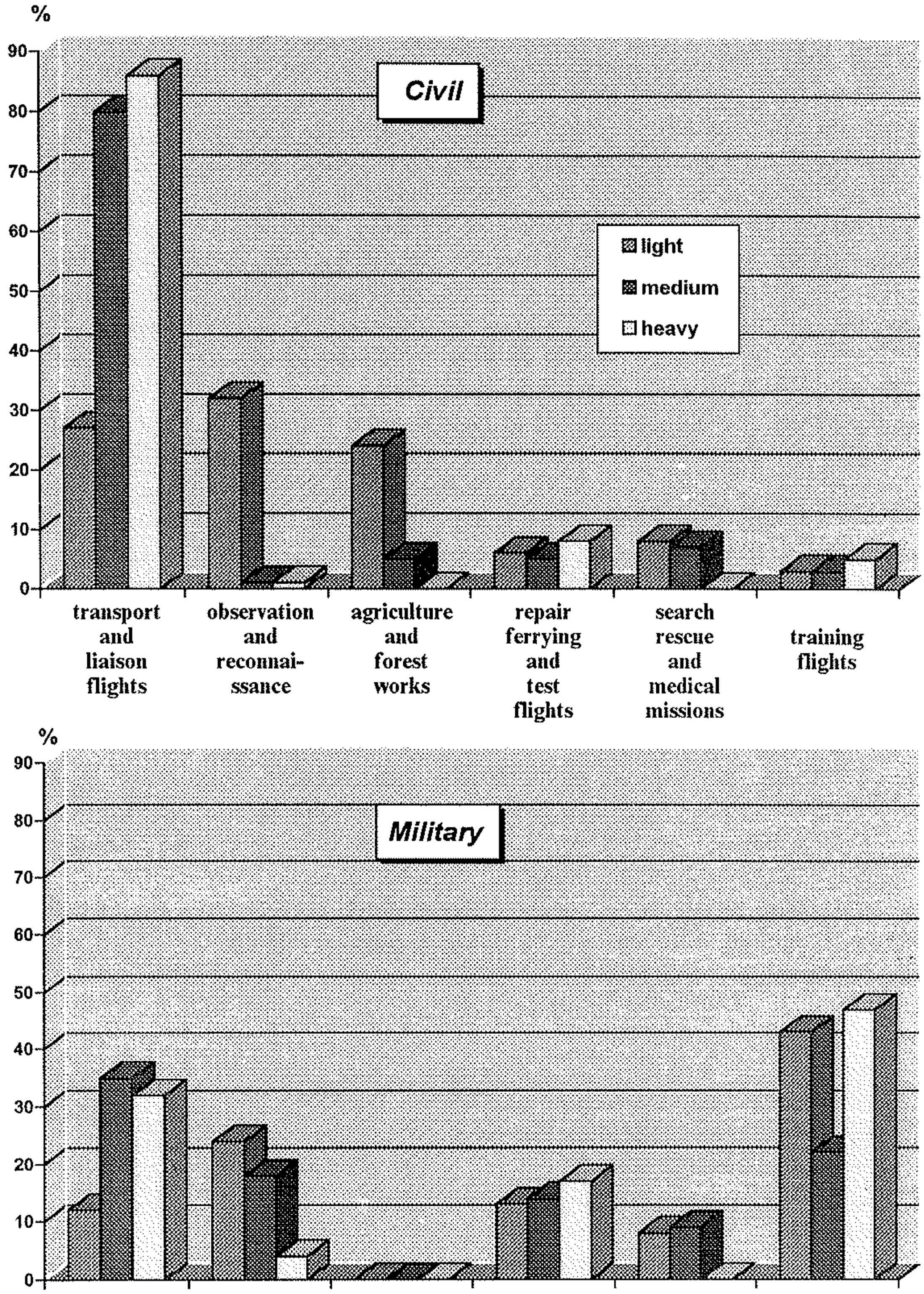


Fig. 1. Flight task distribution of air accidents

