THE NOE FLIGHTS AND THEIR EFFECT UPON A PILOT

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Abstract

In this paper the effect is presented of the Nap-Of-the-Earth helicopter flights upon the emotional state of a pilot and upon the way he is using his sight in such flights. The presented data had been collected in the course of an experiment comprising the execution of ten selected manoeuvres typical for the NOE flights. Six of them were 'horizontal', i.e. with no changes of height, and four were 'vertical'.

All the test flights were carried out at a test site fitted with the cine-theodolites for the three-dimensions recording of the flight path. The test object was the turbine-powered Mi-2 helicopter. The test pilot wore the oculographic gear and his body was labelled with a set of physiological sensors.

Test results have revealed a differentiated effect of particular manoeuvres upon the emotional state of a pilot. The most stressing were the 'vertical' manoeuvres joint with a rapid descent towards the ground. In this case the short-lasting rise of the heartbeats exceeded a normal rate by more than 60 per cent.

The oculographic tests have confirmed that in the NOE flights the pilot's sight isn't stabilized along one direction but travels alternately from the outside sphere to the instrument panel in the cockpit and back. It confirms the thesis that all helicopters destined for the execution of the NOE flights should be equipped with the head-up display of the most important flight data in order to increase the flight safety and to decrease pilot's stresses.

I. Introduction

Very popular in Poland is an old story about mother of a young man called up to the Air Force as an aircraft pilot who, when crossing a boy for goodbye, added a recommendation:
- Remember, my son, keep flying low and slow...

That old anonymous lady, giving in good intention an advice rather dangerous for a fixed-wing pilot, became, not aware of it, a precursor of flights which for many helicopter pilots are a routine today - the NOE flights.

This acronym means namely the Nap-Of-the-Earth flights, the sort of helicopter operations performed in the near vicinity of the ground at the height ranging from 2 to 5 meters.

Are such helicopter flights really necessary? The answer is, unfortunately, yes. They are.

The demand for the NOE flights comes both from the military and civil aviation.

In every Air Force, or rather in every Army Aviation, this demand arises from tactical circumstances. If a combat or assault helicopter has to approach the battle area without being discovered by the opponent, no matter visually or electronically (by radar), it must fly low using the terrain and its canopy as a cover. It must fly among obstacles, jumping over or passing round some of them. The similar tactics is applied when the rescue helicopters are searching for a pilot lost behind the enemy lines.

In more peaceful area, in aerial application of pesticides, the low flight of helicopters is a must that determines the effectiveness of operations. Here also helicopters have to perform the real aerobatics flying near the trees, powerlines and buildings jumping them over or passing round. They have to carry out quick turns at the end of each pass along the sprayed field to cut the non-operational time.

On the pilot's part all such flights require exceptional concentration, high skill and faultless airmanship. Moreover, not to avoid are stresses and emotions which strongly influence the psychological and biological pilot's condition.

There is beyond doubt that all pilot's actions in the NOE flights must be optimum. There is no margin for errors. Therefore, every helicopter pilot whose task is to fly NOE must be properly trained and all elements which condition these flights must be duly recognized.

The desire of recognizing those conditioning elements has inclined the Flight Test Department of the Aviation Institute and the Military Aviation Medicine Institute, both institutions with the seat at Warsaw, to realize a programme the results of which constitute the nucleus of this paper.

II. NOE Flight Model

The first phase of a programme was construction of the NOE flight model. The analysis of all possible helicopter operations, both military and civil, has revealed that, besides the straight flight at low height and far from obstacles, ten manoeuvres

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can be defined as typical for the NOE flights. Six of them are 'horizontal' i.e. performed without the significant change of height and four are 'vertical' i.e. accompanied by changes of height (Fig.1)

1	Circle		6	Quick stop	
2	Tear		7	Jump over obstacle	
3	Slalom		8	Up and down	
4	Omega		9	Quick turn	
5	Quick acceleration		10	Rapid descent	

FIGURE 1. Typical manoeuvres in the NOE flights

To the group of 'horizontal' manoeuvres belong:
Circle. A full 360 deg. turn performed at the constant height commenced and finished over a chosen point.
Tear. Manoeuvre in which the helicopter after passing the particular point returns to it making the 210-230 deg. turn.
Slalom. Manoeuvre in which the helicopter flies along the line of obstacles located about 60-80 meters apart evading them by a series of right and left turns.
Omega. Manoeuvre in which the helicopter passes round a single obstacle without changing the generally straight flight path.
Quick acceleration. Manoeuvre in which the helicopter, after the vertical lift-off, gains the speed by a quick acceleration forward in level flight.
Quick stop. Reverse of a quick manoeuvre; the fast flying helicopter decelerates horizontally to hover and lands vertically in front of an obstacle.

The group of 'vertical' manoeuvres comprises:
Jump over obstacle. Low flight joined with a short change of height and the immediate return to the vicinity of the ground behind an obstacle.
Up and down (pop up). Manoeuvre in which the helicopter resting on the ground behind an obstacle (screen) takes-off vertically, stops for a while in hover, and then quickly descends vertically and lands.
Quick turn. Manoeuvre in which the helicopter flying towards an obstacle carries out the quick 180 deg. turn in the inclined plane; it is accompanied by a speed deceleration in climb and acceleration in descent.
Rapid descent. Manoeuvre in which the helicopter descends as rapid as possible from the height of 200 m (600 ft) to the NOE level without the change of a flight direction.

III. Test Object

It was decided that all maoeuvres constituting the NOE flight model would be performed for the benefit of a programme by a skilled test pilot flying the typical Mi-2 helicopter.

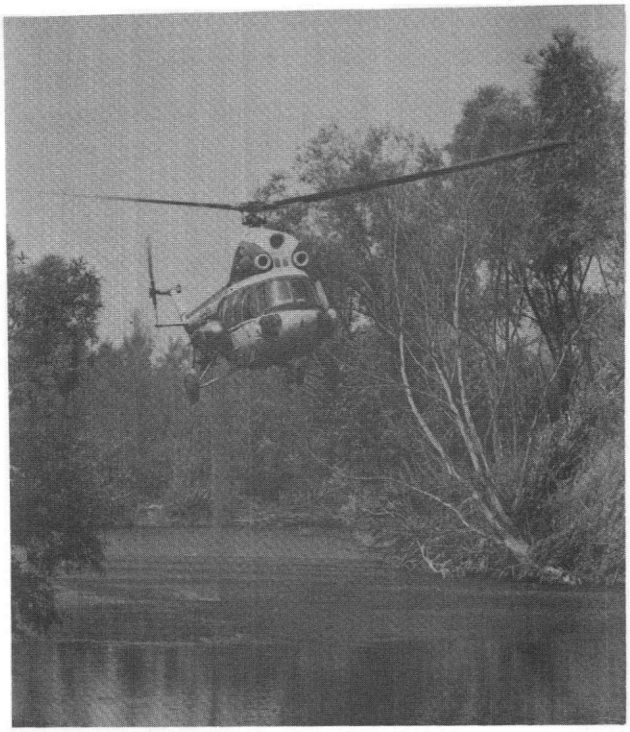

FIGURE 2. The Mi-2 helicopter equipped with the larvicide 'rapid release' system in the NOE flight during the treatment of a watercourse

The Mi-2 double-engine helicopter (Fig.2) is manufactured under the Soviet licence by the PZL works in Swidnik in Eastern Poland. It is a nine-seater with the pilot's seat located on the port side. Empty weight amounts to appr. 2.500 kg (5.500 lb) and the maximum all-up weight to 3.550 kg (7.800 lb). Performance of this helicopter isn't impressive: the never-exceed speed V_{NE} 220 km/h (120 kt), cruising speed V_C 180 km/h (100 kt), maximum rate of climb 4 m/s (787 fpm). Two GTD-350 turbine engines develop the power of 294 kW (400 shp) each and feature the relatively low acceleration - the time to go from idle to intermediate rated power exceeds 10 seconds. Not too good is also the field of view from the Mi-2's flight deck (Fig.3)