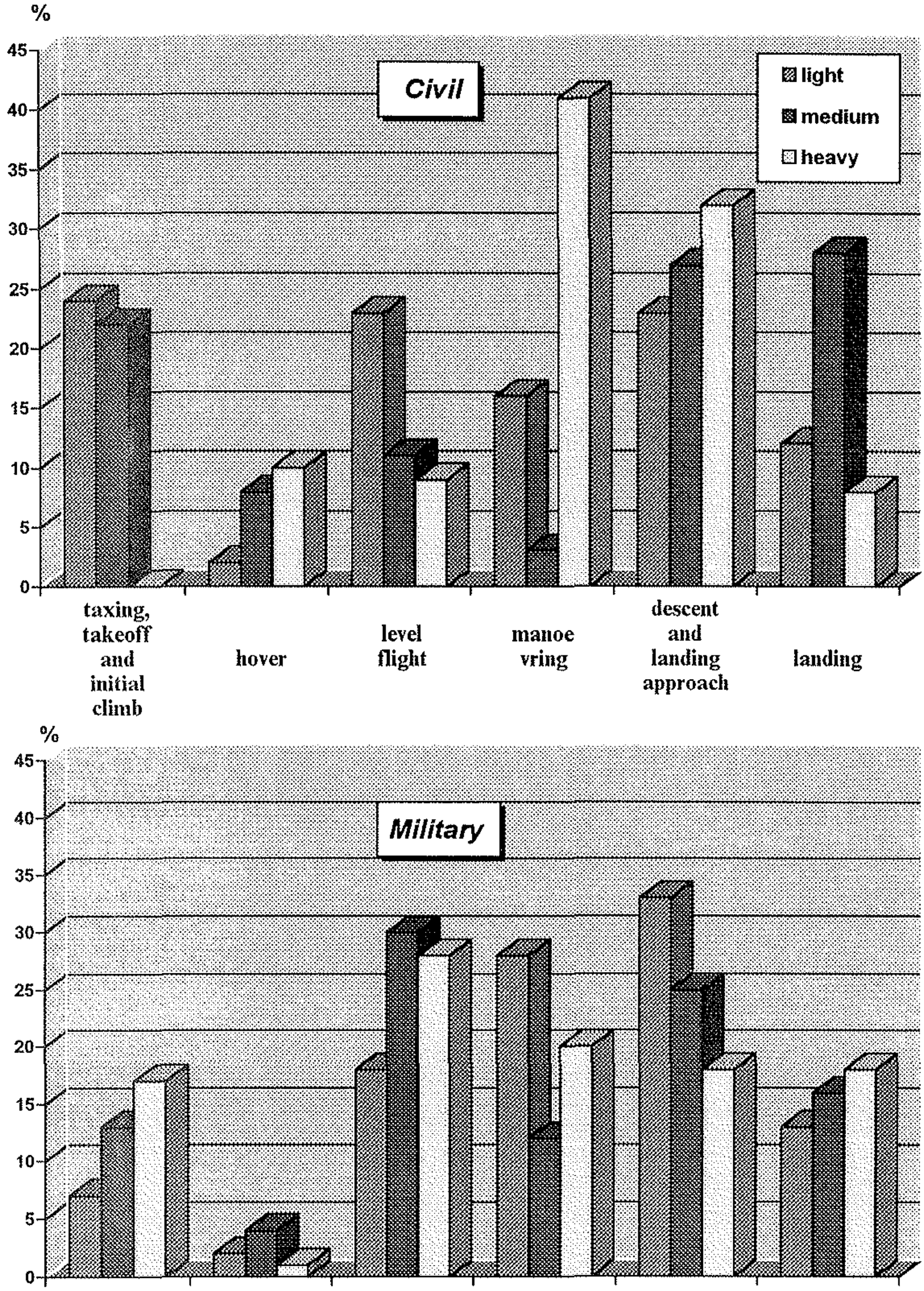


Fig. 2. Flight stage distribution of air accidents

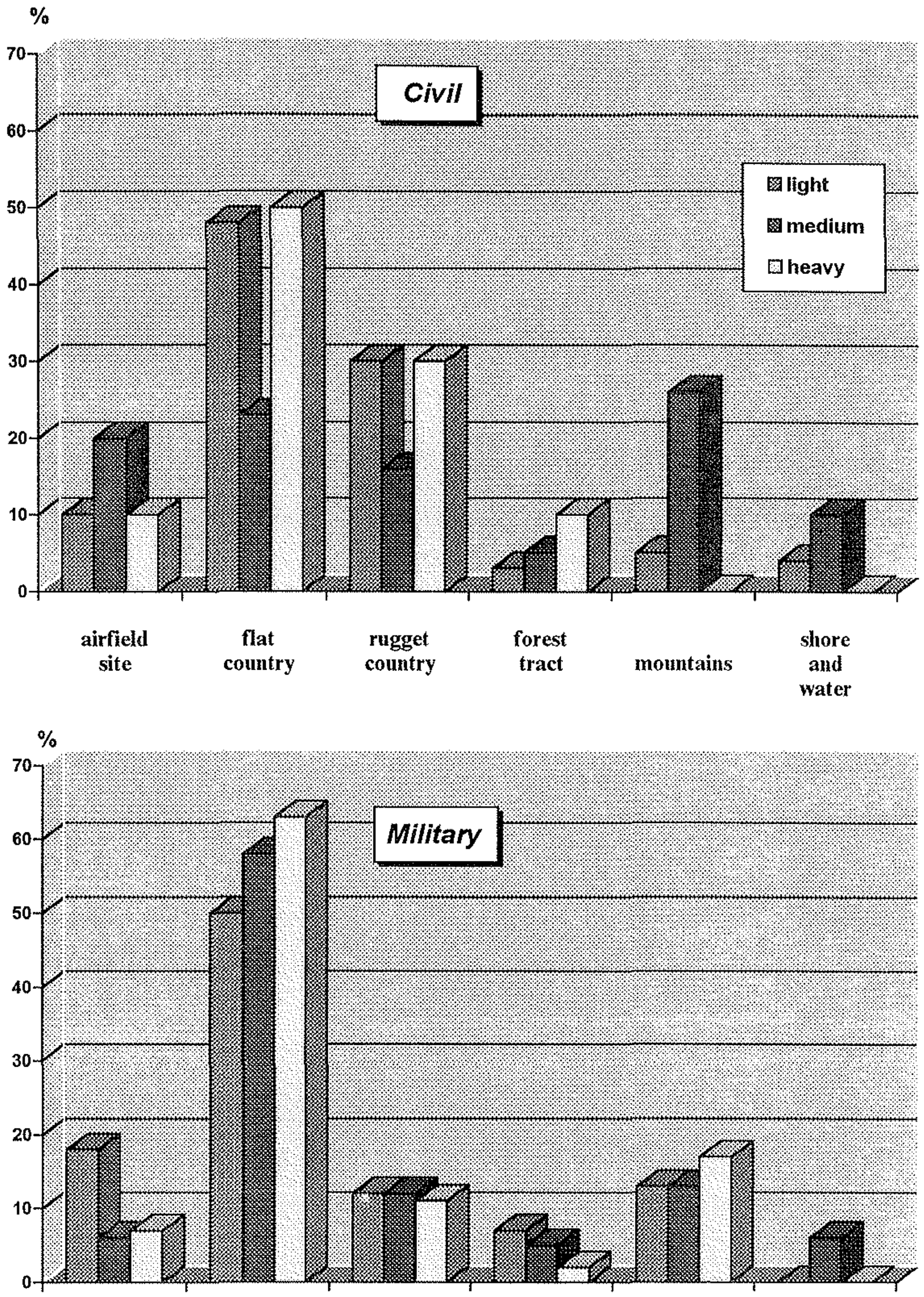
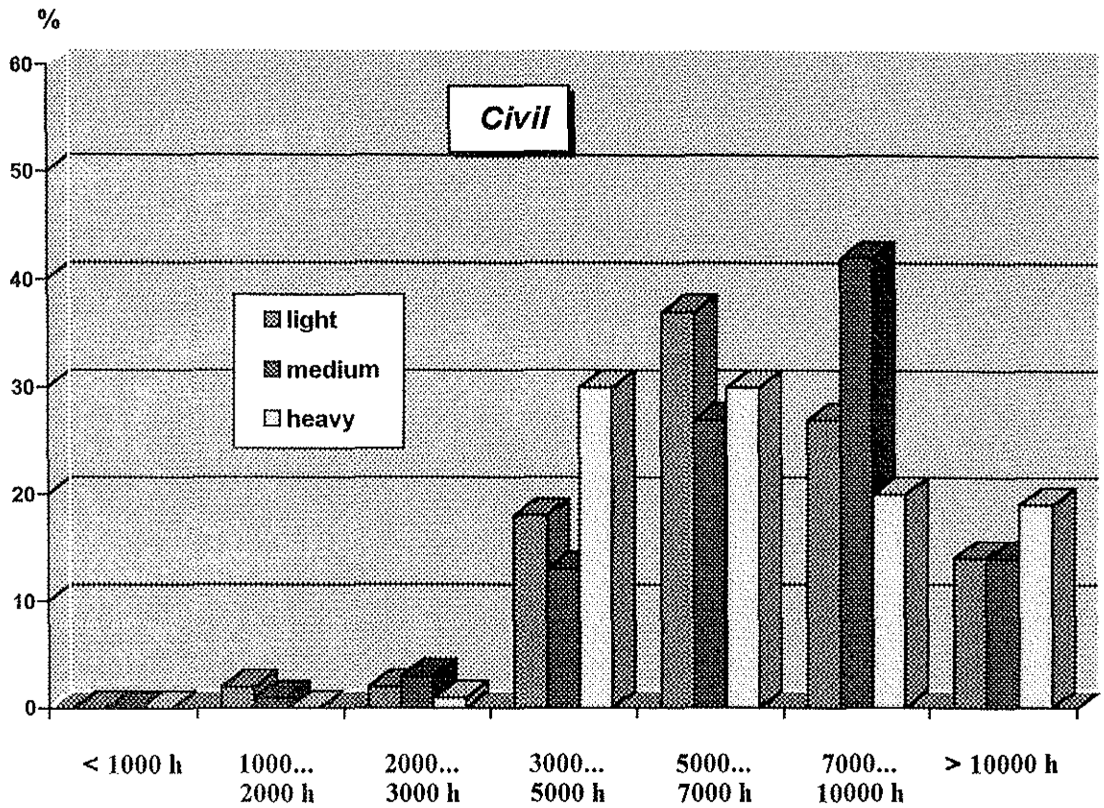