The helicopter used in the experiment was fitted with the typical flight-test equipment for recording the flight data (speed, height, accelerations, attitude magnitudes etc) and with the extra system for measuring and recording the psychological reactions of a test pilot which illustrated his emotional state (frequency of heartbeats, EKG, frequency of respiration, lung ventilation, arterial blood pressure and stick grip force) - Fig.4.

A very special part of the test equipment was the oculographic device that made possible to register the trace of visual observations performed by a pilot outside and inside the helicopter (reading the instruments) during the execution of manoeuvres.

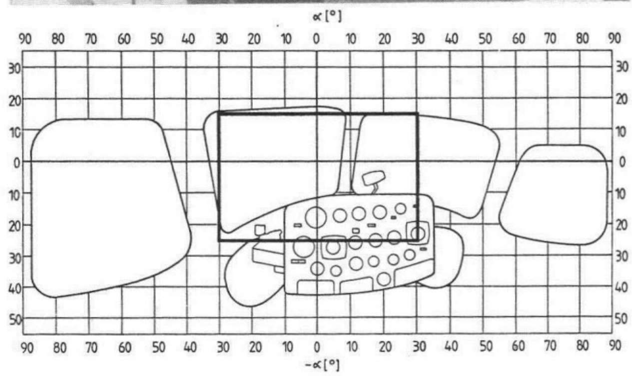

FIGURE 3. The field of view from the Mi-2's flight deck (pilot-in-command seated at the port side) (1)

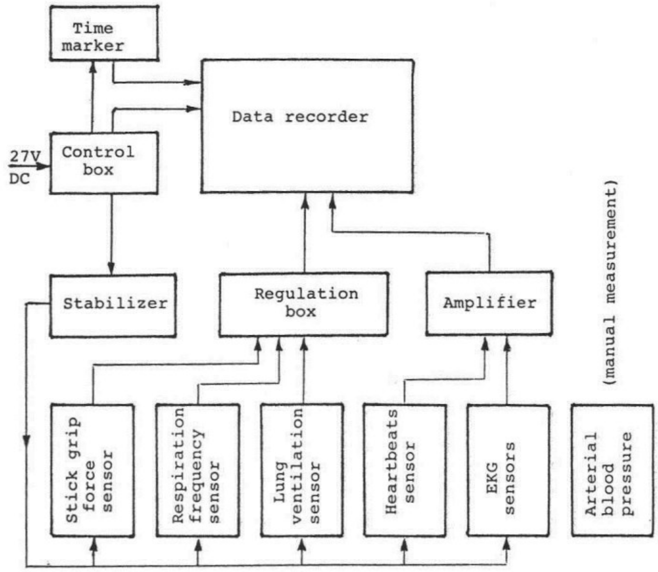

FIGURE 4. Block diagram of a system for recording the pilot's psychological reactions

This equipment consisted of a Japanese NAC-4 head-mounted gear connected with the 16 mm Pentaflex cine-camera. The film band in the camera moved with the speed of 12 frames per second. At each frame the point of observation (fix) was indicated by a triangle mark. The eventual analysis of frame made possible to construct diagrams of visual observations (so-called oculographs) for all typical NOE manoeuvres with numerical data on times and durations of particular parts. E.g. numerical data 37-38 meant that the particular fix occured at the beginning of the 4th second of experiment (37:12 3) and lasted about 0.16 second. (Fig.5).

The precision of execution of planned maneouvres by a test helicopter was recorded semi-automatically by a system of three ETOS cine-theodolites situated in triangle 3 x 3 x 3 km at the test site. The theodolites delivered a lot of extremaly interesting three-dimensional flight path data not being, however, directly relevant to the presented subject and therefore not included into this paper.

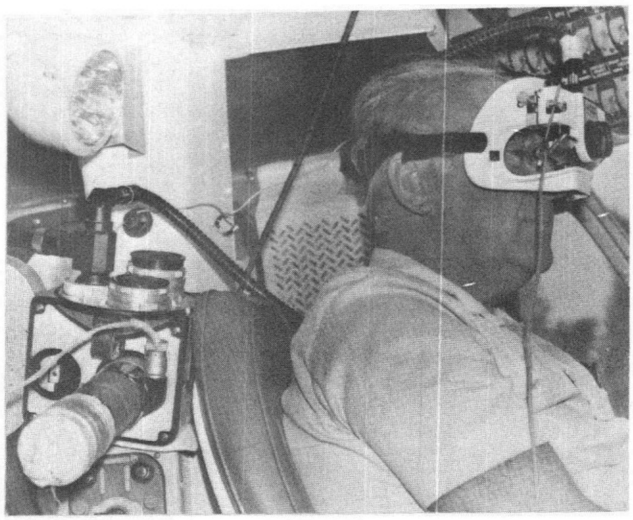

FIGURE 5. The NAC-4 oculograph mounted on the pilot's head

IV. Oculographic Tests

The importance of this part of experiment which included the oculographic record of a track along which travelled the pilot's sight came from the significance of visual information for the conduct of flight. Well-known medical investigations (2) have proved long time ago that optimum human actions in altering environmental conditions depend mainly on the transmission of information through receptors and on the analysis of these information by the central nerve system. 90 per cent of useful information is transmitted through visual receptors, i.e. eyes [3]. There is, however, some trouble created by the motoric activity of an eye. In order to read an useful picture with the maximum 'sharpness' an eye must firstly move to the given point [4], secondly adapt to the changing distance (bring into focus) and thirdly hold at the point of observation until the brain registers required data. All that takes time.

It is easy to recognize this mechanism when studying the oculographs shown below as Fig.6-14 which correspond to nine of ten typical NOE manoeuvres.

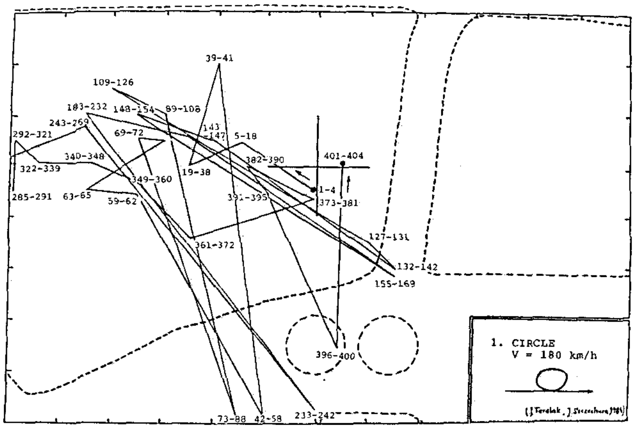

FIGURE 6. Circle

In the circle manoeuvre (Fig.6) which lasted 33.7 seconds the test pilot observed for 29.7 sec the outside sphere and for 4 sec the instrument panel in order to check the helicopter speed (two glances), bank (one glance) and height (one glance). The broken line of the sighting track concentrated primarly around the line of the natural horizon indicates clearly that the manoeuvre was carried out with 30 deg. bank. The outside observation wasn't obstructed by a windshield framing.