Fig. 3. Underlying surface distribution of air accidents



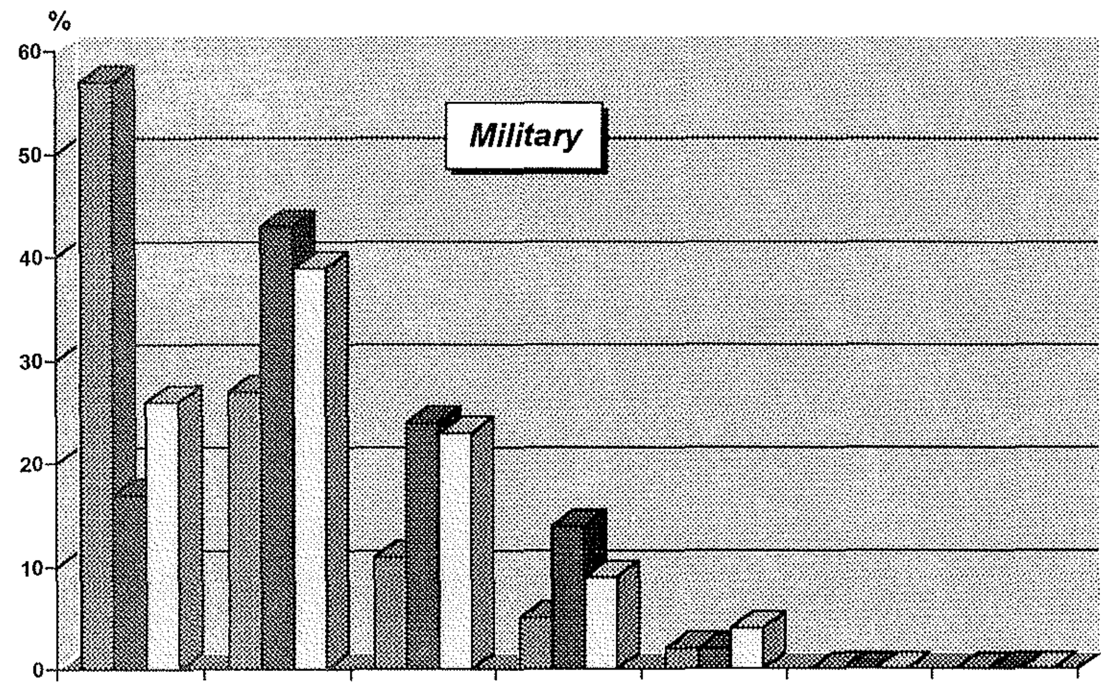


Fig. 4. Crew commanders