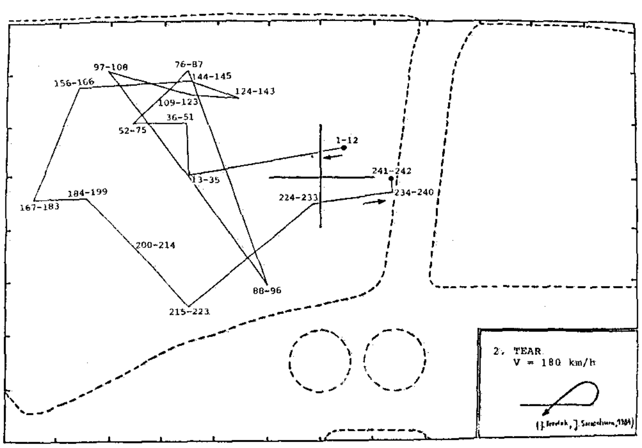

FIGURE 7. Tear

The tear manoeuvre (Fig.7) was carried out in a much shorter time than the circle, in 20.1 sec, and all this time was used by a pilot to observe the outside sphere only and no attention was paid to instruments. As one can easily recognize the bank in turn reached 60 deg. i.e. the manoeuvre was much more violant than the relatively smooth circle and that was the probable reason of omitting the instrument reading.

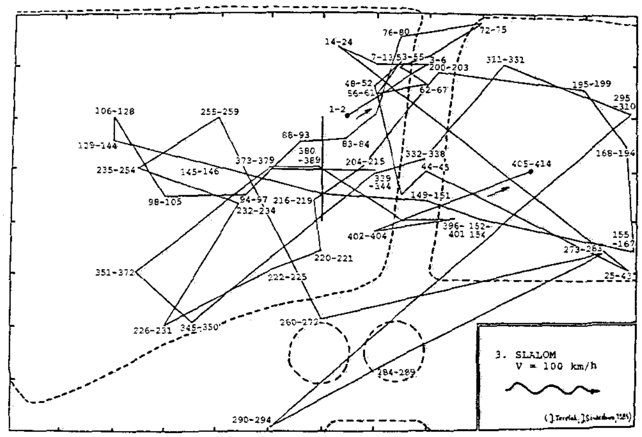

FIGURE 8. Slalom

The slalom manoeuvre (Fig.8) consisted of two l.h. turns and two r.h. turns and lasted 34.5 sec of which the test pilot took for the observations inside the helicopter 2 sec only (0.4 sec for reading speed in one glance and 1.6 sec for reading height in two glances). The bank in all turns ranged from 30 to 40 deg. The pilot's field of view was slightly obscured by a vertical frame dividing the windshield in the middle.

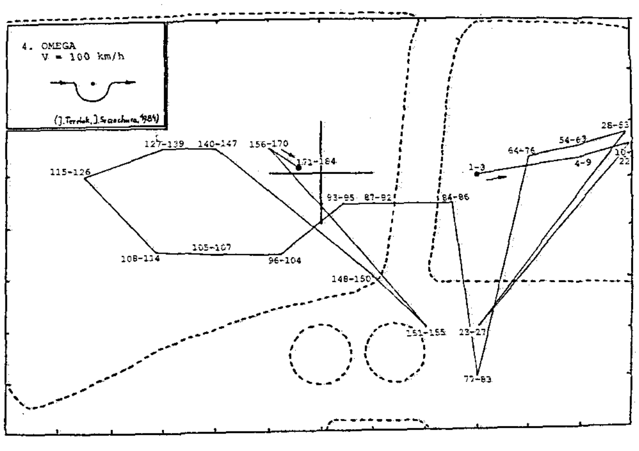

FIGURE 9. Omega

In the omega manoeuvre (Fig.9) three turns were carried out, one violate to the right, one more gentle to the left and one, violant too, to the right, in the total time of 15.3 sec. It is interesting to notice that even such a short time the test pilot has managed to glance three times at the instrument panel to read height and heading. The field of view was undisturbed.

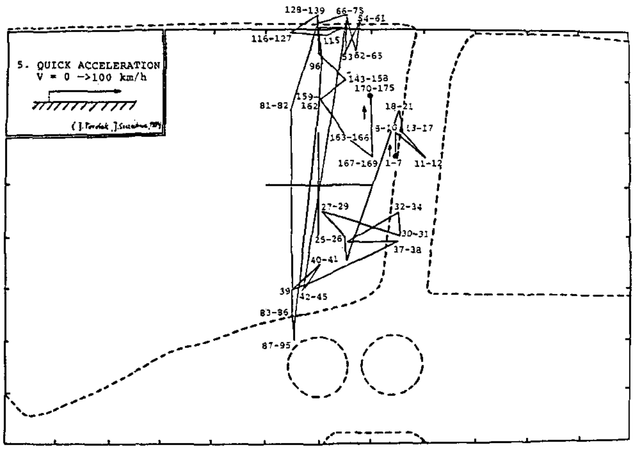

FIGURE 10. Quick acceleration

In the course of the quick acceleration manoeuvre (Fig.10) the points of observation were displaced along the vertical axis coinciding with the helicopter flight path. The whole manoeuvre lasted 14.5 sec. Only once, for less than a secound, the pilot changed the observed area from outside to inside to check height. The poor field of vision from the Mi-2's cockpit found its demonstration in the fact that for 8.3 sec - 57 per cent of the total time! - the pilot's sight was strongly obstructed by the windshield framing. Relatively long the pilot didn't see the horizon at all.

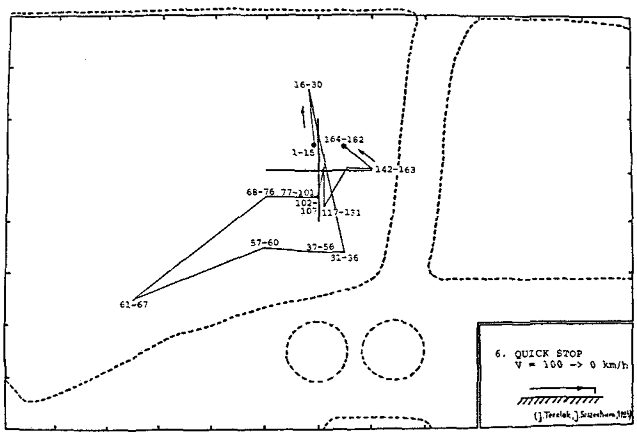

FIGURE 11. Quick stop

The quick stop manoeuvre (Fig.11) took 15.1 sec. Pilot's sight was engaged exclusively in the observation of the ground outside the helicopter. No pilot's attention was paid to instruments, as the ground was the sufficient reference both for assessment of speed and heigh. Moreover, the view through the windshield was not obstructed.

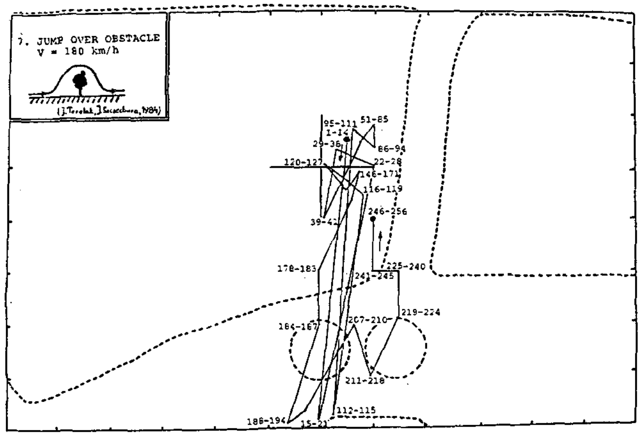

FIGURE 12. Jump over obstacle

The jump over obstacle (Fig.12) lasted 21.3 sec and consisted of three parts: approach to the obstacle, jump itself and return to the straight NOE flight. The field of pilot's observation was shaped vertically and covered both the outside sphere and the instrument panel. When preparing to a jump the pilot checked, in two short glances (0.6 and 0.3 sec), the helicopter speed but after a jump he concentrated much longer, for 3.4 sec, his attention on instrument readings, obviously with intention to return the flight parameters to former values.