flying time distribution of air accidents

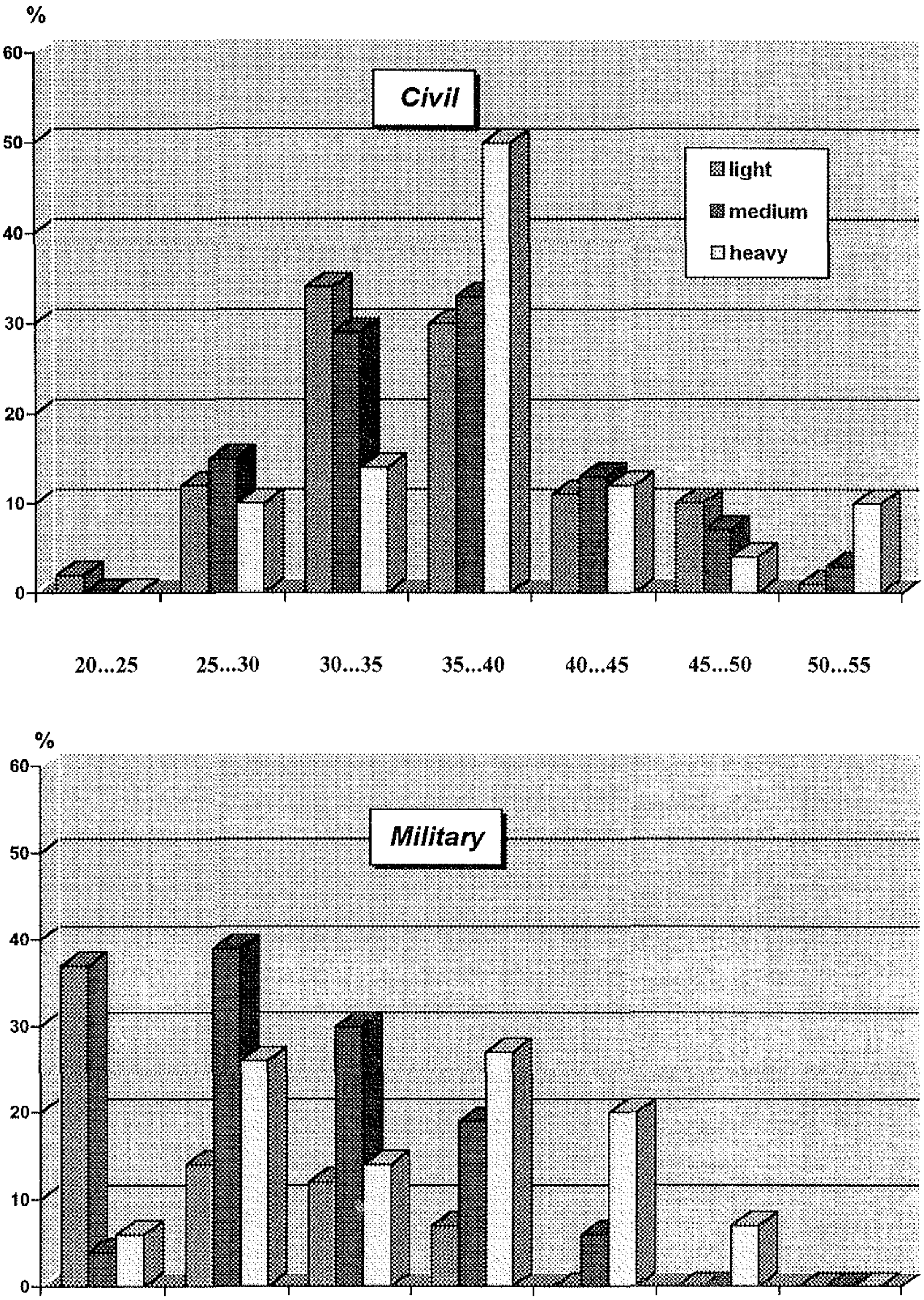
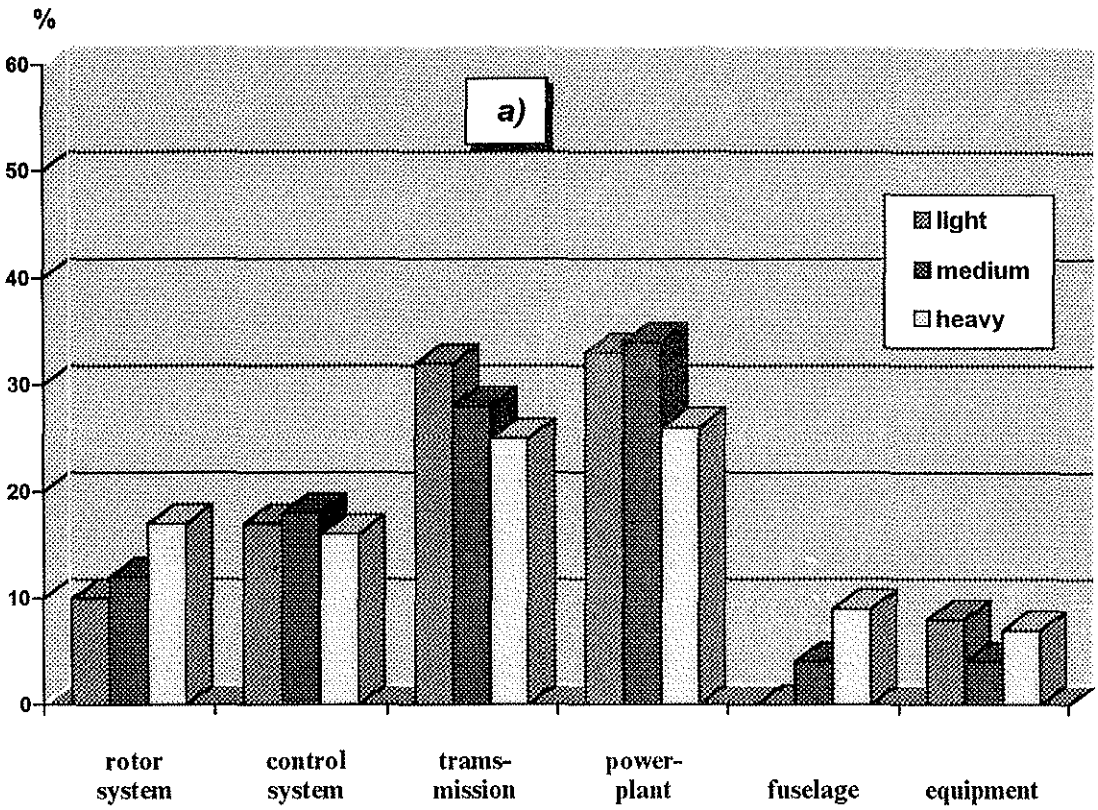