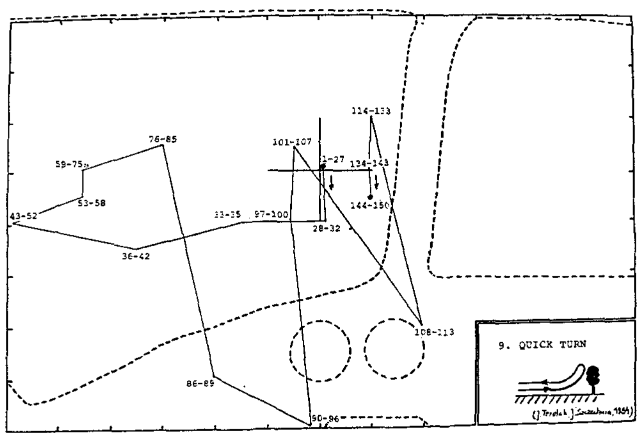

FIGURE 13. Quick turn

The quick turn manoeuvre in front of an obstacle (Fig.13) lasted 12.5 seconds. Except two short-lastings glances for checking the helicopter speed at the top of a figure (0.9 sec) and height during recovery from diving (0.5 sec) the pilot's sight was used for the observation of the outside sphere.

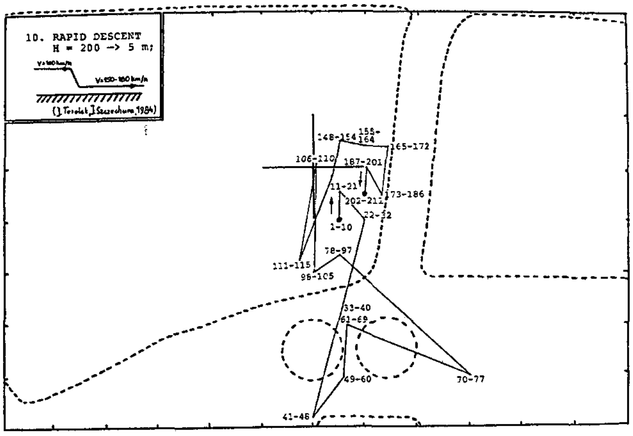

FIGURE 14. Rapid descent

In the rapid descent (Fig.14) one can easily notice that the pilot's attention (and sight) was at first concentrated on the observation of instruments because it was significant for the correct transition to descent. Then, after 3.7 sec, the pilot's sight switched to the observation of the outside sphere and this observation was maintained till the termination of manoeuvre. Even in the most critical phase of recovery to the level flight near the ground no reference to the altimeter reading was made.

It is worth mentioning that in no one manoeuvre the test pilot attempted to read from the instrument panel data other than speed and height (in few cases heading and bank). Fully ignored were e.g. data on the operation of a power unit.

V. Physiological tests

Measurements of physiological parameters were carried out simultaneously with the oculographic tests and were aimed at the assessment of emotional load accompanying the execution of risky NOE manoeuvres. For this purpose a set of sensors attached to the test pilot's body was used.

According to the professional medical sources a most sensitive indicator of human emotions is the frequency of heartbeats which reflects, among other, the pilot's awareness of undertaken risk and difficulty of a task [5].

As one can recognize from the data presented in Table 1 all physiological parameters recorded in the course of the typical NOE manoeuvres were much higher than those measured before the flight, on the ground. The most significant parameter of the heartbeats frequency, being in rest at the level of 69, raised most in 'vertical' manoeuvres: during the jump over obstacle by 52 per cent (up to 105 per minute), in the quick turn by 55 per cent (up to 107 per minute) and during the rapid descent by 62 per cent (up to 112 per minute).

Manoeuvre	Heart-beats	Stick grip force	Lung ventilation	Arterial blood pressure	Frequency of respiration
	per minute	kN	l/min	RR	per minute
0. Rest	69	-	14.4	120/70	16
1. Circle	98	25.5	21.6	132/80	26
2. Tear	96	29.4	24.6	n.r.	26
3. Slalom	97	17.6	26.2	n.r.	24
4. Omega	96	19.6	21.8	n.r.	20
5. Quick acceleration	91	31.3	15.6	n.r.	16
6. Quick stop	95	29.4	22.8	n.r.	26
7. Jump over obstacle	105	45.1	17.0	127/75	24
8. Up and down (pop-up)	n.r.	17.6	n.r.	n.r.	22
9. Quick turn	107	29.4	24.2	n.r.	22
10. Rapid descent	112	45.1	19.6	135/78	24

Note: n.r. - not recorded

TABLE 1. PHYSIOLOGICAL PARAMETERS

The force which the test pilot applied when grasping (instinctively) the control stick grip its highest value also reached in 'vertical' manoeuvres: in the jump over obstacle and in the rapid descent this force was equal to 256 per cent of the smallest force recorded in the 'easy' manoeuvres No 3 and 8.

The parameter of lung ventilation (i.e. the 'depth' of respiration) which the physicians also consider as a measure of emotional state that enables the insight into operation of the circulatory system in far-from-normal circumstances, reached in the slalom manoeuvre the level exceeding the rest value by 82 per cent (up to 26.2 litres per minute) and in the tear and quick turn manoeuvres by 71 and 68 per cent respectively. Higher values reached also the parameter of frequency of respiration: its maximum value exceeding the rest data by 62 per cent (up to 26 per minute) was recorded in the circle, tear and quick stop manoeuvres.

The arterial blood pressure was not measured automatically in all manoeuvres but by the manual method before the experiment, on the ground, and in the air before some selected figures. Of four measurements (including that carried out on the ground) the highest value of RR, exceeding the rest value by about 20 per cent, was measured just after the termination of the rapid descent manoeuvre i.e. the same in which the highest rate of heartbeats had been noticed.

VI. Conclusions

It is, evidently, very difficult to generalize the results of measurements carried out on a single test specimen - such a role played the test pilot in the presented experiment - there's no doubt, however, that even such a single experiment as described made possible to notice that:

(i) The NOE flights, and especially manoeuvres carried out in the near vicinity of obstacles, are from the pilot's point of view a very exciting and stressing exercise. It is demonstrated by changes of physiological parameters and behaviour of a pilot's sight system.

(ii) Although in the NOE flights the principal flight reference system for a pilot is the ground surface, and the whole pilot's attention is practically concentrated on it, in some manoeuvres a pilot finds necessary to check selected flight parameters - e.g. speed and height - by making short glances at the instrument panel inside the helicopter.

(iii) The displacing of a sight in the NOE manoeuvres from the observation of the outside sphere to the helicopter interior jeopardizes the flight course, generates stresses and distracts pilot's attention.

(iv) Against a background of data collected in the presented experiment the fact of fitting the state-of-the-art battle helicopters with the HUD (head-up-display) system, that minimizes the need for excessive sight displacements, becomes obvious. Why, however, no one civil helicopter in the world, being engaged in agriculture and carrying out hundreds of the NOE manoeuvres every day, isn't fitted with a cheap and simplified version of a HUD system, is hard to understand. Is the civilian pilot's life worth less than life of a soldier? The operators' excuse 'we cannot afford that' doesn't hold water.

(v) Helicopters destined for the NOE flights should feature extremely good field of view from the pilot's seat. It should range, at least $\pm$ 90 degrees horizontally and $\pm$ 30 degrees vertically.

(vi) Pilots whose professional duty are the NOE flights should be the subject of a very careful medical and psychological protection.

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