Fig. 5. Crew commanders age distribution of air accidents



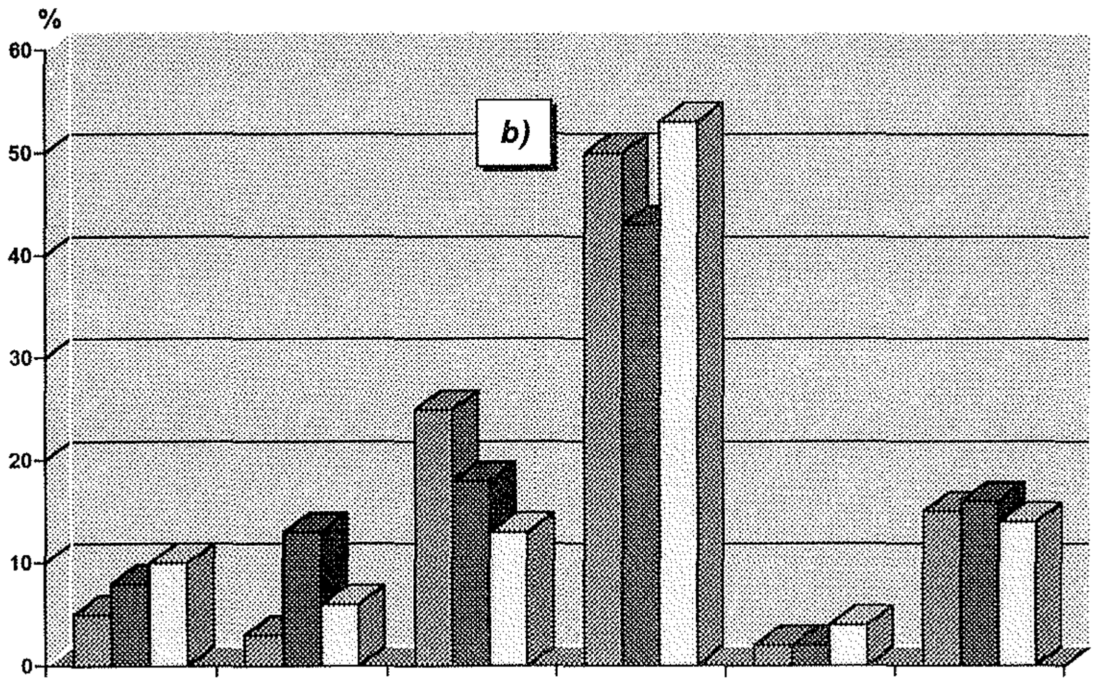


Fig. 6. System failures distribution of air accidents (a) and forced landings (b)